



## February 2009 Teacher's Guide

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## About the Guide

William Bleam, Donald McKinney, Ed Escudero, and Ronald Tempest, Teacher's Guide Editors, created the teacher's guide article material.

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

David Olney created the puzzle. E-mail: [djolney@verizon.net](mailto:djolney@verizon.net)

Patrice Pages, *ChemMatters* Editor, coordinated production and prepared the Microsoft Word and PDF versions of the Guide. E-mail: [chemmatters@acs.org](mailto:chemmatters@acs.org)

Articles from past issues of *ChemMatters* can be accessed from a CD that is available from the American Chemical Society for \$30. The CD contains all *ChemMatters* issues from February 1983 to April 2008.

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

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## Student Questions

### Science at Hogwarts—Chemistry in Harry Potter’s World

1. List three common flame colors mentioned in the article, and name the element salt source most frequently associated with each.
2. What does it mean to say that the bright colors given off by a heated element produce a “fingerprint” of the element?
3. Name two nineteenth century scientists—one who developed the laboratory burner in common use today, and the other who studied the spectra of colored flames produced by a variety of elements.
4. Explain how the emission spectrum of an element is formed.
5. What common chemical will produce a green colored flame similar to the one produced by “floo powder” in Harry Potter and the Chamber of Secrets?
6. Complete the chart below, naming the elements derived from the Latin roots listed in the table found in the article.

<u>Root</u>	<u>Element</u>
<i>Natrium</i>	<i>sodium</i>
<i>Alum</i>	<i>aluminum</i>
<i>Carbo</i>	
<i>Cuprum</i>	
<i>Fluere</i>	
<i>Gallia</i>	
<i>Aurum</i>	
<i>Germania</i>	
<i>Ferrum</i>	
<i>Lutetia</i>	
<i>Magnes</i>	
<i>Nitrum</i>	
<i>Rhenus</i>	
<i>Rubidus</i>	
<i>Scandia</i>	
<i>Argentums</i>	

7. What is the procedure for determining the name and symbol for elements beyond element 111 whose syntheses have not been confirmed?
8. What developer would you use on a message written in lemon juice, to make the invisible ink appear?

### Ancient Soil Chemists of the Amazon

1. How many people lived in the Amazon rainforest in the late 1400s?
2. Why did scientists believe that indigenous people could not have survived in large numbers in the Amazon rainforest?
3. What is *terra preta*?
4. What evidence did Erickson discover that led him to believe that Amazonians were not wandering nomads?
5. How does Amazonian soil differ from soil in the United States?
6. If Amazonian soil is of such poor quality, how were ancient Amazonian people able to grow crops?
7. Where is preta terra found in the Amazon?

8. How does *terra preta* differ from other dark soils, such as those in the U.S.?
9. What hypothesis have scientists proposed to explain why biochar is able to enrich poor soil?
10. Is *terra preta* relevant to today's agricultural practices? Explain.
11. How is biochar made?
12. What do scientists hope to do with pyrolysis today?
13. List two other ways the production of biochar helps Earth.

### **Bringing Chemistry to the Kitchen**

1. Name the physicist who began the experimental cuisine movement.
2. Name the French chemist who helped to start the field of molecular gastronomy.
3. Which forces are the strongest in cooked eggs?
4. Gastronomist Peter Barham has done research on the psychology of food. What does the article say is one of his major findings?
5. Name the Chicago restaurant that serves avant-garde meals.
6. Name two European avant-garde restaurants mentioned in the article.

### **The Art and Chemistry of Dyes**

1. Cotton is actually what natural polymer?
2. Which fabric, wool or cotton, remains neutral in aqueous solution?
3. What is the name of the dye molecule component that produces the dye color?
4. What unusual property is demonstrated by the dye prodiginine?
5. What functional group is added to cotton in order to dye it?
6. Why is wool usually dyed at higher temperatures?

### **Promising New Vaccines**

1. What is the difference between an antigen and an antibody?
2. How does the immune system operate?
3. What are the three types of immune cells and what do they do?

# Answers to Student Questions

## Science at Hogwarts—Chemistry in Harry Potter’s World

1. List three common flame colors mentioned in the article, and name the element salt source most frequently associated with each.

<u>Color</u>	<u>Element Salt Source</u>
Red	lithium
Yellow	sodium
Blue to green	copper

2. What does it mean to say that the bright colors given off by a heated element produce a “fingerprint” of the element?

*The bright colors, lines in the visible spectrum, represent transitions which are unique to each element. No two elements produce the same spectrum.*

3. Name two nineteenth century scientists—one who developed the laboratory burner in common use today, and the other who studied the spectra of colored flames produced by a variety of elements.

*The two scientists are Robert Bunsen, whose name is associated with today’s laboratory burner, and William Kirchhoff, who studied the flame spectra produced by a variety of elements.*

4. Explain how the emission spectrum of an element is formed.

*“When we heat a sample of an element hot enough, the heat energy kicks an electron from its original ground energy state to a higher energy level. When the excited electron returns to a lower-energy state, light with a particular energy and characteristic color is released. Because many transitions between energy shells are possible, there can be many lines in an element’s spectrum.”*

5. What common chemical will produce a green colored flame similar to the one produced by “floo powder” in Harry Potter and the Chamber of Secrets?

*Boric acid will produce a brilliant green flame when held in a Bunsen burner flame.*

6. Complete the chart below, naming the elements derived from the Latin roots listed in the table found in the article.

<u>Root</u>	<u>Element</u>
Natrium	sodium
Alum	aluminum
Carbo	carbon
Cuprum	copper
Fluere	fluorine
Gallia	gallium and francium
Aurum	gold
Germania	germanium
Ferrum	iron
Lutetia	lutetium
Magnes	magnesium
Nitrum	nitrogen
Rhenus	rhenium
Rubidus	rubidium
Scandia	scandium
Argentums	silver

7. **What is the procedure for determining the name and symbols for elements beyond 111, whose synthesis has not yet been confirmed?**

*The names and symbols represent Latinized forms of their atomic numbers. For example, element 112 is called “un un bium” (for “112-ium”) and element 115 is called “un un Pentium” (for “115-ium”)*

8. **What developer would you use on a message written in lemon juice, to make the invisible ink appear?**

*The heat from a 100-watt light bulb will char the sugars in the lemon juice sufficiently to make the writing appear brown.*

## **Ancient Soil Chemists of the Amazon**

1. **How many people lived in the Amazon rainforest in the late 1400s?**

*Clark Erickson believes that as many as 6 million people were living in the Amazon rainforest in the late 1400s.*

2. **Why did scientists believe that indigenous people could not have survived in large numbers in the Amazon rainforest?**

*Scientists knew the soil of the Amazon rainforest did not contain enough nutrients needed to support growing crops.*

3. **What is *terra preta*?**

*Terra preta is the dark, fertile soil found in certain areas of the Amazon River basin.*

4. **What evidence did Erickson discover that led him to believe that Amazonians were not wandering nomads?**

*He discovered large pottery vessels that would have been too large and heavy for wandering nomads to carry around.*

5. **How does Amazonian soil differ from soil in the United States?**

*Amazonian soil appears orange or yellow, and is composed of aluminum and iron oxides. Soil in the U.S., on the other hand, is made of silicate clays containing aluminum, oxygen and silicon. The silicate clay particles adsorb cations on their surfaces; iron and aluminum oxides do not.*

6. **If Amazonian soil is of such poor quality, how were ancient Amazonian people able to grow crops?**

*Ancient Amazonians merely culled out trees that were of no use to them, while maintaining forest nut and fruit trees that were already growing. Continuing this practice maintained the forest and wildlife habitat, while providing crops to sustain the population.*

7. **Where is *preta terra* found in the Amazon?**

*Terra preta is typically found at sites where archaeologists have found remnants from ancient Amazonian towns or population centers.*

8. **How does *terra preta* differ from other dark soils, such as those in the U.S.?**

*The dark color of terra preta is due primarily to biochar, charcoal mixed into the poor soil purposefully by human hands, while other dark soils owe their dark color to a high content of rotting plant material.*

9. **What hypothesis have scientists proposed to explain why biochar is able to enrich poor soil?**

*Scientists have proposed the hypothesis that biochar’s surface may contain carboxylate groups—negatively charged groups of carbon and oxygen atoms. These negatively charged groups would attract cations to them, in much the same manner as silicate clays do in naturally rich soils.*

10. **Is *terra preta* relevant to today’s agricultural practices? Explain.**

Yes, terra preta has potential even today. Eprida, Inc., a Georgia-based company, is trying to use biochar soil mixtures similar to terra preta to improve Georgia's low-quality red soil.

**11. How is biochar made?**

Biochar is made by heating wood or other plant material, but not burning it. They do this by heating wood in the absence of oxygen. Without oxygen, fuel (wood in this case) can't burn. Instead, the molecules of wood (lignin and cellulose) break down into water molecules (hydrogen and oxygen) and leftover carbon.

**12. What do scientists hope to do with pyrolysis today?**

Scientists hope to use pyrolysis to produce hydrogen gas to use for fuel. They note that in normal pyrolysis, hydrogen combines with oxygen to produce water. If they can control the conditions of the pyrolysis process, they can prevent the hydrogen gas from combining with oxygen, thus making hydrogen for fuel.

**13. List two other ways the production of biochar helps Earth.**

Biochar can be used to produce biodiesel fuels through hydrocarbon reforming. Production of biochar captures carbon so that it cannot be released as carbon dioxide, as would happen if the biomass had burned instead of undergoing pyrolysis. This captured carbon prevents the carbon dioxide that would have been produced through burning from adding to the CO<sub>2</sub> content of the atmosphere, thus reducing the effects of global warming.

## Bringing Chemistry to the Kitchen

**1. Name the physicist who began the experimental cuisine movement.**

Nicholas Kurti is the physicist who began the experimental cuisine movement.

**2. Name the French chemist who helped to start the field of molecular gastronomy.**

Herve This helped to start the field of molecular gastronomy.

**3. Which forces are the strongest in cooked eggs?**

Disulfide bridges are the strongest forces in cooked eggs.

**4. Gastronomist Peter Barham has done research on the psychology of food. What does the article say is one of his major findings?**

Barham's findings show that people associate the taste of food to memories related to these foods.

**5. Name the Chicago restaurant that serves avant-garde meals.**

Moto is the Chicago restaurant serving avant-garde meals.

**6. Name two European avant-garde restaurants mentioned in the article.**

Fat Duck (outside London) and Pierre Gagnaire (Paris) are both avant-garde restaurants mentioned in the article.

## The Art and Chemistry of Dyes

**14. Cotton is actually what natural polymer?**

The natural polymer of cotton is cellulose.

**15. Which fabric, wool or cotton, remains neutral in aqueous solution?**

Cotton remains neutral in solution.

**16. What is the name of the dye molecule component that produces the dye color?**

The name of the dye molecule is the chromophore.

**17. What unusual property is demonstrated by the dye prodiginine?**

It exhibits antibacterial activity.

**5. What functional group is added to cotton in order to dye it?**



An amine group  $\text{N}(\text{CH}_3)_3^+$  is added to cotton to dye it.

6. **Why is wool usually dyed at higher temperatures?**

*Wool is dyed at higher temperatures so that the dye molecules can penetrate the lipid layer that surrounds the keratin.*

## **Promising New Vaccines**

1. **What is the difference between an antigen and an antibody?**

*An antigen is any type of molecule that causes an immune reaction in various animals, including humans. The immune response produces antibodies that work against the antigens, or foreign (to the body) objects, trying to destroy them by their ingestion and enzymatic "digestion".*

2. **How does the immune system operate?**

*First, white blood cells (WBCs) called macrophages destroy foreign "bodies", such as bacteria, by engulfing them and shredding them. The shredded pieces, called antigens, become incorporated onto the macrophage's surface, forming what is known as a Major Histocompatibility Complex (MHC). This complex provides feedback (signal) to the immune system to produce more WBCs. A second type of WBC, called a B cell, makes molecules called antibodies that can physically attach to the antigens, marking them for destruction by a third type of WBC called a T cell.*

3. **What are the three types of immune cells and what do they do?**

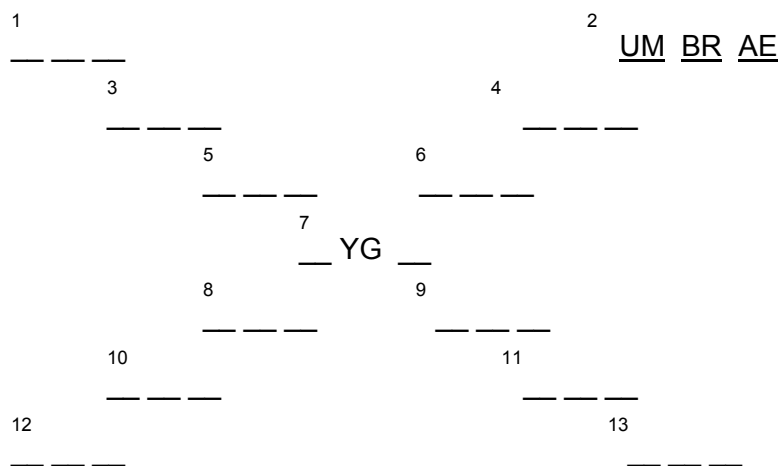
*The three types of immune cells (white blood cells) are the macrophages, the B cells, and the T cells. Their functions are described in the answer to #2 just above.*

## ChemMatters Puzzle

In this crossword variation, we'll test your knowledge of six letter words.

In the X outline below are spaces for inserting doublets of letters that make up words/names, mostly from the world of science. The clues below guide you to the six-letter words each made up of three of those doublets. To help you, in the odd-numbered words the last doublet of clue #1 is identical with the first of #3, etc, while in the even-numbered clues, its just the reverse. For a further help, we'll supply at the bottom ALL the doublets used; you can cross them off as you decipher each clue.

Finally, we'll fill in the letters for clue #2 to get you started, and cross its doublets out.



Clues:

1. Discovered by Marie Curie
2. Shadows created in an eclipse
3. Officiated at clue #5 event
4.  $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$
5. World Series champs in 2007
6. The other driving force besides Entropy
7.  $[\text{He}]2s^2 2p^4$  element
8. Old fashioned way to store  $\text{H}_2\text{O}$  (s)
9. Biological catalyst
10. Sexually stimulating
11. Southern neighbor of USA
12. Father of Coordination Chemistry
13. One of the few paramagnetic elements

The doublets (in alphabetical order):

~~AE~~, BA, ~~BR~~, CO, CO, DI, DS, EB, EN, EN, EN, ER, ER, ER, GY, GY, IC, IC, LT, ,ME, ME, OT, OX, OX, OX, PI, PS, RA, RE, RE, RN, ~~UM~~, UM, UM, UM, WE, XI, ~~YG~~,ZY

## Answers to the ChemMatters Puzzle

- |           |            |            |           |
|-----------|------------|------------|-----------|
| 1. Radium | 3. Umpire  | 5. Red Sox | 7. Oxygen |
| 9. Enzyme | 11. Mexico | 13. Cobalt |           |
| 2. Umbrae | 4. Gypsum  | 6. Energy  |           |
| 8. IceBox | 10. Erotic | 12. Werner |           |

## NSES Correlation

### National Science Education Content Standards Addressed

<b>National Science Education Content Standard Addressed</b> As a result of activities in grades 9-12, all students should develop understanding	<b>Science at Hogwarts — Chemistry in Harry Potter’s World</b>	<b>Ancient Soil Chemists of the Amazon</b>	<b>Bringing Chemistry to the Kitchen</b>	<b>The Art and Chemistry of Dyes</b>	<b>Promising New Vaccines</b>	<b>Research Ethics 101</b>
<b>Science as Inquiry Standard A:</b> about abilities necessary to do scientific inquiry.	✓			✓		
<b>Science as Inquiry Standard A:</b> about scientific inquiry.	✓	✓	✓	✓	✓	✓
<b>Physical Science Standard B:</b> of the structure of atoms	✓					
<b>Physical Science Standard B:</b> of the structure and properties of matter.	✓	✓	✓	✓	✓	
<b>Physical Science Standard B:</b> of chemical reactions.	✓	✓	✓	✓		
<b>Life Science Standard C:</b> about the cell.					✓	
<b>Science and Technology Standard E:</b> about science and technology.	✓	✓	✓	✓	✓	✓
<b>Science in Personal and Social Perspectives Standard F:</b> of personal and community health.					✓	
<b>Science in Personal and Social Perspectives Standard F:</b> about natural resources.		✓				
<b>Science in Personal and Social Perspectives Standard F:</b> of science and		✓		✓	✓	✓

technology in local, national, and global challenges.						
<b>History and Nature of Science Standard G:</b> of science as a human endeavor.		✓	✓			✓
<b>History and Nature of Science Standard G:</b> of the nature of scientific knowledge.	✓	✓	✓	✓	✓	✓
<b>History and Nature of Science Standard G:</b> of historical perspectives.	✓	✓				

## Anticipation Guides

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

**Directions for all Anticipation Guides:** 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.

## Question from the Classroom

**Directions:** In the first column, write “A” or “D” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Heavy noble gases (like radon) attract additional electrons.
		2. The problem with radon is its unstable nucleus.
		3. The strong nuclear force is found only in the nucleus of atoms.
		4. Alpha particles have high energy so if they are inhaled, they can increase the risk of lung cancer.
		5. Radon gas is found only where there are large deposits of uranium.
		6. Radon levels are higher outdoors than indoors.

## Science at Hogwarts—Chemistry in Harry Potter’s World

**Directions:** In the first column, write “A” or “D” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Flame tests are often used to identify nonmetal ions in solutions.
		2. Colored flames are used only by scientists.
		3. Light is emitted when an electron returns to a lower-energy state.
		4. Black flames are easily created in the lab.
		5. Invisible inks are safely made only in a science laboratory.
		6. When the synthesis of a newly created element has not yet been confirmed by other scientists, the provisional name relates to the Latin name of the element’s atomic number.
		7. Both molybdenum and lead make dark marks on paper.



## ***Ancient Soil Chemists of the Amazon***

**Directions:** 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.

<b>Me</b>	<b>Text</b>	<b>Statement</b>
		1. The Amazon rainforest has been sparsely populated until recent times.
		2. Soil can collect carbon dioxide gas.
		3. Amazon soil contains iron and aluminum compounds, making it yellow or orange.
		4. Trees in the Amazon rainforest get their nutrients from the soil.
		5. Soils in North America have silicate clays that help hold nutrients in the soil.
		6. Ancient Amazonians grew mostly maize.
		7. The black soil found in the Amazon contains much rotting matter, making it nutrient rich.
		8. Biochar is made by heating wood in an environment without enough oxygen to burn.
		9. Hydrogen fuel may one day be made using pyrolysis.
		10. The production of biochar contributes to global warming.

## ***Bringing Chemistry to the Kitchen***

**Directions:** 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.

<b>Me</b>	<b>Text</b>	<b>Statement</b>
		1. Chemists understand most of what happens to food as it cooks.
		2. Molecular gastronomists study the chemistry of cooking food.
		3. Very few foods are colloids.
		4. Eggs cook because of the formation of disulfide bridges that form when the proteins in egg white unfold and form cross-links with other proteins.
		5. Molecular gastronomists create food in which the ingredients are unrecognizable.
		6. Some molecular gastronomists study the psychology of eating food.
		7. When people eat food that they consider very tasty, they swallow it quickly.
		8. Foods that are not sweet may be combined to make a dish that is sweet.
		9. You are expected you finish your meal in 3-5 minutes at a restaurant that serves avant-garde food.
		10. A molecular gastronomist might use liquid nitrogen to prepare a special dish.

## ***The Art and Chemistry of Dyes***

**Directions:** 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.

<b>Me</b>	<b>Text</b>	<b>Statement</b>
		1. Wool and cotton are dyed the same way.
		2. An acidic dye bath causes the keratin molecules in wool to ionize.
		3. Dye molecules absorb some colors of light and reflect others.
		4. Molecules to dye both cotton and wool are negatively charged.
		5. Wool is dyed at low temperatures.
		6. The finishing process after dyeing can improve the washing colorfastness of colors on cotton fabric.
		7. Natural red pigments produced by marine bacteria may be used to produce antibacterial dyes.
		8. When you tie-dye a T-shirt, an ionic bond forms between the dye and the fabric.

## Promising New Vaccines

**Directions:** In the first column, write “A” or “D” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. One major problem with producing vaccines to protect against viruses is that the viruses change constantly.
		2. Most vaccines today are made from the microbes that cause the disease.
		3. Infected cells are indistinguishable from noninfected cells in the body.
		4. Cancer vaccines that are being developed contain pieces of cancer cells.
		5. Tumor cells have antigens on their surface.
		6. Antigens consist of only one type of protein.
		7. Once scientists discovered how to deactivate the HIV antigen by using decoy antigens, it took only a few months to figure out how to weaken the decoys so that the immune system could refocus on the HIV virus.

## Research Ethics 101

**Directions:** In the first column, write “A” or “D” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Honest communication is very important in research ethics.
		2. Scientists should report only data that match their expectations.
		3. Using the hypothesis of another researcher is ethical as long as the work has not been published.
		4. Research subjects, whether human or animal, must be treated well.
		5. Scientific journal articles must present your work in such a way that another scientist can repeat your work.
		6. Scientific research ethics has been largely ignored by businesses and schools.
		7. Integrity is crucial to scientific research.
		8. Ethical decision making should be practiced even in high school lab reports.

