ChemMatters

February 2005 Teacher's Guide

About the Guide

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Puzzle: Missing Letter

Here are four groups of words used often by chemists . Each group has something in common. Some letters are given for each word; the letters that fill in the remaining blanks are <u>also</u> used in the category name (perhaps more than once). Your task for each group is twofold: determine each word and determine the theme phrase. You'll be able to go back and forth as you proceed.

For example, suppose the category is _ _ _ _ _ _ _ _ _ and three of the clues are
M _ _ C _ B _ E , D _ _ _ _ E, and _ _ _ V E _ _ .

A little thought generates the words M <u>I</u> <u>S</u> C <u>I</u> B <u>L</u> E, D <u>I</u> <u>L</u> <u>U</u> <u>T</u> E, and <u>S</u> <u>O</u> <u>L</u> V E <u>N</u> <u>T</u> and the category phrase SOLUTIONS can be made from the underlined letters.
Note that seeing the letter M in clue 1 means that the category type does NOT contain an M in its spelling and that the seven different letters that make up the word **SOLUTIONS** are to be found in the BLANKS of the clues.

Completing all four makes you a super missing-letter sleuth !

1. Category : __ . __ . __ __ __ __ __

K E L V __ __
__ E C O __ D
J O __ L E
W A __ __
C __ B __ C M E __ E R

2. Category: __ __ __ __ __ __ __

B O Y __ E
__ __ Y - __ U __ __ __ C
C H __ R __ E __
__ R __ H __ M
__ V O __ __ D R O

3. Category : __ __ __ __ __

V __ L T A G __
__ __ __ U C T I __ N
__ __ I __ I Z __
C __ L L
A N __ __ __

4. Category: __ __ __ __ __ __ __

C __ V A L E __ T
__ __ __ __ C
__ __ P __ L E
__ R __ __ T A L
S __ __ M A

Puzzle Answers

1. **S.I. UNITS**
   Kelvin
   Second
   Joule
   Watt
   Cubic meter

2. **GAS LAWS**
   Boyle
   Gay-Lussac
   Charles
   Graham
   Avogadro

3. **REDOX**
   Voltage
   Reduction
   Oxidize
   Cell
   Anode

4. **BONDING**
   Covalent
   Ionic
   Dipole
   Orbital
   Sigma

Student Questions

More Than Blue

1. What are the main features that distinguish clinical depression from the normal "blues" that everyone experiences from time to time?

2. What are neurotransmitters, and how do they function?

3. What neurotransmitter is involved in depression, and how is it affected?

4. How is serotonin produced in the body, and what happens to it?

5. What are the two most common types of drugs used to treat depression, and how do they function, in general?

6. What is one advantage that SSRIs have over MAO inhibitors?

7. What "black box" warning has the FDA recently directed manufacturers of all antidepressant medications to add to their products?

The Great Hartford Circus Fire

1. Using chemical principles, explain why a mixture of paraffin and gasoline would make an excellent (although flammable) waterproofing material.

2. What is meant by the term "flash point?"

3. Why won't paraffin ignite if touched by a lit cigarette or match, but a mixture of paraffin dissolved in gasoline will?

4. Explain how soap can allow a nonpolar substance like oil to be suspended in a polar substance like water.

5. How do the sizes of the particles in a colloid differ from the particles in a true solution? Can colloidal particles be seen with an optical microscope?

The Silent Killer

1. What kinds of conditions typically result in the production of carbon monoxide?

2. What are typical levels of carbon monoxide in a home with properly adjusted gas stoves? At what level do most people begin to experience symptoms of carbon monoxide poisoning? What standards have been established for carbon monoxide levels for indoor air and outdoor air?

3. Explain how an electrochemical carbon monoxide detector works.

4. Explain why carbon monoxide is so toxic.

5. Why didn't the mother suffer from carbon monoxide poisoning even though she was breathing the same air as the rest of her family and the baby inside her was suffering from carbon monoxide exposure?

6. What is the standard therapy for carbon monoxide exposure? How rapidly can the levels of carboxyhemoglobin in the affected person's blood be expected to decrease?

7. How does a hyperbaric oxygen chamber work to help victims of carbon monoxide poisoning recover?

Water of Life

1. Explain why the fact that ice is less dense than water may be a critical property for living things.

2. How does the boiling point of H_2O compare to that of similar compounds H_2S and H_2Se? What accounts for this unusual property?

3. How does water affect the folding patterns of proteins?

4. Explain how the properties of water are critical to the construction of cell membranes.

5. What are some arguments that ammonia, NH_3, might possibly be able to function as the basis for a life system in a manner similar to the way that H_2O functions as the basis for ours?

6. What are some arguments that NH_3 probably would not be able to function as the basis for a life system?

7. Why might alien beings find it inconceivable that a life form could exist in an atmosphere that contained significant concentrations of oxygen?

Question from the Classroom

1. Where does most of the heat and light given off by a burning candle come from?

2. What is candle wax actually made of?

3. Describe the process that occurs when a candle is burning.

Describe four different purposes achieved by the flame.

What is meant by the "flash point" of a substance?

Explain why a lit match that is brought close to a container of liquid pentane will immediately ignite the pentane, but the same thing will not happen if it is brought close to a container of candle wax.

How could you ignite candle wax without using a wick?

Student Question Answers

More Than Blue

1. What are the main features that distinguish clinical depression from the normal "blues" that everyone experiences from time to time?

   Clinical depression is diagnosed when a person either loses or has no interest in usual activities and takes no pleasure in them. It is characterized by feeling worthless or helpless, being indecisive, or lacking motivation to complete even simple tasks, such as dressing or eating. People suffering from depression may have difficulty sleeping or may sleep constantly, and their appetite may be affected. Depressed individuals can contemplate suicide.

