CHEMMATTERS

October 2008 Teacher's Guide

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Student Questions

The Olympic Flame: Chemistry Held High

1. In what year did the Olympic torch relay begin?
2. The 2008 torch is made of an alloy composed of what two metals?
3. Since 1972, what substances have fueled the Olympic torch?
4. What device is used to light the Olympic flame every four years?
5. In what city and country were the 2008 Olympics held?
6. Which company designed the 2008 Olympic torch?

The Chemistry of Marathon Running

1. Why is it possible that the day after a marathon, a runner may have gained weight rather than having lost it?
2. What is the difference between a calorie and a Calorie?
3. What is the difference between how much fat is used for energy when running compared with energy usage while resting?
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5. What is the difference between glucose and glycogen?
6. What three things must be developed, through training, to keep a marathon runner from “running out” of energy?
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8. What is the function of adrenaline in relation to energy “production”?
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11. Why is anaerobic respiration (fermentation) a less efficient method of energy production (as ATP) than aerobic respiration?

New Materials for Better Athletes

1. What are the benefits of using artificial turf instead of grass?
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3. Name three different polymeric materials that are used today in making artificial turf.
4. What is the purpose of the infill in artificial turf?
5. Why are full-body swimsuits like the LZR Racer® becoming the norm in Olympic competitions, instead of the old skimpy Speedos®?
6. Why are woven fabrics preferred over knitted ones in swimsuits?
7. What three improvements did TYR make on their newest swimsuit?
8. What was Dow Chemical’s contribution to making swimsuits more competitive?
9. The composition of tennis rackets has evolved over the last 50 years. List the three major types of tennis racket that have been produced during this time period.

10. What are the advantages of composite materials for tennis rackets?
11. So, is it fair to compare Olympic champions from years past, who did not have the advantage of modern technology, to today's champions, who are using these marvels?

The Many Looks of the Periodic Table

1. According to the article, how many chemical elements have scientists separated and identified?
2. What are two names for the vertical arrangements of elements on the periodic table?
3. What are two names for the horizontal arrangements of elements on the periodic table?
4. What is a triad of elements?
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7. What is one advantage of the periodic round table?
8. What is neutronium?
9. How does Stewart want people to view his Chemical Galaxy?

Natural, Braided, Bleached, Colored, Straight, and Curly Hair…Thanks to Chemistry

1. Why would someone wish to use a hair conditioner?
2. What two ingredients do hair conditioners usually contain?
3. What role do the two ingredients play in conditioning hair?
4. What property of anti-humectants prevents a greasy feel?
5. What are the three types of hair dyes?
6. Explain the chemical process involved in the three types of hair dyes.
7. How may one temporarily straighten curly hair?
8. Why should de-frizzing products by used when temporarily straightening hair?
9. What chemical mechanism do permanent hair straighteners employ?
10. Name three chemical relaxers. To what class of chemical compounds do they belong?

Answers to Student Questions

The Olympic Flame: Chemistry Held High

1. **In what year did the Olympic torch relay begin?**
The Olympic torch relay began in 1936 for the Berlin, Germany Olympics.
2. **The 2008 torch is made of an alloy composed of what two metals?**
Aluminum and magnesium are the constituents of the alloy in the 2008 Olympic torch.
3. **Since 1972, what substances have fueled the Olympic torch?**
Liquid hydrocarbons like propane and butane have been used to fuel the Olympic torch since 1972.
4. **What device is used to light the Olympic flame every four years?**
The device used to light the Olympic flame every four years is a parabolic mirror, which concentrates the sun's energy to a point.
5. **In what city and country were the 2008 Olympics held?**
Beijing, China was the host of the 2008 Olympics.
6. **Which company designed the 2008 Olympic torch?**
The Olympic torch was designed by the China Aerospace Science and Industry Corporation.

The Chemistry of Marathon Running

1. **Why is it possible that the day after a marathon, a runner may have gained weight rather than having lost it?**
A runner may well have eaten food after the race with calories in excess of what was used in the marathon.
2. **What is the difference between a calorie and a Calorie?**
The big "C" calorie is a kilocalorie or 1000 small "c" calories. One "c" calorie has 1/1000 the value of one "C" calorie.
3. **What is the difference between how much fat is used for energy when running compared with energy usage while resting?**
When running, up to 15% of the energy needed is taken from the breakdown of fat, while at rest, up to 60% of the energy is derived from fat.
4. **What are the two sources of energy for the body besides fat?**
Carbohydrates (sugars) and protein can supply energy, though protein is the source least used, even when there are energy demands as in running.
5. **What is the difference between glucose and glycogen?**
Glucose is a 6-carbon molecule which can form a much larger molecule, glycogen (a polymer), using multiple glucose molecules.

6. **What three things must be developed, through training, to keep a marathon runner from "running out" of energy?** *Training is done to improve the body's capacity to more effectively (efficiently) use oxygen, maximize glycogen reserves, and burn fat.*

7. **What are the benefit(s) of Gatorade for meeting hydration needs that water alone cannot provide?**
Gatorade provides carbohydrates, minerals such as potassium and sodium compounds, as well as water.

8. **What is the function of adrenaline in relation to energy "production"?**
Adrenaline stimulates the release of glycogen from within muscle tissue to be converted to glucose.

9. **Why is it difficult for the body to use fat as the primary energy source compared with utilizing glucose when there is an increased demand for energy?**
Fat, as a large molecule, requires more steps (degradation) to convert it to carbon dioxide and water with energy transfer to ATP than glucose conversion. (The article uses the phrase, "…the body likes its fat…")

10. **How are slow twitch and high twitch muscle fibers related to marathon runners and sprinters?**
All muscle tissue contains a mixture of what are known as slow twitch muscle cells as well as high twitch cells. Sprinters have more high-twitch fibers than slow-twitch fibers. For marathon runners, the ratio of slow and high twitch is the reverse.

11. **Why is anaerobic respiration (fermentation) a less efficient method of energy production (as ATP) than aerobic respiration?**
In aerobic respiration, the oxidation of one glucose molecule produces 38 ATP molecules while in anaerobic respiration, only 2 ATP molecules are produced in the conversion of glucose to lactic acid.

New Materials for Better Athletes

1. **What are the benefits of using artificial turf instead of grass?**
The benefits of using artificial turf instead of grass include:
a) cost-savings associated with not having to cut it or water it,
b) it doesn't become worn or pitted, so it always looks good,
c) it doesn't require the use of pesticides,
d) games can be played on it without waiting for a rejuvenating period, so more games can be played on a turf field, and
e) sports can be played on the turf field year-round, unlike with grass fields.

2. **Where did AstroTurf® get its name?**
AstroTurf® got its name from the fact that it was first installed in the Houston Astrodome in 1966.

3. **Name three different polymeric materials that are used today in making artificial turf.**
Three polymeric materials used to make artificial turf include nylon, polyethylene and polyurethane. (Students may also answer, rubber, since it is used in the infill.

4. **What is the purpose of the infill in artificial turf?**
Infill is necessary because it moves and "gives" so that an athlete is not injured when making sudden stops or quick turns or twists.

5. **Why are full-body swimsuits like the LZR Racer® becoming the norm in Olympic competitions, instead of the old skimpy Speedos®?**

Many Olympic swimmers now prefer the full-body suit because scientists have developed very smooth surfaces on swimsuit materials for the Olympics, and the more material covering the swimmer's body, the smoother their entire surface is. A smoother surface means there is less frictional drag exerted by the water on the swimmer, so he/she expends less energy cutting through the water or, alternatively, assuming the swimmer expends the same amount of energy, he/she can cut through the water more quickly, resulting in a shorter time for the race.

6. **Why are woven fabrics preferred over knitted ones in swim suits?**

Knitted fabrics are not as desirable for swimwear as woven fabrics because scientists have found that knit fabrics trap water between fibers. This would increase the weight of the swimsuit and slow down the swimmer.

7. **What three improvements did TYR make on their newest swimsuit?**

TYR's three improvements include:

a) *using woven fabric instead of knitted fabric,*
b) *adding a polyurethane coating to the entire suit to make it smoother, and*
c) *incorporating compression panels into the suit to make it adhere to the body to minimize muscle movement (drag) against the water.*

8. **What was Dow Chemical's contribution to the swimsuit competition?**

Dow produced an elastic fiber made of polyethylene that is resistant to chlorine. That should make the suits last longer in the chlorine-water environment of the swimming pool.

9. **The composition of tennis rackets has evolved over the last 50 years. List the three major types of tennis racket that have been produced during this time period.**

In the last 50 years, tennis racket composition has evolved from wood (mostly maple or ash) to metal (aluminum or steel) to composites.

10. **What are the advantages of composite materials for tennis rackets?**

The advantages of composite materials for use in tennis rackets include:

a) *they are lighter than wood or aluminum, so the player can hit the ball with more force,*
b) *they are stiffer than aluminum so a player can hit the ball harder, and the ball loses less energy to the racket when it rebounds, so it comes off the racket faster, and*
c) *they help to reduce vibration that ball returns to the racket and the player, which in turn reduces the probability that a player will endure tennis elbow.*

11. **So, is it fair to compare Olympic champions from years past, who did not have the advantage of modern technology, to today's champions, who are using these marvels?**

The author does not provide a clear "yes" or "no" to the question of fairness in comparing past Olympic champions without modern technology to Olympians of today who benefit from the technology. She cites a little evidence for both sides of the debate.

The Many Looks of the Periodic Table

1. **According to the article, how many chemical elements have scientists separated and identified?**

Scientists have separated and identified 117 elements to-date.

2. **What are two names for the vertical arrangements of elements on the periodic table?**

Vertical arrangements on the periodic table are called columns or groups.

3. **What are two names for the horizontal arrangements of elements on the periodic table?**

Horizontal arrangements on the periodic table are called rows or periods.

4. **What is a triad of elements?**

A triad of elements "…consists of three elements arranged in a vertical column and in which the middle element has an atomic number that is the average of the two elements above and below it."

5. **What is different about Scerri's proposed periodic table, compared to the traditional periodic table?**

Scerri moves hydrogen to a position above fluorine to create a triad there. He also proposes to move the halogens and noble gases columns to the far left of the old periodic table.

6. **According to Moran and his spiral periodic table, what are the three serious flaws in the traditional periodic table?**

The three serious flaws of the traditional periodic table, according to Moran are:

a) hydrogen is an element with unique properties and belongs by itself;
b) the lanthanoids and actinoids have similar properties and belong in columns together; and
c) the continuity of the properties of the elements is not obvious in the endings and beginnings of rows on the traditional table.

7. **What is one advantage of the periodic round table?**

"By removing and replacing the disks on top of one another, people can appreciate the symmetry and beauty that characterize the fundamental relationships of the chemical elements."

8. **What is neutronium?**

Neutronium is an additional element placed in the center of the Chemical Galaxy periodic table. It contains neither protons nor electrons, only neutrons. Scientists speculate it may be found in very dense neutron stars.

9. **How does Stewart want people to view his Chemical Galaxy?**

"Stewart hopes that the Chemical Galaxy will be seen as a piece of art that seeks to convey the beauty and wonder of the universe".

Natural, Braided, Bleached, Colored, Straight, and Curly Hair …Thanks to Chemistry

1. Why would someone wish to use a hair conditioner?

Hair conditioners help untangle and improve hair appearance, prevent hair from getting dry and brittle, and make locks easy to untangle.

2. What two ingredients do hair conditioners usually contain?

Hair conditioners usually contain positively charged molecules called quaternary ammonium compounds and molecules called amino silicones.

3. What role do the two ingredients play in conditioning hair?

The quaternary ammonium compounds bind strongly to the hair surface and act as the new hair surface while the amino silicones fill in splits, cracks, and chips present on the surface of damaged strands.

4. What property of antihumectants prevents a greasy feel?

Substances that repel water often feel oily or greasy. Antihumectant molecules like isopropyl palmitate contain some atoms that have nonpolar bonds with their neighbors while other atoms use polar bonds with unequally shared electrons with neighboring atoms. The combination of bonds eliminates the greasy feel, yet allows the molecules to repel water.

5. What are the three types of hair dyes?

Hair dyes may be classified as temporary, semi-permanent, and permanent.

6. Explain the chemical process involved in the three types of hair dyes.

Temporary dyes contain large molecules that don't penetrate the cuticle layer. The molecules may be removed by shampooing. Semi-permanent dyes contain smaller molecules that penetrate and deposit pigments on the hair shaft but do not remove the original hair pigments. Permanent dyes first remove the hair pigments in a bleaching process and remaining dye molecules penetrate the hair shaft and give it a new color.

7. How may one temporarily straighten curly hair?

Curly hair may be temporarily straightened by using a hot ceramic flat iron that works at temperatures between 170 and 230 °C.

8. **Why should de-frizzing products by used when temporarily straightening hair?**

The heat from the iron will also frizz the hair. The de-frizzing products—a variety of silicones—handle the heat of the iron and make the hair shiny and leave it soft after straightening.

9. What chemical mechanism do permanent hair straighteners employ?

Permanent straighteners use a "relaxer". This product permeates the protein structure of the hair and weakens its internal bonds, causing the natural curl to loosen out as the entire fiber swells open.

10. Name three chemical relaxers? To what class of chemical compounds do they belong?

Three common relaxers and potassium hydroxide, lithium hydroxide, and calcium hydroxide. Hydroxides belong to the class of compounds called bases.

ChemMatters Puzzle: Deciphering Chemical Elements

Below you'll see ten common words or phrases. Hidden inside each is the name of an element. To find it, remove one letter from the term, and then unscramble the remaining letters.

For example, given the word CROPPED. If one drops the "D" out, the remaining letters are an anagram of COPPER. Similarly, the phrase NO ONE generates NEON if you drop out one of the O's. Note that the dropped letter may be anywhere in the clue and the remaining letters are in no special order, nor do they necessarily contain the element's symbol in their midst.

Here's one more hint: The sum of the atomic numbers of the five elements in the left column is 257, and in the right-hand column 220.

Have fun deciphering!

ADDLE ______

SARONG ______

LODGE ______

SNIT ______

CLINKER ______

REVILES _______

MISCUES _______

COW BARN _______

ADORNS _______

PRION _______

Answers to the ChemMatters Puzzle

LEAD
ARGON
GOLD
TIN
NICKEL
SILVER
CESIUM
CARBON
RADON
IRON

If you have any suggestions or comments, please feel free to send an e-mail to David Olney at: djolney@verizon.net

NSES Correlation

National Science Education Content Standards Addressed

As a result of activities in grades 9-12, all students should develop understanding:	**Olympic Flame**	**Marathon Running**	**New Materials**	**Periodic Table**	**Hair Products**
Science as Inquiry Standard A: of abilities necessary to do scientific inquiry.					✓
Science as Inquiry Standard A: about scientific inquiry.				✓	✓
Physical Science Standard B: about 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 interaction of energy & matter.	✓				
Life Science Standard C: about matter, energy, and organization in living systems.		✓			
Science and Technology Standard E: about science and technology.	✓	✓	✓		✓
Science in Personal and Social Perspectives Standard F: of personal and community health.		✓	✓		✓
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✓		✓		
History and Nature of Science Standard G: of science as a human endeavor.				✓	✓
History and Nature of Science Standard G: of 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.

The Olympic Flame: Chemistry Held High

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.

Me	**Text**	**Statement**
		1. The Olympic flame is let by a match containing chemicals from Greece.
		2. There is only one Olympic torch.
		3. The Olympic torch is kept lit even on airplanes.
		4. The Beijing Olympic torch can withstand rainfall and temperatures as low as -40°C.
		5. Yellow flames are sooty because the fuel does not burn completely.
		6. Today, the Olympic torches use solid fuel.
		7. A special internal oxidizer for supplying oxygen had to be used when the flame was carried to Mt. Everest.

The Chemistry of Marathon Running

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.

Me	Text	Statement
		1. Adrenalin pumps more oxygen into your blood.
		2. You would burn around 7000 calories by running a marathon.
		3. More energy comes from fat when your body is at rest than when you are running a marathon.
		4. Stored glycogen provides glucose to runners during a marathon.
		5. Your body cools off by sweating.
		6. Fats provide 9 kcal/g of energy, while carbohydrates provide only 4 kcal/g.
		7. Cotton is the best clothing for running.
		8. Marathon runners and sprinters have similar muscle fibers in their legs.

New Materials for Better Athletes

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.

Me	Text	Statement
		1. There are fewer than 2000 fields made of artificial turf in the United States.
		2. Artificial turf has artificial dirt to make it look more realistic.
		3. Most of the infill on artificial turf is made from recycled tires.
		4. New high-tech swimsuits made by Speedo are bonded ultrasonically instead of using stitches.
		5. Swimsuit fabric was tested in a wind tunnel to measure drag.
		6. Tennis rackets made from composite materials are not as stiff as those made from aluminum.
		7. Some people believe that using new materials in sports is not fair because it changes the game.

The Many Looks of the Periodic Table

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.

Me	Text	Statement
		1. Elements with similar properties are found in columns in the Periodic Table.
		2. Elements in the Periodic Table are listed according to increasing atomic mass.
		3. The elements in the f-block have few similarities in properties.
		4. Elements in triads as arranged by Eric Scerri are grouped by averaging their atomic numbers.
		5. The spiral periodic table places the elements in hexagons instead of squares.
		6. Chemical elements are produced in the stars.
		7. The first 3-dimensional periodic table was developed in 1929.
		8. The periodic table we currently use is probably the best we will ever have.

Natural, Braided, Bleached, Colored, and Curly Hair . . . Thanks to Chemistry

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.

Me	Text	Statement
		1. “Flyaway hair” is caused by negatively charged strands of hair repelling each other.
		2. Chemicals with no water are used by people whose hair is frizzy in humid weather.
		3. Styling gels are made of small molecules.
		4. Hydrogen peroxide removes the pigment from the hair.
		5. Ceramic flat irons used for hair straightening work at temperatures near the boiling point of water.
		6. Many hair relaxers use hydroxides to weaken the internal structure of proteins in the hair.
		7. Cosmetic chemists measure viscosity in poises.
		8. The percent of total solids in most shampoos is less than 10%.
		9. Some hair products today are made from petrochemicals.
		10. Hair products made in small batches behave the same way when they are produced in large quantities.

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

The Olympic Flame: Chemistry Held High

Directions: For each part of the Olympic Torch used in the Beijing Olympics, describe the materials used as well as the physical and chemical properties.

Part of Torch	Formula or chemicals used	Properties or reasons for using these materials
Torch itself		
Fuel		
Internal oxidizer		

The Chemistry of Marathon Running

Directions: As you will find while reading the article, the body's source of energy varies during a marathon. By completing the chart below, you will gain a better understanding of each type of compound and its importance in supplying energy.

Energy source	**Percent of energy expenditure during marathon**	**Formulas**	**When used during marathon**
Protein			
Fat			
Carbohydrates			
Glycogen			

New Materials for Better Athletes

Directions: The materials used by athletes undergo constant improvement. In the chart below, describe the different materials used over the years for various sports.

Products	Description, including chemicals	Advantages
Artificial turf	1960s	
	Today	
Swimsuits	LZR Pulse	
	LZR Racer	
	Tracer Rise	
	Aqua Shift	
	XLA	
Tennis rackets	Pre-1960s	
	Late 1960s	
	Today	

The Many Looks of the Periodic Table

Directions: As you read the article, complete the table below to compare the different forms of the periodic table discussed in the article.

Periodic Table	Short Description	Advantages
Long form of the traditional periodic table		
Scerri's periodic table		
Periodic Spiral		
Chemical Galaxy		
Periodic Round Table		

Natural, Braided, Bleached, Colored, and Curly Hair . . . Thanks to Chemistry

Directions: As you read the article, you will learn that different hair products have different purposes, formulas, and properties. Please complete the chart below to compare these products.

Product	Purpose	Formula(s)	Properties
Conditioners			
Ant humectants			
Styling products			
Hair dyes			
Hair straighteners			

The Olympic Flame: Chemistry Held High

Background Information

More on the Olympic torch and flame

As the article notes, there are three flames associated with each Olympics—the original which is lighted by parabolic mirror in Olympia, Greece, the flame in each of the torches used during the relay and the flame which is lighted at the site of the games. For the most part, the article discusses the flame in the torches carried in the relay. The Olympic relay torch presents the greatest engineering challenge, since the flame will be subject to possibly extreme conditions along the relay route. Two extreme locations that are mentioned in the article are the top of Mt. Everest and underwater at the Great Barrier Reef. During the relay the torch will encounter wind and rain that affect its performance.

The challenge, of course, is to maintain the combustion process under these unusual conditions. Your students will likely have heard of the "fire triangle," which relates the three conditions need for combustion to occur. They are fuel, oxygen and sufficient temperature (sometimes given as "heat").
Students can translate these into the language of a chemical equation in which the fuel and oxygen are necessary reactants in the equation and the temperature (or heat) represents activation energy. (Image from U.S. Forest Service: http://www.fs.fed.us/r3/resources/coned/fe-curriculum/2-72.pdf)

In addition, the Olympic torch has several unique requirements of its own. Not only must it contain a fuel but there must also be a system of delivering the fuel to the mouth of the torch so that the flame will be visible. Each torch must be capable of housing sufficient fuel to remain lit for each leg of the relay. The flame in each torch must also be visible to the millions of people who witness the relay. And the torch itself must be light enough in weight for each person in the relay to carry it easily and must protect the runners from the heat produced in combustion. In recent years an environmental requirement has become important—the flame must produce a minimum of soot.

