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Teacher's Guide
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About the Guide

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Student Questions

The Dog Ate My Homework

1. What purpose do enzymes serve in the digestive process?
2. How do enzymes lower the activation energy of a reaction?
3. What factor influences the interaction between an enzyme and its substrate?
4. How do starch and cellulose differ?
5. Why are humans and other animals able to process starch but not cellulose?
6. Why are animals such as cattle, sheep and goats able to thrive on a diet of grass?

Sneeze and Wheeze

1. What are allergens?
2. What purpose do antibodies serve in the immune response?
3. What factors influence the ability for an antibody to bind a particular antigen?
4. How does the body respond to the release of histamine from mast cells?
5. What symptom is common to both allergy and asthma?
6. How do normal airways differ from airways during an asthma attack?

Bling Zinger

1. What characteristics gave lead great appeal to early humans?
2. Why was tetraethyl lead once used as a gasoline additive? Why was it phased out?
3. How does lead interfere with the production of heme?
4. What are the neurological effects of lead exposure?
5. What does a chelator do?
6. What characteristics does a good chelator have?
7. What factor is believed to contribute to the death of many members of Sir John Franklin's crew?

Biomimicry

1. What is biomimicry?
2. What are the building blocks of silk?
3. Name a possible application of the chemistry involved in spider silk.
4. What triggers the reaction between hydroquinone and hydrogen peroxide in the firing chamber of the bombardier beetle?
5. Identify one application of the bombardier beetle's design.
6. What are possible applications of the glue produced and applied by blue mussels?

Nanomotors

1. What are the two main components of any motor?
2. How does electromagnetism cause the rotator to move?
3. What building blocks comprise the flagellar motor?
4. What drives the motor in a flagellar motor?
5. What issue does Dr. Whitesides raise about much of the work on "molecular motors?"
6. What chemical reaction takes place in the catalytic nanomotor?

Answers to Student Questions

The Dog Ate My Homework

1. What purpose do enzymes serve in the digestive process?
   Enzymes significantly accelerate the rate of the chemical reactions that occur as part of the digestive process.
2. How do enzymes lower the activation energy of a reaction?
   Enzymes lower the activation energy of a reaction by securing the reactants in a geometrically favorable position. Less energy is required than if the progress of the reaction depended on the random collisions of the reactants involved.
3. What factor influences the interaction between an enzyme and its substrate?
   The shape and structure of the active site (of the enzyme) and of the substrate influences the extent of the interaction between an enzyme and its substrate.
4. How do starch and cellulose differ?
   Starch and cellulose are both comprised of glucose subunits; however, the manner in which these glucose subunits are linked is different in starch and glucose.
5. Why are humans and other animals able to process starch but not cellulose?
   Humans and other animals are able to process starch but not cellulose because they have the enzymes necessary to digest starch, they do not have the enzymes that will facilitate digestion of cellulose.
6. Why are animals such as cattle, sheep and goats able to thrive on a diet of grass?
   These types of animals have colonies of organisms living in their digestive systems that have the correct enzymes for the digestion of cellulose.

Sneeze and Wheeze

1. What are allergens?
   Allergens are benign foreign substances that causes an allergic reaction.
2. What purpose do antibodies serve in the immune response?
   Antibodies are glycoproteins that bind antigens (foreign matter) and facilitate their removal from the body via the immune response.
3. What factors influence the ability for an antibody to bind a particular antigen?
   The chemical structure and shape of both the antibody and its associated antigen largely influence the ability for interaction.
4. How does the body respond to the release of histamine from mast cells?
   Histamine causes a number of physiological responses such as inflammation of the tissues of the nose and throat, excess mucus formation, sneezing, and itchiness.
5. What symptom is common to both allergy and asthma?
   Inflammation is common to both allergy and asthma.
6. How do normal airways differ from airways during an asthma attack?
   During an asthma attack, the lining of the airways swells, there is increased mucus, and the muscles surrounding the airways constrict.

Bling Zinger

1. What characteristics gave lead great appeal to early humans?
   Lead is malleable, soft, and able to resist most corrosive environments.
2. Why was tetraethyl lead once used as a gasoline additive? Why was it phased out?
   Tetraethyl lead decreased the amount of engine knocking. It was phased out because car exhausts were releasing lead and lead containing compounds directly into the environment, creating a health hazard for the population.
3. How does lead interfere with the production of heme?
   Lead interferes with the activity of the enzyme ferrochelatase which inserts the iron (II) ion into the heme molecule.
4. What are the neurological effects of lead exposure?

Lead exposure can interfere with the normal release of neurotransmitters - this can interfere with the normal development of the nervous system of an infant or a child. Additionally, lead exposure can cause swelling of the brain, leading to increased intracranial pressure and alteration of brain development.

5. What does a chelator do?
   A chelator is a chemical substance that can bind metal ions (such as lead (II) ions) and take them out of solution.
6. What characteristics does a good chelator have?
   A good chelator must remove the target ions but not other essential metal ions. Also, it must have a higher attraction for the target ions than do the binding sites in the body.
7. What factor is believed to contribute to the death of many members of Sir John Franklin's crew?
   Poisoning from the lead solder used to seal tin cans is believed to cause the death of many members of Sir John Franklin's crew.

Biomimicry

1. What is biomimicry?
   Biomimicry means imitating life and applying nature's lessons to new human inventions.
2. What are the building blocks of silk?
   The building blocks of silk are glycine and alanine, two very simple amino acids.
3. Name a possible application of the chemistry involved in spider silk.
   Chemists are trying to make a fiber that is similar to spider silk for use in ropes and cords for rock climbing and parachuting.
4. What triggers the reaction between hydroquinone and hydrogen peroxide in the firing chamber of the bombardier beetle?
   Enzymes catalyze this reaction.
5. Identify one application of the bombardier beetle's design.
   Possible applications include: reignition of aircraft engines, airbags, rocket technology and aerial vehicles.
6. What are possible applications of the glue produced and applied by blue mussels?
   Possible application include the manufacture of plywood without the release of the hazardous emissions associated with the adhesives currently in use.

Nanomotors

1. What are the two main components of any motor?
   Motors are comprised of a rotator and a stator.
2. How does electromagnetism cause the rotator to move?
   Current flows through wire wrapped around the rotator, creating a magnetic field. The rotator moves as a result of the attraction of its north and south poles for the opposite poles of the stator (a permanent magnet placed in its vicinity).
3. What building blocks comprise the flagellar motor?
   The flagellar motor is comprised of multiple protein subunits.
4. What drives the motor in a flagellar motor?
   The motor is driven by a pH gradient- the result of a low concentration of protons inside the cell and a high concentration of protons outside the cell.
5. What chemical reaction takes place in the catalytic nanomotor described in the article?
   Hydrogen peroxide is decomposed to yield water and oxygen gas.

Puzzle: Missing Numbers

Instructions:

In a quote box, the letters are dropped vertically from each column (but <u>not</u> necessarily in the order in which they appear) into the empty squares in the grid. For example, in the warm-up grid below, the very first letter will be either a T or an A, and the last letter a Y.

They will spell out a quotation of some interest to those concerned about our environment. It reads from left to right, line by line. Words may continue from one line to the next; black squares indicate ends of words; three black squares in a row indicates end of a sentence.

First an easy warm-up.
It's a famous slogan from the Earth Day movements of the 80's ..and still valid !

T	**N**	**D**	**N**	**A**	**C**	**G**	**L**	**L**	**B**	**C**	**A**	**L**	**Y**	**Y**
A	**H**	**I**		**K**		**T**		**O**	**O**	**A**	**L**	**L**	**L**	
					■									■
			■				■							

Each of the two longer quotes below also has an ENVIRONMENTAL theme.
The first is from John Muir, the great naturalist who "discovered" Yosemite Valley. The other is by Marshall McLuhan.

T	**N**	**E**		**I**	**N**	**I**	**V**	**A**	**T**	**I**	**E**	**E**	**L**	**A**	**V**	**T**	**S**
T	**H**	**G**		**O**	**N**		**A**	**E**	**S**	**U**	**R**	**G**	**M**	**E**	**N**	**E**	**H**
I	**U**	**G**		**U**	**N**		**N**		**R**	**S**	**N**			**O**		**D**	
			■			■		■							■		
			■			■							■				■
			■									■					

(Hint: the first word in the above quote is NOT "the" !)

L	**H**	**A**	**R**	**T**	**W**	**A**	**M**	**E**	**S**	**B**	**A**	**C**	**E**	**S**	**S**	**A**	**P**
T	**E**	**C**	**R**	**E**	**H**	**O**	**R**	**E**	**W**	**E**	**E**	**A**	**R**	**E**	**H**	**I**	**E**
N	**G**	**E**	**R**	**E**			**N**		**M**	**N**	**O**	**R**	**P**	**A**		**S**	**L**
		E	**R**	**S**						**P**			**S**				
					■				■			■					
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	■					■								■	■	■	■

Answers to Puzzle

WARM-UP: Think globally and act locally.

#1. Tug on a single thing in nature and the universe moves.

#2 There are no passengers on spaceship Earth. We are all crew members.

Content Reading Guide

National Science Education Content Standard Addressed

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**Nanomotors**	**The Dog Ate My Homework**	**Biomimicry**	**Sneeze and Wheeze**	**Bling Zinger**
Science as Inquiry Standard A: about scientific inquiry.	✔	✔	✔	✔	✔
Physical Science Standard B: of the structure of atoms.	✔				
Physical Science Standard B: of the structure and properties of matter.	✔	✔	✔	✔	✔
Physical Science Standard B: of chemical reactions.	✔	✔	✔	✔	✔
Physical Science Standard B: of motions and forces.	✔				
Physical Science Standard B: of interaction of energy & matter.	✔		✔		
Life Science Standard C: of the cell.		✔		✔	✔
Life Science Standard C: of the interdependence of organisms.			✔		
Life 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.	✔		✔	✔	✔

Science in Personal and Social Perspectives Standard F: of environmental quality.				✔	✔
Science in Personal and Social Perspectives Standard F: of natural and human-induced hazards.			✔		✔
History and Nature of Science Standard G: of science as a human endeavor.	✔	✔	✔	✔	✔
History and Nature of Science Standard G: of the nature of scientific knowledge.	✔	✔	✔	✔	✔
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 their 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: 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.

NanoMotors

Me	Text	Statement
		1. A motor usually has two main parts: a rotor and a stator.
		2. The biological nanomotor is made of individual cells.
		3. The rotors in biological nanomotors usually reverse direction when the environment changes.
		4. Biological nanomotors are driven by electrons.
		5. To date, no biological nanomotors have been built.
		6. Motors must be able to do work on other objects.
		7. Many applications have been proposed for biological nanomotors.

The Dog Ate My Homework, and Other Gut-Wrenching Tales

Me	Text	Statement
		1. The process of digestion begins in the mouth.
		2. Typically, one enzyme may be used by the body only once.
		3. Most enzymes can catalyze a number of reactions.
		4. The shape and structure of an enzyme is crucial in the chemical reactions it catalyzes.
		5. Enzymes can help chemical bonds form but they do not help break bonds.
		6. Cellulose is made of the same glucose subunits as starch.
		7. Cellulose is not digestible by humans or dogs.

Biomimicry—Where Chemistry Lessons Come Naturally

Me	**Text**	**Statement**
		1. The goal of green chemists is to prevent chemical pollution by designing products that reduce or eliminate the use of harmful substances.
		2. All chemical processes in nature are nonpolluting.
		3. The U. S. Army is considering a synthetic version of silk form a golden orb weaver spider to catch fighter jets that land on aircraft carriers.
		4. Spider silk is a carbohydrate.
		5. The bombardier beetle dies after spraying irritating chemicals from its abdomen.
		6. Traditional adhesives used to make plywood contain formaldehyde.
		7. Green chemists have found ways to reduce undesired by-products of chemical reactions, minimize waste, and save energy.
		8. Green chemistry is a growing field.

Sneeze and Wheeze

Me	Text	Statement
		1. The great majority of asthma attacks are triggered by allergies.
		2. The immune system of allergy sufferers reacts to substances that are usually considered benign.
		3. Allergy attacks occur when an allergy-prone individual is first exposed to the allergen.
		4. An individual can wait until after exposure to the allergen to take antihistamines.
		5. Allergy shots contain tiny amounts of the allergen.
		6. Asthma attacks can be triggered by strong emotions.
		7. Inhaled asthma medications have more side effects than oral medications.
		8. Most doctors are not in favor of long-term medications to reduce inflammation of the airway in an asthma attack.

Bling Zinger . . . The Lead Content of Jewelry

Me	Text	Statement
		1. A trinket from a vending machine may contain as much as 40% lead.
		2. Lead ores found in igneous and metamorphic rocks are abundant in nature.
		3. Lead was probably the first metal to be extracted from its ore.
		4. Leaded crystal actually contains no lead.
		5. The Romans added lead acetate to foods to sweeten them.
		6. People were unaware of the dangers of lead until the 19^{th} century.
		7. Lead exposure causes permanent brain damage in young people.
		8. Atmospheric levels of lead have remained high even though leaded gasoline was banned about 30 years ago.
		9. Lead mimics the chemistry of calcium.
		10. Chelation therapy treatment for lead exposure works well no matter how long the lead has been inside the body.
		11. Wearing a lead trinket is harmful.

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

NanoMotors

As you read, describe the energy source, stator and rotor in each of the motors listed.

Motor	Stator	Rotor
Electric Motor Energy source:		
Flagellar Motor Energy source:		
500-nanomotor motor (Alex Zettl, professor at UC Berkeley) Energy source:		
Catalytic nanometer Energy source:		

The Dog Ate My Homework, and Other Gut-Wrenching Tales

Process (List steps)

Role of enzymes

Digestio

Cellulose, paper money, and digestion in humans and dogs

Cellulose and digestion in other animals

Biomimicry—Where Chemistry Lessons Come Naturally

Biological inspiration	Chemistry	Advantages and Possible Uses
Spider silk		
Bombardier beetle		
Blue mussels		
Others (name):		

Sneeze and Wheeze

Allergy and Asthma Attacks	
Symptoms	**Causes**

Allergy and Asthma Relief		
Medication	**How it works**	**Problems or Cautions**

Bling Zinger . . . The Lead Content of Jewelry

Date	Use(s) for lead	Rationale	Consequences or Treatment
Roman times			
1800s			
Modern times			

The Dog Ate My Homework

Background Information

[Much of the following information was taken from this Colorado State university web site: http://arbl.cvmbs.colostate.edu/hbooks/pathphys/digestion/index.html]

Digestion in humans can be broken down into several parts:

Pregastric digestion
Stomach digestion
The liver and biliary system
The pancreas
The small intestine
The large intestine

The discussion related to this article can be narrowed down to the pregastric digestion process and everything else. (If you want more specific information on the entire process of digestion, see "Web Sites for Additional Information", "Digestion", below.) The pregastric digestion is the mechanical portion of the process, and it begins with chewing. Chewing is the process by which most of the physical changes of breaking down the lumps of food material into smaller pieces occur. This results in a huge increase in surface area of the food, so that enzymes can be more effective in the actual chemistry of digestion. Chewing also softens the lumps of food and molds them into sizes (called boluses) that are more easily swallowed. In addition to breaking down the food, chewing mixes in saliva, which helps to lubricate the food. Swallowing, the last step in the physical changes of pregastric digestion, moves the lubricated food into the esophagus, on its way down to the biochemical reactions of the digestion process in the stomach and beyond.

