CHEMMATTERS

April 2008
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About the Guide

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Student Questions

The Quest for a Clean Drink

1. Why did the people of India and Bangladesh change from surface water to water from tube wells?
2. What is the source of arsenic found in water from tube wells?
3. How do certain types of soil bacteria (anaerobic) increase the amount of arsenic in water from tube wells?
4. What are some of the detrimental health effects from ingesting too much arsenic in water?
5. What is the chemical function of manganese that is used in the Hussam arsenic filter bucket?
6. What is the chemical function of iron(III) hydroxide in the Hussam filter bucket?
7. How does the SenGupta water filter work?
8. What are the three chemical steps used in the Procter & Gamble (Souter) device to clean water?

Sniffing Landmines

1. What explosive is used in the land mines discussed in the story?
2. What is the chemical formula of this substance?
3. What substances are mine-sniffing dogs trained to find?
4. What is the percentage of DNT in a typical solid sample of TNT?
5. What is the percentage of DNT in the vapor that sublimes from a typical sample of TNT?
6. What is the lowest concentration of hydrogen sulfide in the air that humans can typically smell?
7. What is the lowest concentration of hydrogen sulfide in the air that dogs can typically smell?
8. How many times more receptor cells does a dog have than a human?
9. How many different components are there in gasoline?
10. What is one pollutant can be detected in groundwater using electronic “noses”?

Emma Perry Carr: Fostering Teamwork to Study Organic Molecules

1. At what school did Emma Perry Carr teach?
2. From what school did Carr earn her Ph.D.?
3. At what two schools, other than the one at which she taught, did Carr carry out chemical research?
4. Who worked with Carr when she studied the different kinds of pentene?
5. What two musical instruments did Carr play?
6. What two elements make up hydrocarbons?
7. What do we call hydrocarbons that contain
    a) only single bonds?

b) double bonds?
c) triple bonds?

8. How is the structure of *cis*-2-butene different from *trans*-2-butene?

9. How is the structure of 1-pentene different from 2-pentene?

The Chemistry of Arson Investigation

1. What does depth of charring in wood tell arson investigators about the fire?
2. What kind of fire does the article says produces an actual V burn pattern?
3. Checkering and “alligatoring” of wood surfaces give clues to what part of an arson investigation?
4. Give two examples of accelerants mentioned in the article.
5. What is the “halo effect” in arson investigation?
6. Name the two scientific instruments used most often in laboratory analysis of fire evidence.

Chemicals in the Air: Latest Results from NASA’s Aura Satellite

1. When was Aura launched?
2. What are the three questions that Aura data are trying to help us answer?
3. What is the height of the stratospheric ozone layer?
4. What does data from Aura and other satellites indicate about pollution distribution?
5. What is a *spectral signature*?
6. What is an algorithm?
7. Why is an algorithm needed for the NO_2 data from Aura?
8. What are the man-made sources of the sulfur dioxide Aura detects in the atmosphere, besides that coming from volcanoes?
9. What are the sources of nitrogen dioxide?
10. Why is nitrogen dioxide considered a problem pollutant?

Answers to Student Questions

The Quest for a Clean Drink

1. **Why did the people of India and Bangladesh change from surface water to water from tube wells?**

People were looking for a water source that was free of bacteria. Normally water that passes through soil and rock is filtered, removing bacteria.

2. **What is the source of arsenic found in water from tube wells?**

The arsenic is coming from rock and soil.

3. **How do certain types of soil bacteria (anaerobic) increase the amount of arsenic in water from tube wells?**

Soil bacteria chemically destroy iron hydroxide that normally is able to bind up arsenate and arsenite ions

4. **What are some of the detrimental health effects from ingesting too much arsenic in water?**

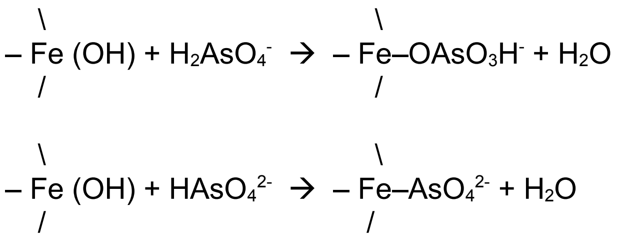
Long-term effects from drinking arsenic-laden water include skin disorders, nerve damage, kidney failure, and liver cancer. Many of these effects are listed under the general term, arsenicosis, or arsenic poisoning.

5. **What is the chemical function of manganese that is used in the Hussam arsenic filter bucket?**

The manganese acts as a catalyst in the oxidation of arsenite ions.

6. **What is the chemical function of iron (III) hydroxide in the Hussam filter bucket?**

The iron (III) hydroxide binds the arsenate ions to its surface, causing them to no longer be dissolved in the water, according to these equations:



$$–\,Fe\,(OH) + H_2AsO_4^{-} \rightarrow\ –\,Fe–OAsO_3H^{-} + H_2O$$

$$–\,Fe\,(OH) + HAsO_4^{2-} \rightarrow\ –\,Fe–AsO_4^{2-} + H_2O$$

7. **How does the SenGupta water filter work?**

The SenGupta filter is placed inside a tube well hand pump. As the water rises into the hand pump, the water is exposed to air. This causes iron in the water to be oxidized to iron (III) hydroxide. This *and the aluminum oxide in the pump tube both adhere to the arsenic compounds and remove them from the water.*

8. **What are the three chemical steps used in the Procter & Gamble (Souter) device to clean water?**
From the addition of a bag of chemicals (ferric sulfate, a polymer, and chlorine compound), arsenic and various minerals first precipitate ("coagulate"), then clump together ("flocculate"). "Disinfection", the third step, is done with chlorine-containing compounds to kill bacteria.

Sniffing Landmines

1. **What explosive is used in the land mines discussed in the story?**
The explosive used in land mines in the story is trinitrotoluene or TNT

2. **What is the chemical formula of this substance?**
The chemical formula for TNT is $C_7H_5N_3O_6$.

3. **What substances are mine-sniffing dogs trained to find?**
Mine-sniffing dogs are trained to find trinitrotoluene or DNT.

4. **What is the percentage of DNT in a typical solid sample of TNT?**
The percentage of DNT in a typical solid sample of TNT is 0.08%.

5. **What is the percentage of DNT in the vapor that sublimes from a typical sample of TNT?**
The percentage of DNT in the sublimed vapor from a typical sample of TNT is 35%.

6. **What is the lowest concentration of hydrogen sulfide in the air that humans can typically smell?**
The lowest concentration of H_2S *that humans can smell in the air is* 10^{-6} *%, or 0.000001%.*

7. **What is the lowest concentration of hydrogen sulfide in the air that dogs can typically smell?**
The lowest concentration of H_2S *that dogs can smell in the air is* 10^{-13} *%, or 0.0000000000001%.*

8. **How many times more receptor cells do a dog have than a human?**
Dogs have 20 to 40 times as many receptors as humans.

9. **How many different components are there in gasoline?**
There are more than 300 components in gasoline.

10. **What is one pollutant can be detected in groundwater using electronic "noses"?**
Trichloroethylene or TCE is one pollutant that can be detected in groundwater using electronic "noses".

Emma Perry Carr: Fostering Teamwork to Study Organic Molecules

1. **At what school did Emma Perry Carr teach?**
Emma Perry Carr taught at Mount Holyoke College.

2. **From what school did Carr earn her Ph.D.?**
She earned her Ph.D. from the University of Chicago.

3. **At what two schools, other than the one at which she taught, did Carr carry out chemical research?**
Carr did chemical research at Queen's University (Belfast) and the University of Zürich.

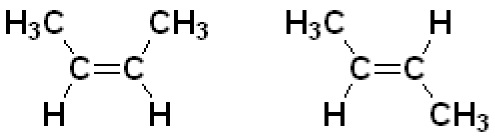
4. **Who worked with Carr when she studied the different kinds of pentene?**
Mary Sherrill worked with Carr studying pentenes.

5. **What two musical instruments did Carr play?**
Carr played the cello and organ.

6. **What two elements make up hydrocarbons?**
Carbon and hydrogen constitute hydrocarbons.

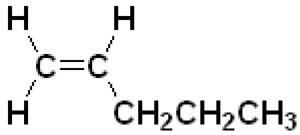
7. **What do we call hydrocarbons that contain**
   - **a) only single bonds?**
     Hydrocarbons that contain only single bonds are called alk<u>a</u>nes.
   - **b) double bonds?**
     Hydrocarbons that contain double bonds are called alk<u>e</u>nes.
   - **c) triple bonds?**
     Hydrocarbons that contain triple bonds are called alk<u>y</u>nes.

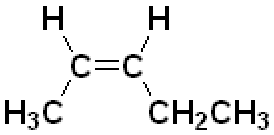
8. **How is the structure of *cis*-2-butene different from *trans*-2-butene?**
In cis-2.butene, the methyl groups are on the same side of the double bond, while in trans-2-butene, the methyl groups are on opposite sides of the double bond.

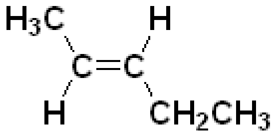


cis-2-butene *trans*-2-butene

9. **How is the structure of 1-pentene different from 2-pentene?**
In 1-pentene, the double bond is between the first and second carbon atoms, while in 2-pentene, the double bond is between the second and third carbon atoms. (Note: Cis- and *trans-* isomers of 2-pentene exist, but in this case a drawing of either isomer would be acceptable. The important point is that the students know the position of the double bond.)


1-pentene


cis-2-pentene


trans-2-pentene

The Chemistry of Arson Investigation

1. **What does depth of charring in wood tell arson investigators about the fire?**
The depth of charring tells arson investigators how long the fire burned in that area.

2. **What kind of fire does the article says produces an actual V burn pattern?**
The kind of fire that produces an actual V burn pattern is a longer-burning fire, rather than one that is extinguished quickly.

3. **Checkering and "alligatoring" of wood surfaces give clues to what part of an arson investigation?**
Checking and "alligatoring" of wood surfaces give clues about how fast the fire spread.

4. **Give two examples of accelerants mentioned in the article.**
The articles mentions gasoline, lighter fluid, paint thinner, road flares, paper and clothing as examples of accelerants.

5. **What is the "halo effect" in arson investigations?**
The "halo effect" refers to the fact that, in fires set using an accelerant, the area saturated by the accelerant may not burn as much as the surrounding area, producing a kind of "halo."

6. **Name the two scientific instruments used most often in laboratory analysis of fire evidence.**
The two scientific instruments used most often in laboratory analysis of fire evidence are the gas chromatograph and the mass spectrometer.

Chemicals in the Air: Latest Results from NASA's Aura Satellite

1. ***When* was Aura launched?**
Aura was launched on July 15, 2004.

2. **What are the three questions that Aura data are trying to help us answer?**
The three questions Aura data should help us answer are: a) Is the ozone layer recovering? b) What can we learn about the chemicals that affect the quality of the air we breathe and how these chemicals move in the air? c) How is Earth's climate changing?

3. **What is the height of the stratospheric ozone layer?**
The height of the stratospheric ozone layer is 20-24 km (12-15 miles).

4. **What does data from Aura and other satellites indicate about pollution distribution?**
Satellite data shows that pollution moves over long distances from polluted areas like cities to cleaner environments.

5. **What is a *spectral signature*?**
A spectral signature is the fingerprint of a chemical substance. It is based on the wavelengths of light absorbed by the molecule.

6. **What is an algorithm?**
An algorithm is a series of steps of a mathematical formula that scientists use, in this case, to adjust Aura's data.

7. **Why is an algorithm needed for the NO_2 data from Aura?**
An algorithm for the NO_2 *data is needed because the light path observed by the satellite is not vertical, but slanted. As a result, it will detect more* NO_2 *than is really there (because the light path is longer it goes through more* NO_2*).*

8. **What are the man-made sources of the sulfur dioxide Aura detects in the atmosphere, besides that coming from volcanoes?**
There are three man-made sources of sulfur dioxide: burning coal, oil refining, and ore smelting.

9. **What are the sources of nitrogen dioxide?**
Nitrogen dioxide is produced in the exhaust gas from cars (vehicle traffic), and it comes from coal-fired power plants.

10. **Why is nitrogen dioxide considered a problem pollutant?**
Nitrogen dioxide is a problem because it combines with other chemicals over time and space to cause ozone pollution where air might otherwise be clean, like in national parks.

ChemMatters Puzzle: A CHEM CROSTIC on the ENVIRONMENT

In the grid below is a quote from Carl Sagan in his book Billions and Billions. The passage (and many of the clues below) deal with environmental concerns as valid now as when Sagan wrote the book in the nineties. Your task is to reveal the quote from the clues provided.

To start, guess as many of the words defined below the grid as you can and write them over the numbered dashes. Then transfer those letters to corresponding numbered squares in the diagram. Black squares indicate word endings. Once you begin to get the sense of the quote, you will be able to work backwards to any clue words left unsolved on the first pass.

Hint: the answers to the clues are arranged alphabetically by first letter.

1E	2G	3J	4B		5C	6A	7H		8L	9K	10 M	11 E	12 K	13 D	14 B	15 E		16 H
17I	18J	19 M		20I	21 H	22J	23 M		24 F	25 K	26 G		27 A	28 L	29 B		30 K	31I
32 E	33 A	34 F	35 E		36 B	37I		38I	39 H	40 K	41 B	42 C	43 E		44 A	45 L	46 A	47 M
48 G	49 E	50J		51 F	52I	53 H		54 M	55 A	56 D	57 F		58 M	59 L	60 C	61 A		

A) __ V __ __ __ __ __ __ His number is 6×10^{23} !
6 46 33 55 44 61 27

B) __ __ __ __ __ A concentrated solution of NaCl, especially from the sea.
41 4 36 29 14

C) __ __ __ Formula of QUICKLIME.
5 60 42

D) __ __ Symbol of the alkali metal with lowest e.n.
56 13

E) __ __ __ __ __ __ __ Gasoline's value for this is about .77 g/mL.
49 11 43 15 32 35 1

F) __ __ __ __ Classic western movie, " ____ NOON".
34 24 51 57

G) __ __ __ Prefix from the Greek, meaning "same as" or "equal".
48 26 2

H) __ __ __ __ __ Wetlands; important breeding grounds for many aquatic species.
16 39 7 53 21

I) __ __ __ __ __ __ A rating system for anti-knock properties of gasoline.
17 38 20 52 37 31

J) __ __ __ __ Ingredient of many solid fertilizers; first synthesized by Wohler in 1840's.
3 18 50 22

K) __ __ __ __ __ H I J K L M N O.
30 12 25 9 40

L) __ __ __ __ Ductility is ability of a metal to form a ___.
28 45 8 59

M) __ __ __ __ __ __ An ingredient of gasoline, $C_6H_4(CH_3)_2$.
47 58 10 54 23 19

Answers to A CHEM CROSTIC on the ENVIRONMENT

The quote is “Your car releases more than its own weight in carbon dioxide gas each year.”

A. Avogadro
B. Brine
C. CaO
D. Cs
E. Density
F. High
G. Iso
H. Marsh
I. Octane
J. Urea
K. Water
L. Wire
M. Xylene

The author of this puzzle, Dave Olney, has explored the substance of Sagan’s claim, Based on an equation for an alkane in gasoline burning and gasoline’s density, one can show by stoichiometry one gallon of gasoline generates about 20 pounds of CO_2 as it burns. Then, some order-of-magnitude calculations show that a typical two ton, fossil fuel-burning car does indeed generate more than two tons of the gas in a typical year of driving.

If any reader would like to see his analysis, he will be happy to E-mail it as a WORD attachment. Contact: djolney@verizon.net

NSES Correlation

National Science Education Content Standard Addressed

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**Question From the Classroom**	**The Quest for a Clean Drink**	**Sniffing Land-mines**	**Emma Perry Carr**	**The Chemistry of Arson Investigation**	**Chemicals in the Air**	**Interview: Gerhard Ertl**
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.		✓		✓	✓	✓	
Physical Science Standard B: of interaction of energy & matter.					✓	✓	
Science and Technology Standard E: about science and technology.	✓	✓	✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of personal and community health.		✓	✓			✓	
Science in Personal and Social Perspectives Standard F: of natural resources.		✓				✓	
Science in Personal and Social Perspectives Standard F: of		✓				✓	

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 their responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

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

The Quest for a Clean Drink

Me	Text	Statement
		1. The scientists who have worked to remove arsenic from drinking water in India and Bangladesh have received no awards for their work.
		2. Arsenic is naturally found in rocks and soil.
		3. Surface water in India and Bangladesh contains arsenic.
		4. Arsenate ions react with hydrated iron (=FeOH), but arsenite ions do not.
		5. The bucket filters developed by Abul Hussam were first tested in the lab.
		6. The arsenic trapped in filters can safely remain there for decades.

		7. Arsenic can be removed from about 10 liters of drinking water by using chemicals in a pouch the size of a ketchup packet.

Sniffing Landmines

Me	Text	Statement
		1. Dogs detect landmines by the vapors that are emitted.
		2. The shock wave produced when a landmine explodes travels at the speed of sound.
		3. High explosives, like TNT, are less stable than low explosives.
		4. Metal detectors cannot detect landmines made of plastic.
		5. Dogs must be trained for more than a year to detect landmines.
		6. A dog has 20 to 40 times more receptor cells to smell odors than humans do.
		7. Scientists have developed odor-detection devices that are more sensitive than a dog's nose.

		8. All breeds of dogs are equally successful at detecting landmines.

Emma Perry Carr: Fostering Teamwork to Study Organic Molecules

Me	Text	Statement
		1. Before Carr, students and professors rarely worked together on research projects.
		2. Hydrocarbons can be analyzed by how they absorb ultraviolet light.
		3. Ethylene has one double bond that rotates or twists readily.
		4. Where the double bond is located in a hydrocarbon chain influences the properties of the hydrocarbon.

		5. The carbon atoms in aliphatic hydrocarbons may be arranged in chains or rings.

The Chemistry of Arson Investigation

Me	Text	Statement
		1. Most fires begin on a wall.
		2. In a structure fire, the most damage occurs where the fire began.
		3. Where char is deepest is where the fire burned the longest.
		4. When a liquid accelerant is set on fire, both the vapors and the liquid burn.
		5. In a home fire, it is difficult to determine if a petroleum-based accelerant was used because many home products are made from petroleum.

		6. Approximately 50% of the more than one million fires reported each year are suspicious.
		7. A fire will go out if the heat produced does not keep the fuel above its kindling temperature.

Chemicals in the Air: Latest Results from NASA's Aura Satellite

Me	Text	Statement
		1. The Aura satellite sends data daily to many computers around the world.
		2. Data from Aura is being used to answer questions about the ozone layer, clean air, and climate change.
		3. All chemicals in the atmosphere absorb and reflect light the same way.
		4. Spectral signatures are matched to determine what chemicals are present in the atmosphere.
		5. Spectral signatures are influenced by clouds and the direction the satellite is pointing.
		6. Algorithms are computer programs that take complicating factors into consideration when analyzing data from the satellite.
		7. Instruments are tested on Earth under extreme conditions before they are launched into orbit.

		8. Several chemicals contribute to depletion of the ozone layer.
		9. City air is always more polluted than rural air.
		10. NASA currently has 6 weather satellites to collect data in different ways.