## 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.

<b>Score</b>	<b>Description</b>	<b>Evidence</b>
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

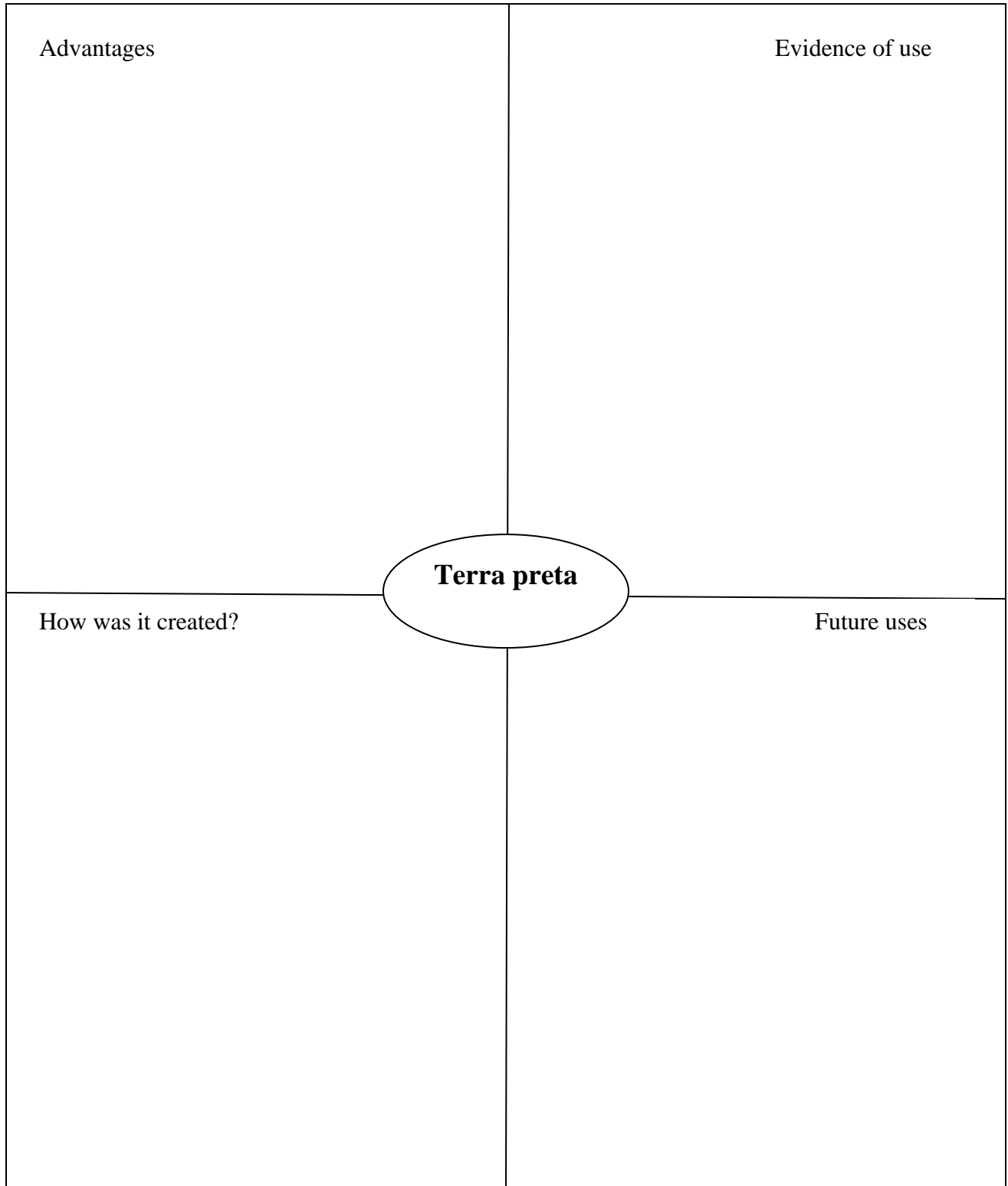
## **Science at Hogwarts—Chemistry in Harry Potter’s World**

**Directions:** As you read, please complete the table below with chemical explanations for some of the activities in Harry Potter’s world.

<b>Chemistry</b>	<b>Description</b>	<b>Possible explanation</b>
<b>Flames, fireworks, stars and elements</b>	<b>Red and gold sparks</b>	
	<b>Black flames</b>	
	<b>Emerald green fire</b>	
<b>School supplies</b>	<b>Invisible ink</b>	
	<b>Color-changing ink</b>	
	<b>Parchment paper</b>	
<b>The language of spells</b>	<b>Common Latin suffixes</b>	

## ***Ancient Soil Chemists of the Amazon***

**Directions:** As you read, please complete the chart below using information from the article.





## ***Bringing Chemistry to the Kitchen***

**Directions:** As you read, please complete the chart below, using examples from the article.

What is it?	Who practices it?
<b>Molecular Gastronomy</b>	
How is chemistry involved?	Examples of creations

## ***The Art and Chemistry of Dyes***

**Directions:** As you read, please complete the chart below describing the problems and solutions involved with dyeing.

	<b>Problems</b>	<b>Solutions</b>
<b>Dyeing a blend of cotton and wool</b>		
<b>Making shrink-proof wool</b>		
<b>Preventing color from fading</b>		
<b>Antibacterial dyes</b>		

## ***Promising New Vaccines***

**Directions:** As you read, please complete the chart below to compare and contrast different types of vaccines.

<b>Type of vaccine</b>	<b>How they work</b>	<b>Future uses</b>
<b>Traditional vaccines</b>		
<b>DNA vaccines</b>		
<b>Immune dampening and refocusing vaccines</b>		

## **Research Ethics 101**

**Directions:** As you read, please complete the chart below about the ethical standards for scientists and researchers.

<b>Standard</b>	<b>Ethical expectations</b>	<b>Consequences of being unethical</b>
<b>Communication</b>		
<b>Ethical treatment of subjects</b>		
<b>Journal articles</b>		

# Science at Hogwarts—Chemistry in Harry Potter’s World

## ***Background Information***

### **More on colors in flames and atomic spectra**

All elements when heated sufficiently will give off light. Gases will give off light when subjected to high voltage electricity. We see the light produced by a flame as a single color. When the same light is viewed with a spectroscope, the single color is broken into a series of lines. The number and arrangement of the lines are unique to each element and are used in the identification of the element present in a sample of unknown composition. Rainbows have been viewed and admired from time immemorial. Isaac Newton was the first person to dissect white light into a series of colors—a spectrum—using a beam of light falling on a prism. Newton was also able to take the spectrum and, reversing the process, combine the colors into white light.

Niels Bohr published the seminal article on the interpretation and explanation of the formation of spectra in the July, 1913 Issue of Philosophical Magazine. He proposed that absorption of energy—heat, light, electrical—moved electrons from their stable ground state orbits into higher unoccupied orbits. As the electrons fell back into their original ground state orbits, energy in the form of electromagnetic radiation was released. The electromagnetic energy with a wavelength of 400 to 700 nm produces the visible light one sees. Without the aid of a spectroscope which breaks the light into its component lines, the naked eye blends the lines into a single color.

The term spectroscope indicates that the detector is the human eye. A spectrograph utilizes light sensitive—photographic—film as the detector. Spectrophotometers and spectrometers use sensitive photomultiplier tubes and electronics as the detector. Each element produces a unique spectrum, a unique set of lines which can be used to identify the element. “A brief (Incomplete) History of Light and Spectra” by John Sparks is available at the ChemTeam site: <http://dbhs.wvusd.k12.ca.us/Electrons/Electrons.html>. The article provides a brief description of the contributions of a significant number of scientists who helped develop the current model on light and spectra.

### **More on creating the colored fire**

The colored fires are created by mixing metal salts with the combustible materials. Candles, both liquid and solid, logs, pine cones, sawdust, and cork are all capable of creating colored fire. The key is to soak, mix, or coat the combustible material with the metal salt(s). A number of websites provide detailed instructions. These can be accessed in the project/demonstration section. Caution must be emphasized. With the current emphasis on safety, working with fire, colored or not, may not be possible. With or without the instructor’s help, students may proceed on their own and attempt to recreate the colored fires.

### **More on building spectroscopes**

The key to building a working spectroscope is the quality of the diffraction grating used to break up the light entering the spectroscope. Diffraction gratings act as “super prisms”. The gratings are made up of a large number of parallel, closely spaced slits. The large number of slits allows for the viewed spectrum to consist of sharp and narrow bright lines. The article provides a

link for making a spectroscope from a CD. Spectroscopes can also be made from 35mm film canisters, small pizza boxes, and shoe boxes. (The reference for construction of the 35 mm spectroscope is <http://www.chymist.com/Make%20a%20Spectroscope.pdf>.) The design in each case requires one to attach the grating to one side of the canister/box and to cut a narrow slit on the side opposite the grating. The source is viewed by placing the eye in front of the grating and centering the light source on the slit. Two sets of spectra are generated one on each side of the slit. The pizza box spectroscope can be made into a very precise and accurate tool for measuring line spectra. The diagram to the right shows the basic construction of the spectroscope. The glass or plastic rod acts as a light pipe.

The scratch inscribed on the rod is visible if light enters the rod. In a darkened room, shine the light from a pen-light source to illuminate the scratch.

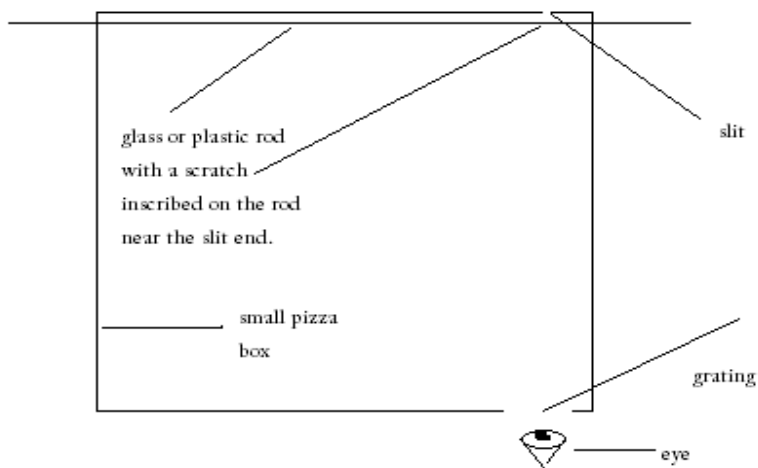
After construction, the spectroscope must be calibrated. If the lab still uses older style fluorescent lights which contain traces of mercury vapor, the mercury spectrum can be used in the calibration. A mercury lamp or mercury discharge tube may be used instead of the fluorescent lights.

Align the scratch over each of the three visible mercury lines. Use a metric ruler to measure the length of the rod that protrudes from the side of the box nearest the slit. Record the length and match it with the known wavelength of the mercury line. Repeat the process for each of the lines. The mercury spectrum consists of a difficult to see violet line at 404.7 nm, a blue line at 435.8 nm, a green line at 546.1 nm and a double yellow orange line at 557-579 nm. To complete the calibration, use a program such as Excel® to plot the length of the glass rod (x axis) vs. the wavelength of the mercury line (y axis). Determine the equation of the line. Correlation coefficients of 1.00 are common.

The equation allows one to observe the line spectra of other sources. Positioning the scratch on a line of the observed spectrum, measuring the length of glass rod that protrudes, and inserting the length into the equation generated for the spectroscope allows one to calculate the wavelength of the observed lines. Wavelengths within 1% of the accepted value have been obtained. Complete instructions on how to build this spectroscope were originally published by Dr. Stephen Thompson in ChemTrek, a most innovative university level lab manual.

The challenge of obtaining spectral data from a hand held spectroscope is the difficulty in maintaining the actual flame color. The colored flame must maintain the color for a period long enough to allow the viewing of the spectrum and to align the scratch over one of the lines. The two methods most often used require the insertion of the salt into the air intake of the Bunsen burner. One method uses salt shakers and finely powdered salts. Shaking the salts at the base of the burner allows the powder to travel up the barrel and results in a long lasting flame.

A second method utilizes a plastic Petri dish. A circular hole is cut into the lid of the dish. Dilute hydrochloric acid, mossy zinc, and a sample of the salt whose spectra is to be examined is placed in the Petri dish. The hydrogen bubbles created by the reaction of the zinc with the hydrochloric acid carry traces of the metal salt. Placing a Bunsen burner above the hole in the



Petri dish cover, allows the bubbles to rise through the barrel of the burner. The long lasting colored flame allows the observer to make the necessary measurements. Separate Petri dishes may be used to examine the spectra of a variety of salts. A number ten can or metal gallon paint can with a hole cut in the bottom may be inverted over the Bunsen burner and Petri dish. The setup allows for a more stable flame. Flinn Scientific sells a kit which includes all of the necessary materials

### **More on invisible and color changing inks**

The article outlines two experiments students are able to carry out. For a more complete description of the chemistry of invisible inks and the large variety of color changing pens available at toy stores or on-line, consult the articles written by David Katz, who has been publishing articles on the chemistry of toys since the early 1980's. Katz gives permission to teachers to use his materials as long as the original copyright is acknowledged. The article on the chemistry of disappearing inks may be found at (<http://www.chymist.com/Disappearing%20Ink.pdf>). Katz discusses the chemistry of color changing pens at (<http://www.chymist.com/color%20changing%20pens.pdf>). He also provides a complete student investigation based on color change pens at (<http://www.chymist.com/color%20changing%20investigation.pdf>).

### **More on names and symbols of the elements**

A wealth of information on the naming of the elements is available in books, journals, and on the web. Peter van der Krogt has posted one of the most comprehensive web sites dealing with the names and naming of the chemical elements. He states in the introduction to his site, "I am not a chemist, but a (map) historian much interested in the origin of names. On several of the sites listing elements you will find historical notes and often an explanation of the origin of element names. However, mostly, the authors of these pages copy each other and the same errors and mistakes are repeated. I tried to do some new etymological research on the element names, and find the original articles where the discoverer of a new element announced his find and explained the naming."

The site does not include any physical or chemical data on the elements. Such data is available from numerous sites. Instead Krogt has produced 117 pages, one for each element. Each element page includes a history of the discovery and naming of the element; a list of the names of the element in 70 languages; and at least one illustration. The illustration may be "the appearance of the element, a mineral in which the element occurs, a portrait of the discoverer, or an example of the use of the element." Links to added information are also found on each of the pages. The site may be accessed at <http://elements.vanderkrogt.net/index.html>.

### ***Connections to Chemistry Concepts***

1. **Atomic Spectra**—Flame colors, atomic spectra, and spectrosopes may be used in the units on the study of the structure of the atom and electrons in atoms.
2. **Operation of a spectroscope**—Information is provided for constructing a CD spectroscope. The guide in the previous section provides information and resources for constructing 35 mm canister and pizza box spectrosopes.
3. **Acid Base Indicators—Disappearing Inks**—The section on invisible and disappearing ink provides an entry into the discussion of acid base indicators.

4. **Elements, Names and Symbols, the Periodic Table**—The concluding section of the article allows one to review the names and symbols of the elements, especially those whose symbols do not match the names. It might also be useful to refer to this article when discussing names and symbols of the elements, typically, early in the chemistry course.

## **Possible Student Misconceptions**

1. **“Chemistry is magic.”** *A demonstration not explained or a concept not understood falls into the realm of “magic”. The many spells described in the Harry Potter books belong to the realm of “magic” until a rational explanation is presented. Almost all of the incidents described in the excerpts can be reproduced in the laboratory, with a possible exception of the black flames.*

## **Demonstrations and Lessons**

1. **Levitation Wand—Fun Fly Stick**  
The fun fly stick, which can be made to look like a wand, allows one to levitate a series of Mylar objects using static electricity. The moving rubber band inside the wand generates an electrostatic charge. Touching the Mylar object to the wand imparts a charge on the object identical to the charge on the wand. The similarly charged objects repel each other. The wand allows the user to suspend or levitate the objects. Decorating the Fun Fly Stick to look like a magic wand and proclaiming the magic words, “Wingardium Leviosa”, as one touches the Mylar object mimics the casting of a spell similar to the one Hermione casts in Harry Potter and the Sorcerer’s Stone, p. 171. You can view a video clip of the Fun Fly Stick in action and obtain additional information and activities at the manufacturer’s website, <http://www.unitechtoys.com>. The wand is available from Educational Innovations (<http://www.teachersource.com>).
2. **Invisibility demos—Polyacrylamide crystals and spheres**  
Polyacrylamide crystals sold under the brand name Soil Moist Crystals are small grains which, when placed in water, seem to disappear. An invisibility spell can be cast on the small crystals to make them grow and disappear in water. Small spheres also made of the crosslinked polyacrylamide polymer are also available. These small beads grow into 2-3 cm spheres which disappear in water. A loop of yarn is placed around one of the beads. When submerged in a glass of water, the bead disappears and the yarn forms a (seemingly empty) circle in the water. Lifting the yarn out of the water results in the previously invisible bead magically appearing as it rises above the water. Polyacrylamide crystals and spheres can be purchased from science supply companies, or from garden shops, where they are used to uniformly provide water to plant roots over watering/drying cycles.
3. **A magic wand that does miraculous things to a stream of water**—An old physics trick involved creating a parabola shaped spray of water by taking a finely tipped glass tube connected to a rubber hose attached to the cold water faucet and allowing the stream of droplets of water to fall into a sink. When the teacher points a black wand (a rubber rod which has been rubbed with flannel or fur) near the stream, the fine spray coalesces into larger drops and into a single stream of water. The fine spray consists of a large number of fine droplets of water carrying the same electrical charge. The water droplets repel each other resulting in the fine spray. The black rod made of ebonite and charged with static electricity by rubbing it with fur or flannel neutralizes the charge on the droplets of water as the rod is brought near the spray. The droplets no longer repel each other. They coalesce into larger drops and form a single stream



of water. The flow of water and height of the stream can be controlled with a pinch cock attached to rubber hose.

4. Color Flame Candles—These candles are available from a number of sources and can be used as a mystery, CSI type exercise to determine the presence of the metal ion producing the various colors. If a diode array spectrometer is available, obtaining the spectra of the candles is a simple matter. If one is not available, a spectroscope can be used to examine the spectra of the candles and compare them to the spectra of known elements. The multicolor novelty boxed candle set includes 12 candles and holders that are biodegradable and non-toxic and made of clean burning soy wax. The candles burn with red, purple, green, blue, and orange flames. The candles are available from Miles-Kimball (<http://mileskimball.com>). A set of solid color flame birthday candles which burn with different colors is available from Target or online (<http://www.target.com>).



5. Rainbow Color Crystals, Sticks, and Cones—The three products available from <http://www.northlineexpress.com> impart colors to already burning fire; e.g., fireplace or camp fire. “Rainbow Flame Crystals is a granular mixture of crystals that make flames into a beautiful panorama of long lasting green and blue colors... Rainbow Flame Sticks are the same granular mixture in a convenient pre-measured sealed stick... The Color Cones package contains a mixture of different species of pinecones; pinion, loblolly, Douglas fir, and sand pine. Color Cones should only be used in wood fires including wood burning fire places and campfires. They should not be used in gas log fireplaces. A well-established fire will completely burn the cones and leave no residue.” As with the color flame candles, students may be challenged to identify the metal salts present in the samples by comparing the spectra of the samples with known spectra.
6. Purchasing colored flame oils—Of special interest is the company More Than Light which creates a variety of oil and paraffin based flames and candles. The oil based products actually burn with different colored flames while the paraffin based products are colored oils but burn with the same bright yellow smokeless flame. More information is available at (<http://www.more-than-light.com/>).
7. Creating Colored Fire—Two sources are available for creating your own colored flames. The first (<http://chemistry.about.com/cs/howtos/a/aa052703a.htm>) provides a set of detailed instructions on how to create colored fire in a variety of venues. “Metacafe”

(<http://www.metacafe.com> a site similar in scope to “U-tube” has two videos which provides hands on instructions on how to create several types of colored fire. [http://www.metacafe.com/watch/701569/how\\_to\\_make\\_colored\\_fire](http://www.metacafe.com/watch/701569/how_to_make_colored_fire) and [http://www.metacafe.com/watch/796180/how\\_to\\_make\\_colored\\_flame\\_trails\\_and\\_fire\\_pools\\_special\\_effects/](http://www.metacafe.com/watch/796180/how_to_make_colored_flame_trails_and_fire_pools_special_effects/).

8. Harry Potter field trip. For those of you living within driving distance of Chicago, Harry Potter: The Exhibition opens April 30, 2009 at the Chicago Museum of Science and Industry. For more information go to [http://www.harrypotterexhibition.com/pdf/HarryPotterTheExhibition\\_MSI.pdf](http://www.harrypotterexhibition.com/pdf/HarryPotterTheExhibition_MSI.pdf).

## Student Projects

1. Preparing materials to color flames, especially the flames in a fireplace. Logs—natural and paper, pinecones, sawdust, and cork can be treated to produce colored flames in an already burning fire in a fireplace. In most instances, the objects are soaked in either alcohol or aqueous solutions. For complete instructions consult the following article in About.com chemistry (<http://about.com/cs/howtos/a/aa052703a.htm?p=1>). If this URL doesn't take you directly to the coloring fire article, but to the about.com homepage, type in “how to color fire” in the search box to take you to the article.
2. More Chemistry at Hogwarts. Have the students read the article, “The Chemical Wizardry of J. K. Rowling,” found in the October, 2006 issue of the *Journal of Chemical Education*. The article purports to serve as a Guide for Chemical Muggles. Copes relates gelled alcohol, sparklers, flash paper, highly exothermic oxidation-reduction reactions, more details on invisible inks and color-changing inks, shrinky dinks, magic sand (hydrophobic material), super slurpers (hydrophilic polymers), carbon dioxide bubbles, copper changed to “silver” and “gold”—all of these—to spells encountered in the Harry Potter series. The references are extensive. Interested students/chemistry club members could use the information in the article to develop a Harry Potter chemistry show.