The article describes the composition of some Olympic torches and the fuels used in them. These substances should be of most interest in a chemistry class. Since most of the article is devoted to the fuels used, they could easily be your point of departure in discussing the article as part of a unit on chemical reactions, combustion or hydrocarbons as organic substances.

Since the article stresses that the design of the Olympic torch has become a major technological endeavor, you might trace the history of the torch and flame in terms of the improvements in efficiency and safety over the years. Countries and companies have competed for the prestige of designing a better torch and flame, beginning with the Krupp steel and munitions company, a company then closely associated with Hitler's growing war effort , and continuing to the state-owned China Aerospace Science and Industry Corporation, designers of the 2008 torch.

As the article suggests, the torch itself has evolved from the original, which was made of reeds tied together with string. The reeds were lighted to produce a flame. The 1948 torch was made of stainless steel. In 1992, part of the torch was made of plastic, which melted under extreme conditions. The article notes that the 2008 torch is made of a lightweight magnesium-aluminum alloy.

Along with evolving torch design, the fuels used have also evolved, as the article states. The original torch was simply a handful of reeds tied together with rope or string (the torch for the 1996 Atlanta games was designed to look like this early torch), and the reeds were burned to make the flame. Prior to 1972, when the torch first employed a gas/liquid fuel, a wide range of sometimes exotic fuels were used to light the torch. For example, the torch used in the 1948 London Olympics used hexamine in tablet form with naphthalene added to produce a visible flame. This naphthalene-hexamine solid mixture was also used in 1956. Other fuels, including olive oil, gunpowder, ammonia, magnesium and aluminum, have all been part of the fuel mix in the Olympic torch. Some of these chemicals are briefly profiled below.

Beginning in 1972 at the Munich Summer Games, liquid/gas fuels have been used. For the most part the fuels have been hydrocarbons that we know well today, hydrocarbons like propane, butane, and propylene. These hydrocarbons are gases at atmospheric conditions but are easily liquefied for convenient storage. Think of the familiar liquid propane tanks used to fuel outdoor grills. The container for the torch fuel can be small and made of a lightweight material—a plus for the torch carriers.

The liquefied gas is stored under pressure. When the torch is lighted the liquid escapes from the storage tank and moves upward in the torch toward a valve, sometimes called a choke cap, which typically has many tiny openings. As molecules move through the tiny valve openings, the pressure drops and the liquid vaporizes to a gas, which is then ignited.

The need to produce a bright visible flame and at the same time keep the torch lighted at all times was solved in 1996 by employing a double flame in the torch. The external visible flame burned at a lower temperature and was, therefore, orange in color and visible to spectators viewing the torch relay to Atlanta. The second flame was smaller and hotter, resulting in a blue flame that resembled a pilot light. This flame burned inside the torch, protected from the elements, and it re-ignited the external flame if it ever went out.

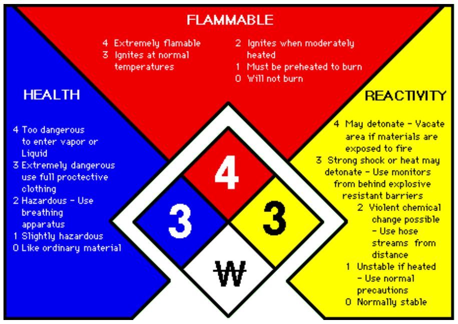
The article mentions the unusual circumstance created when the torch relay organizers in the 2000 Sydney Olympics decided to include in the relay a three-minute underwater leg near the Great Barrier Reef at Agincourt. The main torch for the Sydney Olympics was fueled by the propane-butane mix, but to keep the flame burning underwater where there is no available oxygen, a special flare was designed similar to flares used on marine vessels. Magnesium was the main fuel packed into a solid, along with a chemical oxidizer. The exact fuel formula was especially designed for this torch and was so new that it was patented.

In 2008, a similar torch and fuel were used for the Beijing Olympics as the torch relay included a side trip to the top of Mount Everest. According to Chinese news services, the torch used “missile technology” fuel, which means that an oxidizer was required for the high-altitude trip.

Oxidizers, or oxidizing agents, are important in many areas of chemistry. The article mentions that rocket boosters use ammonium perchlorate (NH_4ClO_4) as the oxidizer. This use of the term refers to substances that readily supply oxygen for the purpose of supporting combustion. Oxidizers are used in situations, like space, where oxygen is not naturally present. Oxidizers react chemically with the fuel.

In a stricter sense, oxidizers are oxidizing agents, a substance that transfers oxygen atoms or that gains electrons in a redox reaction. This connection to an important chemical concept is worth discussing with students, but in the context of this article it is important for students to understand that oxidizers are sources of oxygen.

Oxidizers are rated by class, according to a system established by the National Fire Protection Association (NFPA). It is important to let students know that, in the lab, chemical bottles may carry a label like the one at right. Oxidizing agents (oxidizers) are noted in the yellow portion of the label. In addition, the letters “Ox” may also appear in the white section of the diamond.



The NFPA classes are listed below.
Class 1—May increase the burning rate of combustible material it comes in contact with.
Class 2—Will moderately increase the burning rate of combustible material it comes in contact with.
Class 3—Will severely increase the burning rate of combustible material it comes in contact with.
Class 4—Will undergo an explosive reaction when catalyzed, exposed to heat, shock or friction.

It should be noted that the U.S. Department of Transportation (DOT) also has a rating system for hazardous material. An example of a DOT label is at right.

Examples of oxidizers:
Class 1—Many peroxides, including hydrogen peroxide, potassium dichromate, and potassium nitrate
Class 2—potassium permanganate, sodium peroxide, halane
Class 3—ammonium dichromate, potassium chlorate, perchloric acid
Class 4—ammonium perchlorate (mentioned in the article), ammonium permanganate

More on hydrocarbon fuels

Given that both propane and butane are the fuels used in recent Olympic torches, combined with the current interest in petroleum production and gasoline prices, and it would seem that some background on hydrocarbon fuels would be in order. The relevance of this topic may make it worthwhile for you to introduce it to students even if your curriculum does not require studying organic compounds, which is where you typically find hydrocarbons covered.

The simplest series of compounds made up exclusively of carbon and hydrogen is called the alkane series. The carbon and hydrogen atoms in all of the compounds in this series are bonded with single bonds. Such compounds are known as saturated compounds (the compound has no double bonds). The bond angles are about 109.5°, the carbon-carbon bond distances are about 154 pm and the carbon-hydrogen bond distances are about 109 pm.

Since we know that, in covalent bonding, each carbon atom has a bonding capacity of 4, the simplest hydrocarbon has a formula of CH_4 (methane). If one of the bonds is a C-C bond, then the formula will be C_2H_6 (ethane). The third alkane hydrocarbon has a formula of C_3H_8 (propane), the fourth C_4H_{10} (butane), and the fifth C_5H_{12} (pentane). In general the alkanes fit into a general formula of C_nH_{2n+2}. Beginning with pentane, the names of the rest of the compounds in this series add a prefix to the –ane ending: pent-, hex-, hept-, oct-, non-, dec-, etc.

These hydrocarbon compounds are all found in either natural gas or petroleum or both. The individual compounds, like, propane and butane, can be separated from the natural mixtures. The individual hydrocarbon compounds or mixtures of them can be used as fuels, as propane and butane are used as the fuels in the modern Olympic torch.

Your students will be interested in how this relates to the discussion of petroleum and gasoline. Gasoline is produced by fractionally distilling petroleum (or crude oil), which is a mixture of hydrocarbons, and then remixing some of the individual hydrocarbons to make gasoline, which is itself a mixture. The chart below shows the range of hydrocarbons that make up commercial products which are derived from petroleum.

Refining Fraction	Boiling Point (°C)	Number of Carbon Atoms
Natural gas	Less than 20	C_1 to C_4 (methane-butane)
Petroleum ether	20-60	C_5 to C_6
Gasoline	**40-200**	**C_5 to C_{12}**
Kerosene	50-260	C_{12} to C_{13}
Fuel Oils	above 260	C_{14} and above
Lubricants	above 400	C_{20} and above

Propane

Along with butane, propane is mentioned in the article as the fuel of choice for the modern Olympic torch. As described above, propane is the three-carbon straight-chained alkane with the formula C_3H_8. It is a gas at normal conditions, but is easily compressed to a liquid, making it ideal for use in the Olympic torch. The article refers to liquid hydrocarbon fuels because the propane is stored in the torch as a liquid. It is produced in the refining of petroleum or natural gas. The article mentions that the torch fuel may be a mixture of propane and butane, C_4H_{10}. Students may know this mixture as liquefied petroleum gas or LPG, a common commercial form of the fuel.

The article shows the common equation for the combustion of propane, which is often used as a model equation for complete combustion in high school textbooks. You may also wish to point out to students the idea of incomplete combustion, which occurs when oxygen is not available in sufficient supply. In this case the oxygen is the limiting reagent in the reaction and carbon monoxide rather than CO_2 is produced. The equation looks like this.

$$2\ C_3H_8 + 7\ O_2 \rightarrow 6\ CO + 8\ H_2O$$

The article also notes that if the oxygen-fuel ratio is even lower, carbon, or soot, may be released in this equation.

Some properties of propane:

Appearance = colorless gas
Odor = odorless

Taste = tasteless
Molar mass = 44.1 g/mol
Density = 1.83 kg/m^3 (gas)
0.5077 kg/L, liquid
Melting Point = −187.6 °C
Boiling Point = − 42.1 °C
Flammability = high
Explosive limits = 2.4-9.5 % (Note: this represents the percent of vapor in air that will result in an explosion)

Butane

Butane is identified in the article as one of the component fuels in the modern day Olympic torch. Butane, or n-butane, is a straight chain alkane hydrocarbon with the formula C_4H_{10}. Not essential to the article, but of potential interest in your class is the fact that there are two isomers of butane—n-butane and isobutane or methylpropane. The latter has a formula of C_4H_{10}, but is a branched chain isomer $CH(CH_3)_3$. You may wish to focus on the alkanes and their isomers, even though only propane and butane are important in this article.

Some properties of butane:
Appearance = colorless gas
Odor = odorless
Taste = tasteless
Molar mass = 58.1 g/mol
Density = 600 g/L, liquid
Melting Point = −138.4 °C
Boiling Point = −0.6 °C °C
Flammability = high

Propane-Butane

A commercial mixture of propane and butane is known as Liquefied Petroleum Gas (LPG). This mixture has been used as the fuel in the Olympic torch. Properties of LPG:
Appearance = colorless
Odor = odorless.
Density = 1.75 g/L
Boiling Point = +9 to −42 °C
In liquid form, its density is half that of water and hence it floats initially before it is vaporized.

The LPG mixture may also include small quantities of other hydrocarbons like ethylene, and propylene.

Propylene

Propylene, sometimes referred to as propene, is also a hydrocarbon, but the molecule is unsaturated. That is, two carbons are joined by a double bond. The formula for propene is C_3H_6. It is a colorless, odorless gas under atmospheric conditions.

More on liquid/solid fuels

Olive Oil

Although we don't think of olive oil as a fuel, it can be used that way. In many parts of the world it is used in lamps and burns via a wick system. It is also used as a heating fuel. It is not as volatile as many other oils and it has a high flash point of 550°C. In parts of the world where olive oil is processed, the waste left after pressing the olives is used as the fuel. The waste can be used as a liquid or pressed into solid cakes.

Like most food products, olive oil is not a single substance but a mixture of chemical compounds. Among these are fatty acids such as oleic, linoleic and linolenic acids. Oleic acid is the primary constituent. Olive oil also contains both Omega-3 and Omega-6 fatty acids. Other minor constituents include tocopherols, phenols and sterols.

Hexamine

Hexamine, $C_6H_{12}N_4$, is a solid fuel often used by campers and sold under the name Esbit. It is combined with 1,3,5-trioxane in hexamine fuel tablets.
Some properties of hexamine:
Molar mass = 140.2 g/mol
Density = 1.33 g/mL
Boiling Point = 280°C (where it sublimes)

Naphthalene

Naphthalene, $C_{10}H_8$, is a white crystalline solid. It is an aromatic compound with two benzene rings sharing two carbon atoms. It has a distinctive odor and is very volatile. It sublimes when heated.
Melting point = 80°C
Boiling point = 218°C
Density = 1.14 g/mL

Gunpowder

Gunpowder is a mixture of potassium nitrate with sulfur and charcoal. The nitrate serves as the oxidizer and the charcoal and sulfur are the fuels.

Ammonia

It may come as a surprise to many students that ammonia, NH_3, is a fuel. It has been used in internal combustion engines by companies looking to develop hydrogen-based fuels. Ammonia, of course, contains three hydrogen atoms per molecule and so is s good source of hydrogen. The gas is pressurized for use, in order to increase mileage. A cubic foot of ammonia at atmospheric conditions, for example, would power a car only about 500 feet.

Ammonia is difficult to ignite in an engine. The ammonia that burns best is about 95% anhydrous ammonia combined with about 5% pure hydrogen. The result is a fuel with an octane rating of over 170 (gasoline is about 90). Another drawback is the fact that ammonia is made from natural gas in a process that emits carbon into the atmosphere, thus neutralizing the carbonless aspect of burning ammonia.

Liquid ammonia was used as the fuel in the X-15 rocket. It was used to replace petroleum fuels during the shortages in World War II.

Some properties of ammonia:

Molar mass = 17.03 g/mol
Appearance = colorless gas
Odor = distinctive
Melting point = −77.7°C
Boiling point = −33.3°C

Formaldehyde

Formaldehyde, chemical formula H_2CO, is classified as an aldehyde—a compound that contains a carbonyl group bonded to at least one hydrogen atom. A carbonyl group is a carbon atom double bonded to an oxygen, C=O. Some properties of formaldehyde are:

Molar Mass = 30.03 g/mol
Appearance = colorless gas, but gaseous formaldehyde is unstable and cannot be used as a fuel. Instead, polymeric forms would be used. An example of such polymeric forms is 1,3,5-trioxane is a liquid trimer of formaldehyde (mentioned under “Hexamine”).
Melting point = −117°C
Boiling point = −19.3°C
Water solubility = 100g/100mL (This solution is known as formalin)
Flammability = high
Flash point = 60°C (140°F)
Flammable limits in air (% by volume) = 7-73 %

The MSDS sheet for formaldehyde gives the following information: “Poison! Danger! Suspect cancer hazard. May cause cancer. Risk of cancer depends on level and duration of exposure. Vapor harmful. Harmful if inhaled or absorbed through skin. Causes irritation to skin, eyes and respiratory tract. Strong sensitizer. May be fatal or cause blindness if swallowed. Cannot be made nonpoisonous. Flammable liquid and vapor.”

So while formaldehyde has been used as a fuel in Olympic torches, it is a dangerous fuel.

More on pyrotechnics

The article quotes Paul Smith, a lecture demonstrator at Purdue University, West Lafayette, Indiana, a pyrotechnic expert. He comments about how to change the fuel-oxygen mix to alter the color of the flame and make it more visible. Experts on pyrotechnics also know how to change flame colors by adding chemicals to the fuel mix. The example most familiar to students is fireworks.

Fireworks require a fuel, an oxidizer and a chemical that can produce a colored flame. You may already do lab work or demonstrations to show the colors imparted to a flame by heating metal salts—flame tests. Students will be interested in the fact that this is the mechanism by which fireworks are colored. Some of the possible colors and the metal ions that produce them:

Red—lithium, strontium
Orange—calcium
Yellow—sodium

Green—barium
Blue/green—copper

Connections to Chemistry Concepts

1. **Combustion**—The fact that the fuels discussed in the article undergo combustion makes that a good topic for classroom discussion. If you cover combustion as part of a unit on types of chemical reactions, that would be a good time to have students read this article.
2. **Hydrocarbon fuels**—Because petroleum and natural gas are currently hot topics, in part because of their rising prices and partly because of the on-going political debate about "dependence on foreign oil," students should understand that these chemical substances make up fossil fuels.
3. **Organic chemistry**—If your curriculum includes organic compounds, you can also use the article as an example of the importance of many organic compounds.
4. **Alloys**—Alloys are mentioned only briefly in the article. This may be a topic you would want to expand on with your students. See the Websites section below for a resource on alloys.
5. **Technology**—Students may not understand the difference between science and technology since the two terms appear together so frequently. The design and production of the 2008 Olympic torch provides a good example. By applying what science knows about alloys and combustion, for example, to the design and production of an effective Olympic torch, technology can apply the concepts of science for a useful purpose.

Possible Student Misconceptions

1. **"Combustion can only take place in the presence of oxygen in the air."** *The article mentions the fact that combustion takes place in space where there is no atmospheric oxygen. The combustion reaction in these situations relies on a chemical called an oxidizer (or oxidizing agent) to supply the oxygen for combustion. For more background on this see the last few paragraphs of More on the Olympic torch and flame.*
2. **"The Olympic flame is kept lighted continuously after it is first lighted in Greece."** *Technically that's true, but many of the individual relay torches go out along the relay route. The article mentions several lanterns that are each lighted from the original flame in Greece. They represent the original flame and if any of the torches are extinguished by accident, weather or protester, the torch is re-lighted by one of the lanterns.*

Demonstrations and Lessons

1. You can have students compare fuels in a lab activity like this one. Since the article is about different fuels used in the torches, this might be an interesting activity. http://galileo.phys.virginia.edu/outreach/8thGradeSOL/FuelEnergyFrm.htm
2. The article says that many of the experts who help design the torch and flame are pyrotechnic experts. Among their areas of expertise is making fireworks. You can have students make sparklers using a procedure similar to this one: http://chemistry.about.com/od/demonstrationsexperiments/ht/sparkler.htm. These need to be handled with extreme caution.

3. For a NASA unit on combustion see http://astroventure.arc.nasa.gov/teachers/pdf/AV-Atmoslesson-5.pdf. You may already have combustion labs in your course's lab manual. Students can test for the products of combustion using limewater and cobalt chloride paper, etc.
4. Another lab activity could be a more standard chemistry lab on the flame colors of metal ions similar to this one: http://www.kent.k12.wa.us/staff/carriewattles/chemistry/flametestlab_inst.htm; or you can show these videos: http://jchemed.chem.wisc.edu/jcesoft/cca/cca2/MAIN/FLAME/CD2R1.HTM.

Student Projects

1. You can assign small groups of students (or individual students) one of the summer Olympic games and have them research the torch and flame for those games.
2. Have each student read the three articles in this edition of *ChemMatters* that relate to the Olympics and discuss the ways in which chemistry is important for the Olympics.
3. Assign teams of students to design an Olympic torch according to the specifications given in this Teachers Guide (See More on Olympic torch and flame) and also make a prototype of their torch.

Anticipating Student Questions

1. **"Why would keeping the torch burning on Mt. Everest be a problem?"** *Although the percent of oxygen in the atmosphere remains at about 21% regardless of altitude, the TOTAL amount of oxygen decreases as you rise in elevation. At 29,000 feet (about the height of Mt. Everest) there is about five times less oxygen present, making combustion more difficult. For a somewhat different view, see* http://www.npr.org/templates/story/story.php?storyId=11331007.

2. **"I'm not sure what an oxidizer is."** *For an answer to this see the last few paragraphs of More on the Olympic torch and flame.*

3. **"The article talks about a liquid fuel. Do liquids burn?"** *Liquids do not burn. In general liquids we think of as fuels are conveniently stored as liquids, but in order to burn, the liquid vaporizes and the vapor then combines with oxygen to burn.*

Web Sites for Additional Information

More sites on the Olympic Games

The official web site of the International Olympic Games is http://www.olympic.org/uk/games/index_uk.asp. It includes much more information about the Olympic torch and flame.

More sites on the Olympic Torch

The Olympic Museum publishes a history of the Olympic Torch, which you can read here: http://multimedia.olympic.org/pdf/en_report_655.pdf.

More sites on Oxidizers

For a more complete description and listing of oxidizers, see http://safety.science.tamu.edu/oxidizers.html.

To read a Chemical and Engineering News article on pyrotechnics, which includes discussion of oxidizers, see http://pubs.acs.org/cen/coverstory/86/8626cover.html.

More sites on Extreme Conditions

To read an online article from National Geographic about the Olympic flame, featuring an interview with ACS staff person Jerry Bell, see http://news.nationalgeographic.com/news/2008/04/080409-olympic-torch.html.

More sites on Alloys

For an extensive table of alloys and their composition, see http://www.csudh.edu/oliver/chemdata/alloys.htm

The Chemistry of Marathon Running

Background Information

More on physiology of exercising the human body (A chemical and physical machine!)

When there is a demand on the heart for increased blood flow the heart increases output by increasing stroke volume and beating frequency. The lungs increase capacity by increasing tidal volume (air moved in and out of the lungs) through more rapid breathing and expanding thorax through contracting of muscles in rib cage. The thorax is sealed from the atmosphere—increasing thorax capacity by a lowering of the diaphragm lowers lung air pressure compared with atmospheric pressure and more air enters the lungs. Expanded volume of a fixed amount of gas lowers the pressure of gas.