In humans (and other mammals) digestion of starches actually begins with saliva secretion, as saliva contains alpha-amylase that can initiate digestion of starches into maltose.

Food chemistry

The food ingested by animals (humans or dogs) consists of many different molecules, but the bulk of them are huge macromolecules that cannot be absorbed by cells in the body. Here's a look at the three main groups of macromolecules involved:

Proteins are long chains (polymers) of amino acids linked together by peptide bonds Generally, proteins must be broken down chemically into individual amino acids in order for them to be absorbed through the cells in the lining of the stomach. Proteins can be hydrolyzed into peptides by proteases; peptides can then be further broken down into amino acids by peptidases. Both enzymes break peptide bonds.

Lipids include fatty acids, neutral fats, waxes and steroids. (Waxes and steroids are not closely related to this article, so we will focus on the first two lipids.)

Fatty acids are the building blocks of many complex lipids, although they are not present in large quantities in animal or plant tissue. Fatty acids are chains of carbon atoms, 14-22 carbon atoms long, ending in a carboxylic acid. They usually have even numbers of carbon atoms. Their differences lie not only in the number of carbon atoms, but also in the positions of the double bonds that make them unsaturated.

Neutral fat or triglyceride is the most abundant storage form for fat in animals and plants, and is therefore the most important dietary lipid. A triglyceride molecule is made of one glycerol molecule attached at each of its three carbon atoms to different fatty acids through ester bonds. These triglycerides are very large molecules that cannot be absorbed. They must be digested by pancreatic lipase (another enzyme) into a monoglyceride and two separate fatty acids, all three of which are able to be absorbed by the body. Other lipases are able to hydrolyze triglyceride into three separate fatty acids and a glycerol molecule.

Carbohydrates are aldehydes or ketones derived from polyhydric alcohols, primarily penta- and hexahydric alcohols. Carbohydrates can be broken down into three major groups: monosaccharides, disaccharides and polysaccharides.

Monosaccharides are the simple sugars, mostly hexoses, like glucose, and fructose, or pentoses, like ribose. These are typically produced by the breakdown of more complex carbohydrates, and these are easily absorbed and transported across the wall of the digestive tract and into the bloodstream.

Disaccharides are simply two monosaccharides that are linked together by a glycosidic bond. Common disaccharides are sucrose, lactose and maltose.

Polysaccharides are large polymers made up of smaller sugars, primarily glucose. They are the most abundant carbohydrate food group in most animals. This portion of carbohydrates can be further subdivided into three main groups: starch, cellulose, and glycogen.

> **Starch** is one of the major storage forms of glucose in plants. It consists of two main components, alpha-amylose and amylopectin. Alpha-amylose consists of glucose molecules linked together in long straight chains, while amylopectin has highly branched chains of glucose. The glucose links in most starch molecules are alpha(1-4) glycosidic bonds, which are digestible by animals.
>
> **Cellulose** is the other major storage form of glucose in plants. Cellulose is made of linear (unbranched) chains of D-glucose with beta(1-4) glycosidic bonds. Animals cannot digest this form of carbohydrate. Herbivores that rely on cellulose for their diet do not digest the cellulose – their digestive tracts contain bacteria that produce cellulases that can break down the cellulose to other, digestible saccharides.
>
> **Glycogen** is the major storage form for glucose in animals. It contains glucose molecules linked in chains by alpha(1-4) glycosidic bonds, just like they are in starch, hence glycogen is digestible in animals.

In order to digest any of these larger, macromolecules, they must be broken down, usually by hydrolysis, into smaller particles. This job is usually done by enzymes.

More about enzymes

Enzymes are biological catalysts. The major enzymes involved in digestion are: proteases, lipase and amylase, hydrolyzing proteins, fats, and starches, respectively. A good web site to learn more about the actions of these enzymes can be found at http://arbl.cvmbs.colostate.edu/hbooks/pathphys/digestion/pancreas/exocrine.html. A diagram at that site shows a visual representation of the breakdown of a protein to peptides by trypsin and chymotrypsin. It discusses the precursors to these proteases and, in the second paragraph under “proteases”, the author says, “As you might anticipate, proteases are rather dangerous enzymes to have in cells, and packaging of an inactive precursor is a way for the cells to safely handle these enzymes.” It might be an interesting statement to pose to students, asking why proteases are dangerous enzymes to have in cells.

Most chemical digestion of food actually happens in the small intestine, where the above enzymes are delivered primarily by the pancreas. The liver also plays a pivotal role in digestion as it secretes material into the small intestine – mainly bile acids. These, however, act primarily to emulsify and solubilize lipids so that pancreatic enzymes can act on them chemically to hydrolyze them into fatty acids and monoglycerides, both of which can be absorbed through cell membranes. Without bile acid emulsification of lipids, the fat globules are too large for enzymes to efficiently carry out hydrolysis – the enzymes can only reach the lipids that are on the surface, the outside of the globule. The interior of the globule would never be broken down into usable fatty acids.

There is more information located at the above-cited web site than is needed in this discussion, if you (or any of your students) are interested.

More about Incomplete digestion

The ChemMatters February, 2003 issue had an article on one of the results of incomplete digestion – flatulence. The title is, "Flatus: In the Wind". Your students may be interested in going back to that article for further information. The teachers guide to that article also has some links to sites dealing with digestion: http://www.chemistry.org/portal/resources/ACS/ACSContent/education/curriculum/chemmatters/tg0203_chemistryflatus.pdf

More about lactose intolerance

This article, "Lactose Intolerance: Calling a Chemical Truce", a February, 2004 article in the American Chemical Society's publication *Chemical and Engineering News*, discusses lactose intolerance, including a little chemistry involving the enzyme lactase: http://www.chemistry.org/portal/a/c/s/1/feature_ent.html?DOC=enthusiasts%5Cent_lactose2.html

The Mayo Clinic web site for lactose intolerance gives a good overview of the problem, as well as its symptoms and causes, at http://www.mayoclinic.com/health/lactose-intolerance/DS00530

More about paper

http://www.tappi.org/paperu/welcome.htm takes you to "Paper University", a web site by TAPPI, the Technical Association for the Pulp and Paper Industry. It has a lot of material about paper, including a procedure for making paper and lots of links to other paper sites. It also includes a US map showing sites, state by state, that are possible field trip locations for classes of students.

Check out http://www.hqpapermaker.com/paper-history/ for a brief history of paper-making.

A general web site dealing with many aspects of paper, including paper grading and a historical timeline of paper-making, a glossary of paper terms and links to many other paper-related organizations' web sites: http://www.paperonline.org/history/history_frame.html

Connections to Chemistry Concepts

1. Physical changes vs. chemical changes: the first step in digestion is mastication which results in physical changes of food; then chemical changes take over to complete digestion.

2. Thermo chemistry: endothermic vs. exothermic chemical reactions

3. Metabolism: oxidation-reduction reactions

4. Reaction rates: increased surface area increases rate.

5. Catalysis: enzymes aid in the digestion process by speeding up the rate of chemical reactions.

Possible Student Misconceptions

1. **"Catalysts (enzymes) get used up, just like the other reactants in a chemical reaction."** Not true – as you've no doubt tried to tell your students, and as you've read in the article, a catalyst can be used thousands of times and is still ready to work again. That's what differentiates a catalyst from all the reactants in a reaction – the catalyst still shows up at the end of the reaction.

2. **"I've got a cast iron stomach, I can eat <u>anything</u>!"** Maybe so, but you can't digest everything you eat. Cellulose is indigestible in humans. It passes through us undigested. As mentioned in the article, undigested cellulose is the fiber that doctors want all of us to eat more of.

3. **"I'm sure glad those microbes don't live inside me!"** Don't feel too safe; it's been estimated that the human stomach holds more than 100 different microorganisms, some of which aid our own digestion processes, and some of which help to keep us healthy.

Demonstrations and Lessons

1. A very simple lab procedure to test for fats (using a brown paper bag for the test site) and one to test for proteins using Biuret solution is given at http://chem.lapeer.org/Bio1Docs/ProteinLipidLab.html. There is no visible teacher's version, and no safety information is given.

2. The Chemical Heritage Foundation web site contains a section on "Enzyme Specificity" in their "Antibiotics in Action" module. This module contains three experiments that show the digestion of protein, lipid, and starch, respectively. Student and teacher versions of each activity can be found at: http://www.chemheritage.org/EducationalServices/pharm/antibiot/activity/enzlab.htm. To get to the teacher's version, where all the lab preparation is located, click on "Go to Teacher's Guide" in the upper right corner of the screen, under *Pharmaceutical Achievers*. Clicking on "Go to Student Version" in the upper right corner of the screen under *Pharmaceutical Achievers*, when you are in the Teacher's Version, will return you to the student version. Safety information is included in each activity, as well as alignment to National Science Education Standards.

3. http://lgfl.skoool.co.uk/keystage3.aspx?id=63 is a site with about 70 experiments and lessons discussed and the results of the experiments summarized, all done online. Two of them (#14 and # 15) involve digestion experiments and their results, and three lessons (#16, #39, and #40) deal with enzyme activity. You might use these as ways to teach about digestion processes or enzyme reactions. The experiments give the setting for the experiment and then provide the results of that experiment. Then the explanation of the results is given. The presentation can be stopped at any time, so that you can have students assess the results for themselves before they get the "official" explanation. The lessons are PowerPoint-like presentations and are interactive, with audio and a quiz at the end of each lesson. The audio can be turned off for any part of the experiment or lesson.

4. This site is a set of two wet-lab chemistry experiments to show digestion of proteins and of carbohydrates. It also has one that tracks student eating habits and one that compares food pyramids, and one experiment at the end that allows students to design their own experiment: http://www.smv.org/jil/mll/high/MLL9-12dig-CA-dig.pdf.

5. Another experiment on enzyme activity, this one, from Access Excellence, deals with lactose and Lactaid: http://www.accessexcellence.org/AE/AEC/AEF/1996/crumlish_enzyme.html.

6. Students can make their own paper following the instructions on these sites:
   This site, http://www.funsci.com/fun3_en/paper/paper.htm#3, provides a procedure to make paper and shows photographs to accompany the procedure. It also gives a brief history of paper, and a

follow-up on recycling paper (and other recyclables). This site also gives a short web bibliography of other sites dealing with paper.

The Chemical Heritage Foundation has a paper-making activity on their Science Alive! site at http://www.chemheritage.org/scialive/julian/activities/6a.html. The teacher background material on the experiment can be found by clicking on the "For Teachers" button at the top of the screen. Alignment with National Science Education standards is included.

7. A series of demonstrations and experiments can be found at this part of the NSTA Scope, Sequence and Coordination web site, http://dev.nsta.org/ssc/pdf/v4-0969t.pdf. The demonstrations include genie in the bottle catalysis, digestion of egg proteins (this one's actually a student experiment), baking bread and yeast, and the enzymes in the liver. These are presented as inquiry-based, student-designed experiments.

8. The Access Excellence web site has a cheese-making demonstration using an enzyme to create the cheese from milk. You can find it at http://www.accessexcellence.org/AE/AEPC/WWC/1991/cheese.html.

9. Another Access Excellence site, http://www.accessexcellence.org/AE/AEC/AEF/1994/jensen_monomerpoly.html, uses starch packaging pellets ("peanuts") as the source of starch to differentiate tests for sugars and starches in food.

Student Projects

1. Students might want to do a report on Crohn's disease, or irritable bowel syndrome, or one of the other digestion-related diseases.

2. It might be interesting to give students the following web site, http://www.radianthealth.cc/digestion_the_key.htm, and then ask them to critically analyze the contents. The site is actually an advertisement site for the company, Radiant Health. They don't hide this fact, it's just that when someone enters the site at this screen, it seems to be legitimate scientific discussion. It discusses the need for enzymes in digestion. You might ask students at what point they finally realized its intent.

3. Students could research and report on the benefits and potential problems of enhancing the intake of probiotics in our diet.

4. Students may be interested in making their own paper. You may begin with this site: http://www.swe.org/iac/LP/paper_02.html. While it is listed as grades 4-8, and may therefore not be viewed by students as being "cool", it is a good basic site, and if nothing else, you may use it for yourself as background. Others are listed below, under **Additional Web Sites**, Paper Making, and in **Demonstrations and Lessons**, above.

Anticipating Student Questions

1. **What happened to the check?** It might have survived the trip, but it was probably digested in Midge's digestive tract. The composition of the paper check was probably higher in wood pulp and lower in rag (cotton and linen) than the paper money, making it weaker and thus less digestion-resistant.

2. **What makes enzymes so special?** Where do we begin? 1) They are catalysts, so they never get used up in a chemical reaction. This means they can catalyze the same reaction (with different reactants) over and over again without disappearing. 2) They are usually substrate-specific, based on the shape of the substrate matching that of the enzyme. As a result they usually only work to catalyze one biochemical reaction. This is important because if this weren't true, one enzyme could potentially catalyze ALL biochemical reactions in the body. We would have no internal biological control over cell functions, as all biochemical reactions would be unstoppable. Bedlam (and death) would result.

3. **"Why is notebook paper so different from paper money?"** Paper currency (money) is made with a large plant content, cotton and linen. It contains less wood pulp than most other kinds of paper. Because these fibers are softer to begin with, they require less processing than wood pulp does, and the fibers remain longer and stronger than those from wood pulp. (See number 6, under Demonstrations and lessons, above.)

Websites for additional Information

History of Digestion

This site, "History of the Stomach and Intestines", discusses ancient history of digestion, leading up to dissection of the human body:
http://www.stanford.edu/class/history13/earlysciencelab/body/stomachpages/stomachcolonintestines.html

The "Chemical Theory of Digestion" a small portion of the series, **A History of Science**, by Henry Smith Williams, discusses mid-eighteenth century scientific exploration of the digestive process at this site:
http://www.worldwideschool.org/library/books/sci/history/AHistoryofScienceVolumeIV/chap20.html

The story of William Beaumont (1785-1853), a Michigan physician, and his scientific investigation in 1825 of an accidental gunshot wound of a young Michigan trapper can be found at:
http://www.sportsci.org/news/history/beaumont/beaumont.html#beaumont. The wound left an opening in the side of Alexis St. Martin that was a window on the workings of his stomach. Beaumont observed and experimented with St. Martin's stomach for more than eight years (apparently with St. Martin's permission). His findings changed scientists' understanding of human digestion. He wrote a book detailing all his observations, experiments and discoveries, *"Experiments and Observations on the Gastric Juice and the Physiology of Digestion"* (1833, Plattsburgh: F.P. Allen).

A brief history of olestra, the oil substitute that is undigestible in humans, can be found at
http://www.olean.com/cgi-bin/newsware/questions/index.cgi?Detail=19&Field=key_field&Key=.%2A&Sort=order&Sort_num=on.
This site also includes a timeline of development of this product. Other tabs allow you to learn more about Olean, the Proctor & Gamble brand of olestra.

http://www.open2.net/everwondered_food/history/history_index.htm is a BBC-produced interactive timeline of food discoveries, covering three different aspects simultaneously - science, technology and culture. Flash Player is needed to view the interactive timeline, but if you don't have that, you can still view each of the three lines of discovery, one at a time in a normal screen view.

