April 2009 Teacher's Guide

Table of Contents

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

Patrice Pages, *ChemMatters* Editor, coordinated production and prepared the Microsoft Word and PDF versions of the Guide. E-mail: 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.

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

Purchase information can be found online at www.acs.org/chemmatters

Student Questions

Letting Off Steam

1. What three discoveries have scientists made regarding geysers and hot springs?
2. What volume of water is ejected daily by the hot springs and geysers in Yellowstone?
3. Is the boiling temperature of water always 100°C?
4. What two factors determine if extremely hot underground water surfaces as a geyser or as a hot spring?
5. Describe the cycle of eruption of a geyser.
6. What is the underground source of heat for Yellowstone's hot springs and geysers?
7. How did scientists at the University of Utah discover the underground geology of Yellowstone?
8. According to the author, what are the two main chemicals found dissolved in high concentrations in the hot waters of Yellowstone?
9. Name four other, potentially toxic, chemicals found in hot springs in Yellowstone.
10. How are *Candidatus* Chloracidobacterium thermophilum different from other bacteria growing in hot springs?
11. What limits scientists' understanding about the underground geology of Yellowstone?
12. What do scientists believe is the cause of upward and downward movements of the ground in Yellowstone?
13. How is the simulated volcano, which you might have made according to the directions in the article, different from an actual volcano, in terms of driving forces?

Rainforests: A Huge Natural Resource under Threat

1. What per cent of the earth's surface do rainforests cover?
2. What percent of all known species of plants and animals are found in tropical rainforests?
3. What conditions allow tropical rainforests to thrive?
4. How many acres of rainforests are estimated to be lost to deforestation each year?
5. Approximately how many kinds of plants do we eat that were originally rainforest fruits? List ten common food products that originally came from rainforests.
6. Describe the properties of the katemfe fruit and the miracle berry.
7. Of the 3000 plants that the U.S. National Cancer Institute has identified as active against cancer cells, what per cent come from rainforests?
8. Who are ethnobotanists? What is there role in obtaining information on plants and animals that may have medicinal properties?
9. What drugs have been developed from the rosy periwinkle, the Pacific Yew, and the cinchona tree?
10. List environmental concerns that occur as a result of deforestation.
11. What are some of the suggestions being proposed to slow down, stop, and even reverse rainforest destruction?

Those Blooming Algae!

1. What is meant by the term “Algal Bloom”?
2. What two chemical elements seem to be the primary stimulus to an algal bloom?
3. Why do scientists use computer simulations for an algal bloom?
4. How do algal blooms reduce dissolved oxygen in water, if algae are photosynthetic?
5. Other than indirectly reducing dissolved oxygen, how else can algae kill marine organisms and even humans?
6. What causes “red tide tickle”?
7. How can an algal bloom kill birds and marine animals?
8. What are two possible uses by the algae *Karenia brevis* for its toxin, brevetoxin?
9. How does brevetoxin produce its toxic effects in animals?
10. What are three possible natural (as opposed to human) sources of excess nutrients (primarily nitrogen and phosphorus) associated with algal blooms?
11. What is the main human-generated source of polluting nutrients associated with algal blooms?
12. What seems to be the primary cause of algae blooms (*Karenia brevis)* around the Florida coastline?
13. What is the mechanism by which the toxin, brevetoxin, affects the nervous system of animals?
14. What are the connections between brevetoxin, brevenal, and cystic fibrosis?

Chocolate: The New Health Food. Or is it?

1. At what temperature does chocolate melt?
2. Why is the above temperature a key to chocolates properties?
3. Approximately how may chemicals make up chocolate?
4. Name two of the well known chemicals in chocolate.
5. How do the formulas of the two chemicals in question 4 differ?
6. List the names of two chemicals produced by the brain which are also found in chocolate.
7. What are the physiological effects of the two chemicals in question 6?
8. What are “antioxidants” and how do they protect the body?
9. If chocolate can be shown to be one of the healthiest foods available, why is it often classified as a “junk” food?
10. Cocoa is rich in chemicals called flavanols. What are some of the health benefits of flavanols?
11. It is a popular belief that chocolate causes acne and other skin problems that afflict teenagers. According to the article, is this true? Explain.
12. Briefly describe the steps in chocolate production.
13. What is the chemical composition of cocoa butter?
14. What are scientists doing to find ways to make cocoa trees more resistant to pests and disease and provide healthier, more nutritious, and better tasting chocolate?

Air Pollution: What Weather Satellites Tell Us

1. Name the U.S. agencies that have collaborated to develop satellites that measure air pollution and climate change.
2. Name three greenhouse gases mentioned in the article.
3. What is the term used to describe plants that are burned to produce energy?
4. What does the abbreviation EOS stand for?
5. The NASA IDEA program studies what kind of atmospheric pollution?

6. What is the Kyoto Protocol?
7. What is the role of the Intergovernmental Panel on Climate Change?

Answers to Student Questions

Letting Off Steam

1. **What three discoveries have scientists made regarding geysers and hot springs?**

Scientists have discovered that

a) the water in geysers and hot springs contains chemicals unique to that area,
b) the water contains bacteria that thrive at very high temperatures, and
c) the geysers and hot springs are caused by upward movement of molten rock and hot water through elaborate networks of vents and caves.

2. **What volume of water is ejected daily by the hot springs and geysers in Yellowstone?**

Two hundred fifty million (250,000,000) liters a day are ejected by the hot springs and geysers in Yellowstone.

3. **Is the boiling temperature of water always 100°C? Explain.**

No, the boiling temperature of water is not always 100°C; it varies with pressure. In the underground chambers in Yellowstone, the temperature can reach 300°C or more, yet the pressure is so great that the water remains liquid.

4. **What two factors determine if extremely hot underground water surfaces as a geyser or as a hot spring?**

   a. *If the hot water can rise to the surface quickly, the pressure decreases rapidly, allowing the water to boil and make steam. This is likely to result in a geyser. If the water rises slowly, the pressure is reduced slowly and the water bubbles into a pool of hot water, resulting in a hot spring.*
   b. *If there is a restriction or narrowing in the plumbing system, this will result in a build-up of pressure as the water above the narrowing acts like a lid, keeping the pressure on the water until it blows. This is likely to result in a geyser. If there is no narrowing, the water can simply rise into a pool of hot water, resulting in a hot spring.*

5. **Describe the cycle of eruption of a geyser.**

   a. *The underground chamber fills with water from the surface, heated to extreme temperatures by the hot rocks around it.*
   b. *Then this hot water rises to the surface, turning to steam as the pressure decreases.*
   c. *This boiling water and steam forces its way through the narrowing of the chamber, blowing off the lid of water that had been maintaining the pressure on the boiling water below. The escaping steam/hot water produces the familiar plume of water/water vapor.*
   d. *The escaping underground water empties the underground chamber, and readies the geyser for the next round in the cycle.*

(Note that, since this is a cycle, the description given by the student could begin at any of the steps a-d, as long as the sequence is maintained.)

6. **What is the underground source of heat for Yellowstone's hot springs and geysers?**

Partially molten rock called magma, located about six kilometers below the surface, is the heat source for Yellowstone's hot springs and geysers.

7. **How did scientists at the University of Utah discover the underground geology of Yellowstone?**
University of Utah scientists studied underground waves caused by earthquakes in the area to determine the underground geology of Yellowstone.
8. **According to the author, what are the two main chemicals found dissolved in high concentrations in the hot waters of Yellowstone?**
Silicon dioxide and calcium carbonate are the two main chemicals found dissolved in Yellowstone's hot water.
9. **Name four other, potentially toxic, chemicals found in hot springs in Yellowstone.**
Arsenic, mercury, hydrogen sulfide, and carbon dioxide are four other, potentially toxic, chemicals found in the hot waters in Yellowstone.
10. **How are *Candidatus* Chloracidobacterium thermophilum different from other bacteria growing in hot springs?**
These bacteria photosynthesize, as do some other forms of bacteria, but Candidatus Chloracidobacterium thermophilum have special structures called chlorosomes, containing dense concentrations of bacteriochlorophyll molecues. These structures collect light much more efficiently than other bacteria, allowing them to function in much dimmer light than their relatives.
11. **What limits scientists' understanding about the underground geology of Yellowstone?**
Their "…inability to get down there for a direct look…" limits scientists' understanding about what's happening deep underground at Yellowstone. They don't have instruments like they do for the surface (GPS, radar interferometry) that can tell them about the subsurface.
12. **What do scientists believe is the cause of upward and downward movements of the ground in Yellowstone?**
Scientists believe that continuous motion of hot water and molten basalt and granite coming from the magma chamber below Yellowstone are responsible for the movements at the surface, although scientists still do not understand the causes behind the circulation of hot water and magma over time.
13. **How is the simulated volcano, which you might have made according to the directions in the article, different from an actual volcano, in terms of driving forces?**
Scientists believe that continuous motion of hot water and molten basalt and granite coming from the magma chamber below Yellowstone are responsible for the movements at the surface, although scientists still do not understand the causes behind the large-scale circulation of hot water and magma over time.

Rainforests: A Huge Natural Resource under Threat

1. **What per cent of the earth's surface do rainforests cover?**
According to the article, rain forests cover only 6% of the earth's land surface.
2. **What per cent of all known species of plants and animals are found in tropical rainforests?**
According to the article, rain forests are home to half of all known species of plants and animals.
3. **What conditions allow tropical rainforests to thrive?**
Large amounts of rainfall, humidity, and sunshine allow rain forests to thrive.

4. **How many acres of rainforests are estimated to be lost to deforestation each year?**

According to the article, nearly 40 million acres of rain forest are lost every year.

5. **Approximately how many kinds of plants do we eat that were originally rainforest fruits? List ten common food products that originally came from rainforests.**

Most of the foods we eat originally came from the rainforest. According to the article, we eat 200 kinds of rainforest fruits. Ten common food products that originally came from the rainforest are: avocados, coconuts, pineapples, tomatoes, corn, potatoes, rice, pepper, cinnamon, paprika, and vanilla. Coffee and cocoa powder used to make chocolate are both products of the rainforest.

6. **Describe the properties of the katemfe fruit and the miracle berry.**

Katemfe fruit is bright red and grows in the tropical rainforests of West Africa. It is used to make a natural sweetener called thaumatin. Thaumatin is 1,600 times sweeter than sucrose, table sugar, and is considered the sweetest naturally-occurring substance in the world. It has a licorice-like taste and can be dissolved in water. In the US, it is used as a dietary supplement, although it is not yet marketed as a sweetener.

7. **Of the 3000 plants that the U. S. National Cancer Institute has identified as active against cancer cells, what per cent come from rainforests?**

According to the article, 70% of the 3000 plants so identified come from rainforests.

8. **Who are ethnobotanists? What is their role in obtaining information on plants and animals that may have medicinal properties?**

Ethnobotanists are scientists who work with local "medicine men" who are spiritual guides of local tribes. The medicine men are known for making medicinal concoctions derived from local plants and have extensive knowledge of local plants that has been passed down verbally from generation to generation for centuries. The ethnobotanists first live among a native tribe for some time to gain the trust of the local medicine men. Once this trust is developed, the medicine men provide a wealth of useful information. As native tribes and cultures disappear, these medicine men have no successor. Without someone to receive the knowledge accumulated over centuries, valuable information may be lost.

9. **What drugs have been developed from the rosy periwinkle, the Pacific Yew, and the cinchona tree?**

From the rosy periwinkle, scientists have derived two cancer-fighting medicines called vinblastine and vincristine. Both can inhibit human tumor growth. Vinblastine has been used to treat childhood leukemia and has improved the survival rate from 10% to 95%. Vincristine is used to treat testicular cancer and Hodgkin's disease. The Pacific Yew has produced one of the most effective cancer-fighting drugs. In 1971 a chemical known as paclitaxel was derived from the bark of the yew tree. The chemical, commercially known as taxol prevents tumor cells from spreading. It is used in the treatment of previously untreatable ovarian cancer as well as advanced lung and breast cancer. The bark of the Cinchona tree is used in the production of quinine used in the treatment of malaria.

10. **List environmental concerns that occur as a result of deforestation.**

Deforestation would most likely result in the reduction of food and natural products, an increase in water pollution and flooding, an increase in global warming, and in the destruction of animal habitats and extinction of the species living in these habitats.

11. **What are some of the suggestions being proposed to slow down, stop, and even reverse rainforest destruction?**

Suggestions include planting trees in areas where forests have been cut down, encouraging companies and people to recycle or limit the use of material coming from rainforests, establishing parks to protect rainforests and wildlife, and, as a personal choice, buy products from companies dedicated to using the rainforest in ways that preserve it.

Those Blooming Algae!

1. **What is meant by the term "Algal Bloom"?**

An algal bloom is an abnormal or excess growth of algae due to some chemical stimulus.

2. **What two chemical elements seem to be the primary stimulus to an algal bloom?**

The two chemical elements that seem to stimulate excess algal growth are nitrogen and phosphorus.

3. **Why do scientists use computer simulations for an algal bloom?**

A computer-based simulation allows investigators to alter various environmental conditions (chemical and physical, such as temperature and light) to see possible effects on rate of algae growth.

4. **How do algal blooms reduce dissolved oxygen in water if algae are photosynthetic?**

The blooms indirectly reduce dissolved oxygen only after they die, at which point bacteria cause decay of the algae which is really bacteria digesting the algae and using the nutrients as a source of energy through a chemical process called respiration. Respiration involves the use of oxygen, taken from the water. So it is the bacteria that directly reduce dissolved oxygen.

5. **Other than indirectly reducing dissolved oxygen, how else can algae kill marine organisms and even humans?**

Some algae produce toxins that can kill a variety of marine and non-marine organisms. The toxin in the algae can move through the food chain—fish eating algae, birds and other marine mammals eating the infected fish.

6. **What causes the "red tide tickle"?**

Toxins produced by certain algae can be transported through the air and inhaled by land animals, including humans. The toxin can be an irritant to the respiratory system and the eyes.

7. **How can an algae bloom kill birds and marine animals?**

If the bloom is from algae that produce toxins, then their ingestion by fish will pass along the toxin to predators of fish such as birds and marine animals such as manatees, sea dolphins, and turtles.

8. **What are two possible uses by the algae *Karenia brevis for its toxin*, brevetoxin*?***

The algae can use the toxin to deter predators (herbivores) or possibly to facilitate its metabolism (the several activities of a living organism—nutrition, respiration, synthesis).

9. **How does brevetoxin produce its toxic effects in animals?**

Brevetoxin seems to interfere with the so-called sodium channels of nerve cells, thereby disabling the nerve cells and incapacitating the organism.

10. **What are three possible natural (as opposed to human) sources of excess nutrients (primarily nitrogen and phosphorus) associated with algal blooms?**

- *Iron dust carried from Africa can stimulate the growth of a bacterium that captures atmospheric nitrogen converting it to the compound ammonia that can then be used by the algae (nitrogen cannot be used directly).*
- *Early in an algal bloom, fish killed by the bloom decompose, providing nutrients from the action of decay bacteria and enriching further algae growth.*
- *Nutrients from rivers that drain into the ocean can increase with the right wind and current conditions.*

11. **What is the main human-generated source of polluting nutrients associated with algal blooms?**

Farming with extensive use of commercial fertilizers containing nitrates and phosphates is one of the main sources of polluting nutrients. The same fertilizers are used by homeowners to produce luxuriant lawns. A second source of polluting nutrients is from the wastewater of sewage-treatment plants.

12. **What seems to be the primary cause of algae blooms (*Karenia brevis)* around the Florida coastline?**

Algae blooms in Florida appear to be a more natural source of nutrients—the decay of dead fish. An additional source of nitrogen is from the Trichodesmium bacteria that "fixes" nitrogen. ("Fixes" means it converts elemental nitrogen in the atmosphere into nitrates, the usable form nitrogen for plants, including algae.)

13. **What is the mechanism by which the toxin, brevetoxin, affects the nervous system of animals?**

Brevetoxin interferes with the movement of sodium ions in and out of nerve cells.

14. **What are the connections between brevetoxin, brevenal, and cystic fibrosis?**

Brevetoxin adversely affects the movement of sodium ions in and out of nerve cells through a structure known as a sodium channel. Brevenal is a chemical compound that counters or blocks the effects of brevetoxin on nerve cells' sodium channels. Cystic fibrosis is caused in part by defective sodium channels that regulate the important flow of sodium ions in lung tissue. Therefore, it is possible that administering brevenal may correct the defective sodium channels.

Chocolate: The New Health Food. Or is it?

1. **At What temperature does chocolate melt?**

Chocolate melts between 94 and 97 °F.

2. **Why is the above temperature a key to chocolate's properties?**

Normal body temperature is 98.6 °F, just above the melting point of chocolate. "Melts in your mouth" is true. "A morsel of chocolate slides across your tongue and liquefies into a perfect puddle of taste sensation."

3. **Approximately how many chemicals make up chocolate?**

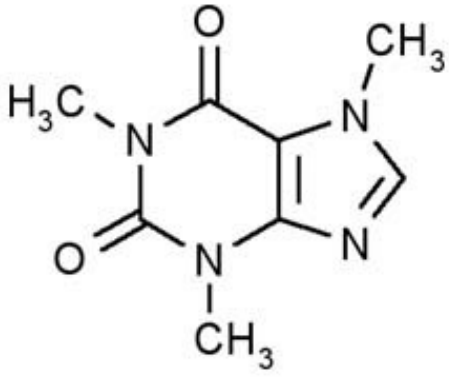
According to the article, chocolate contains more than 300 chemicals.

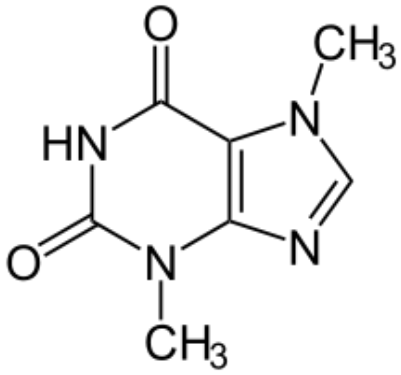
4. **Name two of the well known chemicals in chocolate.**

The two chemicals are caffeine and theobromine. Caffeine is present in small amounts, with theobromine present in slightly higher amounts than caffeine.

5. **How do the formulas of the two chemicals in question 4 differ?**

The two chemicals are identical except for one methyl group (CH3-) present in the caffeine molecule, but not in the theobromine molecule.





Caffeine theobromine

6. **List the names of two chemicals produced by the brain which are also found in chocolate.**

The two chemicals produced by the brain which are also found in chocolate are anandamide and phenylethylamine.

7. **What are the physiological effects of the two chemicals in question 6?**

Anandamide blocks out pain and depression. Chemicals in chocolate appear to slow down or inhibit the breakdown of anandamide and, as a result, the chemicals' persistent presence makes us feel good longer. Phenylethylamine stimulates the parts of the brain that keep one alert and mimics the brain chemistry of a person in love.

8. **What are "antioxidants" and how do they protect the body?**

Antioxidants protect the body from free radicals – atoms, molecules, or ions with unpaired electrons. The unpaired electrons are usually highly reactive and more likely to take part in chemical reactions. Inside cells, free radicals damage DNA and have been associated with Alzheimer's disease, heart disease, and cancer. Antioxidants prevent this damage from happening by blocking the action of free radicals.

9. **If chocolate can be shown to be one of the healthiest foods available, why is it often classified as a "junk" food?**

It is all in the processing of the chocolate. Processing determines whether chocolate is a healthy food or a high calorie indulgence. Roasting and fermenting wipe out scores of antioxidants. Food stores sell mainly processed chocolate, with sugar, milk, and extra fat added because they taste good and cost less, but the more non-cocoa items added to cocoa, the more dilute the healthy chemicals become. And the cheaper the cost, in general, the more a chocolate qualifies as a junk food.

10. **Cocoa is rich in chemicals called flavanols. What are some of the health benefits of flavanols?**

Flavanols appear to increase blood flow to the brain and, as a result, might be used to treat vascular impairments in the brain resulting from a stroke. Consumption of a flavanol-rich cocoa beverage also increases the amount of nitric oxide in the blood vessels, allowing them to dilate and keep them pliable. Cocoa flavanols might then be used to clear clogged arteries in heart disease and stroke.

11. **It is a popular belief that chocolate causes acne and other skin problems that afflict teenagers. According to the article, is this true? Explain.**

Current research does not connect any specific food to skin problems. Chocolate husks contain chemicals that prevent tooth decay, although the added sugar in chocolate confections may offset the health benefits.

12. **Briefly describe the steps in chocolate production.**

Tiny flies called midges pollinate the trees. (2) The pods containing 20 to 60 seeds are removed from the trees, split with a machete, and the pulp and beans are removed and allowed to ferment under banana leaves in the sun. (3) After fermentation, the beans are dried on bamboo mats or wooden floors. (4) The dried beans are shipped to manufacturing plants, where they are cleaned, sorted, and roasted. (5) After removal of the bean shells, the dark chips, called nibs, are crushed to form the solid fat called cocoa butter.

13. **What is the chemical composition of cocoa butter?**

"Cocoa butter is essentially all fat. There are three major kinds: a 'bad-for-you' saturated fat called palmitic acid; oleic acid, a heart-healthy monounsaturated fat; and stearic acid, part of which later converts to oleic acid in the liver. Overall, one third of chocolate's fat is known to be unhealthy. But all three kinds of fats raise the amount of calories they produce in the

body, although they do not cause an increase in blood cholesterol when consumed in chocolate."

14. **What are scientists doing to find ways to make the cocoa tree more resistant to pests and disease and provide healthier, more nutritious, and better tasting chocolate?**

Last June, scientists from Mars, Inc, partnered with IBM and the U.S. Department of Agriculture to launch a five year project to unravel the genome of the cocoa bean. Once unraveled, the scientists may be able to modify the genes of the cocoa tree to produce the desired effects.

Air Pollution: What Weather Satellites Tell Us

1. **Name the U.S. agencies that have collaborated to develop satellites that measure air pollution and climate change.**

The National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) are the US agencies that have collaborated.

2. **Name three greenhouse gases mentioned in the article.**

Carbon dioxide, methane and nitrous oxide are the three greenhouse gases from the article.

3. **What is the term used to describe plants that are burned to produce energy?**

The term for plants burned to produce energy is biomass.

4. **What does the abbreviation EOS stand for?**

EOS means Earth Observing System.

5. **The NASA IDEA program studies what kind of atmospheric pollution?**

Aerosols are the pollutant studied by NASA's IDEA program.

6. **What is the Kyoto Protocol?**

The Kyoto Protocol is an international agreement between nations to reduce the emission of greenhouse gases.

7. **What is the role of the Intergovernmental Panel on Climate Change?**

Its role is to assess the influence of human activity on climate change.