Transport of oxygen gas is primarily in the hemoglobin molecules of red blood cells. Exchange of the gas between lung capillaries and tissue capillaries is based on differences in partial gas pressures (concentration-related) and pH. At higher altitudes, this exchange is compromised, making exchange rate lower as the blood/tissue system is fine tuned to atmospheric pressures near sea level. Carbon dioxide is exchanged between the blood plasma and tissue fluids at the capillary level. Technically, the carbon dioxide first diffuses into the red blood cells (RBCs) and reacts with water to form carbonic acid which ionizes into bicarbonate ion, HCO_3^- (and H^+) which diffuses into the blood plasma and is carried to the lungs.

There is an interesting interplay of partial pressures of gas and pH for the binding of oxygen gas to hemoglobin in the lungs and release at the tissue level. Higher pO_2 and higher pH of blood at the lungs (~7.4, 7.5) affect the taut (T) tertiary configuration of hemoglobin to the relaxed state (R) such that oxygen molecules bind and are carried to tissue where pO_2 is lower, pH is lower (~7.2) and the hemoglobin structure is effected, changing to the taut (T) state, releasing the bound oxygen to the tissues. The release of the oxygen is associated with the lower pH due to the fact that 80% of the carbon dioxide gas in the tissues at a higher partial pressure diffuses into the RBCs, where once again the gas reacts with water to produce carbonic acid through enzymatic influence (carbonic anhydrase). Subsequently, the carbonic acid reaches equilibrium with its component hydrogen ion and bicarbonate ion.

$CO_2\ (g) + H_2O\ (l) \leftrightarrow H_2CO_3\ (aq) \leftrightarrow H^+\ (aq) + HCO_3^-\ (aq)$ (Eq. 1)

The bicarbonate ion diffuses out of the RBCs into the plasma and is carried to the lungs along with a small amount of dissolved CO_2 gas. Additional amounts (15%) of CO_2 are carried to the lungs bound to specific amino acids of the hemoglobin molecule. When the CO_2 binds to the hemoglobin, there is a release of H^+ which contributes to the lower pH in the tissues and the release of oxygen.

$CO_2 + Hb\text{-}NH_2 \leftrightarrow H^+ + Hb\text{-}NH\text{-}COO^-$ (Eq. 2)

At the lungs, the original binding of oxygen to the hemoglobin causes release of hydrogen ions that are bound to the special amino acids of the hemoglobin (in the tissue, hydrogen ions are produced when carbon dioxide binds to certain amino acids on the hemoglobin molecule ($Hb\text{-}NH_2$)- (Eq. 2). These released H^+ ions combine with the bicarbonate ions (HCO_3^-) coming from the tissue via the blood plasma. The ions combine to form carbonic acid which diffuses into the RBCs where once again through carbonic anhydrase, the reaction produces carbon dioxide gas which diffuses out of the blood into the lungs for removal!

So much of what happens with the hemoglobin binding and releasing of oxygen (through change in the tertiary structure of hemoglobin) is closely associated with hydrogen ion concentration. Increases in H^+ concentration decrease the amount of bound oxygen regardless of oxygen concentration—the Bohr Effect. (http://themedicalbiochemistrypage.org/hemoglobin-myoglobin.html, p.3)

Maximum ventilation capacity for resting and active people is never reached or used. So it is not a limiting factor when the body has increased demands for oxygen. But trained athletes use more of their capacity than those not trained. Restrictions on endurance are related more to blood/tissue chemistry limits (glucose to ATP conversion) than to lack of oxygen availability.

More on blood biochemistry

“Blood is an amazing and vitally important part of the body, because it contains many finely-tuned chemical systems that allow it to maintain the chemical environment needed for the body's metabolism. One of the most important functions of blood is delivering O_2 to all parts of the body by the hemoglobin protein. Oxygen is carried in the hemoglobin protein by the heme group. The heme group (a component of the hemoglobin protein) is a metal complex, with iron as the central metal atom, which can bind or release molecular oxygen. Both the hemoglobin protein and the heme group undergo conformational changes upon oxygenation and deoxygenation. When one heme group becomes oxygenated, the shape of hemoglobin changes in such a way as to make it easier for the other three heme groups in the protein to become oxygenated, as well. This feature helps the protein to pick up oxygen more efficiently as the blood travels through the lungs. Hemoglobin also enables the body to eliminate CO_2, which is generated as a waste product, via gas exchange in the blood (CO_2 exchanged for O_2 in the lungs, and O_2 exchanged for CO_2 in the muscles). The species generated as waste by the oxygen-consuming cells actually help to promote the release of O_2 from hemoglobin when it is most needed by the cells. Hence, hemoglobin is a beautiful example of the finely tuned chemical systems that enable the blood to distribute necessary molecules to cells throughout the body, and remove waste products from those cells.” (http://www.chemistry.wustl.edu/~edudev/LabTutorials/Hemoglobin/MetalComplexinBlood.html, p.14)

The body needs to maintain a pH that does not fall much below 7.4 (normal maximum range of 6.8-7.8). Metabolism of glucose produces both CO_2 and H+, both of which contribute to a drop in pH. To prevent this change in pH, certain H ion “absorbers” are available to reduce “free” H ions. These are known as buffers. One of the most abundant hydrogen ion “absorbers” is the bicarbonate ion, HCO_3^-. Interestingly enough, bicarbonate ion is found in the dissociation of carbonic acid, H_2CO_3, which is produced when highly soluble carbon dioxide gas dissolves in the blood (water),

$$CO_2\,(g) + H_2O\,(l) \rightarrow H_2CO_3\,(aq) \rightarrow H^+\,(aq) + HCO_3^-\,(aq)$$

“The following steps outline the processes that affect the buffers in the blood during exercise.

Hemoglobin carries O_2 from the lungs to the muscles through the blood.

The muscles need more O_2 than normal, because their metabolic activity is increased during exercise. The amount of oxygen in the muscle is therefore depleted in the muscles, setting up a concentration gradient between the muscle cells and the blood in the capillaries. Oxygen diffuses from the blood to the muscles, via this concentration gradient.

The muscles produce CO_2 and H^+ as a result of increased metabolism, setting up concentration gradients in the opposite direction from the O_2 gradient.

The CO_2 and H^+ flow from the muscles to the blood, via these concentration gradients.

The buffering action of hemoglobin picks up the extra H^+ and CO_2.

If the amounts of H^+ and CO_2 exceed the capacity of hemoglobin, they affect the carbonic acid equilibrium as predicted by Le Châtelier's Principle or the quantitative treatment in terms of equilibrium constants.

H_3O^+ (aq) + HCO_3^- (aq) = H_2CO_3 (aq) + H_2O (l) = 2 H_2O (l) + CO_2 (g)

As a result, the pH of the blood is lowered, causing acidosis.

The lungs and kidneys respond to pH changes by removing CO_2, HCO_3^-, and H^+ from the blood.

Hence, the body has developed finely-tuned chemical processes (based on buffering and acid-base equilibrium) that work in combination to handle the changes that exercise produces." (http://www.chemistry.wustl.edu/~edudev/LabTutorials/Buffer/Buffer.html, pp14-15)

More on enhancing performance (normal)

The purpose of training is to condition the body to the excess demands when running or exercising. These include cardiac output, maximum volume of oxygen (VO_2Max), and lactate threshold.

- Cardiac Output—training to increase stroke volume (amount of blood pumped at each contraction) and cardiac output (total blood pumped per minute)
- VO_2 Max (Maximum Volume of Oxygen)—This is the maximum volume of oxygen that the muscles can consume per minute. This is determined as much by genetics (limits) as by training.
- Lactate Threshold—This means you can run faster without relying on lactate production.

There are well-designed workouts for improving your body's performance in each of the above. (See ref. http://runningtimes.com/Print.aspx?articleID=13397.) Interestingly enough, lung capacity is not dramatically changed through training. Where cardiac output is changed through training and "on-demand" stimulus (physiological response by the heart under strain), lungs can be conditioned to use up to 90% of its maximum ventilation capacity during exercise but it seems as if the true maximum is not reached (compared with cardiac output). So ventilation capacity is not a limiting factor when running!

Related to all of this is the fact that metabolism associated with running (respiration in the muscle cells) is under the control of enzymes (and the amount of oxygen), with a goal of increasing lactate tolerance by increasing the extent to which the muscle tissue remains in aerobic respiration. Aerobic training appears to produce an increase in enzyme activity which becomes available under running "stress". (http://runningtimes.com/Print.aspx?articleID=13397, p.3) Other studies in sprint training support the notion that enzyme activity is increased for both aerobic and anaerobic respiration.

The extent of oxygen availability to the muscle cells for oxidation of the end product of glycolysis, pyruvate, will also determine if the pyruvate goes through aerobic oxidation to CO_2 and H_2O, or anaerobic "fermentation" to lactate and lactic acid. This latter production is responsible for the development of acidosis that creates muscle fatigue. Further, going the pyruvate route produces 19 times more potential energy (in the form of ATP) than going the lactate route. Training increases the maximum speed of running before the muscle is forced to begin doing anaerobic respiration.

More on performance "drugs"

For the following, visit the website of the Smithsonian, http://invention.smithsonian.org/centerpieces/inventingourselves/pop-ups/02-07.htm

1. **Strychnine**, 1889**:** One of the earlier and stranger chemicals used to enhance performance was strychnine!

In the early 20th century, strychnine was taken in very small amounts by long-distance runners to increase endurance. For example, Thomas Hicks won the 1904 Olympics marathon after ingesting two doses of strychnine diluted in brandy. He collapsed shortly after crossing the finish line, where it took hours to revive him. In larger doses, strychnine can be fatal. If Hicks had taken another dose, it could have killed him. Had the race been run under current rules, Hicks could have been disqualified, but strychnine use was considered an acceptable practice at the time.
http://invention.smithsonian.org/centerpieces/inventingourselves/pop-ups/02-07.htm

2. **Iron supplement**, 1906-08: Iron Bitters, a patent medicine used for a variety of ailments, was commonly taken by long-distance runners in the early 20th century. It was believed to build muscle and boost energy.

3. **PowerGel®**, 2003**:** PowerGel® was invented by the makers of PowerBar® to provide electrolytes and carbohydrates in a dense, semi-liquid emulsion. The product is appealing to runners who don't like sports drinks or find it difficult to digest solid energy bars. This package of PowerGel® also contains caffeine, reflecting how runners have recently returned to the use of stimulants to maintain endurance.

4. **Gatorade®:** Gatorade® dates from about 1967. In 1965 the Florida Gators assistant football coach asked Dr. Robert Cade why players lost weight, but urinated little, during games. Cade, then director of the College of Medicine's renal and electrolyte division at the University of Florida, took the question back to his lab where he and his research fellows started looking into it. They knew that weight was lost through sweat during exercise but were surprised to discover extreme drops in blood pressure and blood sugar in the football players. They began concocting a solution of water, salt, sugar, and lemon juice, which boosted the players' energy levels.

Gatorade was created to re-hydrate the body and replace electrolytes—primarily sodium and potassium—that are lost through sweat. It also contains sugar to help stabilize blood sugar levels.

By the 1966 season, Gatorade®was available on the Gators' sideline. In 1967 the Stokely-Van Camp company purchased exclusive rights to market Gatorade® nationwide and established the Gatorade® Trust to ensure the inventors—Drs. Robert Cade, Jim Free, A. M. de Quesada, and Dana Shires—a share of the Gatorade® fortune. The University of Florida filed a lawsuit against the Gatorade® Trust and Stokely-Van Camp in 1971 and received a 20 percent share of Gatorade® royalties.

Other more recent performance enhancing substances include:

- **Erythropoietin (EPO)** is a hormone that occurs naturally in the body, released by the kidneys. EPO binds to receptors in bone marrow stimulating the marrow to produce additional red blood cells (RBCs). In the late 1980s, genetically engineered recombinant erythropoietin, r-EPO was developed for enhancing the treatment of anemia produced by kidney disease and chemotherapy. The use of r-EPO is as effective as a blood transfusion. http://www.medterms.com/script/main/art.asp?articlekey=7032

- **Creatine** is another substance produced in the human body that is more effective in what is known as power athletics (weight-lifting) compared with endurance athletics (marathon running). (http://www.rice.edu/~jenky/sports/creatine.html, and http://www.nlm.nih.gov/medlineplus/druginfo/natural/patient-creatine.html) (This reference lists the scientific studies done so far on the effectiveness of creatine on different physiological activities.)

- **Anabolic steroids** are also naturally occurring, but increased levels in the blood beyond the normal can be detected.

- Then there is the far-fetched but recent idea of ingesting baking soda, 20 grams about 1.5 hours before competition. There is a measurable improvement in performance in short, quick running sprints, as much as a 2.2 second reduction in time. http://www.acsm.org/AM/PrinterTemplate.cfm?Section=Media&TEMPLATE=/CM/ContentDisplay.cfm&CONTENTID=10115

More on body under stress—high altitude adaptations or equivalents

When the body is subjected to lower atmospheric pressure (mountains), the blood system responds with both increased release of the gas NO in the short term to increase circulation as well as the production of more red blood cells to carry more oxygen. The latter change is taken advantage of by some athletes; they live at higher altitudes to increase the number of red blood cells but train at lower levels.
http://faculty.washington.edu/crowther/Misc/RBC/altitude.shtml

But for some people whose history includes always living at high altitudes, there are other physiological adaptations such as those studied in the Tibetans.
http://www.sciam.com/article.cfm?id=how-tibetans-enjoy-high-life
According to new research, Tibetans avoid altitude sickness because they have broader arteries and capillaries delivering oxygen to their muscles and organs.

At the same time that Tibetans are extremely hypoxic at high altitude, they consume the same amount of oxygen that we do at sea level," says anthropologist Cynthia Beall of Case Western Reserve University in Cleveland. "One of the ways they do that is to have very high blood flow—delivering blood to tissue at twice the rate that we are."

The Tibetans increase their blood flow by producing prodigious amounts of nitric oxide (NO) in the linings of the blood vessels. This gas diffuses into the blood and forms nitrite and nitrate, which cause the arteries and capillaries to expand and deliver oxygen-bearing blood to the rest of the body more rapidly than normal. (http://www.sciam.com/search/index.cfm?q=Nitric+Oxide&submit.x=0&submit.y=0&submit=submit)

Tibetans breathe a lot, too, averaging more breaths per minute than lowlanders or even their peers in other highland regions, such as the Andeans of South America, who boast larger lungs than the average human. Also, giving Tibetans pure oxygen actually slows their heart rates by 16 percent. But these scientists say that Tibetans' ability to produce higher levels of nitric oxide is the key to their ability to thrive among the world's tallest peaks. (http://www.sciam.com/article.cfm?id=how-tibetans-enjoy-high-life)

For the training of long distance runners (and even swimmers!), athletes can go to higher altitudes to increase RBC production in a natural way without the risks associated with what is called blood doping (using a blood transfusion or taking r-EPO). The effectiveness of this technique where the lower partial pressure of oxygen in the atmosphere (and the body) stimulates additional RBC production is coupled with continued training back down at lower altitudes since training at high altitudes does not seem to be effective. So, the regimen is to live at high altitudes for at least four weeks but go to lower altitudes daily for workout regimens. http://faculty.washington.edu/crowther/Misc/RBC/altitude.shtml

More on ethics of performance enhancement

Assuming students want to diverge from the chemistry of running to the ethics of using chemistry to enhance performance, there are many ethical issues surrounding the point of enhancing an athlete’s bodily performance. Should the basic physiological constraints be increased for any one person, assuming each person has equal access to all non-dangerous “drugs” (biochemical imitators of human performance-enhancing chemicals) and physical “dress” materials (streamlined swimsuits, bicycles, prostheses)? If there is equal access, what should not be allowed and why? Is training at high altitudes to increase red blood cells (RBC) for higher oxygen-carrying capacity when running at lower altitudes different from taking erythropoietin, which is a hormone normally manufactured in the body? Is the easy way for forming more RBCs with EPO not considered “sporting” (artificially enhancement of performance) compared with the physical demands of training at high altitudes? Is taking extra blood through transfusion again considered non-demanding (physically), and therefore not sportsman-like? (http://www.medicinenet.com/script/main/art.asp?articlekey=90632)

Hospitals normally test for hemoglobin level (RBCs) with a test known as the hematocrit (HCT) or erythrocyte volume fraction (EVF). This is the proportion of blood volume that is occupied by red blood cells. An elevated level could indicate the presence of EPO. But a “test” of the test for extra EPO in the blood on active athletes has always produced different results from different test facilities. So, athletes know they have a good chance of going undetected or can challenge the results.

Perhaps this is a good point for researching just how chemistry, particularly physical chemistry such as gas chromatography, infrared and mass spectroscopy, is used in detecting a variety of natural and unnatural substances in the blood. How do the anabolic steroids increase performance besides simply increasing muscle mass? How does creatine work? The following articles are good starting points for student research:

http://invention.smithsonian.org/centerpieces/inventingourselves/debates.htm

http://www.sciam.com/article.cfm?id=the-doping-dilemma

http://www.sciam.com/article.cfm?id=the-medicine-show-drugs-i (excellent listing of the different enhancing drugs and what they do—a chart)

Connections to Chemistry Concepts

1. **pH**—This range of numbers that refers to the concentration of H^+ affects many biological (chemical) functions in the body. For instance, an increasing concentration of carbon dioxide because of increasing metabolism of glucose produces more carbonic acid, which in turn briefly increases hydrogen ion concentration which means a <u>decrease</u> in pH.
2. **Buffers and equilibrium**—Buffers are very important in controlling any drastic pH changes in the body's blood oxygen-carbon dioxide equilibrium system. This is done through the use of mixtures of a weak acid and its conjugate base. When hydrogen ions increase in a buffered system, base ions in solution will combine with the hydrogen to form a weak acid which means the acid molecule will have a low ionization value, "tying" up (not freeing) the increased concentration of hydrogen ion. (See #1, pH for an example of the source of increased hydrogen ion.)
3. **Polymers**—Many of the molecules in biological systems are polymers.
4. **Glycogen**—This large molecule is a good example of a type of polymer (-*mer* for "molecule"). The basic unit, (monomer) glucose is linked to other glucose units (under enzymatic control, in which a water molecule is formed per two glucose units) to form the polymer. In plants, with a different enzyme, the glucose units are synthesized into a different polymer, starch, whose molecular spatial geometry is different, giving rise to a molecule with the same empirical formula but different physical properties, including its low solubility in water compared with glycogen. The same is true when the glucose monomer is arranged differently in space to form cellulose, another insoluble structural material of plants.
5. **Molecular geometry**—Shape of a molecule is intimately connected to the physical behavior of that molecule. See #4 above.
6. **Carbohydrates**—This is a category of molecule made of carbon, hydrogen, and oxygen, are considered a prime source of energy for all organisms. In the case of glucose, it is converted to pyruvic acid, and then a "transfer" (conversion) of energy is made in a series of reactions (the Krebs cycle) into another molecule, adenosine triphosphate (ATP) from the phosphorylation of adenosine diphosphate (ADP), an endothermic reaction.
7. **Proteins**—These are more examples of polymers, a polypeptide in this case, in which the monomer is an amino acid and the common elements of the acid are again carbon, hydrogen, and oxygen along with the distinguishing nitrogen atom from which the word "*amine"* is derived (*Am*- of ammonia, NH_3 + -*ine*). The amine group is $–NH_2$. This particular polymer is the basis for large biological structures such as muscle, be it heart (cardiac), leg or arm (striated) or digestive (smooth).

8. **Lipids (Fats)**—These biomolecules are synthesized from fatty acids and either glycerol or alcohols through a dehydration reaction. Reactions between fatty acids and glycerol produce animal fats and oils. Reactions of fatty acids and alcohols produce waxes. The molecule's empirical formula contains again just carbon, hydrogen, and oxygen. But whether the lipid is a fat or an oil, with different physical properties at room temperature (fat is solid, oil is liquid) depends on the presence of saturated or unsaturated bonds. Fats are, like proteins, part of cellular structures, in particular the cell membrane. Oils have many unsaturated bonds and lend themselves to hydrogenation as in the preparation of food products such as mayonnaise and solid peanut butter. Fats as sources of energy in exothermic reactions as in cellular respiration produce more kilocalories per gram than carbohydrates such as glucose. But glucose rather than lipids is the energy source of choice. Other than the resting state, greater energy demands cause fats to be broken down into fatty acids and glyceride by hydrolysis. This will occur in most cell types excepting brain and other nervous cells in order to conserve glucose reserves within these nerve cell types that use glucose almost exclusively, except in starvation situations.

9. **Fatty Acids**—One of the two chemical units for synthesizing lipids, fatty acids are made from carbon, hydrogen, and oxygen. And they are the breakdown products of fats (lipids) that are used in the energy-generating cycle of metabolism.

10. **Calories, Kilocalories**—Body metabolism as a series of chemical reactions is measured in terms of calories or Kilocalories (Calories with a big "C"). The potential energy in food that is used in body metabolism can be determined through a basic calorimetry exercise involving direct combustion in which all energy conversions become heat energy. For known chemical reactions involving carbohydrates, fats and specific amino acids (units in protein), calculations of the delta H for the reaction can be done with bond energy "summations" (bond breaking, bond making).

11. **Thermochemistry**—See #10, above.

12. **Fermentation**—An exothermic reaction, this is a process by which complex organic compounds, such as glucose, are broken down by the action of enzymes into simpler compounds without the use of oxygen. Fermentation results in the production of energy in the form of two ATP molecules, and produces less energy than the aerobic process of **cellular respiration**. The other end products of fermentation differ depending on the organism. In many bacteria, fungi, protists, and animals cells (notably muscle cells in the body), fermentation produces lactic acid and lactate, carbon dioxide, and water. In yeast and most plant cells, fermentation produces ethyl alcohol, carbon dioxide, and water.