An interesting digression is this site, the "History of Gum": http://www.cadburyadams.com/history/
It's written by the Cadbury/Adams company, which manufactures chewing gum, so it's probably somewhat biased, but it's interesting reading nonetheless. (This has precious little to do with digestion; that's why it's a digression.)

Digestion

If you want to learn more about digestion in dogs which, after all, is what the article is about, see this web site: http://b-naturals.com/Sep2005.php. The site is by a marketing firm that sells pet foods, but it seems to be relatively unbiased in its discussion of canine digestion and anatomy. Other articles at the same site treat digestion of proteins in dogs, as well as digestion of carbohydrates.

This site is part of a college course on the digestive system: http://arbl.cvmbs.colostate.edu/hbooks/pathphys/digestion/index.html. The material here is very complete.

This is a good site for visualizing the digestion process, including an interactive screen with full description of the process, in parts, or a question and answer format to learn about digestion: http://www.open2.net/everwondered_food/science/science_digestion.htm#. Flash Player is needed to view this BBC production.
Another part of the above site has an interactive timeline of food discoveries, running three concurrent lines of science, technology, and culture, with details of the discoveries. View it at http://www.open2.net/everwondered_food/history/history_timeline.htm.

A biology study guide for digestion can be found at http://www.bookrags.com/sciences/biology/digestion-ansc-02.html. This is copyrighted material, usable for reference only.

This Wikipedia site, http://en.wikipedia.org/wiki/Enzyme#3D-Structure, discusses enzymes fairly thoroughly. Although we cannot vouch for the validity of the content here, the end of this rather long article does give some legitimate applications of enzymes in industry.

This web site, Digestive Health Online, a subsection of Health Centers Online has a section on the digestion process, including several animations, one of which is on enzymes: http://digestive.healthcentersonline.com/digestivehealthbasics/digestivesystem.cfm

This BBC site takes you through cell metabolism, including food types and enzyme action. It includes animated sequences to help visualize structures and processes. It also includes graphs of concentration of substrate vs. reaction rate and temperature vs. reaction rate for enzyme activity. http://www.bbc.co.uk/education/asguru/biology/02biologicalmolecules/index.shtml

For a very simple, non-chemical description of all phases of the digestion process in humans, see http://health.discovery.com/centers/digestive/digestion.html. This is very basic stuff.

Check out http://www.usprobiotics.org/ for a treatment of probiotics – the beneficial microbes that inhabit our digestive tract, and how to get more good bacteria into our bodies.
The doctor answering Q&As at the Mayo Clinic site, http://www.mayoclinic.com/health/probiotics/AN00389, sums it up by saying, “Initial research results are mixed. More study is needed to determine whether probiotics offer any benefits in treating or preventing illness.”

Food Molecules

Check out this web site, the “Monosaccharide Browser”. It allows you to choose which monosaccharide you want, then it shows you its space-filling structure, or you can choose a structure and then try naming it: http://www.beechtreecommon.org/biochemistry/monosaccharide/

This site shows space-filling molecule samples of the various carbohydrate types: http://staff.jccc.net/pdecell/biochemistry/carbohyd.html#top.

Related ChemMatters article:

"Flatus: In the Wind". *ChemMatters*, 2003 (February), 11-13. Teacher's Guide at http://www.chemistry.org/portal/resources/ACS/ACSContent/education/curriculum/chemmatters/tg0203_chemistryflatus.pdf

Sneeze and Wheeze

Background Information

More on the Respiratory System
Breathing in humans is a process of exchanging oxygen and carbon dioxide between atmosphere and blood. Cells require oxygen, and cellular respiration produces carbon dioxide which must be eliminated from the body. This gas exchange takes place primarily in the alveoli, which are microscopic air sacs in the lungs at the end of the bronchial tubes.

The breathing mechanism is known as negative pressure breathing. It works this way: As a person inhales, the diaphragm contracts and moves downward, which increases the volume of the chest cavity and reduces the pressure in the lungs so that the pressure in the lungs is less than atmospheric pressure (pressure in the lungs is negative with respect to atmospheric pressure). Atmospheric pressure forces air to flow into the lungs. As a person exhales, the diaphragm expands as it returns to its relaxed position. This decreases the volume of the chest cavity and increases pressure in the lungs forcing air out of the lungs.

The breathing mechanism is a natural application of Boyles' Law, $P_1V_1 = P_2V_2$. During inhalation, as the volume of the chest cavity increases, Boyles Law predicts that pressure in the cavity will decrease. Because the pressure in the cavity (and the lungs) is now less that outside air, air is forced into the lungs. As the diaphragm relaxes, the volume of the lungs decreases, resulting in an increase in pressure and air being exhaled. A diagram of the respiratory system can be accessed here:
http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=22576

More on Gas Exchange in the Lungs
Oxygen and carbon dioxide are exchanged between air and blood in the more than 300 million alveoli in the lungs. We can explain the exchange in terms of partial gas pressures. In dry air the partial pressure of oxygen is about 160 mm Hg, and in the alveoli the partial pressure of O_2 is about 100 mm Hg. This creates oxygen flow into the lungs. In general, gases move from areas of higher pressure (concentration) to areas of lower pressure. The venous blood that flows through the alveolar capillaries has an O_2 pressure of about 40 mm Hg. Oxygen, therefore diffuses from alveoli to the blood, increasing the O_2 pressure to about 100 mm Hg. This oxygen is taken up and transported by hemoglobin to cells in the body where it is used in respiration.

Cellular respiration produces carbon dioxide, and in tissue the CO_2 pressure is about 60 mm Hg. The CO_2 pressure in the blood is only 46 mm Hg so CO_2 is exchanged from tissue to blood, which carries it back to the lungs where the pressure of CO_2 is a constant 40 mm Hg. In the alveoli, carbon dioxide is exchanged to the air and expelled.

Anything that acts to interrupt this exchange of oxygen and carbon dioxide between outside air and the cells of the body creates respiratory problems. Asthma and allergies act to interrupt this exchange.

More on Asthma
According to the Centers for Disease Control, asthma is the leading chronic illness among children in the United States. A 2003 CDC report indicates that 18.9% of high school students had been told by a doctor or nurse that they had asthma, 16.1% had current asthma, and 37.9% of those with current asthma had had an episode of asthma or an asthma attack during the 12 months preceding the 2003 survey.

Overall, 18.9% of high school students reported lifetime asthma. Significantly fewer Hispanic (15.6%) than black (21.3%) or white (19.3%) students reported lifetime asthma. Approximately one in six students (16.1%) reported current asthma. Significantly fewer Hispanic (12.9%) than black (16.8%) or white

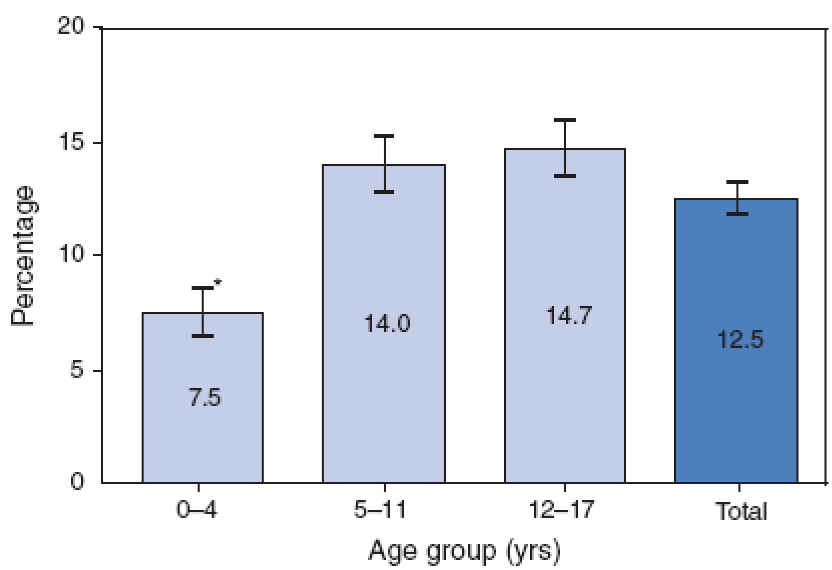
(17.0%) students and significantly fewer 10th-grade (15.0%) than 9th-grade students (17.5%) reported current asthma.

Among students with current asthma, 37.9% reported an asthma episode or attack during the 12 months preceding the survey. Significantly more female (44.5%) than male (31.1%) students with current asthma and significantly more 9th-grade students (45.0%) than 10th- (36.4%), 11th- (34.6%), and 12th-grade (33.0%) students with current asthma reported having an asthma episode or attack.

QuickStats

FROM THE NATIONAL CENTER FOR HEALTH STATISTICS

Percentage of Children Aged <18 years Who Have Ever Had Asthma Diagnosed, by Age Group — United States, 2003



* 95% confidence interval.

From: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5416a5.htm

Asthma's effects on children and adolescents include the following:

- Asthma accounts for 14 million lost days of school missed annually.
- Asthma is the third-ranking cause of hospitalization among those younger than 15 years of age.
- The number of children dying from asthma increased almost threefold from 93 in 1979 to 266 in 1996.
- The estimated cost of treating asthma in those younger than 18 years of age is $3.2 billion per year.

The CDC reports 20.3 million Americans have asthma. For a complete table of statistics about asthma in the United States see this table from CDC: http://www.cdc.gov/asthma/NHIS/2003_table1-1.htm The prevalence of asthma increased 75% from 1980-1994. From 1982-1996, the prevalence of asthma increased by 97 percent among women, compared with 22 percent among men. In 2001, 12 million people had experienced an asthma attack in the previous year. There are more than 5,000 deaths from asthma annually. Asthma accounts for approximately 14.5 million missed work days for adults annually.

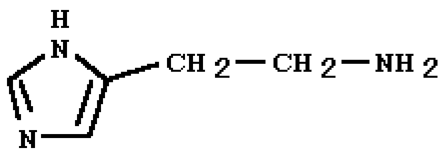
Who will develop asthma? In addition to the allergens listed below, the risk factors for asthma are:

- Parental history of asthma (especially the mother)
- Young age of pregnant mother

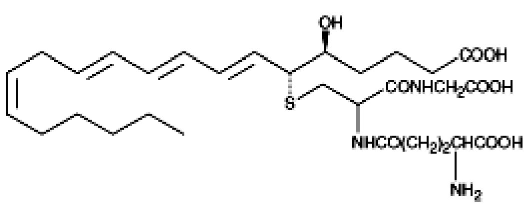
- Low weight gain by mother during pregnancy
- Being male
- Early childhood respiratory disease
- African American (50% higher risk)
- Diet
- Smoking

According to the American Academy of Pediatrics, common triggers of asthma include: Infections in the airways, viral infections of the ear, nose, and throat, things in the environment (outside or indoor air you breathe), cigarette smoke, irritants in the air (air pollution), cold air, dry air, sudden changes in the weather, pollens, dust (house dust mites), animals, mold, exercise and emotional stress

The article mentions two chemicals that are released by the body during and allergy attack --histamine and leukotriene. Histamine is an important protein involved in many allergic reactions. It is produced in the body from the amino acid histidine by the removal of a carboxyl group (COOH). The chemical structure of histamine:



Leukotrienes are complex eicosanoid compounds that are produced from arachidonic acid, a 20-carbon fatty acid. There are four leukotrienes designated leukotriene A_4-D_4. Leukotrienes, specifically C_4 and D_4, cause swelling and edema in the bronchial tubes and increase inflammation. The chemical structure of one of the leukotrienes:



More on Inflammation
The role of inflammation is illness and disease has become much better defined in recent years. Physicians know that inflammation is a general immune system response to disease. Sunburn is a type of skin inflammation, as is poison ivy. Rheumatoid arthritis is also an inflammation disease. The bronchial tubes of asthmatics are thought to be somewhat inflamed even when they are not symptomatic. This chronic inflammation is thought to play an important role in asthma attacks. During an attack the inflammation increases, bronchial tubes swell and mucous is produced. The article describes two types of medications that help to prevent inflammation: cromolyns and inhaled corticosteroids. It should be noted that anti-inflammatory medicines that work to relieve arthritis, that is, the non-steroidal anti-inflammatory drugs or NSAIDs, do not work for asthma.

Spirometry
Spirometry is not mentioned in the article but it is an important tool in diagnosing and managing asthma. A spirometer measures the amount of exhaled breath and the time required to exhale the peak amount. A person being tested inhales deeply than quickly and forcefully exhales as much air as possible in a short period of time, usually six seconds. The spirometer measures the volume of exhaled air in the first

second (FEV1, forced expiratory volume) and the total in six seconds (FEV6, forced expiratory volume capacity). These values are compared that to normal values to determine the condition of the lungs. FEV1 is a simple measure of air flow and FEV6 is a measure of lung capacity. Successive measurements over a period of time provide a profile of lung function. Normal results vary but are in this range: FEV6 should be 75 percent of vital capacity after one second, 94 percent after two seconds, and 97 percent after three seconds. Vital capacity is the maximum volume of air that a person can inhale in one breath. Some other useful terms:

> Tidal Volume: during quiet, relaxed breathing, the volume of air that is inhaled or exhaled with each breath, usually 5 to 7 milliliters per kilogram of body weight.
> Residual Volume : the amount of air remaining in the lungs after the deepest exhalation possible.
> Vital Capacity: The maximum amount of air that can be exhaled after the fullest inhalation possible. Vital capacity is the sum of the tidal volume, the inspiratory reserve volume, and the expiratory reserve volume.
> Total Lung Capacity: the sum of the vital capacity and the residual volume.

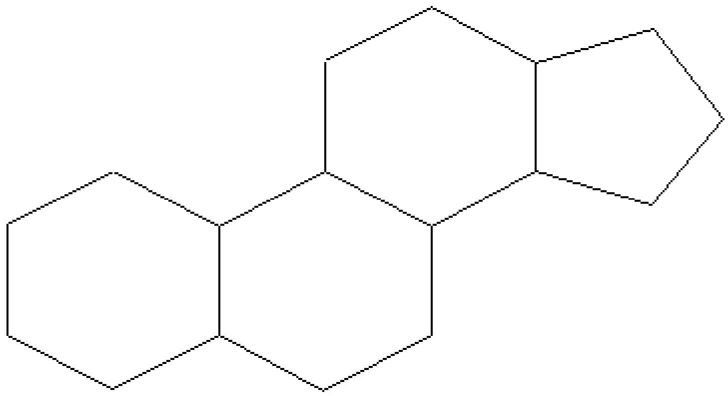
The FEV1 volumes are typically used to classify the severity of the asthma. Normal is considered 80% or more of normal. A mild obstruction corresponds to FEV1 of 65-79% of normal. Moderate is 40-64% and a severe obstruction reduces FEV1 to less than 40% of the expected volume.

Many asthmatics use a type of spirometer called a peak flow meter. It is an inexpensive portable device that permits a person to determine the condition of their own lungs by blowing forcefully into it (like a spirometer) and measuring the reading against a baseline “personal best” measured earlier. For a description of how to use a peak flow meter see
http://www.aaaai.org/patients/publicedmat/tips/whatispeakflowmeter.stm

More on Allergy and Asthma Medicines
The article describes very nicely the type of medications used to prevent and treat allergies and asthma. For an overview of asthma and allergy medications see http://www.emedicinehealth.com/articles/43647-1.asp and use the right hand navigation bar to read about each category of medication. For a detailed web site with reliable information about specific mediations by category see http://www.aaaai.org/patients/resources/medication_guide/ and click on a category to see an illustrated table of information about specific medications.

