



December 2005 Teacher's Guide

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Student Questions

Einstein's Miraculous Year

1. Who first described the photoelectric effect?
2. What was Einstein's explanation for the effect?
3. What is Brownian motion?
4. What was Einstein's starting premise for his work on the special theory of relativity?
5. Does light travel slower in water?

Motion Detectors

1. What is a photo sensor?
2. If you shine light of sufficient energy on a photoelectric surface, what happens?
3. What is the "dual nature of light" that confound classical physics?
4. How do bats locate obstacles in the dark?
5. Photo sensors that can tell the difference between the motion of a tree and the motion of a person detect what type of light?

Secrets of the Samurai Sword Revealed

1. What two sword properties make for the ideal blade?
2. Why is carbon added to steel?
3. What are three microstructures of steel?
4. How does a sword smith make thousand of layers of steel for the core of the blade?
5. What is tempering?

Honey: Bee Food Extraordinaire!

1. What natural process makes the sugar in honey?
2. The enzyme invertase breaks sucrose down into what two simple sugars?
3. Why isn't it wise to eat a banana around a bee hive?
4. What is "mad" honey?
5. Why are some bees being trained to associate the smell of TNT with sugar water?

Poisoned!

1. How were members of the church poisoned?
2. What is the difference between acute and chronic exposure?
3. What is a chelator?
4. Why is DMSA used to treat arsenic poisonings?
5. What are two common uses of arsenic compounds?

Answers to Student Questions

Einstein's Miraculous Year

1. Who first described the photoelectric effect?

Heinrich Hertz first described the effect in 1887. It occurs when you shine light on a surface and electrons fly off.

2. What was Einstein's explanation for the effect?

He suggested that light should be considered as a stream of particles (not just waves) that interact with electrons. If the frequency of this bundle of light (photon) is at or above a threshold frequency, the photon has enough energy to kick out an electron.

3. What is Brownian motion?

It is the seemingly random motion of particles, like pollen, in liquids. The motion is the result of collisions of the particle with "bazillions" of solvent (water) molecules.

4. What was Einstein's starting premise for his work on the special theory of relativity?

The speed of light is constant and light moves at the fastest speed (in a vacuum) in the universe.

5. Does light travel slower in water?

Yes, about 25% slower. Light travels fastest in a vacuum and slower through matter.

Motion Detectors

1. What is a photo sensor?

A general definition is anything that senses light.

2. If you shine light of sufficient energy on a photoelectric surface, what happens?

It ejects electrons from the surface of the sensor and initiates an electric current.

3. What is the "dual nature of light" that confounded classical physics?

Light acts as both a particle and a wave.

4. How do bats locate obstacles in the dark?

Bats use echolocation, a process where bats send a sound wave using minute changes in the returning echo to locate objects and prey.

5. Photo sensors that can tell the difference between the motion of a tree and the motion of a person detect what type of light?

These photo sensors detect infrared light. Objects at human body temperature emit IR radiation and can be detected and distinguished from relatively cool surroundings.

Secrets of the Samurai Sword Revealed

1. What two sword properties make for the ideal blade?

A sword should be flexible and hard enough to keep a sharp edge.

2. Why is carbon added to steel?

Addition of carbon to steel disrupts the crystal lattice of iron, making it much harder for iron atoms to move freely. This makes carbon steel harder than iron.

3. What are three microstructures of steel?

The four microstructure of steel mentioned in the article are austenite, cementite, martensite, and pearlite.

4. How does a sword smith make thousand of layers of steel for the core of the blade?

The soft steel is flattened and folded many times creating thousands of layers (2, 4, 8, 16, 32, 64...)

5. What is tempering?

Tempering is a process that helps relieve stresses with in the steel structure. This process is done at a much lower temperature than previous forging and quenching.

Honey: Bee Food Extraordinaire!

1. What natural process makes the sugar in honey?

Photosynthesis.

2. The enzyme invertase breaks sucrose down into what two simple sugars?

They break down into fructose and glucose.

3. Why isn't it wise to eat a banana around a bee hive?

Bees use the molecule isopentyl acetate, which is also found in banana oil, as a biochemical signal to attack. This banana smell can trigger an unwarranted attack.

4. What is "mad" honey?

When bees forage near wild rhododendrons, they can concentrate grayanotoxin in their honey. The toxic honey can cause hallucinations and a "buzz" if consumed.

5. Why are some bees being trained to associate the smell of TNT with sugar water?

Bees are excellent at detecting trace compounds in the air. If they can be trained to associate TNT with food, they might selective forage near landmines and help detect them.

Poisoned!

1. How were members of the church poisoned?

Coffee at the church was poisoned with arsenic.

2. What is the difference between acute and chronic exposure?

Acute exposure takes place over a short time interval. Chronic exposure usually involves exposure to small quantities of poison over a long time.

3. What is a chelator?

A chelator is a molecule that can bind to a metal ion through more than one point.

4. Why is DMSA used to treat arsenic poisonings?

DMSA is a selective chelator for arsenic. DMSA has sulfur atoms which preferentially bind As.

5. What are two common uses of arsenic compounds?

Arsenic was used to prepare pressure treated lumber. Arsenic is used to make semiconductors. It is used in pesticide and herbicides.

Puzzle ABC

What's in a name ? Well, perhaps a lot of chemistry! Below the grid are clues to 27 five-letter words, three in each line. The terms that fill in sets A and C are all from the world of chemistry, while those in set B are more general. There's only 13 columns in the grid because the LAST letter of a word in set A is also the FIRST letter of the word in set B, and the FIRST letter of the word in set C is the LAST letter of the word in B. Three other hints:

1. Every term in columns A and C are names of some sort: famous chemists, names of elements or their ions, names of functional groups, categories of the periodic table, etc.
 2. Read down the very middle column to reveal a message of interest to a beginning chemist.
 3. We've entered the first answer for you; note then that word #1B must start with the letter n.
- The rest is as easy as ABC !

	SET A				SET B				SET C				
1	X	E	N	O	N								
2													
3													
4													
5													
6													
7													
8													
9													

	Set A	Set B	Set C
1.	element #54	what students take during a lecture	Fe alloyed with C and other metals
2.	R-O-R'	restore to health or good condition (slang)	smallest atomic radius in group 13
3.	BF ₃ is an ex. of a ___ acid	Lead singer of the Police	the halogens or the alkalis, as ex.
4.	H ₂ O(g)	depressive (bi-polar personality)	discoverer of radium and polonium
5.	an ion arranged 1s ² 2s ² 2p ⁶	ridge of sand deposited by a glacier	the radioactive noble gas
6.	noble gas used in lightbulbs	the theme of this puzzle !	family name ends in ose
7.	a.k.a. dihydrogen monoxide	70's television mini-series	one of the states of matter
8.	G, the ___ free energy	Latin-American hot stuff, whether food or style	R-NH ₂
9.	R = C ₂ H ₅ -	a blood-sucking fresh water worm	SI unit of frequency

Puzzle Answers to ABC puzzle

1	X	E	N	O	N	O	T	E	S	T	E	E	L
2	E	T	H	E	R	E	H	A	B	O	R	O	N
3	L	E	W	I	S	T	I	N	G	R	O	U	P
4	S	T	E	A	M	A	N	I	C	U	R	I	E
5	O	X	I	D	E	S	K	E	R	A	D	O	N
6	A	R	G	O	N	A	M	E	S	U	G	A	R
7	W	A	T	E	R	O	O	T	S	O	L	I	D
8	G	I	B	B	S	A	L	S	A	M	I	N	E
9	E	T	H	Y	L	E	E	C	H	E	R	T	Z

The hidden message in column 7 is THINK MOLE

Content Reading Guide

National Science Education Content Standard Addressed	Honey	Einstein's Miraculous Year	Motion Detectors	Secrets of the Samurai Sword	Poisoned
As a result of activities in grades 9-12, all students should develop understanding					
Science as Inquiry Standard A: of abilities necessary to do scientific inquiry			✓	✓	
Science as Inquiry Standard A: about scientific inquiry.	✓	✓	✓	✓	✓
Physical Science Standard B: of the structure of atoms.		✓	✓	✓	
Physical Science Standard B: of the structure and properties of matter.	✓	✓	✓	✓	✓
Physical Science Standard B: of chemical reactions.	✓				✓
Physical Science Standard B: of conservation of energy and increase in disorder.		✓			
Physical Science Standard B: of interaction of energy & matter.		✓	✓	✓	
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.

Poisoned!

Me	Text	Statement
		1. Arsenic and its compounds were not recognized as poisons until the 20 th century.
		2. Arsenic compounds have been used as pesticides and herbicides, as well as making pressure-treated wood.
		3. Arsenic is used in high-tech equipment.
		4. Arsenic compounds have been used for medicinal purposes.
		5. The average person ingests more than 8 g of arsenic daily.
		6. The toxic dose of arsenic for an adult depends on body weight.
		7. There is no antidote for arsenic poisoning.

Honey: Bee Food Extraordinaire!

Me	Text	Statement
		1. Most sweet foods found in nature are safe to eat.
		2. Glucose and fructose have the same chemical formula.
		3. It is safe to eat a banana near a bee hive.
		4. Honey contains about 17% water.
		5. Honey's flavor depends in part upon the soil where the flowers the bees visited were grown.
		6. The pH of honey is less than 2.
		7. If the nectar honeybees gather is toxic, the honey will be toxic.
		8. The honeybees that Americans have depended on for 400 years are native to North America.
		9. Honey can be used to kill infections
		10. Bees may be used to detect biohazards and land mines.

Einstein's Miraculous Year

Me	Text	Statement
		1. In the photoelectric effect, the color of light, not its intensity, determines whether electrons will be ejected from a metal surface.
		2. All metals have the same threshold frequency for the photoelectric effect.
		3. If the incident light is above the threshold frequency, higher intensity light will cause more electrons to be ejected than lower intensity light of the same frequency.
		4. Einstein computed the dimensions of an atom after analyzing the Brownian motion of dust particles in water.
		5. If you were in a spaceship moving at the speed of light, your watch would stop.
		6. According to Einstein, the universal speed limit is the speed of light in a vacuum.
		7. Einstein's conclusions from the theory of relativity have never been supported by experimental evidence.
		8. Einstein's work laid the foundation for understanding the nature of the atom.

Motion Detectors

Me	Text	Statement
		1. All motion detectors work on the same principle.
		2. Photo sensors can be made for many different frequencies of light.
		3. To understand the photoelectric effect, it helps to think of light more like a particle than a wave.
		4. Einstein won the Nobel Prize for the theory of relativity.
		5. Bats and police radar use the same type of signals.
		6. If an object is transparent to visible light, it is transparent to all electromagnetic radiation, including infrared.

Secrets of the Samurai Sword Revealed

Me	Text	Statement
		1. Japanese swords that combine flexibility and hardness were made 1000 years before Europeans mastered the craft.
		2. The higher the carbon content of steel, the softer the blade.
		3. The cooling rate of steel causes has no effect on the crystalline structures that form.
		4. Samurai swords begin using black sand that contains iron.
		5. The inside of the sword is harder than the outside.
		6. The Japanese sword masters use thermometers to know the temperature of the steel during the forging process.
		7. As part of the surrender agreement at the end of World War II, the Japanese were required to give up their Samurai swords.

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

Einstein's Miraculous Year

Einstein's Contribution	Einstein's Explanation	Significance
Photoelectric Effect		
Atomic Theory		
Theory of Relativity		

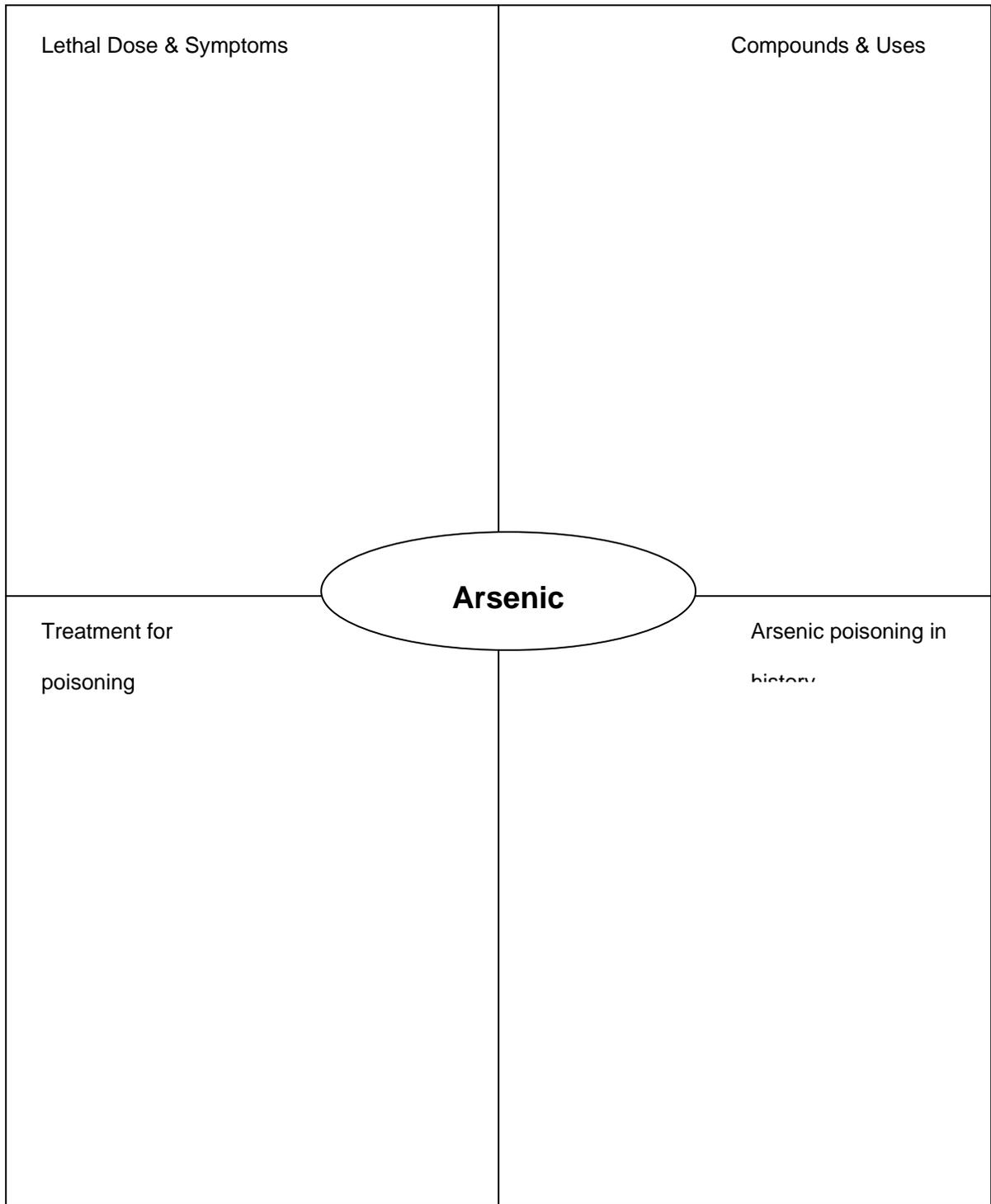
Motion Detectors

Method	Description	Examples
Blocking light beam		
Monitoring reflection		
Monitoring infrared radiation		