ChemMatters Puzzle: Elemental Fluster

A word game named FLUSTER features a 4x4 grid populated by 16 letters (duplicates allowed), chosen at random. See the grid in puzzle #1 as an example. The object is to make as many common words as possible by moving between adjacent squares… horizontally, vertically, or diagonally. There's just one rule: all letters of a given word must be found in different squares. If a given word has 2 R's in it, you must have two different squares supply them. But you may use an R in a given square in more than one word.

We'll challenge you not to get flustered with some names of ELEMENTS in such puzzles! Here goes.

PUZZLE #1

O	D	T	A
I	I	R	D
N	C	O	G
K	E	L	N

One element name in there is IRON, starting in the 2nd row, 2nd column and ending in 4th row, 4th column. Can you find SIX more?! Notice the lack of any U or M's. That eliminates most of the metals!

PUZZLE #2

	F	U	
		M	
B			

Here's a variant that's a bit more challenging. We'll tell you all the names, and give you a few letters in place in a 4x4 grid. Using logic (and perhaps some trial and error), see if you can place the remaining letters. The NAMES: SULFUR, FLUORINE, IRON, BARIUM, ERBIUM
There are several ways to do this, all of them acceptable answers. We'll give you one on the answer page.

PUZZLE #3

Here's your toughest challenge. Identify ALL the elements that have exactly 4 letters in their name. Then figure out a way to place the letters so that all five names appear in a 4x4 grid. Then do it WITHOUT using any diagonal moves! There are many possible solutions, due in part to permutations in the layout. Strive to have as many unused squares as possible. We'll show you a solution with one blank square on the answer sheet, but you can perhaps do better! (Hint: determine the minimum number of letters needed to have all five displayed.)

Answers to the ChemMatters Puzzle

Puzzle #1: Besides IRON, one can find NICKEL, IODINE, RADON, ARGON, NEON, and TIN.

Puzzle #2: This is just one of several possibilities

U	L	O	N
S	F	U	R
A	I	M	I
B	R	E	N

containing the names SULFUR, FLUORINE, IRON, BARIUM, ERBIUM.

Puzzle #3:
Again, there are many correct solutions. Here's just one of them.
Note that there are no moves that go DIAGONALLY to another square.

Z	G	O	L
I	R	A	D
N	O	E	L
C	E	N	

The five elements present are NEON, IRON, LEAD, GOLD, and ZINC.

NSES Correlation

National Science Education Content Standards Addressed

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	Letting Off Steam	Rainforests	Those Blooming Algae!	Chocolate	Air Pollution	Using Chemistry to Protect the Environment
Science as Inquiry Standard A: about abilities necessary to do scientific inquiry.	✔					
Science as Inquiry Standard A: about scientific inquiry.	✔	✔	✔	✔	✔	✔
Physical Science Standard B: of the structure and properties of matter.	✔	✔	✔	✔		
Physical Science Standard B: of chemical reactions.	✔				✔	✔
Life Science Standard C: about interdependence of organisms			✔		✔	
Earth and Space Standard D: about energy in the Earth system.	✔				✔	
Earth and Space Standard D: about geochemical cycles	✔				✔	✔
Science and Technology Standard E: about science and technology.		✔	✔	✔	✔	✔
Science in Personal and Social Perspectives Standard F: of personal and community health.		✔	✔	✔		

Science in Personal and Social Perspectives Standard F: about natural resources.	✔	✔	✔		✔	✔
Science in Personal and Social Perspectives Standard F: about environmental quality.			✔		✔	✔
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.		✔	✔	✔	✔	✔
History and Nature of Science Standard G: of science as a human endeavor.			✔			✔
History and Nature of Science Standard G: of the nature of scientific knowledge.	✔	✔	✔	✔	✔	✔
History and Nature of Science Standard G: of historical perspectives.		✔			✔	✔

Anticipation Guides

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss 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. Thick glaciers can have tiny air bubbles trapped at the bottom.
		2. Even at great depths, ice keeps its form.
		3. After ice core samples are extracted, they must remain below 0 °C.
		4. Ice core samples can provide information about solar activity as well as meteor activity.
		5. Scientists determine the age of air bubbles trapped in ice by determining the age of the ice itself.
		6. The air samples in the ice cores are 800,000 years old, give or take 500 years.

Letting Off Steam

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. The steam from the Old Faithful geyser has a temperature less than 100 °C.
		2. Yellowstone has approximately 1000 geysers.
		3. Water in the chambers under Yellowstone's geysers reach temperatures greater than 300 °C because the pressure is so great.
		4. The height of a geyser is determined by the width of the opening near the surface above the geyser.
		5. The water that is erupting from a geyser today fell as rain or snow about 50 years ago.
		6. Scientists located a chamber of underground magma when studying earthquake waves.
		7. Scientists are concerned that carbon dioxide could be released in areas such as Yellowstone with many geysers and earthquakes.
		8. The water that erupts from geysers contains very few, if any, dissolved minerals.
		9. Photosynthetic bacteria can be found in some hot springs in Yellowstone.
		10. Underground, Yellowstone is much the same as it was centuries ago.

Rainforests: A Disappearing Act

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. More than 75% of all known species of plants and animals live in the rainforests.
		2. Corn, rice, coffee, coconuts, pepper, and cocoa all came from the rainforests.
		3. If you chew a miracle berry which contains the protein miraculin, and then eat something sweet, it suddenly tastes sour.
		4. More than half of the drugs derived from plants come from rainforests.
		5. Plants rich in alkaloids help protect plants, and many are useful in the fight against cancer.
		6. One-fourth of the active ingredients used in cancer-fighting drugs are found only in rainforests.
		7. If scientists gain the trust of local medicine men, they can find information that may lead to development of new cancer drugs.
		8. A plant that is now extinct has provided two cancer-fighting drugs.
		9. Synthetic quinine and natural quinine from the cinchona tree are equally effective in treating malaria.
		10. We can help preserve the rainforest through the choices we make as consumers.

Those Blooming Algae!

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. In an algal bloom, there are between 100 and 1000 algae cells per milliliter of water.
		2. After an algal bloom, people should avoid shellfish from that area for several months.
		3. Brevetoxin, one of the most dangerous toxins produced by algae, contains carbon, oxygen, sulfur, nitrogen, and hydrogen atoms.
		4. The hypotheses scientists have developed about what causes algal blooms point primarily to man-made factors.
		5. Computer models are being used to predict the formation and progression of red tides.
		6. By studying the effect of one compound produced by *Karenia brevis* on guppies, scientists have found a possible antidote to brevetoxin.
		7. Studies of red tide may lead to medicines for treating cystic fibrosis, a breathing disorder.

Chocolate: The New Health Food. Or Is It?

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. Chocolate contains two stimulants that are almost identical.
		2. Anandamide, a chemical that makes us feel good, is found in chocolate and is produced by the brain.
		3. Scientists have found that antioxidant chemicals in chocolate can protect against heart disease.
		4. Some experimental results have shown that flavanols found in cocoa may be used to treat stroke victims.
		5. Chocolate causes acne and weight gain.
		6. Chocolate comes from the pulp of cacao pods.
		7. Cocoa butter has very little fat.
		8. The fats in cocoa butter increase blood cholesterol.
		9. Natural cocoa has fewer antioxidants than chocolate syrup.
		10. The fewer the additives, the less nutritious the chocolate.

Air Pollution: What Weather Satellites Tell Us

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. Satellites are used to detect chemicals that cause air pollution, determine where they come from, and how they travel through the atmosphere.
		2. The evidence from satellites shows that in recently industrialized nations air pollution is increasing to levels that are dangerous to human health.
		3. The amount of carbon dioxide in the atmosphere has increased by 10% since the start of the Industrial Revolution.
		4. Concrete and asphalt found in cities seldom affect rainfall patterns.
		5. Atmospheric aerosols are all man-made.
		6. Atmospheric aerosols travel across oceans.
		7. Clouds with high aerosol concentration allow much sunlight to pass through.
		8. During a 10-year period it was shown that the Clean Air Act is reducing nitrogen dioxide pollution in the atmosphere.

Using Chemistry to Protect the Environment: Interview with Christopher Reddy

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. Standards are compounds with precise formulations and concentrations used by environmental chemists to make sure their equipment is reliable.
		2. Reddy says that environmental chemists should be able to explain their research to average citizens.
		3. Environmental chemists often use chemical insight to help people make decisions about the environment after an accident occurs.
		4. Whale blubber contains a compound that is structurally very similar to man-made flame retardants.
		5. An oil spill is usually undetectable in the environment after 10 years.
		6. Environmental chemists need to be good in chemistry and math.
		7. Environmental chemistry stories are seldom in the news.

Reading Strategies

These matrices and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Letting Off Steam

Directions*:* As you read, complete the chart below to describe the components of geysers in Yellowstone National Park, and how each component affects the geysers.

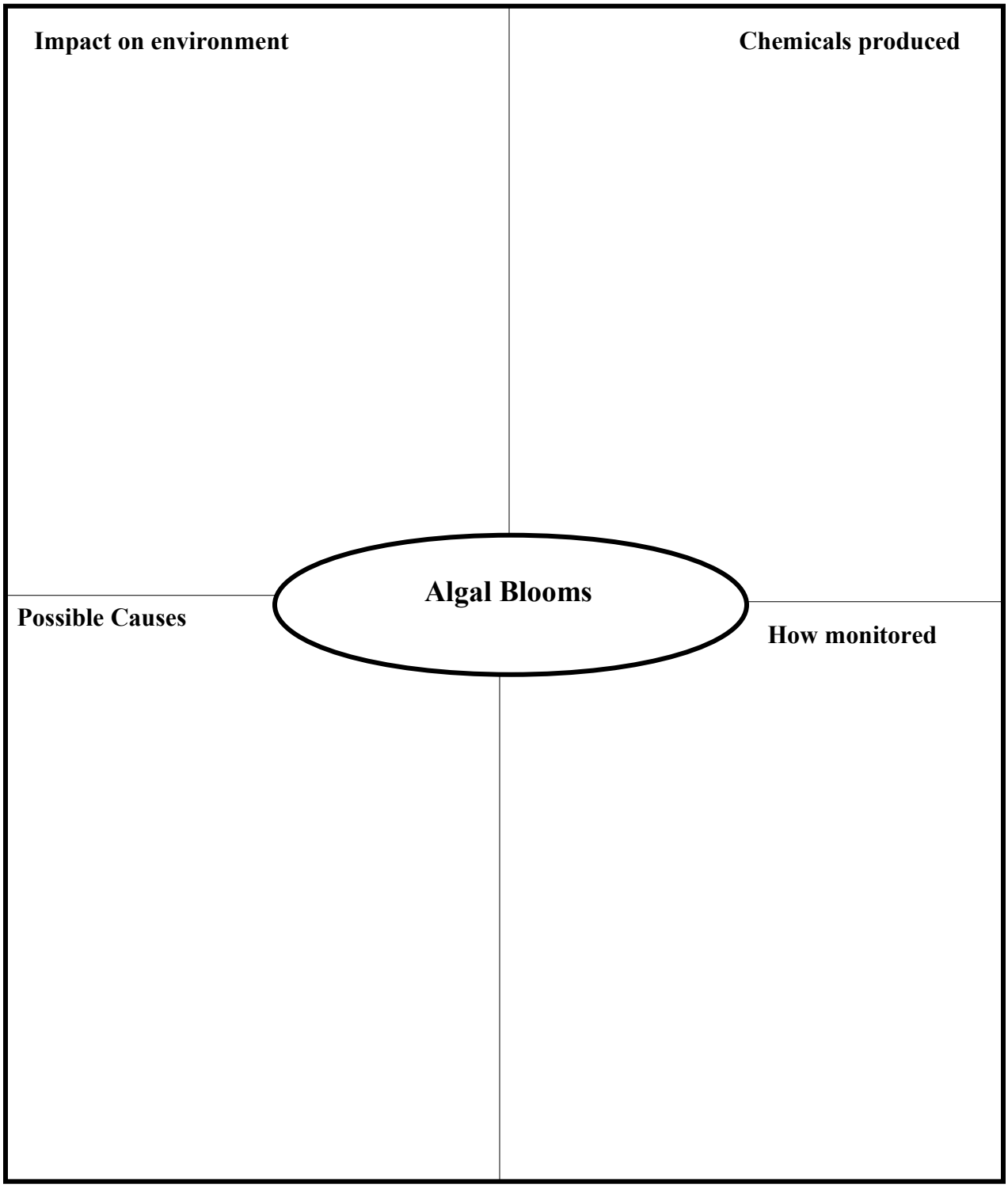
Components	Description	Effects on geysers
Vents and Caves		
Magma chamber		
Water		
Bacteria		
Change		

Rainforests: A Disappearing Act

Directions*:* As you read, list 2 foods and 5 chemicals that come from rainforests, along with benefits we currently enjoy or possible future uses.

Food or Chemical	Benefits or possible future uses
Food:	
Food:	
Chemical:	
Chemical:	
Chemical:	
Chemical:	
Chemical:	

Those Blooming Algae!



Chocolate: The New Health Food. Or Is It?

Directions*:* As you read, give examples of specific compounds found in chocolate, along with the benefits of the chemicals.

TYPE OF COMPOUND	EXAMPLES	BENEFITS OR DRAWBACKS
Stimulants		
Polyphenols		
Flavanols		
Fats found in cocoa butter		

Air Pollution: What Weather Satellites Tell Us

Directions: As you read, complete the chart below describing how scientists study air pollution and what they have found.

Type of pollution	How monitored	Findings
Carbon dioxide (CO_2)		
Urban landscapes		
Aerosols		
Nitrogen dioxide		

Using Chemistry to Protect the Environment: Interview with Christopher Reddy

Directions*:* As you read, complete the chart below describing what you found interesting while reading about Reddy's career, and how it relates to your life.

Topic	Interesting information	How it relates to your life
Early years		
Importance of his work		
Challenges in his work		
Advice		

Letting Off Steam

Background Information

More on the history of Yellowstone National Park

On March 1, 1872, President Ulysses Grant signed the bill that provided for the establishment of Yellowstone National Park, the world's first national park. The bill provided for 2.2 million acres of wilderness to be set aside "…as a public park or pleasuring ground for the benefit and enjoyment of the people." Indeed, Yellowstone was not the first park to be deemed worthy of preservation. Yosemite had been established as a national preserve in the mid-1860s, but Yellowstone was the first to be designated as a National Park.

The name Yellowstone came from the Native American Minnetaree tribe, who named the local river the equivalent of "Rock Yellow River", due to the high yellow rock cliffs along its bank in the northern part of the park. Reports from trappers and explorers from the area included volcanic craters bubbling with hot clay and foul-smelling vapors. These explorers referred to the area as "Colter's Hell", after John Colter, a member of the Lewis and Clark team who remained in the West. Colter had written reports of the area as early as 1810. Although the explorers and trappers wrote reports, their credibility was often questioned. A thorough government survey and an expedition, completed in 1870 and 1871 gave more credible accounts of the area. It is these studies, at least in part, that led to the establishment of Yellowstone as a national park.

Another factor in this story is the construction of the cross-continental railroad. The Northern Pacific Railroad was instrumental in instilling in the minds of US citizens the value of this area as a tourist attraction for the future and the subsequent need to preserve it for posterity. Perhaps this was due to the fact that this railroad ran past the north entrance to the park. Jay Cooke, the railroad's chief financier, was quick to realize the profit-potential for his railroad if people began converging on Yellowstone for vacation purposes. He arranged for many of the major newspapers and magazines of the day to carry stories, written by noted explorers and historians of the era and illustrated by artists who had visited the area, of the magnificence of Yellowstone. Much more of the role of the railroads in the establishment of Yosemite and Yellowstone National Parks can be found at http://xroads.virginia.edu/~MA96/RAILROAD/ystone.html.

Yellowstone National Park contains approximately one-half of all the hydrothermal features found on Earth. It includes more than 10,000 features, including more than 300 geysers.

More on the (geologic) history of the Yellowstone's hydrothermal features

The present-day geysers and hot springs of Yellowstone are caused by a partially molten magma chamber that remains after an enormous volcanic explosion in the Yellowstone region about 600,000 years ago. The exploding volcano collapsed, leaving a caldera, a huge volcanic depression, measuring 28 x 47 miles. The underground heat source for this event was magma from deep within the earth that had surface through fissures in the underlying rock. The cataclysmic eruption probably sealed those fissures, at least temporarily. The magma chamber from that eruption still today supplies the heat needed for all of the hydrothermal features in Yellowstone.

The “Yellowstone Hot Spot” that remains is a section of the earth where the thickness of the crust is extremely thin, allowing the magma below the crust to come within two miles of the surface, closer than anywhere else on earth.

The eruption of 600,000 years ago was not the first eruption of the Yellowstone “supervolcano”. Scientists have evidence that the volcano also erupted about 2.1 million years ago, and again about 1.3 million years ago. The eruption 2.1 million years ago was even larger than the most recent one, and it deposited ash over much of the Midwestern and western states of the US. The eruption 1.3 million years ago was smaller (but still huge). Since the entire area of Yellowstone is still geothermally active, another eruption of the volcano is quite possible and, in fact, many geologists believe one is overdue. (Note the times for eruption: 2.1 million years ago, 1.3 million years ago, 0.6 million years ago. We’re overdue, although scientists see no reason for concern now or in the next few thousand years. Plus, eruptions of this magnitude are not regular or predictable.) Another eruption by this huge volcano would have devastating effects on the entire globe. For this reason, scientists continuously measure seismic activity in the area.

If another eruption were to occur, thick ash deposits would cover vast areas of the US, and ash would be projected upward into the atmosphere as high as 15 miles. This would have devastating effects on climate worldwide, as the ash would block sunlight and quickly cool down global temperatures. Without sufficient sunlight, plants would not be able to photosynthesize and animals depending on plants for nourishment would die. Fortunately, scientists don’t believe the Yellowstone supervolcano will erupt for millennia.

Much of the information above came from http://www.solcomhouse.com/yellowstone.htm. The site contains much more information, including geologic and topographic maps of the Yellowstone area, as well as a video clip taken from the Discovery Channel’s DVD, “Supervolcano—It’s Under Yellowstone. And It’s Overdue.” that shows the effects of the eruption of Yellowstone’s supervolcano.

More on the temperature of boiling water

Water boils at 100°C. Every student of chemistry knows that number; yet, that’s not the whole story. The reason water boils at 100°C is because it is at that temperature that its vapor pressure equals that of the surrounding atmosphere, 1 atm, 760 mm Hg or 29.9 in Hg, or 101.3 kPa. Thus 100°C is only the **normal** boiling point of water, the temperature at which the substance boils at 1 standard atmosphere. If the atmospheric pressure changes, so does the boiling temperature of water.

Old Faithful in Yellowstone is at an elevation of 7360 ft, and at that elevation, the pressure of the atmosphere pushing down overhead is reduced due to less mass of air overhead. Atmospheric pressure at 7360 ft. is approximately 23 in. Hg, and at that reduced atmospheric pressure, water will boil (at the surface) at approximately 199°F, or 93°C.

Of course, the opposite effect happens when “atmospheric” pressure increases, as it does deep under the ocean or deep underground. The deeper one goes, the greater the pressure, and the higher the boiling temperature of water. As has been mentioned, the enormous pressures deep in the plumbing of a geyser can result in water’s boiling temperature being as high as 400°F, or 204°C. This corresponds to a pressure of approximately 17 atmospheres.

Examples of the boiling temperature of water varying with pressure include pressure cookers, car radiators, cooking at high elevations, and nuclear reactors (which use superheated water to absorb more energy from the reactor and then provide that extra energy when the water turns to steam to drive turbines to generate electricity).

More on geysers

Geologically speaking, the restrictions in its plumbing, that a geyser needs to actually be a geyser, are its own doing. The ground rock in a geologic hot spot, where geysers and other hydrothermal features are found, is usually made of rhyolite, a high-silica content volcanic rock. As the superheated water travels through this rock it dissolves some of the silica and carries it with it toward the surface. As the silica-laden hot water cools somewhat, it precipitates some of the silica out of solution and deposits it on the sides of the underground passageways, thus narrowing down these openings. This silica material that coats the geyser's plumbing, called geyserite, makes the openings pressure-tight, and eventually narrows them to the point of becoming the very restrictions it needs to be a geyser. So it is possible that present-day hot springs might someday become geysers, if the geyserites deposits can restrict the openings enough to allow pressure to build up in the passageways.

A bit of elaboration on the description from the article of how a geyser works might be helpful. As mentioned, the underground water is heated to beyond its normal boiling point by the magma. Any bubbles of steam that might form instantly collapse due to the surrounding pressure. The water cannot boil due to the extra pressure caused by the column of rock and water above it. This superheated water is, however, less dense than the cooler water above it, and so it begins to rise through the cracks and fissures in the rock. As the water rises, the pressure above decreases slightly and some of the superheated water begins to boil, forming bubbles in the water.

These gas bubbles become large enough and numerous enough that they cannot get through the constrictions in the geyser's plumbing. The pressure of these very hot bubbles can, however, force liquid water through the constrictions, creating greater upward pressure on the layer of water above the constriction that is acting as a lid on the water below. This increased pressure can force some of the water above to overflow out of the geyser. At this instant, the reduced volume of water in the column greatly reduces the pressure inside the column. This results in almost instantaneous, violent boiling of the water remaining in the column. This steam occupies about 1500 times the volume it did as a liquid, and this greatly increases the pressure on the lid of water above. This forces the water and steam to seemingly explode out of the vent. The eruption subsides when the chamber below ground has been exhausted of its hot water, or when the bubbles of steam can escape through the water without forcing any more water out of the vent, or when the remaining water has cooled below its boiling temperature.

This situation is somewhat analogous to unopened cans of soda pop. If one of the cans has been shaken before opening, the gas (in this case, CO_2, not steam) will escape from the opening so forcefully, that it will push much of the liquid through the constriction (the small opening) ahead of it and spray all over. (This simulates the eruption phase of the geyser.) If the can has been left to sit, the gas can escape easily through the opening, without forcing any of the liquid out with the gas. (This simulates the inactive phase of the geyser, because steam still emanates from a geyser in its inactive phase, but not explosively.)

The Physics Department at the University of Illinois, Urbana-Champaign provides a photo of a model of a geyser at http://demo.physics.uiuc.edu/LectDemo/scripts/demo_descript.idc?DemoID=338. The page also shows a drawing of the apparatus and a description of the eruption process. You can then see a controlled demonstration of the eruption of this man-made geyser by checking out their video clips at http://demo.physics.uiuc.edu/LectDemo/descript/338/me.html. You can see short clips (7-8 seconds each) of two views – one from the side and one from above. The third, longer clip (65 seconds) takes about 2 minutes to download, but it is worth viewing because it gives you a view of the pre-eruption geyser, when the water is heating. You can see lots of activity (called preplay) before the geyser erupts. The eruption doesn't occur until a) you can see some steam (all right, condensed water vapor) and b) a small amount of water flows out of the tube before the violent eruption actually occurs. Remember that it is this slight overflow that reduces the internal pressure sufficiently to allow the bulk of the water in the column to boil, ejecting the water at the top of the column.