Content Reading Guides

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

Notes for teachers about the articles:

1. There are several opportunities in the articles to lean more about structural formulas in this issue. If your students have not already learned about them, you may want to spend some time explaining the information they provide to readers.
2. The article about Emma Perry Carr is an excellent opportunity for your students to learn about isomers and the evidence used to determine their structures. If you have molecular model kits available to build models of the cis-trans isomers described in the reading, it would help the students understand that the double bonds cannot twist or rotate.

The Quest for a Clean Drink

Directions: As you read the article, please complete the table comparing and contrasting the different methods to remove arsenic from drinking water.

	Bucket Filters	**Removing arsenic at the pump**	**Arsenic-removing powder**
Scientists involved			
Chemistry involved			
Challenges			
Advantages			
Disadvantages			

Sniffing Landmines

In the chart below, compare TNT and DNT

	TNT	**DNT**
Chemical formula		
Physical properties		
Detection by dogs		

In the chart below, list the advantages and disadvantages of using dogs to locate landmines.

Advantages	**Disadvantages**

Emma Perry Carr: Fostering Teamwork to Study Organic Molecules

***Directions*:** As you read the article, list some of Emma Perry Carr's accomplishments and their significance in furthering our understanding of chemistry.

Accomplishment	**Significance**

Summary sentence: Complete the sentence below. The first letter of each word is provided.

Emma Perry Carr was one of the first scientists to promote t______________ among scientists as she studied the m________________ s__________________ of a_________________ h_______________ using u_____________________ s____________________.

The Chemistry of Arson Investigation

***Directions*:** As you read, complete the table explaining the significance of each clue, and the chemistry involved (if any).

Clue	Significance	Chemistry involved
1		
2		
3		
4		
5		
6		
7		
Lab		

Chemicals in the Air: Latest Results from NASA’s Aura Satellite

Directions: As you read, complete the chart below to analyze how NASA obtains information about our atmosphere.

	Ozone layer	**Air quality**	**Climate change**
Goal of data collection			
Instruments used			
Chemicals measured			
Problems encountered, with solutions			
Latest results			

The Quest for a Clean Drink

Background Information

More on properties of water

When talking about water, we are almost always referring to a solution with water as the main ingredient or solvent. Except for very special laboratory situations, pure water does not exist. Even triple-distilled water very quickly dissolves atmospheric gases, particularly carbon dioxide. When talking about "clean" drinking water, it might be better to assume we are referring to "safe" drinking water. Depending on its source, drinking water has a whole host of dissolved substances (as opposed to suspended particles) as well as some living organisms, particularly bacteria and viruses. Water that looks clean because it is transparent and essentially colorless may not be safe. It is most certainly not pure.

Water as a chemical substance is unique in a number of ways. Even though its molecular mass is rather low (18 amu), it exists primarily as a liquid at room temperature rather than a gas (compare with ammonia, NH_3, molecular mass 17 amu). The angular molecular structure produces a polar molecule that is quite "sticky" in terms of intermolecular bonds (hydrogen bonds in this case). This is not the case for methane, as methane does not exhibit hydrogen bonding; hence the difference in terms of its primary physical state at room temperature—a gas rather than a liquid. [It might be useful here in class discussion to also mention to students the ammonia molecule and to make comparisons of this molecule's properties to those of water and methane, since ammonia is also a polar molecule.] The polarity of water also gives it the ability to dissolve so many other chemicals, hence the designation of "universal solvent". Is it any wonder that our bodies are 70 percent (by weight) water? And of course, water "hangs around" the earth because of its "stickiness" (intermolecular bonds) and resultant boiling point much higher than an environmental temperature of 25°C.

Water has some other interesting properties that make for good living conditions on Earth. The fact that water expands below 4.0 ° C. rather than continuing to contract as most substances do means that bodies of water have ice on the surface (a good insulator), rather than freezing from the bottom up. This same water has a high heat capacity per unit of weight—ten times that of more dense metals such as copper and iron, for instance. It is this high heat that helps to moderate the earth's temperatures where the oceans and other bodies of water act as heat sinks. This prevents large fluctuations in environmental temperatures. It has one of the highest heats of vaporization (2268 joules per gram at 100 ° C).

Distribution of water in the world breaks down into some interesting and not obvious statistics. The world's oceans contain about 97.2% of the total water on earth. The balance of 2.8% is fresh water. That 2.8% breaks into the following:

- 2.11 % is trapped in glaciers and ice caps
- 0.62 % is groundwater
- 0.009 % is found in lakes
- 0.001 % is atmospheric moisture
- 0.0001% constitutes rivers

Any of the above can be a source of drinking water with a variety of extraction and treatment procedures. It is the source that determines what might be mixed with water to make a solution (assuming no suspended particles that may or not settled out). Looking at the world overall, there are 1.1 billion people (18% of the world's population of 6.2 billion) who lack access to safe drinking water. Related to this issue is the fact that about 2.6 billion people (42% of the total) lack access to basic sanitation which can also affect the quality of water supplies. See http://www.un.org/waterforlifedecade/factsheet.html, a source of basic statistics on the world-wide water situation. In parts of the United States, China, and India, groundwater is being consumed faster than it is being replenished.

- More than 2.2 million people (mostly from developing countries) die each year from diseases associated with poor water and sanitary conditions.
- Every week an estimated 42,000 people die from diseases related to low quality drinking water and lack of sanitation. Over 90 % of the deaths are children under the age of 5.
- Two of the water-related diseases, diarrhea and malaria, ranked 3rd and 4th place in the causes of death among children under 5 years old, accounting for 17 percent and 8 percent respectively of all deaths.
- In sub-Saharan Africa, a baby's chance of dying from diarrhea is almost 520 times the chance of that in Europe or the USA.
- Poor health resulting from inadequate water and sanitation robs the children of schooling and the adults of earning power, a situation aggravated for the women and girls by the time-consuming daily chore of collecting water.

More on solution chemistry

Considering drinking water as a homogeneous mixture or a solution, it is possible to analyze the contents of this water. The US government (Environmental Protection Agency, EPA) has established water quality standards for a large variety of dissolved substances (solutes), as well as bacteria, using *coliform* bacteria counts to indicate levels of bacterial contamination. http://www.epa.gov/OGWDW/. Protozoa such as *Cryptosporium parvum and Giardia lamblia,* which are parasitic pathogens, are also under quality control of the water industry and health officials.

Looking at drinking water from almost any source, several categories of solutes in the water sample will include inorganic and organic chemicals in elemental, molecular and ionic form. There is a plethora of tests for many of these particular chemicals to determine both their presence or absence, and their concentration. Your local water company is required to test for various dissolved substances, and for bacteria. These reports are often mailed annually to households and are available upon request. The following is a list of substances tested for in water samples:

- Turbidity
- Total Organic Carbon (% removal)
- Disinfectants and Disinfection By-Products
    - Chlorine residual
    - TTHM (total trihalomethanes from chlorine interaction with organics)
    - HAA-5 (haloacetic acids five)

- Copper
- Arsenic
- Lead
- Nitrate (as nitrogen)
- Barium
- Chromium
- Nickel
- Volatile Organic Contaminants, Synthetic Contaminants
- Radioactive Contaminants (gross Alpha, combined radium, uranium)
- Total Coliform bacteria, Fecal Coliform and E. coli bacteria

HAA-5 (3, above) refers to a group of chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The regulated haloacetic acids (HHA-5) include monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid and dibromoacetic acid. These acids can be further transformed into the trihalomethanes that are considered carcinogenic. The most recent EPA regulations limit HHA-5s to 60 ppb (annual average).

(See http://www.epa.gov/enviro/html/icr/gloss_dbp.html.)

More on water purification

Water that is to become municipal drinking water is treated in a variety of ways to ensure that is safe to drink. Depending on the source (a river vs. aquifer or artesian well water), it may be first screened, then treated with chlorine (which can kill or inactivate bacteria and viruses but not protozoan pathogens, such as *Giardia* and *Cryptosporium*) before being treated in a flocculation tank using the chemicals aluminum sulfate (alum), $Al_2(SO_4)_3$, and calcium hydroxide (slaked lime), $Ca(OH)_2$. These chemicals react to form aluminum hydroxide, $Al(OH)_3$, a sticky material that traps suspended particles which then precipitate. This is known as flocculation. The liquid is then passed through a sand filter to remove any unprecipitated flocculent. Sand filtration or other types of filters will also remove the pathogenic protozoa that are not killed by chlorination. Additional chlorination follows along with aeration (for taste enhancement), pH adjustment and fluoridation (1 ppm). The adjustment in pH is necessary because, if the water is acidic, it will react later with domestic water pipes, releasing, among others, undesirable Cu^{+2} and Cd^{+2} ions into a household's water pipeline. The water is now ready for public consumption.

Chlorination or chlorine addition to domestic water supplies takes place in one of three ways:

- Chlorine gas is bubbled into the water,
- A water solution of sodium hypochlorite, NaOCl is added,
- The solid, calcium hypochlorite, $Ca(OCl)_2$, is added to the water.

The chemistry of this particular treatment is the production of a weak acid, hypochlorous acid, HOCl. How this compound inactivates or kills bacteria and viruses is not clearly understood but is thought to damage the selective permeability of the cellular wall which in turn is not able to control the entrance/exit of various chemicals that diffuse in and out of the organism's cellular interior (cytoplasm). Some waterborne viruses, such as enteric viruses and hepatitis A may be more tolerant to chlorine disinfection than some bacterial species, but it is not well understood how chlorine inactivates viruses. See http://www.sciam.com/article.cfm?id=how-does-chlorine-added-t.

An interesting aside is the fact that bacteria along with some other organisms both microscopic and macroscopic (water hyacinths) are being studied for use in "cleaning" contaminated water of trace amounts of certain metals including zinc, selenium and even arsenic. Researchers are working with sulfate-reducing bacteria (SRB) that normally bind sulfate in oxygen-free water. Found in a flooded lead and zinc mining tunnel in Wisconsin, the species from the *Desulfobacteriaeceae* family of bacteria can survive in low oxygen environments and bind zinc with sulfate, forming spheres with zinc concentrations a million times higher than that found in the surrounding water. These bacteria have the potential to remove zinc, selenium, and even arsenic traces from various water sources. http://www.sciam.com/article.cfm?articleID=000E6700-23DF-1C68-B882809EC588ED9F

Additional living "filtering" systems include the water hyacinth, which has been known to extract many heavy metals from water systems, concentrating them in the root system. Experiments with the roots dried into a powder have shown that the powder added to arsenic-contaminated water reduces the arsenic levels to the World Health Organization's safe limit of 10 micrograms per liter, even if initial concentrations are 20 times as high. Check out http://www.newscientist.com/channel/health/mg18524916.200-rooting-out-arsenic-in-bangladeshi-wells.html.

While using the water hyacinth as a filtering system may seem very attractive, water hyacinths are banned in many states because once released into water systems, they can take over an ecosystem, causing the usual crowding out of other aquatic plant species, subsequent interference with the food chain that supports a variety of animal life, and the proverbial eutrophication of a water system from the death and decay of the hyacinths, creating reduction of dissolved oxygen which affects many larger aquatic species, particularly fish. Even so, the plants are part of some water treatment facilities for heavy metal removal.

Another recent water purification design makes use of nanoparticles of magnetite (magnetic iron oxide). Arsenic binds strongly to iron oxides. The magnetite nanoparticles are 12 nanometers wide—smaller than a virus. Using such small particles means a very large surface area, high contact, and short diffusion times (the time for the particles to grab a particular chemical of interest). The magnetite particles react with the arsenic. In the presence of a weak magnetic field, the nanoparticles begin to clump and separation can be accomplished. This kind of separation using magnetism is more efficient and less expensive than normal filtration. Further reductions in cost will be accomplished by substituting iron oxide nanoparticles from olive oil and rust for the expensive magnetite. http://www.sciam.com/article.cfm?id=rust-could-be-the-key-to

An interesting new "smart" material is being evaluated that both detects and helps to eliminate organic water pollutants (chlorinated phenols found in preservatives, insecticides, and produced by paper mills, plastic and paint manufacturers). It is zinc oxide (ZnO). The important property of zinc oxide is its ability to emit visible light when it is exposed to ultraviolet light. When zinc oxide is exposed to the chlorinated phenols in water, its light emission decreases. This response is measurable for pollution concentrations as low as 1 ppm and takes less than a minute to occur. In addition, with the detection of the organic molecules, the ZnO can act as a catalyst in the breakdown of the molecules utilizing UV light. With conversion of the organics to harmless molecules, the ZnO again glows more brightly—indicating that the job is done. This material is considered to be a nanosensor.

Another design proposal for filtration utilizes recycled rubber tires which are ground up into crumbs (1-2 mm across). The system (now patented) is touted as being four times faster than standard filtration systems using sand, charcoal and stones of various diameters. The tire system uses tire crumbs of different sizes, starting with the largest crumbs at the top, with a gradient of smaller sizes progressing to the bottom (exit). If the system is used to filter wastewater, larger particles are trapped at the top and do not clog the system further down. A concern for this system using tires is the possibility that old tires may leach toxic chemicals, including heavy metals. Testing of the system and scaling up to full size is ongoing. See http://www.newscientist.com/article.ns?id=dn10637&print=true.

The history of water filtering can be found at http://www.historyofwaterfilters.com/.

Connections to Chemistry Concepts

1. **Polymers**—Larger molecules that can be used to attract coagulated ferric sulfate-based heavy metals, including arsenic, producing an even larger "clump" or flocculant for easier removal from treated water
2. **Organic compound**—Being carbon-based, these can form large molecules that are useful in filtration systems and the coagulation-flocculation of compounds that need to be removed from water systems.
3. **Precipitate, water solubility**—Formed from a low solubility reaction product, the precipitation reaction is a useful way to selectively remove certain chemicals from solution. It is the basis for one water treatment process called flocculation.
4. **Ions**—These charged particles are able to be selected out of solution either in ion-exchange systems or as part of a chemical reaction in which undesirable heavy metal ions can be precipitated from solution.
5. **Oxidation**—This type of reaction is important in converting arsenic (by increase in oxidation number) as the arsenite ion (+3) to less toxic forms, such as the arsenate ion (+5), which can be bound to iron(III) hydroxide for removal in some of the low-cost tech devices created for water purification in poor countries.

6. **pH**—The conversion of various arsenic compounds to other forms is pH-dependent. Certain enzymes (catalysts) and important soil bacteria will only function in a particular pH range.
7. **Adsorb(ent)**—This process is defined by the fact that molecules are attracted and held on the surface of some material. This is in contrast with absorption in which chemicals not only are attracted to the surface of a material but also penetrate to the interior of the material (diffuse). This process is the basis for iron hydroxides attracting arsenic compounds, but it is dependent on the pH of the reacting solution medium as well as the oxidation state of the arsenic.
8. **Secondary bonding**—Hydrogen bonding between water molecules gives rise to an entirely different set of properties from those of methane, which relies solely on van der Waals forces and does not exhibit hydrogen bonding.

Possible Student Misconceptions

2. **"Adding soap to water when making bubbles works because the soap makes the water molecules stick together."** *Actually, the soap works to break the water molecules apart! The strong hydrogen bonds of water make it difficult to "stretch" the water into bubbles. The surface tension of pure water is broken through the addition of soap and the water is "stretched" with the soap molecules connecting to each other and to the water molecules.*
3. **"Water softeners use salt as part of the water treatment. Therefore, the softened water is salty."** *Actually, salt is used to flush the hard water ions (primarily Ca^{2+}, Mg^{2+} and Fe^{3+} ions) out of the exchange resin in the water-softening device at the end of the cycle. During normal use the resin exchanges sodium ions for the hard water ions of calcium, magnesium and iron. Eventually, the resin is filled with these hard water ions and must be replaced with new sodium ions. This is done with a wash of salt water which replaces the hard water ions once again with Na^+ ions and the system is ready to begin again. The hard water ions do not get into the house's water supply because the ions are flushed down the drain, usually at night.*
4. **"Water for drinking is pure water."** *As noted in the article, Asian countries in particular have problems with arsenic contained in their drinking water. And although it is relatively easy to obtain clean drinking water in the U.S., even here drinking water is not pure. It is clean enough to drink, but it contains all kinds of dissolved chemicals as well as bacteria and viruses (dead and living). As noted in the opening paragraph of "More on properties of water", truly pure water is very difficult to obtain.*
5. **"If one melts snow, one gets pure water."** *As this Teachers Guide was being researched, scientists at Louisiana State University published in the journal, Science, their findings that snowflakes contain bacteria. It has long been known that water, either as raindrops or as snowflakes, requires nucleation sites, tiny*

objects on which to collect while in the atmosphere. It had been believed that the two main global nucleators were dust specks blown up into the atmosphere over deserts and dry areas, and tiny salt crystals thrown up over the oceans by wind and wave action. The LSU researchers and colleagues at the National Agronomy Research Institute in Montfavet, France, and at Montana State University in Bozeman, Montana, have discovered that most frequently (as much as 85% of the time) those nucleation sites are airborne bacteria, most commonly Pseudomonas syringae, a bacteria that can affect plants. For more information, you can access a review of the article at the CNN news online website at http://edition.cnn.com/2008/TECH/science/02/28/snow.bugs.ap/index.html. This is the reference for the actual article: Science *29 February 2008:*
Vol. 319. no. 5867, p. 1214. You can view the abstract at http://www.sciencemag.org/cgi/content/abstract/319/5867/1214 and, if you are a subscriber to *Science, you can view the entire article online at this same URL.*

Demonstrations and Lessons

1. There are many programs already available that use water as a major topic within the chemistry curriculum. The most obvious one is the ACS Chemistry in the Community (ChemCom) program. (see the first title listed in the reference section for ordering). A variety of chemistry topics can be taught through the first unit in the text (activities are integrated into the text). One impressive activity for students is to "purify" a water sample (called "Foul Water") that is odorous, oily, "gunky", and seemingly impossible to clean up. Going through the various steps using very common equipment, students end up with what appears to be a colorless, clear, and odorless liquid. They have performed a microscale water purification process as done in municipal water treatment facilities. Other activities include:

- Water testing for common ions such as iron, calcium, sulfate, and chloride
- Determining the solubility of a chemical substance
- Solubility limits of ions and polar/non-polar substances with a particular solvent
- Water softening

2. A plethora of activities related to water studies can be found at the Rivers Project, http://www.siue.edu/OSME/river/index.html and http://www.siue.edu/OSME/river/Ordering%20Materials/Order.html
3. For some visual programs to help illustrate polarity and hydrogen bonding of water molecules refer to http://programs.northlandcollege.edu/biology/Biology1111/animations/hydrogenbonds.html.

4. A demonstration to illustrate the effect of hydrogen bonding on the viscosity of a liquid can be shown by slowly pouring three different 3-carbon alcohols with different numbers of hydroxyl (-OH) groups attached. The one-OH alcohol is propanol, the two-OH alcohol is 1,2-propanediol (propylene glycol), and the three-OH alcohol is 1,2,3-propanetriol (glycerol or glycerin).

5. A complete description of an experiment to measure surface tension of water (pure and with additives) can be found at https://www.sciencebuddies.org/mentoring/project_ideas/Phys_p012.shtml?from=Home. This material includes lesson plans, complete instructions for building the important balance beam needed for measurement as well as references. For other activities related to surface tension from the same program, Science Buddies, click on http://www.sciencebuddies.org/science-fair-projects/search.shtml?cx=006938645102073751460%3A5g77bgclmby&q=surface+tension&sa=Search&cof=FORID%3A9#894. The home page for Science Buddies is http://www.sciencebuddies.org/.