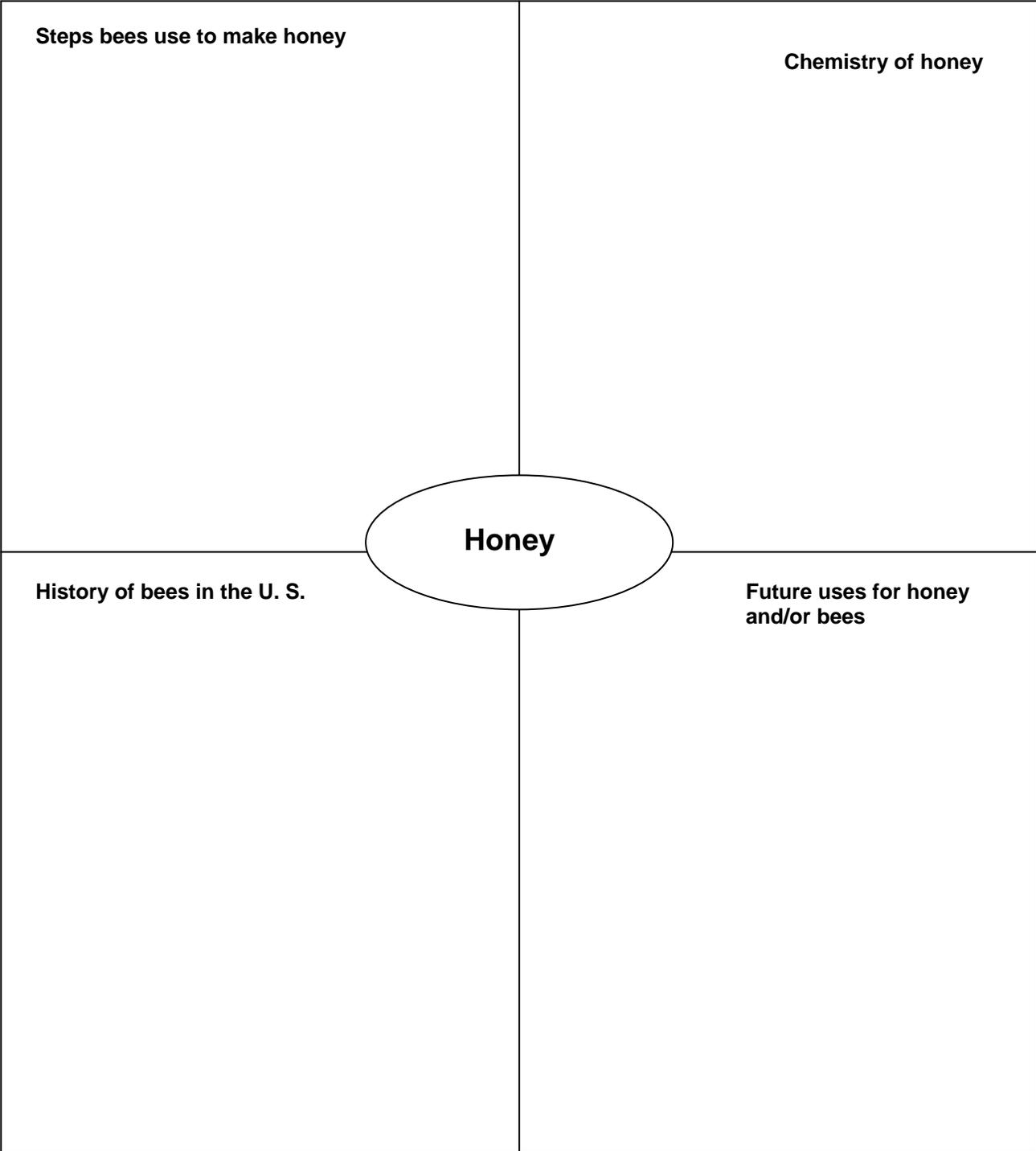
Secrets of the Samurai Sword Revealed

Samurai Sword Smith Process	Crystal Structure	Result

Poisoned!



Honey: Bee Food Extraordinaire!



Einstein's Miraculous Year

Background Information

A Note on Einstein, Chemistry and Physics

In much of the writing about Einstein's work, both physics and chemistry claim him as their own and make the argument that his interests originated in one or the other discipline. The physicists point to the facts that Einstein's Ph.D. was in physics and that he received the Nobel Prize in *physics* for his work on the photoelectric effect. Chemists note that Einstein actually intended to become a chemist and that the first three of the five papers written by Einstein in 1905 were about the behavior of atoms and molecules and, therefore, Einstein's most important work could be properly claimed by chemistry.

In the intervening 100 years, especially the last 30, it has become clear that lines dividing the traditional disciplines of chemistry, physics and biology are artificial and misleading. Much current science research crosses disciplines. Practicing scientists today remind everyone that science is interdisciplinary and that every scientist needs to know some of each of the disciplines, along with engineering and computer skills.

In discussing this article with students in a chemistry class, it may be worth noting the territorial debate to students, but it is much more important to point out to them that Einstein's work has influenced many areas of science. It has changed the way scientists think about matter. Einstein's work provided a new model for thinking scientifically. His work also reminds us of the interdisciplinary nature of modern research. Emphasize to students that the current and future science workforce requires multidisciplinary skills and also demands that chemists, and all scientists, continue to learn new skills in order to keep pace with the changing nature of science.

A Note on The 1905 Einstein Papers.

Although the article describes three important papers written by Einstein in the seven month period from March to September of 1905, he, in fact, wrote five papers in that short period of time. It is why 1905 is called the *annus mirabilis*—the miracle year—for Einstein.

Einstein, married with a child at age 26, was working as a patent examiner in Bern, Switzerland. His 1905 papers were not his first. The leading German physics journal *Annalen der Physik* had published five of his papers between 1900 and 1904. The papers were primarily about the reality of atoms and molecules.

The five papers submitted by Einstein in the seven month period and published by *Annalen der Physik* in 1905, placed Einstein in the company of Sir Isaac Newton who in less than a twelve month spanning 1665-1666 set forth major ideas on gravitation, the calculus, color and a theory of matter. The Einstein papers and the topics, in the order in which he submitted them:

March — photoelectric effect [described in the article]

April — size of molecules (his doctoral dissertation)

May — Brownian motion and the existence of atoms [described in the article]

June — special relativity [described in the article]

September — $E = mc^2$

More on Einstein and Proving the Existence of Atoms

In biology circles, Scottish botanist Robert Brown is best known for his early cataloguing of plants species, for his pioneering description of the cell nucleus and as an advisor to Charles Darwin. In physics circles, however, he is best known for a paper he published in 1828, in which he described the irregular movements of small particles that he suspended in liquids. Brown also concluded that this motion was not due to outside factors but to the particles themselves. This would mean that the motion was due to the internal energy of the particles. Brown's results did not attract much attention, however,

until the late 1800's when Brownian motion arose as an example of the dispute between classical thermodynamics and the kinetic theory of matter that had been developed by James Clerk Maxwell and advanced by Ludwig Boltzmann.

Thermodynamics had been used for nearly a century until the late 1800's to explain much of the behavior of matter, but the "statistical mechanics" theories of Maxwell and Boltzmann were built on the idea of atoms. At the turn of the century, however, the existence of atoms was far from universally accepted. The famous physical chemist Wilhem Ostwald, for example, himself a future Nobel Prize winner in chemistry (1909) opposed the idea.

Just 11 days before Einstein wrote his paper on Brownian motion he had submitted a paper analyzing the size of molecules and calculating Avogadro's number. He relied on the ideas of statistical mechanics in that paper. Atoms were clearly on his mind. The paper was actually accepted as Einstein's doctoral thesis. In the paper Einstein demonstrated that larger particles, like the ones Brown had seen "dancing" around, reflected the behavior of much smaller particles that were not visible. He derived an equation describing the motion of these invisible particles that depended on time, the viscosity of the suspending liquid, temperature and the size of the particle. The paper provided solid theoretical evidence that atoms were actual physical entities. Three years later Jean Perrin, a physical chemist, verified Einstein's calculations and provided experimental proof for the existence of atoms. But it was the third of Einstein's 1905 papers that provided the impetus for belief in the existence of atoms.

This idea of atoms, of course, had a long history going back to Democritus in the 4th century BC and carrying through the work of Robert Boyle, John Dalton, and Amedeo Avogadro. Some of this is typically described in abbreviated terms in most high school chemistry texts, but rarely are Einstein's ideas included in the history. As you study the development of the atomic model with your students, consider assigning this article to provide an important contribution of Einstein to chemistry.

More on Einstein and the Photoelectric Effect

In his first 1905 paper, Einstein explained the photoelectric effect for which he eventually won the Nobel Prize in physics. He said, "According to the assumption considered here, when a light ray starting from a point is propagated, the energy is not continuously distributed over an ever increasing volume, but it consists of a finite number of energy quanta, localized in space, which move without being divided and which can be absorbed or emitted only as a whole."

In this way Einstein re-defined how science thought of light. Until this time it was assumed to behave like a wave, which Einstein agreed was a sufficient explanation for purely optical events. But in order to explain events like the emission of electrons from a metal surface when light strikes the metal, it is necessary to think about light as discrete bundles of energy, later called photons.

The idea of particles of light was not original with Einstein. In a paper published in 1900, Max Planck advanced the idea that electromagnetic energy (light) could exist in discrete packages, or quanta, that had unique values. The energy values, E , for any bundle of light were in proportion to the frequency, ν (the Greek letter nu), of the light. The constant of proportionality would be a universal constant, h . Its value of 6.626×10^{-34} J x s is well known to current students of chemistry from the equation: $E = h \nu$. Planck's idea, called the quantum theory, was not immediately accepted widely. Only when Einstein employed the idea in his 1905 paper to explain what were then discrepancies in the behavior of light did quantum theory begin to gain acceptance. Actually not until 1913 and Bohr's concepts of quantized energy states for electrons in atoms was the quantum theory widely accepted.

Einstein showed that it was the *frequency* of light falling on the metal surface that dislodged electrons. Below a certain frequency, called the threshold frequency, the light had no effect on electrons. Light with frequencies higher than the threshold value caused electrons to be emitted faster. The intensity of the light was only a factor if the frequency was above the threshold value, and then increasing the frequency caused more electrons to be emitted.

The threshold value is the minimum frequency that will cause an electron to be emitted. Einstein said, “The simplest picture is that a light quantum transfers all of its energy to a single electron; we shall assume that happens. Moreover, we must assume that each electron on leaving the body must produce work, P, which is characteristic for the body. The kinetic energy of such electrons is

$$KE(\text{max}) = h\nu - P$$

If the formula derived here is correct, [the maximum KE] must be, if drawn in Cartesian coordinates as a function of the frequency of the incident light, a straight line, the slope of which is independent of the substance studied” (actually the energy of the emitted electron is influenced by temperature, a fact shown to be true in the 1930’s).

The threshold frequency is related to the amount of work done by the electron emitted. The incident energy must be enough to allow the electron to overcome any forces holding it in the metal. The work function, P, is the work done to allow the electron to be emitted. A sampling of the work functions for metals:

Metal	P (eV)
Silver	4.26
Aluminum	4.28
Gold	5.1
Copper	4.65
Iron	4.5

If the work function in the photoelectric effect sounds like the definition of first ionization energy, it should. The concepts are related. Threshold frequencies also form a rough correspondence with the electronegativities of metals.

The photoelectric effect had been observed as early as 1886, by Heinrich Hertz (for whom the unit of light frequency is named). In 1899, J. J. Thomson, following up on his discovery of electrons (or corpuscles, as he called them) in 1897, irradiated metals with ultraviolet light and observed cathode rays, or electrons, being emitted. Three years later Philipp Lenard experimented with trying to stop the electrons from being emitted, and in an experiment very similar to the one described in the article as the Electron Measuring Device, discovered that it was the frequency of the light that determined whether or not electrons were emitted from the metal surface. For example, Lenard found that red light did not dislodge electrons but blue light did. But Lenard did not know how to explain his findings. Einstein did.

The emitted electrons emitted in the photoelectric effect can actually create an electric current. This is important in modern semiconductors, solar cells, light-emitting diodes, X-rays, CAT scans, microwave ovens, lasers, TV screens, LCD screens, photocopiers, night vision devices, and motion detectors, among others.

More on the Electromagnetic Spectrum

In order to understand the importance of the relationship between atomic structure and light, student need to understand the basic elements of the electromagnetic spectrum. Most high school chemistry textbooks cover this concept so just the basics will be supplied here. Discussion of the traditional wave nature of light should provide students with enough background to appreciate the important of Einstein and the photoelectric effect.

The basic characteristic of electromagnetic radiations is that they travel at a velocity of 3×10^8 m/s in a vacuum. The identifying characteristics of any wave are its frequency (ν) and wave length (λ). The equation that relates the three characteristics is:

$$C = (\nu) (\lambda)$$

Any form of electromagnetic radiation, then, can be identified by its wave length or its frequency. From the equation we know that frequency and radiation vary inversely. Different forms of electromagnetic energy have different wave lengths (and frequencies), and regions of the spectrum are variously named. An image from NASA illustrates:

Infrared	$7 \times 10^{-7} - 1 \times 10^{-3}$	$3 \times 10^{11} - 4 \times 10^{14}$	$2 \times 10^{-22} - 3 \times 10^{-19}$
Visible	$4 \times 10^{-7} - 7 \times 10^{-7}$	$4 \times 10^{14} - 7.5 \times 10^{14}$	$3 \times 10^{-19} - 5 \times 10^{-19}$
UV	$1 \times 10^{-8} - 4 \times 10^{-7}$	$7.5 \times 10^{14} - 3 \times 10^{16}$	$5 \times 10^{-19} - 2 \times 10^{-17}$
X-Ray	$1 \times 10^{-11} - 1 \times 10^{-8}$	$3 \times 10^{16} - 3 \times 10^{19}$	$2 \times 10^{-17} - 2 \times 10^{-14}$
Gamma Ray	$< 1 \times 10^{-11}$	$> 3 \times 10^{19}$	$> 2 \times 10^{-14}$

From: <http://imagine.gsfc.nasa.gov/docs/science/known1/emspectrum.html>

More on Einstein and Special Relativity

Einstein's fourth paper of 1905, submitted in June, was titled "On the electrodynamics of moving bodies." We know the topic of the paper as Special Relativity. The two major ideas, or postulates, in this paper were:

1. The speed of light is the same everywhere in the universe, regardless of the frame of reference of the observer. This established the speed of light as a fundamental constant in the universe.
2. Properties of matter and energy are independent of the observer. That means that properties recorded by an observer in one frame of reference will be the same as those recorded by a different observer in a different frame of reference (as long as the frames of references themselves are not accelerating). It is important to note that this postulate does NOT mean that matter, for example, will behave the same regardless of circumstance. Changing the conditions under which an experiment is conducted may well affect the outcome. Changing conditions is *not* the same as changing the frame of reference of the observers. The paper also disproved the then controversial notion of "the luminiferous ether," the 19th century idea of a medium through which light and objects traveled.

These two postulates have become fundamental assumptions in modern science, including chemistry, although chemists tend not to think about them or apply them as often as physicists do. The quantum mechanical model of the atom depends on the speed of light as a constant and so the most fundamental concept in chemistry is a derivation of special relativity. And equally important to chemistry is the idea that the reproducibility of an experiment does not depend on the frame of reference of the observer.

Relativity was not a topic unique to Einstein. Galileo had introduced the idea that the motion of an object moving in a straight line with a constant velocity could be described only by using a specific frame of reference; the motion of the object could only be described relative to something else.

Newton accepted this notion for everyday events, even though he believed that there was an absolute frame of reference in the universe. His three laws of motion are based on relative frames of reference. Einstein's 1905 paper did not contradict Newton's laws; it subsumed them. Newton's laws continue to describe the universe as long as objects are traveling at speeds much less than the speed of light. Special relativity describes behavior as speeds approach the speed of light. It should be noted that Einstein's special relativity actually includes Newton's laws of motion under normal conditions on earth. It might be easiest to think of Newton's laws as special cases of special relativity.