## Anticipating Student Questions

1. **“How can I perform the demonstrations/spells?”** *The previous sections, especially the Demonstrations and Lessons, provide instruction on how a number of demos related to the article and to the books can be performed.*
2. **Are there other demos that relate to the Harry Potter books?** *There are many other demos that can be associated with excerpts from the Harry Potter books. A number of books have been written on the science in Harry Potter. The best introductory source is the article written by Copes, the current author, in the Journal of Chemical Education listed as one of the references.*

## References

**ChemMatters articles:** The three references below can be found on the *ChemMatters* 25-year CD (covering years 1983 through 2008). The CD is obtainable from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. Selected articles and

the complete set of Teacher's Guides for all issues from the last 5 years are also available at this site."

Graham, Tim. Colors Bursting in Air. *ChemMatters*. **1998**, 13 (3) pp 7-9.

Anderson, Cynthia and Katz, David. A Mark of Color: Investigate the Chemistry Behind Color-Changing Markers. *ChemMatters*. **1998**, 13 (3) pp 4-6.

Rohrig, Brian. A Light of a Different Color. *ChemMatters*. **1999**, 17 (2) pp. 4-8.

### **Other sources**

Copes, Jane Snell. The Chemical Wizardry of J. K Rowling. *Journal of Chemical Education*. **2006** 83 (10) pp 1479-1483. Also available on-line at (<http://jchemed.chem.wisc.edu/Journal/Issues/2006/Oct/abs1479.html>). A subscription to *JChemEd* is needed to access the on-line article.

Thompson, Stephen. ChemTrek: Small Scale Experiments for General Chemistry. Englewood Cliffs, NJ: Prentice-Hall, Inc. 1989. (Chapter 2: "Spectroscopy: The Interaction of Light and Matter" contains the detailed explanation and drawings for constructing pizza box spectrosopes.)

Waterman, Ed and Thompson, Stephen. Small Scale Laboratory Manual. Upper Saddle River, NJ: Pearson Prentice Hall, 2005. (Lab 7 Design and Construction of a Quantitative Spectroscope and Lab 8 Visible Spectra and the Nature of Light)

Flinn Scientific Inc. *Flame Test Emission Spectroscopy Kit*. Catalog # AP1716. (<http://www.flinnsci.com>).

## **Web Sites for Additional Information**

### **More sites on flame tests**

[http://www.amazingrust.com/Experiments/how\\_to/Flame\\_Test.html](http://www.amazingrust.com/Experiments/how_to/Flame_Test.html): The site provides a large number of photographs and videos of flame tests. The author gives instructions on how to perform flame tests. Also available is a list of metal ions and the colors they produce. The site also provides a listing of a number of experiments, not related to the article, but which might be of interest to the teacher.

### **More sites on highway flares**

<http://orionsignals.com/highway/Facts/index.html>: The site provides a complete description of the parts of a highway flare, as well as instructions on how to properly use them.

### **More sites on emission spectra of elements**

<http://www.enchantedlearning.com/subjects/astronomy/glossary/spectroscopy.shtml>: The site is an astronomy dictionary, a part of "Enchanted Learning," a subscription site. The term 'spectroscopy' provides historical information as well as descriptions of related terms.

## More sites on building your own spectroscope

<http://www.uwm.edu/~awschwab/specweb.htm>: The site includes a complete set of instructions and templates for building a spectroscope from a CD.

## More sites on making your own quill

<http://www.geocities.com/TimesSquare/5615/quill/english.html>: Leif Euren, a Swede, interested in medieval history, created a beautifully illustrated set of instructions on how to make a quill pen. The site also lists sources of materials needed to produce the pens.

## More sites on encyclopedia of spells

<http://www.hp-lexicon.info/magic/spells/spells.html>: The site is a must for Harry Potter aficionados. An alphabetical listing of each spell used in the books is listed along with a description of the effects, the etymology of the incantation used, and notes from the books telling when and how the spell was used. Spells from the films and games are listed in a separate section.

## More sites on the etymology of the names and symbols of elements

<http://elements.vanderkrogt.net/index.html>: The “More On” section of the teacher’s guide gives a complete description of the website. The site is one of the most complete on the etymology of the names of the elements.

## More sites on ink

<http://pubs.acs.org/cen/whatstuff/stuff/7646scit2.html>: Part of the ACS “What’s That Stuff” series that appears in *Chemical and Engineering News*, the article provides a wealth of information on ink production and sales. Links to other ink related sites are listed.

## More sites on color-changing materials

[www.TeacherSource.com](http://www.TeacherSource.com) is the web site of Educational Innovations, a science supply company that specializes in unique science materials. Several items they sell involve color-changing materials:

1. Goldenrod paper is an acid-base indicator. It changes from bright yellow to red in bases and back again in acids. You can view the paper at <http://www.teachersource.com/Chemistry/pHIndicatorsAndThermometers/ColorChangingGoldenrodPaper.aspx>. The company also provides lesson ideas in a tab at the bottom of this web page.
2. Educational Innovations also sells ultraviolet-sensitive beads that change color in the presence of UV light. See them at <http://www.teachersource.com/LightAndColor/Ultraviolet/UltravioletDetectingBeads.aspx>. Again, lesson ideas are offered.
3. UV nail polish is sold primarily as a novelty item on this page: <http://www.teachersource.com/LightAndColor/Ultraviolet/UVColorChangingNailPolish.aspx>.

4. Color-changing Silly Putty is available at [http://www.teachersource.com/Chemistry/SlimeAndPuttyPolymers/SunburstColor\\_ChangingPutty.aspx](http://www.teachersource.com/Chemistry/SlimeAndPuttyPolymers/SunburstColor_ChangingPutty.aspx) and [http://www.teachersource.com/Chemistry/SlimeAndPuttyPolymers/TwilightColor\\_ChangingPutty.aspx](http://www.teachersource.com/Chemistry/SlimeAndPuttyPolymers/TwilightColor_ChangingPutty.aspx).
5. Thermochromic (heat-sensitive) paper is available at [http://www.teachersource.com/Chemistry/Thermochromic/Heat\\_SensitivePaper.aspx](http://www.teachersource.com/Chemistry/Thermochromic/Heat_SensitivePaper.aspx).

The American Chemical Society also sells thermochromic pens and pencils. Their online catalog can be accessed at [http://portal.acs.org/portal/fileFetch/C/CTP\\_003945/pdf/CTP\\_003945.pdf](http://portal.acs.org/portal/fileFetch/C/CTP_003945/pdf/CTP_003945.pdf). The pens are on page 10 and the pencils, sold as “mood pencils”, are on page 18.

Windy City Novelties, Inc. sells a wide variety of glow sticks, some of which are color-changing glow sticks. You can access their wares at <http://www.windycitynovelties.com/epaysoft/cart/Category.asp?CatID=259>.

### **More sites on teacher information and lesson plans**

“Harry Potter Science Magic with Literature Connections Easy, Interactive, Inexpensive Lessons”: ‘Harry Potter has his magic wand to use at Hogwarts for his magic. But he is not allowed to use it outside of the academy. You can impress, educate and engage your wizards in science class without the use of a magic wand. Here are 10 easy science magic lessons for your science class, home school, play group, day care, after school group, scout troop chemistry badge or for fun with your kids at home.’ The lessons include: Haunted Putty, Ghost Writing or Invisible Ink, Magic Rubber Chicken Bone, Magic ‘Unbreakable’ Plastic Bags, Magic Fire Shield, Magic or Haunted Jumping Bean, and Magic Color Chromatography.’ ([http://www.associatedcontent.com/article/441712/harry\\_potter\\_science\\_magic\\_with\\_literature.html?cat=4](http://www.associatedcontent.com/article/441712/harry_potter_science_magic_with_literature.html?cat=4))

# Ancient Soil Chemists of the Amazon

## ***Background Information***

### **More on rainforests**

Rainforests exist only in the tropical regions of Earth. They occupy approximately 6% of Earth's surface. There are four main areas of rainforest: the Neotropical (~45% of the rainforest cover and  $\sim 1.1 \times 10^6$  mi<sup>2</sup>), the Ethiopian / Afrotropical (30%,  $7.2 \times 10^5$  mi<sup>2</sup>), the Oriental / Indomalayan (~16%,  $3.9 \times 10^5$  mi<sup>2</sup>), and the Australian/Australasian (~9%,  $2.2 \times 10^5$  mi<sup>2</sup>).

The rainforest can be divided into five layers or strata. The top layers consist of the overstory and the canopy. The canopy contains trees that can grow to heights of 100-130 feet. This thick layer of growth at this level prevents the majority of sunlight from reaching the ground. Up to 90% of the existing species of plant and animal life is estimated to reside in the canopy. Occasionally, exceptionally tall trees stick up through the canopy. These trees constitute the overstory. The middle layer, the understory, extends from the bottom of the canopy almost all the way to the ground and is composed of smaller trees, vines, palms and ferns. The lowest part of the understory is known as the shrub layer (5-20 feet above the ground). The bottom layer, the ground layer or floor of the rainforest is covered with tree roots, wet leaves and detritus, and perhaps tree seedlings and vines. The picture most of us have of the forest floor being a jungle of vegetative growth is not the "real deal". There is not enough sunlight penetrating the canopy to allow many plants to grow on the rainforest floor. Plants must "reach for the sky" to get sunlight for growth.

There are two major types of wet tropical forests, equatorial evergreen rainforests and moist forests. Equatorial evergreen rainforests differ from moist forests in that they receive more than 80 inches of rain, distributed somewhat uniformly, throughout the year. They have the highest biological diversity and a well-developed canopy layer of growth. They are near the equator, with little seasonal change, and the length of the day remains relatively constant year round. As a result, these rainforests remain green year round and the trees don't ever drop all their leaves at the same time.

In contrast, moist forests lie farther from the equator and are subject to greater variations in the length of the day and in climate. They only get about 50 inches of rain annually. Cooler dry seasons result in forest-wide leaf drop, creating a reduction of canopy cover which allows sunlight to penetrate to the forest floor and produces greater ground cover than is found in equatorial rainforests.

Forests of all types can be classified as primary or secondary, depending on the level or nature of growth. Primary forest refers to untouched, pristine forest in its original, natural condition, while secondary refers to forest that has been disturbed in some way, either naturally or unnaturally. In rainforest, primary forest probably constitutes a full canopy and a mid-level tier of growth. The ground floor is usually devoid of undergrowth due to the limited sunlight that can penetrate through the canopy down to the forest floor. Occasionally, when a tall tree dies and falls, a temporary gap in the canopy may result in new growth on the forest floor. Primary forest contains the greatest biodiversity.

Secondary rainforest results from re-growth after degradation of the primary forest. This can come from any of several sources: fire from natural causes (lightning), or man-made causes, such as slash-and-burn and slash-and-char for agriculture, or selective logging within the canopy. Secondary forest generally is characterized by a thinner canopy with fewer tall trees, smaller trees (because they don't have to reach such heights just to get sunlight), undergrowth on the floor (because sunlight now can reach the forest floor), and less biodiversity (because many of the animals have moved out and many of the plants may have died out due to the environmental changes they have had to undergo). Secondary forest is frequently referred to as "jungle" due to the dense growth at ground level, although that term also is used when discussing some tropical moist forests as well.

No one knows how long it may take for a secondary forest to regain its primary forest status, but since trees in rainforest canopies can be several hundred years old, this process may take a long time.

### **More on the Amazon River Basin and the Amazon rainforest**

The Amazon River Basin claims the largest rainforest on Earth. It is roughly the size of the continental United States. It covers approximately 40% of the continent of South America. The Amazon contains ecosystems that include tropical rainforest, seasonal forests (similar to savanna, but with more trees, two seasons—wet and dry, leaves drop during dry season), deciduous forests (four seasons, trees lose leaves), flooded forests (flood during rainy season), and savannas (rolling grasslands scattered with shrubs and isolated trees).

Water from the basin drains into the Amazon River, the world's largest river. It is believed to be the second longest, after the Nile, although new developments have traced the source of the Amazon farther upstream and that has caused serious debate about which river is longer, with South American scientists claiming the Amazon is longer. It is known to be 11 times as big as the Mississippi and drains an area roughly as big as the United States. The Amazon River accounts for approximately 20% of the world's total river water flow. The effluent volume of the Amazon is so great (300,000 m<sup>3</sup> per second in the rainy season) that sailors can get potable water from the ocean while still far enough out to sea that the coastline is not yet visible, and ocean salinity is measurably decreased even 500 km from land.

The Amazon Basin is located primarily in Brazil, but it stretches into Peru, Ecuador, Colombia, Venezuela and Bolivia. More than one-third of all species on Earth live in the Amazon rainforest. The forest and river basin stretch more than 2 million square miles. The Amazon River alone is home to more than 3,000 recognized fish species (and still counting). The Amazon Basin typically floods between June and October. The Amazon rainforest is believed to be the oldest rainforest in the world, perhaps 100 million years old.

### **More on deforestation in the Amazon River Basin**

Deforestation is happening at an alarming rate in the Amazon. Brazil's National Institute for Space Research reported that in fiscal year 2008 almost 25,000 km<sup>2</sup> of Amazon rainforest was damaged—razed but not yet cleared. This represents an increase of almost 67% from the previous year. This does not include almost 12,000 km<sup>2</sup> of forest that was completely cleared, nor does it include areas of selective logging for commercial timber, which has been found to be damaging to the rainforest ecosystem also. Satellite images have been instrumental in determining the level of degradation of the forest.

The huge increase in deforestation is thought to be due to the sharp gain in commodity prices very recently. Timber, already mentioned, is one item; others are grain and meat. The latter two require wholesale slash-and-burn to make the land ready for agriculture and pasture. Fires occurred in record numbers in the Amazon Basin in preparation for the next growing season.

Deforestation is believed to account for more than half of Brazil's greenhouse gas emissions. The government there understands that conservation of the forest is necessary to reduce these emissions, but it believes industrialized countries should help pay for it. Some countries have already committed large sums to this project. (Information obtained from <http://news.mongabay.com/2008/1220-amazon.html>. Graphs on this site help to convey the message of the need for conservation of the rainforest, including those that show the relationships between cattle and soy bean prices to the rate of deforestation.)

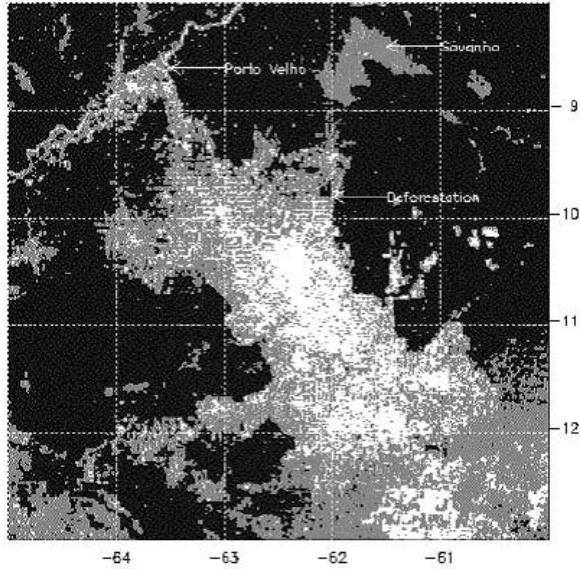
Data from NASA satellites are giving scientists a much clearer picture of the effects of deforestation on local (area) climate. For example, research was done during August of 2000 and 2001, the normal "dry" season in the Amazon and published in June, 2004. This research showed a significant increase in the amount of rainfall and in the ambient temperature over deforested regions of the Amazon River Basin, as compared to the rainforest in the same region. The scientists utilized data from several different sources—NASA, DOD and NOAA satellites—and data that measured different variables: cloud cover, rainfall, temperature, etc.

The data shows that deforested areas heat up faster and reach higher temperatures than forested areas. This results in greater air and moisture circulation which produces greater amounts of rainfall in the deforested area. Researchers found similar increases in cloud cover, temperature and rainfall in areas of savanna (naturally not forested) and in urban areas (deliberately not forested), both of which have less vegetation than the rainforest. Satellite photos illustrating these phenomena are shown below. Other NASA studies show increases in rainfall as great as 28% downwind of urban areas.

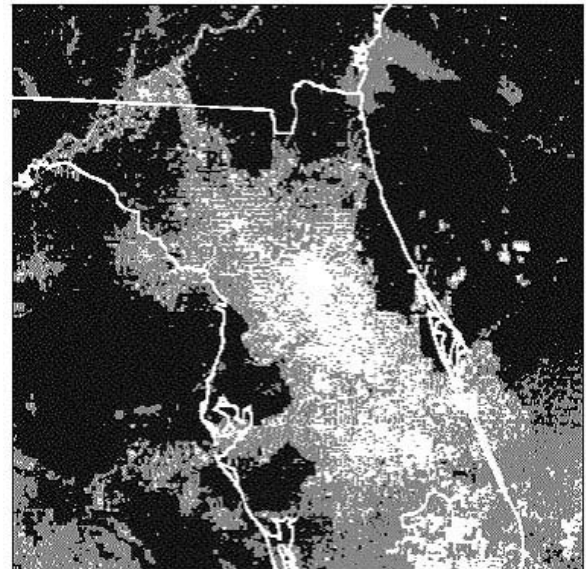
Increases in cloudiness and rainfall occurred earlier in the morning hours in the savanna regions, probably begun by the contrast in surface heating between the deforested rainforest and the savanna. Chopping down the tall trees of the rainforest changes the dynamics of the atmosphere, creating greater air circulation and rising air. This results in greater cooling and subsequent condensation of the warm humid air, resulting in water droplets that form clouds, producing rain.

The results documented by the various satellites agree with computer models developed at the Massachusetts Institute of Technology. These models showed that small-scale circulation that includes greater mixing and rising of air due to changes in local land surfaces could increase cloudiness and rainfall. These findings are based on research done only during the transition from the dry season to the wet season in the Amazon, so the researchers admit that more research needs to be done; nevertheless, there does seem to be a strong connection between changing land topography and climate, and deforestation of the rainforest does have a significant impact on local climate.

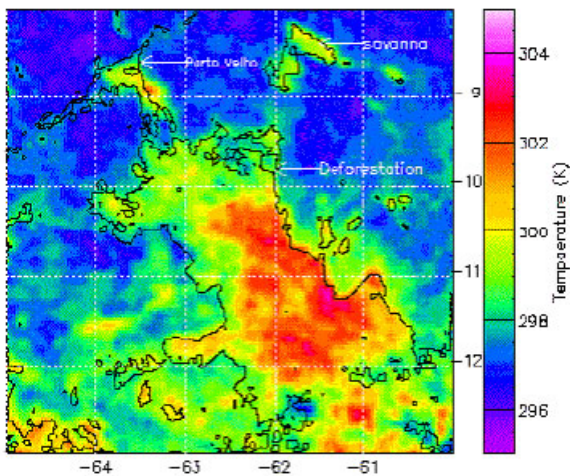




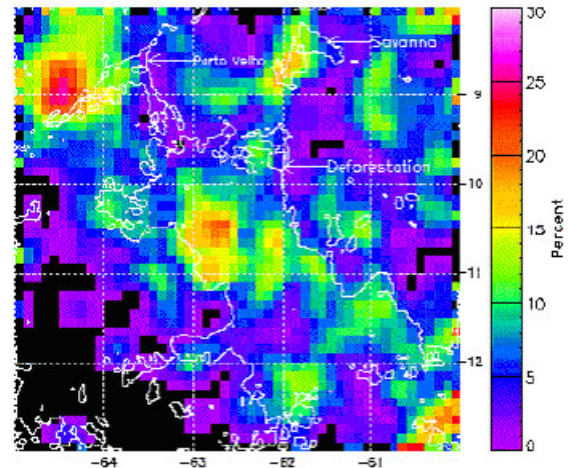
This black and white image was created from the visible channel of the Geosynchronous Operational Environmental Satellite (GOES). Deforested areas are depicted in gray and white shading over Rondonia, Brazil. The lighter shaded area around Porto Velho is a naturally occurring region of savanna and the urban area. CREDIT: NASA & NOAA



This GOES image superimposed over the outline of the state of Florida makes it easier to understand how much land (in gray and white) in Rondonia, Brazil has been deforested. CREDIT: NASA & NOAA



This image shows the mean surface temperature at noon for August 2000. The outlines of the deforestation are in white. A warming of 6 K (11 F) is observed over the non-forested regions with respect to the forested regions. CREDIT: NASA



NASA's Tropical Rainfall Measuring Mission (TRMM) satellite was used to find the percent occurrence of rainfall over the study area. This image was captured during the afternoon hours of August 2000 and 2001. Note the increased frequency of rain (red area) west of, or downwind of the naturally occurring savanna, the urban area of Porto Velho, as well as within the large region of deforestation (white outline). CREDIT: NASA

The images and captions above were taken from the research done at NASA in 2000 and 2001, cited on the NASA web site at <http://www.nasa.gov/centers/goddard/news/topstory/2004/0603amazondry.html>.

But deforestation doesn't only cause local climate problems. It also results in the loss of biodiversity in the temperate region of the globe. Rainforests cover only about 7% of Earth's dry land, but they probably contain roughly half of all plant and animal species on Earth. Many of these species are so specialized to specific microhabitats that they can only be found in small, local areas. Because they are so specialized, they are much more susceptible to minor environment changes, which could easily result in their extinction. Species are always lost when an area is totally deforested, but plants and animals living nearby in the partially deforested areas also become more vulnerable to extinction.