6. Water filters that are used in the home (and industry for that matter) utilize exchange resins. Something like a Brita filter can be opened to show the resin. If can also be used to test its effectiveness with tap water. A lab activity can be organized in which students first test local tap water and distilled water for some of the ions known to be removed by the Brita filter—iron, chlorine as chloride ion, copper, and zinc. The resin also affects pH of the water sample which should be tested. The Brita filter reduces lead and copper [93%], zinc and particulate matter (non-chemical), along with Mg and Ca, so that water should be soft. The charcoal removes taste, odor and chlorine. And there is a small amount of silver for bacteriostatic action.

Testing for the presence of these ions can be done with test kits available from the major science supply companies. Or check the listings in the Rivers Project above (#2) for chemical test equipment. Students could also test for some other common ions such as carbonate ion (CO_3^{-2}), sulfate ion (SO_4^{-2}), and the magnesium ion, (Mg^{+2}). A standard pH test should also be performed. As part of the test, water samples should also be boiled to see if the pH changes (increases) due to the elimination of dissolved carbon dioxide gas—a good way to help students understand that distilled water in the laboratory is acidic, not neutral. Some useful references to illustrate how an ion exchange works can be found at http://wiki.biomine.skelleftea.se/wiki/index.php/Ion_exchange, http://www.ionexchange.books.kth.se/applets.html and http://www.dartmouth.edu/~chemlab/chem3-5/ionx1/overview/procedure.html.

7. A more extensive water studies program that involves field work (the source of the water!) and related activities other than those listed in the Rivers Project above (#2) can be found at the Access Excellence website, http://www.accessexcellence.org/AE/ATG/data/released/0249-JudyWilliams/description.html.

8. An interactive for students that lets them clean up an oil spill is found at http://www.units.muohio.edu/dragonfly/water/h2oindex.shtml. Other activities at this website include "Learn how you can help prevent pollution" and "Learn how environmental workers clean up oil spills". There is background information on various aspects of water pollution.

9. The process of flocculation used in water treatment to settle out suspended material is accomplished using a combination of aluminum sulfate (alum) and calcium hydroxide (slaked lime). The reaction is as follows:

$$Al_2(SO_4)_3\ (aq) + 3\ Ca(OH)_2\ (aq) = 2\ Al\ (OH)_3\ (s) + 3\ CaSO_4\ (aq)$$

You could show this reaction in clear water with the formation of the white gelatinous precipitate of aluminum hydroxide.

You could also prepare some "dirty" water by adding some clay soil to water, stirring, and pouring off the water suspension into a second container—leaving the excess undissolved soil in the first container. Then add the aluminum sulfate and calcium hydroxide to the suspension in the second container to see how much clearing of the water is accomplished by the reaction and formation of the gelatinous precipitate of aluminum hydroxide.

You could also try to see the effect of various sized soil particles in suspension on the precipitate reaction's ability to flocculate the suspended matter.

For every 100 ml sample of water or solution, add a maximum of 3 grams aluminum sulfate to 2 grams of calcium hydroxide. Stir to dissolve the chemicals. (Some of the calcium hydroxide may be insoluble.)

Student Projects

2. Students could obtain information on water quality from their local water supplier. Water companies issue results of periodic tests on water samples. The EPA maximum levels for any one chemical are found either in the report or can be obtained from the EPA main website, http://www.epa.gov/OGWDW/ . Students could also check on the health effects from exceeding the maximum levels allowed for safe drinking water.

3. Students could set up a distillation apparatus for purifying a tap water sample, testing for the various dissolved substances in the sample before and after distillation (the collected distillate). A related research project would be to find where in the world desalination is used to produce drinking water. What is the energy source for running this kind of large-scale distillation? Is solar power possible for the energy source? Is distillation cost-effective for producing safe drinking water in poor countries? What kinds of water treatment are cost-effective in poor countries? A good starting point for this project

might be http://www.coastal.ca.gov/desalrpt/dchap1.html or http://en.wikipedia.org/wiki/Desalination.

4. Students could test for the various common ions in and pH of bottled water. What is the source of the water—underground aquifers, stream or lake water, municipal water, USA or foreign? They could compare the components of their bottled water with what is found in their local tap water. Refer to the *Reader's Digest* article on bottled water, found at http://www.rd.com/special-reports/the-environment/rethink-what-you-drink/article.html.

5. Students could research the issue of mercury in water—what is the chemical form of the mercury, what is its source(s), how can mercury in the environment be reduced, what are the health effects of mercury on different age groups? See http://www.epa.gov/safewater/dwh/c-ioc/mercury.html.

6. If the testing of the resin from a Brita filter is not done as a whole class project, it can be done as a student project (see Classroom Activities, #5 above). Its effect on water softening can also be tested by using the standard "sudsing" test. In this test, a 5 ml sample of water is added to a test tube and one drop of Ivory liquid soap (NOT generic liquid detergent) is added. Stir the mix gently. Look for turbidity (cloudiness). Compare this sample with other samples (tap water without water softening treatment, distilled water). The greater the turbidity, the greater the quantity of soap dispersed (the softer the water). Stopper the test tubes with the soap added and shake vigorously. Check the height of the soap bubbles (suds)—the higher or the more suds, the softer the water. Another test for the hardness of water (the amount of magnesium and calcium ions in water) is to add 10 drops of a sodium carbonate solution to new 5 ml samples of water. Any cloudiness or precipitate is due to the presence of the magnesium or calcium ions that form the insoluble carbonate. How do the results of the "sudsing" tests and the carbonate precipitate tests compare? (See reference #1 for lab techniques and procedures.)

7. Students can do a study (long term) of a local stream or lake, using standard testing procedures including dissolved oxygen (electronic probes or chemicals) biological and chemical oxygen demand. There are standard textbooks on water ecology that include the various tests. Also, refer to the material available from the Rivers Project (http://www.siue.edu/OSME/river/index.html)

8. There is a whole world of interesting chemistry about arsenic that could be explored by students. It has a long history (starting with the Greeks and Persians) in its use for various medical treatments, beauty treatments and, of course, murder! A starting point is found at http://en.wikipedia.org/wiki/Arsenic.

9. Students can build a conductivity meter for testing relative concentrations of ions in various samples of water, including distilled and deionized water.

10. Students could research and report on the special properties of water and the effects on climate and life on Earth as a result of these special properties.

Anticipating Student Questions

1. **"If arsenic occurs in soil and rock, what is the form of the chemical—element or compound?"** *Arsenic in rock or soil is usually found in compound form. Usually it is found in compounds as arsenite (oxidation state +3) and arsenate (oxidation state +5).*
2. **"How does arsenic act as a poison?"** *Basically, when arsenic is taken in by the cells of a living organism, the arsenic interrupts the energy-producing chemical cycle involving ATP. Arsenic in the form of arsenate readily passes through the cell membrane because it has similar chemical characteristics to phosphate, a family member. Various enzymes are inactivated, as occurs with other poisons such as cyanide. A living organism quickly runs out of vital energy production. This explains why arsenic compounds can be used to kill bacteria and fungi (wood preservative) and insects. Arsenic, as the compound arsenic trioxide, has also been used to treat cancer (leukemia). Before antibiotics, the arsenic compound arspenamine was used to treat syphilis and trypanosomiasis (sleeping sickness).*
3. **"What are heavy metals and why are they a problem if found in drinking water?"** *Heavy metals are metallic elements with large atomic masses and generally high densities. They include such elements as mercury (Hg), lead (Pb), cadmium (Cd), and antimony (Sb). They are considered to be toxic because they interfere with the enzyme systems of living organisms. Normally, enzymes contain magnesium ions (Mg^{2+}), calcium ions (Ca^{2+}), or zinc ions (Zn^{2+}), in their structure. Heavy metal ions can displace the magnesium and calcium ions causing the enzyme structure to become inoperable.*
4. **"If water is recycled, how is it possible for me to be drinking water that previously was part of some animal in East Africa? My local water treatment plant is not connected to East Africa!"** *Water moves around the world through the water cycle. Water evaporated from a source in one part of the world can become part of a cloud system that can move to another location in the atmosphere—multiple changes from cloud to rain (precipitation) back to cloud can eventually move that East African water to the USA with one more transformation from cloud to rain to flowing water to a water reservoir above or below ground and transfer to a water treatment plant, then to a home's water faucet. One person's excretion is another person's drink of water, eventually!*

References

Chemistry in the Community, (ChemCom), 4th Edition, W.H. Freeman & Co., NY, ISBN 0-7167-3890-2, Unit 1, "Water: Exploring Solutions".

Chemistry in Context, Wm. C. Brown Publishers, Dubuque IA, ISBN 0-697-21948-8, Chapter 5, *"The Wonder of Water",* Chapter 7, "*Onondaga Lake: A Case Study"*.

Journal of Chemical Education, Vol.85, No.2 Feb. 2008, pp. 185-187, *"Water Streaming Chemistry",* Janice Hall Tomasik (www.JCE.DivCHED.org). This is a helpful article for teachers. The reference highlights the wealth of chemistry on the Internet, emphasizing sites that can be used as teaching tools, from building a solar-powered water desalination device to real-time geographic site data on daily stream flow conditions, state by state.

An interesting story about the possible arsenic poisoning of Napoleon when he was imprisoned on Elba Island is found in an earlier *ChemMatters* issue (December, 1998, p. 4, *"The Case of Napoleon Bonaparte").* This story is a good reading exercise for students because, if they do not read carefully, they will conclude that Napoleon died from an arsenic poisoning conspiracy rather than from his terminal cancer, which is well documented. On the other hand, it is possible that the arsenic found in his tissues may well have contributed to some debilitation and synergistic weakening with his cancer. The possibility of arsenic poisoning from the wallpaper with its Scheele's Green pigment (copper arsenic compound) is highly likely. But it did not kill him directly. So, this article can be used in the classroom for several purposes besides that of a mystery. There is some interesting history and chemistry here.

Another interesting read for students concerns the mysterious death of a deer! The chemistry behind the investigation and the data needed to reach some conclusion about the possible role of arsenic (and its sources) are part of the article, *"Mystery Matters—Deer Kill",* found in *ChemMatters*, October, 1992, pp. 12-14. Again, this article can be used with students for both critical reading and informative practical chemistry.

ChemMatters presents a modern murder mystery involving arsenic with additional historical information on arsenic in society in the article, "Poisoned!", in its December, 2005 issue on pages17-19. Unfortunately, this article is not available in the online content for the Dec. 2005 issue at this time, but you can access the Teachers Guide for the "Poisoned!" article (pp.52-61), which lists a whole host of additional references, classroom ideas, and related chemistry. The Teachers Guide is at http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_ARTICLEMAIN&node_id=1090&content_id=CTP_005702&use_sec=true&sec_url_var=region1.

Web sites for Additional Information

http://www.epa.gov/OGWDW/ is the basic website of the Environmental Protection Agency, with a variety of topics including drinking water quality, source water protection, drinking water standards, public drinking water systems, and an “A-Z” list of topics, among other things.

http://www.epa.gov/OGWDW/arsenic/index.html specific information on arsenic and its health effect, sources of contamination, EPA limits in water.

http://www.unsgab.org/docs/mdgs.htm United Nations Web site (for its Millennium Development Goals, MDGs) that deals with the world picture concerning the problems and some solutions for making safe water available to more people. It includes useful statistics.

A number of websites that provide lessons in water studies include: http://learnweb.harvard.edu/ent/gallery/pop4/pop4_7.cfm, http://www.siue.edu/OSME/river/index.html, http://www.siue.edu/OSME/river/Ordering%20Materials/order_chemistry.html, http://www.wateraid.org/uk/learn_zone/educational_resources/782.asp, http://ga.water.usgs.gov/edu/characteristics.html (source of pictures and explanations of various instruments and techniques used in water studies), http://ga.water.usgs.gov/edu/, http://www.vims.edu/bridge/ (primarily salt water teaching resources), and http://www.epa.gov/safewater/kids/wsb/ (water sourcebooks K-12 in pdf)

Water other than for drinking is needed in agriculture. A world view shows the common use of sewage water for crops and the potential health problems. See http://www.newscientist.com/article.ns?id=dn6297

An interesting problem in terms of availability of safe drinking water is that of providing water for astronauts. This article discusses why it might be necessary to use urine! http://www.sciam.com/article.cfm?id=new-menu-item-on-space-st

Several primers on the basics of water pollution, with diagrams, include http://www.umich.edu/~gs265/society/waterpollution.htm http://ga.water.usgs.gov/edu/specials.html, http://www.nlm.nih.gov/medlineplus/waterpollution.html, http://health.usgs.gov/dw_contaminants/, http://health.usgs.gov/dw_contaminants/arsenic.html, http://phys4.harvard.edu/%7Ewilson/arsenic/countries/arsenic_project_countries. html#USA (deals with distribution of arsenic in US waters as well as the other countries, including Bangladesh. It is part of a project at Harvard that provides a plethora of references, including criticism of various agencies attempts to deal or not properly deal with the water problems. http://phys4.harvard.edu/%7Ewilson/arsenic/arsenic_project_links.html is a related set of extensive references connected to the Harvard arsenic project.

An extensive set of references from the US Geological Survey in the basics of water sources including the water cycle, ground water, and locations worldwide of water can be found at http://education.usgs.gov/common/secondary.htm#groundwater

You can find an extensive collection of articles from the BBC news services on arsenic, including the most recent status of arsenic in Southeast Asian water. at http://search.bbc.co.uk/cgi-bin/search/results.pl?scope=all&edition=i&q=Arsenic+in+water&go.x=0&go.y=0&go=go.

An overview of the world problem of providing enough safe drinking water and impediments to the solution is found at http://www.sciam.com/article.cfm?id=the-challenge-of-sustaina.

A separate topic familiar to most students is bottled water. There are the issues of the water source, its safety, type of government regulation, and comparison of this water with regular tap water. Read all about it at http://www.rd.com/special-reports/the-environment/rethink-what-you-drink/article.html.

Sniffing Landmines

Background Information

More on the senses and the sense of smell

The sense of sight detects light, while the sense of hearing detects compressional vibrations in the air around us. Touch senses physical pressure. Meanwhile, taste and smell respond to the specific chemical nature of substances, and for this reason they are collectively know as the chemical senses.

Much of our detailed understanding of how smell works was discovered by Linda B. Buck and Richard Axel, who independently carried out intensive studies into how olfaction, the process of smelling, works. The two scientists shared the Nobel Prize for Physiology or Medicine in 2004 for their discoveries.

Buck and Axel studied a type of cell found in the nose called olfactory receptor cells, and a family of proteins called receptor proteins found in those cells. By studying mouse olfactory receptor cells, they found that each such cell contained only one type of receptor protein. In mice there are over 1,000 different kinds of receptor proteins, although humans may possess only about 350.

Proteins are long chain-like molecules, made by joining together many amino acid molecules. Receptor proteins are found at the surfaces of receptor cells, and the proteins snake in and out of the cell membrane, crossing it seven times. In the process, receptor proteins are twisted and bent into different shapes, creating cavities of different shapes and sizes. Each receptor protein has a different cavity shape. Odorant molecules can dock with these cavities in the receptor proteins. The shape of the cavity of a particular receptor protein is shaped to allow only members of specific families of molecules to dock with it, in the familiar lock-and-key manner of protein-substrate chemistry. This means that each kind of receptor protein responds to only a specific family of compounds. While a human may only have 350 or so different kinds of receptor cells, many odors are made of combinations of substances. Humans can discern as many as 10,000 different odors, that is, 10,000 different combinations of substances. In addition, within a chemical family, different members may not bind to the same receptor protein, allowing additional levels of nuance in the smell that is perceived.

When a molecule docks with a receptor protein, the shape of the protein changes, triggering an electrical signal which is transmitted first to an organ called the olfactory bulb, which sits just over the bone that forms the roof of the nasal cavity in the skull. From the olfactory bulb, signals are then relayed to the brain where they are interpreted as odor.

A relatively large part of the genome of any given mammal is devoted to coding for receptor proteins. With so many different kinds of receptor proteins, as much as 3% or a mammal’s gene codes for the proteins involved in odor reception.

Inside the nose, receptor cells are attached to a tissue called the olfactory epithelium. In humans, the olfactory epithelium is rather small, and only covers a small part of the surface of the inside of the nasal cavity near the cavity's roof. In dogs, however, the olfactory epithelium covers nearly the entire surface of the interior of the nasal cavity. On top of this, a long-snouted tracking dog like a bloodhound or a basset hound may have a considerably larger nasal cavity than a human. All in all, the olfactory epithelium of a dog may have up to fifty times the surface area as that of a human. While a human may have around 3 cm^2 of olfactory epithelium, a dog might have up to 150 cm^2.

A dog's wet nose also helps it smell more acutely, as odorants are captured as they dissolve in the moisture. The shape of the interior of a dog's nasal cavity also allows odors to be trapped inside during inhalation, without being expelled during exhalation. This allows odorants to concentrate inside the dog's nose for easier detection. A dramatic result of all of these adaptations is that dogs can smell certain substances at concentration up to 100 million (1×10^8) times lower than humans can.

Beagles, bloodhounds, and basset hounds have been bred to have especially keen senses of smell, even for dogs. In addition to sniffing out land mines, dogs are also used to sniff luggage for bombs at airports, to find hidden drugs at border crossings, and even in medical diagnostics. Dogs are trained to detect odors, too faint for humans to smell, that indicate a diabetic patient might be about to go into insulin shock, a condition that results when blood sugar levels drop dangerously low, and can lead to coma and even death. When the dog smells insulin shock on the way, it can alert the patient to take preventative measures, like eating something sweet. If the insulin shock comes while the patient is asleep, a barking dog can be a lifesaver. In the future, dogs may also be used to smell cancers while still too small to be detected by conventional means. Since early detection can mean the difference between life and death, dog diagnostics could save many lives someday.

More on explosions

Hollywood often gives a misleading impression of explosions, when the hero jumps away from a car, or a building, or a boat just as it erupts into a giant ball of flame. The "explosions" you see in movies aren't particularly powerful explosions, but rather rapid combustion, usually of jugs of gasoline placed inside the car or whatever. This trick produces a nice big orange fireball that looks good on the big screen, but it doesn't necessarily produce a powerful explosion. For all its drama, that gasoline fireball really doesn't exert that much outward pressure, and the pressure wave is a big part of what makes an explosion an explosion.

An easy way to generate a pressure wave is to quickly produce lots of gaseous products from solid or liquid reactants. (Remember that the gasoline that gives us those Hollywood fireballs doesn't burn in the liquid phase, but only ignites after it evaporates.) Since gases exert pressure, sudden production of gases means sudden pressure. TNT is an excellent explosive because it can produce so many moles of gas per mole of reactant. The same can be said for nitroglycerin, which reacts in a similar manner to TNT. Likewise, azides can decompose to produce N_2; peroxides can break down to produce O_2. (While peroxides aren't commonly used as explosives, their explosive nature means they must be handled with care when used for other purposes.)