The idea of frames of reference is one that students can relate to in simple ways. For example, if you are sitting in a car stopped at a stop light and the car beside you rolls slowly backward, it may seem that your car is rolling forward, especially if you are focusing on something inside your car and cannot see outside objects. The observation is real enough to cause your car's driver to hit the brakes. If your "frame of reference" is within your own car, it is difficult to know which car, yours or the one beside you, is moving. However, if you shift your focal point outside your car, it is easier to know which car is moving. You can experience somewhat the same sensation riding in a train that overtakes another train traveling in the same direction. From your frame of reference passengers in the neighboring train may be moving slowly, but from the frame of reference of someone standing along the tracks, both trains are moving very fast.

Most students will not be able to relate the unusual effects of special relativity discussed in the article with their daily experience since these effects are observable only as we approach the speed of light. One of the unusual effects of special relativity is time dilation. In the example discussed in the article, the student traveling in a space ship traveling at a speed near the speed of light (the space ship in the article is traveling *at* the speed of light) looks at two clocks, one in her own space ship and the other in the earth classroom. The student sees her own clock operating normally. But she observes that the clock in the classroom is moving very slowly. The frames of reference concept says that the students in the classroom would see their own clock operating normally, and the clock in the space ship running slower (not faster). The two other effects are the contraction of length and the increase in mass as objects travel at speeds approaching the speed of light.

Connections to Chemistry Concepts

The section of the article that discusses Brownian motion will be a good addition to any discussion of molecular motion in general. In your course this may be in any of several spots: kinetic theory, molecular motion, or behavior of gases. It also relates to the concepts of evidence for the existence of atoms or the quantum mechanical model of the atom. By extension you might use this article as you study energy levels in the atom.

Because much of Einstein's work involves light, the article might be used in conjunction with your study of the electromagnetic spectrum (probably connected to the quantum mechanical model of the atom).

Since the photoelectric effect is an example of an energy conversion, you might also have students read the article as you study energy and its relationship to matter.

Possible Student Misconceptions

1. It is likely that most students think of $E = mc^2$ when they think of Einstein, but while the equation is now recognized as important, Einstein did not consider it to be unusual. He believed that of the 1905 papers, the one on the photoelectric effect was the most daring.
2. Students may associate Einstein with physics rather than chemistry. See "A Note on Einstein, Chemistry and Physics."
3. Because they are engaging and somewhat exotic ideas, the special relativity effects on time, length and mass may be more familiar (although less understood) to students than the actual postulates in Einstein's paper. See "More on Einstein and Special Relativity."

Demonstrations and Lessons

1. You can have a class simulate Brownian motion using coins: Each student flips a coin. If the coin comes up heads they turn right and take a step. If it comes up tails they move to the left. They repeat this several times and keep a record of their movements.
2. Molecular motion simulators can be used to show Brownian motion on an overhead projector. In addition to small beads in the simulator, place a significantly larger bead (these often comes with the simulator) in the tray and turn on the simulator.
3. Another simulation for Brownian motion involves placing small marbles in a shallow tray (like a rectangular cake pan) and adding one or two larger marbles. Place the tray on a flat surface and move it around so that the small marbles move randomly. Observe the effect on the larger marbles.
4. Brownian motion can be viewed using a microscope and a Brownian motion cell (sometimes called a smoke cell. Light a match and let it burn for a couple of seconds. Squeeze red bulb on the cell, blow out match and place next to opening on cell. Release the bulb, drawing smoke into the cell. Viewed under

the microscope, smoke particles should begin to appear. A projector attached to the microscope will allow the entire class to view the molecular motion. Detailed directions are here: <http://www.fas.harvard.edu/~scdiroff/lids/ThermalPhysics/BrownianMotionofSmoke/BrownianMotionofSmoke.html>

4. For a more extensive procedure that demonstrates Brownian motion, see http://www.practicalphysics.org/go/Experiment_160.html?topic_id=4&collection_id=54

5. Assign students calculations involving the Planck equation $E = h \nu$.

6. Purchase commercially manufactured photovoltaic cells and have students use them in a lab setting to do useful work, like run a small electric motor or a small fan. Lesson plans in detail are here <http://www.ccmr.cornell.edu/education/modules/documents/PhotovoltaicCells.pdf>

7 A simulation of the photoelectric effect can be found here. Direct students to this web site: <http://physicsquest.homestead.com/quest8ac3.html>

Suggestions for Student Projects

1. Have students do historical or biographical research on Einstein and other scientists whose work was related to his. The might include Aristotle, Newton, Galileo, Boyle, Dalton, Avogadro, Brown, Perrin, Lenard, Maxwell, Boltzmann and Planck, among others.

2. Have student research the work function of the metals and plot them against their electronegativities. The Handbook of Chemistry and Physics lists work functions. <http://www.madsci.org/posts/archives/may99/926654070.Ch.r.html>

3. Refer students to the following article for a modern perspective on Einstein and his 1905 papers: Fine, Leonard, "Einstein Revisited," *Journal of Chemical Education*, 82, 11, November, 2005, 1601-1608.

Anticipating Student Questions

1. Einstein received a Nobel Prize in physics. What does he have to do with chemistry? While it's true that Einstein is usually thought of a physicist, he proved the existence of atoms, verified Avogadro's number, determined the size of molecules and established the speed of light as a universal constant. All of these discoveries are important to chemists. (See also "A Note on Einstein, Chemistry and Physics")
2. I thought light traveled in waves. Until the early 1900's that was the prevailing view of light, and the idea of light traveling in wave form is still helpful in explaining for many events. However, the concept of light traveling as small packages (photons) was the only way to explain the photoelectric effect, and that led to the modern explanation of atomic structure using the quantum mechanical model.
3. I know Einstein for the equation $E = mc^2$. That's not even mentioned in the article. This equation, perhaps the most famous one in the world, was the result of the fifth paper Einstein submitted in 1905. The paper was only three pages long and was titled "Does the inertia of a body depend on its energy content?". It was a follow-up to the paper on special relativity. The equation changed the way scientists look at matter and energy. Einstein declared that they are equivalent.

Websites for additional Information

For much more on the history of atomism see <http://www.seop.leeds.ac.uk/entries/atomism-modern/>

For more on Einstein and chemistry see

<http://www.rsc.org/chemistryworld/Features/2005/September/ClaimingEinsteinforchemistry.asp>

For a translation of Einstein's original paper on the photoelectric effect, see

http://lorentz.phl.jhu.edu/AnnusMirabilis/AeReserveArticles/eins_lq.pdf

For a tour of the electromagnetic spectrum see <http://imagers.gsfc.nasa.gov/ems/waves3.html>

For more on special relativity see http://www.chemistrydaily.com/chemistry/Special_relativity or <http://www2.slac.stanford.edu/vvc/theory/relativity.html>

Motion Detectors

Background Information

More on Motion Detectors

Active Systems: Active motion detecting systems send out a signal and detect the return signal. Any change in the return signal triggers the output device. Two types of active systems are discussed in the article.

Type A in the article is a photo-sensor motion detector. These have two essential components: a source of a light beam (a photodiode) and a light sensor (a phototransistor). If the beam is blocked the sensor notes the decrease in light, which creates an electric current that sends a signal to the output device. The light beam may be reflected by a series of mirrors to cover a larger area.

Type B in the article is microwave motion detector. This type of device emits microwaves into an area and detects the pattern of the return signals. Any change in the echo pattern triggers the output.

Passive Systems:

Type C in the article is a passive system. These are based on detecting infrared radiation. The device measures all incoming IR radiation and responds to any change in the pattern of radiation. These are referred to as passive infrared (PIR) or pyroelectric systems.

More on photo-sensors

The heart of a motion detector is the photoelectric cell, or photocell, which relies on the photoelectric effect to operate. When EM radiation strikes the cell (usually a semi-conducting crystal) a current is initiated that triggers the output device.

More the Photoelectric Effect

Motion detectors are based on the photoelectric effect, which was the topic of one of Albert Einstein's 1905 papers. Einstein won the Nobel Prize in physics for his explanation of the photoelectric effect.

The photoelectric effect had been observed as early as 1886, by Heinrich Hertz (for whom the unit of light frequency is named). In 1899, J. J. Thomson, following up on his discovery of electrons (or corpuscles, as he called them) in 1897, irradiated metals with ultraviolet light and observed cathode rays, or electrons, being emitted. Three years later Philipp Lenard experimented with trying to stop the electrons from being emitted, and in an experiment very similar to the one described in the article as the Electron Measuring Device, discovered that it was the frequency of the light that determined whether or not electrons were emitted from the metal surface. For example, Lenard found that red light did not dislodge electrons but blue light did. But Lenard did not know how to explain his findings. Einstein did.

In his first 1905 paper, Einstein explained the photoelectric effect for which he eventually won the Nobel Prize in physics. He said, "According to the assumption considered here, when a light ray starting from a point is propagated, the energy is not continuously distributed over an ever increasing volume, but it consists of a finite number of energy quanta, localized in space, which move without being divided and which can be absorbed or emitted only as a whole."

In this way Einstein re-defined how science thought of light. Until this time it was assumed to behave like a wave, which Einstein agreed was a sufficient explanation for purely optical events. But in order to explain events like the emission of electrons from a metal surface when light strikes the metal, it is necessary to think about like as discrete bundles of energy, later called photons.

The idea of particles of light was not original with Einstein. In a paper published in 1900, Max Planck advanced the idea that electromagnetic energy (light) could exist in discrete packages, or quanta, that had unique values. The energy values, E , for any bundle of light were in proportion to the frequency, ν (the Greek letter nu), of the light. The constant of proportionality would be a universal constant, h . Its value of 6.626×10^{-34} J x s is well known to current students of chemistry from the equation: $E = h \nu$. Planck's idea, called the quantum theory, was not immediately accepted widely. Only when Einstein employed the idea in his 1905 paper to explain what were then discrepancies the behavior of light did quantum theory begin to gain acceptance. Actually not until 1913 and Bohr's concepts of quantized energy states for electrons in atoms was the quantum theory widely accepted.

Einstein showed that it was the *frequency* of light falling on the metal surface that dislodged electrons. Below a certain frequency, called the threshold frequency, the light had no effect on electrons. Light with frequencies higher than the threshold value caused electrons to be emitted faster. The intensity of the light was only a factor if the frequency was above the threshold value, and then increasing the frequency caused more electrons to be emitted.

The threshold value is the minimum frequency that will cause an electron to be emitted. Einstein said, "The simplest picture is that a light quantum transfers all of its energy to a single electron; we shall assume that happens . . . Moreover, we must assume that each electron on leaving the body must produce work, P , which is characteristic for the body . . . The kinetic energy of such electrons is

$$KE(\text{max}) = h\nu - P$$

If the formula derived here is correct, [the maximum KE] must be, if drawn in Cartesian coordinates as a function of the frequency of the incident light, a straight line, the slope of which is independent of the substance studied" (actually the energy of the emitted electron is influenced by temperature, a fact shown to be true in the 1930's).

The threshold frequency is related to the amount of work done by the electron emitted. The incident energy must be enough to allow the electron to overcome any forces holding it in the metal. The work function, P , is the work done to allow the electron to be emitted. A sampling of the work functions for metals:

Metal	P (eV)
Silver	4.26
Aluminum	4.28
Gold	5.1
Copper	4.65
Iron	4.5

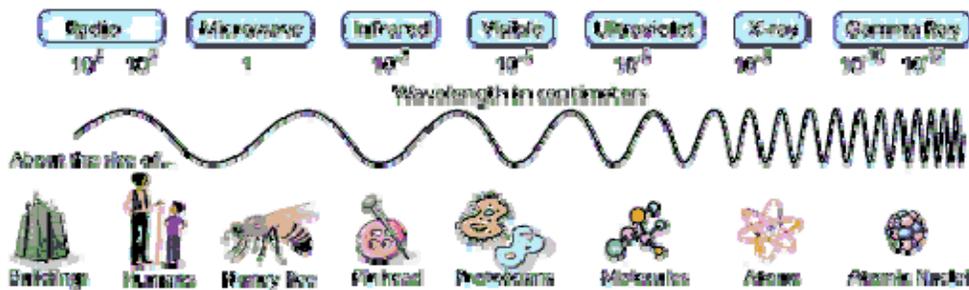
If the work function in the photoelectric effect sounds like the definition of first ionization energy, it should. The concepts are related. Threshold frequencies also form a rough correspondence with the electronegativities of metals.

The emitted electrons emitted in the photoelectric effect can actually create an electric current. This is important in modern semiconductors, solar cells, light-emitting diodes, X-rays, CAT scans, microwave ovens, lasers, TV screens, LCD screens, photocopiers, night vision devices, and motion detectors, among others.

More on Light (IR, radio, microwave, etc)

Electromagnetic (EM) radiation includes radiation related to visible light. The primary characteristics of EM radiation are frequency and wave length. Radiations of varying wave length (and frequency) have varying properties. A small portion of all EM radiation is visible light, which has wave lengths of 4×10^{-7} to 7×10^{-7} m. EM radiation close to visible light but with longer wave length (10^{-7} to 10^{-3} m) is infrared (IR) radiation. As the wave length of the radiation increases, we call the radiation first microwave and

then radio waves. EM radiation with wave lengths shorter than visible light include ultraviolet (UV) light, X-rays and gamma rays.



From <http://imagers.gsfc.nasa.gov/ems/waves3.html>

The article says that the types of EM radiation involved in motion detectors are infrared, radio waves or microwaves. Brief summaries of each of these types follows:

Infrared radiation is electromagnetic radiation that cannot be seen, but can be detected (and felt by humans). All objects with temperatures higher than their surroundings will radiate infrared. A substance that is heated slowly emits infrared before it becomes hot enough to radiate visible light. Infrared is usually divided into three bands. Near IR, with wave lengths from 750 to 1300 nm, is close in wave length to visible light. Intermediate IR has wave lengths from about 1300 to 3000 nm. And far IR has wave lengths ranging from 3000 nm to 14000 nm. Infrared is a non-ionizing form of radiation.

Infrared radiation is used in chemical analysis (intermediate IR), in astronomy, in heat seeking devices, heat lamps, TV remotes, and thermography. The earth absorbs visible light from the sun and re-radiates it as infrared light. If that infrared is then absorbed by gases in the atmosphere, the atmosphere is warmed via the greenhouse effect. Similarly, UV and visible light is absorbed through the glass in a greenhouse, and the objects inside the greenhouse radiate the light as IR. However, IR cannot pass through glass so the greenhouse is warmed. In addition to glass, Plexiglas and water are good IR absorbers.

Infrared radiation was discovered in 1800 by William Herschel, an astronomer of German descent working in England. Using his own telescope, he was making observations on the visible light radiations of astronomical bodies when he discovered the existence of radiation outside the visible spectrum. He is also noted for discovering the planet Uranus.

Microwaves

Microwaves have wavelengths approximately in the range of 30 cm to 1 mm, and may be thought of as high frequency radio waves. Microwaves are good for transmitting information from one place to another because microwave energy can penetrate haze, light rain and snow, clouds, and smoke. Stars also give off microwaves. Mobile phones use microwaves as do traffic speed cameras, and radar, which is used by aircraft, ships and weather forecasters.

Radio Waves

Radio waves have very long wavelengths, in the thousands of meters. Radio, television, cellular telephones, walky-talkies, 2-way police radios, and other such communication systems use a specific wavelength of radio waves. Some examples:

Type	Wave length	Example
Medium frequency (MF)	1 km–100 m	AM Broadcasts
High frequency (HF)	100 m–10 m	Shortwave and amateur broadcast
Very High frequency (VHF)	10 m–1m	FM and television broadcast
Ultra High frequency	1 m–100mm	television broadcast, wireless networks

Super High frequency

100 mm — 10mm

microwave devices, mobile phones

More on the Eye and Vision

The article describes the human eye as a photo sensor for light in the visible range. Human vision works in a way similar to the photo sensors in an electronic motion detector.