More on Steroids
The article refers to steroids, and many students will equate that reference with anabolic steroids, simply because they have heard a lot about them. It is important that you take time to educate students about different types of steroids, because the popular press rarely makes the distinction. The term “steroid” is a catch-all term in magazines and newspapers, and students need to understand how the term is used popularly vs. how chemists use the term.

Steroids are a class of naturally occurring organic compounds that have the basic skeleton shown below. Most are fat soluble. In this structure there are three cyclohexane rings (six carbon atoms) and a cyclopentane ring. Chemical groups are often substituted, especially at C10 and C13. In the body, steroids are derived from cholesterol, which is produced from squalene. Examples of important steroids that students may already know include Vitamin D, cortisone, cholesterol and estrogen. In many cases the natural steroid compounds are modified and the derived synthetic compound is used for medicinal purposes, legal or illegal.



The distinction between steroids depends on their origin or their physiological function. Both anabolic steroids and the steroids mentioned in the article are classified a hormones.

Anabolic steroids are synthetic compounds derived from naturally occurring hormones, like testosterone, which are produced in the sex glands. Steroids used to treat allergies and asthma, on the other hand, are called corticosteroids because the natural substances are produced in the upper surface of the adrenal gland. Today both classes of chemicals are produced synthetically for medical use, and are available *legally* only by prescription.

Anabolic steroids enhance male characteristics (androgenic effect) and increase muscle mass (anabolic effect). These are the steroids used illegally by athletes. It is important to note that since anabolic steroids are hormones, they can have significant undesirable side-effects like risk for heart attack and stroke, liver cancer and acne. They can also trigger mood swings, depression and violent behavior. Anabolic steroids are sometimes referred to as androgens.

Corticosteroids, the ones used to treat asthma, mimic the natural steroid cortisol, which is a hormone produced naturally in the adrenal gland and helps to controls many types of body functions. In addition to preventing inflammation, corticosteroids are used in the treatment of nausea during chemotherapy, as an immunosuppressant for transplant patients, and in treating arthritis. Asthmatics usually use, as the article describes, inhaled corticosteroids to control inflammation associated with asthma. Corticosteroids are not sex hormones.

Connections to Chemistry Concepts

1. Gas Laws – the fact that normal respiratory function depends on pressure-volume relationships and on the partial pressures of oxygen and carbon dioxide, this article can be used in connection with a unit on the gas laws.
2. Biochemistry - Much of the chemistry discussed in the article is actually biochemistry.
3. Health – Since allergies and asthma are significant health concerns, the article provides an opportunity to discuss with students the role of chemistry in human health.

Possible Student Misconceptions

1. People in certain parts of the country get more allergies and asthma. To some extent this may be true, but known allergens and asthma triggers are everywhere. The Asthma and Allergy Foundation of America does publish its list of "Allergy Capitals" each spring and fall (see http://www.allergyactionplan.com/springcaps-map.html) the list changes significantly from year to year.

2. The steroids described in the article are **not** the same as anabolic steroids. See More on Steroids.

Demonstrations and Lessons

1. Students might measure their lung capacities by blowing into balloons and then measuring the volume of air by water displacement using a large graduated cylinder. Alternately see http://www.caosclub.org/freelessons/hbody3.html or http://www.nasaexplores.com/show_912_teacher_st.php?id=030109133912 for a specific procedure.

2. Student directions for making a model of the lungs and diaphragm can be found at http://www.chemheritage.org/EducationalServices/pharm/chemo/activity/lung.htm

3. Vernier sells a computer lab probe that acts as a spirometer for measuring respiratory activity. See http://www.vernier.com/probes/spr-bta.html and http://www.vernier.com/cmat/hpa.html

4. The Starbright Foundation sells a CD that helps students learn to manage their asthma at http://www.hsn.com/com/starbright/default.aspx

5. To see a list of famous people with asthma go to http://www.getasthmahelp.org/famous_people.asp or http://www.aanma.org/playtime/pt_famouspeople.htm or http://asthmatrack.org/famous_asthmatics.html

6. Students can learn about asthma from a Medline tutorial at http://www.nlm.nih.gov/medlineplus/tutorials/asthma/htm/index.htm (Requires Flash)

Suggestions for Student Projects

1. If your class agrees, they might conduct a survey of students in the class or in the school who have asthma. They might also interview the school nurse to get insights on the effect of asthma on attendance. The survey could also be done in the community.

2. Students can view the Pew Foundation report at http://healthyamericans.org/state/ and either compare state results or research results for your state.

3. Assign students to interview physicians in your area about allergies or asthma.

Anticipating Student Questions

1. Are allergies and asthma contagious? No, you cannot contract allergies or asthma from another person.
2. Can I develop allergies or asthma? Although the risk factors and “triggers” for asthma are well known (see More on Asthma), physicians cannot reliably predict who will develop allergies or asthma. Two thirds of asthmatics develop symptoms prior to the age of three, but it can develop at any time.
3. Do people die from allergies and asthma? Yes. Asthma is the sixth leading cause of death in children between the ages of 5 and 14. About 5000 deaths were caused by asthma in 1998.
4. Are the steroids in the article the same as the steroids that athletes use to build up muscle mass? No. See More on Steroids.

Websites for additional Information

In 2000, the Pew Foundation’s Environmental Health Commission issued a major report on asthma. Read it here http://healthyamericans.org/reports/files/asthma.pdf

For a guide to childhood asthma from the American Academy of Family Physicians, see http://www.aafp.org/afp/20050515/1959.html

For a guide to asthma and allergy medications see http://www.aaaai.org/patients/resources/medication_guide/ and use the drop-down box to select the category of medications you wish to learn about. The information is presented in table form with links to product insert pages from manufacturers.

The National Institutes of Health provides a great deal of information on asthma at http://www.nlm.nih.gov/medlineplus/asthma.html

For the CDC's FAQ page on asthma see http://www.cdc.gov/asthma/faqs.htm
The has a web site that provides local pollen counts in the United States and Canada. To see this site go to http://www.aaaai.org/nab/index.cfm?p=pollen and click on your location.

The web site for the Allergy and Asthma Foundation of America is http://www.aafa.org/

The web site for the American Academy of Allergy, Asthma and Immunology is http://www.aaaai.org/

For an asthma curriculum, see http://www.nsc.org/EHC/asthma/asthma.pdf

This Mayo Clinic web site explains how inhalers work http://www.mayoclinic.com/health/asthma-inhalers/HQ01081

For a technical article on inflammation and asthma see http://www.nationaljewish.org/disease-info/diseases/asthma/about/what/inflammation.aspx#intro

An informative training guide for the pulmonary system that includes useful terms and procedures can be found at http://www.cdc.gov/niosh/docs/2004-154c/pdfs/2004-154c-ch1.pdf

For a list of chemicals that are known allergens, see http://allergies.about.com/cs/chemicals/a/blmsds.htm

For a timeline showing the history of spirometry see http://medizin.li/spirometer/spirometer-history.html

For a discussion of corticosteroids from the American Academy of Family Physicians see http://www.aafp.org/afp/980800ap/zoorob.html

For more on anabolic steroids see this site from the National Institute of Drug Abuse http://www.drugabuse.gov/Infofacts/Steroids.html or this site from the National Institutes of Health http://www.nlm.nih.gov/medlineplus/anabolicsteroids.html

Bling Zinger: The Lead Content of Jewelry

Background Information

History of lead

Lead is a substance that has been known from ancient times; hence no date can be given for its discovery. As the article mentions, lead is infrequently found in its natural, elemental state but is normally found in ores, especially galena (lead sulfide), and several other minerals. It is obtained by roasting these ores, forming sulfur dioxide or carbon dioxide as by-products in the process. As the article mentions, lead was probably discovered in/around an ancient campfire, but the discovery was most likely purely accidental; someone used rocks to make a fire-ring, and one or more of the rocks happened to contain a lead ore. The heat of the fire "roasted" the rock, releasing the (probably molten) lead metal from its compound in the rock. When the fire cooled, the metal solidified and lead was discovered.

Deposits of galena frequently contain ores of silver as well (or vice versa), and in the beginning, the lead metal was probably volatilized into the atmosphere as a result of the intense heat of the roasting fire used to extract the silver metal. The galena itself was a necessary ingredient in the purification of the silver ore. Eventually, it was discovered that other minerals could be used to purify silver. At that point, the galena itself could be roasted and from it lead metal could be extracted.

The roasting of galena to produce lead (or even roasting galena and silver ore to extract silver) was a very nasty business. A byproduct of the process is sulfur dioxide, and the lead vapors coming off added to the mix. It was a smelly (not to mention, toxic) process. People "in the business" did not live very long. Residing upwind would have been a very desirable location.

Information in the history of lead above was excerpted from http://www.ancientroute.com/resource/metal/lead.htm#Smelting. This site gives much more information, including present-day roasting and smelting practices, as well as uses for lead in early times.

This "Gallery of Lead Pollution Promotions" site provides images from the 1920s and more recent times, illustrating the uses of lead in our society, published by the National Lead Company, and by Ethyl Corporation: http://www.uwsp.edu/geo/courses/geog100/Lead-Ads.htm

This site, "The Secret History of Lead", provides an 8500 year timeline of the use of lead (and leaded gasoline), beginning with lead's discovery in Turkey in 6500 BC: http://www.mindfully.org/Pesticide/Lead-History.htm. It also provides an extensive history of leaded gasoline.

More about lead additives in gasoline

In 1921 a group of engineers discovered that adding tetraethyl lead (TEL) to gasoline could improve its engine performance and reduce pinging of engines. Major oil companies jumped on this discovery and began adding the compound to their gasolines. After researchers discovered that people who worked directly with the additive or gasoline containing the additive had become ill, and frequently displayed symptoms of madness, workers and journalists covering the story dubbed the gasoline, "loony gas". So the engineers were aware of the dangers of the lead additive at a fairly early stage in the history of leaded gas. Even that didn't prevent companies from capitalizing on the benefits of TEL. Leaded gasoline became the norm for almost all American gasolines (except Amoco). The practice of adding tetraethyl lead to gasoline ended with the government phase-out of leaded gasoline from 1973 to 1996.

“Lead Tetraethyl and MTBE” is a basic site describing the problem with TEL as an additive. It also has structural formulas of heptane, octane, and TEL (and MTBE) that can be manipulated, using Chime, Chemsymphony or VRMLhttp://www.chm.bris.ac.uk/motm/leadtet/leadc.htm
A 3-D animation of a tetraethyl lead molecule can be found from the above site at http://www.chm.bris.ac.uk/motm/leadtet/leadtetraethyl.mol. This site requires the Chime applet. It can be downloaded for free (with registration) from http://www.mdl.com/products/framework/chime/index.jsp.

Sources for the information about additives came from:
http://www.corrosion-doctors.org/Elements-Toxic/Lead-additives.htm and
http://www.dartmouth.edu/~toxmetal/TXSHpb.shtml

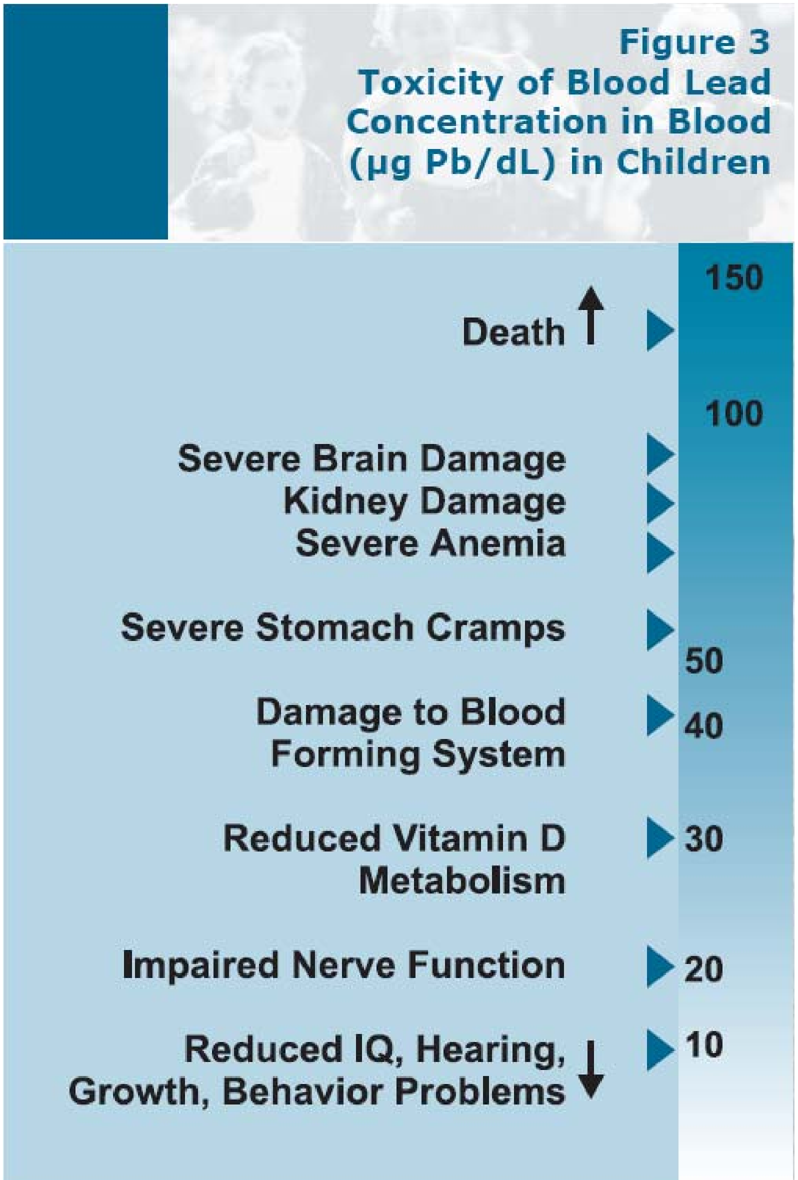
More about lead poisoning

Although the blood does not contain much of the lead found in the body, it is the initial receptacle of lead when it enters the body, whether through ingestion (lead jewelry or lead paint chips) or inhalation (lead paint dust). The blood then distributes lead throughout the body, making it available to soft tissue (from which it may eventually be excreted) and mineralizing tissue (bones and teeth). Of the lead that does travel through the blood, 99% of it stays in the red blood cells. Only 1% is found in blood plasma, yet it is the plasma that transfers the lead to the soft and mineralizing tissues. The plasma may be therefore the more biologically significant entity. Most (as much as 95%) of the lead remaining in the body after exposure is stored in the bones and teeth. There it may remain indefinitely, or it may be released back into the bloodstream in times of stress. Thus the lead once again becomes a threat inside the body. The most widely used test for lead in the body is the blood lead level (BLL). Unfortunately this test only measures lead in the blood, not total lead content of the body, only that small amount that is in the blood at the time of the testing.

The Agency for Toxic Substances and Diseases Registry has published a draft of their “Toxicological Profile for Lead”, published in September, 2005. This site has a series of downloadable pdf files that gives a great deal of information about lead the element, and about its toxicological effects on society. Visit the site at http://www.atsdr.cdc.gov/toxprofiles/tp13.html#.