The sudden release of gases is a big part of what makes a good explosive, but there is another factor in the case of TNT, and other organic nitro compounds, like nitroglycerine. One thing is that they contain an oxidizer and a fuel in the same molecules. The oxygen atoms from the nitro groups can combine with the carbon atoms without the presence of external O_2 molecules. This process is exothermic, like O_2 combustion. This means the decomposition gives off lots of heat. The production of heat isn't necessary for a reaction to be explosive. Acetone peroxide gives off very little heat when it explodes, for example. However, since the pressure of a gas increases with increasing temperature, all that heat can only make the bang bigger.

In all this discussion we have been talking specifically about *mechanical* explosions. In chemistry, we can also speak of *kinetic* explosions. A kinetic explosion is a chemical reaction that proceeds by a runaway chain reaction, specifically a radical reaction in which each successive step results in more radical products than radical reactants. The chemical reactions used in blasting explosives are not necessarily kinetic explosions.

More on explosives history

The first explosive used by people was black powder, which was invented in China in around the 9th Century A.D. Black powder is a mixture of charcoal (carbon), sulfur, and potassium nitrate. The Chinese first used black powder to invent fireworks. Soon after, they developed military rockets propelled by black powder. The knowledge of black powder made its way westward rather quickly for the time, as the English monk and alchemist Roger Bacon wrote about it in the year 1260. Eventually, people in Europe and the Middle East used black powder to invent cannons.

Aside from fireworks, the use of black powder for peaceful purposes was slower to develop. By the 1800s, black powder was being used in engineering projects such as making cuts in rock for railroad construction. This was dangerous business, as black powder could often ignite prematurely, posing a serious risk for the workers who set and detonated the explosive charges. During the construction of the U.S. transcontinental railroad, many Chinese workers were killed in black powder accidents while blasting tunnels and cuts through California's Sierra Nevada Mountains.

Nitroglycerin proved to be a powerful and useful explosive during the same time period, but it suffered from the same problems as black powder, specifically that it was dangerous to handle. A shock could easily set it off, making it difficult to transport, especially in an age where smooth, paved roads were few and far between. Swedish chemist Alfred Nobel solved this problem by mixing nitroglycerin with diatomaceous earth, a form of silica, to form a paste that was much safer to handle. Nobel's dynamite was much more resistant to shock than straight nitroglycerin, and quickly become a popular explosive for civil engineering projects as well as for military use.

Another explosive was discovered by accident in 1846 when Swiss chemist Christian Schönbein accidentally spilled nitric acid on a piece of cotton. The resultant nitrocellulose found many uses. As one of the first moldable plastics to see widespread use, nitrocellulose was used to make shirt collars, billiard balls, and photographic film. However, being flammable and explosive, its use in photographic film often led to movie theater fires as nitrate film was ignited by the heat of projector bulbs. In the western U.S., there were accounts of billiard balls popping explosively on the break, hurting no one but sending cowboys reaching for their six guns. The explosive nature of nitrocellulose was quickly harnessed, and “gun cotton” soon replaced black powder as a propellant for firearms, from handguns to heavy artillery. The main advantage of nitrocellulose was that it burned without smoke, unlike black powder.

Trinitrotoluene was prepared by Joseph Wilbrand in 1863, but its roots go back to 1788, when Haussmann first prepared a similar compound, picric acid, or trinitrophenol. Picric acid is a powerful explosive, but unstable and dangerous to use. Trinitrotoluene is much more stable, and is in fact rather difficult to detonate. It requires a detonator explosive, such as lead (II) azide. (Interestingly, chemists are currently researching “green explosives” which do not contain lead.)

Connections to Chemistry Concepts

1. **Chemical reactions and reaction types**—All explosives work by undergoing chemical reaction. TNT for example, decomposes to nitrogen, water, carbon monoxide, and carbon. What’s more, many explosions are decomposition reactions, including the explosive reaction of TNT.
2. **States of matter**—Explosives work by rapidly producing gases when they react. In addition, dogs can smell the breakdown products of TNT because they are more volatile and can enter the gas phase.
3. **Stoichiometry**—All other things being equal, the more moles of gas an explosive produces, the more forcefully it will explode. For example, 2 moles of TNT produces a total of 15 moles of various gases (3 moles N_2, 5 moles water vapor, and 7 moles CO).
4. **Biochemistry**—Odorants couple with receptor proteins in the nose of a dog (or any other animal), following the same lock-and-key mechanism seen in many protein-substrate interactions. The same principle is at play in enzymatic catalysis.
5. **Entropy and thermodynamics**—In most explosives, a few solid or liquid molecules react to form a larger number of smaller gaseous molecules. This makes explosive reactions entropically favored on two counts. First, entropy is generally increased when large molecules break down into a greater number of molecules. Second, gases are generally at a higher state of entropy than solids. In addition, the enthalpy change of an explosive reaction is usually favorable too, evident by the heat given off in most explosions.
6. **Kinetics**—Explosions are by definition rapid reactions.
7. **Kinetic-molecular theory of gases**—It is only because gas molecules are constantly in motion that volatile substances from land mines can ever reach the nose of a dog.

Possible Student Misconceptions

1. **"Combustion and explosion are the same thing."** *It is possible for a chemical reaction to be both combustion and an explosion, but not all combustion is explosion. (Consider the movie "explosions" discussed above.) What's more, some explosions are not combustion. For example, the explosion of TNT is a simple decomposition reaction, and oxygen is not a reactant in the process.*
2. **"Dogs smell TNT."** *As the article states, dogs smell a volatile n impurity present in the TNT called dinitrotoluene (DNT), rather than the relatively non-volatile TNT itself.*
3. **"TNT explodes easily."** *TNT is a powerful explosive, but it is very stable under normal circumstances. TNT requires powerful detonating explosives in order to set it off.*
4. **"Volatile compounds explode easily."** *Volatility is a measure of how easily a substance evaporates. A substance that is volatile and flammable can be a serious fire hazard, but volatiles are not necessarily explosives. At the same time, TNT is in fact not very volatile, despite being a powerful explosive.*
5. **"Dogs can only smell gases."** *It is true that a substance must be airborne before a dog or any other land animal can smell it. However, substances can become airborne without evaporating. Aerosols, tiny liquid droplets dispersed in the air, can also be smelled. In addition, aquatic animals that can breathe under water can smell substances dissolved in water.*

Demonstrations and Lessons

1. "Experiment: Olfactory Fatigue"—This inquiry-based lab allows students to explore their own senses of smell, and how people can become insensitive to certain smells after a period of time. The website below includes background information on how the sense of smell works, as well as pdf files of the teacher guide and student procedure, linked at the top of the page. Created by Dr. Marjorie A. Murray for Neuroscience for Kids, from the University of Washington. http://faculty.washington.edu/chudler/chems.html
2. "Designer Molecules: Esterification"—This lab activity involves the synthesis of esters found in natural products whose odors students will be familiar with. As part of the activity, students will be asked to compare the odors of the esters with their own experiences of the odors of the natural products. This is done to emphasize the fact that many odors result from the combination of several compounds, and a major odor component by itself may not fully replicate the odor of the naturally-occurring mixture. The activity is part of the *Pharmaceutical Achievers* modules from the Chemical Heritage Foundation. http://www.chemheritage.org/EducationalServices/pharm/chemo/activity/ester.htm

3. Baking soda and vinegar "explosion."—Fill a film canister about 1/3 full with vinegar. Add a spatula tip full of baking soda and quickly cap the canister. Stand back and watch while the build-up of CO_2 gas inside the canister makes the lid pop off and fly into the air. The reaction of sodium bicarbonate and acetic acid isn't normally considered "explosive". The production of CO_2 gas isn't really rapid enough, and it must be contained in a film canister to allow enough pressure for an "explosion" to build up. Even so, this simple activity demonstrates an important aspect of an explosive reaction: the production of gases. In the interest of safety, please make sure students are several feet back from the film canister.

4. Nitrogen triiodide explosive on video—While nitrogen triiodide is easily prepared from aqueous ammonia and iodine, many school districts may frown on making and detonating explosives in the classroom these days. A safer alternative is to show this demonstration on video. The demo was featured on the PBS television program *Wired Science*, Episode 101, in a segment titled "Dangerous Science." This segment is available for viewing online. http://www.pbs.org/kcet/wiredscience/video/82-dangerous_science.html
Nitrogen triiodide exemplifies a basic principle of explosive chemistry in that it works because it easily decomposes into gaseous products. The decomposition reaction is:

$$2\ NI_3 \rightarrow N_2 + 3\ I_2$$

Student Projects

2. Investigating explosives—Assign students or groups of students different explosives and prepare reports on them. The reports should include such information as the chemical reaction of the explosive's action, and the particular application of the explosive. The reports may be in the form of written reports, presentations, or posters.

3. Investigating fragrances—Assign students or groups of students different common fragrances (such as fruits or perfumes) and ask them to report on information such as the chemical substance or substances responsible for the fragrance, whether the active compounds can be prepared synthetically, and what some other uses for those compounds might be. The reports may be in the form of written reports, presentations, or posters.

4. What else are dogs sniffing? —Assign students or groups of students different jobs done by sniffing dogs, such as drug sniffing, bomb sniffing, search and rescue, medical diagnosis, etc. Ask the students to report on what chemical compounds are smelled by the dog in each case, what concentrations the compounds are present in, and what concentrations would be necessary for humans to smell them. The reports may be in the form of written reports, presentations, or posters.

Anticipating Student Questions

2. **"Are the dinitrotoluene fumes poisonous to the dog?"** *The U.S. Occupational Safety and Health Administration (OSHA) has established a permissible exposure limit (PEL) for DNT at 1.5 milligrams per cubic meter (mg/m^3) of air for a worker being exposed to that level for eight hour work day. In the outdoors where land mine sniffing would take place, concentrations are not likely to reach these levels just from the small amounts of DNT present in the TNT in a land mine. What's more, a dog would not likely be sniffing the same land mine for eight hours straight. On the other hand, a beagle is much smaller than a human, and safe exposure levels would be proportionately lower. Even so, the concentrations of DNT in mine fields are probably below safe exposure levels.*
3. **"Why can't you just hose down a mine to keep it from exploding?"** *Water can smother combustion by removing oxygen from the fire (but don't use it on an oil fire!), but explosives don't necessarily work by combusting. TNT does not require oxygen to explode, so water would not keep it from exploding.*
4. **"Why can't dogs smell TNT?"** *Dogs can smell TNT, but as the article says, the fumes coming off a land mine are much richer in DNT than in TNT. This is because DNT sublimes faster than TNT does, that is, DNT has a higher vapor pressure. Because TNT gives off more DNT fumes than TNT fumes, it just makes more sense to train dogs to sniff for DNT, rather than TNT.*
5. **"Are there odorless explosives?"** *Yes. Acetone peroxide, the explosive used in the July 7, 2007 London Underground and bus bombings, has little odor and has long been difficult to detect with sniffing dogs. However, because this explosive is so unstable, it is unlikely to be used in land mines.*

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The Nobel Prize in Physiology or Medicine 2004: http://nobelprize.org/nobel_prizes/medicine/laureates/2004/index.html

Brown, G. I. *The Big Bang: The History of Explosives*. Sutton Publishing, 2000.

Fenichell, Stephen. *Plastic: The Making of a Synthetic Century*. Harper Business, 1997.

Serpell, James ed. *The Domestic Dog: Its Evolution, Behaviour, and Interactions with People*. Cambridge, UK: Cambridge University Press, 1996.

"The Dog's Sense of Smell"—from the Alabama Cooperative Extension System, a service of Alabama A&M and Auburn Universities. http://www.aces.edu/pubs/docs/U/UNP-0066/UNP-0066.pdf

Web sites for Additional Information

More sites on the sense of smell

Nobel Prize in Physiology or Medicine 2004 Illustrated Presentations —This visual tutorial explains how the sense of smell works in an easy-to-follow manner, from the Nobel Foundation.
http://nobelprize.org/nobel_prizes/medicine/laureates/2004/illpres/

Sense of Smell Institute—The official site of the educational arm of the industry group the Fragrance Foundation contains information and news on the science of smell.
http://www.senseofsmell.org/

“Can Dogs Smell Cancer?” —This news story about how dogs can help diagnose cancer by smelling characteristic tumor odors before the cancer can be detected by conventional means comes from *Science Daily.*
http://www.sciencedaily.com/releases/2006/01/060106002944.htm

More sites on land mines

International Campaign to Ban Landmines—This is the official site of the organization aiming to ban land mines by international treaty.
http://www.icbl.org/

“Land Mines: A Deadly Inheritance” —This description of how land mines have affected children living in zones of current and past conflict emanates from the United Nations Children’s Education Fund (UNICEF).
http://www.unicef.org/graca/mines.htm

How Landmines Work—Technical descriptions of land mine operation come from HowStuffWorks.com.
http://www.howstuffworks.com/landmine.htm

More sites on explosives

Versatile Explosive—This site from Los Alamos National Laboratory explores explosives in all their uses, from rockets to air bags, and the chemistry that makes them go bang.
http://www.lanl.gov/quarterly/q_sum03/explosives.shtml#airbags

“Why is Nitroglycerin Explosive?” —Part of General Chemistry Online! created by Fred Senese at Frostburg State University.
http://antoine.frostburg.edu/chem/senese/101/consumer/faq/nitroglycerin.shtml

“Acetone Peroxide - Ordinary Ingredients for an Extraordinary Explosive” —This news story abut the explosives used in the July 7, 2005 London Underground bombings comes from *Chemistry World*, a publication of the Royal Society for Chemistry.
http://www.rsc.org/chemistryworld/News/2005/July/20070502.asp

“Green Explosive is a Friend of the Earth” —news story abut lead-free detonator explosives, from *The New Scientist*, March 27, 2006.
http://www.newscientist.com/article/dn8903-green-explosive-is-a-friend-of-the- earth.html

“The Halifax Explosion” — The Canadian Broadcasting Corporation provides a website telling the story of an explosion that resulted from the collision of two ships carrying military explosives in Halifax harbor in 1917.
http://www.cbc.ca/halifaxexplosion/

Emma Perry Carr: Fostering Teamwork to Study Organic Molecules

Background Information

More on Carbon-Carbon Double Bonds

There are different approaches to predicting the behavior of electrons in carbon-carbon double bonds. In many of them, the carbon-carbon double bond is formed from the combination of π-orbitals in the two carbon atoms joined by the double bond. The two π-orbitals, with parallel orientation, combine to form two molecular orbitals, called the π-bonding and the π-antibonding orbitals, also known as π and π^*, respectively. The π-bonding orbital consists of two lobes, one directly above the axis of the bond, and one directly beneath it, and the two lobes are of opposite phase. The π-antibonding orbital consists of four lobes extending outward from the two carbon atoms, aligned in the plane of the π-bonding orbitals. The π-bonding orbital is lower in energy than the π-antibonding orbital. In the ground state, the two electrons of the π bond exist in the π-bonding orbital, while in the excited electronic state, one electron has been promoted from the π-bonding to the π-antibonding orbital. Visual depictions of these orbitals can be seen at "Molecular Orbitals in Conjugated Systems" (http://www.chem.ucsb.edu/~kalju/chem109C/DielsAlder.html), created by Kalju Kahn at the University of California Santa Barbara. For a more in-depth visual tutorial of this subject, please visit "Conjugated Systems" (http://www.utdallas.edu/~biewerm/15total.pdf) created by Michael C. Biewer at the University of Texas at Dallas. (This site takes a while to load; it's a 44-page pdf file.)

More on C*is-Trans* Isomerism of Double Bonds

Emma Perry Carr used ultraviolet-visible spectroscopy to gain insight into the stereochemistry of molecules containing carbon-carbon double bonds. While the *cis-trans* isomerism of simple alkenes may seem rather arcane, *cis-trans* isomerism is central to a lot of chemistry of practical real-world importance. For example, trans fats have been in the news a lot lately because they have been linked to increased risk of heart disease and other illnesses. Trans fats get their name because they contain carbon-carbon double bonds with trans stereochemistry. Meanwhile, the monounsaturated and polyunsaturated fats, the so-called "good fats" that are linked to lower rates of heart disease, contain carbon-carbon double bonds with *cis*-stereochemistry.

Cis-trans isomerism is also important when making synthetic rubber. Natural rubber made from the sap of *Hevea brasiliensis* trees is still a very important material, but a synthetic rubber called styrene-butadiene rubber (SBR) is also used for many of the same applications (tires, shoe soles, racquetballs, etc.). Natural rubber is an excellent material, but when bad harvests or other vagaries of agriculture send natural rubber prices up, SBR might be more economical, and just as good. SBR was first developed during World War II, when the Japanese conquest of what is now Malaysia cut off the Allies' supply of natural rubber grown in Southeast Asian rubber plantations.

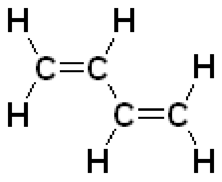
Natural rubber is a polymer called *cis*-polyisoprene. Its molecules contain thousands of carbon-carbon double bonds with *cis*-stereochemistry. *Trans*-polyisoprene is a stiff rigid material that also occurs in nature, and is commonly known as gutta percha. Chemists making SBR (as well as synthetic polyisoprene) need to use clever catalytic chemistry to ensure that their product contains mostly *cis*- rather than *trans*- double bonds.

Vision depends on the conversion of a *cis*-isomer into its corresponding *trans*-isomer. In the eye, light interacts with a compound called 11-*cis*-retinal. This compound contains four double bonds, three *trans*- and one *cis*-. Light causes the *cis*- double bond to convert into a *trans*- double bond. This starts a series of reactions which creates an electrical impulse that is carried through the optic nerve to the brain. These signals are then converted into images in the brain.

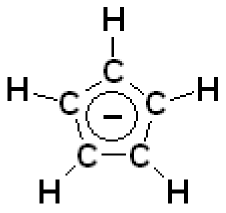
Melting points are also affected by *cis*-*trans* isomerism. Since *trans*-isomers are often more symmetrical than their *cis*- counterparts, *trans*-isomers often pack more effectively in crystals with less void space. This can result in a *trans*- isomer with a much higher melting temperature than the corresponding *cis*- isomer.

More on Conjugation of Double Bonds

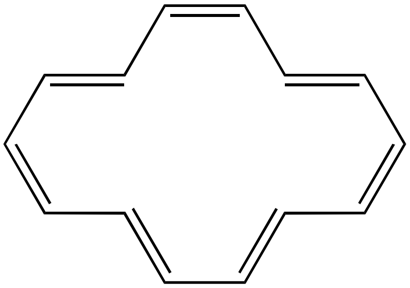
When carbon-carbon double bonds are adjacent to one another, as they are in butadiene for example, the *p*-orbitals of all four carbon atoms combine to form orbitals in which electrons are delocalized over the positions of all four carbon atoms involved in the two double bonds. This is called conjugation of double bonds, and electrons delocalized in this way have less energy and therefore more stability than they would if they were localized in two separate double bonds. That is, the delocalized orbitals are lower in energy than two localized *p*-bonding orbitals. Conjugation is only possible when the two double bonds are arranged so that the π-orbitals in question are oriented in the same direction. Like π-bonding orbitals, the delocalized molecular orbitals in a conjugated π system consist of lobes, one above the axis of the bond, and one below, and the two lobes are of opposite sign. A visualization of the orbitals in benzene can be found at http://www.chem.ucalgary.ca/courses/351/Carey5th/Ch11/ch11-4-1.html, created by Ian Hunt at the University of Calgary.



butadiene



cyclopentadienyl anion



[14]annulene

If an explanation of conjugation in terms of molecular orbitals is too advanced for your students, it may suffice to explain that adjacent double bonds are especially stable, and absorb UV at longer wavelengths than isolated double bonds (see below.)