13. **Aerobic Respiration**—Within a cell (mitochondria), this biochemical process has three major stages that overall contribute to energy transfer. In bond breaking and making, the potential energy in a molecule of glucose, for example, is eventually shifted into the bond making of adenosine triphosphate (net, endothermic). The difference between aerobic and anaerobic respiration is in the products (and reactants): Anaerobic respiration converts glucose to two lactate molecules, which is less exothermic than the different reaction of aerobic respiration, which involves glucose and oxygen forming CO_2 and water.

Possible Student Misconceptions

1. **"Breathing more rapidly for a period of time prior to running will increase dissolved oxygen in the blood."** *In a normal person at rest, blood is normally 96% saturated with oxygen. More rapid breathing's effect decreases dissolved carbon dioxide much more than increasing dissolved oxygen. Reducing* CO_2 *raises blood pH which affects the breathing center in the brain. As a result there is a delayed sensation for wanting to*

breathe. If you were in the water, you could stay under water longer than normal before "wanting" to breathe. Perhaps you have heard about this "trick" but it is based on decreasing the breathing stimulus, carbon dioxide, not significantly increasing dissolved blood oxygen.

Demonstrations and Lessons

1. Exhale into a solution of either limewater of bromothymol blue to show effect of carbon dioxide. Compare with bubbling room air into the same solutions. Elicit from students their knowledge of the % by volume of oxygen and carbon dioxide in room air and in exhaled air. Relate to the results of the demo.
2. A student lab activity or demonstration to show hydrolysis in solutions and the common ion effect relates to buffered solutions. Use a weak acid (conjugate acid) such as acetic acid along with the salt of acetic acid (conjugate base), sodium acetate. Add one drop of 1.0 M sodium hydroxide and note what if any change in pH occurs. Compare this reaction with using just distilled water (that has been boiled) and the addition of one drop of 1.0 M NaOH. Repeat with a 1.0 M solution of acetic acid instead of 1.0 M NaOH. (There are standard lab procedures that students can follow using a variety of buffered solutions which are a weak acid and the salt of that acid or a conjugate acid with a conjugate base.)
3. Demo to show degradation of cane sugar by sulfuric acid in which dehydration generates noticeable heat and steam with a black carbon residue remaining. Compare products to that of respiration (carbon dioxide gas and water). Why the difference? (You are comparing two different systems—dehydration or water formation vs. oxidation and the Krebs cycle, a multi-step process that is highly efficient in the "transfer" of bond energies from glucose to ATP (adenosine triphosphate.)
4. Measure the caloric content of food or calculate the potential energy of the bonds in a glucose molecule and compare with the bond energies of the products, carbon dioxide and water. Is the oxidation of glucose an exothermic or endothermic reaction according to the calculations? Why do we not overheat from the oxidation of glucose in our bodies (in the mitochondria of our cells)? To measure the caloric content of a piece of food, a standard combustion reaction can be done using something like a peanut or walnut to heat a known mass of water in an aluminum soda can (calorimetry). Be aware of student nut allergies before doing this experiment with nuts. Knowing the mass of the fuel converted to energy and products (carbon dioxide and water) by determining the mass before and after combustion, students could calculate a rough value for the heat of combustion of the fuel. This can also be done using a candle (you will have to use a general formula for the candle, such as stearic acid) or vegetable oil with a wick floating in it to provide a flame.
5. Alcoholic fermentation can be done by students using yeast in a sugar solution. The setup for the system should include a delivery tube from an Erlenmeyer flask, containing the yeast/sugar solution, which goes into a solution of limewater. A second set-up could use water with a universal indicator or Bromothymol Blue indicator (relate to the exhaled air demo, #1 above). This basic experiment can be modified to show the effect of a variety of environmental factors including temperature, amount of yeast which contains the enzyme for fermentation, the pH of the sugar solution, and the effect of having the Erlenmeyer open to the atmosphere for oxygen. Students could distill off the alcohol and test for flammability.
6. Respiration and effects on rate can be shown using a simple respirometer for measuring the rate of activity of germinating pea seeds. A useful reference for this activity can be found at http://www.phschool.com/science/biology_place/labbench/lab5/intro.html. An advanced lab procedure which is more quantitative and with better background on the chemistry and

physics of the setup and procedure can be found at www.jdenuno.com/PDFfiles/Respiration.pdf.

7. Identifying the major food groups (protein, fats, and carbohydrates) can be done by chemical analysis. One example of this type of lab activity can be found at the Access Excellence site under “Organic Compounds” at http://www.accessexcellence.org/AE/ATG/data/released/0335-HeidiHaugen/index.php.

8. Related to #7 would be using various digestive enzymes to breakdown the larger polymers of protein, polysaccharides (carbohydrates), and fats (lipids) into smaller molecules for which there are standard tests. In doing these enzymatic activities, various environmental factors can be tested including pH, concentration of the enzyme, concentration of substrate, and temperature. Enzymes, as proteins, are temperature and pH sensitive. Heating the solution beyond body temperature (37 °C) will undo the secondary and tertiary structure of the molecule (breaking a lot of H bonds; “denaturing”) and render the enzyme inoperable.

- Additional enzyme activities related to chemical processes in biological systems can be done both qualitatively quantitatively. A qualitative activity using amylase’s action on starch, converting to simple sugars can make use of the amylase contained in a student’s saliva. The saliva can be collected in test tubes by students. Addition of a starch solution to the test tube and subsequent action of the amylase can be analyzed for results by testing samples of the starch-amylase solution for breakdown products including glucose.
- Another common enzyme is catalase (found in the liver but also in plant tubers such as potatoes). The action of catalase on hydrogen peroxide, produced in living cells and a potential poison, can be measured quantitatively under a variety of environmental conditions (temperature, pH, concentration of substrate and enzyme). See an example of a lab setup for this activity at http://www.accessexcellence.org/AE/ATG/data/released/0074-GenNelson/index.php.
- Some specific background of catalase in biological systems to complement the lab activity can be found at http://www.catalase.com/cataext.htm.

Student Projects

1. Several of the *“**Class lessons/demos**” can* also be turned into student projects, particularly the exercise on “Respiration in Pea Seedlings” which involves as much chemistry as descriptive biology. The same is true for ***“Alcoholic Fermentation”***. An extended series of exercises with the common ion effect as well as setting up buffered solutions can be done using titrations to compare buffered with unbuffered acidic or basic solutions. Reference can be made to a variety of chemistry lab manuals.
2. A second project, again mentioned in “Demonstrations and Lessons”, that provides good investigation opportunities for students is the evaluation of catalase activity under a variety of conditions that affect enzyme activity. See Demo/Lesson suggestion # 8.
3. For the student with good chemistry understanding, literature research into the Krebs cycle (investigated and “explained” by Hans Krebs, Nobel Prize winner in Medicine, 1953) as well as some quantitative experiments will prove challenging. One lab manual containing such an experiment on respiration using mitochondria extracted from lima beans is ***Laboratory Investigations for Biology*** by Jean Dickey (Benjamin Cummings Publishing Company, Inc.1995; ISBN 0-8053-0922-5). More information on the Krebs or Citric Acid cycle can be found at the following-http://en.wikipedia.org/wiki/Citric_Acid_Cycle. An

animation of the Krebs cycle can be found at: http://www.science.smith.edu/departments/Biology/Bio231/krebs.html. Biographical information on Hans Krebs can be found at http://en.wikipedia.org/wiki/Hans_Adolf_Krebs. His Nobel Lecture makes a good read for students because Krebs makes clear all of the work by other chemists that helped Krebs in his research into the biochemistry of the Citric Acid Cycle mechanisms. (http://nobelprize.org/nobel_prizes/medicine/laureates/1953/krebs-lecture.pdf)

4. As mentioned earlier, students could research how chemistry, particularly physical chemistry, (gas chromatography, infrared and mass spectroscopy) is used in detecting a variety of natural and unnatural substances in the blood. Related questions include: How do the anabolic steroids increase performance besides simply increasing muscle mass? How does creatine work? The following articles are a good starting point for student research: http://invention.smithsonian.org/centerpieces/inventingourselves/debates.htm, http://www.sciam.com/article.cfm?id=the-doping-dilemma (This article deals with the reasons athletes take chances by violating drug prohibition rules.) and http://www.sciam.com/article.cfm?id=the-medicine-show-drugs-i (This is an excellent listing in chart form of the different enhancing drugs and what they do.)

Anticipating Student Questions

1. **"Why is a glucose molecule converted to ATP molecules in the respiration process—why is it not used directly as the source of energy?"** *The simplest analogy is that a glucose molecule is like a $100 bill, not practical for normal transactions. The production of ATP molecules from glucose is the equivalent of converting the $100 bill into many smaller denomination bills ($2 bills?!). This conversion process is done through a very efficient series of chemical reactions known as the Krebs cycle.*
2. **"How are glucose molecules made into glycogen?"** *Essentially, a water molecule is formed from every two glucose molecules by the removal of a hydrogen (H) atom on one molecule and a hydroxyl (–OH) ion on the second glucose, utilizing two different enzymes, glycogen synthetase and a branching enzyme. A bond is formed between these two glucose molecules or each glucose molecule bonds to a glycogen molecule either as a straight chain bond or as a branching bond.*
3. **"Why does the body not overheat if converting glucose to carbon dioxide and water is the same as combustion of glucose (think of burning sugar in the oven when baking)?"** *Within the mitochondria of a human body cell is where the glucose conversion takes place in a process called respiration. There are multiple steps(involving both electron and proton transfer) that comprise what is known as Krebs cycles during which there are small energy changes taking place with little energy "lost" as heat energy. Ultimately, essentially all of the energy released on combustion of glucose is released as heat. (Some goes into chemical energy of building cellular structures, but at steady-state, that same energy is ultimately released as those structures are broken down.) The reason the body does not overheat is because the energy is released slowly and because we have ways of dissipating the heat (especially sweat).*

References

http://home.hia.no/~stephens/exphys.htm (exercise physiology—the methods and mechanisms underlying performance; huge section on physiological basis for endurance

performance with embedded articles that extend the investigation of any one chapter or article—a basic reference.)

Web Sites for Additional Information

More sites on the structure and mechanics of muscle tissue

All about muscle physiology, including the details of muscle tissue and its cells, their physics and chemistry of contraction, can be found at the following two websites: http://muscle.ucsd.edu/musintro/jump.shtmlhttp: and http://fig.cox.miami.edu/~cmallery/150/neuro/muscle.htm.

More sites on the biochemistry of muscle activity

For more on the biochemistry of muscle contraction with good illustrations of that chemistry, go to http://www.nismat.org/physcor/muscle.html.

The website, http://www.simpsonassociatesinc.com/physlgy.html, has more on the biochemistry involved with respiration when using muscles.

More sites on understanding physiology and applying to marathon training and other sports

http://home.hia.no/~stephens/traprin.htm (principles of training revisited)

http://www.copacabanarunners.net/i-exercise-physiology.html (concepts of exercise physiology for runners)

http://home.hia.no/~stephens/ventphys.htm (ventilation and endurance performance- do our lungs limit how fast we can go?)

http://runningtimes.com/Print.aspx?articleID=13397 (four lessons a runner has learned from physiology)

http://themedicalbiochemistrypage.org/glycogen.html (all about glycogen)

http://www.mayoclinic.com/health/carb-loading/HQ00385 (carbohydrate loading and its effects on running)

http://jeb.biologists.org/cgi/content/abstract/204/18/3189 (limits to sustainable muscle performance)

New Materials for Better Athletes

Background Information

More on the history of the Olympics

The Olympics of ancient Greece were held from 776 B.C. until the 4th century A.D. In 393 A.D. Christian emperor Theodosius I outlawed all pagan celebrations, which included the Olympic Games. This effectively brought an end to the “Ancient Olympics”.

A series of Greek competitions in the late 1800s paved the way for the revival of the Olympic Games as we know them today. Evangelis Zappas, a wealthy Greek landowner, convinced the Greek government to run an athletic competition, just for Greeks. The government convinced Zappas to include a combination of agricultural and industrial exhibits in the celebration, as they saw these as the true tests of a country’s progress. This format continued through four different stagings of the “Olympia”, as these early games came to be called. Zappas planned to hold the Olympia every four years, patterned after the original Olympics competitions. They were actually held in 1859, 1870, 1875 and 1889. The combination of industry exhibits and athletic competition was not well accepted, and so was not carried through in the new Olympics, when they were reinstituted seven years later.

The modern version of the Olympics was inaugurated in Athens in 1896, thanks in large part to the efforts of Pierre de Coubertin, a French nobleman. Pierre sought to incorporate sport into the educational system, through whatever means he had at his disposal. He saw the Olympic Games as one way to make the world population more appreciative of sports and more aware of the need for physical education in schools. It must have worked, because international interest in the Olympics competition sparked the advent of physical education into schools during the early years of the new Olympics Games.

De Coubertin was president of the International Olympics Committee (IOC), the governing body for Olympics worldwide, from 1896-1925, although he was not the first president of the organization. Originally it was thought that the host country should determine the president, for planning purposes and, since the first Olympics were held in Greece, Demetrius Vikelas was appointed the IOC’s first president. This was quickly changed after the first Olympics, however, and de Coubertin was appointed president in 1896.

The original Olympics rules, overseen by the IOC, required that athletes be amateurs; Baron de Coubertin envisioned the competition involving only amateurs, who competed for the love of the sport, and who were not seeking financial reward. It was his vision that drove the IOC to maintain the amateur status for competitors for almost a century thereafter. Of course, in those days, only the well-to-do could afford to play sports. Thus the lower class was effectively banned from the Olympics, without any specific rules to that effect.

The rule of amateurism held until 1986, when the IOC changed the rule to allow all athletes to participate, amateur or professional. This change was made in large part due to the

Russian training program for their athletes. Their athletes were full-time athletes; they did not work for a living at a job; the government sponsored them and their training. Other countries, since the Russians, have adopted similar policies.

Here are a few of the personal stories behind the Olympic Games of the past:

The 1904 Olympics in St. Louis gave us the first instance of athlete-doping. American Tom Hicks, winner of the marathon, admitted afterward to having drunk a mixture of alcohol and strychnine before his race. The IOC did not take away the medal.

The 1904 Olympics also gave us a unique look into cheating at the Games. Fred Lorz, an American, came in first in the marathon, after the spectators had waited more than three hours for the first runner to appear at the finish line. After he had received the acclamation of the crowd, it was learned that he had run only part of the race, and he had ridden in a bus back to the stadium, gotten off just before the stadium, and ran into the stadium to claim his prize. Lorz was dethroned and given a lifetime ban from the Olympics. Thus it was that Tom Hicks was declared the winner.

In 1912, at the 5th Olympics in Stockholm, George Patton (later to be General George Patton of World War II fame) competed in the pentathlon. Shooting was his best event, and the judges declared that one of his shots had missed the target entirely. He countered that the extra bullet must have gone through the same hole as another bullet that had hit the bulls-eye dead-center. He lost the argument and came in 21st of 42 competing (5th in the shooting event).

Also in 1912 at Stockholm, Jim Thorpe, an American, won gold medals in both the pentathlon and the decathlon, with extremely high scores and seemingly little effort. The King of Sweden called him the greatest athlete in the world, and he returned to the United States with much fanfare. Later, evidence was shown that he had been paid a small sum to play professional rugby in 1910. The IOC declared that he was not an amateur athlete and stripped him of his medals, awarding them to the second-place winners instead. Both winners refused the medals, saying Thorpe was the true winner. Almost thirty years after his death in 1953, the IOC vindicated Thorpe and reinstated him as the medal-winner in both events, returning the medals to his family.

The Union of Soviet Socialist Republics (USSR) abstained from participating in the Olympic Games from 1920 to 1948, participating for the first time in 1952. They won a total of 69 medals in 1952, second only to the United States, with 76.

Information in the preceding section was gathered from several of the web sites referenced at the end of this section of the Teachers Guide.

More on artificial turf

Artificial turf has been used for more than forty years. As mentioned in the article, the first major commercial use was in the Houston Astrodome in 1966. In the 1950s, the Ford Foundation was trying to get children more physically fit and active, but they found children in urban areas had few play areas available to them. So Ford worked in conjunction with Monsanto Chemical Company to develop an artificial grass. The first artificial grass produced was marketed in 1964 as Chemgrass. Demand was not great at first, and little was produced. The limited amount of Chemgrass was used first to cover the field in the Houston Astrodome. The problem with the dome was that the plastic panes of the dome caused glare that made it hard for players to see the ball. The panes were painted to minimize the glare, but that meant little or no sunlight entered, so the natural grass on the field died. Enter Chemgrass in 1966.

Although artificial fields grew in popularity during the 1970s and 1980s, the first round of artificial turf fields was not without its detractors. The original fields had no infill, so injuries to players were prevalent. Indeed, many professional sports players refused to play on artificial fields, or at least complained about them. Many artificial fields were returned to their original natural grass surfaces during the 1990s, until artificial turf manufacturers changed the composition of their fields, producing the second generation of fields. These contained crumb rubber infill that allowed players to make sudden stops and turns without joint damage that had occurred in the fields without that infill. These new fields have quickly gained favor again.

The news of lead in artificial grass was first reported by the New Jersey Department of Health and Senior Services (NJDHSS) and the Agency for Toxic Substances and Disease Registry (ATSDR) in April, 2008. These agencies had tested several artificial fields in New Jersey in the fall of 2007 for lead, because they were located near an abandoned scrap metal facility that was known to have high levels of lead inside and in the nearby surroundings. Not surprisingly, they found high levels of lead in the artificial turf in the nearby fields; surprisingly, it didn't come from the scrap metal facility, but from the blades of grass themselves. Lead chromate is used as a pigment and brightener in the production of the yarn used for the blades of grass. It was believed to be leaching out of the blades of grass as they were degraded by use. Dust containing the lead compound was found on the leaves of the grass. And this dust could be inhaled or ingested by players using the fields.

Discussions and arguments arose between the two sides. The environmental groups claimed artificial turf everywhere could be harboring high levels of lead and should be removed and replaced with natural grass. Artificial turf manufacturers and installers argued that the studies were flawed, that lead only leaches out of really old, worn-out turf, and that lead is not bioavailable—that it will not be taken up by cells in the body even if it is inhaled or ingested. Its bioavailability is minimized by a process of encapsulating the lead chromate inside an amorphous silicon dioxide coating. This coating withstands the normal acidity of the stomach, without allowing the lead chromate to leach out.

The controversy is far from over, but the Center for Disease Control and Prevention (CDC) has issued a turf advisory, alerting users of the artificial grass that there are possible dangers, and how to address these dangers. For example, the CDC recommends that players bathe immediately after exposure to the field, that they remove their uniforms and turn them inside out to transport them home, and that they wash the uniforms separate from other laundry.

And lead isn't the only problem people have with artificial turf fields. The infill in the turf is made of recycled rubber from car and truck tires. This crumb rubber, as it's called, has long been known to release many different pollutants into the air, including polyaromatic hydrocarbons (PAHs) and other carcinogenic materials. Actually, until April, 2008, when it was announced that lead was found to be released from the blades of nylon or nylon/polyethylene artificial grass, the pollutants from the crumb rubber were the major concerns of environmentalists. Now they've added a new one to their list—lead in the blades of grass.

More on high-tech swimsuits

Speedo has been in the business of making swimwear that is faster than its competitors for decades. In the 1936 Berlin Olympics, the entire Australian swim team sported Speedo swimsuits. At the 1992 Barcelona Olympic Games, Speedo introduced S2000®, the first swimwear fabric designed for speed. Swimmers wearing the Speedos won more than 50% of the medals in that year's competition. In the 1996 Olympics, 76% of the swimming medals were won by swimmers wearing Speedo's Aquablade® swimsuits.

FastSkin technology, which was used in the 2000 Olympics, and was improved upon as FastSkin FSII for the 2004 Olympics and FastSkin FS-Pro in 2007, was designed based on research involving sharks. Sharks can travel rapidly through water, yet have seemingly rough skin. This appears to contradict the assumption that smoothness reduces drag. Researchers discovered that sharks have tiny denticles, triangular shaped scales, on their skin. These help to channel water waves to minimize turbulence and to keep the water closer to the body at all times, which minimizes drag. Scientists devised a cloth that mimics these denticles for use in swimwear. Swimmers wearing Speedo FastSkin swimsuits in the 2000 Olympic competition won 83% of the medals that year. Historical data was taken from the Swim-Shop.com web site, http://www.swim-shop.com/swimming/speedo-history.php.

The latest Speedo swimsuit is called the Speedo FastSkin LZR Racer®. It uses a new polymer material, LZR Pulse, which is supposed to have 10% less drag than FastSkin FSII technology and 5% less drag than FastSkin FS-Pro, that its earlier suits used, and the seams are now bonded ultrasonically, rather than sewn in, as had been the practice in the past. It also contains polyurethane inserts to minimize drag in specific areas of the body (and some say, increase buoyancy) and a central stabilizer to aid the swimmer in maintaining top form during the race.