The retina of the eye contains two types of cells—rods and cones. The cones, all three million of them located in the center of the retina, allow us to see color. The 100 million rods are spread out across the retina and “see” in black and white. The active chemical in these photo receptors is rhodopsin, which is a protein called opsin bonded to a reddish purple pigment aldehyde called 11-*cis* retinene, or retinal, which is a vitamin A derivative. Retinene is *cis*, *trans* isomeric. When light in the visible range strikes the retinene, the *cis* form isomerizes to the *trans* isomer by breaking the double bond at the 11 carbon in the side chain of the molecule. The mechanism seems to be that a p electron in the pi bond is promoted to a higher-energy orbital. This breaks the pi component of the double bond and is temporarily converted into a single bond. The process takes just a few picoseconds, and then the *trans* isomer reverts back to the *cis* form. This triggers a complex series of neurotransmissions to the brain that results in our “seeing.”

Connections to Chemistry Concepts

Any place in your course when you discuss interactions between energy and matter would be an appropriate time to have students read this article. You can also relate this article to your discussion of electromagnetic radiation connected to atomic structure. The article also can be used to illustrate a technology based on a scientific concept.

Possible Student Misconceptions

1. Student may not understand the concept of the photoelectric effect, something they must understand in order to understand how motion detectors work. See “More on the Photoelectric Effect.” Since devices like motion detectors are “black boxes” in that the important mechanism takes place hidden from view inside the casing of the motion detector. In addition, the energy that initiates the changes in the motion detector are invisible, which also makes motion detectors more difficult to understand.
2. Student may not understand the idea that when the term “light” is used it actually refers to more than visible light. See “More on Light.”

Demonstrations and Lessons

1. For a tutorial and lesson plans on photovoltaic cells see:
<http://www.ccmr.cornell.edu/education/modules/documents/PhotovoltaicCells.pdf>
2. Refer students to this Newtown’s Apple segment on infrared radiation.
<http://www.ktca.org/newtons/11/infrared.html>
3. Students can simulate Herschel’s original experiment by using a prism to break up white light and by placing thermometers in several spots along the visible spectrum especially just outside the red part of the spectrum.
4. See the “Try This!” section of the article for more ideas.

Suggestions for Student Projects

1. Students can use a TV remote control as a source of infrared radiation and a flashlight as a source of visible light. At home they can experiment with how far each form of light can travel, what can block or deflect each form, etc.
2. Students may have at home a novelty item that consists of a plastic fish mounted on a wall plaque. When someone passes the fish a song is played. These devices contain a motion detector that triggers the recording. Ask students to bring in examples. Be prepared to be annoyed.

Anticipating Student Questions

1. Students may ask about the difference between forms of electromagnetic radiation. See “More on Light.”
2. Students may have questions about the photoelectric effect. See “More on The Photoelectric Effect.”

Websites for additional Information

For a complete explanation of the chemical aspects of human vision, see <http://www.chemistry.wustl.edu/~edudev/LabTutorials/Vision/Vision.html>

Secrets of the Samurai Sword Revealed

Background Information

In *The Ascent of Man*, Jacob Bronowski offers this passage about Japanese swords. It should be of interest to chemists and chemistry teachers, who are used to expressing changes in matter in terms of formulas and equations.

“. . . I will take an Oriental example also of the techniques that produce the special properties of steel. They reach their climax, for me, in the making of the Japanese sword, which has been going on in one way or another, since AD 800. The making of the sword, like all ancient metallurgy, is surrounded with ritual, and that is for a clear reason. When you have no written language, when you have nothing that can be called a chemical formula, then you must have a precise ceremonial which fixes the sequence of operations so that they are exact and memorable.”

Bronowski, Jacob, *The Ascent of Man*, Little Brown & Company, Boston, 1973, 131.

More on Metallurgy

About two thirds of all the chemical elements are metals and about one quarter of the mass of the earth. The properties associated with metals are thermal and electrical conductivity, ductility, and malleability. Most metals also have a high melting point. As you discuss the article with students, keep in mind that the properties of metals and their crystal structures are related to the bonding in metals, a topic covered in most texts.

The bonds in metals, including iron, must be strong, but the bonds must also allow the atoms to move in order to account for malleability, for example. Since metals have relatively low electronegativities they do not attract their valence electrons strongly. The valence electrons are easily given up by metal atoms, creating what is often referred to as a “sea of electrons” surrounding the metals atoms (actually cations). The electrons are shared by many atoms, making the bonding strong. Since the bonds are strong, the atoms are packed close together, accounting for the crystal structures.

Many metals, including iron, are not found abundantly in nature in pure form. They occur naturally as compounds called ores. Most often the metals are combined with either oxygen or sulfur. So in order to obtain pure metals the ores must undergo one or more chemical reactions which produce the desired metal.

Some metals, like gold, silver and copper, may exist in nature in pure, or native, form. These metals were the first to be used by man. Copper, the most abundant native metal, was in use by 8000 BC, and the Copper Age extended through 3800 BC. The discovery that other metals like tin could be combined with copper to make the copper stronger marked the beginning of the Bronze Age. With the discovery of iron as an ore in about 1500 BC, the Iron Age began.

Iron ore is thought to have originated billions of years ago when cyanobacteria consumed carbon dioxide from the atmosphere, which at the time was rich in the dense gas, and produced oxygen as waste. This oxygen reacted with Fe^{+2} dissolved in the oceans to produce the ore. Smaller amounts of native iron do exist on the earth, but these are rare, having been deposited by iron-rich meteorites.

Classified as a base metal, iron slowly took on increased importance over the following 2000 years after the Bronze Age. By 500 AD, small quantities of high quality iron were in use throughout the world. The article suggests that by the 9th century, high-quality Samurai swords were being produced in Japan. It is likely that swordsmiths in Japan helped to develop the skills needed to make these swords.

The two main iron ores are hematite, Fe_2O_3 , and magnetite, Fe_3O_4 . Extracting iron from its ores involves oxidation-reduction reactions. In simplest form, iron ore is mixed with carbon (in the form of coke,

probably charcoal in ancient Japan) and the mixture heated. The reaction for hematite is $\text{Fe}_2\text{O}_3 + \text{C} \rightarrow \text{Fe} + \text{CO}_2$. The process actually takes place in several intermediate steps: First, the carbon reacts with atmospheric oxygen to produce carbon monoxide, which then acts as reducing agent for the ore to produce first Fe_3O_4 , then FeO and finally iron and carbon dioxide in the equation above. In this process the iron is reduced and the carbon is oxidized in an electrochemical reaction. In this way, pure iron is produced, and it can then be alloyed with carbon to make steel.

More on Iron

Iron is the most abundant chemical element on the earth, making up about 35 % of it by mass. The earth's core is thought to be principally a molten iron-nickel alloy. Iron is a transition metal with an electron configuration of $[\text{Ar}] 3d^6 4s^2$. Some properties of iron are

- Density = 7.86 g/mL
- Melting point = 1538°C (1811 K)
- Boiling point = 2861°C (3134 K)
- Heat of fusion = 13.81 kJ/mol
- Heat capacity — 25.10 J/mol x K

More on Alloys

Many metallic substances we use are not pure metals but alloys. Alloys are either heterogeneous mixtures of two or more metals (and sometimes nonmetals like carbon or silicon), solutions of two metals or in some cases metallic compounds (Nb_3Sn , for example, is a compound alloy used in superconducting magnets). The typical reason for alloying metals is to change either the physical or chemical properties of the metal. Some physical properties which can be changed by alloying are conductivity, density, ductility, hardness, malleability, melting point. For example, pure gold is much too soft to use in jewelry, despite its appearance and desirability. Alloying gold with silver and copper increases its hardness and makes it useful in jewelry. Some alloys, like stainless steel, are created in order to resist corrosion.

Alloys that are solutions fall into one of two categories based on the arrangement of the metal atoms in the alloy. If atoms of the two metals are similar in size and properties, atoms of one metal randomly replace atoms of the second metal to form a substitution alloy. Steel is an example of the second type of alloy in which smaller nonmetal atoms (like carbon) occupy spaces in the crystal structure of the metal (iron). These alloys, like steel, are called interstitial alloys.

Some common alloys:

Brass	copper, zinc
Bronze	copper, zinc, tin
Pewter	tin, copper, bismuth, antimony
Sterling silver	silver, copper
22 carat gold	gold, silver, copper
Steel	iron, carbon

More on Steel

Iron alloyed with carbon is called steel. Iron itself has three solid phases, and the structure of each phase affects the degree to which carbon can be added to the iron. The article discusses each of these phases. Up to a temperature of 912°C iron exists in a body centered cubic crystal structure called ferrite or alpha iron. If the temperature of the steel is raised above 912°C, the steel changes its crystalline structure to a face centered cubic arrangement, and this form is called austenite. Above 1394°C, the crystalline structure becomes body centered again and is referred to as delta steel. Note that this form is not mentioned in the article, most likely because Japanese swordsmiths did not have the needed technology to achieve such high temperatures.

If you have discussed allotropes with your class, you might point out that since steel has two distinct forms, body centered and face centered crystals, steel has two allotropic forms. The principal body

centered form, ferrite, is magnetic while the face centered form is not. The two allotropes have other properties that vary as well.

In general, the higher the carbon content of steel, the greater the hardness. Carbon is only slightly soluble in ferrite (alpha) iron. Increasing the temperature of the ferrite changes the crystal structure (see More on Crystals and Crystal Structure) of the iron and allows more carbon to be dissolved. Austenite can dissolve up to 2 % carbon at 1100°C.

The article describes the fact that the slow cooling of austenite to form lower carbon ferrite and cementite (pearlite) produces a soft, flexible steel . Rapid cooling of the higher- carbon austenite traps the carbon atoms in the crystal and creates martensite, a much harder form of steel. The cooling rate needed to produce 100% martensite is called the critical cooling rate.

The relative hardness of the steel can be measured using one of several hardness scales. The Rockwell hardness scale, Brinell hardness scale, and the Vickers hardness scale are the most common for metals, while the better known Moh's scale is used for minerals. All three scales measure the degree of indentation of the metal when subjected to a standard force. For comparison, the hardness of ferrite is 80 and the hardness of cementite is 600 on the Brinell scale.

One of the problems with Japanese metallurgy was that it was nearly impossible to produce steel that had uniform properties. Impurities were virtually a given. Swordsmiths who made Samurai swords learned that by heating, folding and hammering the steel, they could remove virtually all impurities and distribute the carbon uniformly throughout the steel. In the case of the swords discussed in the article, two different kinds of steel, ferrite and martensite, were folded together and by heating and hammering the two types of steel were welded together to form a blade. Then differential quenching of the steel created a blade that was both flexible and hard.

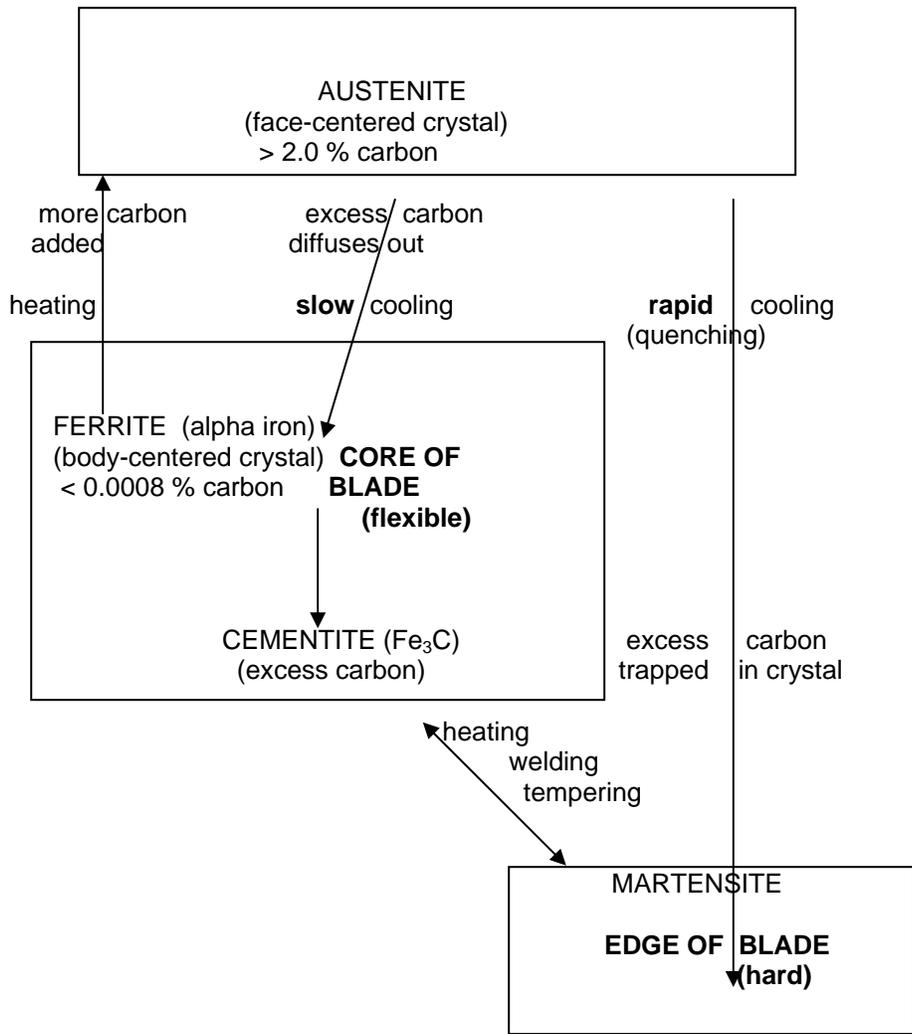


Diagram of Phase Changes to Make a Sword

Below are brief descriptions of the forms of steel discussed in the article:

Ferrite — alpha iron

Ferrite is the term used for pure iron as well as for very low-carbon steel (with carbon content of less than 0.2%). It is a relatively soft substance that is magnetic. It is the stable form of iron below temperatures of 910°C. At that temperature it changes to austenite. Ferrite can dissolve only small amounts of carbon, about 0.02% of its weight at 723°C. This low solubility is because carbon atoms dissolve in iron by locating in empty spaces, called interstices, between iron atoms. The fact that ferrite has a body centered crystal structure limits these interstices.

Austenite

Austenite is a nonmagnetic solution of carbon in iron. It can exist only above the critical temperature of 723°C. At that temperature the crystal structure of the iron changes from body centered to face centered, and this change allows more carbon to be dissolved. It is named for an important 19th century British metallurgist Sir W. C. Roberts-Austen.

Cementite

Cementite is a true chemical compound with the formula Fe_3C , iron carbide. It is a hard, brittle material that forms as austenite cools to ferrite. Since the ferrite is able to dissolve less carbon than austenite, the excess crystallizes as iron carbide. Mixed with ferrite, it forms pearlite. It has an orthorhombic crystal structure.

Pearlite

Pearlite is the form of iron/steel that results from the cooling of the austenite form. As the austenite cools, two other phases are produced: ferrite and cementite. These are deposited in layers, called lamellae, and are known collectively as pearlite. Pearlite is called a lamellar substance. The process in which the austenite decomposes to form the two solids, ferrite and cementite, is known as a eutectoid reaction. The composition by weight of pearlite is 88% ferrite and 12 % cementite.

Martensite

Martensite is formed by the rapid cooling of austenite during quenching. Because martensite has a lower density than austenite, this rapid change causes the edge of the samurai sword (the martensite) to expand and curve. It has body centered tetragon crystals. It is named after the German metallurgist Adolph Martens.