More about the symptoms

Symptoms of lead poisoning vary with concentration and duration of exposure, and by the individual being exposed. Symptoms range from subtle, almost unnoticeable changes to severe brain damage and possibly death. The following table was taken from “Eliminating Childhood Lead Poisoning: A Federal Strategy Targeting Lead Paint Hazards”, published by the President’s Task Force on Environmental Health Risks and Safety Risks to Children. The 2000 report is accessible at http://www.hud.gov/offices/lead/reports/fedstrategy2000.pdf. The report is part of a 10-year plan to eliminate lead as an environmental problem in children. One of the basic tenets of the report is that “Lead poisoning is a completely preventable disease.” The 90-plus page report lists copious data on lead content in paints over the last 100 years, as well as lead exposure and effects to children over many decades.



Adapted from ATSDR, Toxicological Profile for Lead

As you can see from the chart, relatively low level exposure ($\leq$10 μg/dL concentrations) can result in reduced IQ and other negative neurological and behavioral effects. Exposure to lead has also been identified as one cause of attention deficit disorder (ADD).

More about lead's interaction with calcium in the body

Lead and calcium are chemical analogs – they both react in similar ways under similar conditions. Because of this, lead gets absorbed into the body and interferes with reactions normally involving calcium. Since calcium is the major component of bone, lead gets absorbed into bone just as calcium does. Bone thus becomes a reservoir for lead. This is a particular problem for children with growing bones, as lead will be deposited instead of calcium, frequently resulting in stunted bone growth. That same lead can be leached out of bone under stressful conditions, to return to the bloodstream to do further damage to other body parts.

Lead also has a deleterious effect on the blood-brain barrier as it replaces calcium ions in that system. This again is especially problematic in very young children, where the blood-brain barrier is not yet fully developed. One result of the inactivation of the blood-brain barrier is brain edema. The increased pressure on the brain causes headaches and clumsiness at first, but if left untreated, it can result in seizures, coma, and even death.

Lead also reacts with and interferes with various enzyme systems in the body, resulting in its affecting almost every organ in the body.

Because lead replaces calcium in the body, its toxicity can be greatly increased if the exposed body has a calcium deficiency (think LeChâtelier's principle).

(Source: http://www.emedicine.com/MED/topic1269.htm)

Connections to Chemistry Concepts

1. Periodicity and chemical properties of elements – why does lead interfere with calcium uptake? And why does zinc replace calcium?

2. Thermochemistry – check out this psigate web site, which discusses the chemical reactions involved in the roasting and smelting of galena, lead sulfide, and the free energies associated with both reactions. This would be good to use when you're teaching about heats of reaction and free energies of reaction, as real-world applications of chemical theory. http://www.psigate.ac.uk/newsite/reference/plambeck/chem2/p02266.htm

3. Nuclear chemistry and half-life – the half life of lead in the blood of an adult human is estimated at somewhere between 28 and 36 days. This information could be used in a calculation in the discussion of half-life. It is important to make the distinction for students, though, that this is not a nuclear decay process; rather, it is a biological process of cleaning the lead out of the body. It might be a good discussion to talk about the similarities and differences between nuclear and biological half-life processes, and to discuss the factors that might affect the half-life of lead in the body – factors that would not affect nuclear half-lives.

4. Chelating agents and bonding – this might be a good time to look at the structure of EDTA to see if students can find the six sites in this hexadentate structure.

5. Chelating agents and acid-base chemistry – the EDTA molecule can be used to show coordinate covalent bonding.

6. Activity Series of metals and redox – in the arsenic article "Poisoned!" in the December 2005 issue of ChemMatters, it was mentioned that the elemental form of arsenic (the focus of that article) was much less toxic than the compounds of arsenic. That is not the case for lead, primarily because lead is an active metal and it reacts with acid in the stomach to form soluble lead compounds. So even elemental lead poses a danger if it gets into the body.

7. Poisons and lab safety – This is a great opportunity to talk to students about chemicals and toxicity levels and lab safety. Any chemical can be a poison if the dose is right – or wrong! Remind students of the rule about no eating in the lab – and why it exists. And it's a good time to remind them of the need to wash their hands if they've touched chemicals in the lab.

Possible Student Misconceptions

1. **"Metals are in the ground, just waiting to be found."** Very few metals exist in their natural elemental state in nature. Gold and silver are two metals in this rare group. While a small percentage of lead may be found in its elemental state, far more of it is found in the combined state in its ores like galena.

2. **"Unleaded gasoline means chemists must remove lead from gasoline."** Actually, this is false. Unleaded gasoline means that chemists have not *added* lead *to* gasoline. Lead was added to gasoline as early as 1921, in order to increase octane rating and to minimize pinging of the cylinders in the engine. Gasoline had been leaded for so long (about 75 years) that it became commonplace to believe that all gasoline is "leaded". See the history of leaded gasoline, in the background section, above.

3. **"All gasoline today is unleaded."** This is almost true, but not quite. Gasoline used in the United States is all unleaded, as is true for the European countries. But third world countries still use leaded gasoline, some of which is supplied by the United States! Once again, see history of leaded gasoline, above.

Demonstrations and Lessons

1. When discussing redox and the activity series of metals, you might consider providing this quote from a letter from Ben Franklin to a friend concerning the potential dangers of human exposure to lead, and ask students if a viable hypothesis is offered by Franklin. They should offer chemical evidence to support their position. Here's the source: http://www.fi.edu/brain/metals.htm#top, and here's the quote:
   i. "But I have been told of a case in Europe, I forget the place, where a whole family was afflicted with what we call dry bellyache, or colica pictonum, by drinking rain water. It was at a country-seat, which being situated too high to have the advantage of a well, was supplied with water from a tank, which received the water from the leaded roofs."
   ii. "This had been drunk several years without mischief; but some young trees planted near the house growing up above the roof, and shedding the leaves upon it, it was supposed that an acid in those leaves had corroded the lead they covered and furnished the water of that with its baneful particles and qualities."

2. If you're into humor, check out the lead cartoon at this WebElements site: http://www.webelements.com/webelements/elements/text/Pb/key.html.

3. The December, 1998 issue of *ChemMatters* contains an experiment to test for the presence of lead in paint. View it at http://www.chemistry.org/portal/resources/ACS/ACSContent/education/curriculum/chemmatters/tg/98_D_tg.pdf. The actual text of the article relating to the lead paint experiment, entitled "The Demise of the 'Heavy Metal' Artists", (dealing with heavy metal pigments) in that issue of *ChemMatters* can be found on the 20-year compact disk compilation of issues, from 1983-2003. The CD can be ordered online ($25 single copy or $99 for a site license) at

http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education\curriculum\cmprods.html
.

4. Professor Thomas Greenbowe, representing the Chemical Education Research Group of Iowa State University has put together a very nice series of virtual experiments to determine the activity series of selected metals. The experiments, which require Macromedia Flash, can be found at http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/redox/home.html. A group of eight metals and their nitrate solutions are illustrated. A series of 3 experimental groupings of the metals and their solutions allows students to discover the relative activity of the metals and place them in their proper order in the electromotive series. Experiment 4 allows students to place each of the metals in HCl and observe their reaction with the acid, thus providing the evidence they need to properly place hydrogen on the activity series. (Lead is one of the eight metals.) This series of animated experiments also allows students to zoom in to the molecular level to visualize what is happening at that level when the ions interact with the atoms of the various metals. You can approach this less/series of lessons in one of two ways. 1) You can give them the task of discovering for themselves the correct order of activity for the series of metals, providing only the experiment sequence referenced above. 2) You can provide them with tutorial worksheets that accompany the animated experiment sequence. These will allow students to go through the experiment in a more methodical manner. A complete set of (well) prepared worksheets can be found at http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/Metal=MetalIonTutorialtgrt.pdf. (For some reason, this guide stops at the end of experiment 3, and does not include the metals in acid experiment.)
5. Try this web site for the complete worksheets, including the hydrogen reference cell placement: http://intro.chem.okstate.edu/InquiryActivities/ActivityofMetalsGroup.pdf

6. A wet lab version of the activity series can be found in almost any high school chemistry textbook series lab manual, or try one of these: http://www.dbooth.net/mhs/chem/activityseries01.html, or here's one in microscale from Dave Brooks at the University of Nebraska-Lincoln: http://chemmovies.unl.edu/Chemistry/MicroScale/MScale00.html#MS29

7. This site, http://www.chem.unsw.edu.au/highschool/files/metals.pdf, provides a unit on metals, ranging from historical discovery and uses, through classification by activity series and periodic table, through stoichiometry and even gas laws, to society's uses of the metals.

8. *Environmental Health* Perspectives, a publication by the National Institute of Environmental Health Sciences, provides a wet lab activity based on an article they ran on lead toxicity and chelating agents at http://ehp.niehs.nih.gov/science-ed/2005/chemlead.pdf. The wet lab simulates the chelation of lead out of blood by using sodium EDTA (an actual chelating agent) to remove calcium carbonate - simulating lead - from a mixture of aqueous solutions of sodium bicarbonate (baking soda) and calcium chloride (snow-melt pellets) - simulating blood. The site references the web site for the article, and the lab has both a teacher version (first) and a student version of the lab. It is well prepared. The stated time requirement is 1.5-2 hours, which could be reduced if students read the article and the background material outside of class and came prepared to experiment. A list of online references is also provided. The lab is not necessarily written as a chemistry experiment, more an environmental lab; however, there is a lot of chemistry included in the background information, and the authors have also provided a list of extra chemistry terms a teacher might want to include to "beef up" the chemistry content.

9. This site provides a wet lab to quantitatively determine the amount of lead (acetate) in a sample of Grecian Hair formula. (Were you surprised to learn that this hair treatment contains lead?) The experiment uses two different methods – you could choose which one you want to use, or have half the class do one and half, the other. One requires a chromate compound and the other, an iodide compound. If chromates are a problem for you, choose method II, although the author says method I worked better for him. Check it out at http://chem.lapeer.org/Chem1Docs/LeadAnal.html.

Student Projects

1. Students might want to do a report on the history of leaded vs. unleaded gasoline. A good source to begin this report is:

2. If students want to pursue a study of lead toxicity in our society, they might begin at http://www.atsdr.cdc.gov/HEC/CSEM/lead/index.html, the Agency for Toxic Substances and Disease Registry. The site is a case study designed for health care workers, to update them on the problems associated with lead in our environment. There is a pre-test, and the post-test earns the test-taker continuing education credit in the health field. (This part is way over most students' heads, but the process might be intriguing for possible future health care workers.)

3. Does lead in the body cause Alzheimer's? Students (perhaps affected by the disease through elder family members) might want to pursue this question as a student report. Check http://www.fi.edu/brain/metals.htm#sources for a starting point. It references several studies, although there are no links to the studies referenced here.
4. Several other sites describing lead's possible role in Alzheimer's: http://www.grayenvironmental.com/lead%20exposure%20and%20alzheimers.htm
5. http://www.alzheimersupport.com/library/showarticle.cfm?ID=1376

6. Students might want to investigate the historical controversy centered on tetraethyl lead (TEL) as a gasoline additive and ethyl alcohol as a gasoline replacement fuel in the early 1920s. These sites give a detailed account of the controversy. http://www.radford.edu/~wkovarik/ethylwar/#papers and http://www.thenation.com/doc/20000320/kitman Although it might be more in the realm of science fiction rather than science, students might enjoy writing an account of how life might be different if the choice of ethyl alcohol had been made instead of TEL (based on their research, of course).

7. If students want to pursue the oft-mentioned hypothesis that the Roman civilization fell due to lead poisoning (as was hinted at in the article), this site lists non-web-based sources for further research: http://www.nipissingu.ca/department/history/MUHLBERGER/ORB/LEAD.HTM

8. Students looking for a science project might check this site from the *Lake County Reporter*, a Hartland, Wisconsin newspaper report of one seventh grader's project to test for lead in "gumball machine" jewelry. http://www.zwire.com/site/news.cfm?BRD=1399&dept_id=173059&newsid=14369699&PAG=461&rfi=9. A high school chemistry teacher provided the experiment and materials for her chemical tests. This girl's test was qualitative only. High school students might want to "kick it up a notch" by employing quantitative methods to determine amounts of lead in a sample, rather than just detecting its presence.

Anticipating Student Questions

1. **"Does all jewelry contain lead?"** Inexpensive ("costume") jewelry is more likely to contain lead than good (expensive) jewelry. A silver or gold ring, for instance, probably does not contain lead. Gold is typically alloyed in jewelry with silver, platinum, palladium, nickel or zinc and, to make a "rose" gold, copper. No mention of lead was evident in any researched web sites.

2. **"Do I need to worry about lead in my costume jewelry?** First, the jewelry may not contain any lead. Second, if the jewelry doesn't touch your skin directly, you don't rub it incessantly, and you don't put it in your mouth, you probably don't have to worry as your exposure to lead is minimal.

3. **“Are we exposed to enough lead in our daily lives to cause concern?”** Probably not. The major source of lead exposure had been from leaded gasoline, up until the mid-70s. As the article mentioned, atmospheric levels of lead have decreased by 90% from leaded gasoline levels. The most prevalent source today is probably lead paint, and unless you’re gnawing on paint chips around the house, you probably have a minimal risk of exposure to lead through this medium.

4. **“Why don’t atmospheric levels of lead drop to zero?”** Even though North America and Europe have agreed to ban leaded gasoline, many third-world countries still depend on it. So they are still spewing out lead into *their* atmosphere, which eventually becomes *our* atmosphere (although much diluted in lead content by then).

5. **“I used to chew on lead jewelry when I was a child. Should I worry now?”** Students probably can’t really remember what they did as a child, so this might just be an attention-getter. If, however, this is a real question, the student should probably get tested by a doctor for BLL. If BLL is discovered to be high (>10μg/dL of blood) the doctor might prescribe chelation therapy to reduce it. Truthfully though, if the student had chewed on leaded jewelry in his/her earlier life, some of the symptoms of lead poisoning probably would have shown up by now. (Better to be safe than sorry, though.) (This is a tricky question as we are not doctors; nor do we want to scare students concerning their health.)

Websites for additional Information

General

This is a good site for background information on the history of and problems associated with lead: http://www.dartmouth.edu/~toxmetal/TXSHpb.shtml

This site, http://www.luminet.net/~wenonah/hydro/pb.htm#pb-use, gives a brief overview of the physical and chemical characteristics of lead, then lists its uses, a whole series of compounds of lead and their uses, and then discusses lead toxicity, citing and paraphrasing many articles from other sources. It also discusses the use of chelating agents to remove lead from the body, but mentions that removal of lead does not undo biological effects, especially decreased mental acuity. The site even contains an article that relates an increase in teenage violence in the 1950s to 1990s to increased blood lead levels due to inhalation of tetraethyl lead in leaded gasoline. (This hypothesis probably requires further research.) Another connection the author tries to make is that of elevated blood lead levels to cataract formation in elderly men. (Evaluate the information before you believe it – a good lesson to be learned by students, too.)

History of lead

Benjamin Franklin was aware of problems involving the use of lead. Visit this site from the Franklin Institute in Philadelphia, http://www.fi.edu/brain/metals.htm, to read the letter that Franklin sent to a friend, Benjamin Vaughan on July 31, 1786, discussing the danger of lead as he knew it.

Sven Hernberg, an MD, published “Lead Poisoning in a Historical Perspective” in 2000 in the *American Journal of Industrial Medicine*. This article highlights evidence for the toxic nature of lead throughout history. It can be found at http://www.rachel.org/library/getfile.cfm?ID=441.