Aromatic compounds contain special conjugated π systems that are especially stable. In an aromatic compound, the double bonds must be in a ring, they must be planar, and the number of electrons involved must number 4*n* + 2, that is, 2, 6, 10, 14, etc. Benzene is aromatic because its molecules are ring-shaped, planar, and the π system in a benzene molecule contains six electrons. Other aromatic molecules include the cyclopropenyl cation, which has two electrons in its π system, and [14]annulene, which has fourteen electrons in its π system.

Many different hydrocarbons with conjugated double bonds are found in living things. Some terpenes, such as lycopene that gives tomatoes their red color, are conjugated hydrocarbons. Beta carotene, which the body breaks down into vitamin A, also contains conjugated double bonds. This compound gives yellow color to carrots, sweet potatoes, and squash. Because conjugated π systems can interact with visible as well as ultraviolet light, conjugated compounds are often strongly colored. Many natural dyes are highly conjugated.

In addition to color, conjugation affects the electrical properties of a molecule. Polyacetylenes are polymers containing very long chains of conjugated double bonds. In addition to being brightly colored, polyacetylenes can be made to conduct electricity, which is unusual among organic polymers. Graphite, well-known for its electrical conductivity, is also highly conjugated.

More on Ultraviolet Radiation

Ultraviolet radiation, or UV, is one of many forms of electromagnetic radiation. It falls on the electromagnetic spectrum between visible light and X-rays. Like all electromagnetic radiation, UV has wave-like and particle-like properties. In its particle-like behavior, UV acts like a stream of particles called photons, which are higher in energy than photons of visible light, but which have less energy than X-ray or gamma ray photons. In its wave-like behavior, UV has wavelengths that are shorter than those of visible light, which also means it has higher frequencies than visible light. At the same time, UV has longer wavelengths than X-rays or gamma rays, which also means UV has lower frequencies than X-rays and gamma rays. While visible light has wavelengths of ~400-800 nanometers (nm), UV has wavelengths of between 1 nm and 400 nm. However, only UV with wavelengths between 200 and 400 nm is normally used in ultraviolet spectroscopy.

Ultraviolet radiation can be harmful to humans, and is especially dangerous to the skin and eyes. UV from the sun causes sunburn, suntans, and skin cancer. There is little danger of skin damage from the UV lamps used in ultraviolet spectroscopy because the technique uses narrowly focused beams of light (sometimes lasers) that strike only the sample being studied, and are contained inside the instrument housing. Even so, users of UV spectroscopes should be careful not to look directly into the UV source of the instrument, as the beam can cause eye injury.

More on Ultraviolet-Visible Spectroscopy

Ultraviolet radiation and visible light both interact with organic molecules, and are used together in the technique known as ultraviolet-visible spectroscopy, or UV-vis for short. Specifically, UV and visible light interact with organic molecules containing carbon-carbon double bonds, especially those with conjugated or aromatic π systems. For this reason, many organics with conjugated π systems are much more colorful than compounds containing no carbon-carbon double bonds. For example, beta-carotene gets its orange-yellow color from its system of eleven conjugated carbon-carbon double bonds. This π system absorbs blue and violet light, allowing orange and yellow light to pass through.

The means by which π systems in organic molecules absorb UV and visible light is through the excitation of the electrons in π bonds. UV and visible light causes electrons in π-bonding molecular orbitals to be excited to the π-antibonding (or π^*) orbital. This excitation is called a $\pi \rightarrow \pi^*$ transition. Excitations from non-bonding orbitals to *p*-antibonding orbitals, or $n \rightarrow \pi^*$ transitions, are also caused by UV and visible light. The wavelength at which the $\pi \rightarrow \pi^*$ or $n \rightarrow \pi^*$ transitions occur depends on the energy difference between the *p*-bonding and the π-antibonding orbitals, or between the non-bonding and π-antibonding orbitals. The larger the energy gap, the shorter the wavelength of UV or visible light that will be absorbed. The smaller the energy gap, the longer the wavelength of UV or visible light that will be absorbed.

Conjugation lowers the energy gap between the molecular orbitals in question. Therefore, conjugated π systems absorb radiation with longer wavelengths and less energy. For example, the highly conjugated beta carotene absorbs blue and violet light at around 400-500 nm, which has longer wavelengths and less energy than UV. Meanwhile, ethene, whose π system is not conjugated, absorbs UV radiation at around 171 nm, a much shorter wavelength with much more energy. For this reason, one of the main uses of UV spectroscopy is to study the degree of conjugation in the π systems of organic molecules.

In the absorption spectra produced in UV-visible spectroscopy, we do not see sharp peaks corresponding to precise wavelengths. Rather, the absorption peaks are broad, occurring over a range of wavelengths. However, the peaks usually do have discernible maxima, which do occur at specific wavelengths. The wavelength of the maxima of peak is referred to as λ_{max}. A compound may have more than one maximum in its UV-vis spectrum, so some compounds have sets of λ_{max} values rather than a single

λ_{max}. Whether the UV-vis spectrum of a compound contains a single λ_{max} value or a set of them, the λ_{max} values are different for every compound, providing a sort of fingerprint for identifying compounds. UV-vis alone usually isn't enough to identify a compound, but it can help narrow the possibilities, or be used with other techniques to obtain definite identifications.

More on Chemistry at Mount Holyoke College

Mount Holyoke College is a school for women located in central Massachusetts. It has long had a strong chemistry program, and has trained many excellent women chemists. In fact, the school was founded by a woman chemist named Mary Lyon in 1837. Mount Holyoke was one of the first schools where women could study science at the same level as men studied in the all-male universities of the day. Lyon took things one step further and introduced the first laboratory courses in chemistry at any undergraduate institution, whether for men or for women. To understand how revolutionary this was at the time, consider the fact that Justus von Liebig in Germany had only recently introduced laboratory training at the graduate level.

Emma Perry Carr herself strengthened Mount Holyoke's chemistry program by introducing undergraduate research in the 1910s. Among the Mount Holyoke students who went on to become important chemists in their own rights are Anna Harrison, the first woman to become president of the American Chemical Society; Rachel Brown, co-discoverer of the antifungal drug nystatin; and Jane Rideout, co-discoverer of the anti-HIV drug AZT.

Connections to Chemistry Concepts

1. **Organic chemistry**—Carr used UV-vis spectroscopy to study compounds of carbon and hydrogen.
2. **Chemical bonding**—UV-vis spectroscopy is used mostly to study compounds that contain carbon-carbon double bonds.
3. **Molecular orbital theory**—The interaction of *p*-orbitals to form π-bonding and π-antibonding orbitals is central to understanding how UV-vis spectroscopy works.
4. **Conjugation**—Conjugation of π-bonds is one of the main things studied by UV-vis spectroscopy.
5. **Aromaticity**—Aromatic compounds are also extensively studied using UV-vis spectroscopy.
6. **Stereochemistry**—UV-vis spectroscopy is useful for studying the stereochemical properties of alkenes, such as *cis-trans* isomerization. In addition, certain stereochemical requirements must be met for either conjugation or aromaticity to occur.

Possible Student Misconceptions

1. **"An object is the same color as the light it absorbs."** *In fact, it is the light that an object doesn't absorb that determines its color, because that is the light that we see reflected, or passing through an object.*

2. **"UV-vis spectroscopy tells you the structure of a molecule."** *In movies like Medicine Man, scientific instruments are shown yielding structural drawings as output. In fact, UV-vis and other types of spectroscopy must be interpreted by a scientist before a structure can be determined. In fact, a UV-vis spectrum or any other kind of spectrum alone is rarely enough to determine a structure. A combination of more than one spectroscopic technique, such as UV-vis, infrared, NMR, or mass spectroscopy are usually needed to unequivocally determine a structure.*

3. **"Emma Perry Carr discovered double bonds."** *The idea of carbon-carbon double bonds were first postulated in the 1850s and 1860s by scientists like August Kekulé in order to explain why in some compounds' carbon atoms seemed to bond with only three atoms rather than the usual four. This was long before the discovery of electrons, and it was only much later that double bonds were determined to result from the sharing of two pairs of electrons by the same two atoms. Carr's work helped us understand better the stereochemistry of organic molecules that contain double bonds.*

4. **"Aromatic hydrocarbons smell nice."** *Some aromatics do smell pleasant, but others, like benzene, not only have rather unpleasant odors but are inhalation hazards as well.*

Demonstrations and Lessons

1. "As Light Meets Matter: Art Under Scrutiny"—Case study teaching the principles of UV-vis spectroscopy by exploring how the technique is used in art authentification, created by Eleonora Del Federico, Steven Diver, Monika Konaklieva, and Richard Ludescher for the National Center for Case Study Teaching in Science at the University at Buffalo: http://www.sciencecases.org/art_under_scrutiny/art_under_scrutiny.asp

2. Beyond λ_{max}: Transforming Visible Spectra into 24-Bit Color Values"—In this activity students use spreadsheet software to determine the color of an unseen solution based on its visible absorbance spectrum. Williams, Darren L.; Flaherty, Thomas J.; Jupe, Casie L.; Coleman, Stephanie A.; Marquez, Kara A.; Stanton, Jamie J. *J. Chem. Educ.* **2007,** *84,* 1873: http://www.jce.divched.org/Journal/Issues/2007/Nov/abs1873.html

3. "Paint Analysis Using Visible Reflectance Spectroscopy"—This forensic lab activity shows how spectroscopy can be used to match paint samples found on a suspect with those taken from a crime scene. Hoffman, Erin M.; Beussman, Douglas J. *J. Chem. Educ.* **2007,** *84,* 1806: http://www.jce.divched.org/Journal/Issues/2007/Nov/abs1806.html

4. Comparing models of *cis*- and *trans*- isomers—Build or have students build models of cis- and *trans*- isomers of simple alkanes or substituted alkenes, and allow the students to examine the models to see how they are different.

5. “Spec UV-Vis: An Ultraviolet-Visible Spectrophotometer Simulation”—An online computer simulation which allows students to carry out virtual UV-vis spectroscopy. Papadopoulos, N.; Limniou, Maria; Koklamanis, Giannis; Tsarouxas, Apostolos; Roilidis, Mpampis; Bigger, Stephen W. *J. Chem. Educ.* **2001** *78* 1560. http://www.jce.divched.org/Journal/Issues/2001/Nov/abs1560.html

Student Projects

1. *Cis-trans* isomer report project—Assign students or groups of students a pair of *cis-trans* isomers, and ask them to prepare a report including differences in properties like melting point, color, flavor or odor, and toxicity. You may ask students to build models as part of the project. For a simpler variation on the project, you may simply give your students pairs of constitutional isomers, such as ethanol and dimethyl ether, rather than *cis-trans* isomers.

2. Checking for ultraviolet radiation—Give each student UV-sensitive beads of the kind available from many science supply companies. Then ask them to take them home and test various sources of light around the home to see if they give off UV in addition to visible light. http://www.chemheritage.org/EducationalServices/FACES/env/activity/beads.htm

3. Investigating aspects of ultraviolet radiation—Assign students or groups of students to investigate a different use for ultraviolet radiation. In addition to the chemical applications of UV-vis spectroscopy, students can investigate ultraviolet astronomy, the use of UV in water purification, the role of UV in solar power generation, UV and skin cancer, etc. You may ask students to present their findings as written reports, presentations, posters, or some other format.

Anticipating Student Questions

1. **“Why is UV radiation better than other light for studying molecules?”** *Actually, lots of different kinds of electromagnetic radiation are used to study molecules. UV, visible, and infrared are all used in different kinds of spectroscopy. FM-frequency radio waves are used in nuclear magnetic spectroscopy. At the other end of the spectrum, X-rays are used in X-ray fluorescence spectroscopy. Different kinds of radiation are useful for giving us different kinds of information about the substances being studied.*

2. **“Why does it matter whether an alkene is *cis-* or *trans-* ?”** *Cis- and trans- isomers can have very different properties. For example, “trans” fats can be very bad for your health, while comparable cis- monounsaturated fats can be very good for your health. In your eyes, the conversion of a cis- compound to a trans- isomer is the first step in the generation of nerve impulses that your brain interprets as images.*

3. **“Is UV spectroscopy dangerous?”** *While UV radiation is responsible for sunburns and can cause skin cancer, UV spectroscopy is carried out with very focused beams of light that rarely strike anything but the sample being studied.*

4. **“What happens to the energy of UV radiation once it has been absorbed by a molecule?”** *UV radiation is absorbed by the electrons in a molecule. Double bond electrons are especially good at absorbing UV radiation. When this happens, the electrons move into orbitals of higher energy. The electrons then move with more energy. This additional energy was the energy of the UV radiation; that is, the UV energy was transformed into the energy of moving electrons. Eventually, the electrons move back into their ground state orbitals, giving up the extra energy as light, or dispersing it as thermal energy.*

5. **“Why can’t carbon atoms rotate around double bonds?”** *A carbon-carbon double bond can be thought of as being formed from the overlap of two* sp^2 *orbitals (one from each carbon atom) oriented along the axis of the bond, and the overlap of two p-orbitals (one from each carbon atom). The two p-orbitals overlap above and below the axis of the bond, and the two p-orbitals must be lined up parallel to each other to overlap. If the two carbon atoms rotated relative to each other, the p-orbitals would no longer be parallel, and they couldn’t overlap. This is to say that rotating the two carbon atoms relative to each other would break the π-bond formed by the two p-orbitals. This would require a lot of energy, and usually only happens when the molecule is exposed to light, heat, or a catalyst.*

References

March, Jerry. *Advanced Organic Chemistry*, 4th ed., New York: Wiley, 1992, pp. 6-72.

Pavia, Donald L.; Lampman, Gary M.; and Kriz, George S. Jr. Introduction to Spectroscopy: A Guide for Students of Organic Chemistry. Philadelphia: Saunders, 1979.

How Vision Works—from HowStuffWorks.com
http://www.howstuffworks.com/eye2.htm

Web sites for Additional Information

More Sites on Ultraviolet-Visible Spectroscopy

“Visible and Ultraviolet Spectroscopy”—one in a series of in-depth tutorials covering many types of spectroscopy, created by William Reusch at Michigan State University.
http://www.cem.msu.edu/~reusch/VirtualText/Spectrpy/UV-Vis/spectrum.htm

More Sites on Emma Perry Carr

Mount Holyoke College Archives and Special Collections Manuscript Register. Carr, Emma Perry, papers, cs. 1902-1986. Manuscript collection MS-0517—For those interested in researching deeper into the life and work of Emma Perry Carr, her papers are stored in the archives of Mount Holyoke College. A description of the holdings is found at the website below. http://www.mtholyoke.edu/lits/library/arch/col/msrg/mancol/ms0517r.htm

Mary Lyon and Emma Perry Carr—two biographical sketches, part of *Her Lab in Your Life* from the Chemical Heritage Foundation. http://www.chemheritage.org/women_chemistry/know/lyon_carr.html

More Sites on Chemistry at Mount Holyoke

Mary Lyon on the Web—extensive site profiling the 19th-century chemist and educator, created by Mount Holyoke College. http://www.mtholyoke.edu/marylyon/

Mount Holyoke College Chemistry Department—Official site with profiles of faculty and their research interests, http://www.mtholyoke.edu/acad/chem/

General Web References

Organic Chemistry Helper—extensive website with tutorials and more, from Frostburg State University: http://www.chemhelper.com/

More Sites on Teacher Information and Lesson Plans

Smile Program Chemistry Index—listing of chemistry lesson plan ideas, compiled by the Illinois Institute of Technology: http://www.iit.edu/~smile/cheminde.html

The Chemistry of Arson Investigation

Background Information

More on arson in the United States

The FBI provides some data about arson in the United States:

- Nationally, 69,055 arson offenses were reported in 2006.
- Arsons involving structures (residential, storage, public, etc.) accounted for 42.3 percent of the total number of arson offenses. Mobile property was involved in 28.2 percent of arsons. The rest were arsons of other types of property.
- The average value loss per arson offense was $13,325.
- Arsons of industrial and manufacturing structures resulted in the highest average dollar losses (an average of $66,856 per arson).
- The rate of arson was 26.8 offenses for every 100,000 inhabitants of the United States in 2006. http://www.fbi.gov/ucr/cius2006/offenses/property_crime/arson.html

According to FEMA's U. S. Fire Administration these are the data on arson:

Year	**Fires**	**Deaths**	**Loss ($ millions)**
1997	78,500	445	1,309
1998	76,000	470	1,249

1999	72,000	370	1,281
2000	75,000	505	1,340
2001[1]	45,000	330	1,013
2001[2]	--------	2,451	33,440
2002	44,500	350	919
2003	37,500	305	692
2004	36,500	320	714
2005	31,500	315	664
2006	31,000	305	755

[1] Excludes the events of September 11, 2001.

[2] These estimates reflect the number of deaths, injuries, and dollar loss directly related to the events of September 11, 2001.

It should be noted as your students read this article that arson fires and their investigation require a complex analysis of dozens of interrelated factors. The clues presented in the article are just the highlights. This also points up the difference between investigations carried out in a lab setting and the same investigations carried out in a natural environment.

All scientific investigations try to identify and isolate individual variables, and students should learn how to do this. In fact, one of the leading agencies on fire investigations, the National Fire Protection Agency, compares fire investigation to using the scientific method. NFPA notes in its Publication 921 “A Guide for Fire and Explosion Investigations,” (2004) that fires are complex events and that in the investigation it is important to gather data (evidence). NFPA notes that fires destroy much of this evidence. (See Web Sites for Additional Information, below, for the online version of this document.)

Chemistry teachers might compare this concept to a long trail of interrelated chemical reactions which have products that have “used up” or “destroyed” the original starting material and intermediates. Planning ahead to test and identify and to know the possible products and then be able to work back to the beginning is built into a fire investigation. Students should also understand, however, that when investigations of many types—crime scenes, arson, public health, insurance fraud, etc.—take place in society and the natural world, it is often difficult to isolate the variables and more difficult to attribute causation to any of them.

In that same report, (NFPA 921), NFPA also notes the importance of safety for its investigators. Safety in the lab, like safety at an arson scene, should be included in all lessons in chemistry.

More on the inverted “V” pattern

The article suggests that most accidental fires begin along a wall of a room. As the fire produces heat, the heat warms the air around the burning substance and that warm air rises in the room by convection. What is often forgotten is that if the burning substance were in the middle of the room the air around it in three dimensions would be heated and would rise in an inverted cone, where the source is at the apex of the inverted cone—the V pattern. The V pattern results when a wall interrupts this three-dimensional process. The outline of the V is caused by combustion products (e.g., soot or char) being deposited on the wall. It is true that the slower the rate of combustion the wider the angle of the V. This shape of the deposited soot may not always be in the shape of a V. For example, if the fire burns in a tub or bucket, the thermal column will look more like a cylinder than a V.