Edges of fragmented areas dry out and are subject to hot, dry winds, making the area climate inhospitable to pre-deforesting flora and fauna, resulting in many extinctions. Even the tall trees of the rainforest that are now exposed to differing climate may not survive the changes. The changed climate changes the types of plants and animals that remain living in the area, thus drastically reducing the biodiversity of the deforested area.

Continuing extinctions is an even greater concern when one considers that it is theorized that a huge number of species living in the rainforests today have not even been identified; yet these species may contain cures for diseases or solutions to the problem of world hunger. Another factor to consider is the need for genetic diversity in the gene pool in order to ensure life will continue in the event of catastrophic events.

Another problem caused by (or maybe the cause of) deforestation is the human conflict that arises between indigenous populations and loggers, miners, colonizers and refugees. Entire tribes are often displaced by companies looking solely for profit. The existing civilizations can make a living from hunting-and-gathering, subsistence farming, or harvesting forest products, but once their habitat is changed by deforestation, they are forced to move to other, probably less-desirable areas to begin life anew.

One last consideration is how much deforestation should be allowed by law in these areas. National and international governments and aid agencies debate the amount of human existence (if any) that should be allowed, to be compatible with global conservation goals.

One last item regarding deforestation: the Colombian government has repeatedly claimed that the use of cocaine in rich countries is driving deforestation in Colombia, as drug traffickers clear rainforest land for planting of coca, the raw ingredient used to produce cocaine. Mongabay.com reports on this plea at <http://news.mongabay.com/2008/1118-cocaine.html>. The government claims that snorting a gram of cocaine is equivalent to the destruction of 4 m<sup>2</sup> of rainforest. Chemicals used in the production and processing of cocaine—kerosene, sulfuric acid and acetone—have polluted streams and rivers, and armed groups protecting the coca crop have killed wildlife for food and target practice. The U.S. and Colombian governments have sprayed large areas of vegetation that were suspected to be coca fields with herbicides, but these herbicides are not selective for coca and the result has been the destruction of all plants in the area—hardly a solution to the destruction of rainforest. Coca continues to be a cause of rainforest destruction.

On the other hand, the drug-trafficking groups zealously guard their territory, and the fear of these groups has prevented logging and agricultural groups from setting up shop in the Colombian rainforest. Colombia presently has one of the lowest rates of deforestation in South America. (Maybe the cocaine traffic is actually reducing rainforest destruction?)

**More on soil in the Amazon rainforest**

Although lush vegetation is usually associated with rainforests, that growth comes not from the rich soil in the area, but from vegetation that has recently died and decomposed. Actually, soil in rainforests is typically very poor. Rainforests are so named due to the huge amount of rain they receive annually. Over years, or centuries, this rain dissolves soluble salts out of the soil, and they wash away, leaving less soluble compounds behind. Soluble salts contain sodium, potassium, calcium, magnesium, phosphorus and silicon, while the insoluble compounds left behind are likely to be iron and aluminum compounds. Plants use the soluble compounds in soils as nutrients, so if these have been leached out of the soil, little is left for plants to use, except for other decayed plants. Such highly weathered, nutrient-poor, aluminum- and iron-rich soils are called *laterite*.

The canopy of trees and other vegetation that grows in the rainforest protects the floor of the rainforest from the torrential rains. The dead and decayed plant material stays on the floor, available as nutrients for new growth. Since the trees get their nutrients from this detritus instead of the soil, they grow well despite the poor quality of the soil. So chopping down the trees that provide this protection ensures that the rains can more easily wash away the nutrients and decaying plant matter, thus decreasing soil quality even further.

In addition, since the decayed material is reused so quickly, few of its nutrients ever reach the soil, leaving the soil essentially sterile. The decay of the dead plant material is aided substantially by the abundance of decomposers on the forest floor. These include bacteria, fungi and insects. Specialized species of fungi also aid tree roots in the uptake of these organic nutrients once they have been decomposed.

When entrepreneurs first went into the rainforests and saw the lush growth, they assumed that the growth was due to the forest's rich soil, and that this would be a great place to grow very profitable crops. So they cleared the trees and prepared the land and planted crops. The first year or two the crops flourished due to the nutrients left on the soil from the decayed plants that were there before the canopy was removed, and the farmers felt vindicated (and rich). But then in the third or fourth year, all the nutrients that were in the soil had been used up or washed away, and there was nothing left for the plants to grow on. Crops failed after the first few years, and even fertilizers didn't improve the crop yield, since the fertilizers, being soluble compounds, washed away also.

Over centuries, the same thing has been happening to the indigenous groups who inhabit the Amazon rainforest. The only way they can keep growing crops is to cut down trees and plant their crops in new fields every few years, as the soil becomes depleted of nutrients from decayed matter. This is at least in part responsible for the deforestation of the rainforests. (Of course, there are many other, bigger reasons the rainforests are being decimated, but that's a story for another article.)

Although both the indigenous farmers and the large investment farmers both suffer the same fate of having to move on to clear new forest every few years, the after effects of the two groups vary greatly. While both plots were cleared for planting, the small farmer's plot is still surrounded by primary forest growth, and this plot can recover some of its growth within a few years as growth from the surroundings finds its way into this cleared area, although it will not be as biodiverse as it was originally. The large cleared plots, however, are now exposed to the sun and rains and are effectively isolated from primary rainforest plant growth. The microorganisms that are needed for efficient uptake of nutrients by tree roots have died, seeds may or may not sprout, since they're now exposed to the harsh sun—and if they do sprout they may not survive,

and animals living in the rainforest no longer survive, reducing seed dispersal in those cleared areas. All of these problems (and more) almost guarantee that these areas will never fully recover to primary rainforest status. Man has changed the landscape drastically—perhaps forever—and not for the better.

Tree farming is one way to avoid the problems of trying to grow other agricultural crops. In the rainforest, a tree farmer simply needs to chop out trees that don't produce edible fruit or nuts and leave behind the fruit or nut trees that already exist there. Then in subsequent years, they simply allow new fruit trees to fill the gaps made by chopping out the other trees, and continue to cull out the saplings from the undesirable trees. This results in the maintenance of the tree canopy, which protects the forest floor from the torrential rains, which in turn retains the decayed plant material on the forest floor, available for future crop growth. This prevents the farmer from being forced to move on to new areas of the rainforest because the decayed material continues to be produced year after year.

Alternatively, growing crops with the use of biochar to replenish the soil would also maintain soil fertility and crop yields, which would also negate the need for poor farmers to move to new areas of the forest and chopping down even more trees to get to “new” soil.

### **More on *terra preta***

*Terra preta* is the term used for the dark, fertile soils that are found in the Amazon River basin. As the article points out, this soil has a high carbon content, which is what gives it its characteristic dark color. Several theories existed in the past to explain this dark soil in areas where soils are typically red or yellow. One theory held that the soil resulted from ash falling from volcanic eruptions, since these soils were known to occur frequently in areas near the Andes Mountains, along higher terraces. Yet another theory suggested these soils were formed from sedimentation in Tertiary lakes or more recent pools of water. The observations that it contained a high charcoal content and pottery shards eventually led scientists to realize that it must be of human origin, and purposely prepared.

Although *terra preta* is usually associated with the Amazon River Basin, it can be found at sites in other areas of South America, West Africa and Southern Africa. These sites are always associated with human development. It has been estimated that *terra preta* covers at least 0.1 – 0.3 % (6,300 – 119,000 km<sup>2</sup> of the Amazon rainforest. Other estimates put it closer to 1.0 % (63,000 km<sup>2</sup>). The distribution of these areas of *terra preta* typically follows rivers or streams, again indicating agricultural origin.

As has been mentioned, *terra preta* has a high carbon content—typically more than 13-14% organic matter. Archaeologists have shown that carbon content varies with location within a living/farming area; e.g., gardens close to living quarters had higher nutrient composition than fields for crops that were farther from dwellings. This clouds the issue somewhat in that it cannot be clearly established whether the dark earth was prepared intentionally for farming, or whether it is merely a by-product of living in the area. These variations in organic content throughout the Amazon rainforest suggest that an extensive native civilization existed 500-2500 years ago.

Great Britain has its own counterpart to *terra preta*, called Dark Earth. It is found 2-3 ft deep, covering Roman remains, especially in London and other Roman ruins throughout England. It is usually found in urban areas. It seems to date from the 2<sup>nd</sup> – 5<sup>th</sup> centuries AD. As is true of *terra preta*, this soil is especially high in organic matter and charcoal, giving it its characteristic dark color. It also contains pieces of tile and brick, once again suggesting human

preparation. It may also reflect the common practice in farming of plowing under the remains of buildings and other materials.

### More on biochar and pyrolysis

The typical way to clear land of plant vegetation prior to farming the land is **slash-and-burn**. In this method all the original vegetation is cut down completely and then burned away, leaving nothing but the ash of the prior vegetation. This process is usually good enough for new planting, as the soil itself still contains the nutrients needed for plants to grow. Unfortunately, in rainforests, the remaining soil is not rich enough to support new vegetation for very long.

The method of clearing land discussed in this article is referred to as **slash-and-char**. The vegetation is still cut down, as in slash-and-burn, but the difference is that in this method the vegetation is only allowed to smolder in a low, slow burn in a smothered fire. This prevents all the plants from burning outright; instead, they degrade into water and char—free carbon. This is similar to the way that charcoal is produced. Since the char does not burn completely into CO<sub>2</sub>, this method puts much less carbon dioxide into the air, lowering greenhouse gas emissions, and it results in carbon, which is returned to the soil, enriching poor soils.

Biochar has been characterized with aromatic groups in its structure. Carboxylic groups form on the outside of these structures, providing anions to which cations in the decaying plant matter and in the soil can adhere, similar in function to the silicate groups in silicate clays. The aromatic groups are also believed to prolong biological and chemical stability and this prevents microbial degradation of biochar in soil that has been infused with it. Studies have shown that biochar has an extremely high nutrient retention. Adding biochar to soil has also been shown to increase the activity of mycorrhizal fungi, known to help tree roots obtain nutrients from their surroundings by decomposing dead plant matter. The porosity of charcoal also contributes to the high absorption of organic molecules and water. *Terra preta* soils have been shown to have a high concentration of organic matter, which remains stable over many years.

An international non-profit organization has developed, the International Biochar Initiative (IBI), to present to the world the case of biochar as a way to improve soil quality, to reduce carbon emissions, to improve water quality by reducing the use of fertilizers, and to provide clean energy. The organization has published several policy papers on the topic. Its white paper on biochar can be found here: [http://www.biochar-international.org/images/White\\_Paper.doc](http://www.biochar-international.org/images/White_Paper.doc), and the IBI web site can be accessed here: <http://www.biochar-international.org/home.html>. It also has published a series of informational papers for use by the press. These pdf files are available at <http://www.biochar-international.org/ibimaterialsforpress.html>. (It may be interesting to note that Dr. Johannes Lehman, of Cornell University and cited elsewhere in this Teacher's Guide regarding his research into the future of biochar, is the Chairman of the Board of IBI.)

Historically, biochar has been made by the process of pyrolysis. Pyrolysis involves the heating organic material in the absence (or at least greatly reduced concentration) of oxygen. The term pyrolysis originated from the Greek and means, decomposition by fire (*pyro*—fire and *lysis*—decompose). Pyrolysis is a process that is widely used in chemical industries; e.g., to make charcoal and activated carbon, as well as methanol, from wood. Many other chemicals are obtained by pyrolysis; e.g., gasoline from mid-weight hydrocarbons from petroleum.

Burning of any organic solid typically involves pyrolysis as a first step. When wood, for example, burns, it is really the vapors that are burning, not the solid, and the vapors are

produced from the heated decomposition of the solid, which is pyrolysis. Cooking also involves pyrolysis. As foods are heated to high temperatures in a dry setting, as in toasting, roasting, baking, grilling, etc., pyrolysis of the organic material results in the browning of the surface of the food. Pyrolysis of proteins and carbohydrates occurs at temperatures below their ignition temperature, but above 100°C, the boiling point of water. That's why foods brown and don't burn when dry, but can't brown as long as water is present. Pyrolysis temperatures are lower than boiling points of fats, however, so meats can brown (pyrolyze) when basting in its own fat. Pyrolysis is also involved in the roasting of nuts and, especially, coffee. Since nuts and coffee beans are small and dry, pyrolysis can occur throughout the nut or bean. This produces flavors and colors that are totally different from the original, green bean.

Pyrolysis of wood results in charcoal. This is essentially biochar. The process is an ancient one, involving the burning of a pile of wood that is almost completely covered with mud, bricks or wet straw. The heat from the part of the wood pile that burns is sufficient to pyrolyze the rest of the pile. The top coat of mud or bricks effectively blocks oxygen from getting to the hot fuel, thus preventing it from burning wholesale. Making charcoal or biochar is still done this way today in many parts of the world.

Industrially, pyrolysis occurs on a large-scale by heating the organic material in a large airtight metal container. This pollutes less, uses a more efficient fuel source, and provides a mechanism for containment and condensation of the volatile products. It also provides for higher temperatures and pressures within the reaction vessel. One of the largest industrial uses for pyrolysis is to make coke for the steel industry, starting with coal, or more recently, petroleum "bottoms"—the solid residue left at the bottom of the petroleum refinery tower. Biofuels are formed from the pyrolysis of biomass—crops grown specifically to be used as a fuel; e.g., switchgrass, or the waste left from other agricultural products; e.g., corn stalks (called stover).

Pyrolysis is also used to destroy hazardous and medical waste. Much higher temperatures are used in this process to ensure the complete breakdown of the material. The U.S. Army had been using a Plasma Energy Pyrolysis System to accomplish the task. The destruction removal and elimination (DRE) rate was determined to be 99.99999%. A slide show from Vanguard Research, Inc. shows this process in some detail at <http://www.jdmag.wpafb.af.mil/peps.pdf>.

If you are looking for more information basics about pyrolysis, Wikipedia is a good place to start: <http://en.wikipedia.org/wiki/Pyrolysis>.

### **More on the latest research on rainforest soil**

An article published in the January 2009 issue of the journal *Nature Geoscience*, "Molybdenum limitation of asymbiotic nitrogen fixation in tropical forest soils", reports that molybdenum seems to limit nitrogen fixation in bacteria in soils in Panamanian forests. Barron, Alexander, Wurzbarger, N., Bellenger, J.P., Wright, S.J., Kraepiel, A., Hedin, L. Molybdenum limitation of asymbiotic nitrogen fixation in tropical forest soils. *Nature Geoscience* **2009**, 2, pp 42-45

Nitrogen fixation by bacteria is the primary mechanism by which atmospheric nitrogen, dinitrogen (N<sub>2</sub>) is converted to plant-available ammonium ions in ecosystems. This process influences plant growth and carbon exchange both locally and globally. Tropical rainforests are estimated to provide one-third of the Earth's primary production of nitrogen-fixing organisms.

The authors go on to say that molybdenum was tested both with and without phosphorus (which was thought to be responsible for N<sub>2</sub>-fixation), and the molybdenum alone seemed to be responsible for the process. The concern raised is that in the highly weathered, acidic soils of rainforests, molybdenum is likely to be very limited, and this limitation may restrict the ability of forests to obtain free nitrogen, despite proposed carbon dioxide fertilization (a process proposed to increase the rate of plant growth and hence, carbon sequestering—to mitigate the greenhouse effect).

## **Connections to Chemistry Concepts**

1. **Decomposition**—Pyrolysis is essentially a decomposition process. This can fit into a discussion of decomposition reactions as one of the 5 general types of chemical reactions.
2. **Complete vs. incomplete combustion**—Biochar is produced as a result of incomplete combustion. This would ideally fit into lessons on balancing chemical equations involving complete and incomplete combustion.
3. **Cations and anions**—Clays attract cations to their surfaces, while iron oxides and aluminum oxides do not, resulting in nutrient-rich clay soils and nutrient-poor terra preta.
4. **Surface chemistry**—Clays adsorb cations onto their surfaces. These soils could be used as examples of adsorption vs. absorption.
5. **Bonding types**—Silicate clay soils attract cations to their surfaces. Ionic bonds result from anion attractions for cations (and vice versa).
6. **Gases and the atmosphere**—Carbon dioxide is produced in every (organic fuel based) combustion reaction. CO<sub>2</sub> is a greenhouse gas and contributes to global warming. Anything we can do to minimize the amount of CO<sub>2</sub> produced will reduce the problem, and biochar preparation helps to accomplish this.

## **Possible Student Misconceptions**

1. **“All soils can grow plants.”** *Soils vary greatly in their ability to support plant life. The article shows us that clays typically contain the soluble cations plants need for vigorous growth (all other conditions being available), while iron and aluminum oxides-based soils do not. And it was shown that it’s not the soil itself that supports plant growth in rainforests, but the decaying matter on the forest floor.*
2. **“Soil in the rainforests must be rich in organic matter—look at the magnificent plants that grow there!”** *On the contrary, as mentioned previously, it’s the dead plant matter that supports the new and continued plant growth, not the soil itself.*
3. **“The Amazon has always been wild and uninhabited.”** *That’s what scientists had thought, too—until recently. The understanding of the significance of terra preta has resulted in scientists now believing that a great civilization may have evolved in the Amazon, based on biochar being used to enrich the soil to allow crops to be grown in that area.*
4. **“The history of the Amazon rainforest doesn’t affect me.”** *Actually, it does. Rainforests represent a very large segment of the Earth’s surface, and they play a large role in the control of global warming. In addition, the process that these ancient people used for agriculture—incorporating biochar into the poor soil—is being investigated today by several research groups as a possible solution to the problem of farming in third world countries and to the problem of world hunger. And don’t forget using pyrolysis as a means to produce a renewable fuel for our energy needs.*

## Demonstrations and Lessons

1. If you're looking for reasons to discuss soils in your classes, you might want to use this 10-slide Power Point slide show from the USDA, titled, "Helping People Understand Soils: 10 Key Messages", at [ftp://ftp-fc.sc.egov.usda.gov/NSSC/Educational\\_Resources/sellsoil.pdf](ftp://ftp-fc.sc.egov.usda.gov/NSSC/Educational_Resources/sellsoil.pdf).
2. Fertilizers added to soil usually contain phosphorus, nitrogen and potassium, as well as other nutrients. You can use the fertilizer package label to engage students to calculate per cent composition of the various elements contained in the fertilizer. For sample problems and fertilizer labels, see pp. 26-35 of the pdf file, *The Chemistry of Fertilizers*, by Jeanmarie Kennedy, at <http://www.cfaitc.org/LessonPlans/pdf/404.pdf>. This file also contains a lab activity to test fertilizers for phosphates, but note that the lab may be somewhat outdated.
3. The soil covering the Earth has been compared to the skin of an apple. For a lesson that demonstrates this analogy and shows how little of even the skin of the apple is actually available, you can get a pdf of the activity at <http://www.alaskafb.org/~akaitc/alaskaAITC/pdf/earthsoil.pdf>. Farmland Trust, Inc. has a 1-minute video clip showing this analogy of an apple skin related to the Earth's soil needed to grow our food. View it at <http://www.farmland.org/news/audiovideo/default.asp#>. The video link appears to the right of the page.
4. To show that ions exist in soils, you could demonstrate the conductivity of a soil/water suspension/solution. You can find an example lesson at NASA's site: <http://soil.gsfc.nasa.gov/elec/soilelec.htm>.
5. As a review of the elements and ions names and formulas as they apply to plants, you might want to refer to *Chemistry in Plant Nutrition and Growth*, for a lesson and a set of questions for students to assess their learning: [http://www.alaskafb.org/~akaitc/alaskaAITC/pdf/9\\_12/chemistry\\_plant.pdf](http://www.alaskafb.org/~akaitc/alaskaAITC/pdf/9_12/chemistry_plant.pdf).
6. For a how-to manual on characterizing various types of soils, see *Soil Characterization Protocol* at <http://soil.gsfc.nasa.gov/touchtheearth/fieldguide.htm>.
7. In a Bunsen burner flame, the inner cone of the flame is the cooler part of the flame. This is referred to as the "pyrolysis zone". In this area, the methane/ethane mixture of gases is heated sufficiently to break them down into individual atoms or groups of atoms, but these decomposed products are not yet hot enough to ignite. The gases have been pyrolyzed. You could demonstrate this to your classes.
8. The keystonecurriculum.org web page contains a series of lab activities for high school chemistry students involving carbon dioxide. The first lab has students mass CO<sub>2</sub> produced from baking soda and vinegar. A second lab compares the mass of CO<sub>2</sub> to that of methane. An extension lab investigates the reactions in a Bunsen burner flame, including the pyrolysis zone of the flame. You can access the lab at [http://www.keystonecurriculum.org/highschool/2009\\_lessons\\_word\\_pdf\\_ppt/11-CO2%20and%20Mass.doc](http://www.keystonecurriculum.org/highschool/2009_lessons_word_pdf_ppt/11-CO2%20and%20Mass.doc). If you decide to do the methane-CO<sub>2</sub> comparison activity, here's a site that tells you how to prepare the methane: [http://home.att.net/~cat6a/org\\_chem-IV.htm](http://home.att.net/~cat6a/org_chem-IV.htm).
9. The Keystone Center has produced an entire interdisciplinary curriculum for high school students on the subject of climate change. Entitled *High School CSI: Climate Status Investigations*, this curriculum gives students an opportunity to "...first develop an understanding of climate change, the potential contributing factors, and then devise potential solutions." Students begin by acting as citizens of different (imaginary) countries around the world, each of which has been affected by climate change. Throughout the series of about



25 lessons, they react to events based on their country of “citizenship”. It is a very thoroughly developed, cohesive set of lessons. It includes several chemistry lab activities, one of which is mentioned in number 8, above. Find the climate curriculum at [http://www.keystonecurriculum.org/2008middleschool/MAIN\\_nav/HSportal.html](http://www.keystonecurriculum.org/2008middleschool/MAIN_nav/HSportal.html).