Lead jewelry

As mentioned in the article, the lawsuit in California has indeed been settled, as the article was going to publication. This is the official California state government press release from the Office of the Attorney General about the pending lead jewelry litigation:

http://ag.ca.gov/newsalerts/release.php?id=1258. The site also has links to the actual settlement document (152 pages) and petition to the court to allow the settlement of the case (18 pages). The case was brought to the court's attention through Proposition 65, California's premier right-to-know law. Under this law, consumers have the right to know about the content of any product that might jeopardize their health or well-being, especially substances known to be carcinogenic or teratogenic. Lead had been known to cause birth defects and reproductive problems from research published as early as 1987, and it has been on the known carcinogen list since 1992, according to this web site article. Almost all of the named defendants, jewelry producers and distributors, have agreed to the terms of the settlement, requiring the payment of almost $2 million in penalties and funds appropriated to educate the public about the dangers of this type of jewelry. Thirty eight distributors have joined the group, while five remain as litigants in the suit.

This federal government has not been sitting idly by while states such as California establish laws limiting lead in jewelry. The following site describes the federal government's 2005 allowable levels of lead in jewelry, based upon lead levels in children ages 1-5: http://www.cpsc.gov/businfo/pblevels.pdf. Their recommendation is less than 600 parts per million (0.06%) lead in the jewelry. Even this could result in 10 μg/dL of lead in a child's blood, the presently accepted threshold level of concern for children.

This site, http://www.cpsc.gov/businfo/pbjewelgd.pdf, the *Interim Enforcement Policy for Children's Jewelry Containing Lead*, is the February, 2005 publication of the U.S. Consumer Product Safety Commission's Office of Compliance. It outlines the policy the CPSC is taking with regard to possible lead content in children's jewelry. It uses the (then-) present accepted maximum levels established by the scientific community in its enforcement, but it also notes that further research may force CPSC to lower those standards to meet the new evidence. They also establish two standard procedures for testing suspect jewelry. They are found in the next web site.

This site provides the procedure for the two lead tests mentioned in the web site above: http://www.cpsc.gov/businfo/pbjeweltest.pdf. The first test is to determine total lead content of a specific piece of jewelry, or a part thereof, and the second test, the acid extraction test, is to determine how much of the lead is likely to migrate from the jewelry to a person through human ingestion and its subsequent decomposition in stomach acid. It might be interesting to photocopy these procedures and discuss it with students, as they represent "official" experiments that "real" scientists do. You can point out the standardization of technique and need for uniform reporting of results. It might also be interesting to point out the parts of the experiment that sound similar to what your students may already have done in their own labs, versus those parts that use equipment unavailable in your lab, or that require outside standardization methods. (ASTM refers to ASTM International, which is one of the premier standardization and testing associations in the world.)

Lead in our environment

This Dartmouth research site, http://www.dartmouth.edu/~dujs/2003S/graphite.pdf, cites an experiment designed to test the lead content in several Vermont farms' maple syrup samples. It is an interesting article for two reasons. First, it describes the effects of lead exposure in both children and adults and describes a study done to test samples for lead content, after explaining where the lead might come from in what might seem to be an unlikely source – maple syrup. And second, because it describes the study in terms of the actual experiment done, using the terms students are already familiar with – hypothesis, procedure, results, analysis of results, conclusions, and error analysis. And although it goes into much detail about the apparatus, a graphite furnace atomic absorption spectrometer, the article closely parallels what a good student lab report might look like in your classroom. Thus it might be worthwhile using this study in a class discussion of what a good lab report should include. By the way, the findings showed that the tested maple syrup samples were well below acceptable levels of lead.

The EPA web site for lead, http://www.epa.gov/opptintr/lead/index.html, briefly discusses lead poisoning and gives many links to other topics relating to lead, including links to outside agencies/organizations.

The EPA also hosts the National Lead Information Center, at http://www.epa.gov/opptintr/lead/pubs/nlic.htm. This site "…provides the general public and professionals with information about lead hazards and their prevention." It provides an opportunity for individuals to ask questions via email or phone or fax and to get a response to these questions by professionals.

The Agency for Toxic Substances and Disease Registry provides a case study for health care workers on lead toxicity at http://www.atsdr.cdc.gov/HEC/CSEM/lead/index.html. It is designed to provide information that can be used to test health care workers for continuing education credit. It is very detailed (as might be expected, given its audience), but students will find useful information here.

For a definitive statement from the Centers for Disease Control about lead in our environment and its effects on society, and children in particular, see "Preventing Lead Poisoning in Young Children" at http://www.cdc.gov/nceh/lead/Publications/PrevLeadPoisoning.pdf. This August, 2005 document spells out precisely the dangers of lead to society, especially to children, and especially to children in poor areas.

The Franklin Institute site at http://www.fi.edu/brain/metals.htm#sources opens with a very brief history of lead toxicity, and then provides scientific studies relating lead to all types of human maladies, including the usual – lower IQ, antisocial behavior and ADD – and some less common types – Alzheimer's and senile dementia. It offers summaries of scientific studies that show how lead affects the brain as well. It also includes studies that deal with lead's effects in children, and some unusual sources of lead, like fluoridated water and candles.

The Centers for Disease Control provide several tables of information regarding BLL's from 1991-94 and compare them to similar data from 1999-2002 to show how lead levels have decreased over time. View the information at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5420a5.htm

eMedicine provides a site that gives a complete list of symptoms of lead poisoning, as well as patient tests and care at http://www.emedicine.com/EMERG/topic293.htm.

For a *very* detailed account of lead's effects on human systems, see http://www.emedicine.com/MED/topic1269.htm.

Chelation Therapy

(These sites were first listed in the December, 2005 article, "Poisoned!", written by the same author as this article.)

http://scifun.chem.wisc.edu/chemweek/Chelates/Chelates.html is another of Shakhashiri's "Chemical of the Week" articles, which focuses on the chemistry of a chelating agent, and one chelating agent in particular, dimercaprol, an anti-heavy (including arsenic) agent. The site also discusses EDTA.

http://www.dow.com/PublishedLiterature/dh_013c/09002f138013c0bc.pdf is a site that gives background on why chelating agents are used in consumer products. It is a Dow Chemical site, and gives ample advertising, but it also has some useful information.

http://www.portfolio.mvm.ed.ac.uk/studentwebs/session2/group29/treattox.htm a site that describes heavy metals toxicities, as well as the antidotes, where known

Related sites

A story similar to the one in this issue involving lead poisoning on a voyage in the Arctic region in 1845 can be found in the December, 2005 issue of ChemMatters. That issue contained an article, "Poisoned!", detailing the voyage by Charles Hall in 1871 attempting to be the first explorer to reach the North Pole. The major difference is that the poisoning agent in that issue involves arsenic, not lead. Many

circumstances are similar, however, especially the crew's reliance on "canned" food. More information about that story can be found in the following sites (repeated from the December 2005 Teacher's Guide):
http://www.crimelibrary.com/notorious_murders/classics/charles_francis_hall/ is a book about Charles Hall's death close to the North Pole.
http://www.smithsonianmag.si.edu/smithsonian/issues01/feb01/arctica.html provides more information on Charles Hall's death in a book, Top of the World.
http://www.nytimes.com/books/01/02/25/reviews/010225.25wheelet.html cites reviews of two more books recounting Hall's ordeal, Fatal North and Trial by Ice

Biomimicry

Background Information

More on Green Chemistry

Like the article, the American Chemical Society's Green Chemistry Institute (GCI) web site describes green chemistry as "the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances." Further, it states that "Chemists and engineers are designers who have the unique ability to affect molecules, materials, products, processes, and systems at the earliest possible stages of their development.

- What will be the human health and the environmental impacts of the chemicals we put into the marketplace?
- How efficiently will the systems be with which we manufacture products?
- What will tomorrow's innovations look like, and from what materials will they be created?

We begin answering these questions the moment we put pen to paper, and the designs we create affect the course of entire sectors of the world economy. The Principles of Green Chemistry and Green Engineering embrace this power of design, and insist that if we use it wisely, we can make significant contributions in the drive toward sustainability."

The GCI web site says this about the principles: "The principles of green chemistry and green engineering provide a framework for scientists and engineers to use when designing new materials, products, processes and systems. The principles focus one's thinking in terms of sustainable design criteria and have proven time and again to be the source of innovative solutions to a wide range of problems. Systematic integration of these principles is key to achieving genuine sustainability for the simultaneous benefit of the environment, economy, and society."

The twelve principles of green chemistry are:

1. Prevention It is better to prevent waste than to treat or clean up waste after it has been created.
2. Atom Economy Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Less Hazardous Chemical Syntheses Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment
4. Designing Safer Chemicals Chemical products should be designed to effect their desired function while minimizing their toxicity.
5. Safer Solvents and Auxiliaries The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. Design for Energy Efficiency Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. Use of Renewable Feedstocks A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. Reduce Derivatives Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. Catalysis Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Design for Degradation Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. Real-time analysis for Pollution Prevention Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. Inherently Safer Chemistry for Accident Prevention Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

NOTE: See http://www.epa.gov/greenchemistry/principles.html for the EPA version of the principles.

More on Biomimicry

The term "biomimicry" is derived from *bios* meaning life and *mimensis*, to imitate. The idea is actually not new, but the term was coined and popularized by Janine Benyus in her 1997 book *Biomimicry: Innovation Inspired by Nature,* which the article describes briefly. Benyus has assembled ideas from a number of scientific disciplines and constructed a framework of thinking about the ways in which natural processes and organisms produce materials and process energy. According to her web site three major pillars of biomimicry are:

> **Use nature as a model** – study the processes in nature and imitate them or adapt them to solve human problems
>
> **See nature as a mentor** – since nature has learned "what works, what is appropriate and what lasts" use nature as a guide.
>
> **Use nature as a measuring stick** – look at human behavior and modern society in terms of what nature values and what humans can learn from nature.

A classic examples of biomimicry, in addition to those cited in the article (the telephone and the airplane), include the invention of Velcro by Swiss engineer George de Mestral in 1948, when he noticed how burrs from plants stuck to his dog's fur. Leonardo da Vinci often studied nature and based his inventions on natural design, and Buckminster Fuller is often credited with introducing many of the principles of biomimicry.

In current practice biomimicry can also be thought of a part of bionics, which also includes bioengineering, biomechanics, and integrated design systems. Bionic designs fall into one of two categories: analogic and composition synthetic design systems. Analogic systems are technical systems based on biological principles, and these are what most people think about as biomimicry. Examples are radar based on bat echolocation, the strength of spider webs and other examples described in the article. Composition systems are a mix of both technical and biological components. Examples include computer network systems that require human maintenance, chemical syntheses that use biological catalysts and humans wearing prosthetic devices or pacemakers.

Another system of organizing biomimetric engineering is:

1. Mimicking the way in which nature manufactures chemical compounds. This is the strongest link between biomimicry and green chemistry.
2. Imitating mechanisms (like Velcro or echolocation) found in nature.
3. Imitating organizational principles found in nature, like the behavior of bees or ants

Both green chemistry and biomimicry are part of a growing interest in chemistry for sustainability, which means using processes and resources that are less damaging to the environment. Dr. Terry Collins, professor of chemistry at Carnegie Mellon University and a leading expert on sustainability, says:

"When chemists teach their students about the compositions, outcomes, mechanisms, controlling forces, and economic value of chemical processes, the attendant dangers to human health and to the ecosphere must be emphasized across all courses. In dedicated advanced courses, we must challenge students to conceive of sustainable processes and orient them by emphasizing through concept and example how safe processes can be developed that are also profitable.

"Green or sustainable chemistry can contribute to achieving sustainability in three key areas. First, renewable energy technologies will be the central pillar of a sustainable high-technology civilization. Chemists can contribute to the development of the economically feasible conversion of solar into chemical energy and the improvement of solar to electrical energy conversion. Second, the reagents used by the chemical industry, today mostly derived from oil, must increasingly be obtained from renewable sources to reduce our dependence on fossilized carbon. This important area is beginning to flourish, but is not the subject of this essay. Third, polluting technologies must be replaced by benign alternatives." http://www.sciencemag.org/cgi/content/full/291/5501/48

More on the Golden Orb Weaver Spider

The case of the golden orb weaver's web may be a case of double biomimicry. In 1881, a physician, Dr. George Goodfellow, in Tombstone, Arizona noted that bullets fired even at close range could be trapped (and sometimes stopped) by as little as two thicknesses of handkerchief silk. The strength of silk strands has been a focus of research for decades for applications such as stronger ropes, parachutes, improved sutures and bandages, artificial tendons and ligaments, and supports for weakened blood vessels.

Chemists saw the strength of the dragline silk of the golden orb weaver spider (*Nephila clavipes)* as a second source of strong fibers. Golden orb weavers build large, strong, vertical orb webs. Geneticists believe that these spiders have been producing the silk in the same way for more than 125 million years. Harvesting spiders for silk production, however, is difficult because they tend not to live near one another. So a Canadian company has genetically engineered goats to produce spider milk. The dragline silk is then removed from the goat's milk for use

Golden orb weaver spiders produce several types of silk in the form of water-soluble protein. The proteins are extremely long with thousands of amino acids in the chain. As the article describes, the silk is forced out through a spinneret where the folded silk protein are stretched out to form the silk fibers.

More on the Bomdardier Beetle

The chemistry of the bombardier beetle is well defined. The beetle stores the reactants that produce the spray in two separate glands, each having two compartments. In one gland is stored hydroquinone and hydrogen peroxide (each in its own compartment). The other gland contains special enzymes, catalases and peroxideases, which catalyze the reaction. When the reactants are mixed in a chamber in the second gland, the hydrogen peroxide oxidizes the hydroquinone to *p*-benzoquinone. Oxygen is also produced from the hydrogen peroxide and acts as a spray propellant. The reaction is exothermic and the temperature of the spray is about 100^oC.

Hydroquinone, $C_6H_6O_2$, is used as a corrosion inhibitor, in photochemicals, in the manufacture of polystyrene, for printing and in latex production. It has a melting point of
172 – 175^oC, a boiling point of 285^oC. Its density is 1.33 g/cm^3 and is moderately soluble in water.

P-benzoquinone, $C_6H_4O_2$, also referred to as 1,4-benzoquinone, has a melting point of 113 – 115^oC and a boiling point of about 180^oC.

More on Blue Mussels

The glue produced by the blue mussel, *Mytilus edulis*, according to Dr. Herbert Waite, who is now at the University of California at Santa Barbara, is actually "a bundle of threads collectively referred to as the byssus. Byssal threads are permanent holdfasts and extraordinary biomolecular materials; they are strong, rapidly made, durable and adhere to a wide variety of surfaces including glass, metal, paraffin and bone. A careful morphological examination of byssus reveals it to be a complex composite material with at least four functional domains: load-bearing fibers, microcellular solids, sealants and adhesion promoters. . . We are using protein chemistry, molecular biology and a variety of physical methods including laser mass spectrometry, solid-state NMR and atomic force microscopy to reveal sequence, structure and solution behavior. Our aim is ultimately to process the appropriate protein(s) into useful applications that mimic their adapted functions in the mussels."
http://www.lifesci.ucsb.edu/mcdb/faculty/waite/research/research.html

Applications of this "superglue" might include plywood manufacture, wood veneers, particle board and other wood products. Other uses might include biological glue for surgery and dentistry.