Two types of geyser are recognized: fountain geysers, which arise out of a pool of hot water, and cone geysers, which arise out of a geyserite cone, composed primarily of silica that has precipitated out of the cooler surface geyser water. Fountain geysers typically erupt in all directions, forming a spray, while cone geysers generally erupt vertically in a single column to greater heights.

There are more than 500 geysers in Yellowstone Park, more than half of all the geysers on Earth. There are nine prominent geysers within the area closely surrounding Old Faithful. You can view the labeled locations of all 9, including Old Faithful (and a few bison), here: http://www.nps.gov/archive/yell/tours/livecams/oldfaithful/referencephoto.htm.

As was mentioned in the article, the three requirements for a geyser are: a water source, a heat source and a constriction in its plumbing. The second and third of these requirements do not change significantly over relatively long periods of time, barring an earthquake changing the plumbing. Scientists reported in the June, 2008 issue of the *Journal of Geology* that they have discovered that the frequency of eruption of geysers depends at least in part on how much ground water is available to enter the plumbing system. This, in turn, depends on levels of precipitation in the area. About 5% of the snow and rain in an area actually seeps into the ground, while the rest runs off into streams and rivers. In years of high precipitation levels, the geysers of Yellowstone have erupted more frequently. These scientists believe that continued studies will show that eruption frequency will decrease in times of extended drought. Some geysers may even cease to erupt in a very dry time.

Geysers containing gases, primarily CO_2 (80-100%), but possibly also O_2, CO, H_2, CH_4, N_2, Ar, and H_2S in small amounts can erupt for a slightly different reason. The presence of gas in underground water, due primarily to volcanic activity, reduces the hydrostatic pressure on the water. This in turn results in the water boiling at a much lower temperature than would be expected for those depths. Thus eruptions may occur in these "gassy" geysers, even though the heat source (magma) is not sufficient to heat the water to its normal boiling temperature.

Note that geysers don't only occur on dry land, however. Deep in the ocean scientists have discovered hydrothermal vents on the ocean floor along fault lines where the oceanic plates are moving apart. These vents are in effect underwater geysers. The oceanic plates separate slowly over geologic time, creating cracks into which seawater pours. This water is heated by the magma under the surface rock. The vents then spew out this exceedingly hot water (400°C, 750°F) that does not boil due to the intense pressure of miles of water overhead.

You can view a video clip of one such vent, a “black smoker”, at http://www.ocean.udel.edu/deepsea/level-1/geology/smoker.mov.

More on Old Faithful

Old Faithful shoots water and steam 130 ft high, on average, ranging from 106-180 ft. Each eruption lasts between 1.5 and 5 minutes. Old Faithful erupts, on average, every 90 minutes, although the length of time between eruptions varies significantly, from 35 to 120 minutes. Each next eruption’s onset depends on the length of the previous eruption—the longer the eruption, the longer interval until the next eruption. This is probably due to the more complete emptying of the underground water chamber with a longer eruption and the consequent need to take longer to refill before the next eruption. Therefore, only the next eruption can be predicted with any accuracy at all, and even then, the typical published uncertainty is ± ten minutes. During daytime visitor hours, predicted eruptions (one at a time only) are published on the web site.

According to the official National Park Service web site, at http://www.nps.gov/yell/planyourvisit/upload/Yell254.pdf, the constriction in Old Faithful’s plumbing system mentioned in the article is at a depth of 22 feet, and the constriction itself is only 4-1/8” across. You can see a cross-section of the top 50 feet of Old Faithful’s plumbing system in this pdf file.

To view a live streaming video of Yellowstone’s most famous geyser, visit Old Faithful’s web cam at http://www.nps.gov/PWR/customcf/apps/stream/stream.htm?parkcode=yell. This site provides a 4-½-minute narrative explaining how the hydrothermal features of Yellowstone came to be and continue to work. This webcam also swings around occasionally to view other parts of the Upper Geyser Basin, showing many other geysers and some of the other hydrothermal features of the area. You can also view a still camera that updates its image every 20 seconds at http://www.yellowstone.net/ofliveoriginal.htm. On this site, the next predicted eruption is posted at the top of the screen.

More on water and magma circulations

The motion of groundwater in underground is a bit more complex than that described in the article. Cool groundwater is constantly infiltrating the openings in underground rock. As that cooler water encounters the heated water from deep down in the Earth (close to the magma), circulation patterns develop, with the less dense hot water rising over the denser, cooler, subsiding water. This happens continuously as the hot water rises toward the surface. As the superheated (above its boiling point) water rises, it also heats the cooler sinking water.

Eventually the pressure decreases sufficiently (lowering the boiling temperature) and the water heats sufficiently (reaching its boiling temperature) to allow the water to boil. This creates bubbles of gas that are significantly less dense than their surroundings, forcing them to rise. The existence of gas in tight spaces also creates pressure, which forces the water/steam out of the cracks onto the surface with some force.

Magma undergoes a similar circulation pattern as the hot and cooler water. As magma heats the water, it cools off and becomes more dense, sinking closer to the earth’s interior, where it is subject to greater heat and becomes hotter again, thereby becoming less dense and rising through its cooler surroundings once again.

More on hot springs bacteria

Thermophilic microorganisms were first discovered in hot springs in Yellowstone National Park in 1966 by Thomas Brock. Prior to that time, it was assumed that nothing could live in water at or near its boiling temperature. Since the initial discovery, thermophiles have been discovered in geothermal features around the world. The discoveries of these organisms have actually forced biologists to include a new branch on the "tree of life". Besides eukaryotes (organisms with nuclear cells) and prokaryotes (mainly bacteria and organisms with no nucleus in their cells), there are now archaea. Archaea may look like bacteria, but biochemically and genetically, they are entirely different from bacteria.

Archaea are very tiny, usually less than a micron long. Even under the (optical) microscope, the largest of these organisms look like tiny dots. This initially prevented scientists from being able to learn much about them. Electron microscopes, however, can show us their physical characteristics. Many varieties of archaea exist, some similar to those of bacteria.

The distinction among these branches of the tree of life did not occur instantly with the discovery of the first thermophilic bacteria in Yellowstone, but rather developed over the years as scientists looked more closely at the links (or lack thereof) among the organisms' DNA sequences. Many archaeans thrive in extreme conditions of temperature (both hot and cold) and pressure and have thus earned the name, extremophiles, but it has been discovered that archaeans also exist in abundance in the plankton living in the open oceans.

It should come as no surprise that the species of archaea varies with the conditions. Two sites within Yellowstone, Octopus Pool (where the first thermophiles were discovered) and Obsidian Pool contain very different types of microorganisms. Octopus Pool is alkaline, with a pH of 8.5. It has a high dissolved silica concentration and a temperature of 95°C—very near the boiling temperature of water at the altitude of Yellowstone, in the Rocky Mountains. Even within the pool, the species of archaea vary, and often within centimeters. Obsidian Pool, by contrast, has a neutral pH and much cooler temperatures than Octopus Pool, and microorganism species are very different in this pool.

The existence of extremophiles on Earth has given scientists greater hope that life may exist elsewhere in our Solar System and beyond, since the conditions for life are now known to be not nearly so stringent as previously thought.

For a more detailed examination of the domain, Archaea, visit the University of California's Museum of Paleontology's site at http://www.ucmp.berkeley.edu/archaea/archaea.html. Or if you'd like a more complete explanation of the tree of life and the role of Yellowstone's hot springs in the studies of archaea, you might want to take a tour of an electronic field trip into some of the hot springs of Yellowstone in "hot Colors—Windows into Hidden Worlds". It's an imaginary scenario involving a shrunken submarine, similar to "Fantastic Voyage". You can find it at http://www.windowsintowonderland.org/hotcolors/index.shtml. It's designed for students, but it has a lot of information early on about archaea and the tree of life.

Connections to Chemistry Concepts

1. **Boiling points of liquids**—The **normal** boiling temperature of water is 100°C. Most liquids have a specific normal boiling point, specified at standard atmospheric pressure, 100 mb.
2. **Boiling points of liquids vary with temperature—**While the normal boiling point of water is 100°C, its boiling temperature increases at greater pressure. This allows water at great depths (and pressure) close to the magma to reach temperatures in excess of 300°C without boiling.
3. **Solubility of (ionic) compounds varies with temperature**—Higher temperatures (e.g., when the solvent water is closer to the magma heat source) result in greater molecular/ionic motion, resulting in more bond-breaking, producing more ions in solution (i.e., greater solubility). When the temperature cools (e.g., as the concentrated solution reaches the surface) the ions precipitate out of solution. This results in the deposition of the solid on rocks, etc.
4. **Solubility of gases varies with temperature/pressure**—Carbon dioxide can remain dissolved in even warm/hot water when it is held under high pressure (Henry's law).
5. **Light and chemical reactions**—Photosynthesis is light-driven. The chloroplasts (or chlorosomes in the case of bacteria) absorb light and use that energy to drive biochemical reactions.
6. **Density**—Hot liquids are denser than their cooler counterparts (and therefore rise).

Possible Student Misconceptions

1. **"Old Faithful erupts every hour, on the hour."** *It presently erupts every 91 minutes, on average, with eruptions ranging from 35-120 minutes. It never did erupt on an hourly basis.*
2. **"Old Faithful is slowing down or getting shorter in duration."** *The geyser hasn't changed appreciably in either interval (time between eruptions) or duration (length of eruption).*
3. **"Old Faithful has been around forever."** *Scientists believe that geysers are relatively short-lived phenomena, on a geological timescale. Many scientists believe Old Faithful is only about 300 years old and has existed as an active hot spring for about 750 years. It sits atop a much older geyserite formation from an earlier hot spring.*
4. **"Water always boils at 100°C", or "Water's boiling point is 100°C, period."** *As discussed in the article and extensively above in "More on the temperature of boiling water", the temperature at which water boils depends on atmospheric pressure surrounding the liquid. High pressures result in higher boiling temperature, and vice versa. The temperature of 100°C is water's normal boiling point. Here the word "normal" means "standard", not "typical".*
5. **"The color of the water in the various hot springs in Yellowstone is due to the minerals contained in the water, just like some of the chemicals we use in the lab."** *Actually scientists now believe that much of the coloration of the water is due to the bacterial growth in the water.*
6. **"Nothing can live in the hot springs in Yellowstone—they're <u>hot</u>!"** *Until 1966, that's exactly what everyone believed, but in that year, Thomas Brock discovered microorganisms growing in the boiling hot springs of Yellowstone. We now know that life can grow at extreme temperatures and pressures. These so-called extremophiles can exist in supercooled water under the ice sheet of the Antarctic, and in the extreme pressures and temperatures of the "black smokers", hot springs at the bottom of the oceans. Life, in short, seems capable of growing anywhere on Earth (and possibly on other planets and moons).*

Demonstrations and Lessons

1. Another, simpler way to demonstrate the variation of boiling temperature with pressure is to use a large syringe, say 100-140 mL size. Pull the piston about 75-85 % of the way out and mark the shaft at this level. Then use a hot nail to put a hole through the shaft at the mark you made. Get a small stopper, say a # 4, for instance, and cut out a small hole part-way through the stopper so that the tip of the syringe fits snugly (airtight) into the carved-out stopper. You can use a cork borer to do this. For practice, when you stopper the syringe and pull back on the piston, you should be able to place the nail through the hole in the shaft and have the piston remain in place, with the syringe partly evacuated. (You may need an extra set of hands to get the nail in the shaft.) Now carefully remove the nail, allowing the piston to recoil slowly. Also remove the stopper. Now you're ready for the demonstration. Heat water to about 80°C in a beaker. Using the syringe, draw about 20 or so mL of the hot water into the syringe. Stopper the syringe and pull back on the piston and place the nail in position to hold the piston in the "open" position. This increases the volume of space inside the syringe, thus decreasing "atmospheric" pressure. Lower pressure reduces the boiling temperature of water, and the water begins to boil inside the syringe. You will need to extrapolate this information to higher pressures, resulting in higher boiling temperatures. You might also want to discuss the underwater hydrothermal vents found in deep water areas around volcanic activity. The water in these vents is extremely hot (400°C as it erupts out of the holes in the ocean floor), yet it does not boil.
2. You can also allow students to experience this phenomenon for themselves, hands-on, in a "microscale vacuum apparatus", sold by Educational Innovations. This kit contains a large syringe, like in the above demonstration, and a small bell jar to contain a beaker of warm water. The difference is that students can do this experiment themselves, instead of just watching you do a demonstration. The apparatus may be inexpensive enough that you can purchase enough for a class lab set. See the kit at http://www.teachersource.com/AirPressure/MicroscaleScience/MicroscaleVacuumApparatus.aspx.
3. Yet another way to illustrate the variation of boiling point of a liquid with atmospheric pressure is to use a vacuum pump. As ambient pressure is reduced inside a bell jar containing a small beaker of water, the water will begin boiling. Generally you can use room temperature water for this demonstration, and after you've allowed air to re-enter the bell jar, you can quickly insert a thermometer into the water to show students that it is not hot—in fact, it will probably be even cooler than it was when you put it in the bell jar, since the fastest-moving (and hence, warmest) molecules boiled away, leaving the slower, cooler molecules behind in the beaker.
4. The U.S. Park Service web site, "Window into Wonderland" has a middle school lesson for a student hands-on activity to construct simulated geysers out of household materials. It utilizes vinegar and baking soda in place of the Earth's heat as the source of the energy for the reaction. The plan includes National Science Education Standards and a scoring rubric, and it asks students to hypothesize which of the class geysers is the most accurate representation and why, and then asks them to evaluate their prediction after the eruptions take place. After this activity, students can take an electronic field trip to Yellowstone and visit Old Faithful via a family taking a trip there. You can find the geyser activity, "How Does a Geyser 'Geyse'", at http://www.windowsintowonderland.org/GeyserQuest/lesson-geyse.shtml, and you can see the electronic field trip, "Geyser Quest", at http://www.windowsintowonderland.org/GeyserQuest/index.shtml.

5. To simulate a geyser eruption, you can use two cans of soda pop, as alluded to in the "Background Information" "More on geysers" section of this TG. If one of the cans has been shaken before opening, popping the top will cause the gas (in this case, CO_2, not steam) to escape from the opening so forcefully, that it will push much of the liquid through the constriction (the opening) ahead of it and spray all over. (This simulates the eruption phase of the geyser.) If the second can has been left undisturbed, when you pop the top, the gas can escape easily through the opening, without forcing any of the liquid out with the gas. (This simulates the inactive phase of the geyser, because steam still emanates from a geyser in its inactive phase, but not explosively.)
6. Speaking of soda, the now-infamous Mentos and Coke geysers make a great demonstration of a geyser-like eruption – and it is much more obviously related to chemistry. You could have a discussion about what makes it work, and have students find the similarities and differences between a real geyser and the Mentos and coke "knock-off". If you want more information, you can view an explanation and a video of the experiment on the Steve Spangler Science web site at http://www.stevespanglerscience.com/experiment/00000109, or you can check out You Tube for dozens of video clips of this experiment. The best of these are probably the Eepybird videos, one at http://www.youtube.com/watch?v=vmalLG_kEfU&NR=1 (2:30 minutes of eruptions) and another, more polished video, as a lead act for the Blue Man Group, at http://www.youtube.com/watch?v=5MJn99EYC4I. The first one is done in the great outdoors, with a forest in the background, so you can almost envision the eruptions as real geysers. If you look closely, you can even see an eruption that looks like a fountain geyser (a fan-like spray), although most of the reactions are more reminiscent of cone geysers (single large bursts). The TV program "Mythbusters" also has a short video clip to show the role of the Mentos in the reaction, with an animated sequence at the microscopic level at http://dsc.discovery.com/videos/mythbusters-diet-coke-and-mentos.html.
7. "Mythbusters" also has a DVD devoted in part to the Mentos & Diet Coke controversy. It is done as a scientific investigation in chemistry, analyzing each variable in the system to see what actually causes the geyser-like effect. This video can be used early in your course as an illustration of "the scientific method". The DVD is described on the Discovery Store web site at http://shopping.discovery.com/product-61547.html?jzid=40588004-59-0.
8. You can use a car overheating as an example of a geyser-like system. The radiator is analogous to the geyser's plumbing system. The engine is the equivalent of the magma heat source in a geyser. The fill opening on the radiator is akin to the constriction within the geyser's plumbing. The radiator cap on a car's cooling system is pressurized to maintain 15 lbs/in^2 of extra pressure on the water/antifreeze mixture in the cooling system. This allows the cooling liquid to remain a liquid at higher temperatures without boiling under normal circumstances. This is like the lid of water above the constriction in the geyser's plumbing. As long as the cap remains in place, the system is stable and the temperature remains fairly constant – below the boiling temperature of the liquid. But if a car engine overheats, the liquid's temperature increases even more, becoming superheated. If one mistakenly attempts to remove the cap from the radiator, that allows a bit of the liquid out, and it reduces the pressure inside the radiator—just like the lid blowing off the geyser, under increased pressure from below. The reduced pressure results in all the liquid boiling simultaneously and explosively, possibly resulting in severe burns to the person who removed the cap. This might be a good lesson for students, to reinforce the danger of opening that radiator cap when the engine is hot. The same eruption will occur, even if the engine is not overheating, since the liquid is still at a temperature above its boiling temperature inside the radiator, so one should not open the radiator cap while the engine is hot, or if one must open the cap, it should be done a little at a time, to allow the steam to

escape slowly, even as more steam will build up from the hot liquid boiling inside the radiator. Eventually the pressure will subside and it will then be safe to completely remove the cap. There is more to this story, of course. The radiator cap does allow some steam to escape if the temperature goes up too high and the pressure is too great, but that steam goes into a small reserve tank, from which the cap allows that liquid to return to the cooling system when the car cools down and the pressure decreases inside the radiator. That, however, is probably more than students need for this lesson. (Keep in mind that students may have never encountered this situation anyway, as today's cars have closed cooling systems and rarely overheat. Originally, cars had open cooling systems, which had no reserve tank, so when the steam escaped and the liquid level lowered, liquid had to be manually added to refill the radiator That type of system, of course, allowed coolant to escape, which was likely to result in overheating, unless the driver remembered to refill the radiator; hence the advent of the overflow, reserve tank.) You might want to check out FamilyCar.com at http://www.familycar.com/Classroom/CoolingSystem.htm for "A Short Course on Cooling Systems".

9. The "Science Projects" web site contains a suggested activity for middle school students to construct a model power plant run by steam. You could use this as a classroom demonstration to show how steam from the hydrothermal features of Yellowstone could be harnessed to produce electricity. View the activity at http://www.energyquest.ca.gov/projects/geothermal-pp.html. An animated illustration of Hero's Engine, the earliest version of this type of steam engine, can be seen at http://library.thinkquest.org/C006011/english/sites/steam_first_experiments.php3?v=2. If you want to build your own Hero's Engine using a soda can, check out a set of instructions at http://www.cockeyed.com/incredible/hero/hero1.php.

10. If you want to build your own model of a geyser, go to http://www.wyojones.com/science_fair_projects_and_geyser.htm to see one made with a flask and glass tubing. The Exploratorium has the same project, along with a lesson plan, at http://www.exploratorium.edu/snacks/geyser/index.html.

11. You can also show the effects of superheated steam (instead of water) by using a flask of water on a hotplate, connected to a coil of copper tubing (which is itself heated by Fisher burners). The steam emanating from the copper tube will light matches, or char paper. You can see video clips of this demonstration on YouTube and other sites. The sites are listed in "Websites for Additional Information", "More on Superheated Water", at the end of this Teachers Guide.

Student Projects

1. Students could research and explain to the rest of their class how pressure cookers work, how an automobile cooling system works, and why packaging for commercial products like cake and cookie mixes frequently contain special baking directions for people living at high altitudes. All of these are based on the pressure-dependent boiling temperature of water.
2. You might suggest to students to do their own study on the types of bacteria that thrive in the hot springs of Yellowstone, and then compare these to the types that grow in the deep sea hot water/steam vents of the underwater mid-ocean ridges. Their research could include reasons why each ecological niche has their own species of thermophiles.
3. Students could research how geothermal features have been used by individuals and by governments to provide energy for heating and electricity. A follow-up study could be done on the effects of these efforts to harness nature. (Many geysers and hot springs have

ceased to erupt or have disappeared as a result.) Perhaps a debate could ensue between two groups: one, for the private use of hydrothermal features, and one against. Students could begin here: http://snras.blogspot.com/2008/10/geothermal-energy-development-geyser.html. Another site from Carleton College that poses the same quandary for student research (with links) can be found at http://serc.carleton.edu/research_education/yellowstone/geothermal.html. The links are not all current, however.

4. Students might be interested in researching and reporting on the biochemistry of extremophiles, especially in the area of extremozymes, enzymes in extremophiles that operate at conditions well outside those considered normal for enzymes. (http://www.ftb.com.hr/42-223.pdf might be a good place to start.) Also, "antifreeze proteins" in fish that have no hemoglobin, living in the Antarctic might be an area of high interest for student research. Science Daily might be a good place to start their research: http://www.sciencedaily.com/releases/2008/10/081016124049.htm.

Anticipating Student Questions

1. **"How faithful is Old Faithful?"** *The frequency of eruption of Old Faithful varies from 50-120 minutes, averaging around 91 minutes between eruptions. As stated in the Background section, only the next eruption can be predicted with any certainty at all, since each next eruption depends on the extent to which the underground chamber is emptied as a result of the most recent eruption (which is determined by the length of the eruption—the longer the eruption, the more water is emptied out of the chamber).*
2. **"What causes geysers to clog up?"** *The increased solubility of the hot water in the underground chamber and rock fissures allows it to dissolve more of the solids from the underground rock. Then, as the water rises to the surface, it cools and its solubility drops. This forces some of the dissolved solids to precipitate out on the cooler rock surfaces inside the cracks and fissures through which the water travels. This deposition packs the constriction in the plumbing and eventually may result in the complete closure of the constriction, although this may take thousands of years. Earthquakes will sometimes re-open the constriction, restarting the geyser once again. This will likely result in a change of the properties of a) duration of eruption and b) length of the time interval between eruptions.*
3. **"Why do scientists monitor geysers and hot springs?"** *Since Yellowstone is situated directly over a geologic "hot spot", it is subject to earthquakes on a regular basis. It's important for scientists to know if any unusual earthquake activity occurs, both for scientific and for safety purposes.*

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.)

Rohrig, Brian. Volcanoes—Forecasting the Fury. *ChemMatters.* December, **1999**, 12-13.
The author discusses the chemical reactions involved with volcanic activity, specifically sulfur's role.

Stone, Carol. Extremophiles—Life at the Edge. *ChemMatters*. December, **1999,** 14-15.
Discussion in this article focuses on the chemistry involved in the enzyme reactions inside extremophiles. Acidophiles and alkaliphiles exist at the extremes of the pH range, and halophiles exist in the very salty environments of salt lakes.