More on Crystals and Crystal Structure

The article indicates that the properties of samurai swords lies in the crystal structure at the atomic level, so a little more information about the crystal structure of steel is in order. Each crystalline solid, including metals, has a uniform shape defined by the unit cell for that substance. The unit cell is the smallest three-dimensional structure that shows the simplest repeating arrangement of the atoms (or ions) of that substance. Opposite faces of unit cells are always parallel and the edge of the cell connects equivalent points. If unit cells are stacked adjacent to one another, the result is called a crystal lattice. There are 14 unique types of unit cells. This system was first set forth by Auguste Bravais in 1850, and the cells are commonly referred to as Bravais cells. Three of these shapes are cubic, two are tetragonal, two are monoclinic, and four are orthorhombic. The remaining three are rhombohedral, hexagonal and triclinic.

There are three basic types of units cells exhibited by metals:

- Face centered cubic (FCC)
- Body centered cubic (BCC)
- Hexagonal closed-packed (HCP)

As described in the article, steel may have either of the first two types of unit cells. At lower temperatures, ferrite has a body centered cubic arrangement. As the temperature is increased and austenite is formed, this phase takes on a face centered cubic arrangement. Face centered crystals have larger spaces between the atoms in the crystal than do body centered crystals. This greater space permits more carbon atoms to be dissolved in austenite than in ferrite. As the austenite cools slowly to become ferrite, some of the excess dissolved carbon atoms crystallize out of solution and form iron carbide, Fe_3C . The resulting steel is softer and more flexible. If, however, the cooling of the austenite is done rapidly, the excess carbon atoms become trapped in the interstices between the iron atoms, and resulting in a form of steel, martensite, that is very hard. Controlling the cooling step, as the article describes, is key in determining the properties of the resulting steel.

Body centered cubic (bcc) unit cube—In a body centered cube 68% of the space in the cube is occupied by metal atoms. Each atom in the cube has a coordination number of 8 (coordination number is the number of neighboring atoms bonded to a given metal atom). Despite there being more unoccupied space in body centered cubes, there are fewer interstices for carbon atoms to occupy. Because of this, carbon has a lower solubility in body centered cubic ferrite. A diagram of a body centered cube:

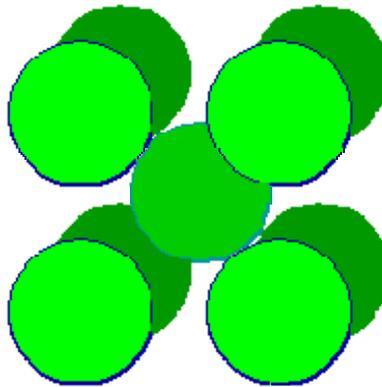


Diagram used by
at http://www.chem.qmul.ac.uk/surfaces/scc/scat1_1.htm

permission of Roger Nix

Face centered cubic (fcc) unit cube — In a face centered unit cube, 74% of the space is occupied by atoms. The coordination number of each iron atom in this arrangement is 12. A diagram of a face centered cube:

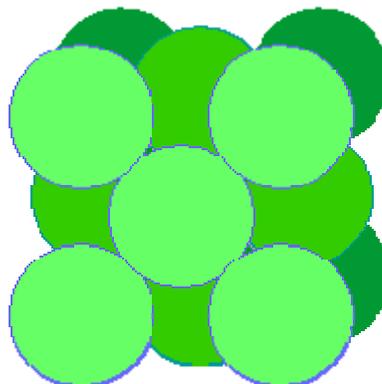


Diagram used by permission of Roger Nix at
http://www.chem.qmul.ac.uk/surfaces/scc/scat1_1.htm

More on Ancient Japanese Metallurgy

Metallurgy was probably brought to Japan from the Asian mainland, probably China, by at least the 4th century since the earliest evidence of metal working in Japan shows already existing advanced techniques. Early swords in Japan were likely imported from China as early as the 2nd century. Alloying, especially of copper, was unique in Japan for centuries. Steel metallurgy, especially hand forging, became particularly advanced in Japan and significantly affected Japanese culture beyond the Samurai.

The ancient Japanese sword-making process required raw materials. Pine trees and chestnut trees provided the charcoal needed as a fuel for the forge. The charcoal was cut into varying sizes to provide different temperatures needed in the manufacture. Originally Japanese swords were made from a single ingot of steel, as opposed to the laminated type blade discussed in the article. Later on, as many as seven different kinds of steel were used in a single blade. Swordsmiths were able to distinguish the carbon content of a type of steel by the color of its flame. Ashes from rice straw provided a source of additional carbon. Moderate heating also allowed the smith to regulate the carbon content of the steel. As the steel was heated and hammered, some of the carbon would form carbon dioxide and escape into the atmosphere.

The heating that accompanied the welding of the steel also oxidized the steel surface, which had the effect of removing some impurities as the oxidation was removed. Clay, as the article describes, was used to coat the sword in varying thicknesses to allow for differential hardening during the quenching step.

One of the major natural resources were the smiths themselves. A swordsmith often required two or three assistants who were responsible for the hammering that welded the steel pieces together. The overall sword-making process could take days or weeks to complete, requiring hundreds of hours on the part of the smiths and his apprentices. It might be worthwhile to draw this fact to students' attention since many students do not consider people to be natural resources

As the article describes, the Samurai sword became synonymous with a way of life. By the late 1500's the Samurai occupied a special place in Japanese society, a status that became formalized in the 17th and 18th centuries as famous Japanese swordsmen recorded for future generations the secrets of their skills and their philosophies of life. One of these 17th century writings was organized into five chapters with titles of interest to students of chemical history: earth, air, fire, water and wind.

More on Japanese terms

The article contains some Japanese terms that are related to ancient swords. The following list includes those terms and several more with definitions.

- satetsu* - black sand
- tamahagane* - type of impure steel
- shingane* — inner core of sword
- hadagane (or kawagane)* — outer layer of sword
- hamon* — temper line
- tatara* — smelting devise
- kitae* — forging the blade (folding hammering, etc.)
- yaki-ire* — the process of hardening the blade
- yakibatsuchi*, - a mixture of water, clay, ash, and other ingredients used to coat the blade before hardening
- toshin* — the blade of the finished sword
- katana* — Japanese long sword
- horimono* - carvings

Connections to Chemistry Concepts

1. Metals — Since the article focuses on the metal iron, you could have students read the article as you study metals, including metallic bonding. This might be early in the courses as you distinguish metals from nonmetals or later as you study the periodic table, condensed phases of matter, the activity series or oxidation-reduction reactions.
2. Alloys — Since steel is a carbon-iron alloy and since the properties of the swords depend largely on the carbon content of the alloy, this topic is a natural connection for this article. Many general chemistry courses do not spend much time on alloys, the article would be a good way for students to learn more about them.
3. Crystals — The idea that metals have a crystalline structure may not always be emphasized in a general chemistry course. The article is an opportunity for students to learn more about how microscopic properties affect macroscopic properties.
4. Natural Resources/Metallurgy - If your course includes any discussion of natural resources and the way they are processed chemically, the article would fit nicely here.
5. History of Science — The article represents an opportunity to discuss with student how chemistry has developed over time and how many diverse cultures have been involved in its history. Although the Japanese sword makers cannot be considered chemists, we are now able to look at their ancient craft and recognize how they used chemical ideas. The Samurai culture might also be studied as an example of how science and technology influence society.

Possible Student Misconceptions

1. Swords and other metal blades are always a single piece of metal. Although the science of metallurgy and steel making are not simple topics, students will benefit from understanding both the science and technology of metal processing. Many of the ancient metal working techniques have been adapted are in use today. Heating and folding and hammering metals is not part of most students' experience, and it is important that students understand that processes that produce important goods in modern society go on "behind the scenes."
2. The term "solution" is limited to mixtures in which water is the solvent. Since aqueous solutions get the most attention in a typical chemistry course, students should be exposed to all types of solutions. Alloys or solid solutions is one way of getting students' attention on this topic, since the terms "solid" and "solution" seem to be mutually exclusive. Typical solid alloys are formed from the molten state, but this is not always so. Some minerals (carbonates, for example) are solids solutions that form in the solid state.
3. Steel has been important only since the Industrial Revolution. Steel has been produced and used in Europe, China and India since at least the 6th century. Some historians and archaeologists believe that iron was used in China and India in the 4th century BC. With the beginning of the Iron Age around 1500 BC iron was used in the form of wrought iron, which contains very little carbon and is comparatively soft. The transition from iron to steel occurred with the advent of real blast furnaces that had the ability to heat iron ore to temperatures high enough to produce steel. By 1300, early blast furnaces were in use in Europe, but it was not until the mid-19th that Henry Bessemer introduced his converter in England that steel making began in the quantities we associate with the Industrial Revolution.
4. Only minerals have crystal structures. Since crystal structures are typically covered in a high school courses using compounds, this is a natural misconception. The article is a good opportunity to note to students that macroscopic properties are generally the result of microscopic structure.
5. Stoichiometry is the only way to determine the correct quantities to use in a reaction. In the modern world, most chemistry is directed by the rules of stoichiometry. The idea that craftsmen like the

Japanese sword makers could determine reactions proportions and conditions by observation is a testament to their skill and experience.

Demonstrations and Lessons

1. For a complete activity using Styrofoam spheres to make models of crystal structures, see <http://www.okstate.edu/jgelder/bondpage14.html> .
2. Students can experiment with face centered arrangement of atoms by layering marbles (all of the same size) in layers in a small box so that 8-10 marbles fit each way. Stack a second and third layer on top and experiment with how the marbles pack themselves. It is not possible to show body centered arrangements in this way.
3. Many chemistry lab books, including *ChemCom: Chemistry in the Community*, include a procedure for making the alloy, brass. NOTE: the procedure includes using a concentrated solution of NaOH. In this procedure a copper penny is first placed in a hot solution of NaOH in which a small quantity of Zn metal is dissolved. The penny is removed, washed and then heated strongly in a hot flame, which produces the Cu-Zn alloy on the surface of the penny. Students can do this activity if you supervise them closely, or you can do this as a demonstration.
4. Properties of metals — student can explore the properties of metals like malleability, electrical conductivity and heat conductivity, which are the result of metallic bonding and crystalline structure
5. For a demonstration that illustrates the austenite-ferrite phase transition in dramatic fashion, see: <http://www.fas.harvard.edu/~scdiroff/lds/CondensedMatter/BCctoFCC/BCctoFCC.html> Extreme caution must be taken while performing this demonstration.
6. See *ChemMatters TG*, February, 1999, page 12 for a lab activity on heat-treating metals.

Suggestions for Student Projects

1. Students might be assigned to research the history of the Samurai and the role that the sword played in Samurai history and culture.
2. Student might research modern methods of making steel and compare the process to the way it is described in the article.

Anticipating Student Questions

1. What's the difference between iron and steel? Iron is a chemical element and steel is an alloy of iron and carbon. Today, steel often contains small amounts of other metals in addition to the carbon. So steel is actually a mixture. (See "More on Steel.")
2. Do metals really have crystal structures? See "More on Crystals and Crystal Structures."

Websites for additional Information

For more on the element iron from WebElements, see <http://www.webelements.com/webelements/elements/text/Fe/index.html>

To see a phase diagram for iron-iron carbide see http://www.sv.vt.edu/classes/MSE2094_NoteBook/96ClassProj/examples/kimcon.html

For more on crystallography and mineral crystal systems see <http://www.rockhounds.com/rockshop/xtal/part1.html> or <http://webmineral.com/help/CrystalSystem.shtml>

An excellent site for the properties of metals and their crystal structures is that of Dr. William Gale at Auburn University: http://www.eng.auburn.edu/~wfgale/intro_metals/section1.htm

For more on the Japanese samurai from National Geographic Magazine see <http://magma.nationalgeographic.com/ngm/0312/feature5/>

To see how atoms are packed to form various unit cubes, see <http://www.schoolscience.co.uk/content/5/chemistry/steel/steelch1pg4.html>

For more on the Historical Note at the end of the article see <http://www.samurai-archives.com/links.html>

Honey: Bee Food Extraordinaire!

Background Information

More on sugars—sucrose, fructose and glucose

<http://www.nhb.org/download/factsht/carb.pdf>

More on Honey—history, composition

From the ChemMatters article: “Finished honey is typically 31% glucose, 38% fructose, 1% sucrose, 18% water and 9% other sugars, plus amino and other acids (citric, acetic, gluconic, etc), enzymes (such as invertase, amylase and glucose oxidase), antioxidants and flavinoids, vitamins and minerals such as calcium, iron, and zinc. Unfiltered honey will also have pollen, bits of beeswax, yeasts, and other debris.”

A table of carbohydrate composition of honey types can be found at <http://www.beesource.com/pov/usda/table2beekUSA82.htm>

“Even though honey has less dextrose than levulose, it is dextrose that crystallizes when honey granulates, because it is less soluble in water than is levulose. Even though honey contains an active sucrose-splitting enzyme, the sucrose level in honey never reaches zero.

Beekeepers as well as honey buyers know that the water content of honey varies greatly. It may range between 13 and 25 percent. According to the United States Standards for Grades of Extracted Honey, honey may not contain more than 18.6 percent moisture to qualify for U.S. grade A (U.S. Fancy) and U.S. grade B (U.S. Choice). Grade C (U.S. Standard) honey may contain up to 20 percent water; any higher amount places a honey in U.S. grade D (Substandard).

Dextrose (glucose) and levulose (fructose) are still by far the major sugars in honey, but 22 others have been found. All of these sugars are more complex than the monosaccharides, dextrose and levulose.

Ten disaccharides have been identified: Sucrose

- Maltose
- Isomaltose
- Maltulose
- Nigerose
- Turanose
- Kojibiose, Laminaribiose, a
- B*-trehalose
- Gentiobiose

Ten trisaccharides are present:

- Melezitose
- 3-*a*-isomaltosylglucose
- Maltotriose
- L-kestose
- Panose
- Isomaltotriose
- Eriose
- Theanderose
- Centose
- Isopanose.

Two more complex sugars, isomaltotetraose and isomaltopentaose, have been identified. Most of these 22 sugars are present in quite small quantities.

Most of these sugars do not occur in nectar, but are formed either as a result of enzymes added by the honeybee during the ripening of honey or by chemical action in the concentrated, somewhat acid sugar mixture we know as honey.

The flavor of honey results from the blending of many "notes," not the least being a slight tartness or acidity. The acids of honey account for less than 0.5 percent of the solids, but this level contributes not only to the flavor, but is in part responsible for the excellent stability of honey against microorganisms. Several acids have been found in honey, gluconic acid being the major one. It arises from dextrose through the action of an enzyme called glucose oxidase. Other acids in honey are formic, acetic, butyric, lactic, oxalic, succinic, tartaric, maleic, pyruvic, pyroglutamic, α -ketoglutaric, glycollic, citric, malic, 2- or 3-phosphoglyceric acid, α - or β -glycerophosphate, and glucose 6-phosphate.

Material above taken from <http://www.beesource.com/pov/usda/beekpUSA82.htm> This site is an excerpt from an agricultural handbook, **HONEY COMPOSITION AND PROPERTIES**, by J White and Landis Doner. It provides detailed information about the composition of honey, and the processes used in its manufacture.

A chart of composition of honey can be seen at:

<http://www.chemsoc.org/exemplarchem/entries/2001/loveridge/index-page3.html> the "Chemistry of Bees" — including some chemistry of pheromones and bee stings.

<http://yunus.hacettepe.edu.tr/~ayguns/Honey%20composition.htm> a list of the materials found in a 100-gram sample of honey.