10. An experiment in physical science back in the days of IPS had students do the destructive distillation of wood in a test tube. Destructive distillation is actually pyrolysis. The wood is heated in a test tube and it decomposes, producing solid, liquid by-products, as well as gaseous methanol. A description of this activity can be found at <http://home.att.net/~cat6a/fuels-1.htm>, and this may be the original lab exercise, written in *Laboratory Exercises to Accompany First Principles of chemistry* by Brownlee et al, 1917: [http://books.google.com/books?id=rh9IAAAIAAJ&pg=PA132&lpg=PA132&dq=destructive+distillation+wood+lab&source=web&ots=qjhQF2APOR&sig=-pqNCIH1gs9IJPZBxpyYfOUAXAs&hl=en&sa=X&oi=book\\_result&resnum=3&ct=result#PPR1.M1](http://books.google.com/books?id=rh9IAAAIAAJ&pg=PA132&lpg=PA132&dq=destructive+distillation+wood+lab&source=web&ots=qjhQF2APOR&sig=-pqNCIH1gs9IJPZBxpyYfOUAXAs&hl=en&sa=X&oi=book_result&resnum=3&ct=result#PPR1.M1). Scroll down to pages 132-134 in the book.
11. After doing the destructive distillation of wood lab you could discuss with students the pros and cons of producing methanol, a good fuel, by this method. This process is similar to what some energy companies are studying using biomass as their fuel source. Would destructive distillation make a good process to make fuel?

## **Student Projects**

1. Students could research the causes of (driving forces behind) rainforest deforestation.
2. Students could research the effects of rainforest deforestation.
3. You might suggest to students to do their own study on the advantages of *terra preta* by maintaining controlled plots of ground at home, one with charcoal and one without, and compare plant growth between the two plots.
4. Some of the ideas contained in the Keystone Center’s *CSI: Climate Status Investigations* curriculum described in Lessons and Demonstrations above could be used as student projects.
5. Students could research and report on the causes and effects of global warming.
6. Students could research and report on carbon dioxide’s role in global warming—based on its chemical and physical properties.
7. Students could research and report on the historical demise of the Amazonian cultures.

## **Anticipating Student Questions**

1. **“What happened to the ancient Amazonian civilization?”** *Anthropologists and archaeologists don’t really know what happened to these people, although some have proposed the hypothesis that diseases brought to South America by the Spanish explorers may have run rampant among the Amazonians, who would have had no natural immunity to the diseases because they were never exposed to them before the Spaniards arrived. The few people who did survive probably reverted to hunting and gathering for their survival. There is some evidence that some of the modern hunter-gatherer tribes in the Amazon may be descendants of the ancient civilization. They have words in their languages for crops like corn and cotton, even though they don’t use these crops themselves. And they have very hierarchical and complex social structures, more resembling a large civilization. Small bands like theirs today typically are more egalitarian.*

2. **“How could almost all evidence of their civilization have disappeared—and so quickly?”** *Unlike other great civilizations, like the Incas and the Mayans, the Amazonians had no appreciable amounts of stone with which to build lasting monuments to their existence. The only building materials readily available to them were trees and mud. When they inhabitants died out, the buildings quickly rotted away and the rainforest quickly reclaimed the land, leaving little or no trace of their existence.*
3. **“Is biochar the same thing as charcoal?”** *Both are essentially carbon. Ancient biochar may have been made at lower temperatures than today’s charcoal, resulting in more biological/organic molecules remaining within the structure of the biochar (not being as fully decomposed as would happen at higher temperatures), which fungi consume, helping them decompose organic matter more quickly.*
4. **“Why do silicate clay particles have negative electrical charges on their surfaces?”**
5. *Simple silica is  $\text{SiO}_2$ , or perhaps  $\text{Si}_2\text{O}_4$ , and is neutral. But in clays one of the silicon atoms is replaced with an aluminum atom to give  $\text{SiAlO}_4^-$ , an anion. Silicon clays are made of sheet-like crystals with this or similar construction. So the main building block of a clay particle can be charged. Of course, there are cations present that are immediately attracted to these anions, and the silicate clay then is really a salt whose anion is macroscopic. The attached cations can easily exchange with cations of other salts within the soil. If a calcium compound is available, the calcium cation could exchange with, say, potassium ions already attached to the clay surface.*
6. **“How do scientists know when the Amazonian civilization was in the area?”**  
*Radiocarbon dating of the pottery sherds and of the biochar itself tells them the range of time over which their civilization flourished.*

## References

### More articles from *ChemMatters* (CM) archives

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. Selected articles and the complete set of *Teacher’s Guides* for all issues from the past five years are also available free online at this same site. (Full articles and *Teacher’s Guides* are available on the 25-year CD for all past issues, up to 2008.)

Fruen, Lois. Soil Chemistry—Sifting Through the Past. *ChemMatters* **2001**, 19 (2), 6-7. Author Fruen trails James Myster, an archaeologist who tests soils to tell about the people who lived in that area. The *Teacher’s Guide* to this same issue gives you some historical background on the scientists who furthered the cause of soil chemistry, and it discusses how radioactive dating of artifacts found at a site using Carbon-14 works.

Scott, Dan. Life on Mars. *ChemMatters*. December, **1994**, 10-13. Although the topic of this article seems rather remote from the Amazon rainforest, it discusses the soil of Mars, which surprisingly, is not so unlike some soils on Earth, specifically the red clay of Georgia and some of the nutrient-depleted soils in the Amazon. All three contain large concentrations of iron(III) oxide.

Stone, Carol. Clues from a Dusty Planet. *ChemMatters*. April, **1998**, 7-9.

This article follows up on analysis of rock and soil samples tested by the Pathfinder rover on Mars.

Alper, Joseph. Biosphere II: Out of Oxygen. *ChemMatters*. February, **1995**, 8-11. Once again, the topic of the biosphere seems somewhat remote from the Amazon, but this article focuses on problems the scientists had with maintaining good oxygen/carbon dioxide balance within the sphere, and the problem traced back, at least in part, to the organic matter content of the soil!

Withgott, Jay. Student Chemist Gets Plants to Do the Dirty Work. *ChemMatters*. **2003**, 21 (2), 4-7.

Marc Burrell, a high school student, did research and discovered that specific plants can be used to clean heavy metals from contaminated soils.

Goldfarb, Bruce. Fascinating Fungi. *ChemMatters*. **1998**. 16 (4), 7-8. In this article, Goldfarb discusses the role of fungi in soil chemistry.

Stone, Carol. The Terra Cotta Warriors—Army from the Earth. *ChemMatters*. **2000**. 18 (1), 14-15.

Thousands of clay statues of Chinese warriors were unearthed in 1974. This article discusses them and their composition—terra cotta clay. The chemistry of clays is discussed.

GLOBE—View from the Ground Up. *ChemMatters*. **2001**. 19 (Special Issue 1), 16. The GLOBE project is discussed. It is an ongoing project whereby students from around the world input their own local data on atmosphere, hydrology, soil, and land cover to an international database.

Barnwell, George. Your Personal Greenhouse. *ChemMatters*. December, **1990**, 8-10. This article discusses the causes of global warming, the responsibilities of the student reader, and what he/she can do to help solve the problem.

Cardulla, Frank. Global Warming—Hot Topic Getting Hotter. *ChemMatters*. . 19 (Special Issue 1), 14-15.

This entire issue is about what we know about the Earth. NASA is featured, as is carbon dioxide.

Herlocker, Helen. Life in a Greenhouse. *ChemMatters*. **2003**. 21 (3) (Special Issue), 18-21.

This is another Earth-based special issue of *ChemMatters*, focusing on the Earth's atmosphere. In this article, updated data is offered on global warming, and the idea of carbon sinks is presented. The *Teacher's Guide* offers extensive background information on global warming.

Vanderborght, Claudia. Flatus—Chemistry in the Wind. *ChemMatters*. **2003**. 21 (1), 11-13.

The author relates this very personal chemistry to atmospheric chemistry. Methane is thought to be a major contributor to global warming, second only to carbon dioxide.

Bleacher, Lora. Follow the Carbon. *ChemMatters*. **2008**. 26 (1), 16-19.

This is another article dealing with the soil chemistry or Mars, based on the new instruments that have already landed, and the new one scheduled to land on Mars in 2010. A description of the Mars Science Laboratory (MSL) rover and what it will do is presented. The focus of the

article is scientists' attempts to detect life (hence, carbon) on Mars. As usual, the *Teacher's Guide* offers more extensive background information and ideas to use in your classroom.

## **Web Sites for Additional Information**

### **More sites on the Amazon River Basin and rainforest**

For a travelogue-type description of the flow of the Amazon River, see <http://www.greatestplaces.org/notes/amazon.htm>.

[http://www.google.com/archivesearch?hl=en&q=Amazon+River+Basin&um=1&ie=UTF-8&scoring=t&sa=X&oi=timeline\\_result&resnum=11&ct=image](http://www.google.com/archivesearch?hl=en&q=Amazon+River+Basin&um=1&ie=UTF-8&scoring=t&sa=X&oi=timeline_result&resnum=11&ct=image) provides an expandable timeline of the history of the Amazon River Basin. This is actually a cool site, as it provides a graph plotted with the number of web sites within the timeline that deal with specific times in the history of the basin vs. the century/decade/year referenced.

### **More sites on deforestation**

Mongabay.com provides much information on the rainforests around the world. You can find photographs of the effects of deforestation at <http://travel.mongabay.com/deforestation.html>.

Mongabay.com also offers charts and graphs depicting the effects of deforestation, along with the context information for each graph or chart at [http://www.mongabay.com/general\\_tables.htm](http://www.mongabay.com/general_tables.htm). The webmaster of mongabay.com also provides numerous photographs of plant and animal life in the tropical rainforest on the same site.

There is also a kids' section of mongabay.com that attempts to educate children about rainforests, deforestation, and the effects it has on rainforests and on the rest of the world.

YouTube provides several video clips on deforestation: <http://www.youtube.com/watch?v=HfQgmlwzRXg> shows slash-and-burn techniques to clear the land and the danger of clear-cutting and grazing. <http://www.youtube.com/watch?v=QFxFW7juOE-o&NR=1> is a photographic essay with a few slides of statistics about deforestation.

You can view a NASA satellite photo of an area of rainforest alongside a deforested area showing myriad cloud formations over the deforested area and none over the forest at [http://earthobservatory.nasa.gov/Features/Deforestation/deforestation\\_update2.php](http://earthobservatory.nasa.gov/Features/Deforestation/deforestation_update2.php).

### **More sites on ancient civilizations**

The New Scientist published an online article about the cultures of the Amazon 500 years ago. You can read it at <http://www.newscientist.com/article/dn14624-amazon-hides-an-ancient-urban-landscape.html>.

### **More sites on Amazon soil and *terra preta***

Cornell University researchers have produced a web site describing some basic information about *terra preta* and its discovery in Amazonian dark earths. You can see this at <http://www.css.cornell.edu/faculty/lehmann/research/terra%20preta/terrapretamain.html>.

A brief summary of the unveiling of the role of *terra preta* in the Amazon's history is presented in a BBC production, "The Secret of El Dorado", and can be seen at <http://www.bbc.co.uk/science/horizon/2002/eldorado.shtml>.

Dr. Lehman, the primary researcher in *terra preta* at Cornell has also published a science brief describing the use of biochar to produce *terra preta*, and its historical use in the Amazon rainforest. View it at <http://www.css.cornell.edu/faculty/lehmann/research/terra%20preta/Flyer%20terra%20preta%20landuse%20strategy.pdf>.

OK, this one isn't about Amazon soil, but did you know that there were (in the U.S.) *state* soils? Well, there are. Check out your state soil at this USDA web page: [http://soils.usda.gov/gallery/state\\_soils/](http://soils.usda.gov/gallery/state_soils/).

For a list of quotations about soil, see the list compiled by the National Resources Conservation Service (NRCS) at [http://soils.usda.gov/education/resources/k\\_12/quotes/](http://soils.usda.gov/education/resources/k_12/quotes/).

For a discussion of the role of soils in sequestering carbon, download the pdf fact sheet, *Carbon Sequestration in Soils*, from the Ecological Society of America, at <http://www.ecoed.net/app/webroot/files/Carbon%20Fact%20Sheet%20Final-2-1.pdf>. You'll need to register on their site to access their publications, but the registration is free.

*Scientific American* published a special report online on May 15, 2007, discussing *terra preta*, the Amazonians and global warming. You can find it at <http://www.sciam.com/article.cfm?id=pyrolysis-terra-preta-could-eliminate-garbage-generate-oil-carbon-sequestration&ref=rss>.

## More sites on biochar and pyrolysis

Dr. Lehman of Cornell University has published a series of articles in many journals, all of which are designed to show the viability of biochar as a partial solution to several problems facing mankind: global warming, increased need for ever-greater food production capabilities, and energy production. Here are several of those articles:

<http://www.css.cornell.edu/faculty/lehmann/publ/Nature%20447,%20143-144,%202007%20Lehmann.pdf> suggests that putting biochar back into the soil is way better than burning it,

<http://www.css.cornell.edu/faculty/lehmann/publ/PlantSoil%20249,%20343-357,%202003%20Lehmann.pdf> is an article from *Plant and Soil*, in which Dr. Lehman compares the effects of fertilizer, manure and biochar added to Amazonian soils.

In this online publication, Lehman and colleagues compare cation exchange capacity (CEC) in various types of soils and conclude that biochar increases the CEC in all types of soils tested when biochar was added:

<http://www.css.cornell.edu/faculty/lehmann/publ/SoilSciSocAmJ%2070,%201719-1730,%202006%20Liang.pdf>.

Farmers planning to use biochar in their fields may be able to profit from it in a more direct way than waiting for crop yields—they may be able to sell carbon credits to companies

trying to offset their production of greenhouse gases. See this article in *Science Daily* for more details: <http://www.sciencedaily.com/releases/2007/05/070518125608.htm>.

Here is Eprida's web site, showing their vision of the future of pyrolysis in a flash presentation: [http://www.eprida.com/eprida\\_flash.php4](http://www.eprida.com/eprida_flash.php4).

The International Biochar Initiative has published a paper on biochar production, using pyrolysis and gasification of the fuel. The paper includes the terminology and technology involved in the processes. Find it at <http://www.biochar-international.org/images/Terminology.doc>.

Scott Bidstrup wrote an online essay entitled, *Saving the Planet while Saving the Farm*, in which he discusses the history of the Amazonians, *terra preta*, soil replenishment, saving the Earth by decreasing CO<sub>2</sub> emissions, and an easy, cheap way to make biochar happen. You can read his essay at <http://www.bidstrup.com/carbon.htm>.

### **More sites on teacher information and lesson plans**

NASA has a web page that deals with soil science for educators, "The Soil Science Education Home Page", which you can access at <http://soil.gsfc.nasa.gov/index.html>. It includes references to the National Science Education Standards that pertain to soil science.

The Soil Science Society of America (SSSA) web site lists many resources for teachers and students of all grade levels at <https://www.soils.org/lessons/resources/>.

If you would like to give students an idea of career possibilities in the area of soil science, you can send them to *Careers in Soil Science* from the NRCS at <http://soils.usda.gov/education/facts/careers.html>.

Or they could try CollegeGrad.com's web site at <http://www.collegegrad.com/career/sciencecareer.shtml>.

The University of California, Riverside also has a site that lists careers for soil science at <http://careers.ucr.edu/students/careersoilsci.htm>.

And here's a whole list of career possibilities with links, from NASA: <http://soil.gsfc.nasa.gov/links/careers.htm>.

### **General Web References**

Mongabay.com provides a wealth of information on the rainforests of the world, including up-to-date research and discoveries that relate to the rainforests. The mission of mongabay.com, according to the author, Rhett Butler (yes, Rhett Butler!) is to save the rainforests of the world. You can access his work at <http://www.mongabay.com/>.

The World Wildlife Foundation (WWF) sponsors conservation projects all around the world. It has nineteen ongoing projects in the Amazon River Basin. You can check on these projects as well as the people working on the projects at <http://www.worldwildlife.org/what/wherewework/amazon/item1376.html>.

# Bringing Chemistry to the Kitchen

## *Background Information*

### **More on Molecular Gastronomy**

The article gives a brief history of molecular gastronomy, focusing on the contributions of Nicholas Kurti and Hervé This (pronounced “Tees”). See below for a few more details on the origins of this discipline. This section of the Teachers Guide will concentrate on the science of molecular gastronomy and how it can be related to chemistry concepts.

As the article describes, molecular gastronomy was established in the 1980’s as a scientific discipline that studies the physical and chemical processes involved in cooking. The article breaks these down into three areas of study:

- the chemicals in food
- how these chemicals change when food ingredients are mixed together
- the transformations that happen to food during cooking.

The article also extends the influence of molecular gastronomy to the study of food psychology, avant-garde cooking and experimental cuisine restaurants and the public perception of food sciences. These sections of the article will be referred to later.

When This first outlined the objectives of molecular gastronomy in 1995, he listed five:

- i. to investigate culinary proverbs and old wives tales;
- ii. to examine and model recipes;
- iii. to introduce new tools, ingredients, and methods into the kitchen;
- iv. to invent new dishes based on new knowledge discovered through pursuing aims one through three; and
- v. to use molecular gastronomy to promote the sciences to the general public.

We might think of these objectives as a description of the history and role of chemistry in the culture. Alchemy, the early forerunner of modern chemistry, was based on untested aims such as finding immortality and changing base metals into gold and silver. It was in this phase of chemistry’s history that primitive forms of experimentation began. These are comparable to This’ first objective of testing in some experimental way what he called “old waives tales” and culinary proverbs. As chemistry began to take a form that we would recognize today, somewhere in the late 18<sup>th</sup> century, new model formulations were discovered, much like This’ second objective of model recipes. Along the way, like This, chemists had to develop new tools, ingredients and methods for their discipline. As chemistry grew as a science, it began not just to formally describe previously known substances but to create new ones, just as molecular gastronomy seeks to create new dishes, according to This. And today, one of the most important objectives faced by chemists is to promote understanding of chemistry in modern life, an aim shared by chemistry and molecular gastronomy.

This eventually narrowed the scope of the discipline to include primarily objectives 1 and 2, saying that objectives 3 and 4 were simply outcomes of the first two objectives and that the last of his original five objectives was not within the realm of science.

The examination of recipes led This to create what the article calls a “theoretical formalism to describe the ingredients of food.” Recipes are divided into “definitions” and “precisions.” A recipe’s definition is the list of ingredients and specific steps needed to make the ingredients into a food dish. The “precisions,” according to This, are the hints (or in the language of his original objectives) the “old wives tales” to help make the recipe come out better. If the “definitions” sounds to the chemistry teacher like the materials and equipment list for an experiment, it is no accident. That is the approach molecular gastronomy takes. And perhaps the precisions might be compared to the teacher’s notes for students to guide them through the experiment.

Another part of the formalism devised by This came in 2002, as he devised a set of symbols that would allow a scientist to describe a recipe according to the chemical components. The symbols, given below and called the Complex Disperse System (CDS), would look in use very much like a chemical equation. The symbols represent the three phases of matter and four processes:

W = water  
O =oil  
Solid1 – first solid  
Solid 2 = second solid  
G = gas  
/ = dispersed into  
+ = mixed with  
 $\sigma$  = superposed  
 $\square$  = included into

This provides this example from a 1905 French cookbook:

*“Take a dozen **pears** of middle size, remove the skin and put them immediately in cold **water**. Then melt 125 g of **sugar** with some **water** in a pan at low heat: as soon as the sugar is melted, add the pears, add some lemon juice if you want to keep the pears white; if you prefer them red, do not add lemon juice and **cook** them in a pan lined with tin.”*

This adds, “In this recipe, the words in bold characters give a definition of the dish; it can be observed that this definition here is less than 10% of the recipe. The words in italics add ‘precisions’, a category that includes old wives’ tales, proverbs, and sayings. . . .”<sup>1</sup>

Students should know that prepared foods are mostly mixtures, not pure substances. Any food prepared by a recipe is a mixture of “the definitions” in the recipe. This argues, as the article states, that most dishes requiring a recipe are actually dispersions of some kind. Chemists and chemistry students should know these dispersions as colloids-- gels, sols, suspensions, emulsions, foams, etc. Using This’ example of ice cream, the dispersion is air dispersed by foaming into a condensed medium that contains ice crystals, protein aggregates, sucrose crystals and fats. His formal system provides a way to describe such a complex system.

This says, “Let us be systematic and consider the following possibilities: the involved phases in food are gases, liquids or solids. The liquids, hydrophobic or hydrophilic, are named ‘water’ or ‘oil’, depending on their chemical composition. The solids are many, and they generally do not mix, so that different names should be given: solid 1, solid 2, etc. All these different phases can be dispersed, or mixed, or included into one another, or superposed . . .

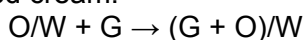


“Hence the proposal of using letters to envision rapidly all the possible systems. The phases can be written: G (for gas), O (for oil), W (for water), S1 (for solid 1), S2 (for solid 2), etc. The main processes can also be described by a few symbols: / (dispersed into), + (mixed with), □ (included into), σ (superposed). In order to consider all possibilities, a number of k phases A1, A2, . . . Ak (k is a natural number) is chosen in the set {G, O, W, S1, S2, S3, . . .}. Then symbols from the set {/, +, σ, □ } are introduced between successive letters. And finally, parentheses are added.”<sup>2</sup>

<sup>1</sup> This, “Modeling dishes and exploring culinary ‘precisions’: the two issues of molecular gastronomy, British Journal of Nutrition (2005), 93, Suppl. 1, S139.