Speedo is not the only company in the race for a faster swimsuit. TYR Sport, Inc. has focused their research on creating bumps on their suits at critical points. Although this increases drag, rather than decreasing it, the company scientists say that this extra drag causes the water to flow closer to the swimmer's body, thus in fact reducing water's resistance, and increasing speed, or at least requiring less energy expenditure by the swimmer. The TYR Tracer Rise® suit that French swimmers will use in the Beijing Olympics was unveiled in Paris in June, 2008. Already, records have been set by swimmers wearing this suit.

USA Today reported on July 4, 2008, that the International Olympic Committee had approved swimsuits for competition in the Beijing Olympics from three other companies: Arena®, Adidas® and Mizuno®.

Costs of high-tech swimsuits have sky-rocketed in the recent rounds of research and development. The Nike Swift® suit sells for $280, although it has only a 5-event life guarantee. (The company says they can only guarantee the effects of the suit for 5 events.) The FS-Pro® ("FS" for Fast Skin), the Speedo® predecessor to the LZR Racer®, was priced at $280. TYR's Tracer Light® is priced at $300. And finally, the Speedo LZR Racer® is selling for $580. People in the sport of competitive swimming are worried that the prices of these suits will drive potential athletes, or school athletic departments with no scholarship support, right out of the sport. This concern is moving many groups to propose specific uniform rules for their competitions.

More on tennis racket development

Wood rackets were essentially the only racket that existed up until the 1960s. Wood rackets were very stiff and fairly heavy. The stiffness assured players that their shots would go where they were aimed. Unfortunately, these rackets had a small "sweet spot", the area in the center of the racket that provides the accuracy of the shot, and this made them harder for amateurs to use.

Rene Lacoste, a French tennis player, patented a steel tennis racket in 1965. The Wilson Sporting Goods Company's T2000® was the first commercially successful metal racket. The T2000 was made of aluminum. The metal racket was lighter and stronger than wooden rackets, which resulted in more powerful shots. Unfortunately, it was also more flexible than the wood racket, resulting in shots going where they were not expected to go. Jimmy Connors was one of the first professionals to use the T2000, and he used it for many years with great success. Many professionals found it difficult to adapt from wood to metal rackets, but for the amateur, the metal racket offered the hopes of a much-improved game.

Aluminum rackets can be made of several different alloys. One of these contains a small percentage of silicon, and traces of copper, magnesium and chromium. Another popular alloy contains about 10% zinc, with copper, magnesium and chromium. The silicon alloy is easier to work into shape, while the zinc alloy is harder, although also more brittle.

Professional players required a stiffer racket than the metal ones could provide. For them, the composite racket, made of graphite and plastic resin, was a much-needed improvement. The composite racket took over the game of tennis in the 1980s. It is a much stiffer racket, while maintaining the lighter weight. (Actually, graphite or composite rackets are lighter than metal rackets.) The impact of these composite rackets on the game has been huge, especially in the area of the "sweet spot" of the racket.

Because these composite rackets don't flex as much as the metal rackets, they tend to have a much larger sweet spot. This increases the accuracy of balls hit off-center in the racket. It has been said that these rackets increased the power of the ball as well, but that increase has come mainly from the fact that professional tennis players of today are built bigger than tennis players of the past, by as much as 2-3 inches taller and 15-25 pounds heavier than players of the 70s and 80s, according to ITF statistics. The larger sweet spot allows these stronger players to hit balls harder and faster (due to their own power), and with more accuracy (due to the racket's larger sweet spot).

Composite rackets may contain a sandwich of layers surrounding a polyurethane foam core or a hollow core. The layers may be fiberglass, graphite, boron or Kevlar. Often, ceramic fibers are used for additional strength. The newest developments in tennis racket composition include titanium and other lightweight metals, and even nanotechnology and Aerogel®.

The International Tennis Federation (ITF) rules on tennis rackets have changed over the years, sometimes to accommodate the development of new rackets. ITF had no rules at all concerning the construction of rackets prior to 1978. Wood was the only material for making rackets up to that time, and the strength of the wood limited the force which could be used to string the rackets, so little variation was possible. But in the 1970s, the Prince racket emerged. It was an oversized racket, providing a larger than normal sweet spot, thus easily improving a player's game. And in 1977, two touring tennis pros, a Frenchman and a German, challenged the lack of rules by using double-strung rackets. These rackets had two sets of strings, and the effect of this was that much more spin could be put on a ball, since the two sets of strings both had an effect on the ball. Using the double-strung rackets (dubbed "spaghetti strings") these two players were able to defeat much higher-ranked players than themselves. The defeated players complained to the ITF. This resulted directly in the ITF putting rules in place in 1978 to define the racket and its strings. (Double-stringing was declared out of bounds and size limitations for rackets were specified in the rules.) The changes in the ITF rules, starting in 1978 and continuing to 2006 are listed at http://www.itftennis.com/technical/rules/history/racket.asp.

Connections to Chemistry Concepts

1. **Mixtures**—Composite materials are mixtures of several different starting materials. They are put together so that one component can provide, e.g., strength under compression while the other provides strength under tension.
2. **Polymers**—Swimsuits, artificial turf and tennis rackets, on which the article focuses, all utilize polymers in their composition.
3. **Hydrophobic/hydrophilic**—Swimsuits can be made to repel water in order to minimize the amount of water soaking into the fabric, which would normally add weight to the swimmer and slow him/her down.
4. **Solubility**—Pigments are used in artificial turf based on their very low solubilities; if they were soluble, the color would "run" in the rain.
5. **Making a product with the desired properties**—Artificial turf is made of nylon and polyethylene due to their wear-resistant properties and their relative softness, and pigments are added to make the artificial grass appear green (blue and yellow pigments are blended).
6. **Organic**—The crumb rubber used for infill in artificial turf contains many organic compounds.

Possible Student Misconceptions

1. **"Olympic champions win because they're the best in the world."** *All things being equal and fair, that is a true statement, but if one athlete gets a slight advantage because of the suit or shoes he/she wears during the competition, then other athletes don't necessarily have a fair shot at winning. (The same argument holds for athletes who gain an unfair advantage through the use of illegal drugs, but that is another story.)*
2. **"The best athlete will always win."** *See response to misconception 1, above. There is also a random component to athletics (a sprinter does not always record exactly the same time every time she runs), so an athlete who typically would perform worse than another might, by chance, do better on a specific (critical) event.*
3. **"Olympic records are broken because athletes are getting stronger/faster/smarter, etc."** *[This has generally been true over the decades of Olympic competition, but recent Olympics competitions have seen records broken as a direct result of new technology applied to the games.*
4. **"There's no contest; natural grass (or 'artificial turf') is way better to play on."** *Both varieties of turf offer benefits – and costs and risks. See Student Projects, number 1, below for a place to start researching the differences.*

Demonstrations and Lessons

1. You could cut swatches of varying kinds of cloth and have students design an experiment to test the amount of drag on each as they are pulled through a large trough of water, and then

relate this to the “feel” of the fabrics (done by surveying students anonymously). You could use spring balances to measure the force needed, or electronic probes could be used.

2. A lesson described online called, “Keeping the Heat” asks students to do online research involving an exothermic/endothermic reaction involved in Olympic sports, and then to make a poster/ad about their reaction, including the pertinent chemical details. They are also to find a chemical experiment online that could be done in their own classroom. (You can decide if you want them to actually do the experiment.) The lesson plan introduces the assignment in terms of heat/cold influences on athletes; e.g., preventing frostbite at the Winter Games, and preventing heat exhaustion or dehydration at the Summer Olympic Games. It includes assessment and extension ideas. You can find the lesson plan at the Salt Lake 2002 Winter Olympic Games “Light the Fire Within” web site at http://governor.utah.gov/olympiced/curriculum/lesson_plans/science/10to12/chemistry.html. There are other science lesson plans for other grade levels at this same site. Beware: the site was designed around the time of the 2002 Winter Games, and some of the links no longer work.
3. The Royal Society of Chemistry (UK) has a web site on “Chemistry and Sport”. The three main sports and the chemical connections are: Formula 1 racing and fuels—fractional distillation, Golf and materials and their properties, and tennis and hard and soft water (for cleaning the white tennis clothes). The lessons are aimed at various grade levels, 2nd to 10th grades. The lessons are tied to actual current events in sports (marked on their calendar); e.g., the U.S. Open in August, 2008, to increase student interest. Although the tennis lesson is linked to this article, the focus is on soap vs. detergent and cleaning ability, not on composites and equipment improvement. The site lists several science topics in their pull-down menu that presently have no lessons associated with them, perhaps meaning more lessons are planned; however, their last “just-released” module was uploaded (“new”) in April, 2007.
4. A unit plan involving sports and the concept of using chemistry to improve on existing sports equipment can be found at http://www.cmu.edu/gipse/materials/pdf-2001/sports_chem.pdf. The lab activity described there has students classify a selected set of elements into metals, nonmetals and metalloids, on the basis of their properties. The results are then used as a way for the students to begin their quest to find materials that will improve a piece of sports equipment of their choice. The lab activity can be distributed to students as-is. The accompanying assignment is spelled out in great detail. An outside (fictitious) sports equipment manufacturer is holding a contest for students to present ideas about how to improve on any piece of sports equipment. It requires students to do research involving their chosen sports equipment, how it works, and how they could improve on it. They then must prepare a report describing their research findings to the sports equipment manufacturer. Students help in the design of the rubric used to assess the project. The unit plan is incomplete at this site; it refers to various student “skill building exercises” and “ChemQuandaries”. These are mentioned only; their content does not appear on the site. The gist of the unit includes earth’s resources, the Law of Conservation of Mass, and changing metals by alloying them. (This all seems to fit with materials from the “Chemistry in the Community” textbook, published by W.H. Freeman, which they list as one of their references.) This activity/unit could easily be adapted to an Olympic sport and its equipment.
5. The Polymer Ambassador web site contains a unit dealing with running shoes. The unit is directed at middle school students, and it takes 9-16 days to complete. Students study shoe design and then experiment with Glue-Goo (Elmer’s glue and borax) polymer to determine the variations in its properties when they change the relative amounts of the ingredients, and then they build a prototype of a shoe they design themselves using the proportions of reactants they determined gave them the properties they desire. You can find the PDF files

for student and teacher versions of both the long and short units toward the bottom of their web page at http://www.polymerambassadors.org/PolymerActivities2.htm. You can probably just pull out the lab activity for use in your classes.

Student Projects

1. You may want to ask students to debate the developing lead-in-artificial-turf controversy. You can have them base their research on the turf companies vs. the environmental agencies. Each professional group has engaged their own researchers to study the problem, and each has an obvious personal interest in the results of the research. Students could begin their research with "Artificial Turf and Lead—The Truth about Lead in Synthetic Turf", a position paper by a field turf company, at http://www.fieldturf.com/leadissues/ and "Synthetic Turf: The Science Behind the Safety", by the manufacturer of AstroTurf, at http://www.astroturfusa.com/resources/pdfs/Science.pdf, and compare/contrast them with the recently released Center for Disease Control and Prevention (CDC) Health Advisory release in June, 2008, "Potential Exposure to Lead in Artificial Turf: Public Health Issues, Actions, and Recommendations", at http://www2a.cdc.gov/HAN/ArchiveSys/ViewMsgV.asp?AlertNum=00275 and copies of two letters sent to the Consumer Product Safety Commission from the NJDHSS, dated April 11, 2008 and a follow-up on June 3, 2008. These can be found at http://www.state.nj.us/health/artificialturf/documents/cpsc_letter.pdf and http://www.state.nj.us/health/artificialturf/documents/cpsc_letter_0608.pdf. And not to be outdone by the artificial turf companies, there is also the natural turf component of the market, represented by the Turfgrass Resource Center. They've published a 32-page booklet, "Natural Grass and Artificial Turf: Separating Myths and Facts", which itemizes many details about artificial turf that the artificial turf proponents frequently overlook. The PDF of the booklet can be found at http://www.turfgrasssod.org/pdfs/ArtificialTurfBooklet2.pdf.
2. You might want to have students investigate the temperatures of artificial fields vs. natural grass fields in your school district or nearby parks. They could follow this up with literature research on the effects of these temperature differences on nearby ecosystems, or even the contribution of these differences to global climate changes.
3. You could have students research other types of athletic equipment used at the Olympic Games (not mentioned in the article), and have them do research on those, including a timeline of improvements made to the equipment, and the role that chemistry played in each of the improvements.
4. You can have students research the different kinds of instrumentation that chemists use to detect drug abuse by Olympic athletes and how they work.

Anticipating Student Questions

1. **"Can the LZR Racer® make <u>me</u> an Olympic champion?"** *It is highly unlikely that using the new swimsuit by itself would make you a competitor at that level, unless you were already practicing to be an Olympic competitor. Remember, all the other Olympic hopefuls – who <u>are</u> practicing at that level – will be wearing the new suit, too.*
2. **"What if an Olympic qualifier can't get or can't afford a LZR Racer® for the Olympics? Is that fair to him?"** *Speedo has actually said that it would provide suits for any Olympic qualifiers who want them, just to make it fair for everyone (and maybe to boost sales of the suits after the Olympics?).*

3. **“Where does the lead come from in the artificial turf?”** *Lead is found in the form of lead chromate, a pigment used in the preparation of the nylon or nylon/polyethylene yarn that is used to make the blades of artificial grass. The compound is yellow and, when blended with a blue pigment, results in green grass. The pigment has very low solubility, hence the claim by the artificial turf associations that it has low bioavailability – meaning it is unlikely to be taken up by cells in the human body upon ingestion or inhalation.*
4. **“The article describes numerous advantages to artificial turf. Are there any disadvantages?”** *The biggest disadvantage to using artificial turf seems to be the upfront cost of installing the field (hundreds of thousands of dollars). Maintenance after that is advertised by turf companies as being minimal (although that is not the whole story), but then at some point later, the cost of replacing the entire field must be faced - again. Guarantees for artificial turf fields from companies who install them typically run from 8-10 years. Natural grass proponents are quick to mention that soil on a natural turf field causes the biodegradation of bacteria and molds from athletes’ cuts and scrapes and body fluids, as well as bird or other animal droppings, while artificial turf requires the repeated application of disinfectants to accomplish the same task. The lead controversy mentioned elsewhere in this section of the Teachers Guide may also prove to be a very serious disadvantage to using artificial turf.*

More articles from *ChemMatters* archives

The references below can be found on the *ChemMatters* 25-year CD (covering issues from February 1983 through April 2008). The CD can be ordered from ACS for $30 (or a site/school license is available for $105) at: http://www.acs.org/chemmatters

In the December 2000 issue of *ChemMatters* (Vol. 18, No. 4, pp. 7-9), author Robert Morton discusses “Drug Detection at the Olympics—A Team Effort”. The Teachers Guide for the December, 2000 issue gives more background and classroom information about drug detection.

The April 2000 issue of *ChemMatters* (Vol. 18, No. 2, pp. 12-13) contains an article, “Anabolic Steroids—The Down Side of Bulking Up”. It mentions the IOC ban of steroids. The TG for that same issue contains extended information.

Web Sites for Additional Information

More sites on the history of the Olympics

There are many Web sites that cover the history of the Olympics. Several are listed here:

The official web site for the Olympics can be found at http://www.olympic.org/uk/index_uk.asp. Be aware that some of the links on this site are no longer valid.

The Foundation of the Hellenic World (FHW), a Greek organization, has a very nice site that shows the progress of the Olympics from ancient Greece to the modern-day competitions. You can access it at http://olympics.fhw.gr/. This site also provides highlights of each of the Olympics competitions, by year. Most pages have four major headings, “The Games”, “Leading

Athletes", "Snapshots", and "Did you know?" The latter heading gives specific tidbits of information about events at that competition.

This site http://www.fanbay.net/olympics/modern_history.htm has a complete list of the Olympic Games, both Summer Games and Winter Games, by year. They are clickable and take you directly to that year's games on the official Olympics web site.

The 1984 Los Angeles Olympic Games Organizing Committee has put together "An Olympic Games Primer" that has much information about the Games. Find it online at http://www.la84foundation.org/6oic/primer_frmst.htm.

More sites on artificial turf

The AstroTurf® Web site has a good history of the development of artificial turf, at http://www.astroturf.com/history.htm.

In "Artificial Turf", *How Things are Made*, Volume 7, discusses the process by which artificial turf is made at http://www.madehow.com/Volume-7/Artificial-Turf.html.

You can find more information about all the controversy about artificial turf fields that preceded the lead scare in the March, 2008 (Vol. 116, No. 3) article in *Environmental Health Perspectives*, "Synthetic Turf: Health Debate Takes Root", on pages 116-122, at http://www.state.nj.us/health/artificialturf/documents/cpsc_letter.pdf.

In May, 2008, AstroTurf® published a press release soon after the NJDSS study was published (April, 2008), affirming that the New Jersey study confirmed the safety of artificial turf. You can read their letter at http://www.astroturfusa.com/resources/pdfs/NJResults.pdf.

School Administrative Unit #70, representing Hanover, NH and Norwich, VT, has compiled a list of links and summaries concerning artificial turf. They've eliminated sites with vested interests. The list is available at http://www.sau70.org/spotlight/athletic_fields/Supporting_documents/Turf_Studies.html.

The CDC recommendation, as well as other agencies' recommendations regarding levels of lead in our environment can be found at this page of the Agency for Toxic Substances and Disease Registry (ATSDR) site: http://www.atsdr.cdc.gov/csem/lead/pb_standards2.html.

The New York City Department of Health and Mental Hygiene released a 200-page report in May, 2008, entitled "A Review of the Potential Health and Safety Risks from Synthetic turf Fields Containing Crumb Rubber Infill". It contains many appendices with detailed information about the chemical content of tire rubber and the crumb infill. The study also includes 11 pages of references. It can be found at http://www.stma.org/_Files/_Items/STMA-MR-TAB1-2637/Docs/New%20York%20City%20turf_report_05-08.pdf.

More sites on grass fields

The Turfgrass Resource Center has published a 32-page booklet, "Natural Grass and Artificial Turf: Separating Myths and Facts". The booklet compares and contrasts natural grass vs. artificial grass in many areas that are not normally discussed by artificial turf proponents. The PDF of the booklet can be found at http://www.turfgrasssod.org/pdfs/ArtificialTurfBooklet2.pdf.

More sites on high-tech swimsuits

The March 11, 2004 issue of *CAD Digest* contains an article, "Virtual Swimmer Helps Speedo Create a Faster Swimsuit", which discusses the role of computational fluid dynamics that Fluent Europe Limited used in the quest for the fastest swimsuit. The focus is on Speedo's creation of FastSkin FSII, the material which Speedo used in the 2004 Athens Olympics swimming competition. You can find the article at http://www.caddigest.com/subjects/cae/select/031104_fluent_speedo.htm.

Fluent Europe Limited shows an animation of one of the illustrations mentioned in the above reference at http://www.fluent.com/news/pr/img/swim_draft-fin.mpg. It takes a while to load, but it goes through three sequences with a gliding swimmer: first, it shows bubbles flowing past the glider, and then it shows the forces exerted on the glider by the water passing by, and then it shows the overall effect of the water passing over his body.

Speedo's February, 2008 press release on the LZR Racer can be found here: http://www.speedointernational.com/?option=com_content&task=view&id=822&Itemid=158&lc=en&cc=global=en.

For more information on the TYR Sport, Inc. Tracer Rise® swimsuit and the technical innovations it contains, read the Reuters April 23, 2008 article, "TYR Sport Introduces Latest Technical Swimsuit at French Olympic Trials", at http://www.reuters.com/article/pressRelease/idUS211189+23-Apr-2008+PRN20080423.

More sites on new tennis rackets

Anyone interested in the official rules of the game of tennis can find them at the International Tennis Federation web site, at http://www.itftennis.com/technical/rules/index.asp.

The July/August, 2006 issue of *Atlantic Monthly* contains an article entitled, "Spin Doctors", in which Tom Perrotta, a writer for *Tennis Magazine*, discusses a bit of the physics of tennis and its effects on graphite vs. wood tennis rackets. You can find it at http://www.theatlantic.com/doc/200607/tennis.

For a description of how tennis rackets are made, see "Tennis Racket: How Things are Made" at http://www.encyclopedia.com/doc/1G2-2896700101.html.

More sites on the Olympic controversy

In "Is the Use of Advanced Materials in Sports Equipment Unethical?" F.H. Froes, in the February, 1997 issue (49 (2) (1997), pp. 15-19 of the journal, *JOM*, published by the Minerals, Metals and Materials Society, presents some scientific evidence about the improvements that have been made in sports equipment by scientific research. You can find the article at http://www.tms.org/pubs/journals/JOM/9702/Froes-9702.html.

More sites on technology in other areas of competition

Swimming is not the only Olympic sport that is doing research to improve its records. Check out the result of research by Adidas in trying to improve spiked track shoes at http://www.press.adidas.com/DesktopDefault.aspx/tabid-11/16_read-9399/.

Nike is also doing research to improve running shoes. Find out about its latest product at http://www.fastcompany.com/magazine/127/innovation-of-olympic-proportions.html.

The American Chemical Society's *Chemistry & Engineering News* has an article about the evolution of golf balls in an article titled: "What's that Stuff: Golf Balls" in the July 18, 2005 (Vol. 83, No. 29, page 34) issue. You can find it online at http://pubs.acs.org/cen/whatstuff/83/8329golfballs.html.