Rosenthal, Anne. Vents and Giant Tubeworms. *ChemMatters*. December, **2003**, 14-16.
Hydrothermal vents along mid-oceanic ridges are investigated in this article. These vents are classified as undersea geysers. The author includes a diagram showing a cut-away view of a mid-ocean ridge and the chemicals produced from a "black smoker". Several links to deep sea vents are given on the last page of this issue, and more links are listed in the TG for this issue.

Holzman, David. Bacteria Power. *ChemMatters*. **2004,** *22* (2), 11-13.
This article shows one practical application of an extremophile (archae)—to make a battery.

Web Sites for Additional Information

More sites on geysers

The Old Faithful WebCam offers a live still-motion shot of Old Faithful. It updates the image every 30 seconds. You can find it at http://www.nps.gov/archive/yell/oldfaithfulcam.htm.

The idea of the carbon dioxide-induced volcano/geyser from the activity described in the article may not be so far-fetched. Geologist Alan Glennon discusses cold-water geysers, driven by carbon dioxide, at http://www.uweb.ucsb.edu/~glennon/crystalgeyser/.

Alan Glennon, referenced above, provides a nice web site about geysers, replete with photographs of various geyser fields around the world. Find it at http://www.geyserworld.com/.

If you enjoy watching geysers erupt, here's a web site (related to Glennon again) that has a series of video clips, some with sound, of more than 100 geysers erupting. Almost all of these are found within Yellowstone's borders, with a few from Chile. "Geyser Cinema" can be found at http://www.gigagraphica.com/geyser/basin.html.

See http://www.nasw.org/users/sperkins/geyser.html for a discussion of the plumbing system of Old Faithful. Cameras and temperature probes were used to unveil (some of) the secrets of the geyser. This article appeared in the October 11, 1997 issue of *Science News.*

If you're interested in a list of the largest geysers in the world, you can find at the WyoJones web site, at http://www.wyojones.com/tall.htm.

The National Parks Service has a web site that explains how geysers work and discusses the 4 major ingredients needed to make geysers. It is animated and can be found at http://www.nps.gov/yell/naturescience/geyser_ingredients.htm.

For a mathematical treatment of the temperatures and eruption times for a geyser, visit http://www.umich.edu/~gs265/geysers.html.

Geysers even erupt on other planets' moons! The March 13, 2007 *BBC News* has an article on Saturn's icy moon Enceladus, with erupting glaciers. Scientists report in the article on a hypothesis they have about how the icy geysers occur. Read about it at http://news.bbc.co.uk/2/hi/science/nature/6445323.stm.

Astronomy magazine also has an article on Enceladus' geysers, with conflicting hypotheses, at http://www.astronomy.com/asy/default.aspx?c=a&id=6617.

More sites on the geology of the Yellowstone area

The official web site of Yellowstone National Park is located at www.nps.gov/yell.

See the US Geological Survey article, "Volcano Hazards Fact Sheet: Yellowstone: Restless Volcanic Giant" on its web site at http://vulcan.wr.usgs.gov/Volcanoes/Yellowstone/Publications/OFR95-59/OFR95-59_inlined.html for more information on the geology of the Yellowstone Caldera, the 53 x 28 mile crater left over after the last volcanic eruption in the Yellowstone area, about 650,000 years ago. This site discusses the rise and fall of the ground level over years, which was discussed in the article, and it provides a map of the Yellowstone area with the caldera overlaid on the park.

The USGS provides a wealth of information about volcanoes, calderas, geothermal activity, geysers, hot springs, fumaroles, mud pots, etc. The site also lists many links to other pages on its site. You can access this information at http://vulcan.wr.usgs.gov/Glossary/ThermalActivity/description_thermal_activity.html.

Another fact sheet from the USGS focuses on the geologic activity of the Yellowstone area. "Steam Explosions, Earthquakes, and Volcanic Eruptions—What's in Yellowstone's Future?" is a 6-page document that discusses the geologic history of Yellowstone, including comparisons of past volcanic eruptions worldwide with those of Yellowstone, the history of earthquake activity in Yellowstone, including fairly recent earthquakes (e.g., Lake Hebgen in 1959), and comparisons of the relative hazards of volcanic eruptions, lava flows, earthquakes, and hydrothermal explosions. You can find it at http://pubs.usgs.gov/fs/2005/3024/.

Yellowstone Volcano Observatory (YVO) monitors the geologic activity in the Yellowstone Park area, both for science and for public safety. The public can see the results of their ongoing studies at http://volcanoes.usgs.gov/yvo/. The site contains a list of frequently asked questions (FAQ's) about volcanic/earthquake activity in the Park.

Photographs of the various types of monitoring equipment used in the Yellowstone area can be seen on the USGS site at http://volcanoes.usgs.gov/yvo/publications/gallery2/gallery_monitoring.php.

Encyclopedia Britannica has an illustration of a cut-away view of the Earth in the vicinity of a geyser and a hot spring. You can view it at http://media-2.web.britannica.com/eb-media/29/95629-004-7EF6B7AB.jpg.

If you want to keep up to date on the latest seismic activity in the Yellowstone area (or if you don't believe there is any seismic activity), go to the USGS web page http://volcano.wr.usgs.gov/yvostatus.php to see the latest monthly seismic summary. The site mentions that Yellowstone area commonly experiences from 1000-3000 earthquakes annually! Recently (Dec. 08 into Jan. 09) there was a swarm of earthquakes in the north end of Yellowstone Lake, numbering 813 quakes. *Time* magazine even reported on this flurry of activity, at http://www.time.com/time/health/article/0,8599,1869313,00.html.

More sites on the bacteria of Yellowstone

For more information on Prof. Bryant's research on Cab. (short for Chloracidobacterium) thermophilum, visit his web site at http://www.bmb.psu.edu/faculty/bryant/lab/Project/Acido/index.html. He also has a list of links to other sites that discuss the bacteria.

National Geographic has a short video clip on the extremophiles of Yellowstone at http://news.nationalgeographic.com/news/2007/05/070524-yellowstone-video.html.

More sites on superheated water

Jamie and Adam of the TV show, "Mythbusters", investigate superheated water in the microwave oven in a short (1:40) video clip at http://video.google.com/videosearch?sourceid=navclient&gfns=1&rlz=1T4GGLL_enUS301US301&q=superheated+water&um=1&ie=UTF-8&ei=YAinSfnAJ9G3twfkl8HyDw&sa=X&oi=video_result_group&resnum=4&ct=title#.

Several other video clips of superheated water reside at youtube.com:

http://video.google.com/videosearch?sourceid=navclient&gfns=1&rlz=1T4GGLL_enUS301US301&q=superheated+water&um=1&ie=UTF-8&ei=YAinSfnAJ9G3twfkl8HyDw&sa=X&oi=video_result_group&resnum=4&ct=title# shows what happens to superheated water when a granular solid (sugar?) is added.

http://video.google.com/videosearch?sourceid=navclient&gfns=1&rlz=1T4GGLL_enUS301US301&q=superheated+water&um=1&ie=UTF-8&ei=YAinSfnAJ9G3twfkl8HyDw&sa=X&oi=video_result_group&resnum=4&ct=title# shows superheated water heated in a pan on the stove and what can happen if it is jostled—nothing is added except a little energy, and it still "explodes".

Just as water can be superheated, so too, steam can be heated beyond the boiling temperature of water. Many industries use superheated steam to provide more heat (higher temperatures) for specific purposes. You can watch a video clip on YouTube showing a chemistry demonstration that superheats steam using a flask, a hot plate, a copper coil and 2 Fisher burners at http://www.youtube.com/watch?v=czoxOqZ8rxk. The video seems to have been pirated from the *Journal of Chemical Education*'s "Chemistry Comes Alive!" CD-ROM. You can see a lesson plan to accompany the demonstration, and still photos from the video and the explanation of what's happening at http://jchemed.chem.wisc.edu/JCEsoft/CCA/CCA3/MAIN/STEAM/PAGE1.HTM. The original video is at this site also, but you can't view it here; you must purchase the CD-ROM from JCE.

Sharp Electronics even has a superheated steam powered oven, which is described at http://sharp-world.com/products/shs_oven/. Clicking on the tab, “What’s Superheated Steam?” takes you to the next page that contains two very short video clips with sound that show normal steam and superheated steam in the flask and copper coil system, just like the two sites above, except these clips may be a little sharper (no pun intended) and easier to view the effects. Using superheated steam, you can light a match in the steam stream, and paper in the stream of superheated steam actually chars.

General Web References

“The Total Yellowstone Page” is a web site that contains the usual tourist-y stuff, but it also has detailed information about the science behind the hydrothermal features. Check it out at http://www.us.national-parks.net/.

Rainforests: A Disappearing Act

Background Information

More on where rainforests are found

Most of the attention given to rainforests is focused on the Amazon Basin. Rainforests are actually present in 85 countries around the world. Ninety percent of these rainforests are concentrated in 15 countries. All are located near the equator and experience high temperatures and abundant rainfall. The rainforests are located in Central America, South America, Africa and Southeastern Asia.

Central America, at one time, was completely covered in rainforest. The arrival of the Spaniards at the end of the fifteenth century eventually resulted in the clearing of large tracts of land for cattle ranching and sugar cane production.

Central Africa is the site of the world's second largest rainforest. The island of Madagascar, off the east coast of Africa, at one time was covered by rainforest, most of which has been cleared. Even with the limited remaining rainforest, Madagascar still serves as a habitat for plants and animals found nowhere else on earth. The rainforests of Central Africa range from high cloud forest, to mangrove swamps, to flooded forests.

Asian rainforests are bounded on the west by India and Burma and to the east by the islands of Java and Borneo. The mangrove swamps of Bangladesh are the most extensive in the world.

The north eastern section of Australia and the island of New Zealand contain lush and dense tropical rainforests. These rainforests lie in the path of water-laden Pacific winds.

A full color map locating the world's rainforests may be found at http://www.srl.caltech.edu/personnel/krubal/rainforest/Edit560s6/www/where.html.

More on temperate rainforests

While most discussions focus on tropical rainforests, usually the Amazon Rainforest, a second classification of temperate rainforest is important to the United States and North America.

Tall trees characterize the tropical rainforests. Rainforests are millions of years old and require year-round warm conditions. Some specific requirements are: a temperature range between 34 °C (93 °F) and 20 °C (68 °F); rainfall between 125-660 cm (50-260 inches); and average humidity between 77% and 88%. The tropical rainforests produce 40% of the world's supply of oxygen. Ocean phytoplankton is the single largest producer of oxygen. The trees have similar bark and no branches for the lowest 100 ft.

Temperate rainforests are much younger than tropical rainforests. Most are less than 10,000 years old. The soil is richer and contains more nutrients than tropical rainforest soil. Temperate rainforests are scarcer than tropical rainforests. The temperate rainforests include the Pacific temperate rainforests of Western North America, the Appalachian rainforests of the

Eastern United States, the temperate rainforests of Northwest Europe, as well as temperate rainforests found in parts of South America, South Africa, Turkey, Iran, Taiwan, Japan, Australia, and New Zealand.

Conditions needed for the existence and sustenance of the temperate rainforests include: a mild coastal climate; heavy summer fog; and very generous rainfall. The warm, water-laden Pacific winds strike the coastal mountain ranges that stretch from Washington State to Oregon and Northern California. The moisture forms the heavy rains, summer fog, and winter snow. The mountains also act as a barrier and mediate the extremes found in temperature further inland. The coastal rainforests infrequently experience temperatures above 80 ºF or below freezing.

Indicators that characterize temperate rainforests are: the presence of Sitka Spruce; nurse logs (fallen logs from which seedling trees grow); colonnades (straight rows of trees which grew from the nurse logs); trees standing on stilts (decay of the nurse logs leads to trees standing on roots); a profusion of lichens and mosses; and bigleaf maples with clubmoss draperies. The source of the above information as well as a more in-depth description of temperate rainforests may be found at http://www.scsc.k12.ar.us/2001Outwest/PacificNaturalHistory/Projects/LachowskyR/Default.htm . An online atlas of the temperate rainforest region of North America may be found at http://www.inforain.org/. Inforain is a project of Ecotrust and has maintained the atlas since 1996. Inforain takes a special look as the social, ecological and economic benefits of alternative resource management systems.

More on rainforest medicines

The article states that 25% of the prescription drugs derived from plants come from rainforests. Discovery of a drug derived from a rainforest plants can yield millions of dollars to the pharmaceutical company that can perform the necessary testing and clinical trials and bring the drug to market. An area worth further study is the possible exploitation of the knowledge gained from the shamans who have used plants for medicinal purposes for countless generations. In a number of instances the indigenous people received little or no compensation from the wealth derived from the sale of the drugs. The term biopiracy has been coined to describe the stealing of knowledge or plants without compensation.

Wikipedia defines biopiracy as “the appropriation, generally by means of patents, of legal rights over indigenous knowledge—particularly indigenous biomedical knowledge—without compensation to the indigenous groups who originally developed such knowledge.” Last century rubber plant seeds were smuggled out of Brazil by the British to their colony in Malaysia. Prior to that time, Brazil enjoyed a monopoly on the production of rubber. Drugs produced from the Madagascar rosy periwinkle were worth more than $100 million a year. None of the money made its way back to Madagascar until the patents taken out on the drugs had expired. More recently a sample of yage, a hallucinogenic material with potential for use as a psychiatric and cardiac drug, which grows on the rainforest liana in Ecuador, was smuggled out of the country. The drug was consequently patented in the US and a company, the International Plant Medicine Corporation, was created to work on getting the drug to market.

On a more positive side, the National Cancer Institute is returning part of the royalties from the sale of the drug prostialin back to the Samoans in whose rainforests the drug was discovered. The drug was isolated in 1984 from a plant in a Samoan rainforest. It proved to show strong activity against HIV. The funds returned to Samoans have been used to create the

50th national park on the island. The park allows local healers to pass on their knowledge to the next generation. As in other issues where great sums of money are involved, there is usually a clash of cultures and of value systems. The website http://rainforests.mongabay.com/1007.htm has a number of links and examples of other cases of biopiracy.

More on rainforests in general

The February, 2009, issue of *ChemMatters* includes the article, "Ancient Soil Chemists of the Amazon", dealing with soils of the Amazon rainforest. The article and the Teachers Guide are both available here:
http://portal.acs.org/portal/fileFetch/C/WPCP_011827/pdf/WPCP_011827.pdf.
The Teacher's Guide for the article contains a wealth of added information on rainforests including: added classifications of rainforests; more details on the Amazon River Basin and the Amazon Rainforest; and photos of progressive deforestation in the Amazon Rainforest.

More on alkaloids

Dr. Sneden, a professor emeritus at Virginia Commonwealth University, describes an alkaloid as a plant-derived compound that is toxic or physiologically active, contains a nitrogen atom in a heterocyclic ring, is basic, has a complex structure, and is of limited distribution in the plant kingdom. Many of the earliest isolated pure compounds with biological activity were alkaloids. This was due to the ease of isolation. The nitrogen generally makes the compound basic and the compound exists in the plant as a salt. Thus, alkaloids are often extracted with water or mild acid and then recovered as crystalline material by treatment with base.

Quinine is one of the most important alkaloids isolated from the bark of the Cinchona tree found in the South American rainforests. Quinine is one of 31 alkaloids produced by the tree. Native Indians taught the Spanish and Portuguese explorers how to use tea made from the bark to treat malaria. The explorers and missionaries, in turn, introduced the use of the cinchona bark to Europe which, at the time, was ravaged by cases of malaria. The first documented case of the use of cinchona bark to treat malaria occurred in 1633. The association of the bark with the missionaries and the Catholic church led to its colloquial name of "Jesuit's bark." As the Protestant Reformation pitted Catholics against Protestants, a number of Protestant refused to have their malaria treated with the tea from "Jesuit's bark." Oliver Cromwell, a very important Protestant, is one of those who purportedly died of malaria after refusing to drink the tea.

Malaria is transmitted by the anopheles mosquito. The bite of the mosquito transfers the spores of a plasmodium protozoan to the victim. Today, in the treatment of malaria, quinine has largely been replaced by synthetic anti-malarial drugs. As in the case of other diseases, strains of malaria are becoming resistant to the synthetic drugs. Quinine once again has to be used to treat these strains. The search for new drugs from tropical plants becomes ever more important.

More on taxol or paclitaxel

In searching for background information on taxol or paclitaxel, several "dry" clinical reports listing chemical properties and results from clinical trials were found. The two clinical sites are http://www.rxlist.com/taxol-drug.htm and http://www.drugs.com/pro/paclitaxel.html. Two other sources reported on the history of the discovery of taxol as a treatment for cancer. The story is fascinating, replete with topics of government intervention in what would usually be a free market enterprise, the depletion of a natural resource—the yew trees of the Northwest, and

solutions to the challenges posed by the earlier issues. A closer look at these two articles, one from Wikipedia and the second from answers.com revealed that the entire Wikipedia article was incorporated into the answers.com article. The articles are identical. This includes the wealth of citations. As a teacher making such a discovery, one can broach the issue of plagiarism to the students who are facing similar issues and challenges on an almost daily basis. The Wikipedia article concludes with (1) the date last modified - 26 January 2009, at 2:57 and (2) with the statement "All text is available the terms of the GNU Free Documentation License." A link to the copyright explanation follows. Since the Wikipedia allows free use with proper documentation, plagiarism is not involved.

Answers.com begins its article with (1) a dictionary definition of paclitaxel, (2) the Oncology Encyclopedia detailed entry on paclitaxel, (3) a brief dental dictionary entry, and (4) the complete Wikipedia article then follows. The Wikipedia article details the discovery of taxol from the yew tree, the involvement of the pharmaceutical industry and the government in research and production, the potential environmental impact, and synthesis of the paclitaxel. It may be found at http://en.wikipedia.org/wiki/Paclitaxel.

Connections to Chemistry Concepts

1. **Environmental Chemistry**—Environmental issues all depend on humanity's stewardship of natural resources. The exploitation of, and loss of increasing amounts of the remaining rainforests provide an entry into a timely discussion of these issues.
2. **Interpretation of chemical formulas**—Figure 2 of the article gives two examples of alkaloids, caffeine and quinine. Have the students interpret the formulas, deriving a molecular formula from the structures.
3. **The Carbon Cycle**—The "slash and burn" technique of deforestation provides an introduction into carbon dioxide-producing reactions, the loss of carbon dioxide-consuming vegetation, and loss of oxygen-producing vegetation.

Possible Student Misconceptions

1. **"The majority of drugs now in use originally came from the rainforests."** *Drugs developed from rainforests plants are certainly important, but the loss of potential drugs from chemicals extracted from disappearing rainforests is often overemphasized. The article states that 25% of prescription drugs derived from plants come from the rainforest. The number is certainly significant, but pales in comparison to the total number of drugs available on the market.*
2. **"Loss of rainforest habitat will result in significant loss of food sources."** *Most of the food products that can be traced back to the rainforests are now grown commercially throughout the world. Rainforest harvests are not the major source of the foods.*

Demonstrations and Lessons

1. The Chemical Heritage Foundation has developed a WebQuest on "Taxol and Yew". "You are going to be involved in a committee hearing in the United States Senate. Your class will be divided into teams. Each team will research one role, and a member of your team will "testify" at the hearing. You will be part of a three-member team assigned to

research one aspect of the Taxol®-Pacific yew debate. Other students in your class will be assigned one of eight different roles." The teacher will determine the time required to do research. "On the day of the Senate hearing each team will present its position and supporting research. Your teacher will also tell you how much time each team will be allotted. Following the hearing there will be time for discussion and consensus. The final agreement for the class will be written and assembled by the Senate staff." The WebQuest serves as a model for organizing other such simulations on the environmental and economic issues presented in the article. Web references are given for each of the roles.

2. Human Impacts in the African Rainforests, what can we do? High school students should be encouraged to think about possible solutions to the environmental degradation that humans can cause, and to the ways in which people can work together to protect the environment from further negative human impacts. They also need to think about the root causes of tropical rainforest degradation (i.e. poverty, population growth, exploitation, and debt) in addition to the more obvious, immediate causes (i.e. logging). The above site is from National Geographic's Xpeditions.

3. This lesson asks students to examine the human impacts that conservationist Michael Fay noticed on his Congo Trek, and Africa MegaFlyover projects as well as the areas that are so far free from human impacts. Students will write recommendations to the region's governments and businesses, explaining what should be done about human impacts and considering some of the underlying causes for environmental threats. (http://www.nationalgeographic.com/xpeditions/lessons/14/g912/fayhuman.html)

4. The Trans-Amazon Expedition. Between April 2007 and November 2008, Dave Freeman and Eric Frost led a team of scientists, journalists, and educators on a 2,900 mile journey across South America. You and your class are able to follow the expedition utilizing Google earth. (http://transamazon.triptracker.net/)

5. The "Exploring the Temperate Rainforest Canopy" site provides a six-activity curriculum for grades 4 to 12 that includes hands-on, student-centered lesson plans. The activities include a canopy hydrology field experiment, a tardigrade microscope lab and international data base where students can submit their samples, two interactive, cooperative learning activities on canopy structure and ecology, and two activities that engage students in creative expression and presentation. (http://academic.evergreen.edu/projects/ican/education/TRFwebsite/curriculum.html)

6. Have your students view the short video narrated by Richard Preston on Climbing the World's Biggest Trees. The video may be accessed at http://www.ted.com/index.php/search?q=california+red+wood&x=0&y=0. Richard Preston, a science writer, talks about some of the most enormous living beings on the planet, the giant trees of the Pacific Northwest. The talk was filmed in Feb. 2008 and posted in Dec. 2008. In the talk, Preston describes what might be classed as an unexplored frontier—the canopy of the giant redwood. The tallest of the trees has been measured at 380 ft—equivalent to a 38-story building. The age of the oldest of these trees may range from 2500 years to almost 5000 years old. Of special interest and worth discussion is the clear-cutting that took place in the 1970's to the early 1990's that resulted in the loss of 96% of the coastal redwoods. Only 4% of the original forest remains. Preston describes climbing with his children into the canopy of Hyperion, one of the oldest redwoods. In the canopy, once thought to resemble an arid desert, they discovered a land when the animals were not afraid of humans since they had never encountered a human. Preston goes on to describe the blight that is devastating the Eastern Hemlock tree, which represents the last fragment of primeval temperate rainforest east of the Mississippi. The trees have been infected by an organism called the Hemlock Wooly Adelgid, which arrived in the US in Richmond, VA in the 1950's. The organism made a trans-species jump to the Eastern Hemlock where it had no predator.

These past two or three summers have seen the massive devastation of the hemlock forests. Preston also notes that the news media has not picked up the story of the devastation of one of the most important ecosystems in North America. Students are able to view comments and add their own after they view the talk.

7. Rainforest lesson plans, teacher resources, help for school reports and school projects are all available at http://kids.mongabay.com/lesson_plans/. The site provides a large number of handouts and lesson plans, photo tours, games and activities, news articles, advice from scientists and experts, interviews with scientists, and links to other useful sites.