<sup>2</sup> Ibid, S140

Here is a simple example of this formal system. It describes the process of making whipped cream:



Cream is an oil-in-water emulsion (“oil dispersed in water”) and the whipping process introduces air (gas) into the system.

You might portray this formalism to students by comparing it to the rules for writing a chemical equation. The symbols for the phases of matter are comparable to the symbols for the elements, and the operational symbols can be compared to symbols like (aq) or Δ in a chemical equation.

The system of symbols is used in molecular gastronomy to describe culinary transformations or “cooking,” a term that This suggests this is not as simple as it might sound. He argues that “cooking” usually means transforming plant or animal matter by means of heat. But, he reminds us, heat is not the only way to transform matter. He uses egg white as an example. When an egg is boiled, the complex protein molecules that make up the egg white, molecules that are “folded” over onto themselves, “unfold” as they are exposed to heat. But this same egg white undergoes a similar transformation when immersed in ethyl alcohol. Are these two methods of “cooking” eggs the same or different? This introduces the term “coction” to refer to new means of transforming food. This also invented a numerical system for rating the consistency, or firmness, of food. On this scale a gas would be a zero, a liquid would equal one, an emulsion would be a two and so forth.

In addition to devising this formal system of description, molecular gastronomists also test “precisions” as a means of analyzing the cooking process. Some examples of “precisions” include:

- Pears stay white in jellies when treated with lemon juice (true)
- Pears turn red when cooked in tin covered copper pots (false—it is low pH that causes the red coloration—the anthocyanidins in pears turn red in acidic solution)
- Mayonnaise prepared during a full moon fails. (false)
- Green beans should not be cooked in a covered pan. (false)
- Vinegar is less acidic when boiled. (it depends)
- Water will boil faster in a covered pot. (true)
- Cooking with alcohol is OK because in the cooking all the alcohol either boils off or burns off. (false)
- Cook meat at high temperature to seal in the juices. (false)

Testing these bits of “lore” produces a more analytic view of cooking by applying scientific principles to the process and testing ideas rigorously against those principles.

What are some the processes, equipment and materials that are being used in molecular gastronomy kitchens and labs today?

## Processes

Spherification is a process in which food liquid is shaped into a sphere and the “skin” of the sphere is a gelled form of the liquid. Pioneered by a Spanish company called Texturas, the process involves submerging a liquid containing Algin into a bath of calcium chloride. According to the Texturas web site, algin is a “natural product extracted from brown algae (of *Laminaria*, *Fucus*, and *Macrocystis genera*, among others) that grow in cold water regions of Ireland, Scotland, North and South America, Australia, New Zealand, South Africa.” Calcic is “a calcium salt traditionally used in the food industry, for example in cheese making. Calcic is essential in the reaction with Algin that produces spherification.

Sous vide, or cryovacking, is a process in which food is placed in vacuum bags and cooked in a temperature-controlled water bath. Popularized by Thomas Keller, chef at the French Laundry in California, in his book *Under Pressure: Cooking Sous Vide*, this process cooks foods to optimum temperatures rather than to a set time. The key is the ability to control the water bath temperature exactly so that the temperature of the food is uniform throughout. The process has been used since the 1970’s.

Flash-freezing is accomplished by pouring liquid nitrogen over food or by placing food onto an Anti-Griddle, which instantly freezes either the outer layer of, for example, sauces or purees, leaving the center in liquid form, or freezes the entire mass throughout. The “cooking” surface is maintained at -30°F (-34.4°C). The liquid nitrogen method immerses the food into an insulated metal bowl filled with liquid nitrogen and covered with a metal plate, which is used as the freezing surface. A short article and photo can be viewed here [http://nymag.com/daily/food/2008/05/tailors\\_liquid\\_nitrogen\\_dispen.html](http://nymag.com/daily/food/2008/05/tailors_liquid_nitrogen_dispen.html)

Frothing or foaming occurs when vegetable or fruit juice is mixed with gelatin or agar and then either propelled through a pressurized canister or aerated by hand. Ferran Adrià is most famous for his foams, which can be made of such varying foods as raspberries or potatoes. You can view a video of foaming here <http://hubpages.com/hub/Molecular-Gastronomy--Where-Science-Meets-Cuisine> .

## Equipment

The article mentions that chefs are applying new equipment to food preparation. Some of the equipment is familiar to researchers in a chemistry lab. A gas torch is used for caramelizing. Ultrasonic stirring devices are used to rapidly make emulsions. Buchner funnels can be used to clarify stocks in much less time than usual. The Anti-Griddle is used to flash freeze sauces and gels.

A rotary evaporator is used to distill liquid flavoring from foods. The food goes in a glass evaporation flask, which is heated in a rotating water bath. Air is vacuumed from the flask while it is heated. Moisture is removed from the food, strawberries, say, then vaporized, cooled and collected in a separate vessel. The liquid can then be added to foods for flavor.

The Gastrovac is another tool used in the new cooking style. It is a high-tech variation of a pressure cooker. According to the company's web site (<http://www.cookingconcepts.com/ENG/gastrovac.html>), "by creating an artificial low pressure, oxygen-free atmosphere, the Gastrovac considerably reduces cooking and frying temperatures, maintaining the texture, colour and nutrients of the food. Moreover, the Gastrovac creates the "sponge effect": when the atmospheric pressure is restored, the food absorbs the liquid around it, allowing infinite combinations of foods and flavours."

## Materials

The article does not suggest specific substances, but a review of the literature produces a few substances in common use in molecular gastronomy. **Agar** is a gel which is derived from red algae. It is a polymer, a polysaccharide of galactose. It is used as a thickener. **Calcium chloride** is dissolved in water and used in the spherification process. **Sodium alginate** an emulsifying agent also derived from algae, used to create self-encapsulated spheres of liquids or purées. **Xanthan gum** is a polysaccharide. It is used as a thickener, a stabilizer, an emulsifier, and as a foaming agent. The substance is thixotropic. That is, with respect to its viscosity, it is stable when the substance is at rest, but becomes less viscous when shaken. Both toothpaste and Ketchup are thixotropic. **Lecithin** is a phospholipid that is used in food preparation as an emulsifier and as a lubricant. It is the emulsifier in candy bars that keeps the cocoa butter from separating. **Tapioca maltodextrin** is a modified food starch used to thicken and stabilize fatty compounds.

You can purchase molecular gastronomy kits that contain some or all of these ingredients. See [http://www.pastrychef.com/MOLECULAR-GASTRONOMY-TOOL-KIT\\_p\\_7-1414.html](http://www.pastrychef.com/MOLECULAR-GASTRONOMY-TOOL-KIT_p_7-1414.html) for more information.

## More on the history of molecular gastronomy

For obvious reasons there has been a keen interest in the mechanics of food preparation and cooking throughout the centuries. As early as the second century BC there are records of the weight measurements of meats. Chemists have been interested in cooking since the origins of chemistry in the 1700's. In 1783, for example, Lavoisier studied the preparation of stock from meat using density as a guide. Liebig also was interested in producing stock, and Count Rumford made recommendations for new cooking methods.

The article attributes the origins of molecular gastronomy to Nicholas Kurti and Hervé This. Kurti was a Hungarian-born physics professor at Oxford. As a scientist he was best known for his work in separating uranium isotopes in the early 1940's and for his low-temperature physics. Cooking was his hobby, and, like other scientists mentioned above, was interested in applying scientific principles to his cooking. He demonstrated some of these techniques in his television show in the UK entitled "The Physicist in the Kitchen." Kurti's lecture to the Royal Society was also titled "The Physicist in the Kitchen," and it began to spur interest in the scientific approach to cooking. The Royal Society even published a cookbook titled *But the Crackling is Superb: An Anthology on Food and Drink by Fellows and Foreign Members of The Royal Society of London*.

In the 1980's Herve This, a physical chemist, began to collect and test "culinary old wives tales." This actually wrote his thesis on molecular and physical gastronomy for his PhD in

Physical Chemistry of materials. Kurti and This met in 1986, and in 1988, agreed to begin a new scientific discipline—molecular gastronomy. In order to promote the new science, they began a series of workshops, the first of which was held in Erice, Italy in 1992. This has since published several books on molecular gastronomy and speaks on the topic around the world.

### **More on experimental cuisine and avant-garde meals**

The article describes some of the unusual dishes available at restaurants serving experimental cuisine—restaurants like Moto in Chicago and WD-50 in New York City. In order to give you and students a “look” at these restaurants, the web sites for eight such restaurants are given below. Students can explore the web sites and learn more about the cuisine and experimental methods and processes used in these restaurants, all of which are examples of molecular gastronomy dining. Students should look for both the menu section and video sections of these web sites.

**Alinea**, Chicago, IL [http://www.alinea-restaurant.com/pages/gallery/gallery\\_cuis.html](http://www.alinea-restaurant.com/pages/gallery/gallery_cuis.html)

**French Laundry**, Yountville, CA <http://www.frenchlaundry.com/>

**The Fat Duck**, Bray, Berkshire, United Kingdom <http://www.fatduck.co.uk/menu.html>  
[http://www.pbase.com/jp\\_photos/lunch\\_at\\_the\\_fat\\_duck](http://www.pbase.com/jp_photos/lunch_at_the_fat_duck)

**Pierre Gagnaire**, Paris, France <http://www.pierre-gagnaire.com/index-fr.htm>  
<http://www.pierre-gagnaire.com/francais/cd24-new.htm>

**El Bulli**, Spain <http://www.elbulli.com/> (Be sure to click on El Bulli General Catalogue)

**Moto**, Chicago, IL <http://www.motorestaurant.com/> (Be sure to check out the Gallery section)

**Rosendales**, Columbus, OH <http://www.rosendales.com/>

**WD-50**, New York, NY <http://www.wd-50.com/>

### **More on the psychology of food**

Food experts think that a series of factors affect our feelings about food and how we eat. Among these are cultural, evolutionary, social, family and individual factors.

The article describes the work of Peter Barham, professor of physics in England, and his interest in the psychology of food and eating. Barham has set out for molecular gastronomists a set of five research goals:

- How the physiology of human taste has evolved
- How food flavor is influenced by the way the food is prepared
- How can cooking methods be improved in order to improve food flavor
- How flavor is processed in the brain
- How surroundings affect how food is enjoyed

Barham collaborates with Heston Blumenthal, chef at Fat Duck outside of London, to find answers to the second research goal. Blumenthal uses equipment in his kitchen that he

purchases from science equipment suppliers rather than from kitchen suppliers. Some examples include a temperature-controlled water bath to cook fish and meats and a vacuum still to extract flavors from herbs and stocks.

Barham gives two examples of how he and Blumenthal work on his third research goal—how cooking methods influence flavor. The chef asked Blumenthal why cooks add salt to boiling water when cooking vegetables like beans (another of Hervé This' "old wives tales."). Barham's answer was that there is no scientific foundation for adding salt in this case. The beans do not retain more than a negligible amount of salt after cooking and the texture of the beans is dependent only on the water's acidity and calcium content.

The second example involves cooking meat. Barham says: "One of the most dramatic examples relates to the way in which meats are cooked at the Fat Duck. These days most meat and fish are cooked at low temperatures for long times using temperature controlled water baths. This allows the restaurant to serve wonderfully tender and pink meats in a totally consistent fashion. The problem with traditional methods has been that meats were cooked by exposing the outside to a high temperature (in a pan or oven) and then letting the heat diffuse inside until the temperature at the centre is just right. If the temperature is too high the meat proteins contract and expel water making the meat tough and start to go grey, rather than pink. If the temperature is not high enough the meat seems raw. The ideal temperature varies between meats, but is usually around 55 to 58°C; above 60°C the meat will soon lose moisture and become dry and tough; below 50°C it will still be very red and seem raw and cold. Normal cooking processes mean that if the centre is at the ideal temperature the outside is much hotter and thus tough.

"However, at the restaurant now the meat is first vacuum sealed in a plastic bag (to prevent any oxidation of the meat surface and avoid any contact with the hot water). Then the bag is put in a temperature controlled water bath (a standard piece of laboratory equipment) with the water kept at the desired temperature want (say 58°C for lamb). The meat is then left in the bath for a long time (several hours) so that it reaches a uniform temperature throughout; it ends up as a perfectly cooked pink and tender piece of meat."

[http://www.discoverychannel.co.uk/science/kitchen\\_chemistry/science/index.shtml](http://www.discoverychannel.co.uk/science/kitchen_chemistry/science/index.shtml)

However, some of the most interesting of Barham's ideas come from his fourth and fifth research goals—how the brain perceives flavor and how surroundings affect taste. Barham challenges readers to this test:

"Try this experiment for yourselves. Try tasting some ice cream—it should taste good, like ice cream. Now take the same ice cream and while putting a spoonful in your mouth close your eyes and fondle a piece of velvet cloth. It will taste creamier than before! But even more astonishing if you rub your hand over a piece of fine sandpaper while taking yet another spoonful, the ice cream will seem to become gritty. It seems that what we feel with our hands with our eyes closed can be transferred in our brains to the tongue.

"Another truly astonishing fact is that the sound of food changes our expectations. One simple example comes from the humble potato crisp. The marketing people have known for a long time that they need to sell crisps in packets that themselves crackle—if they try to market crisps in packs that don't have the right sound then we consumers think the crisps are stale."

[http://www.discoverychannel.co.uk/science/kitchen\\_chemistry/molecular\\_gastronomy/index.shtml](http://www.discoverychannel.co.uk/science/kitchen_chemistry/molecular_gastronomy/index.shtml) .

Many researchers besides Barham are investigating the psychology of food and taste. One of the leading research centers is the Food and Brand Lab at Cornell University. The Lab's web site contains the results of scores of research studies into food and eating. Below is one such study.

### **“Environmental Factors that Increase the Food Intake and Consumption Volume of Unknowing Consumers”**

“Environmental factors such as package size, plate shape, variety, and social interactions influence how much you eat to a greater extent than you may realize.

#### **Abstract**

“Why do environmental factors influence consumption volume? The environment can be organized into two categories: the eating environment and the food environment. The former includes atmospheric factors that are not associated with the actual food itself such as the effort of obtaining the food, lighting, socializing, and eating distractions. The latter refers to the presentation of the food such the structure and variety of food assortments, portion sizes, and shapes of plates, glasses, and bowls.

“The environment plays a major role in determining consumption volume because it affects the accuracy of consumption monitoring and alters consumption norms. Consumption norms and consumption monitoring partially mediate or explain why many seemingly unrelated environmental factors consistently influence eating behavior in predictable ways.

“Four important drivers in the eating environment are discussed: 1) eating atmospherics, 2) eating effort, 3) eating with others, and 4) eating distractions. Atmospherics influence eating duration. Increased effort decreases consumption. Socializing influences meal duration and consumption norms. Distractions (such as watching TV or reading while eating) can initiate, obscure, and extend consumption.

“In regards to the food environment five factors are discussed: 1) salience, 2) variety, 3) package and portion sizes, 4) stockpiling, and 5) size of serving containers. Salient food promotes salient hunger. Increasing perceived variety can increase consumption. The size of packages and portions suggest consumption norms. Stockpiled food is quickly consumed. Serving containers that are wide or large create consumption illusions.

“For more information see Wansink, Brian (2004), “Environmental Factors that Increase the Food Intake and Consumption Volume of Unknowing Consumers,” Annual Review of Nutrition, Volume 24, 455-479. Posted with permission, from the Annual Review of Nutrition, Volume 24 © 2004 by Annual Reviews, [www.annualreviews.org](http://www.annualreviews.org)”

Researchers also have discovered that smell is a much bigger influence on taste than previously thought. Only 20% of a taste experience comes from the tongue while the other 80% is due to the aroma. Because of this molecular gastronomists are investigating the importance of the volatile chemicals that produce food's aroma. They theorize that if two foods yield the same volatile chemical(s) the foods might taste good if paired and eaten together. This approach is based entirely on the chemistry of the foods involved. Some of the tested pairings include unusual combination like carrot and violet (ionone is the common volatile chemical),

pineapple and bleu cheese (ketones), white chocolate and caviar (trimethylamine), oysters and kiwi (methyl hexanoate) and jasmine and pork liver (indole).

## **Connections to Chemistry Concepts**

1. **Chemical language and symbols**—The article discusses the formalism developed by This. This set of symbols can be compared to the symbols for elements and the symbols used in writing chemical equations.
2. **Chemical change**—The major idea behind molecular gastronomy is to discover the chemical reactions that take place in the cooking process and to use them to prepare food that tastes good. Your students should understand that when a chemical change takes place, a new substance is formed, and they should understand that this is what occurs when food is cooked. The brown edge on a steak, the fact that a boiled egg has a solid white and yolk, the change in a vegetable's texture after cooking are all the result of chemical changes in the substances making up those foods.
3. **Research methods**—Your students can get a glimpse of research methods used in chemistry as they read about food research in the article. Using nuclear magnetic resonance on foods, testing foods at varying temperatures, using vacuums to cook foods all reflect the influence of chemical research.
4. **Organic compounds and food**—You might wish to use the article as a way to introduce organic compounds to your students, since foods are organic compounds.
5. **Heat, temperature and heat transfer**—Conduction, convection and radiation are all important in food cooking. These methods of heat transfer are implied in the article but not given much emphasis. The temperature of foods during the cooking process is discussed in the article.
6. **Sense of taste and smell**—The article is a good introduction to these two senses and to the more general process of observing using senses not often used in a chemistry class.

## **Possible Student Misconceptions**

1. **“My mother always says to brown the outside of meat before cooking it and to salt water when cooking vegetables. How can those ideas we thought we knew about cooking be wrong?”** *As Hervé This has discovered, many of the ideas about food and cooking written in cookbooks and passed down through generations by word of mouth have no scientific basis. That's what molecular gastronomy seeks to do—discover the scientific principles that govern the processes of cooking and use them to produce more and better-tasting dishes.*
2. **“I haven't heard much about molecular gastronomy before. Is it really a major trend in cooking?”** *Molecular gastronomy represents a novel way of applying scientific principles to cooking. Not everyone sees the benefits of this or thinks that it's the right thing to do, so not every restaurant uses the ideas. In addition, the equipment used is expensive, and not every restaurant can afford to purchase new equipment. But molecular gastronomy has gotten a lot of publicity. And besides, readers of ChemMatters often are the first to hear about new chemistry-related ideas.*

## **Demonstrations and Lessons**

1. An activity on the science of egg white foam can be found here: [http://members.ift.org/NR/rdonlyres/50809C08-F9A2-4845-B9F7-A9292A6D6D2D/0/activity\\_bafflingbeaters.pdf](http://members.ift.org/NR/rdonlyres/50809C08-F9A2-4845-B9F7-A9292A6D6D2D/0/activity_bafflingbeaters.pdf).
2. Students can make alginate gummies by following this procedure: [http://members.ift.org/NR/rdonlyres/1D889FCE-7C48-4273-ABA9-3B4ED101D7D2/0/activity\\_alginategummie.pdf](http://members.ift.org/NR/rdonlyres/1D889FCE-7C48-4273-ABA9-3B4ED101D7D2/0/activity_alginategummie.pdf).
3. “Freezing Foam” is the title of this ice cream making activity: [http://members.ift.org/NR/rdonlyres/1063060A-A00E-4CF6-9B00-238BD0B99570/0/activity\\_freezingfoams.pdf](http://members.ift.org/NR/rdonlyres/1063060A-A00E-4CF6-9B00-238BD0B99570/0/activity_freezingfoams.pdf).
4. Your students can safely experiment with taste discrimination in this activity featuring Oreos: [http://members.ift.org/NR/rdonlyres/3BFD59B7-48A6-42D9-B33A-467781F18EAE/0/activity\\_trianglesensory.pdf](http://members.ift.org/NR/rdonlyres/3BFD59B7-48A6-42D9-B33A-467781F18EAE/0/activity_trianglesensory.pdf).
5. A well-designed set of food chemistry activities on carbohydrates, lipids and proteins are produced here: <http://members.ift.org/IFT/Education/EduResources/fc.htm> by the Society for Food Science and Technology.
6. Another set of food chemistry experiments from the Society for Food Science and Technology can be found here: <http://members.ift.org/IFT/Education/EduResources/mini.htm>.
7. You can select from a list of food science experiments produced by the Utah State Board of Education: [http://www.uen.org/utahlink/lp\\_res/nutri375.html#lesson](http://www.uen.org/utahlink/lp_res/nutri375.html#lesson).
8. Clemson University’s Department of Food Science and Human Nutrition provides a list of food chemistry experiments: <http://www.clemson.edu/foodscience/teachers.htm>. The list includes topics like hydrogen bonding in gels, texture profile analysis, and measuring color in oranges.
9. From MIT Open Courseware comes this complete set of course materials on food chemistry, including topics like chocolate, tea and scones, chili peppers, meringues, and crème brûlée: <http://ocw.mit.edu/OcwWeb/Special-Programs/SP-287Spring-2006/RelatedResources/index.htm>.
10. Penn State’s Food Science program gives a long list of food science web sites: [http://www.foodscience.psu.edu/Outreach/Fun\\_Food\\_Science.html](http://www.foodscience.psu.edu/Outreach/Fun_Food_Science.html).
11. A “Cooking with Chemistry” WebQuest can be found at <http://chsweb.l.r.k12.nj.us/kshimp/cooking/chemwebquest.htm>.
12. A lab activity on making an emulsion (mayonnaise) can be found here: [http://members.ift.org/NR/rdonlyres/89F6970F-B435-447E-8AF8-DA3AD08A543C/0/activity\\_isecondthatemulsion.pdf](http://members.ift.org/NR/rdonlyres/89F6970F-B435-447E-8AF8-DA3AD08A543C/0/activity_isecondthatemulsion.pdf).
13. A series of three activities on the role of enzymes in food are located here: <http://members.ift.org/IFT/Education/EduResources/eif.htm>.