In the case of an arson fire, however, it is likely that an accelerant is used to start the fire. In this case the rate of combustion will be greatest across the surface of the accelerant, which has probably been spread over a significant area. In this case the char pattern will be wider at the bottom and narrower as the combustion products get farther from the source. This means the shape of the deposited combustion products will be in the shape of an inverted V, with the wide part at the bottom. However, an inverted V can also be the result of a fire that burned only for a short time and is not at all related to the use of accelerants. For example, if there is a gas leak from the floor below which burns for only a short time, the combustion will produce an inverted V on a wall.

Arson investigators are cautious in "reading" char patterns like the V or inverted V because a fire in a confined space will interact with walls and ceilings to distort simple patterns. If there is flashover, for example, the fire will actually burn downward from the ceiling, thus reversing expected patterns. If an accelerant is used, it may ignite other combustible material in the room, producing interacting V patterns. Arson investigators must take into account multiple sources of evidence as they attempt to determine the cause of the fire.

For photos illustrating "V" patterns in arson, see http://www.interfire.org/res_file/patterns.asp.

More on how fires spread

A fire, arson or not, spreads by means of one of the normal methods of heat transfer—conduction, convection or radiation. Fire investigators use heat transfer methods to analyze the cause and spread of a fire.

By far the most important method is convection, which is the method by which hot gases are moved upward from the source of burning. This updraft is called a plume. Fires can spread this way very rapidly, as fast as an equivalent speed of 65 miles per hour. As heated gases come in contact with solids in the room, heat is transferred to the solid, and if the temperature of the solid is increased sufficiently, it will ignite. At the same time cooler air is drawn in near the base of the plume, delivering more oxygen to the process.

If the fire begins in the center of a room—not often the case since there are typically fewer combustibles in the center of a room—the plume is three dimensional. However, if the fire begins against a wall, the plume is cut off on one side (see More on the V Pattern). In a corner of a room the plume may be reduced by as much as three quarters. The latter two cases mean that the rate of spreading is probably slower.

The hotter room temperatures become, the more radiation plays a role. As in all cases, heat is transferred from the area with a higher temperature to an area of lower temperature. For example, wood ignites at temperatures ranging from 190°C to 260°C, depending on the type of wood. Ignition temperatures of other common materials include paper (233°C) and leather (212°C). Heat transfer from gases to solids depends on the temperature difference, the area of the solid exposed to the gas and the velocity of the heated gas.

In a heated solid, heat is transferred by conduction. The heat transfer properties of solids are ones that chemistry students may be familiar with—density, heat capacity and (to a lesser extent) thermal conductivity. Solids with low heat capacities conduct heat easily. Solids with high densities conduct better than those with lower densities. And high thermally conductive materials obviously conduct heat easily. Metals, for example, have high thermal conductivities. In addition to spreading by convection, fires are spread by conduction. Arson investigators look for things like fire spreading along a metal beam or along a pipe in a wall. Some examples of these properties for substances that might be involved in a fire:

Substance	**Thermal Cond. (W/m x K)**	**Density (g/mL)**	**Heat Capacity (J/g x °C)**
Copper	387	8.9	0.38
Concrete	0.8-1.4	2.0	0.88
Gypsum plaster	0.5	1.4	0.84
Oak	0.2	0.8	2.38
Pine	0.1	0.6	2.85
Polyethylene	0.4	0.9	1.90
Polystyrene	0.1	1.1	1.20
Polyurethane	0.03	0.02	1.40

Radiation is not often considered in relation to arson fires, but does play a role. For example, as hot gases collect at ceiling level in a burning room, they may radiate sufficient heat to cause flashover. Flashover occurs when hot gases at ceiling level in a burning room reach approximately 590°C. At this temperature the gases radiate heat to combustible materials in the room. Fire causes solids to break down into combustion products in a process called pyrolysis. Some of these products are gases, which are ignited instantly by the radiant heating from above. A sudden rapid combustion engulfs the room.

The spread of arson fires and the consequent heat transfer are also related to the temperature of the burning substances and the temperature differential. For example, in a building fire the gases near the ceiling may be at a temperature of 600°C or more while the temperature at floor level is less than 200°C. This case is especially significant because under these circumstances flashover will occur. That is, heat will be transferred rapidly to combustibles at floor level and these materials will then ignite and burn.

The amount of heat produced and the rate of production are also important to consider. Students should know about heats of reaction, in this case heat of combustion. You may have already discussed this with students, in which case the article provides a good application of the concept. Textbooks often give heats of combustions for familiar elements and compounds. Here are some examples for substances related to fires:

Substance	**Heat of Combustion (kJ/g)**
Paper/wood	13.9 - 16.3
Coal	27.7 - 30.2
Liquid accelerants	37.2 - 48.6
Flammable gases	46.4 - 51.1

More on accelerants

An accelerant is any substance that is used to initiate or promote the spread of a fire. The most common accelerants are flammable organic liquids. Most are also less dense than and not miscible with water and so will produce a "rainbow" effect on puddled water at a fire scene. Investigators look for these kinds of clues. Accelerant liquids form vapors that are flammable, and this is important to note because only the vapors actually burn. When accelerants are poured on a floor, for example, and ignited, the flooring under the liquid pool is protected from burning by the accelerant liquid. The pool burns from the edges in and so exposed flooring will burn in the shape of the edge of the receding pool. Investigators use this fact when looking for the point of origin of a fire. This sequence of events produces the "halo" effect.

Accelerant vapors are also typically denser than air and so will travel down stairways and through cracks and crevices. Most are also good solvents and so will dissolve substances like floor waxes, polishes and adhesives.

The most common substances used as fire accelerants:

Acetone—dimethyl ketone, 2-propanone (C_3H_6O)
Carbon Disulfide—carbon disulfide (CS_2)
Coleman fuel—Coleman fuel C-2538, white gasoline
Ethyl alcohol—ethanol, grain alcohol (C_2H_5OH),
Ethyl ether—ether, diethyl ether $(C_2H_5)_2O$
Fuel Oil No. 1—kerosene, range oil, coal oil
Fuel Oil no. 2—home heating fuel, diesel fuel
Gasoline—gas, motor fuel
Isopropyl alcohol—(isopropanol, 2-propanol ($CH_3CHOHCH_3$)
Kerosene—same as Fuel Oil No. 1
Lacquers—like shellac
Lacquer thinner
Methyl alcohol—methanol, wood alcohol (CH_3OH);
Methyl ethyl ketone—2-butanone ($CH_3COCH_2CH_3$)
Paint thinner—mineral spirits
Toluene—methylbenzene, phenylmethane ($C_6H_5CH_3$);
Turpentine—oil of turpentine ($C_{10}H_{16}$)
Xylenes—dimethylbenzene $C_6H_4\ (CH_3)_2$

The property called flash point is one of the most important properties of substances used as accelerants. Flashpoint is the lowest temperature at which the liquid produces a sufficient concentration of vapor above it that it forms an ignitable mixture with air. The lower the flashpoint, the easier it is for vapor to form above the liquid. You might consider correlating this property with vapor pressure and with boiling point. Flashpoints of a few common accelerants:

Substance	**Flash Point (°C)**
Acetone	-20
Turpentine	35
Alcohol	13
Paint thinner	39

As mentioned above, it is not the liquid accelerant that burns, but the vapor produced by the liquid. When sufficient vapor forms above a liquid, it is said to be in its flammable range. This is the range of concentrations of vapor in air of a flammable substance necessary for combustion to occur. The lower concentration is called the lower explosive limit (LEL) and the greater concentration is called the upper explosive range (UEL). Also, the liquid must be at its flash point and there must be an ignition source available for combustion to occur.

Substance	**Flammable Range (%)**
Gasoline	1 - 6
Aromatic hydrocarbons	1 - 7
Ketones	2 - 12
Natural gas	5 - 15
Esters	1 - 9
Amines	2 - 14
Alcohols	1 - 36
Ethers	2 - 48
Aldehydes	3 - 55
Acetylene	2 - 85

Flashpoint and flammable range must be combined with knowledge of ignition temperatures in order to understand the mechanism of accelerant use in fires. Listed below are a few common ignition temperatures and the temperatures of some common substances that cause fires in homes (plus the Bunsen burner for classroom reference).

Ignition temperatures		**Common ignition sources**	
Substance	Ignition Temp. (°C)	Substance	Temp. (°C)
Wood	200	Lighted cigarette	288
Fuel oil #1	229	Lighted match	800
Paper	233	Candle flame	600
Gas (60 octane)	280	Electric stove	550
Acetylene	299	Fluorescent light	80
Propane	466	Incandescent light	100
Wheat flour	398	Electric arc	1,093
		Bunsen burner	1,570
		Lightning	30,000

On a fire scene, the investigator has a number of tools available to detect the presence of accelerants. This first is a well developed sense of smell. Olfactory detection is useful early in the investigation, but our sense of smell deteriorates rapidly in the presence of many hydrocarbons. In addition, many of these vapors are harmful. Portable gas detection instruments are also often used, although these vary in sensitivity and reliability. Many instruments simply monitor the change in oxygen concentration and cannot, therefore, distinguish between different accelerants. Students may also be aware of "sniffer dogs" which are trained to detect vapor from accelerants at fire scenes. More recently, portable gas chromatographs have been developed for use at the site of a fire. There are also chemical test systems that can be used to detect vapors on site, but these are not frequently used, in part because they are not very discriminating and because they are not very reliable when done on site.

More on point of origin and degree of burning

The article says that the determining the point of origin and the degree of burning are solid arson clues. They are closely related and so are considered together in this section of the Teachers Guide.

As the article says, finding the point of origin of a fire is important because other clues about the fire's origin will likely be near this area. The article mentions that multiple points of origin are a clue to arson. However, it is important for investigators to determine if objects were moved in the area during fire suppression. Firefighters often must move objects in a room to better fight the fire. If material originally located near the ceiling of the room burns and then drops to the floor during the fire, it might look like a point of origin. This is a big part of the arson investigator's task—deciding on the order of events.

If there is a sharp line of demarcation between areas affected by the fire and those not affected, this may indicate a fast-moving, high-temperature fire. Such differences give clues about the path of the fire and its origin. Another clue, as the article suggests, is the charring pattern. Charring is simply the result of pyrolysis leaving carbon on the surface of burned wood. By measuring the depth of charring and comparing that to the original wood, investigators get an idea about the length of time the fire burned. The article gives the char rate for ordinary building lumber—one inch for every hour of burn time. This rate, however, is dependent on a host of other variables such as ventilation, direction of wood grain, moisture content of wood and the original surface coating, if any. Charring is a good tool to determine the spread of the fire. By taking char measurements at different places at a fire scene, investigators can often trace the route of the fire back to its origin.

Arson investigators can use their knowledge of what happens to substances at varying temperatures to work backwards to relate temperature, degree of burning and point of origin. For example, it is known that wood chars at temperatures between 120°C and 150°C, but ignites at temperatures above 190°C. By examining both char and burn patterns, investigators can trace the path of the fire.

Investigators can examine melted substances on the scene to track temperature changes and the path of the fire. For example, acrylics, like fibers or Plexiglas, melt at temperatures between 91°C and 125°C. If an object made of acrylic is found melted at a fire scene, investigators can deduce upper temperature limits in that area.

Spalling is a condition produced in concrete, masonry and brick as a result of exposure to fire. The surface is discolored and may be pitted. Spalling had been one clue that investigators always looked for, but recent testing indicates that it may not be a reliable arson clue. Gypsum wallboard and plaster are also affected in a predictable way by fire. Gypsum wallboard becomes discolored when exposed to fire. The depth of the discoloration gives a clue to exposure to fire. Both plaster and wallboard also lose water from their molecular structure at a known rate. The article mentions the distortion of glass by fire as a clue to where the fire started and how it traveled. Depending on the type of glass and the specific meting pints involved, the arson investigator can determine how hot and how long the fire burned.

Locating the presence of accelerant residue can pinpoint the origin of a fire. Samples of residue-containing materials are collected at the scene and taken to a lab for analysis (see More on laboratory analysis, below). The article suggests also that finding multiple points of origin indicates arson. If an accelerant is used, it is sometimes spread throughout a location so that it can be ignited from a single location. Arson investigators look for the resulting increased burning where the accelerant was spread to help determine the point of origin.

A slow-burning fire will often leave fairly uniform damage on walls and ceilings. Painted surfaces will have a baked look. There will be smoke stains around and on windows. In a fast-moving fire, on the other hand, there will often be severe ceiling damage, the V or hour glass patterns on walls, extensive charring on wood surfaces and a sharp line of demarcation between burned and unburned areas, as the article says.

If there are eyewitnesses to the fire who can describe the color of the smoke and flame, this information can give clues to the fire. For example, here are colors of smoke and flame from early stage fires. These colors only apply at the beginning of a fire.

Substance	**Smoke**	**Flame**
Wood/paper	Gray to brown	Red to yellow
Gasoline	Black	Red to white
Turpentine	Black to brown	Yellow to white
Kerosene	Black	Dark red to orange yellow

Flame color can also indicate the temperature of the fire and, therefore, give clues to what is burning. The color differences are not easily distinguished and so are only guides. In general, the lighter the flame color, the hotter the flame temperature.

Flame Color	**Temperature (°C)**
Light red	900 - 1000
Bright red	1400 - 1500
Orange	1700 - 1880
Light yellow	1900 - 2100
White	2150 - 2250

More on arson laboratory analysis

Lab analysis of arson evidence begins at the scene. Investigators are trained to collect samples very carefully on site since the ensuing lab analysis can be severely compromised if samples are not collected properly. Investigators know that many accelerants have burned away by the time investigators reach the scene. So they are trained to look within burn patterns at locations where excess accelerants may have collected and not burned. Looking in the lowest areas, like drains, and most isolated areas may find some residue. Any porous material, like cloth, fibers, carpet, cloth, paper or cardboard, is also sampled. Another important location is around the edges of the burn pattern where unburned accelerant may remain. In some cases where removing an accelerant sample might be difficult, the investigator captures the remnant liquid using an absorbent like diatomaceous earth or industrial absorbents. Most samples are stored in metal paint cans for maximum protection.

In the lab, the samples are heated and removed from the can and transferred to a vacuum chamber where the vapors are trapped in a charcoal tube. The vapors are then dissolved in a solvent and transferred to the analytical instrument.

The article says that the most often used analytical instruments are the gas chromatograph and mass spectrometer. These instruments allow investigators to identify the accelerants. Other instruments used in arson cases include high performance liquid chromatography, and the scanning electron microscope.

Connections to Chemistry Concepts

1. **Safety**—The article mentions that arson investigators must be concerned about their safety as they search through the remains of suspicious fires. This is a good connector to classroom laboratory safety for students.
2. **Combustion/Oxidation**—Since this article is about arson, it provides a good opportunity to connect to combustion as an example of an important chemical reaction. The article includes combustion basics, and you can expand on related ideas easily.
3. **Thermochemistry/Thermodynamics**—Heat production, the rate of heat production and methods of heat transfer are important topics in arson investigation. You can highlight these with students and relate these to traditional thermochemical and thermodynamics topics.
4. **Physical Properties of Matter**—Many of the physical properties of matter, like vapor pressure, specific gravity, density and thermal conductivity are important to arson investigations. The article will allow you to integrate them into discussions of chemistry topics.
5. **Investigation in Chemistry**—It is sometimes difficult to find good applications of how a scientific investigation is conducted. This article and arson investigations can provide a model for you to teach students basic characteristics of a good scientific investigation.
6. **Forensic Chemistry**—Many students are motivated to study chemistry when it is set in the context of forensics. This is not only a good way to motivate students but also a good opportunity for you to discuss careers in chemistry.

Possible Student Misconceptions

1. **"Flammable solids and liquids burn readily—take gasoline, for example."** *As cited in the Background Information section, usually it is only gases or vapors that burn, not solids and liquids. Liquid gasoline, for example, does not burn readily. Gasoline volatilizes easily due to its high vapor pressure; it is the vapors of gasoline that ignite easily and burn. It is only these vapor (gaseous) molecules that come in contact with oxygen molecules at a sufficient rate to allow combustion. Even in a candle, which is solid, the wax fuel must first melt and then vaporize before it can burn. It is only the vapors which come in contact with gaseous oxygen molecules at a sufficient rate to maintain the combustion process.*

> *In the case of solids and liquids that do burn, these fuels only burn on their surface, since it is only at the surface that the oxygen molecules from the air collide with the fuel. And substances with greater surface area will burn more rapidly for the same reason. Think about the rate of combustion of kindling —or sawdust—vs. that of a large log. The log only burns on its surface (which is true for the kindling or sawdust, also, except that these have much greater surface area). This is why a log burns much longer than the same volume (or even mass) of kindling. Dust explosions are the extreme example of this phenomenon.*

2. **"Arson only occurs in cities."** *This is not true, although metropolitan areas do have a higher rate of arson than suburban and rural communities, and there are more arson cases in urban areas. But if we use as a measure of arson cases the rate per 100,000 people, large cities have a rate of 44.5, typical suburban communities have a rate of 25.6 and more rural areas have a rate of 21.5 (2006 data.) In addition, 2006 FBI data shows, arson cases are increasing more rapidly in less populated areas.*

3. **"Arson investigations have always been based on scientific evidence."** *As recently as 1977, the U.S. Department of Justice issued a guide to arson investigation that contained inaccurate information. Arson investigators then were not certified and there was no body of scientific knowledge to support investigative techniques. For example, arson investigators used to test for accelerants by tasting residue at the scene, a method that is not reliable, and potentially fatal.*

4. **"Arson crimes are increasing."** *This may be a perception students have, but it is not true. The FBI reports indicate slightly decreasing number of arson cases annually. In fact, in 2006, arson cases were at an all-time low.*

5. **"Arsonists burn buildings to collect insurance, and arson cases increase in difficult economic times."** *Although it is clear that some individuals commit arson in order to collect insurance, there are no data to support a larger trend. In fact, in the recession of 1982, arson crimes decreased.*

Demonstrations and Lessons

1. You can do any number of chemical analysis labs that relate to arson. One example is here: http://educ.queensu.ca/~science/main/concept/gen/g09/J.%20Heal/arson.htm.
2. For a NASA unit on combustion see http://astroventure.arc.nasa.gov/teachers/pdf/AV-Atmoslesson-5.pdf. You may already have combustion labs in your course's lab manual. Students can test for the products of combustion using limewater and cobalt chloride paper, etc.
3. Many of you are familiar with the Faraday's paper "The Chemical History of a Candle" and the lab activity "Observations on a Burning Candle" from the ChemStudy series. One such procedure is here: http://boomeria.org/labschem/exper1.pdf. It might be of interest to compare those experiments with information provided in this paper from the National Institute of Standards and Technology: Characterizations of Candle Flames." http://fire.nist.gov/bfrlpubs/fire05/PDF/f05141.pdf.
4. A case study on arson lab analysis is given here. The lab work is aimed at the college level but you might be able to adapt it. http://www.sciencecases.org/burning_house/burning_house_notes.asp
5. Detecting odors at a possible arson scene is important. You can do a simple odor bar to test student's ability to detect odors. A sample that uses relatively safe materials can be found here http://media.nasaexplores.com/lessons/03-055/5-8_1.pdf.
6. Several vendors of calculator- or computer-based probes sell thermocouples that can be connected to your calculator or computer to indicate temperatures more extreme than the normal laboratory temperature probe. You might want to try using them to show students the differences in temperature among burning fuels, such as candle vs. Bunsen burner vs. alcohol lamp. Use proper safety precautions. See http://www.vernier.com/innovate/innovativeuse46.html for an example of an activity using the thermocouple to show changing temperatures within different parts of a flame.