Student Projects

1. The site "Help with Rainforest School Reports" provides topics and the necessary information for the writing of formal reports on topics such as: what are rainforests and why are they important; current events – what is happening how; maps of the rainforest, images and pictures of the rainforest; statistics and facts on destruction rates; cause of rainforest destruction; results of rainforest destruction – why it is bad; solutions to rainforest destruction, animals of the rainforest; indigenous people and Indian tribes of the rainforest; and what one can do to help. (http://www.rain-tree.com/schoolreports.htm).
2. Adopt an Acre project—CREA (Conservation Research Education Action) is a non-profit organization dedicated to the conservation of our natural environment by conducting innovative research, increasing ecological literacy and halting unsustainable natural resource use. A $39 donation will help protect an acre of rainforest in Panama. Donors receive a certificate with the donor name(s) and a description of the protected acre, admission to the Rainforest Guardians community, and a newsletter with updates about the acre and its surrounding acres of rainforests. (http://www.cocobolonaturereserve.org/adoptanacre.php)
3. Adopt-A-Rainforest allows individuals, school groups, and other organizations to contribute funding to small conservation groups in tropical countries that work to stop rainforest destruction. Free educational materials are available to students and teachers, which feature Adopt-A-Rainforest projects. (http://www.rainforest-alliance.org/aar.cfm?id=main)
4. Alkaloids—Quinine was discussed in the Background section. Other alkaloids that might be used as short research topics include: atropine—a tropane alkaloid, scopolamine, cocaine, caffeine, ergot alkaloids which include the hallucinogenic drug LSD (lysergic acid diethylamide), the morphine alkaloids, and vincristine and vinblastine which are mentioned in the article. Student groups can research individual alkaloids and then compare/contrast their structures, properties, and effects on the body.
5. The story of the rosy periwinkle can be developed into a class discussion or "town meeting" with one group of students playing the role of lawyers or scientist representing the native tribes whose healing traditions are being exploited by multinational pharmaceutical companies and a second group of students taking the role of scientists and administrators at Eli Lilly, the developer of vincrastine and vinblastine from the rosy periwinkle. The rosy periwinkle story is often cited as the major historical example of biopiracy. A look at all of the facts may paint a different picture. An excerpt from Michael F. Brown's, *Who Owns Native Culture?* (Harvard University Press 2003) provides a brief analysis of the potential discussion or town meeting. The excerpt is available at: http://www.williams.edu/go/native/rosyperiwinkle.htm.

Anticipating Student Questions

1. **"How can one verify the statement that "Nearly 40 million acres of rainforest are lost every year, and 25% of mammals and 15% of birds are at risk of extinction"?** *NASA satellites are able to record changes in the forest structure on a day to day basis. Satellites images are analyzed on an annual basis and acres lost to deforestation are calculated. The reporting of species loss is a more difficult question. Few sources which give the statistics actually list specific species in danger of extinction. This would make a challenging research question.*
2. **"Are the rainforests really one of the major oxygen producers on the planet?"** *Plants and particularly rainforests do supply a significant part of the oxygen produced on planet earth. Some authorities point out that the oceans cover 71% of the earth's surface and the green algae in the oceans are truly the main producers of oxygen. Algae may produce from 70% to 80% of the world's oxygen, an estimated 330 billion tons of oxygen a year. (http://ecology.com/features/mostimportantorganism/)*

References

As noted above, Mark Michalovic's article, "Ancient Soil Chemists of the Amazon" in *ChemMatters,* Vol. 27, No.1, Feb. 2009, pp 7-9 (available at http://portal.acs.org/portal/fileFetch/C/WPCP_011827/pdf/WPCP_011827.pdf), contains information about soils in the Amazon rainforests.

Marent, Thomas. *Rainforest*. New York: DK Publishing. 2006. This coffee table size book showcases the world's rainforests as seen through the lens of nature photographer Thomas Marent, who spent sixteen years travelling through five continents. It includes a collection of more than 500 exquisite animal and plant portraits, as well as the stories behind them. The book also comes with a CD of atmospheric rainforest sounds that go hand in hand with the photographs.

Web Sites for Additional Information

More sites on rainforest environmentalism

Rain Forest Action Network (RAN) is made up of staff members, volunteer scientists, teachers, parents, students and concerned citizens around the world. Campaigns center on "freedom from oil", "global finance", "old growth forests", and "rainforest agribusiness". A wealth of information on past campaigns and on how interested parties can get involved in helping to preserve the rainforests can be found at http://ran.org/.

More sites on rainforest facts and conservation

The RainforestMaker is an organization committed to growing back the earth's rainforests. The group is committed to raising awareness, encouraging people to live more in balance with nature, and inspiring them and the companies they work for to replant trees they have used. The site has a wealth of information on rainforests and the environment, on

medicines, on food, and on species, as well as data on the value of rainforests, paper consumption, etc. Documentation is provided for all of the information. (http://www.rainforestmaker.org/home/index.php)

More sites on deforestation in the Amazon

http://www.mongabay.com/brazil.html provides a wealth of information on the "progress" of deforestation. It includes much data and myriad photos.

More sites on paclitaxel—taxol

The following sites provide detailed clinical information on the drug taxol: http://www.drugs.com/pro/paclitaxel.html; http://www.answers.com/topic/paclitaxel; and http://www.rxlist.com/taxol-drug.htm.

More sites on the implications of deforestation

The NASA site contains a wealth of information on biodiversity impacts, soil impacts, and social impacts, the carbon cycle and global warming. Direct and underlying causes of deforestation and rates of deforestation are documented. Of special interest is the discussion of the use of high- and moderate-resolution satellite images in determining worldwide rates of deforestation. Strategies for preserving tropical rainforests are also presented. A large number of references on the individual topics are at the conclusion of the site: http://earthobservatory.nasa.gov/Features/Deforestation/printall.php.

General Web References

More websites on teacher information and lesson plans

The site "Help with Rainforest School Reports" provides topics and the necessary information for the writing of formal reports on topics such as: what are rainforests and why are they important; current events—what's happening now; maps of the rainforest; images and pictures of the rainforest; statistics and facts on destruction rates; causes of rainforest destruction; results of rainforest destruction—why it's bad; solutions to rainforest destruction; animals of the rainforest; plants of the rainforest; indigenous people and Indian tribes of the rainforest; and what you can do to help. (http://www.rain-tree.com/schoolreports.htm)

Those Blooming Algae!

Background Information

More on algae

Biologically speaking, the category of Algae comes in many different forms, sizes and colors. They can be found in soil, on rocks, and in bodies of water—fresh, brackish, and saline. Looking at the oceans, algae growth and production occur close to shore due to the concentration of nutrients that flow from the land. Algae are crucial to the food web in the ocean. And they, along with other photosynthetic organisms in the ocean, contribute some 40-70% of the oxygen found in our atmosphere.

The sizes of algae vary from microscopic to that of small underwater "trees" (known as kelp, such as *Sargassum*). The microscopic algae are part of the "wandering" (plankton) collection of both plants (Phytoplankton) and microscopic animals (Zooplankton) that form a most fundamental portion of the food chain or web. There are single-cell as well as multi-cellular algae. The so-called "sea weeds" are usually attached at the bottom of the ocean's shallow parts (less than 200 meters) where nutrient concentrations are the highest. Green (*Fucus)*, brown (kelp), and red algae are most common. Some so-called blue-green algae (actually cyano- or blue-green bacteria) are important in terms of converting atmospheric nitrogen (N_2) to a more usable form (for plants) of nitrogen called nitrate (NO_3^{1-}). This nitrogen-conversion activity is linked to algal growth (and plant growth in general)—the more nitrate, the higher the level of plant growth (or reproduction). This growth is energy-dependent, which comes through photosynthesis indirectly. The cause of red tide is technically not from an algae but a dinoflagellate (a unicellular protist with flagella for locomotion; often photosynthetic but not classified as an algae). http://www.geo.ucalgary.ca/~macrae/palynology/dinoflagellates/dinoflagellates.html).

A useful article on the varieties of phytoplankton with good photos is found at http://oceancolor.gsfc.nasa.gov/SeaWiFS/TEACHERS/sanctuary_4.html with additional links provided within the article.

Photosynthesis is an endothermic reaction—the conversion of light energy to chemical potential energy. This chemical potential energy is then available, through respiration, to power the reproductive (growth) process. Could this interaction be used to reduce the amount of carbon dioxide in the atmosphere through uptake in photosynthesis and its synthesis into carbon-based compounds, including sugars? This is currently a question of great interest, remembering that photosynthesis's uptake of carbon dioxide is balanced by the release of carbon dioxide in respiration. Can there be more photosynthesis than respiration? Or can the carbon that becomes incorporated into algae be contained (sequestered) and not released both through respiration and the decay process of these algae? Is there a way to have the dead algae sink to lower depths in the ocean where decay, another respiration process by bacteria, will not occur? Currently there are a number of debates about this issue, since global warming is associated with excess levels of carbon dioxide (along with methane and some nitrogen compounds) in the atmosphere. Increasing photosynthetic rates of algae (reducing carbon dioxide) without equivalent rates of carbon dioxide production/release (respiration, the reverse chemical equation of photosynthesis) would be the goal. It is known that adding iron (as iron sulfate) to the ocean dramatically increases the rate of growth of algae (and the photosynthetic

rate). Is the amount of carbon dioxide incorporated into the algae greater than the amount of carbon dioxide released through respiration? If so, there would be a net reduction of atmospheric carbon dioxide. The debate in scientific circles continues with additional large-scale experiments planned for ocean research.

More on algal nutrient stimulation

The interesting idea of adding iron to areas of the oceans (the entire Southern Ocean, equatorial Pacific, and the Gulf of Alaska) that were nutrient-rich (nitrates and phosphates) but low in phytoplankton production was first tested in the laboratory. These areas are known as high nutrient, low chlorophyll zones (HNLCs). There was doubt that iron would make a difference because it was a micronutrient in plant productivity. But observations about algal blooms in other parts of the world's oceans, including the Antarctic, suggested the idea that iron was being blown into the oceans from the land, particularly from deserts, and was seasonal. In the late 1980s a proposal was made by John Martin, an oceanographer, that blooms were related to concentrations of iron. A large scale experiment was endorsed in 1991 and carried out after Martin's death in 1993. (biographical and scientific story at http://www.palomar.edu/oceanography/iron.htm)

The tracking of iron added to the ocean was done by tagging the iron (as iron sulfate) with sulfur hexafluoride. The iron compound was delivered to the ocean by allowing sea water into the ship's hold and mixing with the iron sulfate and sodium hexafluoride, then flushing out the solution at the rear of the ship. Iron has difficulty dissolving in salt water. Using satellite sensing, it was apparent that the addition of iron into the ocean around the Galapagos Islands produced large algal blooms. Satellite pictures of algal blooms related to excess nutrients and/or iron are shown at the following: (http://www.whoi.edu/oceanus/viewImage.do?id=59628&aid=35609, http://www.whoi.edu/oceanus/viewImage.do?id=57454&aid=34167, http://www.whoi.edu/oceanus/viewImage.do?id=57456&aid=34167.

More on carbon dioxide reduction through photosynthesis

Are there limits on the iron experiment to increase photosynthesis and reduce carbon dioxide (sequester carbon in plankton structures and their waste)? Is it a wash, considering that respiration, even in photosynthetic organisms, releases carbon dioxide? How can you have a ratio of photosynthesis-to-respiration that is greater than one in terms of carbon dioxide (uptake/release), particularly in a natural setting such as the oceans? On land, algae might be used to reduce atmospheric carbon dioxide in a simple set-up that utilizes the photosynthetic ability of blue-green "algae" (actually blue-green bacteria, *cyanobacteria*). One idea that has been tested uses these cyanobacteria in industrial settings such as coal-burning power plants. Here the algae are able to survive in very warm water (55 ^{o}C) that is used to cool the condensed steam from electricity-generating turbines. Some of these algae species are found in very hot environments such as hot sulfur springs. These algae are placed on screens for exposure (and growth) to the warm water and the flue gases containing the CO_2 produced by coal combustion. The set-up is considered to be scalable to industrial size. But the algae growth rate is high (algal bloom!). The excess algae could be used as a biomass fuel. If the biomass is used as a fuel, as a carbon-containing compound, it will also contribute carbon dioxide. But you might want to consider, chemically, how much CO_2 will be produced per kilogram of fuel compared with coal. Why is coal considered a higher emitter of carbon dioxide than other fuels, such as natural gas and oil (and even wood, for that matter)? You could have students do calculations based on balanced chemical reactions to answer the question. Current projections are for a bioreactor

that utilizes 1.25 million square meters of algae screens to handle the output of a 10-megawatt power plant by 2010.

Other considerations for reducing the carbon dioxide in the atmosphere include directing the gas into the ocean itself. However there are unanswered questions as to how much the ocean's chemistry can buffer the potential increase in acidity from the dissolving of the gas to form carbonic acid. This increase in acidity could affect a number of different types of organisms in the oceanic ecosystem. The thought is that the carbon dioxide would have to be pumped into the seafloor sediments at depths greater than 3000 meters. At such depths, the extremely low temperatures (close to freezing) and intense pressures would convert the carbon dioxide to a dense liquid heavier than the water above, keeping it at or near the sea floor.

Another approach to capturing both industrial and atmospheric carbon dioxide makes use of both zooplankton and phytoplankton. As with the iron-stimulating experiment, phytoplankton growth is increased with the introduction of more "fertilizer" (particularly nitrates and phosphates) and iron. The larger mass of phytoplankton utilizes more carbon dioxide through photosynthesis. The phytoplankton support large populations of zooplankton called *salps* that would eat the phytoplankton. The carbon of carbon dioxide is incorporated into the phytoplankton (sugars and related carbon compounds), which, when eaten by the salps, becomes biochemically incorporated into the animals. The excretions of the salps are considered to be dense enough to sink into the ocean depths, thereby carrying carbon away from the ocean surface. (see http://www.whoi.edu/oceanus/viewArticle.do?id=35609 for a related article that includes pictures of the excretion pellets of salps, copepods and euphausids) There are a variety of ideas as to how the "fertilizer" can be provided to the phytoplankton in the first place.

More on ocean chemistry

Some interesting and basic chemistry of ocean waters is found at http://oceancolor.gsfc.nasa.gov/SeaWiFS/TEACHERS/CHEMISTRY/. Another article that starts with the question, "Why is the Ocean Salty?" expands into an interesting discussion of the various factors that contribute to the chemical soup known as the ocean. This includes the role of living organisms as well as abiotic factors such as land runoff, temperature, dissolved gases and the hydrological cycle. Refer to http://www.palomar.edu/oceanography/salty_ocean.htm.

A comprehensive look at the effect of greenhouse gases and global warming on the ocean's ability to physically and chemically ameliorate the build-up of carbon dioxide and concomitant increase in atmospheric temperatures is found at http://www.sciencedaily.com/releases/2007/03/070308084525.htm. There is a series of related stories at this site including "Whatever the Warming, Ocean Acidifies from Carbon-dioxide Buildup", Oceanic Acidity: Researcher Outlines Coral's Future in an Increasingly Acidic Ocean", and "Climate Change will affect Carbon Sequestration in Oceans (Model Shows)". An additional study on the effect of increased ocean acidity on the ability of clownfish larvae to find coral reefs through "tasting" (smelling) is found at http://www.newscientist.com/article/dn16518-acid-oceans-no-laughing-matter-for-clownfish.html?DCMP=OTC-rss&nsref=climate-change-.

A proposal to make better use of the oceans to absorb carbon dioxide by certain chemical activities on land is found at http://www.sciencedaily.com/releases/2007/11/071119112231.htm, with related articles linked.

More on algae as the new biofuel

The idea of an algal bloom is not necessarily a negative thing. Currently algae are being considered as the next potential source for biofuels. First there was ethanol from corn (fermentation of sugars from starch), then ethanol from the cellulose of plants, including corn. Now what seems to be a better idea is the use of genetically-altered algae to produce an oil rather than an alcohol. Bio diesel or even gasoline is the result. The design goal is to manage algae under controlled conditions of light, temperature, and reactant concentrations (including nitrates and phosphates necessary for a "bloom"!) to support maximum production of single-celled algae such as *Chlorella* and *Chlamydomonas*. Algae produce an oil which is the storage form of energy for algae; much like fat is the storage form of energy for animals. First, algae species must be found that are most efficient in energy conversion to cellular oil, then growing them at optimal rates, genetically changing their metabolic pathways to produce maximum concentrations of oil, and extracting the oil in an economic manner. A desired goal is the development of algae that can accumulate more than 30% of their body weight in oils.

The oils that are found in algae are known as triacylglercerides (essentially a fat made from a triglyceride and a fatty acid). These triacylglercerides chemically resemble jet fuel made from kerosene (known in the trade as JP8). A calculation by the Department of Energy (DOE) suggests that microalgae such as *Chlorella* and *Chlamydomonas* have the potential to produce 100 times more oil per acre than any terrestrial plant, including soybeans. Scientists are still trying to completely understand the metabolic mechanism whereby algae produce oil. It seems as though algae produce these oils under stressful conditions, which would make sense if one considers the fact that the oil is a storage form for energy originally produced (transformed) through photosynthesis and captured in the basic product of a simple sugar such as glucose. The goal in the research is to understand how fluctuating temperatures or lack of nitrogen stimulate the production of the oils. If the mechanisms for "translating" environment clues into oil production within an alga cell can be determined, then these biochemical triggers could be used to directly stimulate maximum oil production under the best, not the worst, environmental conditions. This would include high levels of nitrogen (as nitrate) and phosphorus (as phosphate), two of the chemicals in high concentration associated with algal blooms in the ocean!

Another approach in the use of algae for producing oil is to use genetically modified algae that do not depend on light and photosynthesis but rather convert sugar water into oil in what are known as bioreactors (fermentation tanks). Not needing a light source means reducing the problem of finding "containers" with maximum exposure to light but of the minimal size to contain maximum volume for algae fermentation. A similar approach is used for producing other Biofuels, such as butanol and isobutanol, utilizing bacteria and yeast cells. One side benefit of using this fermentation process is that the algae can be grown in both saltwater and wastewater. This translates into using water that is available from other industrial processes such as breweries or power-generating plants. Because these algae are functioning as heterotrophs rather than autotrophs (photosynthetic) means that they are bathed in their energy source (sugar) rather than having to compete for enough light to undergo photosynthesis. This translates into more choices of bioreactor containers that are not controlled by the need for large surface areas exposed to light.

Connections to Chemistry Concepts

1. **Nitrates**—This ion (NO_3^{-1}) is an important source of nitrogen for the synthesis of plant protein. Most plants cannot directly use elemental nitrogen (N_2) found abundantly in the atmosphere (roughly 79% by volume). Through oxidation, elemental nitrogen is converted to nitrate in biological systems, particularly bacteria and some blue-green algae.
2. **Nitrogen fixation**—Bonding in N_2 is very strong (a triple bond), and as a result, molecular nitrogen is unavailable for use in most living organisms, unless it is first "fixed"—broken apart and incorporated into single-bonded compounds, like NH_3, or nitrates. Legumes, like clover, beans and peanuts, can fix nitrogen by way of bacteria called rhizobia that coexist on the roots of these plants. This is a good application of bonding in class.
3. **Phosphate**—This ion (PO_4^{-3}), is a primary nutrient for plant life, including algae. The phosphate is a component of a number of biologically important compounds, starting with what is known as the monoester of triphosphoric acid, adenosine triphosphate (ATP). This compound is used in living organisms for the important chemical process called phosphorylation, by which the transfer of chemical energy takes place—the driving force in the metabolism of all living organisms.
4. **Oxidation**—The decay of dead algae in a bloom is an oxygen-dependent process, since it is the result of bacteria utilizing the plant material for its energy (the biochemical process is called respiration), as well as essential nutrients. This oxidation process is energy-releasing involving carbon-containing compounds (sugars, fats, proteins) that are eventually chemically reduced to carbon-dioxide. Elemental oxygen (O_2) is involved in this process (part of oxidation-reduction or redox), hence the depletion of dissolved oxygen in water when the dead algae are "eaten" by bacteria (the decay process), which is based on oxidation-reduction. Oxidation is also involved in the critical process of converting atmospheric nitrogen (N_2) to the form of nitrogen most useful to plants; i.e., nitrates (NO_3^{-1}).
5. **Ether**—Ether compounds are di-substituted derivatives of water meaning that both hydrogen atoms are replaced by carbon chains or rings. The oxygen atoms in ethers are hydrogen acceptors, contributing to their solubility in water (but not as soluble as alcohols because they lack the hydroxyl for hydrogen bonding). The more ether linkages (bonds between oxygen atoms and carbon chains or rings), the more soluble in water.

Possible Student Misconceptions

1. **"Photosynthetic organisms use carbon dioxide, but they don't produce carbon dioxide."** Any photosynthetic organism uses carbon dioxide in the conversion of light energy to chemical potential energy in the form of chemical bonds of carbon-containing molecules (carbon dioxide to glucose). But all living organisms need energy to function (stay alive!) and photosynthetic organisms cannot use sunlight directly as an energy source. They must use the process of respiration as do all non-photosynthetic organisms (animals). Therefore, they release carbon dioxide.

Demonstrations and Lessons

1. Measure plant productivity using what are known as light and dark bottle techniques to measure both the production of oxygen through photosynthesis and the uptake of oxygen by respiration. (This is a standard lab for AP Biology-http://wardsci.com/category.asp?c=977&bhcd2=1233952992). Using an algae such as chlorella, the biological activity of photosynthesis and respiration is determined by measuring the amount of dissolved oxygen.

This can be done through a chemical evaluation (the Winkler test) or electronically, using a dissolved-oxygen probe. References for this activity can be found at the following: http://www.phschool.com/science/biology_place/labbench/lab12/intro.html, http://www.phschool.com/science/biology_place/labbench/lab12/model.html , http://www2.vernier.com/sample_labs/BIO-A-12B-COMP-primary_productivity.pdf, and http://www2.vernier.com/sample_labs/BIO-A-04B-COMP-photosynthesis.pdf.

2. Students can test various water samples from different water systems (effluent discharge from a sewage treatment plant, a regular fresh water stream, a lake, a wetlands, a brackish area such as a tidal marsh, and the ocean). There are standard water testing kits for nitrate, ammonia, phosphate, chloride, and carbonate as well as pH. The least expensive are from aquarium shops. (http://www.marinedepot.com/ps_AquariumPage~PageAlias~test_kits__index.html). More professional kits are available from Hach and LaMotte through science educational supply companies. (http://www.hach.com/# and http://www.lamotte.com/.) A good description of the value of these tests is found at http://www.gem.msu.edu/gw/wtr-test.html.