Science magazine has six articles in the August 1, 2008 issue about the Olympics. Two of these deal with advances in materials technology:

"SCIENCE AT THE OLYMPICS: Can Ice Vests Provide a Competitive Chill?" (Science, 1 August 2008, Vol. 321. no. 5889, p. 625), investigates whether chilling the body temperature prior to an athletic event improves performance. You need a subscription to the magazine to access the article, but if you do subscribe, you can find the article online at http://www.sciencemag.org/cgi/content/summary/321/5889/625a;

"SCIENCE AT THE OLYMPICS: Do New Materials Make the Athlete?" (Science, 1 August 2008, Vol. 321. no. 5889, p. 626a) discusses the possibility that the perceived edge that innovative technological material provides may be merely psychological. You can view this article, with your (or your library's?) subscription, at http://www.sciencemag.org/cgi/content/summary/321/5889/626a.

The Many Looks of the Periodic Table

Background Information

More on the history of the periodic table

Mendeleev’s table was the first published table to relate all the known elements into one cohesive tabular arrangement.

Eric Scerri is not the first chemist to try to arrange elements in triads. (Not by 150+ years!) Johann Dobereiner was the first to discover relationships in properties among elements in triads in 1850. He used the elements’ atomic masses to do the calculations mentioned in the article, since atomic numbers were unknown in his time. The calculations (adding the smallest and largest atomic masses and dividing by two to get the atomic mass of the middle element) yielded correct results in a few cases, but only close, approximate, values for others. (See below.) If he had known about and used the atomic numbers of those elements, the values would have matched perfectly.

	Atomic “Weights” (1850)			Atomic Numbers (present)	
Li	7		Li	3	
Na	23	$\frac{7 + 39}{2} = 23$	Na	11	$\frac{3 + 19}{2} = 11$
K	39		K	19	
Cl	35.5		Cl	17	
Br	80	$\frac{35.5 + 127}{2} = 81.25$	Br	35	$\frac{17 + 53}{2} = 35$
I	127		I	53	

(Data for the examples above were taken from “Chemogenesis, Database of Periodic Tables – Johann Dobereiner’s Triads”, at http://www.meta-synthesis.com/webbook/35_pt/pt_database.php?Button=pre-1900+Formulations.)

In 1862, French geology professor Alexandre-Emile Béguyer de Chancourtois presented a paper to the French Academy of Sciences. He drew a plot of the element number (not atomic number) vs. atomic weight. He plotted the information on a cylinder, with atomic weight increasing downward and the number of the element across the top. As the positions of the elements wound around the cylinder, elements with similar properties were situated directly beneath one another. It is unfortunate that his presentation was very difficult to understand, and his drawing, which should have helped to clarify the issues, was itself very complex. The diagram was never published with the article, so he is not given credit for the discovery. For a better coverage of de Chancourtois’ paper and table, see http://www.rsc.org/education/teachers/learnnet/periodictable/pre16/develop/chancourtois.htm.

But Dobereiner and de Chancourtois weren’t the only ones trying to find a way to organize the elements. In 1865, John Newlands first publicly proposed his Law of Octaves, which stated that the elements seemed to group into octaves, much like octaves in music, and produce repeating patterns in properties. The eighth element repeated the properties of the first.

For example, Li, Be, B, C, N, O, F, and Na made up the first octave, Na, Mg, Al, Si, P, S, Cl and K made up the second octave, etc. But wait! That's only seven elements in that row (as we know now). What happened to Ne and Ar? You may recall that the noble gases were not discovered until late in the 1890s, so Newlands did not have the benefit of this knowledge.

Problems arose in octave groupings after calcium, due in part to the fact that some elements had not yet been discovered at this time. This caused Newlands to group elements together that had very dissimilar properties. These results restricted the usefulness and hence the acceptance of Newlands discovery. Newlands was never credited for the discovery of the Law of Periodicity, until the centennial of his death in 1998, when the Royal Society of Chemistry (UK) placed a plaque on the wall of his birthplace, recognizing him as the discoverer of the Periodic Law of the chemical elements. (It's doubtful the Russians were impressed.)

Four years after Newlands public presentation of the Law of Octaves, in 1869, Mendeleev published his periodic table. Mendeleev's creation of the periodic table was prompted by his desire to write a textbook, "Principles of Chemistry", for his chemistry students at the University of St. Petersburg. He found that he had so much to write about each of the elements for his descriptive chemistry book that the book would have had to be more than a thousand pages long! As a result, he was inspired to simplify all this information into a tabulated form—his now-famous periodic table.

Much of the success of his periodic table came because he believed so strongly in the law of periodicity that as he placed elements in his table, when the next element in line didn't have the matching properties, he left a blank in his table to accommodate an element with the correct properties that he said had not yet been discovered.

In 1871 Mendeleev published a second paper on the periodic law, this one focusing on his predictions of the properties of the missing elements in his original periodic table. Using data on the properties of elements on the periodic table above and below and left and right (and even diagonals) of the missing element, he interpolated the data to make predictions about the properties of the missing elements—predictions that turned out to be extremely close to the actual values for those properties, once they were discovered and measured. Although his predictions are often viewed as evidence of his unshakeable belief in the periodic law, in truth, after several years had passed and no new elements had been discovered, he wavered in his faith, and he even suggested a later retraction of these predictions, and expressed hope that someday the elements might be discovered.

In November, 1875, the discovery of gallium by P.E. Lecoq de Boisbaudran renewed Mendeleev's and the scientific world's faith in the periodic law. The properties of gallium matched almost perfectly with those of Mendeleev's predicted missing element, eka-aluminum. Gallium's discoverer admitted that he had not known of Mendeleev's prediction of the properties of his missing element, and if he had, he might not have discovered it as easily, as one of the properties of gallium, namely solubility in ammonia, did not match with prediction, and it was this property that de Boisbaudran used to isolate the metal. The discoverer of gallium also determined the density of gallium to be 4.9 g/cm^3, whereas Mendeleev had predicted a density of 6.0 g/cm^3. When Mendeleev heard that all the other properties matched almost exactly, he suggested to de Boisbaudran that he go back and re-measure and re-calculate the density. He did so and found he had miscalculated the value. The next time he got 5.9 g/cm^3, almost exactly Mendeleev's predicted value. You can read de Boisbaudran's own account of the discovery of gallium in an electronic copy of his original paper at http://dbhs.wvusd.k12.ca.us/webdocs/Chem-History/Disc-of-Gallium.html.

In 1879, Lars Nilson isolated and identified scandium, Mendeleev's eka-boron, with properties that matched the Mendeleev's predictions. Yet another of Mendeleev's predicted missing elements, eka-silicon, germanium to us, was discovered by Clemens Winkler in 1886. Again, its properties matched precisely with Mendeleev's predictions. Even if other chemists had problems accepting his concept of periodic law and his table at first, after several of the missing elements had been discovered, those chemists were forced to accept Mendeleev's discovery of the periodic law, and the usefulness of his periodic table.

Just to set the record straight, Mendeleev did not "bat a thousand" in the prediction category. He occasionally struck out. For example, he predicted the existence of element "X", the simplest element of all, which was never discovered. (See the December, 1987 issue of *CM*, pages 8-9. The article is available on the *ChemMatters* Archive CD.)

Another chemist of Mendeleev's time, Julius Lothar Meyer, had also been working on organizing the elements, and he had constructed several periodic tables that looked very similar to that of Mendeleev. In 1864, five years before Mendeleev's table, Meyer had created a table using only the first 28 elements. And in 1868, his newer version contained many of the transition metals. The table was organized by increasing atomic weight, with all elements of the same valence in the same column. Unfortunately, Meyer did not publish his version of the table until 1870, a year after Mendeleev's published paper. Meyer focused more on the physical properties of the elements (valence notwithstanding), whereas Mendeleev focused more on their chemical properties.

Since that time, many scientists have developed varying versions of the periodic table. In the January, April and May, 1934 issues of the *Journal of Chemical Education*, Quam and Quam published the series of reports, "Types of Graphic Classifications of the Elements", 3 separate papers dealing with the development and revisions of five major types of periodic tables: short-form, long-form (now, medium-form), spiral, helical, and miscellaneous forms. http://www.meta-synthesis.com/webbook/35_pt/JCE_PTs_1934_short.pdf, http://www.meta-synthesis.com/webbook/35_pt/JCE_PTs_1934_medium.pdf, and http://www.meta-synthesis.com/webbook/35_pt/JCE_PTs_1934.pdf.
The 3-part report discusses 28 periodic tables, and cites 108 references. Spirals, circles, helixes and even spheres are illustrated in this report, yet none of these has supplanted the basic medium-form periodic table to this day, almost 75 years later. Despite the speculation by the author of this ChemMatters article, it is unlikely that any of these new forms will replace the table now in common use in the near future.

More on the traditional periodic table

The traditional periodic table has itself undergone changes over the years. Mendeleev's original table was drawn as (what would now be known as) a short-form periodic table. In this version, transition elements are interspersed with main-group elements. The result is a compact, but complex, table. Many scientists stayed with this version over the years. It was much more prevalent in Europe than in the United States. One company, the Sargent-Welch Science Supply Company, adopted this version and published (and sold and still sells) this form of the table for decades. This is referred to as the Hubbard version of the table. You can find an image of Sargent Welch's periodic table at http://www.sargentwelch.com/pop_largerview.asp?pn=WLS18808-10_EA&pnm=Periodic Chart of the Atoms&img=WLS18808-10_EA.jpg.

Later versions of the table separated the transition metals from the main groups and placed these separate rows between the alkaline earth elements and the boron family elements. This has the benefit of clarity at the expense of size. The long-form of the table is more spread out. This form has become the most widely accepted and used version of the table, with the s-, d-, and p-orbital elements running across the periodic table, and the f-orbitals placed in rows below the other elements.

One major change to the periodic table occurred in 1988. In the mid-1980s, the International Union of Pure and Applied Chemistry's (IUPAC) Commission on the Nomenclature of Inorganic Chemistry (CNIC) proposed a new notation system for the groups on the periodic table. Instead of having Roman numerals I-VIII for the main group elements and I-VIII with A's and B's for the transition elements (Remember this system?), CNIC proposed numbering the columns 1-18 continuously across the periodic. They invited public comment—and got it! Many chemists complained about the system and provided suggested changes of their own. Large scientific organizations, like the American Chemical Society, also lodged their protests and concerns.

High school teachers, especially, were outspoken in their criticism of the new system. The effect of IUPAC's recommended change was to negate the teaching tool teachers had in the old system. An obvious connection teachers could make for students using the old system was that the column number coincided with the number of valence electrons in an atom of any element in that column. Where oxygen had been in column VI (with the obvious 6 valence electrons), it now was in column 16 (with no apparent significance to that number for students). The change made it more difficult for students to comprehend the organization of the elements in the periodic table. Despite widespread disagreement with the system (although, to be fair, it was not without its supporters—in large numbers), IUPAC made the ruling in 1988 that this new numbering system would be the accepted international system. Scientific organizations like the American Chemical Society—and high school chemistry teachers around the world—could do little but go along with the decision.

Even though the two-dimensional table seemed, from its inception, to be the preferred way to display the elements, many chemists, including the table's creator, Mendeleev, noted that a table does not do justice to visualizing the continuity of the periodicity of the elements. Mendeleev suggested that a cyclical arrangement of the elements would be more correct, perhaps a 3-D view. Perhaps this opened the door to all the other varieties of periodic tables we see today.

More on spiral periodic tables

As you read in the article, scientists are not the only ones to design versions of the periodic table. In 1951, Edgar Longman, an artist, produced a spiral version of the periodic table in a mural for the science pavilion of the 1951 Festival of Britain. (http://www.ww2poster.co.uk/artists/longman.jpg) This seems to have been the inspiration for Jeff Moran's spiral version of the periodic table.

Sir William Crookes, of Crookes' tube fame, designed a 3-dimensional figure eight periodic table, with two spirals interweaving. You can see a copy of his design at http://www.gutenberg.org/files/16058/16058-h/images/oc-009.png.

More on the Janet periodic table

It is possible that you got the idea from reading the article that Janet's periodic table was the precursor to Katz's round periodic table. While it may have inspired Katz, actually, Janet's table was a two-dimensional, long-form periodic table that was then brought about on itself to form a cylinder. The difference between periodic tables of old and Janet's table is that Janet used the idea of electron arrangements to establish his table, rather than atomic number or other properties. His table arranges the elements based on the order of their electrons' orbital-filling, top-to-bottom, left-right. Since the f-orbitals are placed at the left of Janet's table, and the s-orbitals are on the top right, his table is often referred to as the Left-Step periodic table. Bringing this 2-dimensional table around, tip to tail, you get his periodic helix.

The Janet table is effective at clearly organizing the elements according to electronic structure, it does not clearly distinguish between metals and non-metals, and it places helium in a weird spot, in column 2, the alkaline earth elements, over Be, not fitting there according to its properties. You can see an image at http://www.meta-synthesis.com/webbook/35_pt/ptqm2.jpg or http://www.webelements.com/nexus/?q=node/981.

More on round periodic tables

Reference to a round periodic table is found in the Wikipedia archives. The image can be found at http://en.wikipedia.org/wiki/Image:Circular_form_of_periodic_table.svg, although no reference is given about the source of the table.

Here is another round periodic table: http://www.nfinity.com/~exile/periodic.htm. This table merely lists the elements in straight lines, radiating out from the center of a circle. The family connections are obvious. The design of this table is very different from the one referred to in the Wikipedia archive above.

Connections to Chemistry Concepts

1. **Periodicity**—This one's pretty obvious. Elements can be arranged so that their order presents recurring patterns; e.g., similar chemical properties for all the elements in each column of elements, increasing ionization energy (with exceptions) across rows of elements, decreasing ionization down columns of elements, etc.
2. **Scientific methods**—This topic includes observing, collecting data, organizing data, asking questions, designing experiments, and communicating your results (publishing), all in no prescribed order.
3. **Physical and chemical properties**—Properties of the elements were the foci of chemists' early work in attempting to organize the elements.
4. **Atomic structure/electronic configurations**—The periodic table can be said to be arranged according to electronic configurations, and the atomic structure of members of groups of elements are similar.

Possible Student Misconceptions

1. **"Mendeleev was a genius because he discovered the periodic table."** *This is quite possible, but as you can see from the "More on the history of the periodic table"*

section above, others were working on the same ideas of organizing the elements. Mendeleev was the first to publish his results. All the scientists were using data available at the time to generate their ideas. Mendeleev's "genius" was his realization that some elements were missing, and his leaving room for them in his table. The other scientists simply tried to force the elements into alignment on their versions of the table. This made the failure of their versions inevitable.

2. **"There's only one periodic table."** *After reading the article, students will see that there are many variations on today's periodic table (literally hundreds). See "More sites on alternative periodic tables" in the Websites for Additional Information section below for even more varieties of periodic tables.*
3. **"Mendeleev's table was unanimously accepted by all chemists."** *Many chemists did not instantly accept his table or his Periodic Law, until years later, with the discoveries of the very elements whose existence (and whose properties) he predicted.*
4. **"Only scientists can create periodic tables."** *As described in the article, several creators of modern variations on the periodic table are artists. This might be worthwhile mentioning to students—that even non-scientists can work in the fields of science.*
5. **"All the variations on the periodic table have already been created."** *New varieties of the periodic table keep turning up. And we haven't even started talking about virtual periodic tables yet.*
6. **"Mendeleev's periodic table organized the elements according to atomic number, just as today's tables do."** *Actually, the concept of atomic number had not yet been elucidated. Mendeleev did not know about atomic number. His table was based on increasing atomic masses. It is, however, no coincidence that Mendeleev's periodic table matches up exactly with modern periodic tables. As long as there are no missing/undiscovered elements, both tables will have almost all the elements in the same positions. It is also no coincidence that the electron configurations relate to both tables, since the chemistry of elements is based on their electron configurations, specifically on their valence electrons.*

Demonstrations and Lessons

1. If you want to teach a lesson on the history of the early periodic table, visit the Royal Society of Chemistry (UK) web site at http://www.rsc.org/education/teachers/learnnet/periodictable/pre16/develop/index.htm. The site has an introductory Periodicity web page and four more web pages dealing with four major contributors to the discovery of the periodic table: Newlands, Meyer, de Chancourtois, and Mendeleev. Each page contains information about that person's contributions, and each page ends with a series of questions for the student to assess what they've learned from the reading. The page on de Chancourtois also contains a diagram of his "vis Telluricus", his original table/cylinder of elements. Scrolling over the table changes the figure from his original, very complex table, to a simplified set of elements. This makes it easy to see the relationships of the elements that he discovered.
2. If you want students to sharpen their periodic table skills, you might take them to the Merck web site, http://pse.merck.de/merck.php?lang=EN. There they can work with an interactive periodic table that gives them lots of facts about the elements, but they can also choose to play a quiz-style game online that tests their knowledge/understanding of the periodic table. Some of the questions are fact-based, and some are based on trends in properties of the elements. Several more games for students ("Mendeleev Activity", "Identify

the Element", and "Find the Element") can be found at the Royal Society of Chemistry (RSC) Periodic Table of Data website at http://www.rsc.org/education/teachers/learnnet/ptdata/games/identifyelement.htm. Any of these "games" could be used as part of your lesson on, or a review of, the periodic table.

3. The TouchSpin.com web site, http://www.touchspin.com/chem/DisplayTable.html, provides very visual graphs that accompany their periodic table. These would allow you to show specific trends in various properties of the elements, via large-screen projection, as part of your lesson on trends of the periodic table.
4. "Stargazers", a NASA website, contains a classroom activity for students to graph atomic number of elements vs. their atomic radius and their ionization energy. Scroll down to Activity #11, "Graphing Trends on the Periodic Table, on this web page, http://stargazers.gsfc.nasa.gov/resources/science_activities/science_activities.htm. The activity has students use graphing calculators or computer spreadsheets (or graph paper?) to complete the exercise. Student worksheet, teacher guide, student response sheet, a sheet of directions for uploading data into graphing calculators, and an answer key are all provided in PDF files for downloading.
5. There are several different quiz types available online. One set of them is at the Syvum Web site. Students can do these individually, or you could use them in class as part of a lesson on the periodic table. Be aware that this site has lots of ads and they sometimes get in the way of the information. Here is a website that links to ten different sites with quizzes. http://doe.sd.gov/octa/ddn4learning/themeunits/elements/activities.htm. Many of them focus on naming elements from their symbols and vice versa.
6. Many high school lab manuals contain an experiment to investigate the properties of elements and to find similarities in those elements.
7. The *Journal of Chemical Education Online* website contains a classroom activity in which pieces of paper of varying colors are to be organized by students in recurring patterns to reflect the process Mendeleev might have used to organize the elements. Multiple sets of theses papers could be used by an entire class in a simulated lab exercise. Access the lesson here: http://forums.jce.divched.org:8000/webx?50@78.bjqFadQjeeH.7@.1adb20d6.
8. Labs or demonstrations regarding the properties of groups of elements can be found on *JCE Online* in the section, ""The Chemistry of the Main Group Elements". There is a wide variety from which to choose. View them here: http://forums.jce.divched.org:8000/webx?14@78.bjqFadQjeeH.3@.1adb2ac2.
9. You could pre-select some of the University of Nottingham's Periodic Table of Videos" video clips to use in your classroom to show similarities in properties of the elements. (http://www.periodicvideos.com/#)
10. Students can investigate periodic table trends with an online activity at the Lynchburg City Schools web site, http://www.lynchburg.net/hhs/chemistry/trends/. Trends include atomic radius, ionization energy and electronegativity.
11. Students can set up their own Excel spreadsheet to input data about the elements in order to prepare line graphs or bar graphs to develop their understanding of periodic trends. A PDF file that gives them explicit instructions to do just that can be found here: http://www.science-class.net/Lessons/Chemistry/Periodic%20Table/Graphing%20Periodic%20Properties.pdf. This site uses WebElements for its data, but you could use any online source you choose.

Student Projects

1. Students could do historical research (possibly beginning with Giunta's historical website containing classic original papers of scientists, at http://web.lemoyne.edu/~GIUNTA/), to produce a skit (or video or Power Point) about Dobereiner, Newlands and Mendeleev as they worked to uncover the secrets of the organizing of the elements according to their properties. If more students are involved, more scientists could be included; e.g., de Chancourtois.
2. Students could each choose one element and research and write a paper on "their" element. You could decide as a class the information you would like to know about each element. They could then display their papers in a periodic table wall poster format.
3. Students could work in groups to research and report on families of elements, as discussed in 2, above.
4. Students could do a "reality show" on a family of elements. ("Al Kali's" family comes to mind, or "Hallie Gen's" family.) Let them use their imaginations!
5. You could have students work in groups to compare the features of several different versions of the periodic table and determine pros and cons of each; e.g., short form, long form, spiral, galaxy, 3-D, etc. Each group would get the same versions (1 per student in the group?), each group would discuss and determine pros and cons, each group would then report out to the rest of the class.