Student Projects

1. Students can read sections of the Forensic Handbook and report on their findings: http://www.fbi.gov/hq/lab/handbook/forensics.pdf
2. Arson is closely related to fire safety. Students can prepare a fire safety plan for their homes and submit them as individual projects or you can provide several home floor plans for students to use in groups. More information can be found here: http://www.usfa.dhs.gov/downloads/pdf/fswy9.pdf.
3. Students can interview local fire officials and report on the interviews or record them for class viewing.
4. Many forensic web sites and books contain sections on arson. Assign students to research topics like those in the article and present reports.

Anticipating Student Questions

1. **"Is arson investigation really as simple as the article makes it seem?"** *Arson investigations are very complex. Many variables interact at the scene of a fire, which makes it difficult (and sometimes impossible) to determine if a fire is arson. The article highlights a few of the more traditional clues in a fire investigation.*
2. **"If accelerants are burned in a fire, how can they be detected after the fire is over?"** *Fire investigators look for traces of unburned accelerants at the scene. These traces are submitted for identification in the lab.*
3. **"I'm not sure how the V pattern is different from the inverted V pattern."** *If a fire begins near a wall and then is extinguished quickly, the soot pattern left on the wall will look a lot like the flame you would see coming from a candle—wider near the bottom and narrower near the top—an inverted V. However, if the fire burns for a longer time, the pattern will look like a normal V. This is because the combustible material near the base of the wall is probably not very wide. But the rising air currents spread out over a wider area, leaving soot patterns wider at the top and narrower at the bottom—a regular V.*

Web sites for Additional Information

More on arson basics

For a range of articles on arson, see http://www.interfire.org/res_file/menu_ab.asp.

More on arson investigation

For a list of terms and definitions used in arson investigations, see http://www.jus.state.nc.us/NCJA/w-mw-1199.htm.

More on Fire Research Laboratory

The U.S. Bureau of Alcohol, Tobacco and Firearms has established a unique Fire Research Laboratory in Maryland. Read more about it here: http://www.fbi.gov/hq/lab/fsc/backissu/jan2002/donahue.htm.

More on FBI's *Forensic Examinations Handbook*

The FBI provides a handbook for forensic examinations. You can view a copy of the handbook at http://www.fbi.gov/hq/lab/handbook/forensics.pdf.

More on U. S. Fire Administration

FEMA has a separate agency for fire and fire investigations. Read more here: http://www.usfa.dhs.gov/.

More on chemical analysis of arson

See the article in *Chemical and Engineering News* at http://pubs.acs.org/hotartcl/ac/96/sep/sep.html.

More on the V pattern

For more on misconceptions about the V pattern, see http://www.uis-usa.com/documents/Patterns.pdf.

More on canines in accelerant detection

To read more about using dogs to detect the presence of accelerants at a fire scene, see http://www.interfire.org/res_file/canine.asp#gen.

More on accelerant detection

This handbook describes methods of detecting accelerants used in arson cases: http://www.usfa.dhs.gov/downloads/pdf/publications/fa-127.pdf.

More on arson statistics

The FBI collects data on arson. You can find the data here: http://www.fbi.gov/ucr/cius2006/offenses/property_crime/arson.html.

More on laboratory analysis and arson

An article from *Analytical Chemistry* on lab analysis of arson evidence can be read here: http://pubs.acs.org/hotartcl/ac/96/sep/sep.html.

More on fire investigation

NIST has published a *Handbook of Fire Investigation* that describes many of the methods used currently. View the handbook here: http://fire.nist.gov/bfrlpubs/fire80/PDF/f80004.pdf.

More on fire investigations

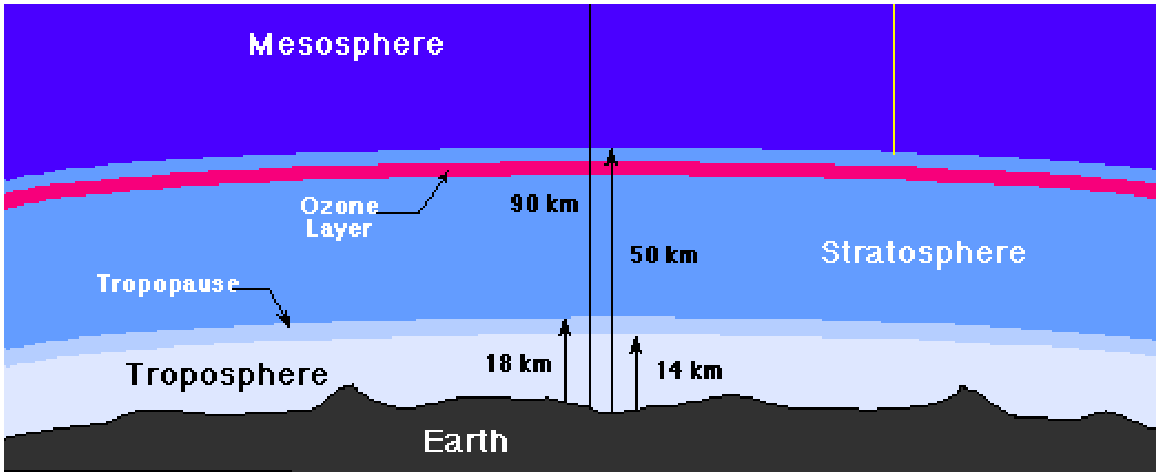
A very complete guide to arson fire investigation is published by the National Fire Protection Association (NFPA). The 2004 edition is available for online reading here: http://www.nfpa.org/freecodes/free_access_agreement.asp?id=92104&cookie%5Ftest=1

Chemicals in the Air: Latest Results from NASA's Aura Satellite

Background Information

More on 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. The ozone layer is found in the stratosphere. 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.



Reprinted from NASA

More on the Earth Observing Satellite, Aura

According to NASA, there are three scientific questions which Aura was designed to help solve by gathering data. 1) Is the ozone layer in the stratosphere recovering? 2) What are the processes that control air quality? 3) How is Earth's climate changing?

Collectively, the instruments aboard Aura were designed to gather sufficient data to answer these questions. The Aura satellite contains 4 major instruments to measure changes in Earth's atmosphere. Each instrument has a job of its own to do, and each gathers data about all three questions above. In addition, all four instruments complement each other's tasks.

The first of these four instruments is HIRDLS, High Resolution Dynamic Limb Sounder. HIRDLS is an infrared limb-scanning radiometer that measures trace gases, temperatures, and aerosols in the upper atmospheres. (Limb-scanning refers to measuring in a horizontal plane, sideways through the atmosphere, rather than looking down at Earth.) By taking quick successive scans at different angles through the atmosphere, the instrument can give a clear picture of a gas's concentration with great vertical clarity. HIRDLS measures NO_2, HNO_3, and CFCs, all gases that are involved in ozone depletion. It will also measure ozone and water vapor concentrations which, when combined with HNO_3 data, will allow scientists to estimate the amount of air in the stratosphere that descends into the troposphere, and will allow them to distinguish ozone pollution occurring naturally from that from man-made sources. HIRDLS, by keeping track of ozone and water vapor, also will help scientists better understand climate changes, as both these gases are greenhouse gases.

The Microwave Limb Sounder, MLS, the second of the four instruments, makes measurements across the atmosphere in the microwave radiation ranges, GHz and THz frequencies. Since it measures in different wavelengths than HIRDLS, MLS looks for different substances; e.g., HCl and ClO. These two give 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.

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 data is combined with that of HIRDLS and MLS to produce maps of ozone and NO_2 that help scientists better understand how these gases affect air quality. OMI's ozone measurements, combined with cloud cover measurements, contributes to the National Weather Bureau's UV index. OMI also maps aerosols and dust, and distinguishes differentiate reflecting and absorbing aerosols, which will help scientists build better mathematical models of climate change.

The last of the four instruments is TES, the Tropospheric Emission Spectrometer. This instrument is a Fourier Transform Spectrometer. It 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 vertical (nadir) and horizontal (limb-scans). This dual ability allows it to measure the entire lower atmosphere, from the surface to the stratosphere. TES's spectral range overlaps that of HIRDLS, so the two can verify each other's data on ozone concentrations and changes. 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.

The four instruments function independently of each other, and each provides data for specific substances within various parts of the atmosphere. The overlap of the accumulated data from all four instruments when combined gives scientists much more information than they have ever had upon which to base interpretations and predictions. EOS Aura is providing scientists with the data they need to answer those difficult questions.

The Aura satellite, seen here in an artist's rendition, houses instruments that monitor the chemical make-up of the atmosphere and help researchers understand ozone chemistry. Credit: NASA

More on ultraviolet radiation and ozone

Ultraviolet light is just one small part of the electromagnetic spectrum. It has wavelengths shorter than visible light, but longer than x-rays. Its shorter wavelength means its photons have higher energy than those of violet light, its closest visible light neighbor on the continuum that is the spectrum. As a result of its higher energy, it is able to break chemical bonds, which is why it is a problem for ozone—and for us. UV's breaking bonds for us means possible severing of DNA strands and subsequent cancer growths. This is why the ozone layer is so important to the continued survival of life on Earth.

Ozone in the troposphere absorbs ultraviolet light, preventing it from reaching the earth's surface. Ultraviolet light causes skin cancer. Thus the ozone layer provides protection for life on the surface of Earth. This in turn explains why the formation and expansion of the ozone hole over the last several decades has caused such concern. All life as we know it could be adversely affected by the increase in ultraviolet radiation reaching the Earth's surface. Indeed, there is evidence that adverse effects have already occurred in many species of plants and animals.

More on the ozone hole over Antarctica

The 1987 Montreal Protocol banned all chlorofluorocarbons from aerosol propellants in the hopes of stopping the expansion of the ozone hole. Unfortunately the CFCs already in the atmosphere will take decades to decompose or circulate out of the stratosphere. The hole will remain until well into the second half of this century.

The ozone hole typically reaches its maximum during the month of September, when sunlight begins to return to the area as a prelude to summer. Aura data has shown that the size of the ozone hole over Antarctica in September, 2007 was just an average size, compared to the size of the hole for the same month each year during the last several decades. The hole in 2007 measured approximately 9.7 million square miles (slightly greater than the size of North America). The minimum size, 8.3 million square miles, occurred in 2002, while the maximum size, 11.2 million square miles, was reached in 2006. The size of the ozone hole over the Antarctic is expected to continue to decrease gradually over the next several decades.

More on the chemistry of the Antarctic ozone hole

Most ozone forms in the stratosphere. The process begins there as diatomic oxygen molecules are bombarded by ultraviolet light, forming individual oxygen atoms.

These free radical oxygen atoms then collide and form bonds with other oxygen molecules, producing triatomic oxygen, ozone.

$O_2 + h\nu \rightarrow 2O$

$O + O_2 \rightarrow O_3$

The ozone then absorbs UV light, splitting the molecule. This absorption of the UV radiation is the step that protects us from UV radiation here at the Earth's surface.

$O_3 + h\nu \rightarrow O2 + O$

Ozone is also broken down when it reacts with a free oxygen atom, forming diatomic oxygen once again.

$O_3 + O \rightarrow 2 O_2$

The competition between the reactions producing ozone and those destroying ozone should result in an equilibrium concentration of ozone that remains relatively stable over time. Such is not the case, of course, as measured by ground and air instrumentation. Scientists quickly discovered that there are additional reactions, those that depend on man-made chemicals that enter the stratosphere from below.

The culprits responsible for these new ozone-destroying reactions are primarily chlorofluorocarbons, CFCs. CFCs react with UV light and break down, usually producing a free chlorine atom. These free radicals are very reactive, and they react with almost any atoms or molecules with which they collide.

If the molecule colliding with the CFC is an ozone molecule, the Cl free radical will grab an oxygen atom to produce a ClO chlorine oxide molecule and an O_2 molecule, according to this equation:

$Cl + O_3 \rightarrow ClO + O_2$

The ClO can then react with an oxygen free radical, producing an oxygen molecule and a Cl free radical again.

$ClO + O \rightarrow Cl + O_2$

This completes the cycle, and the chlorine free radical is available to decompose more ozone molecules.

If the molecule colliding with the CFC is not ozone, new molecules are formed. The new molecules are referred to as "reservoir compounds", since they in effect hold the Cl atom until it can react again. The primary reservoir compounds are HCl and $ClONO_2$. These relatively reactive chlorine compounds can react in the upper stratosphere to produce diatomic chlorine molecules, according to the following equations:

$HCl + ClONO_2 \rightarrow HNO_3 + Cl_2$

$ClONO_2 + H2O \rightarrow HNO_3 + HOCl$

$HCl + HOCl \rightarrow H_2O + Cl_2$

If man-made pollution were the whole story behind the ozone hole, then it should happen over cities and other areas where pollution is great. Instead, scientists discovered the greatest ozone loss over Antarctica. Scientists discovered, after much research, that several factors affect the rate of ozone destruction in the stratosphere. The chlorine-ozone reactions listed below actually occur only on the surfaces of crystals in polar clouds. These clouds are called Polar Stratospheric Clouds (PSCs), and they only occur at very cold temperatures and at very high altitudes. The long polar night produces a phenomenon known as the polar vortex, a very high column of very cold air that circumnavigates the pole during its winter. This column of cold air tends to isolate frigid air over the pole, which causes PSCs to form. Clouds we are most familiar with are made of water droplets. The PSCs are not made exclusively of water, however. They also contain nitric acid dissolved in water droplets.

The reactions above that produce diatomic chlorine molecules occur very rapidly, but they only occur on the surface of the ice-nitric acid crystals in the PSCs. Chlorine molecules build up in the stratosphere over the South Pole during this intense cold period. The chlorine molecules are relatively stable in the dark, so they increase in concentration in the stratosphere throughout the cold months (6 months of no sunlight). But as the sun returns in the spring, in the presence of sunlight (and its UV), the chlorine molecules quickly decompose to form free chlorine atoms.

$$Cl_2 + h\nu \rightarrow 2\,Cl$$

The chemically reactive chlorine atoms, in turn, collide with ozone molecules and quickly cause its decomposition into stable diatomic oxygen molecules and oxygen chloride molecules.

$$Cl + O_3 \rightarrow ClO + O_2$$

This explains why the ozone hole develops so quickly once September (spring in the Antarctic) arrives.

The depletion is compounded by the fact that ClO molecules themselves are not very stable, and they will react further, according to the following reaction series:

$$\begin{array}{l}
2\,ClO + M \rightarrow Cl_2O_2 + M \\
Cl_2O_2 + h\nu \rightarrow Cl + ClO_2 \\
ClO_2 + M \rightarrow Cl + O_2 + M \\
2\,Cl + 2\,O_3 \rightarrow 2\,ClO + 2\,O_2 \\
\hline
\end{array}$$

$$\text{Net:} \quad 2\,O_3 \rightarrow 3\,O_2$$

(M represents any other particle close enough to impact the reacting molecules.)

This series of 4 equations is referred to as a catalytic cycle because, as you can see, the two ClO molecules are regenerated at the end of the reaction series, freeing them to react again to decompose more ozone molecules into diatomic oxygen molecules. This explains why chlorine compounds have such a large effect on ozone concentrations—because they can react again and again. It also explains why the ozone hole isn't going to disappear any time soon, as these catalytic molecules are stable enough to remain in the stratosphere for long time periods.

Much of the information for the ozone-depletion discussion above came from the Centre for Atmospheric Research, University of Cambridge, UK web site at http://www.atm.ch.cam.ac.uk/tour/index.html.

The equations and diagram below summarize the process of ozone destruction.

Ozone Depletion
In the Antarctic Springtime

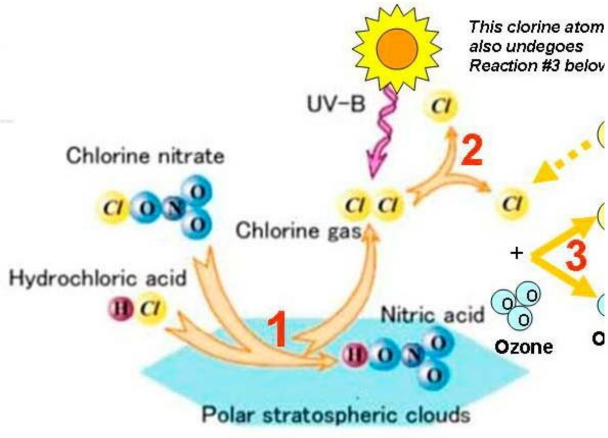
1) $HCl + ClONO_2 \rightarrow HNO_3 + Cl_2$

2) Cl_2 + sunlight $\rightarrow Cl + Cl$

3) $2Cl + 2O_3 \rightarrow 2ClO + 2O_2$

4) $2ClO + 2O \rightarrow 2Cl + 2O_2$

NET = $2O_3$ **to** $3O_2$



This excerpt was taken from the National Oceanic and Atmospheric Administration (NOAA) *NOAA Magazine* at its web site, http://www.magazine.noaa.gov/stories/mag210.htm.

More on ozone in the troposphere

We've focused so far on stratospheric ozone, but ozone also appears in the troposphere, down here where we live. This "ground-level" ozone accounts for about 10% of all the ozone in the entire atmosphere. Since the ozone in the stratosphere is useful to us as a UV shield, it is usually considered "good" ozone, while ground-level ozone is usually considered "bad" ozone because it can damage cells and cause the deterioration of certain materials; e.g., plastics.

Ozone in the stratosphere is produced primarily by natural processes, as described above. While there are several natural sources of ground-level ozone, they account for only a tiny fraction of the 10% of all ozone that is ground-level ozone in the atmosphere. The bulk of the ground-level ozone comes from man-made processes; e.g., automobile emissions and industrial emissions. This ozone is not produced directly, but it is produced as UV light interacts with the hydrocarbons and nitrogen oxides produced by our industrialized society. Ozone production is pretty much a daily cycle, with much sunlight in late afternoon reacting with the pollutants spewed out all day long by cars and industries causing increasing concentrations throughout the afternoon and early evening, until sunlight wanes and the processes slow down. Ozone concentration diminishes overnight, and the cycle begins anew the next day.

The effects of ground-level ozone are numerous. Growth of crops and forests is adversely affected in two ways: 1) Plants close the stomata on their leaves when exposed to high concentrations of ozone, and this reduces photosynthesis and thus plant growth; 2) Ozone itself can get into plants through the stomata, and this will cause cellular damage within the plants. Ozone can also cause cellular damage in animals, especially in humans. It is also an irritant to those with respiratory ailments. Ozone also accelerates the decomposition of inanimate organic materials, like plastics and rubber, which decreases the life expectancy of products made of these materials.

It would be ideal if we could transfer all the ground-level ozone, which is detrimental to life, to the stratosphere, where it would help protect us. Unfortunately, this is impractical for several reasons: 1) There isn't enough tropospheric ozone (only 10% of the total, remember?) to have a large effect in the stratosphere; 2) The energy required to move all the ground-level ozone to the stratosphere is enormous, and burning fuel to provide that energy would produce enough pollution to wipe out the gains made in moving the ozone. A better approach is to vastly reduce the pollutants produced by cars and industries, to prevent the ozone from being formed in the troposphere in the first place.