3. An important dynamic of algae growth and phytoplankton in particular is the influence of iron in ocean systems. As mentioned in the article, iron may indirectly spark an algal bloom by first stimulating the growth of so-called nitrifying bacteria which in turn convert atmospheric/oceanic nitrogen to nitrates which algae can then use for accelerated growth rates. Students could evaluate this phenomenon of inducing a bloom, indirectly, through a demonstration (or experiment): Go to a nearby stream or pond and scrape some of the algae off the rocks. "Inoculate" a series of clean baby food jars with the algae. Set one baby food jar aside as a control, and add increasing amounts of Miracle-Gro or similar fertilizer. (A very small amount suffices—the amount you can pile on the end of a coffee stirrer is enough!) There should be a control and three jars with 1 portion, 2 portions, and 4 portions of the fertilizer. Put the jars in a bright-light place. (Control temperature by using fluorescent lamps.) Monitor daily (taking comparison photographs each day is a good way to do this). What you'll see is that algal growth will be enhanced in the fertilized jars compared to the control, but in the over-fertilized jar, growth will be rapid and then the algae will turn brown and die—that's what happens with eutrophication. Students could test for the concentration of the important ions (nitrate, phosphate, chloride, carbonate, and pH) through the water testing kits mentioned above.

4. Students could work from real data of biological and chemical activity, taken from the transect of an aquatic sampling station. Lesson plans for working with the data (graphing, interpretive questions) can be found at http://www2.vims.edu/bridge/DATA.cfm?Bridge_Location=archive1099.html.

Student Projects

1. Students could study the issues associated with the desire to inoculate certain areas of the world's oceans with iron to stimulate phytoplankton production and subsequent reduction of atmospheric carbon dioxide (related to global warming). What are the potential benefits and potential problems with trying to make large-scale changes in the dynamics of the world's oceanic and atmospheric environments? There is already nascent commerce revolving around the concept of selling carbon credits (from those who reduce carbon dioxide to those who produce an amount of carbon dioxide beyond treaty-based limits). How do you estimate (calculate) the extent of the changes desired? A very good series of lectures and seminars on the subject can be found at the Woods Hole Oceanographic

Conference held in September, 2007 (see all the presentations, including power points and PDF files, at http://www.whoi.edu/page.do?pid=14617).

2. Students could investigate the relative contributions of various fossil fuels to the production and emission of carbon dioxide to the atmosphere, based on mass considerations; e.g., coal, as carbon, produces 3.7 g of CO_2 for every gram of coal burned (neglecting impurities) [12 g carbon produces 44 g CO_2], while propane produces only 3.0 g of CO_2 for every gram of propane burned [44 g propane produces 132 g CO_2]. Of course, the amount of heat produced must also be considered. In short, what is the best fossil fuel to use to produce the most heat possible, while producing the least carbon dioxide? Perhaps students can calculate an energy / mass of CO_2 ratio and then an energy/g fuel to g of CO_2 ratio?

Anticipating Student Questions

1. **"Do all algal blooms produce toxins?"** *An algal bloom is sometimes erroneously called a "red tide", referring to a particular single celled organism called* ***Pfiesteria****, a dinoflagellate (technically not an algae) that produces a red appearance and also produces a toxin. But many algal blooms are of various colors and do not all stem from toxin-producing algae.*
2. **"If nitrogen and phosphorus compounds are needed by algae to grow, why is their presence in water considered to be pollution?"** *It is not a question of their presence being considered pollution but rather the concentrations of these and essentially any other chemicals in a given environment (or ecosystem, which involves living organisms). If the concentrations exceed the amount that can be "processed" (biological activities), then increased levels of various chemicals can either exert their effect on a collection of living cells from the outside (think of the process of osmosis) or from the inside where the chemical(s) might accumulate in excess quantities. Essentially an ecosystem can be thought of as a large chemical system in equilibrium. Adding too much to the reactant side can shift the equilibrium to the product side. But there is a limit to this shift due to the rate that living organisms can convert reactants to products, hence an eventual accumulation of a particular chemical reactant that can prove biologically detrimental. Sodium chloride is essential to living organisms. But exposure to excess amounts of sodium chloride will dehydrate the cells of that living organism causing temporary injury or death.*

Web Sites for Additional Information

More sites on the red tide and brevetoxins

This reference addresses the causes of Florida red tides through the use of computer models that suggest the red tides occur because of a particular combination of wind patterns and tides along with available nutrients originally from the Mississippi River, but at much lower concentrations than previously projected:
http://oceanservice.noaa.gov/news/pressreleases/nov07/supp_110707.html.

The following references provide very specific and factual details about the effects of red tide-produced brevetoxins, particularly with regard to aerosols of the toxin causing respiratory problems:

http://oceanservice.noaa.gov/facts/redtide.html,
http://www.ehponline.org/docs/2007/115-4/forum.html#redt, and
http://www.ehponline.org/members/2005/7499/7499.html.

More sites on eutrophication (resulting from algal blooms)

A reiteration of the basics of the biological process of eutrophication can be found at the following:
http://oceanservice.noaa.gov/education/kits/estuaries/media/supp_estuar09b_eutro.html. Note again that excess living algae do not deplete the oxygen in the water—they are producing the oxygen. It is only when the algae die and undergo decomposition by bacteria that oxygen is removed from the water because the bacteria use the oxygen in the decomposition process.

More sites on biodiesel from algae

http://www.the-scientist.com/templates/trackable/display/article1.jsp?type=article&o_url=article/display/55376&id=55376 is an article from *The Scientist*, titled, "Future Oil from Algae". The article provides a lot of detail about the alternative ways by which algae can be used to produce oil in different forms, and the problems of scaling up the laboratory conditions to commercial parameters for production.

http://www.oilgae.com/ is a comprehensive site that includes good information on all aspects of the commercial side of producing biofuels from algae. There is also reference material on such things as classification and properties of algae, their cultivation on a macro-scale, bioengineering of the algae for oil production, pictures of bioreactors, and current news.

More sites on biofuels

http://www.the-scientist.com/2009/02/1/24/1/ shows another source of biofuel, this one from genetically engineered bacteria rather than algae.

More sites on oceans as heat and carbon dioxide sinks

The following web sites are from a conference at Woods Hole Oceanographic Center in 2007 to consider all aspects of engaging the physical, chemical and biological parameters of world's oceans in modifying global warming.

http://www.whoi.edu/oceanus/viewArticle.do?id=17726 (Effect of Oceans on Global Warming)

http://www.whoi.edu/oceanus/viewArticle.do?id=35866 (circulating nutrients to ocean surface from depths; unique concept of using tubing to move nutrients from the depths to the surface of the oceans)

http://www.whoi.edu/oceanus/viewArticle.do?id=35746&sectionid=1000%20 (Lessons from Nature, Models and the Past related to global warming trends and the effects of stimulating algae growth to reduce atmospheric carbon dioxide)

More sites on satellite pictures of plankton (phytoplankton) blooms and ocean circulation

http://www.whoi.edu/oceanus/viewArticle.do?id=34167&sectionid=1000 provides satellite photos of plankton blooms off Argentine and Alaskan coasts.

Global views of the effect of climate change on plankton life can be found at http://www.sciencedaily.com/releases/2005/07/050705232102.htm.

More sites on nitrogen cycle in oceans

http://www.whoi.edu/oceanus/viewArticle.do?id=53946 (Tracking nitrogen circulation in oceans and background chemistry on the nitrogen cycle)

More sites on iron and fertilizing the oceans

http://www.whoi.edu/oceanus/viewArticle.do?id=34167&sectionid=1000 (Part of a forum convened over the experimental approach to adding iron to oceans to encourage algae blooms to reduce atmospheric carbon dioxide as related to global warming. One part of a six-part report on the conference)

http://www.whoi.edu/oceanus/viewArticle.do?id=35826&sectionid=1000 (Dumping iron and trading carbon- profits, pollution, and politics all play a role in ocean iron fertilization)

http://www.whoi.edu/oceanus/viewArticle.do?id=35668 (Uncertainties and unintended consequences of manipulating ocean ecosystems by adding iron to oceans)

Entire symposium on Ocean Iron Fertilization at Woods Hole Oceanographic Institute in September, 2007 is recorded on video and includes PowerPoint and PDF files of Slides used in the proceedings. Go to http://www.whoi.edu/page.do?pid=14618.

More sites on satellite imagery of the oceans

Some good satellite pictures of various physical and biological features of the ocean can be found at http://oceancolor.gsfc.nasa.gov/SeaWiFS/TEACHERS/sanctuary_6.html which is part of a larger topic called “Monitoring the Earth from Space with SeaWiFS” at http://oceancolor.gsfc.nasa.gov/SeaWiFS/TEACHERS/sanctuary_1.html.

Chocolate: The New Health Food. Or Is It?

Background Information

More on the history of chocolate

Theobroma cacao, the botanical name for chocolate, literally means food of the gods. (In Greek, theo = god(s) and broma = food). Linnaeus, the Swedish scientist who gave us our modern binomial classification scheme for plants and animals, gave chocolate its botanical name in 1753. The second term "Cacao" has pre-Columbian roots. It can be traced to the term "akawa" found in the Olmec culture which thrived in the hot and humid southern region of Mexico between 1500 and 400 BC. The pre-Columbian Aztecs of Mexico made xocolatl (xoco means bitter and atl means water) from the cacahuatl. The Spanish conquistadors in Mexico, circa 1520, were the first Europeans to be introduced to the wonders of chocolate by the Aztecs. The Aztecs learned the secrets of processing and preparing chocolate from the Mayans who, in turn, learned the techniques from the Olmec. Since the cacao beans are rich in fat, simply mixing the crushed beans with water would cause the mixture to separate. The problem was solved by stirring vigorously while adding the water to the crushed cacao beans. The process is similar to today's homogenization of milk in which the milk fat particles are reduced to a uniform size and suspended in the mixture. The Aztecs then poured the mixture from one container to another from a height high enough to create the froth that was considered the ultimate feature in drinking the beverage.

The Golden Book of Chocolate produced by Anne McRrae of McRae Books provides the following added historical anecdotes:

> Among the Aztecs the drinking of chocolate was confined to the elite: the royal house, the lords and nobility, the long-distance merchants and the warriors. The ceremonial importance of the substance was profound. Not only was it provided at banquets at which noblemen and merchants displayed their wealth, it was also offered to the gods, and was used to anoint newborn children on the forehead, face, fingers and toes.
>
> A report by Bernial Diaz del Castillo noted that Montezuma drank xocolatl several times a day from a beaker made of pure gold, and that warriors and nobles of the court kept the ground cacao in golden containers, which they carried around with them. The local dignitaries spiced the drink with native vanilla, wild honey, pita juice, and occasionally chili, whereas the Spanish officers preferred anise seed, cinnamon, almonds, and hazelnuts. Moreover, they increasingly chose to make their drink with hot water, and sweeten it with the cane sugar they had introduced into the New World. Instead of obtaining the coveted broth with pouring, their slaves used a wooden whisk called a molinello to stir the hot beverage until it foamed invitingly.
>
> Fortunately for the Spaniards, the Church recognized the new drink as a beverage rather than a food, which meant it could be enjoyed during periods of fasting. This must have encouraged them to bring chocolate back to Spain in the late 1500's. A hundred years later it had become the new national drink.

McCrae goes on to fill in the details of the spread of the use of chocolate. She also traces the founding of the firms whose names are still with us today; e.g., Cadbury, Tobler,

Nestle, and Hershey. The book includes a discussion the discoveries that led to what we today call cocoa, as well as the processes that led to the development of a solid chocolate/cocoa bar. As with most products, costs of production and profit motives resulted in adulterated chocolate products that have given chocolate the stigma of being a "junk" food. The development of organic chocolate, the spread of cacao plantations to Hawaii, and the desire by the public for the healthy, beneficial chocolate are well documented. The sale of this "gourmet" accounted for roughly 10% of chocolate sales in the US. Estimates place total "gourmet" chocolate sales at $1.3 billion in 2005 with a projected $1.8 billion in 2010.

What we today know to be the physiological effects of the many chemicals in chocolate took on almost mystical proportions in the early 1500's and into the 1600's when use of chocolate was spreading through Europe. Today's association of chocolate with Valentine's Day and all things romantic, traces its roots to the belief that chocolate was an aphrodisiac. As such, chocolate was first considered a drug, a medicine with a pleasant taste, something new and different for the time. Samuel Pepys, the English diarist, wrote in his entry for April 24, 1661 of chocolate's ability to settle the stomach and alleviate the discomfort of a hangover. Chocolate's psychological attraction may have been documented for the first time by the mid-seventeenth century French letter writer, Marie de Rabutin-Chantal, marquise de Sevigne. She wrote, "I have reconciled myself to chocolate. I took it the day before yesterday to digest my dinner, to have a good meal, and I took it yesterday to nourish me so that I could fast until evening: it gave me all the effects I wanted. That's what I like about it: it acts according to my intention." The article discusses the physiological response of the brain to some of the chemicals present in chocolate which stimulate the brain to produce natural opiates and which slow the breakdown of other chemicals which produce the overall feeling of well being.

A temperature than never drops below 60 ^{o}F (16 ^{o}C), high humidity, protection from the direct rays of the sun are three conditions required for the cacao tree to produce the fruit from which chocolate is made. The rainforests that spread between Southern Mexico and the northern Amazon basin provide the necessary conditions. The rain forests also provide the natural habitat for the midges which are responsible for the pollination of the cacao tree flowers.

Connections to Chemistry Concepts

1. **Interpretation of organic structures**—Review the writing of organic structures, two different types are present in the article.
2. **Organic nomenclature**—Discuss the important of suffixes in determining the functional groups that make up organic molecules.
3. **Free radicals**—Explain the importance of unpaired electrons in accelerating the rate of chemical reactions.
4. **Saturated vs. unsaturated molecules**—Discuss the structure of saturated molecules (no carbon double bonds) and unsaturated molecules (those with at least one carbon double bond).
5. **Oxidation and reduction**—Review oxidation as involving the loss of electrons and reduction the gain of electrons.

Possible Student Misconceptions

1. **"I always get zits from eating chocolate."** *The article states that research does not support this widespread belief.*
2. **"Chocolate is a junk food."** *Popular literature labels chocolate as a junk food. The general public may not know and appreciate the different varieties of chocolate, and which of those are healthy and which are not.*
3. **"I don't think the role of free radicals and antioxidants in food is well understood."** *The article discusses the role of free radicals and how they may damage DNA, as well as, the role of antioxidants in terminating the reactions that produce free radicals.*
4. **Students may not fully understand the interpretation of the structural formulas presented in the article.** *Representing chemical structures in various ways provides a chance to review the rules for writing organic structures.*

Demonstrations and Lessons

1. The M&M statistics analysis lesson can be used with students of all ages. The lesson described can be used in a beginning or advanced chemistry class to introduce the use of statistics, a chi square analysis in analyzing data. All of the information and worksheets are available at: http://schools.nashua.edu/myclass/fitzgeralds/apbiology/Ecology%20Documents/MM%20lab%20**chi**%20**square**.doc. If the site requests a log-in, simply click "enter" to access the document.
2. Here is a lesson about testing the hardness of chocolate bars: http://www.teachersdomain.org/resource/psu06-nano.sci.hardchoc2/. Although it is more physics than chemistry, perhaps you could relate the hardness to the content or to the processing of the chocolate as an extension to the experiment.
3. An activity that focuses on the density of chocolate bars can be found on Hershey Chocolate's web site at http://www.hersheystory.org/lib/docs/lessonPlans/DiscoveringChocolateDensity.pdf.

Student Projects

1. The first of the questions in the "Anticipating Student Questions" (below) lists the chemical names of the chemicals that have been identified in chocolate. Depending on the number of students in the chemistry classes, assign each student one or more of the chemicals. Have the students print the name and chemical structure and create a major display in the classroom or in a hallway that portrays all of the chemicals found in chocolate.
2. If the above project seems too imposing, a similar project was proposed in the Teacher's Guide for the Dec. 1999 issue of ChemMatters. "A group of students could study and prepare a presentation of the different structures of many of the different types of organic molecules that might be encountered in discussing the substances that are either contained in chocolate or are involved in its creation from the cocoa bean."
3. If your school teaches statistics or psychology on the introductory level or on the AP level, your students might propose a project in conjunction with one or both classes. Again, the Dec. 1999 issue of the Teacher's guide proposes that "a group of students might survey their classmates to determine both their perceived craving for chocolate and their actual consumption, both by quantity and by type of chocolate consumed. If they wanted to extend the study, they could consult with the school's psychology teacher or guidance counselor to obtain or develop a test for determining whether personality profile and chocolate

consumption are, in any way, related. Students could develop a Likert scale test in which individuals could rate their craving for chocolate. The data could be grouped in various ways —by gender or age, for example."

4. Have students visit the sites of the various chocolate manufacturers and report back on the resources available at the commercial site. The following site has links to all of the chocolate manufacturers. (http://www.mce.k12tn.net/chocolate/index.htm)

Anticipating Student Questions

1. **"The article states that there are more than 300 chemicals found in chocolate, yet it only discusses a few. What are the names of the other chemicals found in chocolate?"** *The chemical will vary depending on the source of the chocolate tested. A listing of the chemicals found in chocolate follows*: *Acetic acid, aesculetin, alanine, alkaloids, alpha-sitosterol, alpha-theosterol, amyl acetate, amyl alcohol, amyl butyrate, amylase, apigenin-7-o-glucoside, arabinose, arachidic acid, arginine, ascorbic acid, ascorbic acid-oxidase, aspariginase, beta-carotene, beta-sitosterol, beta-theosterol, biotin, caffeic acid, caffeine, calcium, campesterol, catalase, catechins, catechol, cellulase, cellulose, chlorogenic acid, chrysoeriol-7-o-glucoside, citric acid, coumarin, cyanidin, cyanidin-3-beta-l-arabinoside, cyanidin-3-galactoside, cyanidin-glycoside, cycloartanol, d-galactose, decarboxylase, dextrinase, diacetyl, dopamine, epigallocatechin, ergosterol, ferulic acid, formic acid, fructose, furfurol, galacturonic acid, gallocatechin, gentisic acid, glucose, glutamic acid, glycerin, glycerophosphatase, glycine, glycolic acid, glycosidase, haematin, histidine, i-butyric acid, idaein, invertase, isobutylacetate, isoleucine, isopropyl acetate, isovitexin, kaempferol, l-epicatechin, leucine, leucocyanidins, linalool, linoleic acid, lipase, luteolin, luteolin-7-o-glucoside, lysine, lysophosphatidyl-choline, maleic acid, mannan, manninotriose, mannose, melibiose, mesoinositol, methylheptenone, n-butylacetate, n-nonacosane, niacin, nicotinamide, nicotinic acid, nitrogen, nonanoic acid, o-hydroxyphenylacetic acid, octoic acid, oleic acid, oleo-dipalmatin, oleopalmitostearin, oxalic acid, p-anisic acid, p-coumaric acid, p-coumarylquinic acid, p-hydroxybenzoic acid, p-hydroxyphenylacetic acid, palmitic acid, palmitodiolen, pantothenic acid, pectin, pentose, peroxidase, phenylacetic acid, phenylalanine, phlobaphene, phosphatidyl choline, phosphatidyl ethanolamine, phosphatidyl inositol, phospholipids, phosphorus, phytase, planteose, polygalacturonate, polyphenol oxidase, polyphenols, proline, propionic acid, propyl acetate, protocatechuic acid, purine, pyridoxine, quercetin, quercetin-3-o-galactoside, quercetin-3-o-glucoside, quercitrin, raffinase, raffinose, reductase, rhamnose, riboflavin, rutin, rutoside, saccharose, salsolinol, serine, sinapic acid, stachyose, stearic acid, stearodiolein, stigmasterol, sucrose, syringic acid, tannins, tartaric acid, theobromine, theophylline, thiamin, threonine, trigonelline, tyramine, tyrosine, valerianic acid, valine, vanillic acid, verbascose, verbascotetrose, vitexin (source: http://www.rain-tree.com/chocolate.htm)*

2. **"Why does one feel good or more relaxed after eating chocolate?"** *Some students may or may not have experienced such a sensation. Chocolate contains anandamide, a chemical known to make us happy. The word anandamide is derived from the Sanskrit root for "bliss." Ordinarily, anandamide is broken down quickly in the brain. Research shows that some of the chemicals present in chocolate inhibit the break-down of anandamide. Thus eating chocolate keeps the anandamide molecules in the body longer, making us feel good for a longer period of time.*

References

The 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 past 5 years are also available at this site."

Miller, Judy. Chocolate. *ChemMatters*. April, 1987. Vol. 5, No. 4, pp. 16-20. This article speaks primarily to the history of and the processing of chocolate.

Baxter, Roberta. Chocolate—How Sweet It Is! *ChemMatters*. Dec. 1999. Vol. 17, No. 4, pp. 4-5. Ms. Baxter discusses history and processing also, but also cites two studies that show no correlation between chocolate consumption and acne.

The Teacher's Guide for Chocolate—How Sweet It Is! in *ChemMatters*, Dec. 1999, contains more information for teachers about chocolate.

McRae, Anne, Project Director. The Golden Book of Chocolate. New York: Barrons' Educational Series, Inc. 2208. (First English language edition.) ISBN-13: 0-7641-6157-5. This is a 700 page volume of everything chocolate. The introduction includes the history of chocolate as its use spread to the new world, a discussion of production methods from the cacao tree to the variety of available products, an economic look at world production of chocolate, and environmental issues surrounding the production of organic, high grade, gourmet chocolate, and 650 pages of more than 300 recipes for chocolate delicacies.

Dreiss, Meredith L. and Greenhill, Sharon Edgar. Chocolate: Pathway to the Gods. Tucson, AR: University of Arizona Press. 2008. 208 pp + 60 minute DVD. $30. ISBN 9780816524648. The authors discuss the religious, social, cultural and medicinal roles that chocolate has played in the lives of Mesoamericans for some 3500 years. The profusely illustrated book grew out of the authors' 2005 documentary film (provided on the DVD). The DVD includes photographs of ceramics, carvings, murals, monuments, and codices that were too numerous and not able to be incorporated into the documentary.

Coe, Sophie D. and Coe, Michael D. The True History of Chocolate. London: Thomas and Hudson, Ltd. 2007. ISBN: 978-0-500-28696-8. "A beautifully written, indexed, and illustrated history of the Food of the Gods, from the Olmecs to present-day developments. It begins with the origins of the cacao tree and follows the story up to today's mass produced candy and its expensive boutique counterparts."

Belitz, H. D., Grosch, W., Schieberle, P. Food Chemistry. New York: Springer-Verlag, 2004. (21.3.3 Chocolate, pp. 966-968).

Web Sites for Additional Information

More sites on chocolate, in general

http://www.exploratorium.edu/exploring/exploring_chocolate/index.html is the ultimate chocolate site, with following sections: a visit to the Amazon, a source for chocolate; The Olmecs, the Mayans, and the Aztecs; Chocolate conquers the continent; Take a video tour of the Scharffen Berger chocolate factory; Can chocolate help prevent heart disease?; and More than a food, but less than a drug.

http://en.wikipedia.org/wiki/Chocolate, the Wikipedia site is complete well-documented in its present state. All aspects of chocolate are discussed: etymology, history, types of chocolate, production, health, labeling, manufacture, chocolate in popular culture, and an extensive list of resources and references.