Anticipating Student Questions

1. **"How many different ways are there to make a periodic table?"** *No one knows for sure how many different ways there are, but there are literally hundreds of periodic tables online.*
2. **"Why are there so many different versions of the periodic table? Isn't there one perfect periodic table?** *Well, there is a website that thinks they have the perfect periodic table (http://perfectperiodictable.com/), but not everyone agrees with this author's claims.*
3. **"How do these scientists and artist keep coming up with all these brand new versions of the periodic table?"** *Most of the periodic tables mentioned in the article are only modifications (sometimes minor, at that) of tables designed by other scientists many years ago.*
4. **"Will all these tables become obsolete when new elements are discovered?"** *Almost all periodic tables today have "room for growth", for more elements as they are discovered.*
5. **"Why don't any other periodic tables have neutronium listed as an element?"** *Neutronium has not been proven to exist, except in some astronomers' hypotheses. Since most periodic tables are organized according to the number of protons and/or electrons in each element, and since neutronium contains no protons or electrons, there would be no place for it on most tables.*

References

More Articles on elements and the periodic table in *ChemMatters*

Previous issues of *ChemMatters* have explored topics covered in this article. The references below all can be found on the *ChemMatters* 25-year CD, obtainable from ACS for $30 (or a site/school license for $105) at this site: http://www.acs.org/chemmatters

The October 1984 issue of *ChemMatters* (pp. 7-9) contains an article on the origin of the elements: "Starborn: The Origin of the Elements". A later article, "The Birth of the Elements" covers some of the same material. It can be found on pages 4-5 of the October 2000 issue of *ChemMatters*.

In "Bringing Helium Down to Earth", Derek Davenport tells of the discovery of the inert gases in the October 1985 issue of *ChemMatters* (pp. 14-15). Another article, "Happy Birthday Helium" is found on page 12 of the December 1995 issue of *ChemMatters*. It also discusses some of the history of the discovery of the noble gases.

In the October 1987 issue of *ChemMatters*, pages 18-21, "Superconductivity" focuses on a description and explanation of superconductivity. It also discusses the scientists' decisions to substitute several different elements on the basis of the similarities in their group/family properties, in order to change the conditions under which the metal alloys undergo superconductivity.

"Element X" is a short article about Mendeleev's work on the periodic table, focusing on his prediction of a mysterious element, X, that he was sure existed—but doesn't. It (the article, not element X) can be found in the December 1987 issue of *ChemMatters*, pages 8-9.

The December 1990 issue of *ChemMatters* contained a center-fold of a spiral 3-D periodic that students could cut out and tape together. It is available on the *ChemMatters* CD. "This spiral three-dimensional table is based on a 1914 design by Ingo Hackh." You can find it between pages 10 and 11 on the PDF file.

Have you ever heard of the Periodic Table of the Elephants (PToE)? Each elephant represents an element. The elephants were designed by students in Washington, DC schools. Page 16 of the October 2002 issue of *ChemMatters*, available on the *ChemMatters* CD, has an article about how this got started. You can buy PToE T-shirts from the American *Chemical* Society, here http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_ARTICLEMAIN&node_id=894&use_sec=false&sec_url_var=region1. And you can download a PDF file of the Elephant/Element list with explanations for all the designs at http://portal.acs.org/portal/fileFetch/C/CTP_005593/pdf/CTP_005593.pdf.

Web Sites for Additional Information

More sites on Moran's spiral periodic table

The web site alluded to in the article, http://www.periodicspiral.com/spiral.html, is a demonstration page only. It shows you what features the web site has, but you must subscribe to be given full access to the site. It has the usual tables of data, and a clickable periodic table, but it also has some unusual features, which unfortunately are only available on the full-access site. Features include 700+ pages of data, the ability to show which elements will form compounds, and searchable tables of data based on eight different physical properties. The price for full web access is $49.95 for what appears to be a single-user license.

The **New York Times** Oct. 23, 2006 issue contains an article on different types of periodic tables, and Jeff Moran's spiral periodic table is highlighted there. You can view it online at http://www.nytimes.com/imagepages/2006/10/23/science/20061024_ILLO_GRAPHIC.html.

More sites on Stewart's "The Chemical Galaxy"

Wikipedia has a picture of Stewart's Chemical Galaxy at http://en.wikipedia.org/wiki/Image:ChemicalGalaxy_Stewart_2004.jpg.

You can read P. Stewart's original notes, both the beginner and the advanced levels, at http://www.chemicalgalaxy.co.uk/page3/page3.html. Here he discusses a brief history of his idea for a spiral periodic table, and he explains in greater detail about neutronium, the placement of elements, and the colors he chose to represent each element.

More sites on other spiral periodic tables

Moran's was not the first spiral periodic table. Here is someone's copy of Ted Benfey's 1960 version, found on Wikipedia: http://en.wikipedia.org/wiki/Alternative_periodic_tables.

More sites on Janet's periodic table

The original paper by Janet, written in December, 1929, can be found here: http://www.ipgp.jussieu.fr/~tarantola/Files/Professional/Mendeleev/Janet_1929.pdf. If you or your students speak French, you're in luck.

WebElements has a diagram of the Janet's periodic table at http://www.webelements.com/nexus/?q=node/981.

More sites on Mendeleev's periodic table and its predecessors

The Chemical Heritage Foundation's Web site has a Web page as part of their book, *Chemical Achievers*, called "The Path to the Periodic Table", which outlines the story of the periodic table leading up to Mendeleev's publishing of the table. Find it at http://www.chemheritage.org/classroom/chemach/periodic/index.html.

A version of Mendeleev's periodic table (in Russian) from 1872 can be found at WebElements Chemistry Nexus, at http://www.webelements.com/nexus/Mendeleev_Periodic_Table.

Carmen Giunta's Web site contains electronic copies of many original documents in the history of chemistry. Newland's original 1865 presentation of his Law of Octaves can be found here: http://web.lemoyne.edu/~giunta/EA/NEWLANDSann.HTML.

You can view an 1869 draft of Mendeleev's original periodic table at the Chemical Heritage Foundation Web site, at http://www.chemheritage.org/classroom/chemach/pop/04periodic/meyer1.html. The actual first published Mendeleev periodic table can be found here:

More sites on general periodic tables

If you just want to add a little spice to your classes, go to Mike Stanfill's PrivateHand.com website, where he has made a flash video presentation to go along with Tom Lehrer's "The Elements" song: http://www.privatehand.com/flash/elements.html. And if you want the "words" to the song in print for your students to sing along, go to the "Chemistry Daily" website at http://www.chemistrydaily.com/chemistry/Elements_song. The names of the elements are also clickable and direct you to a separate page for each element. (The site has a periodic table that is also clickable.) The actual lyrics, including his introductory (and in-between stanzas) patter, can be found at Sing365.com's web site, http://www.sing365.com/music/lyric.nsf/The-Elements-lyrics-Tom-Lehrer/7885B39D64892C1048256A7D0025211C.

Perhaps the best website for useful periodic table information for students is WebElements, http://www.webelements.com/. It has an interactive periodic table that allows you to find all sorts of chemical information (almost 100 items) about individual elements, including their history. The site also includes downloadable periodic table PDFs for printing out.

Chemical and Engineering News (C&EN) has an interactive periodic table on its Web site to celebrate the magazine's 80th anniversary. The page is entitled, "C&EN: It's Elemental: The Periodic Table". Clicking on any element will take you to another page that contains a personal story involving that element, written by a famous chemist/scientist. Students may enjoy reading these stories, to give them a feel for the human side of chemistry. You can access the periodic table at http://pubs.acs.org/cen/80th/elements.html.

Mark Leach's website, Chemogenesis, has a page that shows more than 75 different forms of the periodic table. This page also has tabs that allow you to see the tables grouped according to different times and different styles of tables. You can access the page, "Database of Periodic Tables" at http://www.meta-synthesis.com/webbook/35_pt/pt_database.php.

For a definitive periodic table, visit the International Union of Pure and Applied Chemistry (IUPAC) website at http://old.iupac.org/reports/periodic_table/IUPAC_Periodic_Table-22Jun07b.pdf and print out a PDF of the official IUPAC periodic table, dated 6/2/07. This table should be the most authoritative version in existence.

Here's another interactive periodic table, the "EniG. Periodic table of the Elements". The site also contains downloadable PDFs of the table in black and white and in color for printing. Find it all at http://www.periodni.com/en/.

The ChemiCool site provides another clickable periodic table, with each element having a wealth of information on a separate page. Find it at http://www.chemicool.com/.

Another site that contains an interactive periodic table is the TouchSpin.com website at http://www.touchspin.com/chem/DisplayTable.html. In addition to the typical information, the table contains a graphic of electron configuration and one of atomic mass that change as you scroll over the elements on the table, to give instant visual reference to that property. A series of tabs allows you to highlight specific properties; the colors change on the elements on the table to reflect general trends in that property. This is a very graphic site, great for visual learners. It would also be good to use this site as part of your lessons on a large-screen display, to highlight specific trends in properties of the elements.

The CRC Press has a periodic table with typical information about each element at http://www.chemnetbase.com/periodic_table/per_table.html. One added piece of information is cost for each element.

Theodore Gray has put together a photo periodic table at http://periodictable.com/. Scrolling over any element photo gives you an enlarged photo of the same picture. Clicking on the element's photo takes you to a detailed page on that element. You can then click on a photos page, or a technical data page, or an isotopes page. Any of the pages provides a wealth of information about that element. To be fair, Gray sells posters of his photographic periodic table on the site, also, as well as element samples and element sets, but the information he provides is free—and well worthwhile. He also encourages students and teachers to use his material in class projects, provided they use proper citations.

The *Journal of Chemical Education* has produced the Periodic Table Live! Website. It provides an interactive periodic table with the standard fare of chemical and physical data, but it also includes photos of each element, and video clips of the element reacting with air, water, acid or base. It also shows a model of the crystal structure in 3-D of each element.

University of Nottingham's chemistry department offers "The Periodic Table of Videos". It contains short video clips of each element on the table. You can access the You Tube® videos at http://www.periodicvideos.com/.

For the artistic student, you might want to send them to The Visual Elements Periodic Table web site. The Royal Society of Chemistry (UK) provides a very artistic version of elements, including alchemical symbols. The site, which requires Flash Player, is at http://www.rsc.org/chemsoc/visualelements//pages/pertable_fla.htm. The site contains "landscapes" of periodic trends in properties of the elements—very cool, futuristic stuff. In addition to the artistic flair, this site also provides data on the elements.

For students (or teachers) who are "into" comic books, there's the "Periodic Table of Comic Books" from the University of Kentucky Department of Chemistry. It's at http://www.uky.edu/Projects/Chemcomics/. The site has a clickable periodic table that will show you the comic books in which that particular element has been cited.

More sites on the short form of the periodic table

Sargent-Welch Science Supply Company has sold a short-form version of the periodic table for years. It is very compact, but its compactness adds considerably to its complexity. You can view it at http://www.sargentwelch.com/pop_largerview.asp?pn=WLS18808-10_EA&pnm=Periodic Chart of the Atoms&img=WLS18808-10_EA.jpg.

Here's a PDF file of a short form periodic table, s- and p-orbital elements only: http://www.slc.k12.ut.us/staff/meland/ap_resourse/Ptable-short%5B1%5D.pdf.

Were you teaching in the 1980s, when IUPAC changed the numbering system of the periodic table from Roman numerals (I – VIII) and A's and B's, to a continuous Arabic numbering system (1-18) across the periodic table? Here is the official IUPAC paper that discusses the history of the changes and the rationale behind their decision to change the periodic table: http://www.iupac.org/publications/pac/1988/pdf/6003x0431.pdf. (And if you aren't that old to remember all that, you may want to look at a piece of periodic table history anyway.)

More sites on alternative periodic tables

Dr. P. G. Nelson of Hull University has produced the Hull Periodic Table. T. Bayley suggested this general shape in 1882. View the Hull table at http://www.hull.ac.uk/chemistry/hullptable/hullptable_v6.html.

This table isn't really an alternative form, just rotated 90° counterclockwise. The print is still horizontal, but the table runs vertically and, oddly, from bottom to top. It was designed this way to allow the table to fit on the screen, scrolling down. Thus, "columns"/groups/families are horizontal and "rows"/periods are vertical. It comes from Syncopated Systems and can be found at http://www.oddgods.com/articles/2007/m28d.

Sargent-Welch still carries the short-form periodic table in their online catalog, and you can now find a spiral version in poster format. View the short form on their online catalog at http://www.sargentwelch.com/search.asp?ss=periodic+chart&x=6&y=11. You can see the spiral table at http://www.sargentwelch.com/pop_largerview.asp?pn=WLS1764-81_EA&pnm=Cyclical Continuum Elemental P&img=WLS1764-81WebF.jpg.

There's a 3-dimensional periodic table on Drexel University's "Drexel Island" on *Second Life*. You can see the image at this Google images site: http://images.google.com/imgres?imgurl=http://bp0.blogger.com/_R3jz5f_NkRo/RwJVNL-IkDI/AAAAAAAAAM8/ANVnhK7UcTU/s400/3dtable.JPG&imgrefurl=http://usefulchem.blogspot.com/&h=312&w=400&sz=28&hl=en&start=32&um=1&usg=__t5xvXhYM8uE144ZVgam7TErl3bQ=&tbnid=dDpG1ZFWtLkWAM:&tbnh=97&tbnw=124&prev=/images%3Fq%3DJanet%2Bperiodic%2Btable%26start%3D18%26ndsp%3D18%26um%3D1%26hl%3Den%26rlz%3D1G1GGLQ_ENUS289%26sa%3DN. You must register on *Second Life* to gain access to the table and other chemistry information on "DrexelIsland".

A "New Periodic Table of the Elements" can be found at http://www.egregoralfa.republika.pl/english/newtable.html#image. This table arranges the elements in a square-triangular arrangement. (You have to see it to understand this terminology.) The families/groups are not nearly as obvious in this arrangement, but according to the author, it allows for infinite expansion as new elements are discovered.

This one may be the best use of a tattoo in chemistry class, a tattoo of a periodic table on a man's forearm: http://farm1.static.flickr.com/45/149500684_b7084f5aee.jpg. (How could you stop this guy from cheating on his chemistry test, make him wear a long-sleeve shirt?)

More sites on non-chemistry periodic tables

Seeing the success of organizing so much information into such a small, compact design, other groups began using the periodic table concept for their own information. For example, you can now find information organized according to these very diverse topics:

- The Periodic Table of Comic Books:
- The Periodic Table of the Vegetables: http://www.allposters.com/-sp/Periodic-Table-of-Vegetables-Posters_i338062_.htm
- The Periodic Table of the Fruits and Nuts: http://www.allposters.com/-sp/Periodic-Table-of-Fruits-and-Nuts-Posters_i338065_.htm

- The periodic table of produce: http://www.ethicurean.com/wp-content/uploads/2006/09/foodstorage_big.jpg
- The Periodic Table of Condiments That Periodically Go Bad: http://web.mit.edu/dryfoo/www/Info/condiments.html
- The Periodic Table of Drinks: http://threadless.com/product/437/Tasty_Table/
- The (non-periodic) Periodic Table of the Desserts: http://www.pugsly.com/10-FT4.jpg
- The (more periodically correct) Periodic Table of Dessert: http://www.eblong.com/zarf/periodic/
- The Periodic Table of Rare and Endangered Species: http://www.pugsly.com/10-FT12.jpg
- Periodic Table of the Internet: http://www.wellingtongrey.net/miscellanea/archive/2007-06-23--periodic-table-of-the-internet.html
- The Periodic Table of Rejected Elements (in *The Atlantic*, August, 1999): http://www.theatlantic.com/issues/99aug/9908elements.htm
- The Periodic Table of the Criminal Elements: http://www.horse-you-rode-in-on.com/periodic/images/names.jpg

General Web References

Your best bet for finding forms of the periodic table, go to Mark Leach's Chemogenesis web site at http://www.meta-synthesis.com/webbook/35_pt/pt_database.php.

Dubber's Computer Resources web site lists links to 103 periodic tables, as well as links to 80 lesson plan/activity sites on the periodic table. Find it at http://dubber6.tripod.com/whereisit/id52.html. Note that many of the links are invalid.

Natural, Braided, Bleached, Colored, Straight, and Curly Hair … Thanks to Chemistry

Background Information

Lois Fruen's article barely opens the lid to a Pandora's Box of anecdotal information, experimental findings, chemical formulae, health concerns, etc., related to hair, hair products, and techniques used in styling hair. The article describes how hair interacts with chemicals that are used to style, shampoo, condition and color hair. Although the names and structures of many of the chemicals may remain a mystery for most high school chemistry students, it is important to stress that hair products are made up of chemical compounds. In addition, there are some familiar chemistry concepts—like cation/anion, acid/base, hydrogen bonding and hydrophobic/hydrophilic molecules.

More on fun/interesting facts about hair

The average person's head carries about 100,000 hair follicles.

A baby's head has about 1,100 follicles of hair per square centimeter.

Follicles grow about 20 new hairs in a lifetime. New hair grows for several years and can measure more than a meter in length. As a hair falls out it is replaced by a new one.

Not all follicles grow hair at the same time. Follicles, from the time of their formation, undergo cycles of growth and rest. The length of the cycle depends on the individual and where the hair is growing. Growing and shedding appear to be random events but, for each follicle, the process is precisely controlled. Over the years, the number of follicles growing hair declines naturally.

The main constituent of hair is the protein keratin which makes up feathers, claws, nails, and hoofs and is resistant to wear and tear. Hair also contains fats, the pigment melanin, small amounts of vitamins, and traces of zinc and other metals. Water, a final constituent, makes up only 10-13% of the hair but is extremely important for its physical and chemical properties.

Between starting to grow and falling out years later hair passes through three stages: anagen (1000 days or more), catagen (10 days), and telogen (100 days). The stages trace the path of the hair from deep with the scalp to its being shed.

Under normal circumstances, nothing interrupts the activity of the hair follicle. Nothing that is put on the scalp or hair can interfere with the growth of the hairs. Only severe burns or scars can affect hair follicles. Drugs used in chemotherapy can prevent hairs from growing, but this is only temporary with hair growth continuing after the medication is stopped.

Baldness is not due to any of the following: wearing any kind of hat or head gear, presence of 'poisons' in the air, use of shampoos, conditioners, or other cosmetics. Scalp tonics rubbed on scalp do not make hair grow.

Whether your hair is straight or naturally curly depends on your genetic background. Any alteration of the natural state of the hair must be brought about by either mechanical or chemical means or both.

Modern shampoos do not damage hair and conditioners that make up part of the shampoo protect the cuticle against harm from brushing and combing.

Over two thousand years ago the Greeks used a mixture of lead oxide and lime and water to dye hair black.

More on hair structure

A few words about the structure of hair are in order so that students can understand how styling and treatment can affect hair.

There are three structures that make up human hair. The first is the follicle, which is located in the fatty region of the scalp. Inside the follicle is the bulb, which is where new hair cells grow. As these new cells grow, they push older cells upward to form the hair shaft in which the cells are already dead. The shaft is the hair we see above the scalp. The fact that the visible hairs are made of dead cells and cannot repair themselves is the reason for the plethora of hair treatments available today.

The dead cells in the shaft are mostly composed of a chemical substance called keratin. A natural oil called sebum lubricates the shaft. Keratin is a fibrous protein which takes a helical shape. These helices can be extremely strong due to the presence of a compound called cysteine disulfide (human hair is about 14% cysteine). When the disulfide bond is present, the sulfur atoms are able to bond with each other in what are known as disulfide bridges. The degree to which they bond determines the stiffness or flexibility of the hair. This is what give each hair much of its shape. The presence of sulfur is also important in some hair coloring processes. Keratin can also be found in the skin. Hair also contains some fats, melanin, trace amounts of metals and about 10% water.

In addition to the disulfide bonds holding the keratin in place a number of other bond types give hair its shape. Students will recognize one type of bonding—hydrogen bonds. While much weaker than disulfide bonding, hydrogen bonds are estimated to provide 35% of hair's strength and 50% of its elasticity. When the hair is wetted these hydrogen bonds break and as the hair dries, the bonds reform but in a new configuration. This is the basis of hair "setting."

Each human hair shaft has three layers—the cuticle, the cortex and, in the case of people with coarse hair, the medulla. Hair's color, curliness and elasticity come from the cortex, which is found in the interior of the shaft. The cuticle forms the outer layers of the hair, like the bark of a tree. It is the condition of the cuticle that determines the health of hair. If the cuticle layers are intact, hair has a typically healthy shine to it.

Elasticity—Hair can be stretched and it will return to its original shape. Elasticity reflects this ability. Hair can be stretched up to 30% of its length. Elasticity can be reduced by chemicals (perms and bleaches) and by light.

Static Electricity—Students will know about this if they have ever rubbed a balloon on their hair and had it "stick" to the wall due to static electricity. Rubbing the hair causes the individual hairs to repel each other. Conditioners help to reduce hair friction.

Porosity—If the outer cuticle layers are undamaged, they resist water absorption by the hair. Anything that alters the cuticle layer allows water to penetrate the hair. In order to perm or color hair, the cuticle layer must be "opened up," typically by heating or by applying an alkaline solution. Ultimately this allows water to flow through the hair, weakening its structure over time.

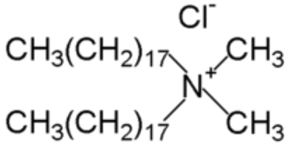
Texture—several factors are at work here: the diameter of each hair, the coarseness of the hair, and how the hair has been treated.

More on shampoo

Both shampoos and conditioners are the basis for most hair care. Modern shampoos contain a long list of chemicals that address many of hair's properties. Surfactants are the most important ingredients. They are the cleaning agents in shampoo. Surfactants molecules are typically long molecules with two distinctive "ends." One end is polar and is, therefore, attracted to water. The other end of the surfactant molecule is non-polar, which allows it to attract other non-polar molecules like the grease and dirt found in hair. The hyrophobic end of the surfactant is attracted to the sebum on hair and the hydrophilic end is attracted to water molecules, which are rinsed away, the surfactant-oil combination going with it.