<http://www.nhb.org/foodtech/rsrchref.html> honey research around the world: a selected list of scientific resources

<http://www.brownielocks.com/honey.html> some light history of honey and recipes

<http://membership.acs.org/C/Chicago/ChmShort/CS04.html> gives brief information on honey for pre-teens, but has some heavy-duty terms in the chemical composition section

<http://www.ibiblio.org/herbmed/eclectic/kings/honey.html> provides history and detailed chemical composition of honey

<http://www.foodtimeline.org/foodfaq1.html#honey> history and health aspects

<http://www.nhb.org/> the National Honey Board's web site

<http://www.nhb.org/download/factsht/HoneyReferenceGuide.pdf>

This National Honey Board site has several tables of information relating to honey's benefits and its composition, including 22 properties and how they beneficially affect 10 different food group applications.

<http://www.news.uiuc.edu/scitips/02/0408honey.html> The antioxidant benefits of dark honey are described here.

<http://www.sciencenews.org/articles/20020427/food.asp> This news source discusses a potential threat to honey lovers - pyrrolizidine-alkaloid toxicity. Apparently, about 3% of flowers produce these PA's, and bees gather this in their search for nectar. It can be concentrated in honey.

More on Sweetness

While students may think honey is as sweet as it gets, the following two tables, taken from <http://www.elmhurst.edu/~chm/vchembook/549sweet.html>, give a more complete picture of sweetness, both history and data:

Relative Sweetness Scale - Sucrose = 100	
Compound	Rating
Sucrose	100
Fructose	140
High Fructose Corn Syrup	120-160
Glucose	70-80
Galactose	35
Maltose	30-50
Lactose	20

Sweeteners Introduction

Introduction:

Carbohydrates are an important dietary nutrient which is mostly used to supply energy to the body, as well as, a carbon source for synthesis of other needed chemicals.

In addition mono- and disaccharides are craved because of their sweetness. All carbohydrate sweeteners (sugar, evaporated cane juice, turbinado sugar, honey, high fructose corn syrup, maple syrup, juice concentrates) contain primarily sugars and do not provide significant amounts of vitamins and minerals. We value sugar and other natural sweeteners because they enhance taste and enjoyment of a wide variety of nutritious foods.

USDA estimates that for 1997 about 67 pounds of sugar (cane and beet); 86 pounds of corn sweeteners; and 1 pound of other sweeteners (honey, maple syrup) per capita were delivered into the food supply. That adds up to a total carbohydrate sweetener availability of about 154 pounds per capita.

Saccharides have varying degrees of sweetness on a relative scale as illustrated in the table on the left. Fructose is the sweetest, while lactose is only slightly sweet by comparison.

Originally the needs of diabetics and more recently the soft drink industry has provided the stimulus in the search of other sweeteners.

	<p>Discovery of Non-Carbohydrate Sweeteners:</p> <p>Saccharin was discovered in 1879 by Constantine Fahlberg, while working in the laboratory of Ira Remsen, quite by accident as were most other sweeteners. While working in the lab, he spilled a chemical on his hand. Later while eating dinner, Fahlberg noticed a more sweetness in the bread he was eating. He traced the sweetness back to the chemical, later named saccharin, by tasting various residues on his hands and clothes (unsanitary conditions) and finally chemicals in the lab (not a safe lab practice).</p> <p>By 1907, saccharin was used as a replacement for sugar in foods for diabetics. Since it is not metabolized in the body for energy, saccharin is classified as a noncaloric sweetener. By the 1960s it was used on a massive scale in the "diet" soft drink industry.</p>														
<table border="1"> <thead> <tr> <th colspan="2">Relative Sweetness Scale - Sucrose = 1</th> </tr> <tr> <th>Compound</th> <th>Rating</th> </tr> </thead> <tbody> <tr> <td>Saccharin</td> <td>300 X</td> </tr> <tr> <td>Cyclamate</td> <td>30 X</td> </tr> <tr> <td>Aspartame</td> <td>180 X</td> </tr> <tr> <td>Acesulfame</td> <td>200 X</td> </tr> <tr> <td>Sucralose</td> <td>600 X</td> </tr> </tbody> </table>	Relative Sweetness Scale - Sucrose = 1		Compound	Rating	Saccharin	300 X	Cyclamate	30 X	Aspartame	180 X	Acesulfame	200 X	Sucralose	600 X	<p>Aspartame: In 1965, Jim Schlatter, a chemist at G.D. Searle was working on a on a project to discover new treatments for gastric ulcers. One of the steps in the research process was to make a dipeptide intermediate, aspartyl-phenylalanine methyl ester. He accidentally and unknowingly spilled some on his hand. Later he licked his finger as he reached for a piece of paper (unsanitary lab technique), and noticed the sweet taste. He and a friend decided to test some in coffee and confirmed the identity of the chemical with the sweet taste. The result was the sweetener, aspartame.</p>
Relative Sweetness Scale - Sucrose = 1															
Compound	Rating														
Saccharin	300 X														
Cyclamate	30 X														
Aspartame	180 X														
Acesulfame	200 X														
Sucralose	600 X														
	<p>Cyclamate: Michael Sveda, while a graduate student at the University of Illinois, discovered cyclamate by smoking a cigarette. While working on the synthesis of anti-pyretic (anti-fever) drugs in the laboratory in 1937, he put his cigarette down on the lab bench. When he put it back in his mouth, he discovered the sweet taste of cyclamate (unsanitary lab technique).</p> <p>Acesulfame was discovered by another chemist, Karl Claus, in 1967. He noticed a sweet taste when he licked his finger to pick up a piece of paper (unsanitary lab technique).</p> <p>Sucralose may have the strangest "accidental discovery" story. Tate & Lyle, a British sugar company, was looking for ways to use sucrose as a chemical intermediate. Halogenated sugars were being synthesized and tested. A foreign graduate student, Shashikant Phadnis, misunderstood a request for "testing" of a chlorinated sugar as a request for "tasting," leading to the discovery that many chlorinated sugars are sweet with potencies some hundreds or thousands of times as great as sucrose. Substituting three chlorine ions for hydroxyl groups on an ordinary sucrose molecule makes Sucralose.</p>														

As you can see from the above tables, fructose is perceived as being approximately twice as sweet as glucose, and Sucralose is approximately 800 times as sweet as glucose. [With this information, ask students, "Why would food manufacturers/processors want to use fructose (or high fructose corn syrup) instead of glucose or sucrose?"]

<http://www.nhb.org/download/factsht/carb.pdf> another National Honey Board publication on carbohydrates and the sweetness of honey

http://www.chemistry.org/portal/a/c/s/1/feature_ent.html?DOC=enthusiasts%5Cent_candychemistry.htm | a brief ACS article on sugars — natural and synthetic — in candies

<http://www.landfood.ubc.ca/courses/fnh/301/carb/carb4.htm> part of a course on sweetness chemistry — heavy-duty chemical structures and theory about sweetness

<http://food.oregonstate.edu/sugar/sweet.html> ranking sweetness of sugars and sweeteners On this scale, honey comes in at 97, compared to sucrose at 100.

<http://www.shodor.org/succeed/compchem/projects/fall00/sweeteners/> A study showed no relationship between perceived sweetness of a sweetener and selected physical/chemical properties; i.e., electric potential, heat of formation, and dipole moment

<http://science.kennesaw.edu/~mhermes/nutra/> This site gives a case study approach to the study of NutraSweet (aspartame artificial sweetener). It's geared to college level students, but it could be adapted to high school.

More on Bees

<http://www.chemsoc.org/exemplarchem/entries/2001/loveridge/> This site gives much background information on bees; e.g., the chemistry of: bees, honey, honeycomb, royal jelly, bee pheromones, and bee stings. Very informative

[http://www.chemistrydaily.com/chemistry/Pheromone_\(honey_bee\)](http://www.chemistrydaily.com/chemistry/Pheromone_(honey_bee)) The site provides a list of more than a dozen bee pheromones. Coverage is spotty; some pheromones have very detailed coverage of the organic chemicals involved, while others just mention the name of the pheromone.

<http://www.chem.ox.ac.uk/mom/hyaluronidase/hyaluronidase.html> The site is one page that simply compares the pros and cons of a bee sting. Cons are evident, pros involve bee sting therapy.

<http://gears.tucson.ars.ag.gov/beebook/sec1/sec1.html> This site provides a significant history of bees and a very detailed study of the life of bees — queen, workers, and drones. It also has what appear to be drawings of electron photomicrographs of the parts of each of the types of bees. Did you know that the top speed of a worker bee is about 29 km/hr?

http://www.sciencenews.org/pages/sn_arc97/5_24_97/bob1.htm Honeybees act as sensors for pollution as they forage for nectar and bring home with them all sorts of contaminants from their environment.

More on Mead

<http://www.gotmead.com/history-of-mead/>

As the name in the site suggests, this site gives a brief history of mead, the drink made of fermented honey.

<http://home1.gte.net/richwebb/mead.htm> Another site with some history of mead.

Milk and Honey

<http://www.nhb.org/download/factsht/HoneyBeauty.pdf> This is another National Honey Board site, this one with beauty tips using honey.

Connections to Chemistry Concepts

Photosynthesis reaction

Catalysis/enzyme action

Isomerism C₆H₁₂O₆

<http://www.creative-chemistry.org.uk/molecules/geometrical.htm>. This site shows models of 3 butene molecules that exhibit isomerism. They can be animated to show rotation or changed from ball & stick to space-filling to wire models, etc.

<http://www.biology.creative-chemistry.org.uk/molecules/sugars.htm>. This is a new addition (11/6/05) to the site listed above. It shows glucose, fructose, sucrose and maltose structures, also capable of changing to animated or ball and stick, etc.

<http://employees.csbsju.edu/hjakubowski/classes/ch331/cho/monosaccharides.htm>. This site contains a nice overview of the various types of isomerism that exist in sugars, particularly in glucose. It also contains chime images of many isomers of carbohydrates.

Dextro- and levorotatory isomers

Bond breaking and bond forming

Crystallization, crystal size, seed crystals

<http://www.nhb.org/download/factsht/crystal.pdf> a National Honey Board publication on crystallization and factors affecting it.

Water of crystallization/water of hydration

$(\text{C}_6\text{H}_{12}\text{O}_6 + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{H}_2\text{O})$

Freezing point depression—just a brief mention and a temperature lowering at

<http://www.nhb.org/download/factsht/carb.pdf>

Possible Student Misconceptions

1. Honey is just sugar, right? Although honey is mostly sugar(s) (82%), honey is a complex mixture of sugars, acids, proteins, vitamins, minerals, pigments, flavors, aromatic substances, sugar alcohols, and colloids.
2. I've heard that, "Honey is the "perfect food". Not quite...while it's true that honey contains lots of easily digestible carbohydrates (primarily monosaccharides), and vitamins B₁ (thiamine), B₂ (riboflavin), B₃ (niacin), B₅ (pantothenic acid), B₆ (pyridoxine), B₁₂ (cobalamin), and C (ascorbic acid), as well as numerous minerals, it's also true that the vitamins and minerals are present in such small quantities that a person might need to ingest **pounds** of honey to get even close to minimum daily requirements (MDR's) for many of the substances in these two groups.
3. "Honey is about as sweet as it gets, right?" Nope, see the tables listed earlier under "More on Sweetness", and you'll discover that, while honey is about as sweet as sucrose (table sugar), it is not as sweet as fructose alone, nor is it even close to being as sweet as some of the synthetic sweeteners; e.g., aspartame.

Demonstrations and Lessons

1. Viscosity — drop identical spheres in liquids, including honey and measure time to fall equal distance. On the Web here: <http://atlas.geo.cornell.edu/education/student/viscosity.html>
2. Determine glucose concentration of honey—this is a biochemistry experiment designed at the college level, but may be adaptable for a second year high school chemistry course: <http://chemeducator.org/sbibs/s0009004/spapers/940239ld.htm>
3. Make artificial honey
http://www.uniregensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/D-art_honey-e.htm This simple experiment shows how citric acid can be used to catalyze the hydrolysis of sucrose into fructose and glucose, just as invertase does in the production of honey by bees.
4. Test for amylase in bee honey http://www.uniregensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/D-honey_amylase-e.htm
The chemistry gets a little detailed here, although the experiment itself is fairly simple. The experiment

compares the ability of “artificial” honey (the honey prepared in number 3, above) with that of natural (bee) honey to break down starch (amylase). This experiment shows that natural (bee) honey will test negative for starch, even when starch has been added, because of the enzyme amylase that honey contains. This enzyme breaks down the starch (amylase) into a simpler sugar (maltose) that does not give a positive starch-iodine test. Teachers might have a difficult time with this experiment as it utilizes materials that are readily available in Europe (not here). Substitutions would have to be made, although they should be simple.

Suggestions for Student Projects

“How It’s Made” Discovery Channel, a segment on honey. Airs Fri, Dec 9, 2005 at 6:30 PM, Sat, Dec 10, 2005 at 1:30 PM, Mon, Dec 12, 2005 at 6:30 AM, Mon, Dec 12, 2005 at 11:30 AM, Tue, Dec 13, 2005 at 5:30 PM (all times ET) Perhaps you could assign a student report on this segment.

Students could research the chemistry behind bee sting therapy—or the chemistry of the bee sting itself. (See number 1 in “Anticipating Student Questions”, below.)

Students could contact the local “4H” club to see if any students maintain hives in their area, and then do an interview with that student. Or they could check the Web for professional beekeepers in their area and interview them. Either of these projects could result in a student report.

Anticipating Student Questions

1. Why does a bee sting hurt so much? The venom of a bee sting is an intricate mixture, containing 63 components, including:

“[histamine](#), pheromones (discussed on the pheromone page), enzymes, peptides, amino acids and other acids, with 63 components in total. The main enzymes present are phospholipase A, hyaluronidase, and lecithinase; while the main peptides are mellitin, apamin and peptide 401. Bee venom is cytotoxic (ie. cell-destroying), and has the contradictory effects of inhibiting the nervous system, while stimulating the heart and adrenal glands.”

Phospholipase A makes up 12% of the venom, and destroys cells by breaking up phospholipids, the main component of cell membranes. Lecithinase converts lecithine to lysolecithine (or phospholipase B), which breaks down the membranes of blood cells. Hyaluronidase (3%) acts as a spreading factor, by breaking down hyaluronic acid, a polysaccharide interstitial fluid in connective tissue.

Mellitin, a 26 amino acid peptide, makes up 50% of the dry weight of bee venom, and acts to destroy blood cells by breaking up their membranes. It also lowers blood pressure, causes histamine release, and is the main pain-causing component. Both mellitin and apamin cause the body to release [cortisol](#), a natural steroid, while peptide 401 is a powerful anti-inflammatory agent. The main amino acids in bee venom are [cysteine and methionine](#), both of which contain sulphur. Sulphur is important in inducing cortisol release from the adrenal glands.

Histamine makes up 0.9% of venom, and causes itching and pain at the site of the sting. The acids present, which include formic, hydrochloric and orthophosphoric acids, are now believed to be much less important in causing pain than was previously thought.” - excerpted from “The Chemistry of Bees, at <http://www.chemsoc.org/exemplarchem/entries/2001/loveridge/index-page8.html>

2. Are Africanized (aka, “killer”) bees really a threat? They are definitely more aggressive than the European variety (that we have here in the US). <http://www.bees-online.com/AfricanBee.htm> This site gives a little background about where Africanized honey bees come from, and a map of where these bees are now in the United States. *Apis mellifera scutellata* is the scientific name for these bees.

3. Do all kinds of honey taste the same? Not according to honey lovers and beekeepers! The table on the first page of the “Honey” guide shows more than 35 different floral types of honey. Each could be said to have its own distinctive flavor. Most commercial honeys are blends of several different types of floral sources, to ensure a more uniform product.

Websites for additional Information

<http://www.beesource.com/pov/usda/beekpUSA82.htm> good source of information on the composition of honey—all parts, not just the sugars.

<http://www.bumblebarf.com/bbarfart.html> If you want a tongue-in-cheek discourse on how bees produce honey, this is the site for you. The author has trouble staying focused on the topic, but he is very descriptive about honey production—on a level kids can relate to. It is actually pretty correct scientifically, but if students read this, they’ll never look at honey the same way again.