Erowid, like Wikipedia, is a non-commercial organization that has operated for more than 12 years in the controversial and politically challenging niche of trying to provide accurate, specific, and responsible information about how psychoactives are used in the United States and around the world. Chocolate, because of the presence of theobromine and caffeine is labeled as a stimulant. The reference provides a wealth of information. The timeline is especially valuable. (http://www.erowid..org/chemicals/chocolate/chocolate.shtml)

More sites on how chocolate is made

In this clip from Modern Marvels at http://www.history.com/video.do?name=valentinesday&bcpid=65555685001&bclid=1672160848&bctid=1586359513, we learn how chocolate is made at the Hershey factory in Hershey, Pennsylvania. The cocoa beans are dried and mixed with milks and butters until you get a sweet chocolate paste that is used to make chocolate.

More sites on the chemicals found in chocolate

http://www.rain-tree.com/chocolate.htm is the Plant Database file that includes all of the names of the chemicals found in chocolate. The site includes web resources to numerous databases that have added information on each of the chemicals. Included is a collection of cacao—chocolate photographs.

You can find 3-dimensional models of the structures of caffeine and theobromine at http://www.3dchem.com/molecules.asp?ID=138 and http://www.3dchem.com/molecules.asp?ID=155#, respectively. You need to have the Java Applet downloaded to your computer. These models can be rotated, and you can switch from space-filling to ball-and-stick to wire-frame structures. If you have 3-D stereo glasses, you can even view the molecules in 3-D. The site also provides basic information about each chemical. Many other chemicals are available on this site as well.

More sites on the history of chocolate and its physiological effects

The article “Discovering the Sweet Mysteries of Chocolate” written by Ellen Kuwana, a staff writer for Neuroscience for Kids, parallels much of the information in the *ChemMatters* article. It is handsomely produced with numerous technical references. It can be found at http://faculty.washington.edu/chudler/choco.html.

More sites on teacher information and lesson plans

A variety of lesson plans for possible class use (mostly elementary and middle school) are available at http://www.theteacherscorner.net/lesson-plans/math/miscellaneous/hershey.htm, http://www.mrsmcgowan.com/chocolate/currmaterials.htm, and http://www.mce.k12tn.net/chocolate/index.htm.

Air Pollution: What Weather Satellites Tell Us

Background Information

More on weather satellites

The article says that until recently air quality was thought of as a local issue and was often monitored using local ground-based or plane-based measurement. Using remote sensing satellite data adds two important dimensions to air quality monitoring and modeling—better coverage in terms of land area and in the atmosphere and better integration of atmospheric data.

Each of the substances in the Earth's atmosphere—ozone, water vapor, CO_2, etc.—absorbs and transmits electromagnetic radiation in a very special and unique way. Your students may know that each chemical element has a unique spectral "signature" that can be used to identify that element. For example, below is the helium emission spectrum. The bright lines are helium's signature.

Weather satellites like the ones described in the article are able to collect the energy emitted, scattered, absorbed and reflected by substances in the atmosphere. This energy "fingerprints" various atmospheric substances in a way similar to the helium spectrum above. The energy is typically in either the visible range of the spectrum or the infrared range. Through a process called "retrieval", information of interest to scientists is extracted from the data sent back to Earth by the satellites. That information is then interpreted by scientists using computer modeling techniques.

More on the Earth Observing System (EOS)

In 1991, NASA launched a comprehensive program to study the Earth as an environmental system, now called the Earth Science Enterprise. By using satellites and other tools to study the Earth, scientists hope that the information will yield improved weather forecasts, tools for managing agriculture and forests, information for fishermen and local planners and, eventually, the ability to predict how the climate will change in the future.

The Earth Science Enterprise has three main components: a series of Earth-observing satellites carrying instruments like those described in the article, an advanced data system, and teams of scientists who will study the data. Key areas of study include: clouds; water and energy cycles; oceans; chemistry of the atmosphere; land surface; water and ecosystem processes; glaciers and polar ice sheets; and the solid Earth.

Phase I of the Earth Science Enterprise comprised focused, free-flying satellites, Space Shuttle missions, and various airborne and ground-based studies. Phase II began in December of 1999, with the launch of the first Earth Observing System (EOS) satellite Terra (formerly AM-1). EOS is the first observing system to offer integrated measurements of the Earth's processes. It consists of a science component and a data system supporting a coordinated series of polar-

orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans.

More on Infusing satellite Data into Environmental air quality Applications (IDEA)

IDEA (Infusing satellite Data into Environmental air quality Applications) is a joint venture of NASA, NOAA and EPA. The intent of the program is to improve air quality assessment, management, and prediction by infusing NASA satellite measurements into EPA and NOAA analyses for public benefit. The program began in 2003, with a demonstration project using particulate matter data obtained from satellites, which was successful. We know the results as the Air Quality Index. The early program was housed at the University of Wisconsin (Madison). The program is now part of NASA National Environmental Satellite Data and Information Service. According to NASA, "NESDIS provides timely access to global environmental data from satellites and other sources to promote, protect, & enhance the Nation's economy, security, environment, & quality of life." The satellites involved include Aqua, Terra, and MODIS. The IDEA project demonstrates one way to use the nation's satellite observation ability, operational forecasting skill, and air quality analysis for public benefit.

More on MODerate resolution Imaging Spectroradiometer (MODIS)

MODIS is part of the Earth Observation System, as the article describes. It is a 225 kg measuring instrument that is carried by two satellites—Terra (EOS AM) and Aqua (EOS PM). The two satellites pass over the earth north to south and south to north once each day, acquiring spectral data in 36 bands, ranging from 0.40 μm to 14.385 μm. The two satellites provide an electromagnetic image of the earth every two days. It has a scanning span of 2330 km. The data is used to study changes in the atmosphere, on land and in the oceans and to assist in predicting global climate change.

Among the data sets that MODIS produces are:

- Aerosol concentration and optical properties
- Cloud optical thickness
- Temperatures in the atmosphere
- Vegetation and land surface cover
- Surface temperature

MODIS provides information on land issues like deforestation, surface reflection, surface water and urban areas. Deforestation data, for example, can give clues to the migration of carbon (dioxide) through the environment, thereby giving additional clues to climate change.

More on Multi-angle Imaging SpectroRadiometer (MISR)

NASA describes MISR this way: "MISR instrument measures Earth's brightness in 4 spectral bands, at each of 9 cameras spread out in the forward and aft directions along the flight path. Spatial samples are acquired every 275 meters. Over a period of 7 minutes, a 360 km wide swath of Earth comes into view at all 9 angles. Special attention has been paid to providing highly accurate absolute and relative calibration, using on-board hardware consisting of deployable solar diffuser plates and several types of photodiodes. To complement the on-board calibration effort, a validation program of *in situ* measurements are being conducted, involving field instruments, one of which is the "PARABOLA III", which automatically scans the sky and ground at many angles, and a multi-angle aircraft camera (AirMISR). Global coverage with

MISR is acquired about once every 9 days at the equator; the nominal lifetime of the mission is 6 years.

"MISR was built for NASA by the Jet Propulsion Laboratory in Pasadena, California, and is one of five instruments launched into polar orbit aboard NASA's Terra spacecraft in August 1999. The spacecraft flies in a "sun-synchronous" orbit, designed so that it crosses the equator every 98 minutes, always at 10:30 a.m. local time, as Earth rotates below."

The unique aspect of MISR is that it measures in nine different directions at the same time, and it measures at four different wave lengths of light—blue, green, red and infrared. This allows MISR to produce data about carbon and carbon dioxide, aerosols, clouds and land surface which yields a three dimensional model of the atmosphere. Specifically, MISR monitors the monthly, seasonal, and long-term trends in:

- The amount and type of atmospheric particles (aerosols), including those formed by natural sources and by human activities
- The amounts, types, and heights of clouds
- The distribution of land surface cover, including vegetation canopy structure

The three other instruments mentioned but not described in the article are the Microwave Limb Sounder (MLS), the Ozone Monitoring Instrument (OMI), and the Tropospheric Emission Spectrometer (TES). Brief descriptions follow:

More on Microwave Limb Sounder (MLS)

MLS makes measurements across the atmosphere in the microwave radiation ranges, GHz and THz frequencies. MLS provides information about the rate at which ozone molecules are being destroyed. MLS also measures CO and O_3 in the stratosphere. CO is an indicator of air exchange between the lower troposphere, where it is produced, and the stratosphere. The presence of CO in the stratosphere indicates a large degree of exchange of gases between those two layers of air. This in turn may mean a large transfer of pollutants. MLS also measures water vapor and ice, as well as temperature in the upper troposphere, and also measures ozone and N_2O—greenhouse gases in the upper troposphere. These will help scientists better understand how climate is changing over time. The (EOS) Microwave Limb Sounder (MLS) is one of four instruments on the NASA's EOS Aura satellite, launched on July 15, 2004. (This section was adapted from the Teachers Guide for the April 2008 *ChemMatters* article, "Chemicals in the Air: Latest Results from NASA's Aura Satellite")

According to NASA, MLS is important in our understanding of atmospheric chemistry. "MLS measures lower stratospheric temperature and concentrations of H_2O, O_3, ClO, BrO, HCl, OH, HNO_3, HCN, and N_2O, for their effects on (and diagnoses of) ozone depletion, transformations of greenhouse gases, and radiative forcing of climate change. These measurements will be especially valuable for diagnosing the potential for severe loss of Arctic ozone during the critical period following the turn of the century when an abundance of stratospheric chlorine will still be high, and slight cooling of the stratosphere could exacerbate ozone loss due to chlorine chemistry. The measurements will help determine whether the stratosphere is responding as expected to the effects of the Montreal Protocol agreements for phasing out ozone-depleting substances. MLS also measures upper tropospheric H_2O, O_3, CO, and HCN for their effects on radiative forcing of climate change and for diagnoses of exchange between the troposphere and stratosphere.

"MLS observes the details of ozone chemistry by measuring many radicals, reservoirs, and source gases in chemical cycles which destroy ozone. This set of measurements will provide stringent tests on the understanding of global stratospheric chemistry, will help explain observed trends in ozone, and can provide early warnings of any changes in the chemistry of this region."

More on Ozone Monitoring Instrument (OMI)

OMI, the Ozone Monitoring Instrument, views reflected light from Earth's surface. It detects radiation in the UV and visible range of spectra. It continues a 30-plus year tradition of ozone observations performed by earlier satellites, but with much greater resolution, and it observes over a broader range of wavelengths of light. OMI also measures concentrations of free radicals that contribute to the destruction of ozone molecules. OMI maps columns of sulfur dioxide and aerosols, two of the six criteria pollutants established by the Environmental Protection Agency. (The other four are tropospheric ozone, nitrogen dioxide, carbon monoxide and lead.) OMI's ozone measurements, combined with cloud cover measurements, contribute to the National Weather Bureau's UV index. OMI also maps aerosols and dust, which will help scientists build better mathematical models of climate change. (This section taken from the Teachers Guide for the April 2008 *ChemMatters* article, "Chemicals in the Air: Latest Results from NASA's Aura Satellite")

OMI is one of the detecting devices on EOS Aura for monitoring the recovery of the ozone layer in response to the phase-out of chemicals, such as CFCs, agreed to by the nations of the world in the Montreal protocol and later modifications to it at Copenhagen, and London. OMI continues the TOMS record for total ozone and other atmospheric parameters related to ozone chemistry and climate.

In 2008, sections of bad data began to show up in OMI information. Scientists think that this is caused by a physical obstruction in the instrument field-of-view, perhaps some of the Mylar sheathing used to protect OMI. In 2009, the obstruction increased and now partially blocks a larger part of the field-of-view.

More on Tropospheric Emission Spectrometer (TES)

TES observes thermal radiation from the Earth's surface and atmosphere, 24/7. It also measures ozone and other gases that contribute to pollution in the troposphere. Clouds make atmospheric chemical observations difficult. TES observes both in the vertical and horizontal direction. This dual ability allows it to measure the entire lower atmosphere, from the surface to the stratosphere. TES measures how gases are distributed throughout the troposphere, and it measures critical gases involved in ozone processes; e.g., HNO_3 and CO. These are used to improve models of lower atmosphere ozone pollution. This instrument also measures water vapor, ozone, methane and aerosols in the troposphere. These are all key substances in climate change. (This section adapted from the Teachers Guide for the April 2008 *ChemMatters* article, "Chemicals in the Air: Latest Results from NASA's Aura Satellite")

Its high resolution enables TES to measure concentrations of ozone, carbon monoxide, water vapor and methane at various altitudes in the atmosphere, which reveals important information about global warming and climate change, the water cycle, and air pollution.

More on air pollutants

Following are brief descriptions of atmospheric chemical constituents which are measured by one of more of the satellites mentioned in the article. The satellite instruments are capable of measuring substances that we would consider air pollutants and substances we consider greenhouse gases. This may be a fine distinction to make for students, but too often students confuse air pollution issues with climate change issues. Smog and ground level ozone are examples of substances that are dangerous to people—substances generally thought of as affecting local air quality.

However, there are another types of gases related to global warming and climate change—carbon dioxide, methane, nitrous oxide, for example. The article does not make a distinction between types of gases, but you may wish to do so, since the article discusses both issues. Some of the substances described below can be in both categories.

Following is a table that lists substances measured by one or more of the satellite instruments mentioned in the article, and following the table are brief descriptions in a little greater detail on many of the more important substances.

Chemical species and related products from sensors on the NASA satellites

Chemical species	NASA satellite
Aerosol properties such as aerosol optical depth	MISR, MODIS, OMI
Bromine monoxide (BrO)	OMI
Carbon monoxide (CO)	MLS, TES
Formaldehyde (HCHO)	OMI
Glyoxal (OCHCHO)	OMI
Nitric acid (HNO_3)	MLS
Nitrogen dioxide (NO_2)	OMI
Nitrous oxide (N_2O)	MLS, TES
Ozone (O_3)	MLS, MODIS, OMI, TES
Sulfur dioxide (SO_2)	MLS, OMI

Table adapted from http://pubs.acs.org/doi/pdf/10.1021/es7031339?sessid=6006l3

More on sulfur dioxide (SO_2)

Roughly 10% of the gas emitted from an erupting volcano is sulfur dioxide. This gas can either stay in the troposphere, if the eruption is of limited scope, or it can be thrust all the way up into the stratosphere from a cataclysmic eruption. If the gas stays in the troposphere, it can react with water to form acid rain, and it can be irritating to people downwind of the volcano. If the gas rises into the stratosphere, it can result in lower Earth surface temperatures and enhanced depletion of the ozone layer.

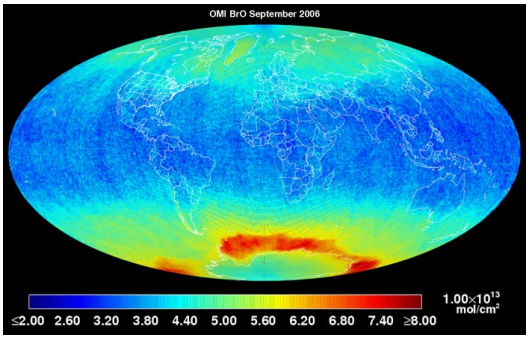
The SO_2 combines with water to make sulfurous and sulfuric acids and these gas molecules will condense in the cold of the air at these levels. These tiny condensed particles, called aerosols, add to the particulate content of the stratosphere and increase the albedo, the reflective quality, of the atmosphere. This increase in reflectance results in less sunlight reaching Earth's surface and therefore lower ground and troposphere temperatures. After the explosive eruption of Mount Pinatubo in 1991, for example, surface temperatures in the

Northern Hemisphere decreased by about 0.5°C due to the addition of millions of tons of SO_2 into the atmosphere.

Since SO_2 can play such a large role in both our climate and the ozone layer of the stratosphere, it is vitally important to monitor SO_2 concentrations globally in our atmosphere. (This section adapted from the Teachers Guide for the April 2008 *ChemMatters* article, "Chemicals in the Air: Latest Results from NASA's Aura Satellite")

More on bromine monoxide (BrO)

Bromine monoxide is a key compound in the cycle of events called ozone depletion events (ODE). According to NASA, "Bromine monoxide (BrO) is important in the catalytic destruction of stratospheric ozone, especially in the lower stratosphere. Model studies indicate that catalytic cycles involving BrO may account for as much as 60% of ozone loss for very cold Arctic winters. Students will likely know the role of CFC's (chlorofluorocarbons) in the destruction of ozone, and they should be able to recognize bromine as a member of the halogen family along with chlorine and fluorine. Students should not be surprised to learn that a bromine compound plays an important role as a catalyst in the destruction of ozone.



At right is an OMI image of polar BrO concentrations from NASA.

More on aerosols

The article places a great deal of emphasis on aerosols as one of the pollutants studied by satellite data. Students may have heard the term "particulates" as part of air quality reports during weather forecasts. Aerosols are small particles of either solid or liquid which are suspended in the atmosphere. They range in size from about 1 nm to 100 μm.

Some aerosols occur naturally as a result of volcanic activity, dust storms, forest fires or sea spray. Volcanic activity often produces sulfur dioxide gas, which is converted to tiny droplets of sulfuric acid in the troposphere. The droplets are carried by winds around the Earth. They reflect incoming light and cool the Earth. This effect was observed when Mt. Pinatubo erupted in 1991. See "Sulfur Dioxide" (above) for details.

Dust storms in desert regions also produce aerosols naturally. Satellites have detected streams of dust particles from the deserts of Africa over the Atlantic Ocean and from Asian deserts over the Pacific. These aerosol particles are mineral in nature (primarily silicon, aluminum, iron and calcium compounds) and so absorb energy from the sun as well as reflect it. The absorption warms the atmosphere and reduces cloud formation, thus decreasing rainfall. As a result, desert regions are expanded, further affecting the Earth's climate.

Human activity also produces aerosols, most from burning fossil fuels or biomass. Car exhaust, for example, produces fine particulate aerosols. The figure below shows some sources of aerosols. Naturally occurring aerosols are most concentrated in the troposphere, but these particles are usually washed out by rainfall within days. Aerosols can also form in the

stratosphere, as a result of volcanic activity. Rainfall originates below the stratosphere, which means these aerosol particles remain for months or years.

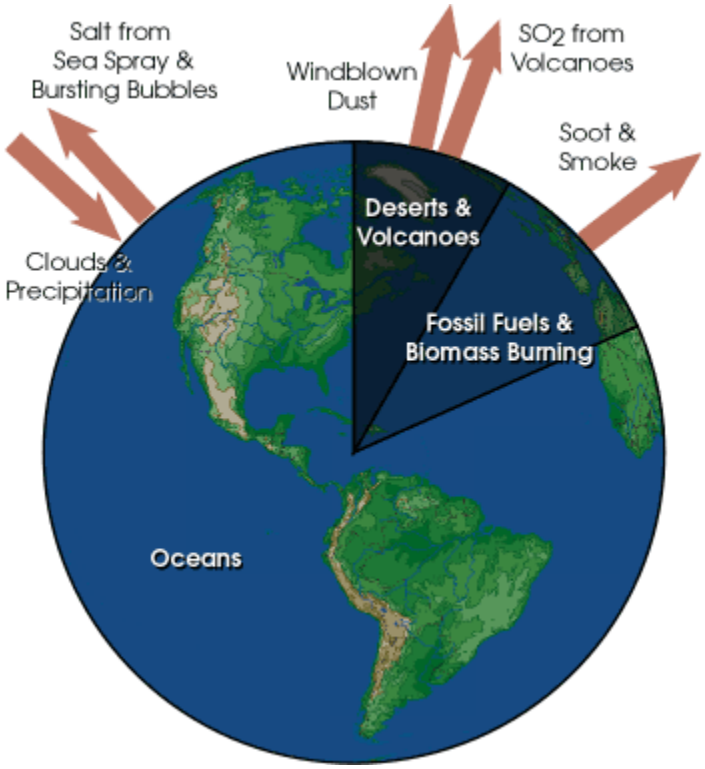
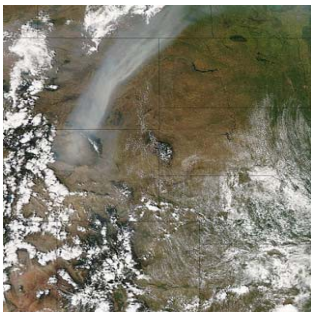


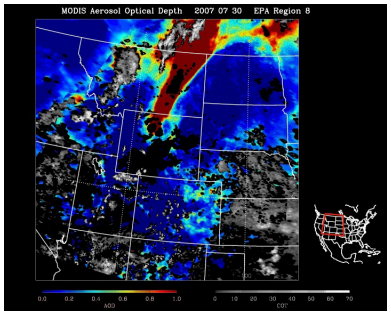
Image from http://earthobservatory.nasa.gov/Features/Aerosols/

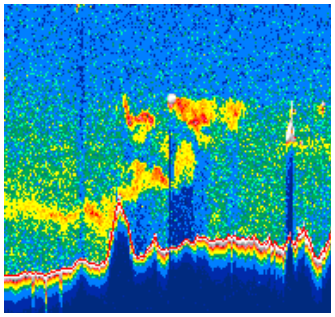
Aerosols are important factors in climate and pollution. Because they reflect sunlight back into space, they cool the Earth's surface below them. This, of course, counters the greenhouse effect to some degree. Aerosols are also important factors in cloud formation. Clouds begin to form around small particles that act as nucleation sites for water droplets to form. If aerosol concentration increases, the water droplets are spread out over all the particles and are less concentrated. The particles themselves are relatively smaller in this case and they fall to Earth more slowly, thus decreasing rainfall.

Another reason that aerosols are important factors in climate is that they are potential sites for chemical reactions that take place in the atmosphere. Many students will know, for example, that monatomic chlorine atoms are nucleation sites for reactions that destroy ozone in the stratosphere. In the same way research has shown that aerosols from volcanic activity play a role in ozone destruction in the atmosphere.

One example of how aerosol data from several satellite sources can be integrated to provide a clear idea of events in the atmosphere is shown in the images below. They are of wild fires in Montana in 2007. The images were derived from satellites on July 30 and 31, 2007. The image at left is a MODIS Aqua photo of the grey smoke plume from the fires. The middle image is the aerosol optical depth data from MODIS showing the particles produced by the fires in dark red. And the right image shows the fine particulate scattering (yellows and red, at 532 nm) over Montana at the time.