## **Student Projects**

1. Students can explore the web sites and menus of the avant-garde restaurants: see “More on Experimental Cuisine and Avant-garde Meals”.

## **Anticipating Student Questions**

1. **“Chefs and cookbooks seem to produce good food. Why does the article say that we don’t know much about the cooking process?”** *We do know a lot about cooking and making good food, but we don’t necessarily know **why** the food cooks the way it does.*



*That's why molecular gastronomy is interesting. It seeks to understand the underlying scientific principles related to cooking.*

2. **“The article talks about the chemicals in food. Aren't chemicals in food bad for you?”** *You probably know from biology class that there are some basic classes of food—like carbohydrates, fats and proteins. Those categories are really chemical categories. Carbohydrates are chemicals with certain distinctive properties which are different than proteins or fats, for example. Chemicals make up all living things, plant and animals, and since we eat both plants and animals we are eating chemicals that occur in nature. It's these chemicals that the article refers to. The chemicals you have heard about are primarily chemicals that are not part of nature but are added to foods for a variety of reasons. Some of those additives have proven to be unhealthy.*
3. **“What is nuclear magnetic resonance?”** *NMR is a form of spectroscopy that uses strong magnetic fields to analyze substances. It is used to find the kinds of chemical bonds in a molecule and to determine the structure of complex molecules.*

## References

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. Selected articles and the complete set of *Teacher's Guides* for all issues from the past five years are also available free online at this same site. (Full articles and *Teacher's Guides* are available on the 25-year CD for all past issues, up to 2008.)

“Future Food”. *ChemMatters*, April, 1989, page 8.

“Chocolate”. *ChemMatters*, April, 1987, page 16.

“Edible Wraps”. *ChemMatters*, April, 2003, page 14.

“Egg Cookery”. *ChemMatters*, December, 1984, page 4.

## Web Sites for Additional Information

### More sites on molecular gastronomy

Videos on various processes in molecular gastronomy can be viewed here:  
[http://video.google.com/videosearch?source=ig&hl=en&rlz=&q=%22molecular+gastronomy%22&um=1&ie=UTF-8&sa=X&oi=video\\_result\\_group&resnum=4&ct=title#](http://video.google.com/videosearch?source=ig&hl=en&rlz=&q=%22molecular+gastronomy%22&um=1&ie=UTF-8&sa=X&oi=video_result_group&resnum=4&ct=title#).

An article on the subject can be read here:  
<http://members.ift.org/NR/rdonlyres/FFB5F58C-ECF0-40C1-B90F-A3F5BB3549DB/0/0608featgastronomy.pdf> .

### More sites on reading about molecular gastronomy

This web site, [http://khymos.org/books\\_mg.php](http://khymos.org/books_mg.php), has a list of books about molecular gastronomy and related topics.

### **More sites on Hervé This**

You can read a *Wired* magazine interview with Hervé This here: [http://www.wired.com/techbiz/people/magazine/15-08/ps\\_foodchemist](http://www.wired.com/techbiz/people/magazine/15-08/ps_foodchemist).

### **More sites on sous vide cooking**

You can read a technical discussion of sous vide cooking at <http://amath.colorado.edu/~baldwind/sous-vide.html>.

### **More sites on avant-garde chefs**

This *New York Times* article gives some background on several of the chefs at restaurants mentioned in the article: [http://www.nytimes.com/2007/11/06/science/06food.html?\\_r=3&fta=y](http://www.nytimes.com/2007/11/06/science/06food.html?_r=3&fta=y).

### **More sites on El Bulli Restaurant**

You can read a *Time* magazine story about Ferran Adria, chef at Spain's El Bulli restaurant, here: <http://www.time.com/time/arts/article/0,8599,1866040,00.html>.

### **More sites on Moto YouTube**

Take a look at a You Tube video from Moto: <http://www.youtube.com/watch?v=47ggz4ToBfE>.

### **More sites on the psychology of eating**

View a slide show of the seven things that make you eat more food: [http://www.time.com/time/photogallery/0,29307,1626481\\_1373607,00.html](http://www.time.com/time/photogallery/0,29307,1626481_1373607,00.html).

Cornell university has a web site that explores the psychology of eating. Find it at <http://foodpsychology.cornell.edu/>.

The Discovery Channel web site has a series of interviews with Peter Barham here: [http://www.discoverychannel.co.uk/science/kitchen\\_chemistry/taste\\_flavour/index.shtml](http://www.discoverychannel.co.uk/science/kitchen_chemistry/taste_flavour/index.shtml).

# The Art and Chemistry of Dyes

## ***Background Information***

### **More on dyes**

Dyes are chemical substances which absorb and reflect different specific wavelengths of light. The mechanism for this is related to a familiar topic to chemistry students—electrons absorbing and radiating energy as they change energy levels. In molecules used as dyes, the exact mechanism is more complicated than electrons simply changing energy levels, but is similar. Organic molecules with conjugated bonds do absorb energy of specific wavelengths and, therefore, reflect only certain wavelengths. If the reflected wavelengths are in the visible range, the dye molecule imparts a specific color to the fiber.

Dyes have general properties called hue, brightness, strength and color-fastness. A dye's hue refers to the specific wavelength of light that it reflects. Brightness is a measure of the amount of light reflected. The strength of a dyed surface is inversely proportional to the amount of white light the surface reflects. White light interferes with the hue wavelengths. And color-fastness is a measure of resistance to fading.

The article discusses some of the chemical bonding that takes place in dyeing fibers. In addition to the ionic bonds formed during acid dyeing and basic dyeing, hydrogen bonding and van der Waals forces are also involved.

There are several types of dyes, as suggested in the article, and the type of dyeing process is typically matched to the substance being dyed. Categorizing dyes can be done in several ways. They can be categorized by their chemical structure, by the types of fibers they can dye most easily, or by the process used to apply the dye.

### **More on the chemical structure of dyes**

Chemical compounds that are good dyes have two structural characteristics—a chromophore and an auxochrome. A chromophore structure has unsaturated covalent bonds that are capable of absorbing light of certain wavelengths and reflecting or transmitting other wavelengths. The reflected or transmitted wavelengths produce the color. Common chromophore structures include azo ( $-N=N-$ ), carbonyl ( $=C=O$ ), carbon ( $=C=C=$ ), nitroso ( $-NO$  or  $N-OH$ ), nitro ( $-NO_2$ ) and sulfur ( $>C=S$ ). Auxochromes are functional groups within a molecule that affect the intensity of the color by interacting with the chromophore to insure that the reflected light is in the visible range. Common examples of auxochrome structures are  $-COOH$ ,  $-OH$ ,  $-SO_3H$ ,  $-NHR$ ,  $-NR_2$ , and  $-NH_2$ .

This relationship between molecular structure and color has been known since the late 1800's when it was noted that organic compounds containing conjugated double bonds ( $-C=C-C=C-$ ), either aliphatic or aromatic, correspond to color. Quinones and aromatic azo compounds were identified as early examples. Today the major chromophore-containing compounds include azobenzene, xanthenes, triphenylmethane and anthraquinone.

### **More on fibers**

The article focuses on dyeing of wool, an animal fiber, cotton, a plant fiber, and composites of the two. Wool and cotton are examples of two of the five major types of fibers that are typically dyed. The five major types are all polymers: proteins like wool, leather and silk; polyamides, which are synthetic fibers; polyester (polyethylene terephthalate or PET) also synthetic; acrylics; and celluloses like cotton. (Rayon is a semi-synthetic form of cellulose.)

Proteins are polymers of amino acids, and often contain ionic components that provide a connecting site for acidic or basic dyes. Polyamides are similar to proteins with the amides separated by carbon chains. The terminal groups in polyamides are often either  $\text{-COOH}$  or  $\text{-NH}_2$  and are the sites for polar interactions with dyes, as mentioned in the article. Polyester is the major synthetic fiber. A terminal  $\text{-OH}$  group is the dyeing site for these fibers. Acrylics are carbon chains which often themselves contain polar sites with which dyes react. Cellulose, as the article says, is a polymer containing glucose units, and within these units are hydroxyl groups that react with dyes.

### **More on types of dyes**

There are a variety of names given to dyes, some because of their chemical structure and some because of their method of application or mechanism of action. Some of the more important terms are described briefly below.

One of the most common types of dyes is acid dyes. These are the wool dyes referred to in the article. Acid dyes are water soluble, and although a weak acid is often used in the process, the name derives from the fact that the dyeing action is the result of an ionic salt formation between the dye and the fabric. The article states that when wool is dyed the amine functional groups in the amino acids making up the keratin become positively charged (cations) and the carboxyl group from the acids become negatively charged (anions). Acid dyes are often anionic and combine easily with the cations in the wool. Other compounds, including sulfuric acid, acetic acid, sodium sulfate, and surfactants may be added to the dye. Acid dyes are used for wool, silk, nylon and acrylic fibers. These dyes come in a wide variety of colors, and are fairly colorfast to light and to washing.

Like acid dyes, basic dyes are water soluble and act in the form of cations. These dyes are used mainly for acrylic fibers but sometimes for wool and silk. They have only fair fastness to light and to washing.

Azo dyes make up about 60% of all dyes. They produce intense color in fibers. Chemically they all contain at least one azo group ( $\text{-N=N-}$ ) along with formic acid, caustic soda, metallic compounds, and sodium nitrate. They are especially used to produce yellow, red and orange colors. These dyes rely on the use of coupling components in the dyeing process to insure the dye bonds to the fiber. Azo dyes produce red, orange and maroon colors and are very fast to light. Azo dyes are especially used with cotton fibers.

The term "direct dye" refers to any dye that does not require "fixing." That is, they are retained by the fiber without using strong chemical bonds. The strength of direct dyes is increased by using larger dye molecules, but larger dye molecules are duller since larger molecules have more locations within them that can absorb light. Direct dyes are used to dye cotton. Direct dyes are nearly always azo type dyes.

Reactive dyes act by covalently bonding the chromophore directly to the fiber, forming a single stable molecule. Reactive dyes are permanent and are, therefore, colorfast and resistant

to fading by washing. These dyes can be used for either cotton or wool, but are most often used for cotton.

Disperse dyes were designed for cellulose acetate fibers. They are water insoluble, and must be dispersed in a solvent before using them.

### More on natural dyes

Natural dyes are for the most part acid dyes. Among the earliest known natural dyes are indigo, Tyrian purple (extracted from sea mollusks), cochineal (carminic acid), Longwood tree, and green walnuts.

Fruits, nuts and flowers from plants can be used as dyes. Some natural dye sources and the colors they will produce:

- Orange—onion, bloodroot, turmeric
- Brown—oak bark, walnut hulls, tea, coffee grounds
- Pink—strawberries, cherries, lavender
- Blue/Purple—red cabbage, blueberries, grapes
- Red—leaves, dandelions, rose hips, beets
- Green—artichokes, spinach, grass
- Yellow—saffron, celery, goldenrod, paprika

The chemistry of some common natural dyes is shown in the following table:

Color	Chemical Name	Common Source
Yellow-Brown	Flavones	Osage, chamomile, marigold
Yellow	Iso-quinolines	Barberry
Orange	Chromenes	Kamla
Purple-Gray	Napthoquinones	Henna, walnut
Red	Anthraquinones	Lac, cochineal, madder
Blue	Indigoids	Indigo

### More on synthetic dyes

Before the mid-1800's, natural dyes were used to color clothing and other textiles. But with William Henry Perkin's inadvertent discovery of mauve, natural dyes were replaced with synthetics. Perkin was trying to synthesize quinine. After several false starts, he used aniline extracted from coal tar as his raw material. Perkin got a black product (aniline black), but upon extraction with alcohol, he obtained a purple product, mauve, which proved to be a spectacular dye for silk fibers. Synthetic dyes quickly replaced natural dyes because the former produced more and better colors and reacted better with most fibers.

Following Perkin's discovery, scientists did further experiments with aniline and produced many new synthetic dyes. In 1864 the first azo dye, Bismarck brown, was discovered. Today more than half of all dyes are of the azo type. The first sulfur dye was developed in 1873 and in 1884 Congo red was developed. It was the first cotton dye that did not require a mordant.

## Connections to Chemistry Concepts

1. **Natural vs. synthetic**—Dyes may be naturally occurring substances or may be synthesized in the lab. Today most dyes are synthetic. You can relate this difference to many areas of chemistry in which chemists have synthesized compounds that mimic or replace those that occur in nature.
2. **Ions and ionization**—The article describes the differences between dyeing wool and cotton. One of the main differences is that wool ionizes in solution while cotton remains neutral. You can use this difference in chemical behavior to illustrate the difference between ionic or molecular compounds and to examine the behavior of substances placed in aqueous solution.
3. **Bonding**—Because both ionic and covalent bonding are involved in the dyeing process, in addition to hydrogen bonding and van der Waals forces, you can show students a concrete application of these bonding types in this article.
4. **Chemical structure and function**—Chemistry students should know that certain chemical structures correspond to properties of the molecule as a whole. For example, ionizable hydrogen corresponds to acidic properties. The article describes the function of the auxochrome and chromophore parts of a dye molecule. The chromophore structure produces the actual dye color.

### ***Possible Student Misconceptions***

1. **“Don’t fabrics have color naturally? Why is dyeing necessary?”** *Many students have no concept of where consumer products come from or how they are manufactured. Natural fibers come from either plant or animal sources. Plants and animals do not have the range of vivid colors that we see in fabrics today. The vivid colors are added to fibers in the dyeing process.*

### ***Demonstrations and Lessons***

1. Directions for dyeing wool with Koolaid can be found here:  
<http://www.woolfestival.com/articles/koolaid.htm>.
2. This long article about dyes features a process that immerses fabric in a blue solution with the fabric emerging dyed a range of colors from blue to yellow:  
[http://findarticles.com/p/articles/mi\\_6957/is\\_/ai\\_n28500357](http://findarticles.com/p/articles/mi_6957/is_/ai_n28500357).
3. The Bakken Library and Museum provides activities relating to natural plant dyes:  
<http://www.thebakken.org/education/scimathmn/plant-dyes/dyes1.htm>.
4. Students can do a lab activity about using plants as sources of dyes. This activity also places the activity in the context of Native American history:  
[http://www.museum.state.il.us/muslink/pdfs/dye\\_plants.pdf](http://www.museum.state.il.us/muslink/pdfs/dye_plants.pdf).
5. This article from the World Bank discusses the chemistry of dyes as well as environmental concerns:  
[http://www.ifc.org/ifcext/sustainability.nsf/AttachmentsByTitle/gui\\_dye\\_WB/\\$FILE/dye\\_PPAH.pdf](http://www.ifc.org/ifcext/sustainability.nsf/AttachmentsByTitle/gui_dye_WB/$FILE/dye_PPAH.pdf).

6. For the original article by Cardamone and Marmer on wool-cotton dyeing mentioned in the article see <http://www.ars.usda.gov/is/AR/archive/nov00/dye1100.pdf>.

## **Student Projects**

1. Students, working in groups or individually, can research and report on one of the types of dyes.
2. Students can collect natural plant products that can be used as dyes and prepare a poster on each.
3. Students can use the natural plant products they collect to actually dye fabrics and make this part of their report/poster/slide show.

## **Anticipating Student Questions**

1. **“Why is dyeing wool different than dyeing cotton?”** *The two types of fibers have different chemical structures. Wool is an animal protein and cotton is cellulose, a plant product. Both are polymers but with different structures. Wool has sites within its structure that become ionized in water, and this allows some dyes to form ionic bonds with the fibers. Cellulose does not ionize in water, so dyes for cotton must rely on covalent bonds to fix themselves to the fibers.*
2. **“Aren’t there anti-bacterial fabrics in use already?”** *Yes, there are. Anti-bacterial fabrics have been developed for medical use (in wound treatment, for example) and for general use. Clothing has been treated with anti-bacterials like chitosan. However, this requires a separate treatment of the fabric after it is dyed. The anti-bacterial agent described in the article serves as a dye as well as an anti-bacterial.*

## **References**

### **Web Sites for Additional Information**

#### **More sites on the history of dyes and dyeing**

A history of dyes can be found here: <http://www.straw.com/sig/dyehist.html>.

Another history of dyes can be found here: <http://www.colorantshistory.org/>.

#### **More sites on the chemistry of dyeing**

Paula Burch’s site provides the chemistry background for dyeing:  
<http://www.pburch.net/dyeing.shtml>.

#### **More sites on dye chemistry**

A slideshow with information suitable for teachers can be viewed here:  
[http://www.morechemistry.com/publ/colours\\_dyes/toc.html](http://www.morechemistry.com/publ/colours_dyes/toc.html).

### **More sites on professions in dyeing**

The web site for AATCC, the American Association of Textile Chemists and Colorists has a great deal of information about dyeing and the profession:

<http://www.aatcc.org/about/index.htm>.

### **More sites on tie-dyeing**

Students may be interested in the chemistry of tie-dyeing found here:

[http://www.dharmatrading.com/info/dye\\_chemistry.html](http://www.dharmatrading.com/info/dye_chemistry.html).

### **More sites on dyeing**

This site has thirteen links to other sites on dyes and dyeing:

<http://www.chemlin.net/chemistry/dyes.htm>.

### **More sites on textile chemistry**

The American Chemical Society provides this information on the textile industry:

[http://portal.acs.org/portal/acs/corg/content?\\_nfpb=true&\\_pageLabel=PP\\_ARTICLEMAIN&node\\_id=1188&content\\_id=CTP\\_003403&use\\_sec=true&sec\\_url\\_var=region1&\\_uuid](http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_ARTICLEMAIN&node_id=1188&content_id=CTP_003403&use_sec=true&sec_url_var=region1&_uuid).



# Promising New Vaccines

## ***Background Information***

### **More on history of vaccine development**

Although we tend to think about current vaccine development as a fairly recent event (students are most likely wholly unaware of how the idea of vaccines came into being), the origins begin essentially in the 18<sup>th</sup> century with the clever reasoning of Englishman Edward Jenner that culminated in pioneering inoculations in 1796. Jenner had observed that people who worked with cows were unlikely to contract small pox because they were exposed to a variant of small pox, cow pox, which infected milk cows. He found a volunteer who was willing to be inoculated with the exudates from the sores of a girl infected with cowpox. Some months later, Jenner repeated the inoculation of the same person, but this time used materials scraped from the sores of people with the dreaded smallpox. Smallpox did not develop in the person previously inoculated with the cowpox.

Jenner's prediction was borne out, that the person who had contracted cow pox would be protected against small pox. (The word *vaccine* comes from the Latin, *vaccus*, meaning cow.) It was a daring experiment, using a human subject for deliberate exposure to the greatly feared smallpox. It wasn't until 1871 that an artificial method was developed to produce immunity against a variety of diseases. This was done through the work of another brilliant biochemist, Louis Pasteur. Small pox as a worldwide disease was officially eliminated in 1977. A series of historical scientific papers related to the Jenner era ("Edward Jenner and the Discovery of Vaccination") that were part of a library exhibit at South Carolina College can be found and read at <http://www.sc.edu/library/spcoll/nathist/jenner1.html>. And there is a website for the British museum about Jenner at <http://www.jennermuseum.com/> where there is a good section on Immunology, including an extensive glossary.

Pasteur was a polymath of sorts in the worlds of both chemistry and biology. His early research on behalf of the French wine industry revealed the existence of chiral compounds, optically active isomers of an organic chemical that cause rotation of polarizing light, right or left, hence the French terms, *dextro-* and *levo-*. His other major topics of research included disproving spontaneous generation by using sealed flasks and "pasteurization", studying the dynamics of fermentation (verifying the need for living microorganisms) and a variety of diseases of economic importance in the agriculture sector. In this latter realm, Pasteur worked to establish the connection between the disease and microorganisms as the causative agent. In the process he accidentally discovered the basis for developing vaccines.

### **More on the work of Louis Pasteur**

Louis Pasteur's major contribution to the rational development of vaccines was based on a concept still in use today—the use of attenuated microbes, that is, disease-causing organisms that are weakened by chemical or thermal means. Pasteur was working with the disease, fowl cholera. He established cultures of the cholera-causing microorganism. Every few days, he would re-infect chickens to keep the microbe strain going (it of course killed the chickens!). But, on an occasion when he went on a vacation, the cultures were left standing for a much longer period during which time the bacteria lost some of their virulence which became apparent when Pasteur once again injected the cultures into chickens to revitalize the strain. But this time the

chickens did not become severely ill and die. Pasteur figured out that the microorganism must have lost its virulence through the sustained period while in culture. (See <http://www.answers.com/topic/louis-pasteur>.)

Pasteur used this technique to develop vaccines for other farm animal diseases including anthrax. Although the credit for developing this vaccine was given to Pasteur, it was really a contemporary, Jean JH Toussaint, who first developed the vaccine that Pasteur eventually used to show immunization in sheep against anthrax. While his work was done with farm animals, the crucial test was in developing and testing vaccines to be used on humans, a la Jenner. That was of course another difficult act to carry out with the public. The challenge and “opportunity” came with the need to develop a vaccine against the deadly disease of rabies.

Rabies was particularly difficult to deal with because it could not be easily cultured outside of an animal host—it could not be cultured in vitro because it was a virus and not a bacterium. Culturing of the organism was first done through inoculation of monkeys and later in rabbits. It was the use of rabbits that allowed the development of a vaccine (attenuated virus) by using sterile air to dry rabbit tissue (nerve tissue of the spinal cord) taken from an infected animal (1884). This technique was first developed by a lab colleague of Pasteur’s, Emile Roux, who was also involved with Pasteur in the work on anthrax. Later he was responsible for developing a vaccine against diphtheria as well as carrying out investigations on the microbiology and practical immunology of tetanus, tuberculosis, syphilis, and pneumonia.