The term applied to the polar end is "hydrophilic," and the term applied to the non-polar end is "hydrophobic." Because one end is water soluble, surfactants in shampoos are easily rinsed away.

The hydrophilic end of a surfactant usually has a charge, either positive or negative. The conventional chemistry terms are used here—anionic, cationic, or nonionic. Anionics are the foaming and cleaning ingredient in shampoos. Cationics help condition and add viscosity. Some common surfactant compounds include:
Anionic—sodium laureth sulfate or ammonium laureth sulfate
Cationic—olealkonium chloride or distearyldimonium chloride (at right)



In addition to cleaning agents, most shampoos contain conditioners as well as other additives which regulate the thickness and pH of the shampoo. Preservatives are also added to prevent germs from growing. In addition some shampoos include chemicals like coloring and perfume to make the shampoo more pleasant to use.

More on conditioners

The reason hair requires conditioning is that over time it is affected by friction (from combing and the wind), sunlight, heat, and chemicals (as in swimming pools). These weathering agents speed up the destruction of the cuticle layers and causes hair to look dull and dry. In more extreme cases the cuticles layers are completely worn away exposing the cortex.

Conditioners essentially serve to replenish the natural oils that lubricate the hair. They also re-hydrate the hair. They work because they contain cations, which are attracted to the anions present in hair. Therefore, these conditioners are not washed out with water and remain with the hair, giving it weight, shine and also preventing fizzing hair.

Some of the typical ingredients in conditioners include:

- stear-alkonium chloride to repair split end
- phenyl trimethicone to lubricate the hair
- polyacrylamide as a holding agent
- cyclopentasiloxane as a solvent

Historically a number of natural products, typically oils and essentials oils, have been used as hair conditioners. One such oil is tea tree oil, the main constituent of which are terpenoids, which are derived from isoprene units. Another oil is jojoba oil, which is a polyunsaturated liquid wax, up to 46 carbons in length. Carrier oils have also been used as solvents for natural conditioners. Modern hair conditioning began with the introduction of a product called Brilliantine, invented by French perfumer Edward Pinaud around the turn of the 20th century.

More on hair dyes

The chemistry of hair dyes is intimately related to the chemistry of healthy hair. To maintain structural health, hair should have a pH in the 4.5-5.5 range. That makes healthy hair slightly acidic. Under these conditions the cuticle is closely packed and the cortex is well protected. Hair can become alkaline (pH above 7) in a number of ways. Alkaline hair products, chemical solutions like perms and bleaches or heat from blow dryers, hot roller, and curling irons all serve to increase the pH of hair.

The chemical composition of human hair is approximately 45 % carbon, 28 % oxygen, 7% hydrogen, 15 % nitrogen and 5 % sulfur. These elements make up the amino acids, keratin and protein in hair. At least 16 amino acids are present in hair, with cysteine the most important.

The primary bonding in hair includes peptide bonds that link amino acids in keratin. Peptide bonds link the ends of amino acid molecules. There are also cross-linking bonds that affect the condition of hair. Some of these have been mentioned earlier (see More on hair structure).

Keratin is in reality a bundle of helical structures which are held together by four types of bonds. The strongest of these are the polypeptide bonds holding amino acids together. Disulfide bonds (sometimes called cystine bonds) are cross-linking bonds between adjacent sulfur atoms in keratin. (Please note that cysteine is the sulfhydryl form and cystine is the disulfide form.) These bonds help hold the helical polymer-like structures together. Hydrogen bonds also hold the peptide strands together, but are weaker than disulfide bonds. Because there are charge centers in the polypeptide strands, there are also ionic bonds (termed “salt bonds”) that cross-link. The fourth type of bond is a variation of van der Waals forces, but in the context of hair it is of minimal importance.

The natural color of hair is determined by the melanin content. There are two main types of melanin—eumelanin and phaeomelanin. Eumelanin is most common and is brown/black in color. Phaeomelanin is reddish in color. The visible color of a person’s hair depends primarily on the ratio of eumelanin to phaeomelanin. Hair color also depends on the thickness of the hair and the total number of melanin granules.

Hair coloring is not new. It has been going on for thousands of years. Originally, natural products like henna or black walnut shells were used as colorants. Mineral materials such as lead acetate, silver nitrate, and salts of bismuth, copper and cobalt have also been used.

These naturally occurring materials were used to dye hair until the early 1900's when chemist Eugene Schiller created the first safe hair coloring. The chemical he used was paraphenylenediamine. Schiller's company later became L'Oreal.

More on temporary hair coloring

The article mentions that some temporary hair dyes are spray-on hair powders with vegetable dyes, such as chamomile (1,3,4-trihydroxyflavone). Other temporary coloring agents are acidic textile, which do not penetrate the hair but are deposited on the outside of the cuticle. Since they remain on the surface, they are easily washed out. They are available as rinses, gels, mousses and sprays.

More on semi-permanent color

In permanent hair coloring the hair is first lightened. However, semi-permanent color deposits color onto the hair only and has no lightening effect. In semi-permanent coloring the cuticle of the hair shaft is raised slightly so that the color can be deposited there. Semi-permanent color doesn't penetrate into the cortex of the hair, but it will usually last from six to eight weeks, gradually washing out after about a dozen shampoos. These dye molecules are smaller than those in temporary coloring and so are able to move through the cuticle more easily. They are also, however, more easily washed out.

More on permanent color

The article mentions that permanent hair dyes contain either permanent or semi-permanent coal tar dyes. These products contain chemicals such as p-aminophenol (Fig. 13) and p-phenylenediamine. Other chemicals involved include:

Chemical	**Purpose**
Hydrogen peroxide	bleaching
Ammonia	bleaching
Monoethanolamine	bleaching
Disodium phosphate	buffer, stabilization
Sodium lauryl sulfate	foaming, thickening
Cocoamide MEA	foaming, thickening
Glyceryl stearate	emollient
1-naphthol	dye
4-amino-2-hydroxytoluene	dye

When hair is dyed permanently it involves a two-step chemical reaction between hydrogen peroxide (an oxidizing agent) and a solution of ammonia mixed with compounds that are color intermediates and compounds called couplers that form a dye color when oxidized. Examples of intermediates include ortho- or para- diaminobenzenes, aminohydroxybenzenes or dihydroxybenzenes. Couplers includes phenols, meta- disubstituted phenylenediamines and phenyleneaminophenols, and various resorcinol (1,3-dihydroxybenzene) derivatives. The peroxide first removes the existing color in the melanin and the ammonia-intermediate-coupler reaction develops the new color. All of this involves breaking bonds in the cortex. The disulfide bonds are among those broken, which accounts for the odor of hair coloring.

The ammonia causes the cuticle layers to swell, which allows dye molecules to penetrate the cuticle. The chemical reaction that takes place is a slow one, which is why the hair color develops slowly. The greater the concentration of intermediates, the darker the hair color. Conditioners in the dye return the cuticle to its former state after the reaction is complete.

Connections to Chemistry Concepts

1. **Viscosity**—Viscosity is generally defined as the resistance of a liquid to flow. The test described in "Hair Product Tests Students Can Try" may be related to other tests students may have encountered; e.g., the viscosity of different brands of catsup or other condiments, as well as tests on the viscosity of oil or other fluids. The concept of viscosity may also be related to the density of a liquid and the types of bonding found in the liquid.
2. **Percent total solids**—This portion of the article allows for a review of the mathematical concept of percent—parts per hundred. The same idea will show up again in per cent composition problems and labs in which a formula is determined from mass composition data.
3. **Specific Gravity**—This is a difficult concept for students to grasp. The concept is not often discussed in introductory courses. The specific gravity of a solid or liquid is defined as the ratio of the density of the substance compared to the density of water at 4°C. At this temperature the density of water is 1 gram/cm^3 in the system most often used in class. Specific gravity thus becomes a dimensionless unit. Any substance with a specific gravity greater than 1 is denser than water and will not float on water. Substances with a density less than 1 are less dense than water and will float on water. For specific gravity to be without a unit, the units given for the density of water must match the units for the density of the liquid or water. The term "relative density" is becoming the preferred term in modern scientific terminology.
4. **Interpretation of molecular formulas**—Students may need help interpreting the organic molecular structures presented in the articles. They need to redraw the skeleton structures and add the missing hydrogen atoms. Students new to chemistry will not know how to draw or interpret complex organic structures.
5. **Benefit/Risk Analysis**—Some chemicals used in hair products may pose health risks to some individuals. You might want to direct students to an internet search on dibutyl phthalate, diethyl phthalate, dimethyl palmitate. A report on these chemicals may be found at (http://www.cir-safety.org/alerts.shtml) (08/10/08). The use of lead products in Grecian Formula men's hair products is another example where the students must make a decision whether or not to use a product based on conflicting information.

Possible Student Misconceptions

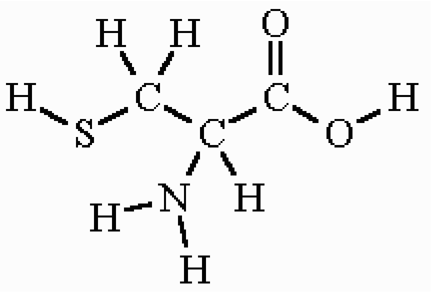
1. **"All shampoos are the same."** *A listing of ingredients from a variety of shampoos allows the student to see what chemicals are common to all shampoos and which ones are unique to a particular brand.*

2. **“Shampooing too often will damage hair**.” *Even frequent washing does not damage hair. Modern shampoos do not damage hair, and conditioners that make up part of the shampoo protect the cuticle against harm from brushing and combing.*

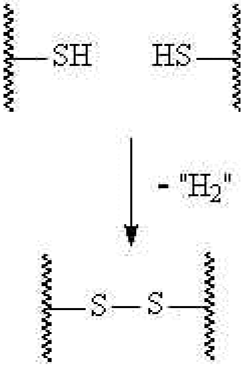
Demonstrations and Lessons

1. Analysis of lead in available hair products. Grecian Formula 16, one of the more popular men’s hair coloring products utilizes the formation of a black precipitate of lead(II) sulfide to darken the hair. If lead is banned in almost all products, how can the FDA allow the sale of a personal care product that contains lead? The lab, Quantitative Analysis of Lead, allows your students to determine the amount of lead in the hair product. (http://chem.lapeer.org/Chem1Docs/LeadAnal.html)
2. What are the pH values of some hair shampoos? Have the students bring in samples of shampoo. Determine the pH of the shampoo from the bottle as well as the pH of the shampoo that has been diluted with tap water. For the latter test, use 1 mL of shampoo and 9 mL of tap water. Class results can then be charted. The water used to dilute the shampoo is important and can change the pH. For example, tap water in Cincinnati, OH, has a pH of approx. 8.5 and turns phenolphthalein pink.
3. Students may determine the pH of rinses and conditioners following the procedure given in #2 above.
4. Science Netlinks provides an on-line set of experiments called “The Chemistry of Hair.” Besides determining the pH of shampoo samples, the activity includes instructions for testing hair samples in solutions of varying pH. Worksheets are provided. (http://thinkfinity.org/PartnerSearch.aspx?orgn_id=7)
5. The online version of the Exploratorium provides an activity “Better Hair Through Chemistry.” Instructions are given for building a hair hygrometer and using it to measure changes in humidity. The hygrometer utilizes hair’s ability to stretch in a moist atmosphere. The coiled protein, keratin, which makes up the hair, is wound up in a coil held together by hydrogen bonds. These hydrogen bonds break in the presence of water and allow the coiled protein to stretch. Instructions are given for calibrating the hygrometer. (www.exploratorium.edu/exploring/hair/hair_activity.html)

Hair is composed of keratin, a protein with a large amount of the amino acid, cystine. About 16% - 18% of keratin is cysteine. Characteristic of cysteine is the –S-H group known as the thiol group. In hair these thiol groups form disulfide bridges.



Cysteine molecule



disulfide linkage in hair

When applying a relaxer to straighten curly hair or a curling treatment to curl straight hair, the disulfide bridges are first broken. Because the curler or straightener reshapes the hair, the original sulfur atoms are too far apart to reform the original bonds. New bonds, disulfide bridges, are formed with closer, neighboring sulfur atoms. The tightness of the new curl is determined by the diameter of the hair curlers used.

Ionic bonds also act as bridges between two keratin protein chains. The amino group ($-NH_2$) on one protein chain and a carboxyl group ($-COOH$) on a neighboring protein chain will form an ionic bond a pH between 4 and 9. At a pH of 4.1, protons (H^{1+}) are added to the amino ($-NH_2$) groups and removed from the carboxyl ($-COOH$) groups. The proton transfer results in a positively charged $–NH_3^{1+}$ group and a negatively charged $–COO^{1-}$ group. If the two groups are found on neighboring chains, an ionic bond forms.

If the pH is increased, the keratin swells and becomes soft and the bonds cross-linking the two chains break. For this reason, most shampoos have a pH greater than 4.

As the ionic bonds break, wet hair can be stretched approximately one and a half times its dry length.

If teachers are interested in performing the lab, arrangements must be made ahead of time to obtain the required hair bundles. Ask a local hair stylist to save locks of hair that are at least 15 cm (6 in) long. When students run the lab, they need to make sure to use identical hair samples.

a. Testing the effects of four solutions on hair

Have a group of four students perform the lab with each student testing one of the solutions and sharing his/her results with the group.

Approximately 250 mL of the following solutions are needed for 28 students working in groups of four.

1. dilute hydrochloric acid, $HCl (aq)$ with pH = 4. (Add 10 drops of 0.1 M HCl to 500 mL of water. Test the pH with pH paper or pH meter.)
2. dilute sodium hydroxide, $NaOH(aq)$ with pH = 8. (Add a drop of 0.1 M $NaOH$ to 250 mL water. Check the pH after the addition of each drop.)
3. a permanent wave solution, and
4. a permanent wave solution followed by the permanent wave neutralizer.

To perform the lab, each group of four students will need two 25 or 50 mL graduated cylinders, a test tube rack to hold the four small (19 x 150 mm) test tubes, scissors to cut the hair, narrow wooden splints, and orthodontist rubber bands (14 rubber bands/team) to attach the hair to the splints.

1. In each case, obtain a bundle of hair (15-20 strands). Wrap the bundle around a wooden splint and secure the wrapped bundle to the splint with orthodontist's rubber band.
2. Place 15 mL of each of the solutions in four test tubes, one for each student in the group. Lower the hair on the splint into each of the solutions and allow it to stand for 15 min. In the fourth sample, keep the hair in the permanent wave solution for 10 min, remove the splint and rinse with running water, and then place the splint into the neutralizing solution for 5 min.

3. At the end of the fifteen minutes remove each splint from its test tube and place the four splints on four labeled paper towels. Partially dry the hair by dabbing with the paper towels.
4. When the hair appears fairly dry, carefully take off the rubber band and, without disturbing the curl, remove the bundle of hair. At this point, the group of four students should rank the hair with respect to the curliness of the bundle and record the data.
5. Remove one hair from each bundle, grasping each end and pull gently until the hair breaks. Perform the same procedure with a group of five hairs from each splint. Record the observations.
6. To complete the testing, rinse the remaining hairs on each of the four splints under running tap water. Grasp the ends of the bundles between the thumb and a finger and gently squeeze out any excess water from the hair. After allowing the hair to dry, compare the amount of curl left in each bundle. Record the observations.
7. Perform a second stretch test with a single hair and then with a bundle of five hairs as was described above. Record the observations.

From their recorded observations, students should be able to predict which solutions were the best at curling the hair prior to wetting, which were the best keeping the curl after wetting, which solutions produced the most brittle hair, or caused the most damage to the hair. Based on the structure and bonding in hair, students should be able to provide an explanation for the difference in curl produced by just water and that produced by the permanent wave solutions. Are acidic or basic solutions more damaging to the hair? Determine to which class, acid or base, the two permanent wave solutions belong.

Student Projects

Have students bring in a variety of shampoos, rinses, and conditioners they use at home and record the ingredients from the labels. List the ingredients in a spread sheet. This can become a class project with individual students adding product names and ingredients to the list. If a variety of products are not available at home, students can visit local stores and record the list of ingredients for use in the data base. Once the list has been completed, students research the literature and determine the role of each product in a particular formulation. Which ingredients are common to all of the products?

Anticipating Student Questions

1. **“Are men and women’s hair coloring agents the same?”** *Men and women’s hair products utilize different chemical mechanisms. Women’s products use a variety of organic dyes while the more common men’s products, the Grecian Formula brand, actually precipitate black lead(II) sulfide onto the hair follicles.*
2. **“Are the chemicals used in the hair treatments dangerous?”** *The availability of a wide variety of hair products may lead to the assumption that hair products must be safe. While drugs must be proven safe prior to FDA approval, this is not the case with cosmetics. As stated above in Connections to Chemistry Concepts, students may look up the chemicals that make up a particular formulation and determine whether or not the chemical has been determined to be safe.*

3. **“Is it possible to over-shampoo one’s hair?”** *Modern shampoos do not damage hair, and conditioners that make up part of the shampoo protect the cuticle from harm from combing and brushing. A daily shampoo should not damage one’s hair. A web search will result in a variety of opinions.*
4. **“How many hairs are there on an average person’s head?”** *The average person has about 100,000 hair follicles. That number decreases with advancing age.*
5. **“Does cost determine the efficacy of a particular product?”** *More expensive products frequently seem to do a better job. Encourage students to explore Consumer Reports. Most consumer products have been studied and, as is often the case, a less expensive product may match the efficacy of the most expensive products.*

References

More Articles on Hair in ChemMatters

Previous issues of *ChemMatters* have explored topics covered in this article. The references below all can be found on the *ChemMatters* 20-year CD, available from ACS for $25 (or a site/school license for $99) at this site: http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccurriculum%5Ccmprods.html#CDsite.

The April, 1983 issue contains two articles on “pH & Hair Shampoo” and “Permanent Waves.” The pH article discusses the effect of various pH levels on the structure and bonding in hair. A brief experiment testing pH in shampoos concludes the article. The permanent wave article provides a detailed explanation of the hydrogen, covalent, and ionic bonding found in hair. The author explains the “unzipping” and “zipping” of the bonds. The five figures presented in the article are useful in discussing the bonding.

The April, 2002 issue presents “Hair Color: Chemistry to Dye For.” The article concentrates on the chemistry of permanent hair dyes. The author focuses on those dyes that both lighten and color in one process. The identical article also appeared in *Chemical and Engineering News* “What’s That Stuff” Section. (http://pubs.acs.org/cen/whatstuff/stuff/7811scit4.html)

The December, 1992 issue has the article, “A New Kind of Bad Hair Day.” This article discusses the efficacy of testing hair for drug use. The article also discusses the in-home hair sample collection kits for drug testing. The topic of these kits should lead to serious discussions in class on the psychological effect such testing would have on the family unit as well as discussions on the confidence level of the “black box” lab procedures.

Web Sites for Additional Information

More sites on hair styling terminology

The hair styling industry employs a distinct set of terms. The following website provides a glossary of hair styling terminology.
(http://www.saloniq.com/resources/glossary.php)

More sites on danger of lead in hair products

Students interested in the use of heavy metal ions in men's hair products will find the following sites useful.

Lead Based Hair Products: Too Hazardous for Household Use. (http://www.uwsp.edu/geo/courses/geog100/MielkeHairLead1.htm)

Hair'em Scare'em (http://www.junkscience.com/news/grecian-formula.html)

More sites on the structure of hair

Students interested in a closer look at the structure of hair will find the following websites useful.

A more detailed diagram of the structure of hair is available at (http://science.howstuffworks.com/hair-coloring1.htm)

For diagrams of hair and scalp as well as a detailed explanation of the stages of hair growth go to (http://www.natural-hair.com/structure.html)

The salon website provides a more detailed description of the effect of hydrogen bonding on various types of hair. (http://www.salonweb.com/gold/tri.htm)

For a detailed, 34 slide presentation on the structure of hair including diagrams and electron micrographs of hair and scalp visit (http://www.slideshare.net/dralisyed/1-structureof-hair-euro-july-08?src=embed)

The Proctor and Gamble Hair Care Research Center makes available "The World of Hair," a detailed on-line reference by Dr. John Gray covering every possible aspect of hair care. Of special interest are the sections on problems and disorders the reader might face when using hair styling products. The photos and diagrams make this a must see reference. (http://www.pg.com/science/haircare/hair_twh_toc.htm)

More sites on a typical cosmetology two-year curriculum

For someone interested in possibly pursuing a career in cosmetology, the Career Tech website outlines a two year course of studies. (www.ccc.cc.ms.us/ie/CareerTech/Cosmetology/)

More sites on "The Best of Hair Talk #1 DEA & Chemicals in Hair Care Products"

An interesting discussion about chemicals in hair especially DEA (diethanolamine) and how to interpret data found on the internet can be found at **(**http://www.hairboutique.com/tips/tips067.htm).

The websites "Wikipedia" and "How Stuff Works" provide details on an ever growing variety of topics. Access the site and type in your search topic. In most instances, the topic will not only be covered, but the references posted at the end of the article offer other avenues for pursuing research on the topic. The websites may be found at:
Wikipedia (http://en.wikipedia.org) and
How Stuff Works (http://www.howstuffworks.com).