All images from http://alg.umbc.edu/3DAQS/doc/3DAQS_ProjectSummary.pdf

More on carbon monoxide (CO)

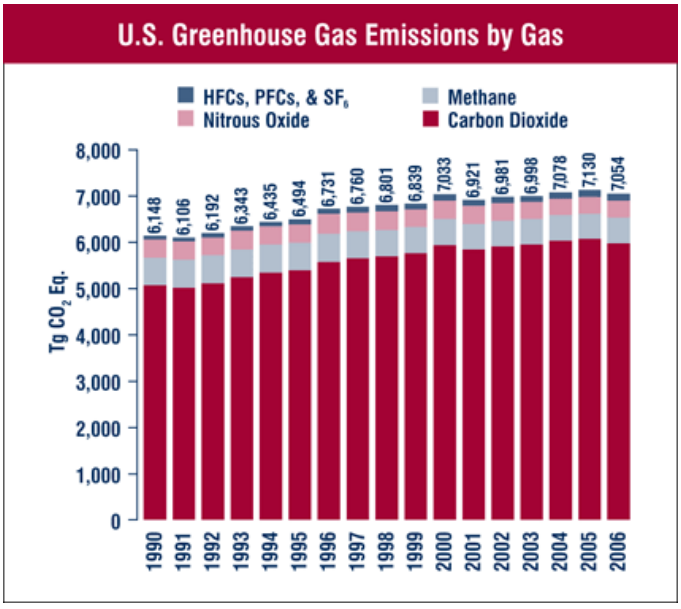
As many of your students will know, CO is a colorless, odorless gas that is dangerous to humans. It is present naturally in the Earth's atmosphere in amounts roughly equal to 100 parts per billion (ppb), and exists in greater concentrations in the northern hemisphere than in the southern hemisphere.

A molecule of CO can last for several months since it is relatively unreactive, but eventually it reacts with oxygen to form CO_2. Sources of CO in the atmosphere include volcanoes and auto emissions that result from incomplete combustion. CO can build up in local regions of the atmosphere, since it takes longer for the gas to diffuse in the troposphere than it does for Co to react with oxygen to produce CO_2.

Satellites can detect unusual concentrations of CO in the troposphere. Because it is a precursor to CO_2, it is usually referred to as a secondary greenhouse gas. Measuring CO concentrations gives chemists an indication of carbon dioxide buildup in the atmosphere. CO also reacts with other chemicals that would, in turn, destroy ozone and methane so it is an important indicator chemical.

More on carbon dioxide (CO_2)

Carbon dioxide is likely the best known of the greenhouse gases because it is a product of combustion and because so much attention has been paid to its role in climate change. Prior to the Industrial Revolution the CO_2 concentration in the atmosphere was about 280 parts per million. Today CO_2 concentration is about 370 ppm. It is important to note—however obvious—that carbon dioxide occurs naturally in the atmosphere.



(From http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html)

Carbon dioxide is part of the carbon cycle. The reason that measuring greenhouse gases has become so important is that industrial processes tend to increase the rate at which CO_2 is produced into the atmosphere, even while many photosynthetic processes are removing it at traditional rates. Carbon dioxide concentrations are, therefore, an indicator of the state of complex geochemical and biochemical processes.

More on nitrogen dioxide (NO_2)

Nitrogen oxides**,** or NO_x, is the general term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying proportions. There are several nitrogen oxides that are mentioned in the article or measured by one of the satellite monitors. They are nitrogen dioxide, NO_2, nitrous oxide, N_2O and dinitrogen pentoxide, N_2O_5. NO_x compounds are not only air pollutants but are also ozone precursors. Therefore, measuring the concentrations of NO_x gases is important in both air quality and climate change.

Nitrogen dioxide enters the atmosphere from burning of gasoline in automobiles, and from burning of fossil fuels in industries. Autos are blamed for as much as 70% of the NO_2 produced by man. In addition, ships at sea produce large volumes of NO_2.

Nitrogen dioxide is a reddish-brown gas and it reacts with water to produce nitrous and nitric acids, prime components of acid rain. The gas can do the same thing when inhaled—produce acid in the lungs and throat. This results in respiratory problems in humans and animals. NO_2 can also react with organic compounds in the air to produce ozone, and thus contribute to photochemical smog. This is especially true over large cities. NO_2 is measured by both OMI and MLS satellite instruments.

More on nitrous oxide (N_2O)

Nitrous oxide is produced primarily at the Earth's surface, the largest percentage from biological decay processes, but also from human activities, especially industrial and agricultural practices. Large volumes of N_2O are produced from the oxidation in the atmosphere of ammonia, which is emitted from livestock waste. The gas is also produced from fossil fuel-fired power plants, nylon production, nitric acid production and vehicle emissions. Since the 1950's an increase in N_2O of about 0.3%/year has been seen in this important greenhouse gas.

N_2O is important to measure because it has a long lifetime in the atmosphere and so can be a tracer of air movements and atmospheric chemical processes.

More on nitric acid (HNO_3)

According to NASA, **"**nitric acid (HNO_3) plays several pivotal roles in the processes controlling stratospheric ozone depletion. It is a key component of the polar stratospheric clouds (PSCs) that form in the very low temperatures of polar winter, removing HNO_3 from the gas phase. PSC particles provide surfaces on which heterogeneous chemical reactions occur, converting chlorine from its reservoir species (e.g., $ClONO^+$, HCl) to the highly reactive forms that participate in the catalytic cycles of ozone destruction (e.g., ClO). On the other hand, photolysis of HNO^+ vapor releases NO^+, enabling a major pathway for the deactivation of chlorine, via the reformation of $ClONO^+$ from ClO and NO^+. If PSC particles grow large enough,

then they can settle out of the lower stratosphere, carrying the HNO^+ with them in a process known as denitrification. Severe denitrification curtails $ClONO^+$ formation, allowing enhanced ClO and thus chemical ozone destruction to persist. Therefore, as a central participant in both the activation and the deactivation of chlorine, HNO_3 indirectly regulates the extent, duration, and cumulative magnitude of stratospheric ozone depletion."

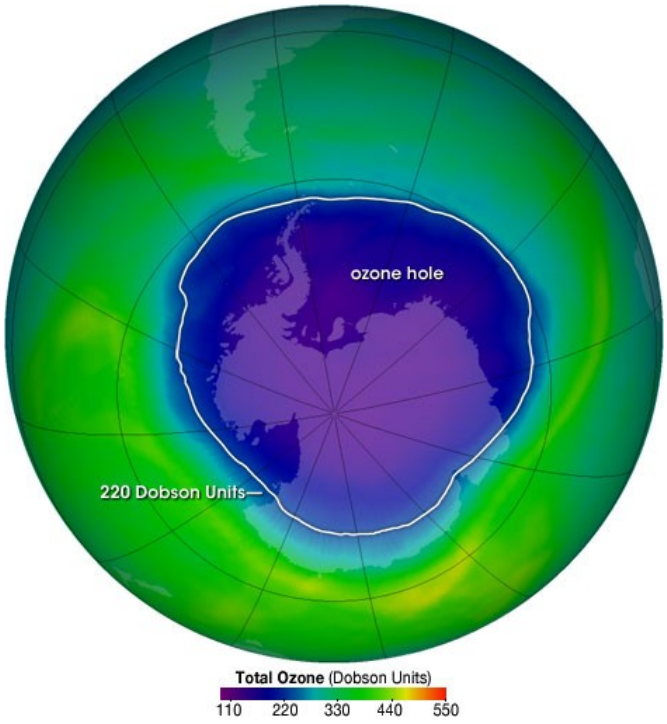
More on ozone (O_3)

Most of your students will have heard of ozone. However, they may be confused about the dual role of the gas, depending on its location. You can note that ozone is an allotropic form of oxygen with a formula of O_3. High in the stratosphere, ozone shields us from the sun's harmful UV rays. This is the "ozone hole" ozone.

UV radiation in the upper atmosphere produces ozone (O_3). The radiation breaks typical oxygen molecules (O_2) into free oxygen atoms (O). A free oxygen atom (O) can then join with an oxygen molecule (O_2) to form a molecule of ozone (O_3). Ozone absorbs UV, shielding the Earth from harmful rays. For more on ozone chemistry see the EPA's web site at http://www.epa.gov/ogwdw000/mdbp/pdf/alter/chapt_3.pdf. To see a video about stratospheric ozone see http://learners.gsfc.nasa.gov/mediaviewer/ozStr/.

The TES satellite system and the OMI system tracks the abundance, creation, destruction, and movement of this ozone at various altitudes in the stratosphere.

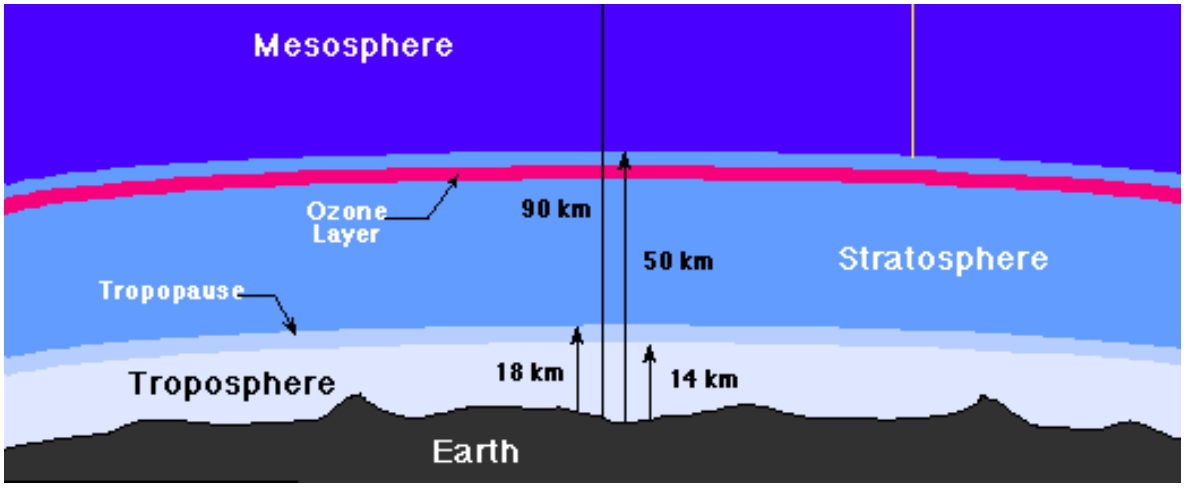
The ozone hole image (from NASA) at right shows the very low values (blue and purple colored area) centered over Antarctica on October 4, 2004. Total ozone values of less than 220 Dobson Units were not observed prior to 1979. A total ozone level of less than 220 Dobson Units is a result of catalyzed ozone loss from chlorine and bromine compounds. For these reasons, we use 220 Dobson Units as the boundary of the region representing ozone loss. A Dobson unit is a measure of the amount of ozone in the atmosphere.



At the top of the troposphere, ozone acts as a greenhouse gas and contributes to global warming. And in the lower troposphere near the surface of the Earth it contributes to smog and is toxic to plants and animals. Here ozone is produced in a chemical reaction between oxides of nitrogen (NO_x) and volatile organic compounds, mostly from auto emissions, in the presence of sunlight. To see a video about ground level ozone, see http://learners.gsfc.nasa.gov/mediaviewer/ozTro/.

More on the Earth's atmosphere

Earth's atmosphere is divided into several layers. The troposphere is the lowest layer, ranging from 6 to 15 km above the surface of Earth. Airplanes fly primarily in the troposphere. Roughly 80% of all the mass of the atmosphere is found in the troposphere, only 0.2% of the height of the entire atmosphere. The next layer is the stratosphere, from 18 to 50 km up. Large weather balloons will also travel up into the stratosphere. The mesosphere is next, from 50-90 km up, followed by the thermosphere, from 90-700 km above Earth. The outermost layer of Earth's atmosphere is the exosphere, ranging from 700 km out to about 10000 km. The diagram below, from NASA, shows the lower layers (but not the thermosphere or the exosphere), about 1% of the entire atmosphere's height—and far less than 1% of its volume. (This section taken from the Teachers Guide for the April, 2008 *ChemMatters* article, "Chemicals in the Air: Latest Results from NASA's Aura Satellite")



Reprinted from NASA

More on the Kyoto Protocol

The Kyoto Protocol is an international agreement that sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions .These amount to an average of five per cent against 1990 levels over the five-year period 2008-2012.

The Protocol recognizes that developed countries are mostly responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity; it requires developed nations to reduce GHG to a greater extent than other countries under the principle of "common but differentiated responsibilities."

Under Kyoto, industrialized countries agreed to reduce their GHG emissions by 5.2% compared to the year 1990. Reduction limits range from 8% reductions for the European Union to 7% for the United States, 6% for Japan, and 0% for Russia. The treaty permitted GHG emission increases of 8% for Australia and 10% for Iceland.

It should be noted that although the United States signed the agreement in 1998, the agreement was never ratified by the U.S.

More on the Intergovernmental Panel on Climate Change

This description comes from the IPCC web site (http://www.ipcc.ch/):

The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information about climate change. The IPCC does not conduct any research nor does it monitor climate related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio economic factors. They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage.

The IPCC is a scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). Its constituency is made of:

- The governments: the IPCC is open to all member countries of WMO and UNEP. Governments of participate in plenary Sessions of the IPCC where main decisions about the IPCC work programme are taken and reports are accepted, adopted and approved. They also participate in the review of IPCC Reports.
- The scientists: hundreds of scientists all over the world contribute to the work of the IPCC as authors, contributors and reviewers.
- The people: as United Nations body, the IPCC work aims at the promotion of the United Nations human development goals

Climate change is a very complex issue: policymakers need an objective source of information about the causes of climate change, its potential environmental and socio-economic consequences and the adaptation and mitigation options to respond to it. This is why WMO and UNEP established the Intergovernmental Panel on Climate Change (IPCC) in 1988.

The IPCC is a scientific body: the information it provides with its reports is based on scientific evidence and reflects existing viewpoints within the scientific community. The comprehensiveness of the scientific content is achieved through contributions from experts in all regions of the world and all relevant disciplines including, where appropriately documented, industry literature and traditional practices, and a two stage review process by experts and governments.

Because of its intergovernmental nature, the IPCC is able to provide scientific technical and socio-economic information in a policy-relevant but policy neutral way to decision makers. When governments accept the IPCC reports and approve their Summary for Policymakers, they acknowledge the legitimacy of their scientific content.

The IPCC provides its reports at regular intervals and they immediately become standard works of reference, widely used by policymakers, experts and students. The findings of the first IPCC Assessment Report of 1990 played a decisive role in leading to the United Nations Framework Convention on Climate Change (UNFCCC), which was opened for signature in the Rio de Janeiro Summit in 1992 and entered into force in 1994. It provides the overall policy framework for addressing the climate change issue. The IPCC Second

Assessment Report of 1995 provided key input for the negotiations of the Kyoto Protocol in 1997 and the Third Assessment Report of 2001 as well as Special and Methodology Reports provided further information relevant for the development of the UNFCCC and the Kyoto Protocol. The IPCC continues to be a major source of information for the negotiations under the UNFCCC.

Connections to Chemistry Concepts

1. **Remote sensing**—Satellites rely on observations made "at a distance." The idea of remote sensing or indirect measurement is an important one for students to understand.
2. **Periodicity and properties of elements**—Bromine compounds have effects on ozone depletion similar to those of their chlorine counterparts.
3. **Allotropes**—Ozone (O_3) is an allotropic form of oxygen gas (O_2).
4. **Light scattering and reflection**—Satellites collect electromagnetic radiation that has been reflected or scattered by chemicals in the atmosphere.
5. **Chemistry and the environment**—A major topic for chemistry classes is the relationship between the chemistry that they are studying and the environment. The environment is important to many students so this article is a way to show how knowledge of chemistry can be used.
6. **Spectroscopy**—Many of the instruments described in the article are spectroscopic instruments.
7. **Careers**—Students are interested both in space and in the environment around them. This article is an easy way to connect chemistry to these interests.

Possible Student Misconceptions

1. **"Ozone is ozone. There's no difference between 'good ozone' and 'bad ozone'."** The substance called ozone is the same everywhere. All ozone consists of three atoms of oxygen bonded together. The role that ozone plays in our lives depends on where in the atmosphere it is located. *The ozone layer, the "good ozone", is located in the stratosphere and is responsible for absorbing much of the harmful ultraviolet light from the sun that would otherwise impact Earth (and us). The depletion of this layer of ozone has gotten the majority of the attention by the news media. The ozone close to the surface of the earth (in the troposphere) causes respiratory distress in people when they breathe the gas, and it contributes to smog pollution.*
2. **"Climate change and air pollution are the same thing."** *Many of the same chemicals are involved in both air pollution and climate change. Usually when we refer to air pollution we are thinking about chemicals in the atmosphere that cause harm to humans in some way. The chemicals involved in climate change may also be harmful to humans in an immediate sense, but the concern about them is that over longer time spans they are changing the basic structure of Earth's climate.*
3. **"Satellites can't see through clouds."** *Clouds which are opaque to visible light may not be opaque in other regions of the electromagnetic spectrum. Radio waves (radar) and microwave radiation can penetrate water vapor clouds.*

Demonstrations and Lessons

1. Lawrence Hall of Science has a climate change curriculum. Details on ordering can be found here: http://www.lawrencehallofscience.org/gss/.
2. The World Wildlife Federation has a series of students activities available here: http://www.worldwildlife.org/what/globalmarkets/Climate%20Change/Climate%20Cirriculum/item5944.html
3. An activity on an important greenhouse gas, CO2, can be found in *ChemMatters*, September, 2001 edition on pages 10-11.
4. This NASA web site has a lot of Earth Observing Systems resources, including lesson plans and activities: http://earthobservatory.nasa.gov/.
5. UCAR has a lesson, found at http://www.ucar.edu/learn/1_2_2_9t.htm, which uses playing cards to illustrate variability in the Earth's climate.
6. Some students may not know what a greenhouse is and therefore may not understand the term "greenhouse effect." This activity lets students discover for themselves the greenhouse effect: http://www.ucar.edu/learn/1_3_2_12t.htm.
7. And in this activity student can identify the factors that affect a greenhouse: http://www.ucar.edu/learn/1_3_2_13t.htm.
8. This UCAR web page, http://www.ucar.edu/learn/1_4_1.htm, contains seven excellent activities on climate change, including activities on concentrations, the carbon cycle, carbon dioxide, transpiration, wind and the effect of human activity. All of the UCAR activities include well-written background information.
9. Included in this UCAR page are seven more activities on climate cycles, climate change, the greenhouse effect and ozone: http://www.ucar.edu/learn/1.htm.
10. This site is a guide to teacher demonstrations related to climate change: http://www.scienceinschool.org/2008/issue10/climate.

Student Projects

1. Students can view "An Inconvenient Truth" and follow the study guide, which is available here: http://www.climatecrisis.net/. You may already have a copy of the DVD, but if not, there is a link on this page where you can purchase it.
2. This NASA web site has a lot of Earth Observing Systems resources, including lesson plans and activities. http://earthobservatory.nasa.gov/.
3. Students collect and interpret weather data in this activity from UCAR: http://www.ucar.edu/learn/1_2_2_8t.htm.
4. You can become a ground station to receive data from satellites like those discussed in the article by clicking on this site: http://www.met.fsu.edu/orgs/explores/.
5. Students collect weather satellite data and interpret it in this activity: http://www.rmcdenver.com/useguide/bank/16.htm.

Anticipating Student Questions

1. **"Can the satellites in the article interpret the data they collect?"** *No, the satellite provides the raw data, but scientists must then "retrieve and interpret" the data; i.e., remove*

irrelevant information, like aerosol density. Sophisticated computer systems then interpret the data and construct mathematical models of the atmosphere.

2. **"How can satellites tell the concentration of substances in the atmosphere?"** *As the article states, the more concentrated a substance is in the atmosphere, the more it will scatter light, for example. Satellites can measure the light scattered by a substance at a given altitude and temperature and deduce from the scattering the relative concentrations.*

3. **"Why are we spending so much money on satellites to study the atmosphere when there are so many other things we could use the money for?"** *This is not an easy question to answer. It is obvious that federal, state and local governments have many challenges in funding projects. Large expenditures on something as apparently distant as global climate change may not be everyone's first priority. But the research is being funded because scientists believe that climate change is already happening and that we should learn as much about the process as possible, to minimize its effects.*

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.)

"Sensing the Unseen" in the September, 2001 special NASA issue of *ChemMatters* discusses the electromagnetic spectrum. It also discusses limb-sounding.

"Beefing up Atmospheric Models" in the October, 2003 *ChemMatters*, relates the collection of data by satellites and how this data is used to create models of atmospheric chemistry.

"Studying the Energy of the Universe" is an article in *ChemMatters*, September, 2002. The article discusses the use of satellites to measure the energy radiated by atmospheric chemicals.

The article "Shining Light on Atmospheric Ozone" *ChemMatters*, September, 2002, features the Ozone Monitoring Instrument discussed in the current article.

In the September, 2005 *ChemMatters* is an article titled "What's So Equal about Equilibrium?" which describes the chemistry of the atmosphere in equilibrium terms.

A special supplement to the December, 2000, *ChemMatters* details the EOS Aura satellite, which carries many of the instruments described in the current article, including MLS, OMI, and TES.

The April, 2008, edition of *ChemMatters* featured an article on NASA's Aura satellite.

Web Sites for Additional Information

More sites on Satellite Images

Real-time images from the Geostationary Operational Environmental Satellites (GOES) satellite system can be seen here: http://www.ghcc.msfc.nasa.gov/GOES/.

More sites on IDEA

The IDEA web site can be found here: http://www.star.nesdis.noaa.gov/smcd/spb/aq/.

More sites on MODIS

For a non-technical description of the MODIS system, see http://modis.gsfc.nasa.gov/about/media/modis_brochure.pdf.

More sites on Satellite Data and Air Quality

For an ACS article titled “Practical Aspects of Using Satellite Data in Air Quality Monitoring”, see http://pubs.acs.org/doi/pdf/10.1021/es7031339?sessid=6006l3.

More sites on MISR

The MISR web site can be found here: http://www-misr.jpl.nasa.gov/mission/introduction/welcome.html. It has case studies and graphics from the satellite.

More sites on Microwave Limb Sounder

The Microwave Limb Sounder web site is http://mls.jpl.nasa.gov/.

More sites on Climate Change

The National Science Digital Library has hundreds of resources on climate change here: http://nsdl.org/search/?verb=Search&s=0&n=10&q=climate+change&submit=Search.

More sites on the Intergovernmental Panel on Climate Change

The Panel’s web site, which contains a wealth of documentation, can be found here: http://www.ipcc.ch/.

More sites on Ozone Chemistry

The EPA has an extensive document describing ozone chemistry at http://www.epa.gov/ogwdw000/mdbp/pdf/alter/chapt_3.pdf.

More sites on the Kyoto Protocol

You can find the text of the Kyoto Protocol here: http://unfccc.int/resource/docs/convkp/kpeng.pdf.

More sites on the Earth Observing System

Links to dozens of resources about the Earth Observing System are provided by NASA at http://eospso.gsfc.nasa.gov/eos_homepage/for_educators/educational_links.php.

More sites on Climate Change from the EPA

The Environmental Protection Administration has a series of resources on climate change available here: http://www.epa.gov/climatechange/wycd/school.html.