Poisoned!

Background Information

Arsenic has been in man's arsenal (pun intended) for centuries. We've had what might be classified as a love-hate relationship with the element almost since the beginning of recorded history. We've known of its ability to act as a poison, but we've also noted that it can act as a tonic or medication (e.g., Fowler's solution, a very famous tonic used for 150 years as a general cure-all) as well, depending on dose.

We'll spend some time later in this guide discussing the poisonous properties of arsenic, but for now, let's focus on its beneficial uses (for mankind). Several of arsenic's uses are listed in the article itself. It has been used as a poison, a tonic, an insecticide, a pesticide (rat poison), an herbicide, and in pressure-treated wood. Its major use today is in the semiconductor industry to make the components of diodes, lasers, and transistors.

Much of the following background information comes from Bentley and Chasteen, in their article, "Arsenic Curiosa and Humanity" (<http://chemeducator.org/sbibs/s0007002/spapers/720051rb.pdf>). They tell us that arsenic has also been used in the treatment of parasitic diseases, and recently (1997) doctors at Memorial Sloan Kettering Cancer Institute developed an arsenic compound, arsenous trioxide (arsenic(III) oxide) [As₂O₃] (Trisenox®), to be used as an anti-cancer drug. It was approved by the FDA in 2001 as a treatment for leukemia.

Industrial uses for arsenic and arsenic compounds

"Over the years, arsenic compounds have found application in the manufacture of cosmetics, food, glass, insecticides, medications, pigments, pyrotechnics, rodenticides, and wood preservatives, as well as in embalming, metallurgy, tanning, and taxidermy."

As a result of all these uses for arsenic, there has been a significant number of cases of poisoning in the chemical industry. The Toxic Exposure Surveillance System reported in 1998 there were 956 non-pesticide exposures to arsenic in the US, and 339 pesticide-related exposures. Four of the non-pesticide exposures were fatal. To reduce these fatalities, the US is gradually phasing out most of the industrial uses of arsenic. We no longer produce any arsenic; we import most of our arsenic from China.

"In 1997, for the United States, the imported amounts were 1,200 metric tons of arsenic metal, 30,000 tons of arsenic trioxide, and 1 ton of arsenic acid. Of these quantities, 88% of the metal was from China, the remainder being from Japan, Hong Kong, and other countries. For arsenic trioxide, 48% came from China, 20% from Chile, 12% from Mexico, and 20% from elsewhere. Prices for arsenic trioxide in 1997 averaged 26 cents per pound, and for metal from China, 44 cents per pound."

Most of the previously mentioned uses for arsenic are on the decline. We used to use arsenic to alloy with lead in the production of lead shot, as it helped to make the shot harder and more spherical; we don't use it now. (In fact, lead shot is on the way out in the US, too.) Arsenic is still used with lead in lead storage batteries, however. We used to use arsenic in the embalming business as it helped to prevent bacterial and insect growth in bodies; we don't any more. We used to use arsenic compounds in making brightly colored pigments, especially green. We no longer use arsenic compounds in weed killers. And the US only recently (2003) banned the production and use of CCA, chromated copper arsenate, the wood preservative, in the residential building industry and in playgrounds.

Several industries still rely on the use of arsenic. The glass industry still employs arsenic, as does the herbicide industry, especially in the control of growth of special grasses, as on golf courses. It is also used as an additive in animal feed, to control parasites and mold growth. There is also one major area, where arsenic's use is on the rise; that is in the area of electronics. Arsenic is used as a dopant with germanium and gallium in semiconductors, and in manufacturing lasers, diodes, and transistors.

Medical uses for arsenic and arsenic compounds

Historically, arsenic compounds have been widely used in the medical field. A few of the diseases treated by arsenic in the past are: malaria, diabetes, bronchitis, cancer, warts, and eczema. It was also used in cosmetics.

Fowler's solution became a cure-all in the 1800s. Fowler's solution is a 1% potassium arsenite (K_3AsO_3) solution. It was discovered in 1786 and was used as a tonic for many ailments for about 150 years. In addition to being used as a general tonic for well-being, it was also used as an anti-tumor agent and for skin conditions. It is no longer used in medicine, as scientists have determined that it can cause hepatic cirrhosis, and skin and urinary bladder cancers.

Knowing the ubiquity of arsenic in medical treatments resulted in Paul Ehrlich's experimenting with hundreds of arsenic compounds, hoping to find the "magic bullet" that would treat a specific disease without harming the individual being treated. His arsenic-containing compound Salvarsan was the first effective treatment for syphilis. His research started the era of synthetic chemotherapy. (Prior to his work, scientists relied on plant and animal remedies — "natural" remedies — for disease control.)

Arsenic poisoning

The literature is replete with citations of arsenic used as a poison. Arsenic is mentioned in Chaucer's "Canterbury Tales", in Flaubert's "Madame Bovary", in many of Agatha Christie's mystery novels, and in "Arsenic and Old Lace", to name but a few.

The Borgias in Renaissance Italy, were well-known for their poisonings, and in France arsenic's use as a poison of (and by) royalty was so widespread that it was dubbed, "poudre de succession", or inheritance powder. It seems that few kings and queens lived their full lives, as they were frequently cut short by poisoning. Stories involving arsenic poisoning abound in literature. Several more are listed in Bentley and Chasteen's article, as well as in the following web sites:

More on Charles Hall and the North Pole expedition

http://www.crimelibrary.com/notorious_murders/classics/charles_francis_hall/ a book about Charles Hall's death close to the North Pole

<http://www.smithsonianmag.si.edu/smithsonian/issues01/feb01/arctica.html> more information on Charles Hall's death in a book, *Top of the World*

<http://www.nytimes.com/books/01/02/25/reviews/010225.25wheelet.html> a review of two more books recounting Hall's ordeal, *Fatal North* and *Trial by Ice*.

More on the *ChemMatters* "Poisoned!" story follow-ups from New Sweden

<http://www.bangornews.com/news/templates/default.aspx?a=122337&template=print-article.htm> Bangor Publishing Company—news of a lawsuit by relatives of the deceased Walter Morrill.

http://www.boston.com/news/local/maine/articles/2005/10/21/civil_suit_filed_in_2003_arsenic_poisoning/ Civil suit filed in 2003 arsenic poisoning (Boston.com.)

Historical/Literature-based

<http://www.victorianweb.org/history/arsenic.html> Arsenic poisoning and Napoleon

<http://www.grand-illusions.com/napoleon/napol1.htm> Grand Illusions, Napoleon's wall paper may have poisoned him

Also check out *ChemMatters*, December 1998, for an article on Napoleon and arsenic.

<http://www.tigersweat.com/movies/arsen/> the movie site for "Arsenic and Old Lace"

<http://news.bbc.co.uk/1/hi/health/3889903.stm> a BBC production discussing King George III's bouts with madness being caused by arsenic poisoning

<http://aolsvc.news.aol.com/news/article.adp?id=20050722092109990013> a second version of King George III's arsenic poisoning

<http://www.medicalnewstoday.com/medicalnews.php?newsid=27824> Madness of King George III due to arsenic poisoning, report from the Lancet

http://www.pbs.org/wnet/secrets/case_jamestown/clues.html Secrets of the Dead . Death at Jamestown, a PBS project — see also, “Lesson Plans”

<http://www.dartmouth.edu/~toxmetal/TXSHas.shtml> Dartmouth Toxic Metal Research - Toxic Metals — has good history of uses of arsenic, including poisonings of historical importance

<http://web1.caryacademy.org/chemistry/rushin/StudentProjects/ElementWebSites/arsenic/history.htm> History and background of the origin of the Marsh test for arsenic poisoning

http://www.crimelibrary.com/notorious_murders/family/richard_lyon/10.html Richard Lyon murdered his wife with arsenic—the Crime Library - The Crime library This book seems to have some questionable passages for students. It may be a book for your eyes only.

An interesting sidebar about arsenic poisoning is that cemeteries may become the next site for arsenic to leach into the groundwater. Prior to the Civil War, most bodies were simply buried, without the benefit of embalming. But the preponderance of bodies from the Civil War, and the desire of relatives to have the bodies returned “home” to be buried, resulted in the rapid growth of the embalming industry. Bodies were embalmed using arsenic compounds that kept the bodies supple and the skin an acceptable white color. After the end of the war, between 1880 and 1910, the embalming business flourished. After 1910, embalmers turned to formaldehyde as their preservative agent, but prior to that, arsenic was the embalming chemical of choice. Those embalmed bodies were buried in wood or metal coffins. Over the years, both types of coffin deteriorate, and soon, as the arsenic used in the embalming of all those bodies leaches out of the deteriorated coffins into the groundwater, we may experience our newest ecological disaster.

Arsenic Compounds

While “arsenic” gets the reputation for being such a great (?) poison, it is really compounds of arsenic that are typically responsible for the toxic properties. Arsenic compounds fall into two categories, inorganic arsenic compounds and organic arsenic compounds. The inorganic compound group is the more toxic of the two groups. Arsenic(III) oxide is the most popular of the inorganic compounds.

Organic arsenic compounds are frequently found in marine life. The concentration of organic arsenic that we get from eating fish, especially shellfish, is much greater than the concentration of the inorganic arsenic to which we are exposed. Nevertheless, it is the inorganic arsenic that is the cause of greatest concern because of its much greater toxicity. Some of the greater toxicity of inorganic arsenic compounds seems to be due to their greater solubility in water.

Inorganic Arsenic

<http://www.inchem.org/documents/ehc/ehc/ehc224.htm> provides detailed scientific information on sources, availability, and health effects of arsenic, from an international group whose task it is to consolidate current, internationally peer-reviewed chemical safety-related publications and database records from international bodies, for public access. This site provides data on the effects of arsenic on other forms of animal life, in addition to human life.

<http://64.233.161.104/search?q=cache:g7bsltgROAoJ:ntp.niehs.nih.gov/ntp/roc/eleventh/profiles/s015arse.pdf+arsenic+compounds&hl=en> a National Institutes of Health site that gives information on the effects of inorganic arsenic on human health, from the 11th edition of *Report on Carcinogens*

http://www.scorecard.org/chemical-profiles/summary.tcl?edf_substance_id=EDF-222 Scorecard site that provides chemical profiles of various substances — this time, inorganic arsenic compounds

<http://www-cie.iarc.fr/htdocs/monographs/vol23/arsenic.html> a brief review of toxicological studies done on animals is given at this site. It seems to conclude that most of the studies indicating heightened occurrence of cancer in subjects cannot unequivocally be attributed to inorganic arsenic compounds.

http://www.aocd.org/skin/dermatologic_diseases/bowens_disease.html Bowen's disease is an in situ form of squamous cell cancer. One cause of this disease is arsenic.

Organic Arsenic

<http://www.osha-slc.gov/SLTC/healthguidelines/arsenic/recognition.html> an OSHA fact sheet concerning organic compounds of arsenic

General Information

Most of the web sites listed below provide information on arsenic — the element. This is probably the area of most interest to chemistry teachers because the material contained in these sites can be used within their already existing curriculum. Almost all of these sites provide some basic data on the element arsenic, as noted.

<http://chemeducator.org/sbibs/s0007002/spapers/720051rb.pdf> a very good source of information, including literary references, common uses, and health effects for arsenic

<http://reference.allrefer.com/encyclopedia/A/arsenic.html> background information, including the Marsh test to identify arsenic poisoning

<http://www.scescape.net/~woods/elements/arsenic.html#History> Arsenic—history & uses, but includes more scientific information also; e.g., states, atomic sizes, abundances of isotopes, etc.

<http://www.nsc.org/library/chemical/arsenic.htm> Arsenic - National Safety Council site — lists general info, also gives biological info — health effects, exposure values, economics, regulation

<http://nautilus.fis.uc.pt/st2.5/scenes-e/elem/e03300.html> background info, including detailed scientific data and rotating crystal structure model

<http://www.du.edu/~jcalvert/phys/arsenic.htm> background info - properties, compounds and minerals, uses

<http://www.chemicalelements.com/elements/as.html#citing> Chemical Elements.com — gives a page of arsenic info (and one for each other element) and contains periodic tables of general info

<http://www.dartmouth.edu/~toxmetal/TXQAas.htm> Dartmouth Toxic Metal Research - Toxic Metals — a health Q & A fact sheet about arsenic

http://www.essays.cc/free_essays/f4/rsk38.shtml Essays.cc — essay on Arsenic basic information

<http://www.abdn.ac.uk/chemistry/ex/cm03/min/> Properties of Arsenic — typical background info, but with pictures of people suffering from arsenic poisoning

http://www.scorecard.org/chemical-profiles/summary.tcl?edf_substance_id=7440-38-2 a chemical profile of arsenic and a list of info re: arsenic's health effects on the world's population, from Scorecard, "the pollution information site"

<http://scifun.chem.wisc.edu/chemweek/arsenic/arsenic.html> Arsenic is chosen as the "chemical of the week" by Bassam Shakhshiri in his chemistry course.

<http://books.nap.edu/books/0309026040/html/1.html> It appears that this may be the source for many of the other references about arsenic on the web. This 1977 book (sold here, but readable online) has all the arsenic information you might want (although it is rather dated now).

<http://www.portfolio.mvm.ed.ac.uk/studentwebs/session2/group12/arsenic.htm> Arsenic — background info, including photo of realgar

<http://www.emedicine.com/emerg/topic42.htm> Medicine - Toxicity, Arsenic Article by Steven Marcus, MD gives background, but in medical terms, includes DMSA chelator

<http://www.osha.gov/SLTC/arsenic/index.html> Safety and Health Topics — arsenic in the workplace

<http://pubs.acs.org/cen/coverstory/83/8325/8325salvarsan.html> Ehrlich's Salvarsan is an arsenic-containing drug to combat syphilis.

More on CCA (chromated copper arsenate)

Chromated copper arsenate is very effective as an additive to lumber to prevent mold growth and insect infestation. Even though it is impregnated into the wood, chromated copper arsenate (CCA), the preservative used in pressure-treated lumber, can be rubbed off the wood by friction. This has caused it to be a particular hazard to children playing on playgrounds constructed of this wood. Children who play there regularly might ingest or even inhale quantities of arsenic compounds from this source. CCA wood is also used in outdoor construction, as for picnic benches and tables, decks, etc. Construction workers who cut the lumber can be exposed to airborne particles containing arsenic, and people who burn CCA wood in their fireplaces, for example, can breathe in the arsenic containing combustion products, and they can be exposed to large quantities of arsenic in the ash from burning CCA wood. This prompted the US to enact a ban on CCA wood in playground and residential construction. Of course, if use of CCA ceases, some other chemicals must be used to take its place. Home improvement industry scientists are experimenting with copper compounds to replace the arsenic. Will the new products be more environmentally friendly?

See the following web sites for more information:

<http://www.cvm.uiuc.edu/ope/enotes/showarticle.cfm?id=81> small amount of basic data on levels of arsenic in marine animals

<http://www.origen.net/arsenic.html> CCA wood and arsenic toxicological effects of arsenic

<http://www.cpsc.gov/phth/cca.html> CCA-Treated Wood Questions and Answers

<http://www.safe2play.org/assets/docs/safetychecklist.pdf> checklist for parents to check on safety of children on playgrounds with CCA wood

<http://www.washingtonpost.com/ac2/wp-dyn?pagename=article&contentId=A1149-2002Feb12¬Found=true> Use of Arsenic in Wood Products to End (washingtonpost.com) — interviews producers of preserved wood

<http://www.theonion.com/content/node/31939> Concerned Parents Demand Removal Of Arsenic From Periodic Table Of Elements The Onion - America's Finest News Source — spoof (I think) about removing an element from the periodic table. This article was probably a direct result of someone's having read this article in JC&EN: <http://pubs.acs.org/cen/topstory/8112/8112notw7.html#top>, where parents sued to be reimbursed for purchasing CCA-preserved play equipment.