### **More on other vaccine pioneers**

Jump to the 20<sup>th</sup> century and we find another Pasteur-like individual responsible for developing some of the most important vaccines for protecting the population against the flu, measles, mumps, rubella (German measles), chicken pox, bacterial meningitis, and hepatitis B (40 vaccines to his credit). Enter Maurice Hilleman of the USA (1919-2005). This was an extremely creative vaccine researcher who once remarked that his hobby was “working”! He combined an indefatigable work ethic with an uncanny ability to figure out the design for cultivation of the antigens needed for a vaccine’s effectiveness. And he is not a household name compared with that of Louis Pasteur because he did not play the publicity card. (See [http://www.njabr.org/njsor/science\\_superstars/maurice\\_hilleman/](http://www.njabr.org/njsor/science_superstars/maurice_hilleman/), <http://www.nature.com/nm/journal/v11/n4s/full/nm1223.html> and <http://www.slate.com/id/2116690/>).

Of great importance was the involvement of Hilleman in the development of a flu vaccine to deal with the epidemic of 1957. He mobilized the resources of Merck to produce 20 million doses of flu vaccine and prevented one of the last great flu pandemics. He was also of the opinion that flu viruses periodically recycle themselves rather than always being a new reiteration of its former self. Generally, it is true that each year the flu virus undergoes some change in a predictable manner, allowing for change to the antigen structure that is to be included in the new vaccine product. Because the flu virus can be found in its reservoir of pigs and fowl (particularly ducks), virologists from the Centers for Disease Control (CDC) visit places like China in advance of the next flu season in order to sample pig and duck blood for the presence of the next viral form of influenza. From this biological information, cultures can be made that produce large quantities of the virus from which the vaccine can be “manufactured” and the necessary antigen can be expected. How is that done?

### **More on producing a vaccine**

“For five decades, billions of arms have been injected with flu shots containing clear liquid drawn from 11-day-old fertilized chicken eggs. Companies inject the eggs with flu strains. The eggs become tiny incubators, brewing viruses that are then killed and bottled in vials. The nation's entire flu vaccine supply is produced that way.”

“One idea is gaining traction: Instead of incubating the nation's entire vaccine supply in chicken eggs, regarded by many as an antiquated system too inflexible and time-consuming to respond to pandemics or vaccine shortages like this year's, federal health officials are encouraging several biotech companies to develop cell-based vaccines.”

“Cell culture vaccines are a twist on the chicken egg method of vaccine production. Instead of injecting viruses in eggs, scientists infect cells—drawn from insects, African green monkeys, dogs, or human fetal retinas—with flu strains or their components. Then they grow the virus using large fermenting vats in manufacturing plants that look like breweries.”

“Producing the flu vaccine the way it's done now is very much a matter of time and patience. After acquiring millions of specially purified chicken eggs, companies need about six months to create and distribute the vaccines. The process takes too long to be of much help if an unexpected strain erupts or if, as happened this year, something goes awry with the current season's batch.”

“Cell culture vaccines may hold safety advantages. Unlike those produced in chicken eggs, some cell culture vaccines are not processed with chemicals that can cause rare side effects, and people with egg allergies won't have dangerous reactions to them. Also, cell cultures could produce vaccines for the deadly avian flu, which might kill the chicken embryo needed to develop vaccine in an egg.”

<http://www.washingtonpost.com/wp-dyn/articles/A15336-2004Nov26.html>

Another interesting approach to developing a flu vaccine uses a virus that infects army worms. The virus has been altered to produce certain proteins called hemagglutinins which normally are produced by the influenza virus, invading our body cells to produce the flu condition. The hemagglutinins are then used as a basis for producing a vaccine rather than the entire influenza virus, which varies from year to year. And it means the normal vaccine production methods are severely reduced, time-wise. See the website, <http://www.sciam.com/article.cfm?id=caterpillar-cells-could-prove-key-to-mass-producing-flu-vaccine>

And for a different delivery system of a vaccine against hepatitis, see the website <http://www.sciam.com/article.cfm?id=potatoes-deliver-hepatiti> which describes the use of potatoes for producing the hepatitis antigen.

Other newer techniques being explored in vaccine production are clearly described at the Univ. of Arizona website, [http://photoscience.la.asu.edu/photosyn/courses/BIO\\_343/lecture/vaccine.html](http://photoscience.la.asu.edu/photosyn/courses/BIO_343/lecture/vaccine.html).

### **More on HIV/AIDs vaccine development**

The difficulties in developing a vaccine against the HIV virus are clearly outlined in a recent Scientific American article [October 2008] at <http://www.sciam.com/article.cfm?id=the-aids-vaccine-search-goes-on>. It would be helpful to get a print copy of this article, as visuals accompanying the print copy add greatly to the understanding of the article.

One of the main reasons that a successful vaccine has not been developed is because the HIV virus routinely (and spontaneously) changes its antigenic makeup. The HIV virus reproduces, as most viruses do, using a host cell's nuclear machinery (DNA and RNA). When injecting the DNA into the host, there are many errors generated that change the virus's DNA coding. So, the virus is altered without the need for spontaneous mutations or natural selection and the host's immune system cannot be prepared by vaccination to destroy the virus because its antigenic nature is no longer recognized; it is different than what was programmed, through the vaccine, in the host's antibody system. The challenge in developing a vaccine is to determine what antigenic material in the virus is unlikely to change through the program errors mentioned.

### **More on basics of developing immunity at the cellular level**

There is a short video explaining the way in which a vaccine stimulates production of antibodies, T-cells, etc. at <http://health.howstuffworks.com/vaccine9.htm>.

### **More on developing a vaccine against malaria**

The development of a vaccine to protect against a malarial infection has been a difficult task because the malaria-causing organism (*Plasmodium falciparum*) transmitted by female mosquitoes of the *Anopheles* genus has a variety of developing stages, any which could be a target for a vaccine. Which to focus upon? One of the vaccines that has been reported upon recently (2008) by the *New England Journal of Medicine* (<http://content.nejm.org/cgi/content/full/359/24/2521->) suggests an efficacy rate of between 30 and 50 percent with young children. Because the effectiveness is not as high as would be needed to prevent malaria in 80-90% of the population, continuation of other preventive methods such as insecticide-impregnated mosquito netting and blankets is necessary.

The vaccine targets the protein of one of the sporozoite stages of the *Plasmodium* as it emerges from a person's liver on its way to infect red blood cells. While the sporozoite stage of the *Plasmodium* is within the red blood cells of the host, the infectious agent is immune from antibody attack. Further, like the HIV virus, the plasmodium sporozoites continue to change their antigenic properties, reducing the effectiveness of a specific antibody response. Developing a specific antigen-based vaccine is complicated. (See <http://www.malariavaccine.org/malvac-faqs.php>.)

From a researcher's own words comes a good conversation about the challenges in developing a vaccine against malaria that is found at the following website: (<http://www.xconomy.com/seattle/2008/12/09/the-quest-for-a-malaria-vaccine-sbris-stefan-kappe-stares-down-a-leading-candidate/>)

The approach to developing this particular vaccine is to affect the protozoan during its first seven days while in the liver, before releasing into the blood stream and infecting the red blood cells where the malarial effect is most pronounced, including anemia (from the rupturing of the red blood cells), stroke and lung failure. The mechanism for vaccine effectiveness depends on first identifying some genes (out of 5,000) of the parasite that control its development in the liver, deleting these select genes, then creating a vaccine with these modified parasites that would induce an immune response in the host organism. (See <http://www.malariavaccine.org/malvac-approaches.php>.)

Additional information about the development of a vaccine against malaria can be found at the following websites:

[http://www.undispatch.com/archives/2008/12/the\\_malaria\\_vac.php](http://www.undispatch.com/archives/2008/12/the_malaria_vac.php),  
<http://www.cdc.gov/malaria/cdcactivities/research.htm>, and  
<http://www.malariavaccine.org/malvac-state-of-vaccine-dev.php>.

### **More on cancer vaccine**

One of the most successful and, perhaps, most useful vaccines developed to date against cancer is the product marketed to prevent cervical cancer. This vaccine (commercial name is Gardasil) is a Recombinant Vector vaccine and is given to female children between ages 9 and 18. It is working against a cancer of the Human Papillomavirus (HPV) category. A good explanation about the workings of the vaccine is found at <http://health.howstuffworks.com/how-the-cervical-cancer-vaccine-works2.htm>.

Because the vaccine is being used to prevent a cancer associated with a virus transmitted sexually, there was controversy associated with its approval by the federal Food and Drug Administration (FDA), since some groups felt it would promote sexual activity in teenagers if they mistakenly thought it could prevent a number of sexually transmitted diseases (STDs), such as AIDS, syphilis, as well as herpes-related conditions. These groups did not want the vaccine inoculations to be mandated by law. Others felt that teens should be protected, that their health considerations were ahead of any contrary social or religious beliefs. Additional information about the use of Gardasil is found at

[http://pediatrics.about.com/od/immunizations/p/07\\_gardasil.htm](http://pediatrics.about.com/od/immunizations/p/07_gardasil.htm) and  
<http://www.metrofamilymagazine.com/what-every-parent-should-know-about-gardasil>.

### **More on myths about vaccines**

In recent years, there has developed a good example of anecdotal evidence becoming scientific “fact”. In particular there is a concern among parents that the high incidence of autism is due to vaccination, more specifically to the presence of either the measles virus RNA or a mercury-containing compound (thimerosal) used as a preservative in some vaccines. It is not used in the measles vaccine. The original medical thought made public came from a British physician making what he thought was a connection between vaccination of some of his patients and their development of autism. The scientific community, through government as well as academia and commercial circles, has thoroughly investigated this assertion. Even so, there is a segment of the population that refuses to vaccinate their children against some childhood diseases (some of them rather fatal) such as measles, mumps and rubella (German measles) through the so-called MMR vaccine. Measles is considered one of the most infectious of viral diseases. It is said that if an infected person walked into a room of a hundred unvaccinated people and coughed, 90 people or more will get measles. See <http://www.sciam.com/article.cfm?id=new-study-measles-vaccine> and <http://www.sciam.com/article.cfm?id=investigating-environmental-origins-of-autism> which covers a whole host of ideas concerning the root causes of autism, including the environment (mercury, pesticides, and antibiotics) and genetics.

There are a few other myths about vaccines, including the autism “connection”, that can be found at <http://health.howstuffworks.com/vaccine9.htm>,  
<http://www.quackwatch.org/03HealthPromotion/immu/autism.html> and  
<http://www.washingtonpost.com/wp-dyn/content/article/2008/09/03/AR20080903033396.html>.

## More on organ transplants and immune systems

Because the human body has an immune system, it becomes a liability when there is a need to replace human organs and tissue with donor material. Interestingly enough, a pregnant woman's body initially "sees" a fetus as potentially a foreign object. But mammals have evolved a system for immune tolerance of the newly developing embryo/fetus. The system is a complicated one. One interesting aspect is the fact that the maternal blood system does not reject the fetus yet is still capable of fighting infections that could ultimately affect the fetus. (See <http://www.rbej.com/content/1/1/121>.)

When a person undergoes an organ or tissue implant, the immune system of the recipient has to be suppressed in order to prevent the implanted organ from being destroyed ("rejected") by the host's immune system. Ideally, the goal would be to convert the recipient's immune system to that of the donor! That has happened spontaneously on at least one occasion. Another approach that is being investigated involves the use of a naturally occurring immune molecule called HLA-G that may regulate/inhibit the immune response to a foreign tissue or organ. The goal is to find a mechanism by which the levels of HLA-G can be increased in an organ recipient but also suppress such a molecule when the immune response is needed to treat cancer. It is also possible to identify transplant patients who require little if any immune system suppression by measuring their levels of the HLA-G suppression molecule. (See <http://www.medicinenet.com/script/main/art.asp?articlekey=90522> and <http://health.usnews.com/articles/health/healthday/2008/06/23/immune-molecule-key-to-preventing-organ-rejection.html>.)

Currently, transplant patients are treated with a variety of chemicals to suppress their immune response to a newly donated organ or tissue. The most widely used drug is Cyclosporine, derived from a fungus and approved for medical use in 1983. (See <http://www.chfpatients.com/tx/txmeds.htm> for a listing and the working mechanisms of Anti-Rejection Drugs.)

One of the newer approaches to prevent rejection involves a number of different techniques. Researchers at Massachusetts General Hospital have delineated a number of steps to both prepare a transplant patient and to maintain that person after organ implant surgery. First, the bone marrow of the recipient is pretty much destroyed using chemotherapy five days before transplantation to make room for the DONOR's bone marrow which will be injected during surgery. In addition, the thymus gland is irradiated and given a drug to eliminate the production of the famous T-cells of the immune system that would normally destroy foreign tissue. On the day of surgery, as the donated organ is being attached, some of the DONOR's bone marrow is injected into the patient's circulatory system, producing a temporary mix (called a "mixed chimerism") that seems to confuse the patient's immune system such that it recognizes the donated organ as belonging to the recipient. This altered state of recognition may last for years. After surgery, the patient's immune system is in flux and anti-rejection drugs are given, but taper off over about a nine-month period. (See [http://www.boston.com/news/health/blog/2008/01/mass\\_general\\_tr.html](http://www.boston.com/news/health/blog/2008/01/mass_general_tr.html).)

## Connections to Chemistry Concepts

## Possible Student Misconceptions

1. **“A live vaccine can give me the disease it’s supposed to prevent.”** Vaccines can cause extremely mild symptoms. But these are minor and quite different than having the full-blown disease. Measles and mumps can be deadly.
2. **“Vaccines aren’t necessary anymore because all the diseases associated with the vaccines are gone anyway.”** According to the Centers for Disease Control (CDC), if we stopped vaccinating, many diseases that appear to have gone away would return and cause catastrophic results for those not inoculated. You can see the results of the non-vaccinated state in some of the poorer countries where polio and measles wreak their medical destruction, particularly on the young.
3. **“Use of the vaccine to prevent cervical cancer, a cancer caused by a herpes-related papillomavirus, (which is a Socially Transmitted Disease or STD), will protect women against other STDs such as HIV (a virus) and syphilis.”** Each vaccine is specific for a particular antigen whether from a virus or a spirochete, a type of bacteria. So, the cervical cancer vaccine will not be effective against an HIV or syphilis-causing spirochete. (A useful reference on all aspects of cervical cancer including its STD component is found at <http://health.howstuffworks.com/how-the-cervical-cancer-vaccine-works1.htm>.)

## Demonstrations and Lessons

1. The basic type of antigen-antibody reaction can be illustrated with a short lab exercise, using the blood-typing reaction (blood type A, B, AB and O). This was a standard biology lab exercise, using the student’s own blood and antibody serums provided by educational science supply companies. Because of HIV/AIDS transmission through blood, the activity is now done with fluids that simulate the antigen-antibody reaction rather than a student’s blood (and the squeamish reaction of students when their fingers were pricked with a flat needle).
2. The commercial testing of many substances in food (e.g., additives) as well as the presence of illicit drugs in a person’s blood or urine can be shown to students either through a simulation or an actual lab exercise. The process is called ELISA (enzyme-linked immunosorbent assay). The actual lab exercise is expensive (\$135) and is available from Bio-Rad ([http://www.bio-rad.com/B2B/BioRad/product/br\\_category.jsp?BV\\_SessionID=@@@@0524053847.1230316737@@@@&BV\\_EngineID=cccfadegdfkljkjcfngcfkmdhkkdfll.0&divName=Life+Science+Education&categoryPath=%2fCatalogs%2fLife+Science+Education%2fClassroom+Kits%2fELISA+Immuno+Explorer+Kit&loggedIn=false&lang=English&country=HQ&catLevel=4&catOID=-26164&isPA=false&serviceLevel=Lit+Request](http://www.bio-rad.com/B2B/BioRad/product/br_category.jsp?BV_SessionID=@@@@0524053847.1230316737@@@@&BV_EngineID=cccfadegdfkljkjcfngcfkmdhkkdfll.0&divName=Life+Science+Education&categoryPath=%2fCatalogs%2fLife+Science+Education%2fClassroom+Kits%2fELISA+Immuno+Explorer+Kit&loggedIn=false&lang=English&country=HQ&catLevel=4&catOID=-26164&isPA=false&serviceLevel=Lit+Request)).
3. The ELISA virtual lab, showing the same process that is used in the ELISA student lab, is available free from two sources. One is from the Howard Hughes Medical Institute’s teacher resource site at <http://www.hhmi.org/biointeractive/immunology/vlab.html>. A second site is from the Univ. of Arizona’s BioProject at <http://www.biology.arizona.edu/immunology/activities/elisa/main.html>.
4. In addition, the BioProject at the Univ. of Arizona mentioned above has a number of tutorials in Immunology at <http://www.biology.arizona.edu/immunology/immunology.html>. This includes such topics as Antibody Structure, HIV and AIDS (showing interactions with the immune system and current treatment actions) along with additional www resources.

5. Video references for a Virtual Immunology Lab can be found at the Howard Hughes Medical Institute website, <http://www.hhmi.org/biointeractive/vlabs/immunology/index.html> and <http://www.hhmi.org/biointeractive/immunology/index.html>.

## ***Student Projects***

1. Students could do literature research on the evidence for the causes of autism that has now reached a statistical level of one in 150 newborns developing the condition. In this particular research, students could examine the data that eliminates vaccines as the cause of autism. (See references given above under Autism.)
2. Students could do literature research on the progress and problems in developing a vaccine against HIV or malaria. Both conditions, one from a virus, the other from a one-celled flagellate (a *Trypanosoma*), present major difficulties to vaccine researchers. What are those major impediments?
3. What is malaria? Students need to learn about this world-wide disease.
4. Students could develop arguments for and against the mandatory vaccination of preteen girls against cervical cancer.
5. Louis Pasteur was an extraordinary 19<sup>th</sup> C investigator in the realms of both biochemistry and bacteriology. His work in organic chemistry dealing with chiral compounds, and his disproving the idea of spontaneous generation, are among his many scientific achievements. Students have a great opportunity to research his life and work in light of the state of science in the late 19<sup>th</sup> C.

## ***Anticipating Student Questions***

### ***References***

The April 1988 issue of *ChemMatters* magazine has an article about the use of antibodies to determine the degree of genetic similarity (or lack thereof) between different mammal species as diverse as chimps, mastodons, Egyptian mummies and modern humans. The technique is related to the current ELISA testing mentioned under Demonstrations and Lessons. The article, “*Fossil Molecules*”, is found on pp. 4-7.

The reference above can be found on the *ChemMatters* 25-year CD (covering years 1983 through 2008). The CD is obtainable from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. Teacher’s Guides for the last five years are also available free online at this same site. (Teacher’s Guides for all articles from all issues are available on the 25-year CD.)

### ***Web Sites for Additional Information***

#### **More sites on anecdotal science**

Several references on the importance of rational science, using data rather than anecdotal “evidence” can be found at:



<http://www.sciam.com/article.cfm?id=how-anecdotal-evidence-can-undermine-scientific-results>,

<http://www.metrofamilymagazine.com/what-every-parent-should-know-about-gardasil>,

<http://www.sciam.com/article.cfm?id=investigating-environmental-origins-of-autism>,

<http://www.sciam.com/article.cfm?id=vaccine-injury-case-offer>, and

<http://www.sciam.com/article.cfm?id=cures-and-cons>.

### **More sites on decision-making about vaccine usage**

Information about the use of Gardasil to prevent cervical cancer can be found at [http://pediatrics.about.com/od/immunizations/p/07\\_gardasil.htm](http://pediatrics.about.com/od/immunizations/p/07_gardasil.htm),

<http://www.metrofamilymagazine.com/what-every-parent-should-know-about-gardasil>,

<http://www.sciam.com/blog/60-second-science/post.cfm?id=gardasil-cervical-cancer-vaccine-sa-2008-10-23>, and

<http://www.sciam.com/article.cfm?id=to-banish-a-cancer>.

Another reference that deals with all the societal concerns about vaccinating a child against an STD (the anti-vaccination movement in general) and the rational arguments for vaccinating are found at

<http://www.sciam.com/article.cfm?id=vaccine-programs-kids-shot-in-arm>.

A related issue concerning stem-cell research and societal/government efforts to block this category of research is found in an interview in a *Scientific American* article at

<http://www.sciam.com/article.cfm?id=congresswoman-degette-slams-religious-right-on-science>

### **More sites on cancer vaccines**

<http://www.sciam.com/article.cfm?id=cancer-vaccine-looking-beyond> deals with an approach that enhances cancer vaccine effectiveness through the use of what are known as adjuvants, drugs that augment the activity of vaccines. One important criterion for the effectiveness of a cancer vaccine is the length of time a cancer patient survives, not the extent to which a tumor's size is reduced.

Additional experimental approaches to developing immune responses in cancer patients employ the use of what are normally considered to be dangerous viruses and bacteria.

References follow:

<http://www.sciam.com/article.cfm?id=cancer-vaccine-tobacco-plants> and

<http://www.sciam.com/article.cfm?id=recruiting-a-dangerous-foe>.

Another approach using radioactive antibodies is found at

<http://www.sciam.com/article.cfm?id=radioactive-antibody-miss>.

### **More sites on teacher information and lesson plans**

The following website is a composite of websites that relate to various curricula and projects on immunology. It is the Biochem4Schools, a British program site, at [http://www.biochem4schools.org/results\\_topic.htm?qry=immunology](http://www.biochem4schools.org/results_topic.htm?qry=immunology).