In January, 2004, Jonathan Wilker, Mary Sever and their colleagues at Purdue University announce their discovery that iron in seawater is the key binding agent in the glue. In trying to make the glue synthetically, the researchers discovered that mussels and other bivalves extract the metal iron from the surrounding seawater and use it to join proteins together, linking the fibrous molecules into a strong, adhesive mesh. Wilker says, "We are curious as to whether or not this newly discovered, metal- mediated protein cross-linking mechanism of material formation is a prevalent theme in biology. We will be exploring systems such as barnacle cement, kelp glue and oyster cement to see how other biomaterials are produced," http://www.eurekalert.org/pub_releases/2004-01/nsf-ccs010704.php

Other Examples of Biomimicry
The article describes several examples of biomimicry besides the golden orb weaver spider, the bombardier beetle and the blue mussel. The list of substances and processes based on natural design is growing by the month. Examples include:

1. Smart clothing, based on the behavior of pine cones. As temperature increases, the cones open and as the temperature decreases, the cones close up. Clothing has been designed by Julian Vincent using this principle.
   http://news.nationalgeographic.com/news/2004/10/1013_041013_smart_clothing.html
2. Airplane wings that change shape based on the speed of the plane and distance of the flight, much the same as birds change the shape of their wings. According to Dr. George Lesieutre, professor of aerospace engineering at Penn State University, “Flying efficiently at high speed requires small, perhaps, swept wings. Flying at slow speed for long periods requires long narrow wings. The morphing wings designed by the Penn State team can change both wing area and cross section shape to accommodate both slow and fast flight requirements.”
   http://www.psu.edu/ur/2004/morphingwings.html
3. Photonic crystals that behave like the wings of a colorful butterfly are being developed for optical application. http://europa.eu.int/comm/research/headlines/news/article_04_11_16_en.html
4. Antimicrobial gases. Montana State University biologist Gary Strobel Strobel found that a fungus collected from a cinnamon tree in Honduras was able to emit a gas mixture that has antimicrobial properties. Says Strobel, “This little thing is a chemical factory," says Strobel. "When we put all the chemicals together in the same ratio, we can reproduce its effect against other microbes. You can grow it on one half of a plate and put almost any microbe on the other side and [the microbe] will grow for an hour and die." http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=104473&org=NSF
5. Mechanical cochlea. According to the National Science Foundation, “ Researchers at the University of Michigan are developing a mechanical cochlea, a device that functions much like its human counterpart in the ear. Yet, because it is composed of micromachined parts and integrated circuits, the apparatus should be inexpensive to manufacture and could potentially capture a range of frequencies well beyond those of human hearing. While designed primarily as a highly efficient sensor to detect sound waves underwater, the machined cochlea could one day substitute for the microphone and much of the electronics in cochlear implants at a much lower cost.”
   http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=104071&org=NSF

6. A company called Interface has designed carpet tiles mimicking the forest floor. Company president Ray Anderson says, “Our product designer asked his design team to go into the forest, spend a day and figure out nature's design principles. How would nature design a floor covering? It finally dawned on them that if you look at the forest floor, there are no two things alike. No two sticks, no two stones, no two leaves, no two anything alike.
   “So you got this sort of chaotic mix of diversity and you can pick up a rock here and drop it there and you can't tell you've changed a thing. They came back to the studio and designed carpet tiles where the design in the face of the carpet tile, no two tiles were alike. We introduced that product -- we called it Entropy, for obvious reasons: disorder -- and in a year and a half it became the bestselling product in our line, faster than any other product ever has.”
7. Lobsters are able to “smell” molecules in their aquatic environment using olfactory antennules. According to researcher Mimi Koehl at UC Berkeley, “If you look across the animal kingdom you see that many kinds of organisms have appendages with rows of tiny hairs on them that catch molecules from the surrounding fluid.” Continues Kroehl, “We now understand the mechanism that allows the chemosensory hairs to catch odor traces. Lobsters and other crustaceans are very successful at

finding the sources of odors in the messy, turbulent water flow in the ocean. By understanding the physics, we gain insights for the design of man-made chemical-sensing antennae that can be used in the same kind of environments." The discovery of this mechanism in lobsters may allow scientists to mechanical design systems for detecting dangers in water or air environments where it may be dangerous for humans to go. http://sciencereview.berkeley.edu/articles.php?issue=4&article=lobsters

8. One of the classic cases of biomimicry is the development of barbed-wire fencing in the American west. As farmers settled in the west, they wanted to protect their land from herds of sheep and cattle. One solution offered by nature was the Osage Orange tree, which has branches with sharp thorns that grow out in all directions. Planting a row of these trees provided a natural fence to ward off animals. However, it took years for the trees to mature. Michael Kelly of Illinois filed the first patent for barbed wire in 1868. His invention was based on the Osage Orange tree. At the time he said, "My invention [imparts] to fences of wire a character approximating that of a thorn-hedge. I prefer to designate the fence so produced as a 'thorny fence'." Kelly inserted pieces of sharp metal between two strands of fencing wire and twisted the strands to hold the barbs in place. By the late 1800's barbed wire dominated the west.

9. The abalone, a marine mollusk, builds its strong shell from just calcium carbonate and protein. The layers of carbonate are connected by protein to make a very strong laminate. Compared to a brick walls, the calcium carbonate forms the bricks and the protein is the mortar. Such laminates can be used for lightweight armor and has made and ceramic-metal composites. A team of researchers at Princeton University, lead by Ilhan Aksay developed the composites in the late 1990's. Says Aksay, "When people ask me if I needed to study biological systems to invent laminated ceramic-metal composites," he says, "I tell them, no, I might have come up with the idea anyway, but studying biological systems helped get me there faster." More recent developments mimicking the hardness of the abalone shell have been done at the University of California at San Diego. The laminated composites will find potential uses in tooth repair and in the manufacture of cutting surfaces that will not dull.

10. Professors Jerzy W. Rozenblit and Salim Hariri at the University of Arizona are developing computer software that mimics the human immune system. This "immunity software" screens a computer for anything out of the ordinary, isolates any viruses it finds, develops software "antibodies" to fight them. Hariri says this new approach — mimicking biological systems — is necessary because conventional methods used to protect computers from attack have failed. "The vulnerability of computer systems to malicious attacks, as well as the number of attacks, is threatening national security, business, industry and educational institutions."

Connections to Chemistry Concepts

This article illustrates several topics normally covered in a general chemistry course.

1. Properties of Matter - Along with the usual physical and chemical properties of matter, consider adding toxicity or environmental hazard to the list. Green chemistry looks to use chemicals that are least dangerous to the environment.

2. Types of reactions and reaction mechanisms – As you discuss reactions, reaction mechanisms and reaction conditions, you might include examples of natural reactions in the article. For example, the reaction involved in the bombardier beetle includes synthesis, catalysis, and energy of reactions.

3. Catalysts – Several of the examples in the article (and in "Other Examples of Biomimicry") include the use of catalysts.

4. Environmental chemistry, Natural resources and Sustainability – These are larger issues in chemistry that might fit as topics for projects or class discussions. The article might be used as a discussion starter, for example.

Possible Student Misconceptions

1. Students may associate chemistry, at least on the industrial scale, with pollution and accidents since much of the news about the chemical industry is focused in that direction. It is important to acknowledge to students that some of chemistry's reputation is correct, but that efforts are being made to change the industry. This article and related resources provide you with an opportunity to paint a more realistic picture for students.

2. Students may have the idea that chemical reactions take place only on a lab table in their classroom or in a research lab. This article provides you with the chance to remind students that chemical reactions are an integral part of nature and that chemistry essential to many areas of our lives.

3. Students may tend to think that substances in their world (like the Kevlar mentioned in the article for its strength) with "extreme" properties (strong, long-lasting, etc.) are exclusively the result of human design and manufacture. The fact that chemistry is now looking to mimic the natural world in meeting the needs of society is a worthwhile concept to teach.

Demonstrations and Lessons

1. This page on the ACS web site contains a list of students activities and lessons that could be used with this article: http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=greenchemistryinstitute\education\edresources-highschool.html

2. The University of Oregon has a searchable database of activities and lesson that students can do: http://greenchem.uoregon.edu/gems.html

3. Students can view two films from Bullfrog Films, based on Benyus' book. Each film is about 45 minutes in length and is appropriate for grade 7 and up. Ordering information can be found here: http://www.bullfrogfilms.com/catalog/bmic.html

4. Advanced students might be able to work in groups to solve the biodesign challenge posed here: http://www7.nationalacademies.org/keck/Keck_Futures_Nano_Conferences_Nano_Factory_Description.html.

5. A list of possible biomimicry activities from Janine Benyus can be found here http://www.biomimicry.net/pdf/biomimicry_methodology.pdf

Suggestions for Student Projects

1. Students can read a description of a real-world case of green chemistry at http://www.chemistry.org/portal/resources/ACS/ACSContent/education/greenchem/case.pdf and identify as many Green Chemistry principles as possible. *Real-World Cases in Green Chemistry* by Michael C. Cann and Marc E. Connelly is an educational resource published by the American Chemical Society. For more information see http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Cgreenchem%5Ccases.html

2. Students can do a typical chemistry experiment (iodine clock reaction) using household chemicals. For background and a procedure (with teacher notes) see http://www.chemistry.org/portal/resources/ACS/ACSContent/education/greenchem/SafeStart.pdf. The activity is taken from "Introduction to Green Chemistry" which is available from ACS. See

http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education\greenchem\order.html for ordering information.

3. Assign students one or more of the introductory articles on green Chemistry that can be found here http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education\greenchem\greenreader.html and have them report on the topic.

4. Refer to Other Examples of Biomimicry (above) and the websites below marked with an asterisk for examples of biomimicry other than the three in the article. Assign each student one of the examples and have them prepare a report.

5. Students can research several phytochemicals (chemicals found in plants) using this ACS publication as a guide http://www.chemistry.org/portal/resources/?id=e67744d869ba11d7f2c16ed9fe800100

Anticipating Student Questions

1. What is Green Chemistry? (See "More on Green Chemistry.")
2. What is biomimicry? (See "More on Biomimicry.")

Websites for additional Information

Visit the American Chemical Society's green Chemistry Institute web site at http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=greenchemistryinstitute%5Cindex.html

For more on the Environmental Protection Agency's Green Chemistry program see http://www.epa.gov/greenchemistry/

You can read a Chemical & Engineering News article from 2001 that describes advances in Green Chemistry at http://pubs.acs.org/cen/coverstory/7929/7929greenchemistry.html

The Biomimicry web site set up by Jane Benyus with much more about the topic is located here: http://www.biomimicry.net/
The Green Chemistry site at the University of Oregon can be viewed here http://darkwing.uoregon.edu/~hutchlab/greenchem/index.html

* For an online article on biomimicry that includes examples of biomaterials and bioengineering see http://www.bioteach.ubc.ca/Bioengineering/Biomimetics/ (Use this article as a place for students to begin their research on the many examples of biomimicry in this article.)

For lists of additional articles about the silk of the golden orb weaver spider see http://www.arachnology.be/pages/Silk.html and http://www.arachnology.org/Arachnology/Pages/Silk.html

For an article on spider silk fibers published in Chemical & Engineering News in 2003, see http://pubs.acs.org/cen/science/8124/print/8124spidersilk.html

* For a link to more than 30 articles on chemistry in animals from *Chemical & Engineering News*, see http://pubs.acs.org/cen/critter/critterchemistry.html (Use this article as a place for students to begin their research on the many examples of biomimicry in this article.)

* National Academy Press has published a book called *Chemical Ecology*, which can be read online at http://www.nap.edu/books/0309052815/html/index.html . It contains examples of biodesign. Most entries are for more advanced students. (Use this article as a place for students to begin their research on the many examples of biomimicry in this article.)

* For an online article on natural design from Smithsonian Magazine called “Second Nature” seehttp://www.smithsonianmag.si.edu/smithsonian/issues02/jul02/pdf/smithsonian_july_2002_second_nature.pdf (Use this article as a place for students to begin their research on the many examples of biomimicry in this article.)

Related ChemMatters articles:

Black, H. “Green Refrigerants,” *ChemMatters*, 2000 (February), 11-13.
Jones, Don. “Hydrogen Fuel Cells for Future Cars,” *ChemMatters*, 2000 (December), 4-6.
Rohrig, Brian. “Food Packaging-Wrapping Up Freshness,” *ChemMatters*, 2000 (October), 9-11.
Ryan, Mary Ann. “Benign by Design,” *ChemMatters*, 1999 (December), 9-11.
Zelaya-Quesada, Myrna. “Chemical Foams in the Line of Fire,” *ChemMatters*, 2001(April), 8-9.

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Lucien Gerardin, *Bionics*, McGraw-Hill, New York, 1968.

NanoMotors

Background Information

History Of Nanotechnology

(Note: The following section about the history of nanotechnology is a copy of material found originally in the February '06 issue of the ChemMatters Teacher Guide.)

Dr. Richard Feynman, the brilliant Nobel Laureate physicist, was one of the first people to recognize the importance of nanoscale materials. He is credited as the "father of nanotechnology for the statement he made In his 1959 lecture, "There's Plenty of Room at the Top", that the properties of materials at the nanometer scale would present great opportunities for the future. He said, "…the principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. It is not an attempt to violate any laws; it is something, in principle, that can be done; but in practice, it has not been done because we are too big." For a complete copy of Feynman's speech, go to http://www.its.caltech.edu/~feynman/plenty.html, or http://www.zyvex.com/nanotech/feynman.html.

Almost 30 years later (in 1986), Eric Drexler wrote a book called, "Engines of Creation: The Coming Era of Nanotechnology", which caused greater public awareness – and perhaps fear – of the new technology. This book is accessible on the web at http://www.foresight.org/EOC/Engines.pdf.

In 1985, C_{60} molecules, buckminsterfullerenes (fullerenes or buckyballs) were discovered by Harold Kroto, James Heath, Sean O'Brien, Robert Curl, and Richard Smalley. These were the first carbon polyatomic molecules discovered. It was recognized that these were essentially graphite molecules wrapped into 3-dimensional shapes. Nanotubes were the next variety of these distorted graphite sheets, discovered by Iijima in 1991.

Richard Smalley's personal papers are now part of the Chemical Heritage Foundation's collection. They are not yet completely catalogued, but they will be in the near future. When they are catalogued, they will be available online at www.chemheritage.org.

The U.S. federal government got in on the nanotechnology revolution in 2001 when it initiated the National Nanotechnology Initiative, a directive that seeks to further nanotechnology research, while keeping an eye on the implications for ethics, health and the environment. You can access the site at http://www.nano.gov/index.html

For a timeline of some of the important discoveries in nanoscience, see the following web sites:
http://www.nanoscience.com/education/chronology.html, a chronology of scanning probe microscopy, responsible for being able to see materials at the nanoscale,
http://www.msc-nanoscience.tudelft.nl/nanotimeline.html provides a brief timeline that stops at 2001.
http://www.pa.msu.edu/cmp/csc/nanotube.html is a 10-kyear timeline of nanotube discovery, from 1991-2001.

For a succinct history of technology (not in timeline form), visit http://www.nanotech-now.com/Press_Kit/nanotechnology-history.htm

History Of Nanomotors

Nanomotors are a very recent discovery in the history of science.

Myosin has been known as a protein for over a century (it was discovered by Kuhne, a German scientist, in 1864); however, its connection to nanomotors was not made until recently.