More on sulfur dioxide from volcanic emissions

Roughly 10% of the gas spewed 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.

The sulfate aerosols ejected into the stratosphere also contributed to the drastic decrease in ozone levels during the Pinatubo eruption. This occurred because the aerosol particles served as reaction sites for the complex chemical reactions described in the "More on the chemistry of the Antarctic ozone hole".

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. That is exactly what the Aura instruments do.

Information here was obtained from the USGS web site at http://volcanoes.usgs.gov/Hazards/What/VolGas/volgas.html and from Wikipedia, at http://en.wikipedia.org/wiki/Volcano.

More on nitrogen dioxide in the air

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. A rather surprising source that satellites have been able to track is ships crossing the oceans, which bellow out copious quantities of pollutants from their smokestacks.

The reddish-brown gas 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. The problems are exacerbated if the person has allergies. 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. (Recall the problems that Los Angeles had with smog in the 1970s and '80s.)

It's interesting to note that NO_2 pollution is not limited to the atmosphere, or even outdoors. Indoors, kerosene heaters are good sources of the gas, as are unvented gas stoves or gas heaters, and cigarette smoke. Here the problems are likely to be serious, as people are exposed to these high concentrations in small areas for long periods of time.

Since nitrogen dioxide contributes to at least two of the three essential questions that Aura is supposed to help us answer, it is critical that the satellite continue monitoring NO_2 concentrations globally.

Connections to Chemistry Concepts

1. **Light absorption**—Amounts of light absorbed can be related to the concentration of particles present; wavelengths of light absorbed can be related to the types of molecules present.
2. **Light interactions with electrons**— Light promotes electrons from lower-lying energy levels in molecules to higher-lying empty energy levels in molecules.
3. **Molecular structure**—The wavelengths at which molecules absorb electromagnetic emissions (light) depend on the vibrational frequencies of the bonds within those molecules.
4. **Molecular stability and reactivity**—Some chlorine compounds will decompose when exposed to UV light. This begins the series of photochemical reactions leading to the destruction of ozone.
5. **Free radicals**—Chlorine and oxygen atoms are highly reactive and contribute to the ozone destruction process.
6. **Oxidation-reduction**—Many of the chemical reactions involving the process of ozone destruction involve redox, as do the reactions producing acid rain.
7. **Analytical chemistry**—Tools chemists use to analyze real-life problems include various types of spectroscopy.

8. **Dealing with variables**—Scientists from NASA must interpret the data they receive from the satellites by filtering out (physically or mathematically) the "noise"; e.g., angle of the observer, amount of cloud cover.

9. **Verifying data**—The article describes verification of data by four simultaneous sources—Aura, ground observations, balloons and aircraft. Gathering group data in the laboratory serves a similar purpose for students—to gauge the validity of their laboratory findings.

10. **Careers**—The people featured in the September, 2002 NASA issue are great role models for students, and the interviews with these scientists focus on what got them interested in their chosen fields of scientific study, and what role family played in their choices. These would be great reading assignments to give, ostensibly for the science content, but much more subtly for their humanizing of science.

Possible Student Misconceptions

1. **"Scientific instruments tell scientists what they want to know."** *[The instruments merely provide scientists with raw data. It is up to the scientists to interpret the data, to make sense of it.*

2. **"Scientists rely solely on data obtained from the Aura satellite."** *The article states that scientists compare Aura's satellite data with data retrieved simultaneously from ground observations, from balloons, and from aircraft for verification.*

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.*

4. **"Ozone only occurs in the stratosphere."** *While it is true that the ozone layer is located in the stratosphere and the depletion of this layer has gotten the majority of the attention by the news media, there is also a significant amount of ozone closer to where we live—in the troposphere. This is usually referred to as the "bad" ozone, since it causes respiratory distress in people when they breathe the gas, and it contributes to smog pollution.*

Demonstrations and Lessons

1. To simulate the difference in apparent concentration of NO_2 from actual concentration, resulting from the angled view (and hence greater depth or distance of view) made by observations by the Aura satellite, you could fill a clear container (a vial, test tube or tall beaker) with a colored liquid and have students view the container from the side looking across the container, and compare that with the view from the top looking down through the liquid. The liquid will appear darker (more concentrated) when looking from top to bottom. If you wanted to demonstrate this for the entire class, use an overhead projector, and a tissue culture flask. (If you don't know what this is, ask your biology teacher colleagues or check a science catalog.) You can place this capped "flat flask" flat on the projector to allow light to flow through the "short" side, or you can set it on edge so that light must travel through the longer side. The longer side will appear darker.

2. NASA has a lesson plan that utilizes actual data from Aura. "Investigating Seasonal Variability in NO_2 Concentrations" asks students to download the data and prepare graphs for specific time intervals. It then poses a series of questions for students to answer based on the graphs. The site also provides links to definitions of terms and background information on NO_2's role in ozone depletion. You can find the activity at http://mynasadata.larc.nasa.gov/preview_lesson.php?&passid=59. The

"Live Access Server" (LAS) it alludes to in the procedure is found simply by scrolling back up to the top and clicking on the "+ Data Access" tab.

UCAR, University Corporation for Atmospheric Research, and NCAR, National Center for Atmospheric Research, provide lesson plans for science teachers on topics involving atmospheric science. These are primarily geared for middle school students, since that's where earth science frequently is found in the curriculum. The lessons could easily be adapted, however for high school students. #3-#7 below come from this site: http://www.ucar.edu/learn/index.htm.

3. You can show students one way to detect UV light—using tonic water (it contains quinine). A lesson that does just that, "Detecting Ultraviolet Light Using Tonic Water", can be found here: http://www.ucar.edu/learn/1_5_2_23t.htm. Extensions are provided that could allow students to test various suntan lotions for UV protection. You can substitute those UV color-changing beads, sold by science supply companies for the tonic water.

4. In the background information of the section "Stratospheric Ozone, the Protector" there is a diagram showing the role of a simple CFC and its role in the destruction of ozone. Shortly thereafter there is a brief animation showing the cyclic nature of the chlorine atom as it destroys ozone and is regenerated to "kill" again. Teachers could use these directly in classes. Find it at http://www.ucar.edu/learn/1_6_1.htm.

5. For kinesthetic learners, this web site provides a lesson plan for students to role play the atoms and molecules involved in the formation and destruction of ozone molecules in the stratosphere. "Whole Body Chemistry" can be found at http://www.ucar.edu/learn/1_6_2_26t.htm.

6. "Stratospheric Ozone: A Balancing Act" is an activity that simulates the equilibrium that used to exist with ozone in the stratosphere, compared to the effects that CFCs have had on ozone concentration. The lesson uses a drip rate for water as the analogy. The rate of flow out of a container is made to equal the flow in, establishing equilibrium. Then the rate of egress is increased, akin to more rapid destruction of ozone with CFCs. Find the lesson at http://www.ucar.edu/learn/1_6_2_25t.htm.

7. You can have students monitor ground-level ozone by preparing a test paper and using it to test for ozone. NCAR has a lab activity entitled, "Making and Using Schoenbeim Paper". The test paper is named after the scientist who first devised a way to detect ozone and showed its natural presence in the atmosphere. This activity is designed for middle school students, but a greater focus on the reactions taking place would easily upgrade it to high school level work. The activity is found at http://www.ucar.edu/learn/1_7_2_29t.htm. NASA developed an ozone test kit for home use. A private company, AlerG, is now marketing the kit for $7.95. It appears to utilize the same test paper as the above lab. View the advertisement for the OzoneWatch kit at http://www.alerg.com/page/A/PROD/AVC2000?gclid=CMGb5_PX85ECFRGoGgodbSz0yA.

8. Here's another NASA lesson plan dealing with variations in ozone levels over time: http://www.ucar.edu/learn/index.htm.

9. Check NASA's web site for a list of lesson plans dealing with the atmosphere: http://mynasadata.larc.nasa.gov/User_lessons.html.

Student Projects

1. Students could do a longitudinal study of the changes in the ozone layer of Earth over years/decades.
2. Students could do research to gather data regarding skin cancer and compare that data to the data collected by students in the ozone study above.
3. Students could do a research project to study the history of the ozone hole. They could begin with a trip to the Chemical Heritage Foundation's "Faces in the Molecular Sciences" web site to learn more about Susan Solomon and her discovery and the science behind the ozone hole at http://www.chemheritage.org/EducationalServices/FACES/env/readings/solomon.htm.
4. Students could do research on current trends in pollutant concentrations; e.g., ozone levels or NO_2 levels, based on daily Aura updates. They can obtain the data here: http://mynasadata.larc.nasa.gov/index.html.

Anticipating Student Questions

1. **"Can the Aura satellite give scientists an interpretation of the data it collects, so they know what it means?"** No, the satellite provides the raw data, but scientists must then "tweak" the data; i.e., remove irrelevant information, like the cloud cover. The scientists can then try to make sense of the refined data.
2. **"Was Aura the first Earth Observing Satellite?"** *No, NASA has launched many satellites designed to observe Earth, but Aura was much refined and contained four different sensing instruments.*
3. **"Is the Antarctic ozone hole 'fixable'?"** *The evidence isn't all in yet, but scientists believe we have stemmed the tide. Aura's data show that the rate of ozone depletion is decreasing. Although the hole reached a maximum size only in 2006, they believe it is on the mend. Recovery is projected to take decades, however.*
4. **"Why do the scientists use so many instruments to measure the same things?"]** *Scientists need to make sure the data they are obtaining are accurate. If several different instruments, especially independent instruments, measure the same variable and get the same results, that shows the data are accurate, and all the instruments agree. They have "validated" their findings.*
5. **"Why did everyone use CFCs, if they are so bad for the environment?"** When CFCs were first used, p*eople didn't know they would be bad. Chemically, they seemed to be unreactive, and they served a need we had for substances that would change phase at low temperatures and exchange large amounts of heat in the process. Refrigerators and air conditioners required substances that could absorb lots of heat to vaporize (this removed heat from the inside of the refrigerator and cooled it down), and then release that heat (somewhere else) when they recondensed. They also needed to be able to do that cycle repeatedly in order to cool down objects like refrigerators or homes. It wasn't until decades later that scientists discovered their effects on the ozone layer tens of miles up in the atmosphere.*
6. **"Can Aura solve our atmospheric problems?"** *No, that's not what Aura is designed to do. It will provide us with all the data we need to tackle them, but solving the problems is up to us.*

References

NASA has published a booklet describing the goals, and the instruments designed to carry out those goals for the EOS Aura satellite. The 32-page booklet, entitled, *Earth Observing*

Satellite, Aura: NASA Earth Science Enterprise, discusses the scientific questions Aura was designed to answer, describes in detail each of the four scientific instruments aboard Aura, discusses the people who made it happen, and is lavishly illustrated with full-color photos of the output of the various instruments. You can view or download the pdf file at http://aura.gsfc.nasa.gov/images/outreach/Aura_Brochure.pdf. The last few pages of the booklet describe the collaboration between NASA and *ChemMatters* staffs to plan for educational outreach for the mission.

The University Corporation for Atmospheric Research and the National Center for Atmospheric Research have established a great resource site on all things atmospheric. It includes student lesson plans. Find it at http://www.ucar.edu/learn/index.htm.

Web sites for Additional Information

More from ChemMatters archives

The first three *ChemMatters* special issues covering the EOS Aura mission referenced below all can be found on the *ChemMatters* 20-year CD (covering years 1983 through 2003). The CD is obtainable from ACS for $25 (or a site/school license is available for $99) at this site: http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccurriculum%5Ccmprods.html#CDsite.

As author Allen mentioned in the article, *ChemMatters* teamed up with scientists at NASA to launch a project to publish four special issues over as many years to keep teachers and students up-to-date on the NASA Aura mission. These updates occurred in the September, 2001, September, 2002, October, 2003 and September, 2005 issues. The first three issues can be found, in their entirety, on the *ChemMatters* CD listed above. The CD only includes 1983 to 2003, so the last issue is not found on the CD. The first three issues are also available, along with the last (September, 2005) issue on the *ChemMatters* archive web site at http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_ARTICLEMAIN&node_id=1090&content_id=CTP_005702&use_sec=true&sec_url_var=region1. The list of archive issues shows the first three of the four NASA specials asterisked to denote their special NASA issue status. The fourth, the September, 2005 issue, does not have the asterisk attached. The entire list of online archived issues actually begins with the September, 2001 special issue. The list contains only the September issue for both 2001 and 2002, but then it is continuous from the October, 2003 issue forward to December 2007. (Although the four special NASA issues are complete online, this is not generally the case. Several articles have been selected for each issue, but each issue is not complete.)

Or if you prefer, you can find each issue separately, at the ACS sites listed here.

The September, 2001 issue can be found at http://portal.acs.org/portal/fileFetch/C/CTP_005387/pdf/CTP_005387.pdf. This first issue introduces students to the Aura mission and its goals. Unfortunately, the Teacher's Guide to accompany this issue is not presently available online. (It is, however, available on the *ChemMatters* CD.)

The September, 2002 issue can be found at http://portal.acs.org/portal/fileFetch/C/CTP_005388/pdf/CTP_005388.pdf. This issue focuses on the people involved in the Aura program. It covers both professional and private lives of these scientists, to help provide role models for students in science careers. Once again, its Teacher's Guide is not presently available online. (It is, however, available on the *ChemMatters* CD.)

The October, 2003 issue is found at http://portal.acs.org/portal/fileFetch/C/CTP_005392/pdf/CTP_005392.pdf. This third issue investigates the chemistry of the atmosphere, and material flow in the atmosphere. This issue actually contains twice the normal number of pages in a typical issue, 32 pages vs. 16. It is jam-packed with information. This is the first of the special issues to have its accompanying Teacher's Guide available online at http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/CTP_005392. The Teacher's Guide for this issue is also available on the *ChemMatters* CD.

The September, 2005 issue is the fourth in the series. This issue relates to students some of the results obtained from the Aura instrumentation studies. The pdf file can be found at http://portal.acs.org/portal/fileFetch/C/CTP_005390/pdf/CTP_005390.pdf, and its companion Teacher's Guide is at http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/CTP_005434.

Another *ChemMatters* article dealing with Earth's atmosphere, entitled "The Atmosphere of Planet Earth", in the February, 1983 issue, page 10, and written by Cyril Ponnamperuma, can be found on the *ChemMatters* 20-year CD.

The table below shows the names and topics of the articles contained in each *ChemMatters* NASA special issue.

Issue Date	September, 2001	September, 2002	October, 2003	September, 2005
	“Spectroscopy—Sensing the Unseen” (remote sensing gives us some answers)	Interviews with Five Scientists: Their Stories	“Whose Air is it Anyway?” (where air goes and where it’s been)	“How Earth Got its Aura” (the whole story behind the satellite)
	“Ozone—Molecule With a Split Personality” (good or bad ozone depends on location)	1) Andrea Razzaghi: “Getting People and Hardware Working Together” (launching Aura and its instruments)	“Smoke Bugs” (living spores travel through air)	“Flight of the WB-57” (confirming data)
	“Asthma—Attack from the Air” (dealing with air pollution)	2) Peter Seigel: “Studying the Energy of the Universe” (far infrared radiation)	“Alien Atmospheres: No Place Like Home” (“air” on other planets)	“What’s So Equal About Equilibrium?” (reactions in the atmosphere)
	“Global Warming—Hot Topic Getting Hotter” (begin sorting out the big questions)	3) Pieternel Levelt: “Shining Light on Atmospheric Ozone” (her team designs ozone detector)	“Clouds” (and cloud formation)	“Clearing the Air” – Treaties to Treatments”
	“GLOBE—View from the Ground Up” (students get ground data to compare to Aura)	4) John Gille: “Searching for Patterns in the Clouds” (Why do clouds obey ‘laws’?)	“Life in a Greenhouse” (greenhouse gases)	
		5) Anne Douglas: “Making the World Safe for Blondes” (ozone and UV light)	“Chemistry in the Sunlight” (smog formation)	
	Activity: “Carbon Dioxide—A Pourable Greenhouse Gas”	Activity: “Measuring Ground-level Ozone” (make your own O_3 indicator)	Activity: “Cloud In a Bottle” (make your own cloud)	Activity: “Your Mission: Validate a Stick!”
			“Beefing Up Atmospheric Models” (mathematical models)	
			“Nobel Prize Winner Sherwood Rowland: A Conversation” (CFCs)	
			“The GLOBE Program: Science in the Sunshine”	

More sites on the chemistry of the ozone layer

NASA has a short simplified animated sequence showing the production of ozone and its subsequent destruction as it reacts with chlorine in the upper atmosphere. Find it at http://www.nasa.gov/vision/earth/environment/ozone_hole101.html.

More sites on the ozone hole

The Montreal Protocol was instrumental in reducing CFCs in our daily lives, and thus reducing the rate of ozone destruction in the stratosphere. The entire agreement is available online at http://www.unep.org/ozone/pdfs/Montreal-Protocol2000.pdf.

The EPA has a 2-page timeline poster of ozone and related substances from 1928 to 2075. You can access this pdf file, “A Walk Through History”, at http://www.epa.gov/ozone/pdffile/10spd_annual_report_highres_walk.pdf

“Then and Now” is a 2-page poster from the EPA that shows substances we used to use in our daily lives, and the alternative substances we now employ instead, and how Earth’s atmosphere will benefit from these changes. View it at http://www.epa.gov/ozone/pdffile/3spd_annual_report_highres_thennow.pdf.

NASA provides several short animation sequences to show the progression of the ozone hole. This one, which requires QuickTime, shows annual changes from 1979-2006: http://ipy.nasa.gov/multimedia/m000000/m000000/m000025/ozoneminimum_79-06-lrg-H.264.mov.

The NOAA, the National Oceanic and Atmospheric Administration, web site presents a celebration of the 20th anniversary of the discovery of the ozone hole at http://www.magazine.noaa.gov/stories/mag210.htm. The article, taken from their *NOAA Magazine*, updates the reader on progress that’s been made since Susan Solomon first discovered the cause of the ozone hole.

The EPA web site provides a list off ozone-depleting chemicals at http://www.epa.gov/ozone/science/ods/classone.html.

More sites on spectroscopy

“Sensing the Unseen” in the September, 2001 special NASA issue of ChemMatters discusses the electromagnetic spectrum. It also discusses limb-sounding. You can find it on the 20-year ChemMatters CD, or you can access it online at http://portal.acs.org/portal/fileFetch/C/CTP_005387/pdf/CTP_005387.pdf.

More sites on gas pollutants in the air

On February 15, 2008, Hawaii Volcanoes National Park issued a press release restricting access to walking trails along Crater Rim Drive, near Mt. Kilauea, due to high levels of SO_2. The press release cited the highest levels since 1982. See http://www.govisithawaii.com/2008/02/15/hawaii-volcanoes-national-park-elevated-sulfur-dioxide-so2-warning/.

More sites on Teacher Information and Lesson Plans

The National Center for Atmospheric Research, NCAR, with a grant from the National Science Foundation, NSF, has developed a web site that contains a whole series of lessons, covering a wide range of topics related to atmospheric science, for teachers to use in their classrooms. Although the activities were originally developed for middle school teachers (these are earth science topics, after all), many of them are adaptable for high school students as well. See the list of topics from “LEARN: Atmospheric Science Explorers”, which includes background information for teachers and activities for students at http://www.ucar.edu/learn/index.htm.