More on Chelating Agents

The article discusses chelating agents as possible drugs for the treatment of arsenic (and other heavy metals) poisoning. The following web sites provide more information.

<http://scifun.chem.wisc.edu/chemweek/Chelates/Chelates.html> another of Shakhshiri's "Chemical of the Week" articles, focuses on the chemistry of a chelating agent, and one chelating agent in particular, dimercaprol, an anti-heavy (including arsenic) agent

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

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

Periodic Tables of information re: Arsenic

Arsenic—the element gives the chemistry teacher the chance/excuse to use chemical information/data from the web in the classroom. The following list of web sites provides a series of periodic tables, focusing on arsenic. The periodic tables themselves are worthwhile to keep bookmarked somewhere for future use.

<http://www.webelements.com/webelements/elements/text/As/> Chemistry Periodic Table arsenic index — contains much info, including geological, biological, and historical info, electronic structure, etc. Includes graphs and charts for wide variety of data

<http://education.jlab.org/itselemental/ele033.html> Jefferson labs provides this 1-page fact sheet on arsenic, linked to JL's own periodic table. Several element activities are available at this site — element hangman, element crossword puzzles, etc., as well as lots of teacher resource materials

<http://www.radiochemistry.org/periodictable/elements/33.html> Los Alamos'

periodic table, w/arsenic's page showing, featuring a downloadable pdf of the interactive table

<http://environmentalchemistry.com/yogi/periodic/As.html> Periodic Table of Elements - Arsenic (EnvironmentalChemistry.com) - comprehensive information for the element Arsenic is provided by this page including scores of properties, element names in many languages, most known nuclides and technical terms are linked to their definitions. Elements are sortable by properties.

http://www.qivx.com/ispt/elements/ptw_033.php Qivx Inc. Integral Scientist Periodic Table Properties of Arsenic, Element 33, As

<http://www.chemsoc.org/viselements/pages/arsenic.html> Visual Elements - Arsenic

<http://www.theonion.com/content/node/31939> Concerned Parents Demand Removal Of Arsenic From Periodic Table Of Elements. The Onion - America's Finest News Source — spoof (I think) about removing an element from the periodic table. This article was probably a direct result of someone's having read this article in JC&EN: <http://pubs.acs.org/cen/topstory/8112/8112notw7.html#top>, where parents sued to be reimbursed for purchasing CCA-preserved play equipment.

Arsenic Poisoning

This series of web sites focuses on arsenic's use as a poison (not a hard thing to do, eh?).

General

http://highwire.stanford.edu/lists/topic_dir/608683/608684/614920/614942/615031/focus.dtl HighWire— Browse Journals - Arsenic Poisoning — a linked list of journals with articles about arsenic

<http://www.mic.ki.se/Diseases/C21.613.html#C21.613.097> contains several links to arsenic poisoning

<http://www.patient.co.uk/showdoc/40001631/> Arsenic poisoning - Patient UK

http://en.wikipedia.org/wiki/Arsenic_poisoning Arsenic poisoning - Wikipedia, the free encyclopedia

<http://www.answers.com/topic/arsenic-poisoning> Arsenic poisoning Information From Answers.com

<http://www.abdn.ac.uk/chemistry/ex/cm00/arsenic/> Arsenic Poisoning Through Drinking Water

<http://www.sums.ac.ir/semj/vol3/apr2002/arspoison.htm> Arsenic Poisoning, Vol. 3, No. 2, SEMJ.

http://phys4.harvard.edu/~wilson/arsenic/countries/arsenic_project_countries.html. Arsenic project.

<http://www.umainetoday.umaine.edu/Issues/v2i5/arsenic.html>. Arsenic Has an Accomplice — microbes may add to arsenic's effectiveness as a poison.

http://news.nationalgeographic.com/news/2004/06/0630_040630_arsenic.html Arsenic in Asian Drinking Water Linked to Microbes.

<http://www.sciencedaily.com/releases/2005/06/050625223204.htm> Arsenic not the same for everyone — arsenic's toxicity seems to be related to one specific gene.

<http://www.atsdr.cdc.gov/tfacts2.html> ATSDR - ToxFAQs™ Arsenic — a list of frequently asked question about arsenic.

Arsenic in Drinking Water

Arsenic compounds, especially inorganic arsenic compounds, are usually very soluble in water. This makes contamination of water particularly worrisome. World health organizations are facing the problem

of arsenic-contaminated water on a very large scale. In Bangladesh, India, alone, millions of people are being affected by arsenic poisoning. It may not be killing people outright in such large numbers, but it is inflicting pain and suffering on millions of residents in those areas. Arsenic contamination also affects people in more affluent countries, like China and the US, not just poverty-stricken countries. The following web sites discuss the problems.

Arsenic in US drinking water

<http://www.metrokc.gov/health/tsp/arsenic.htm> Arsenic Facts — toxic hazards in Washington state

http://www.agiweb.org/geotimes/nov01/feature_Asmap.html Geotimes - November 2001 - Mapping Arsenic in Groundwater (in the US)

<http://www.umeciv.maine.edu/MacRae/Arsenic%20Main.htm> site that provides background information about Maine's problems with arsenic in its drinking water

<http://nationalatlas.gov/natlas/Natlasstart.asp> Map Maker — map of arsenic in US groundwater

<http://water.usgs.gov/nawqa/trace/arsenic/> USGS - Arsenic in ground water of the United States — also provides links to other arsenic sites

<http://water.usgs.gov/nawqa/trace/pubs/NEarsenicRiskstudy.html> USGS - NYTimes article - Study Outlines Arsenic Risk in Some New England Well Water, from Massachusetts to Maine

Arsenic in drinking water in Bangladesh

<http://ehp.niehs.nih.gov/members/2002/110p1147-1153frisbie/frisbie-full.html> The Concentrations of Arsenic and Other Toxic Elements in Bangladesh's Drinking Water — a good introductory article about the whole problem of Bangladesh's arsenic in drinking water problem

<http://pubs.acs.org/cen/NCW/html/8042sci1.html> C&EN SCIENCE & TECHNOLOGY - Tackling Arsenic in Bangladesh

http://phys4.harvard.edu/~wilson/arsenic/arsenic_project_introduction.html Chronic Arsenic Poisoning History, Study and Remediation — most extensive site re: Bangladesh problems with arsenic, frequently cited in other articles

<http://www.sciencedaily.com/releases/2005/06/050625223204.htm>http://news.nationalgeographic.com/news/2003/06/0605_030605_arsenicwater.html Arsenic-Laced Well Water Poisoning Bangladeshis

<http://www.who.int/mediacentre/factsheets/fs210/en/> WHO Arsenic in drinking water factsheet — gives global picture of arsenic poisoning, especially in Bangladesh

<http://www.sos-arsenic.net/> Arsenic Poisoning in Bangladesh-India

<http://pubs.acs.org/cen/80th/arsenic.html> C&EN It's Elemental, The Periodic Table — Arsenic — highlights Bangladesh's arsenic problem, written by Feroze Ahmed, recognized expert on the problem

http://www.sunybroomer.edu/~flynn_b/arsenic.htm This site gives limited background on the chemistry of arsenic, its uses, and its effects on man, focusing on Bangladesh. In addition to pointing out the problems, it also provides a possible solution to the problem.

<http://www.earthinstitute.columbia.edu/library/earthmatters/sept1999/pages/page13.html> provides info on Bangladesh's arsenic problem — and tells of UNICEF's role in identifying and solving the problem
<http://www.nap.edu/books/0309076293/html/R1.html> Arsenic in Drinking Water, 2001 Update, book published by National Academy Press

<http://www.bgs.ac.uk/arsenic/> Arsenic contamination of groundwater — contains maps of India with exposure rates by location

<http://www.asee.org/about/publications/connections/2005march.cfm> ASEE - Publications - Connections Newsletter - March 2005 Connections - simple solution to drinking water arsenic contamination problem

<http://www.water-research.net/arsenic.htm> Arsenic Drinking Water Groundwater Contamination and Water Testing

http://www.sos-arsenic.net/english/toxic_effect/asinfood.html SOS arsenic poisoning in Bangladesh — arsenic in the food chain

<http://pubs.acs.org/cen/news/83/i14/8314notw3.html> This article from the American Chemical Society's Journal of Chemical and Engineering News describes a plant whose roots can extract arsenic from soil.

Arsenic in drinking water elsewhere in the World

<http://www.scidev.net/Features/index.cfm?fuseaction=readFeatures&itemid=382&language=1> Safer stoves can prevent arsenic poisoning in China — coal briquettes contain arsenic in China

Demonstrations and Lessons

Many sites exist that have complete lesson plans dealing with arsenic. These usually involve arsenic poisoning in some way, and there is usually a social studies context for the lesson, but there is frequently some good science in the lesson plan, as well.

<http://toxtown.nlm.nih.gov/index.html> Tox Town - Toxic chemicals and environmental health risks where you live and work, has an animated town to tour

<http://www.yale.edu/ynhti/curriculum/units/2003/5/03.05.03.x.html> The Journey of New Haven Water — a curriculum unit for grades 5-8 that focuses on the hydrologic cycle, including water's trip through the New Haven Water treatment facility

<http://www.atsdr.cdc.gov/HEC/CSEM/arsenic/index.html> ATSDR - CSEM - Arsenic Toxicity Case Study Environmental Alert This is designed for continuing education credits for nurses and so is rather academic, but the study highlights the symptoms an arsenic-poisoned person might display.

<http://science.education.nih.gov/supplements/nih2/chemicals/guide/lessons.htm> Chemicals - Manual - Using the Student Lessons — a good introduction to a very complete set of lesson plans on the toxicology of poisons

http://www.bcoonline.org/tools/lesson_view.cfm?IKey=2768 CTAP Online - Lesson Plan on Madeline Smith's mysterious death (arsenic poisoning)

<http://www.nytimes.com/learning/teachers/lessons/19981111wednesday.html> Daily Lesson Plan-arsenic in Bangladesh's waters — social studies lesson

<http://www.thirteen.org/edonline/lessons/jamestown/b.html> Death at Jamestown — a complete lesson plan to investigate mysterious deaths at the early Jamestown settlement, including an extensive list of web sites for clues/evidence about

<http://ehp.niehs.nih.gov/science-ed/2005/arsenic.pdf> a lesson plan that looks at the global problem of arsenic poisoning and what can be done about it

http://www.collegeboard.com/prod_downloads/yes/holmstrom.pdf Epidemiology in Action lesson plans, 4 units of web-based material for 10-12

Debate

Teachers might want to stage a debate over the need for the new EPA standard for arsenic, being instituted as of January, 2006. This new standard reduces the allowed arsenic in drinking water from 50 ppb to 10 ppb. Many scientists and water treatment facilities believe there is no evidence that this reduction will have any health benefits, while it will have huge negative effects on small communities that must pay for the new technology needed to meet the more restrictive requirements. Some sources of information include:

<http://www.heartland.org/Article.cfm?artId=12290> The Heartland Institute - EPA Arsenic Standard May Be Unconstitutional - by Environment & Climate News staff

<http://www-cie.iarc.fr/htdocs/monographs/vol23/arsenic.html> a brief review of toxicological studies done on animals is given at this site. It seems to conclude that most of the studies indicating heightened occurrence of cancer in subjects cannot unequivocally be attributed to inorganic arsenic compounds.

<http://www.heartland.org/Article.cfm?artId=8634> The Arsenic Controversy — the lead article in this heartland series (the next 4 listed web sites) questioning the wisdom of the new EPA law to reduce arsenic in drinking water from 50 ppb to 10 ppb by January 2006

<http://www.heartland.org/Article.cfm?artId=8211> Arsenic and Old Politics gives some legal background about the controversial law.

<http://www.heartland.org/Article.cfm?artId=9032> EPA, the Arsenic Dictator takes the position that the EPA regulation is more harmful than helpful.

<http://www.heartland.org/Article.cfm?artId=9558> Opposition mounts to new arsenic rules

<http://www.heartland.org/Article.cfm?artId=8294> Review of Arsenic Standards May Save Lives takes the position that the cost of the new 10 ppb rule will actually cost lives, rather than saving them

http://www.nesc.wvu.edu/ndwc/ndwc_OTSU02_F1.html This site gives a relatively balanced view of the arsenic controversy centered on the US reduction in As level from 50 ppb to 10 ppb by January 2006.

<http://www.newswise.com/articles/view/507262/> Newswise New Arsenic Drinking Water Standard May Still be Toxic — an article that says the new regulation of 10 ppb may be too lenient

Extensions

<http://www.ktf-split.hr/periodni/en/as.html> - Periodic Table of the Elements-contains redox potentials for many arsenic chemical reactions. Many calculations could ensue here.

Miscellaneous

<http://www.healthteacher.com/teachersupports/content/tobacco/teacher2.asp> Teacher Supports Page — arsenic is in cigarettes

<http://www.thewaterpage.com/arsenic.htm> The Water Page - Arsenic Feature — this is a good site to learn about water in general, but the arsenic page doesn't have anything new to offer.

<http://pubs.acs.org/cen/news/83/i12/8312arsenic.html> ancient Indians may have migrated due to arsenic contamination of their water supply

Connections to Chemistry Concepts

Arsenic compounds and oxidation numbers — Arsenic's most toxic compounds come from As^{3+} . As^{5+} compounds seem to be much less toxic.

Elements vs. compounds — Elemental arsenic is much less toxic than its compounds, mainly due to the element's low solubility, relative to the solubilities its compounds.

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

Chelating agents and acid-base chemistry — The EDTA molecule can be used to show coordinate covalent bonding.

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

Possible Student Misconceptions

Arsenic as an element is a potent poison. Elemental arsenic is hardly toxic at all, when compared to its compounds; see above.

“Arsenic is arsenic.” All arsenic compounds are the same (in their effectiveness as a poison). As we saw above, inorganic arsenic compounds are far more toxic than their organic counterparts.

Suggestions for Student Projects

Students could research CCA (chromated copper arsenate) — its

- history,
- chemistry
- uses,
- problems,
- economics,
- future

Students could research the relative toxicities of various poisons to determine which is the “most toxic”.

Anticipating Student Questions

Where does arsenic exposure come from? There are many sources of arsenic — herbicides, poultry feed, CCA treated wood, but the most likely is drinking contaminated groundwater

Should I be worried? If you drink municipal water from a treatment plant, your exposure should be minimal, especially if the municipal treatment plant meets the January, 2006 regulations, which are 10 ppb or less. If you drink well water, you should have the water tested for arsenic contamination.

Why did Bondeson put the arsenic in the coffee pot? With Daniel Bondeson dead, we may never know for sure, but the story is still unfolding as some relatives of Walter Morrill (the man who died) have filed a civil suit against the church members in the town of New Sweden. Stay tuned — or see “ChemMatters New Sweden story follow-ups” in the guide section on “arsenic poisoning”.

Is arsenic the most toxic poison known to man? It doesn't even come close! Botulism is touted (?) as being the most toxic substance. “Botulinum toxin A has an LD₅₀ of 3×10^{-8} mg/kg, justifying its reputation as the most lethal substance known.” (taken from ChemMatters Teachers Guide for “The Poison that Heals”, December, 1994.) The equivalent LD₅₀ for arsenic is a staggering 29 mg/kg! (Source: http://ptcl.chem.ox.ac.uk/MSDS/AR/arsenic_III_oxide.html)

That makes botulinum toxin A almost 1 **billion** times more toxic than arsenic! (This doesn't mean we can neglect arsenic's toxic effect, only that botulism is much, much worse.)

Websites for additional Information

See sites listed throughout arsenic guide.