Actin was first observed experimentally in 1887 by Halliburton as he noted a substance that coagulated myosin. Unfortunately, he couldn't actually identify the substance, so the actual discovery was made in the early 1940's by Straub and Szent-Gyorgi in Hungary. Shortly thereafter, the interaction between myosin and actin was ascertained, but since the actual mechanism by which these two accomplished muscle contraction remained a mystery, their connection to nanomotors remained to be discovered.

Dynein, discovered in 1963, had been known to be a motor involved in cilial and flagellar motility; however, its role in intracellular activity remained elusive until the mid 1980's. Microtubule motors had been suspected to be involved in cellular reproduction, particularly in mitosis and meiosis, but little more definitive information was discovered until the mid 1980's. In 1985, kinesin was discovered by Ronald Vale of University of California, San Francisco. He was studying the neural axons in squid, and he transferred that knowledge to smaller axons, and then to cells in general. And in 1987, dynein was discovered to be involved in intracellular transport, in addition to kinesin.

To show you the state of nanotechnology, and of nanomotors in particular, note this quote from Steven Block, Department of Molecular Biology, Princeton University: "Much of what we've learned about kinesin is so new that researchers have scarcely had time to digest it." – quoted from his article, "Kinesin: What Gives?", published in *Cell*, Vol. 93, 5–8, April 3, 1998
Visit the article's website for more information on what was known at the time regarding kinesin's role in intracellular motility. http://www.stanford.edu/group/blocklab/Block-Cell%20Review.pdf

In 2002, a University of Florida chemistry professor reported producing a "nanomotor" from a single DNA molecule. The motor is so small that hundreds of thousands could fit on the head of a pin. "It curls up and extends like an inchworm", said Weihong Tan, the principal investigator and lead author of an article about the motor in the April 2002 edition of the journal *Nano Letters*. This was the first of many nanomotors that have been developed by scientists. See "**Websites for Additional Information**", **Chemical Nanomotors (non-biological, man-made)**, below.

Connections to Chemistry Concepts

1. Oxidation-reduction: the electron-transport chain in nanomotors. See these websites for the animated details of the redox chemistry that happens at the mitochondrial level: http://www.science.smith.edu/departments/Biology/Bio231/etc.html and http://www.sp.uconn.edu/~terry/images/anim/ETS.html

2. Thermochemistry: energy considerations in cells, exo/endothermic reactions ATP → ADP + energy.

3. Electrostatic attraction: self-assembly relies on charge attractions to pull atoms and groups of atoms together to build nanoparticles into larger assemblages

4. Units and conversions: nanometer scale = 10^{-9} meters

Possible Student Misconceptions

1. **Motion in cells "just happens" (osmosis and all).** There are driving forces behind all motion – and nanomotors are those driving forces within cells. Viewing some of the videos mentioned below in the "Websites for Additional Information", below, may help students see the directional motion of the parts of the cell. Then, seeing the animations that simulate the motion of the proteins along the microtubules, students may be able to better visualize the nanomotor's role in cellular function.

2. **Only living things have nanomotors.** See "Anticipating Student Questions", number 1, below. Chemists have created nanomotors using only inorganic chemicals; e.g., metallic nanorods and hydrogen peroxide.

Demonstrations and Lessons

1. http://workbench.concord.org/ is the home page of the Molecular Workbench. This site focuses on molecular modeling as a way to teach students about the microscopic world. The site hosts literally hundreds of modeling lessons for biology, chemistry, and physics. Topics on the site include x-ray crystallography and self-assembly, the first step in producing nanomotors – or anything nanotechnological. The site also contains more basic chemistry topics, like how reactions occur, and behavior of gases. Use of this software requires that you download the latest version of Java software and then MW software to your computer, but then you can access myriad lessons from other sources from their site. The software allows you to keep a record of each student's access to specific lessons, and you can make your own lessons and keep track of your student's usage. This is a very versatile site.

2. This site gives a curriculum plan for teaching nanotechnology in high school chemistry classes. It does not speak directly to nanomotors, but to nanotechnology in general. The 43-page document shows how teaching nanotechnology meets National Science Education Standards and provides hard copies of actual student experiments to introduce them to the concept of nanoscale dimensions. http://thenanotechnologygroup.org/docs/Teaching%20Nanotechnology%20in%20the%20High%20School%20Curriculum.pdf

Student Projects:

1. You might encourage students to get involved in a debate regarding the feasibility of molecular manufacturing, a la that between Richard Smalley, buckyball discoverer and Nobel Prize winner and K. Eric Drexler, author of "Engines of Creation". See http://www.ghandchi.com/iranscope/Anthology/KurzweilDrexler.htm for a good starting place. Also see the C & E News "Point/Counterpoint" article on the Smalley/Drexler debate at http://pubs.acs.org/cen/coverstory/8148/8148counterpoint.html

2. Students interested in developing their own molecular animations should visit http://workbench.concord.org/. This site, referenced under "Demonstrations and Lessons", above, not only hosts existing modeling lessons, including their own and others created by teachers and students, but also provides the mechanism for your students (or you) to create your own molecular modeling lessons. The site then will act as host for your lessons as well.

3. This site shows you how to build a demo/model of a flagellated organism using a large plastic hypodermic syringe as the body: http://students.washington.edu/ledel/LowRe/dino.html. Students who are mechanically inclined might enjoy constructing this model.

4. Students could research the debate about the conflicting hypotheses about kinesin movement ("hand over hand" model vs. the "inchworm" model) and present their findings to the class. Here are a few sites to begin their search:
   Inchworm: (Evidence for this model is minimal. The hypothesis is there, but most research shows the other method of locomotion.)
   i. http://my.brandeis.edu/news/catalyst/catalyst_v3n2_spring02.pdf
   ii. http://www.sciencemag.org/cgi/content/short/295/5556/844
   iii. http://valelab.ucsf.edu/research/res_mec_overv6.html This site still favors the hand over hand model, but at least it cites a study that gives a little background on evidence for the inchworm model – just before it cites evidence favoring the former model.

5. Hand over hand: http://www.hhmi.org/news/vale2.html
   i. http://www.physics.uiuc.edu/Research/Highlights/Kinesin.htm
   ii. http://www.physics.uiuc.edu/People/Faculty/Selvin/tcb.2005.pdf
   iii. http://www.sciencemag.org/cgi/content/abstract/303/5658/676
   http://gtresearchnews.gatech.edu/newsrelease/KINESIN.html
   iv. http://www.medicalnewstoday.com/medicalnews.php?newsid=12738
   v. This site, another from Vale labs, gives a good description of the investigation of the kinesin motion, as well as that of myosin. It also has very nice diagrams of the proteins involved, as well as still photos of the kinesis locomotion process. These stills are taken from the video alluded to in the CM article.
   http://valelab.ucsf.edu/publications/2000valescience.pdf
6. This site shows three competing models for the mode of kinesin transport:
   i. http://mc11.mcri.ac.uk/wrongtrousers.html

7. And just when you thought you knew which hypothesis is correct, chemists have discovered that kinesin walks "with a limp". This is a 2003 report from Stanford University of the discovery of kinesin movement, aka "walking": http://news-service.stanford.edu/news/2003/december10/kinesinproof-1210.html
8. This site shows a series of images that accompany the above Stanford article: http://www.stanford.edu/group/blocklab/ScienceLimping/

Anticipating Student Questions

1. **Are nanomotors found only in living systems?** While the article focuses primarily on *in vivo* nanomotors, research chemists have created their own versions of nanomotors. These projects involve inorganic chemicals, sometimes at the simplest levels. And while life has had a long time to develop its own levels of nanotechnology, man has only really been involved in nanotechnology for less than 40 years. (No wonder our attempts are so much more simplistic, eh?) See "Additional Websites" section below for more information on the inorganic, man-made nanomotors.

2. **Have scientists found uses for nanomotors yet?** This is cutting edge research. Naturally, we see the uses that nature has made of nanomotors in living cells and organisms, and we will use these ideas to make our own uses of nanomotors. This is another example of biomimicry (See "Biomimicry—Where Chemistry Lessons Come Naturally", in this issue of ChemMatters). There are lots of ideas out there about how to use nanomotors (See "Websites for Additional Information, Nanomotors in the Future", below), but most of them must wait until chemists have developed the actual nanomotor, before it can be put to use. Many scientists believe that they will become indispensable in medicine and allied health fields.

Websites for Additional Information

History and Early Research

The article at this site, from the Howard Hughes Medical Institute, http://www.hhmi.org/bulletin/winter2005/kinesins/kinesins2.html, provides a humanistic viewpoint of the discovery of kinesins by Ronald Vale (from his earlier graduate studies on squid axons), and his subsequent research work. It is easy reading and might show students how exciting scientific study can be.

Eukaryotic Flagellar Motion (non-rotational)

This site provides several diagrams that help to explain how flagella change shape to move an organism. Although they are not animated, they do show the interconnectedness of all the parts of the body. This site treats eukaryotic flagella. This propulsion system is based not on rotational motion, but on dynein movement along microtubules.
http://academic.brooklyn.cuny.edu/biology/bio4fv/page/microtubules.html

Another site, this one from the University of Texas, Medical Branch, which gives background information about cilia and flagella movement:
http://cellbio.utmb.edu/cellbio/cilia.htm

This site shows the pattern the paramecium (a eukaryote) flagellum makes as it moves:
http://www.zoology.ubc.ca/courses/bio332/flagellar_motion.htm

This one page shows how the question of whether or not flagella rotate (in prokaryotes) was finally solved: http://202.114.65.51/fzjx/wsw/newindex/Myweb1/3/big3/8.jpg

Prokaryotic Flagellar Motion (rotational motion)

This site shows a diagram of the mechanism of a rotating bacterial flagellum in E. coli, as mentioned in the article:
http://www.arches.uga.edu/~afowler8/flagella.htm

This site shows the method of locomotion in eukaryotic cells and flagella:
http://academic.brooklyn.cuny.edu/biology/bio4fv/page/flagella-movement.html

This site shows an animated photomicrograph of a flagellum with motion in both directions along its long axis. Click on the “What We Do” smiley face at the top to see the animation:
http://www.yale.edu/rosenbaum/

This site explains the flagella structure and function in Chlamydomonas. It also shows a simplistic animation of one organism’s flagella:
http://www.uwlax.edu/biology/faculty/Howard/Chlamy.htm

This shows two diagrams of different rotational mechanisms in a cell’s flagellum, as well as a photomicrograph of such a cell: http://www.uccs.edu/~rmelamed/MicroFall2002/Chapter%204/motion.jpg

Kinesin in Action

This is the Kinesin Home Page. It contains many links, including many of the movies alluded to in the ChemMatters article. It's where students might start a research project on kinesins.
http://www.proweb.org/kinesin//index.html

This site gives a brief description of the way that kinesin moves within a cell:
http://tissue.medicalengineer.co.uk/How+Kinesin+Moves.php

This is a 2003 report from Stanford University of the discovery of kinesin movement, aka "walking":
http://news-service.stanford.edu/news/2003/december10/kinesinproof-1210.html
This site shows a series of images that accompany the above Stanford article:
http://www.stanford.edu/group/blocklab/ScienceLimping/

This site shows a simplified animated sequence of a kinesin molecule transporting its cargo along a microtubule: http://python.rice.edu/~kolomeisky/transport.htm

This site has several photos and movies involving vesicle transport in vivo by kinesin. Click on the box on the left, Research Project Overview with images. Each photo/movie has a short explanation.
http://www.wfu.edu/physics/cellmotors/

This site, http://www.scripps.edu/cb/milligan/projects, has an animation simulating the motion of kinesin along a microtubule. It shows the two heads of the protein and the effect ATP has on them to create movement. This is actually the same animation as the Vale site mentioned in the ChemMatters article, but it is more useful to educators as it also has a page of description accompanying it.

Here's yet another animation of kinesin transporting a vesicle along a microtubule:
http://home.earthlink.net/~shalpine/anim/Life/kinesin.htm

Myosin and Muscles

This site gives several diagrams of muscle structure, and the role that actin and myosin play in muscle movement, as well as flagellar motion. The site also includes nice diagrams:
http://www.life.uiuc.edu/crofts/bioph354/lect16&17.html

An animation of myosin moving along an actin helix is available at this site:
http://www.sci.sdsu.edu/movies/actin_myosin_gif.html

Helicases and DNA

This site, from the New Scientist.com News Service, highlights another of Steve Block's discoveries at Stanford. This time he shows that DNA is transcribed by RNAP one base-pair at a time.
http://www.newscientist.com/article.ns?id=dn8319&print=true

The department of biochemistry at Brandeis University displays this web site of the work of research scientist Jeff Gelles. Some of the movies on this site have explanatory text accompanying them to tell students what they're viewing. The movies include kinesin and helicase motion at the cellular level.
http://www.bio.brandeis.edu/~gelles/movies.html

X-ray crystallography

A very nice simulation of the whole process of x-ray crystallography is available at:
http://mw.concord.org/modeler1.3/part1/xray/intro.cml

Chemical Nanomotors (non-biological, man-made)

This site gives a report of two engineers from Carnegie-Mellon who have designed and tested a microrobot mimicking the flagellar propulsion system of E. coli bacteria. (Not quite nanomotors, but getting closer):
http://www.me.cmu.edu/faculty1/sitti/nano/publications/IMECE2004-59621.pdf

This article describes carbon nanotube motors being driven by laser light:
http://www.newsfactor.com/perl/story/21246.html

This American Chemical Society *Chemical and Engineering News* article describes actual nanomotors that involve chemicals on the nano scale, but are not based on a biological phenomenon:
http://pubs.acs.org/cen/science/83/i08/8308sci1.html

This Eureka Alert! Site discusses a nanomotor based on atomic tin and copper interacting on the liquid surface: http://www.eurekalert.org/pub_releases/2000-11/AAft-NItm-2311100.php

This site shows you the world's smallest motor (in 2003):
http://www.abc.net.au/science/news/stories/s911572.htm. The site also shows an actual movie of the motor in action.
This site shows an animation of the above smallest motor and describes how it was done:
http://www.berkeley.edu/news/media/releases/2003/07/23_motor.shtml.

This article from Live Science, a commercial web site, reports on an even smaller nanomotor with no moving parts: http://www.livescience.com/technology/050412_smallest_motor.html.
The Live Science report is verified in the article at this second website, which gives more background information about the experiment: http://www.voyle.net/Nano%20Research-05-100+/research-05-0106.htm.
This last site gives still photographs and movies of the same phenomenon:
http://www.physics.berkeley.edu/research/zettl/projects/Relax_pics.html

Nanomotors in the Future (?)

The article, "ATP-driven Rotary Biomolecular Nanodevice for Arterial Blood Clot Removal", discusses a proposed nanotool to remove clots from a human patient by using nanomotors to propel the tool and to power the cutting tool:
http://pbl.cc.gatech.edu/bmed8501b/uploads/20/Rotorootor%20final%20report%20v1.doc

This article cites several possible future uses for nanomotors, and also describes a 4-year, million dollar NSF grant to produce such a nanomotor product by 2007:
http://www.devicelink.com/mddi/archive/03/11/019.html

Nanoatechnology in the Future

For a look into the future of nanotechnology, check out the Foresight Nanotech Institute's views at http://www.foresight.org/UTF/Unbound_LBW/index.html#TOC. This is a 13-chapter book that shares their views.