2. What are neurotransmitters, and how do they function?

   Neurotransmitters are chemicals that allow brain cells to communicate with each other. Each neurotransmitter binds to a particular receptor site on the outside of the cell and triggers a particular response inside the cell.

3. What neurotransmitter is involved in depression, and how is it affected?

   The neurotransmitter serotonin is involved in depression. People suffering from depression have much lower levels of serotonin than nondepressed people.

4. How is serotonin produced in the body, and what happens to it?

   Serotonin is produced in the brain from the amino acid tryptophan, which comes from the food you eat. It is released by one nerve cell and triggers a response in another nerve cell. Once this is done, two things occur. First, it is reabsorbed by the cell, either in the brain or through the bloodstream into the liver. Then it is metabolized by an enzyme called monoamine oxidase, or MAO.

5. What are the two most common types of drugs used to treat depression, and how do they function, in general?

   The two most common types of drugs are selective serotonin reuptake inhibitors (SSRIs) and MAO inhibitors. The MAO inhibitors work by inhibiting the enzyme monoamine oxidase. They react with the enzyme in place of the serotonin. Since the serotonin is not being destroyed, it can build up in the brain.

   The SSRIs work by slowing down the reuptake of serotonin into the cell. Since the serotonin isn't reabsorbed by the cell, levels outside the cell can gradually increase.

6. What is one advantage that SSRIs have over MAO inhibitors?

   They have fewer side affects and do not require that the patient follow a special diet that avoids certain foods.

7. What "black box" warning has the FDA recently directed manufacturers of all antidepressant medications to add to their products?

   The warning describes the increased risk of suicide in children and adolescents who take antidepressant medications and notes what uses the drugs have been approved or not approved for in these patients.

The Great Hartford Circus Fire

1. Using chemical principles, explain why a mixture of paraffin and gasoline would make an excellent (although flammable) waterproofing material.

   Paraffin and gasoline are hydrocarbons, so they are made of only carbon and hydrogen atoms. Because carbon and hydrogen have similar electronegativities, carbon-hydrogen bonds are basically nonpolar, which makes hydrocarbon molecules basically nonpolar. But in a water molecule, the oxygen atom carries a slight negative charge while the hydrogen atoms are slightly positively charged, making water a polar molecule. Water molecules would rather adhere to themselves than to a nonpolar waxy surface made of a mixture of paraffin and gasoline, so water will run off of a canvas that has been treated with a paraffin-gasoline mixture rather than soak in. But hydrocarbons like paraffin and gasoline are very flammable.

2. What is meant by the term “flash point?”

   The flash point of a material is the lowest temperature at which a liquid can form an ignitable mixture in air near the surface of the liquid.

3. Why won’t paraffin ignite if touched by a lit cigarette or match, but a mixture of paraffin dissolved in gasoline will?

   It has to do with their relative flash points. Paraffin has a high flash point, so it will not be easily ignited if touched by a lit cigarette or match. Gasoline, on the other hand, evaporates readily and has a relatively low flash point. You can safely bring a lit match near the sides of a candle and nothing will happen, but if you do this with a container of gasoline, it will ignite. When paraffin is dissolved in gasoline, the gasoline lowers the flash point to where the mixture can be ignited relatively easily.

4. Explain how soap can allow a nonpolar substance like oil to be suspended in a polar substance like water.

   Soap molecules are able to form spherical structures in water known as micelles, with hydrophobic (water-fearing) tail interiors and hydrophilic (water-loving) head exteriors. The oil droplet is in the center of the micelle. It is basically surrounded and dissolved in the hydrophobic ends of the soap molecules, while the hydrophilic ends of the soap molecules are dissolved in the surrounding water.

5. How do the sizes of the particles in a colloid differ from the particles in a true solution? Can colloidal particles be seen with an optical microscope?

   In a true solution, the dissolved particles are individual molecules or ions, which are typically less than one nanometer in diameter. In a colloid the particles are larger, up to 100 nm, but this is still too small to be seen with an optical microscope.

The Silent Killer

1. What kinds of conditions typically result in the production of carbon monoxide?

   Carbon monoxide is typically produced when hydrocarbon molecules are burned under conditions that limit the amount of available oxygen.

2. What are typical levels of carbon monoxide in a home with properly adjusted gas stoves? At what level do most people begin to experience symptoms of carbon monoxide poisoning? What standards have been established for carbon monoxide levels for indoor air and outdoor air?

   A typical home will have carbon monoxide levels that range from about 0.5–0.15 ppm. If the home contains gas stoves that are not properly adjusted, the level may rise to about 30 ppm. People begin to experience symptoms such as headache, fatigue and nausea when levels approach about 70 ppm. No standards have been set for indoor exposure. Outdoor standards are 9 ppm for 8 hours and 35 ppm for every 1 hour.

3. Explain how an electrochemical carbon monoxide detector works.

   The detector has a gas-permeable membrane that allows CO to enter a chamber that contains platinum electrodes in an electrolytic solution. At an electrode called the sensing electrode, the platinum catalyzes a reaction between the CO and H_2O that produces carbon dioxide, hydrogen ions, and electrons. These electrons travel to a counter electrode where oxygen from the room reacts with the hydrogen ions and electrons to form water. This flow of electrons from the sensing electrode to the counter electrode produces a current that is proportional to the concentration of CO. If the current reaches a certain value, an alarm sounds.

4. Explain why carbon monoxide is so toxic.

The oxygen carrying molecule in human blood is hemoglobin. It binds to some of the oxygen you breathe and then carries it to every cell in your body, where it is released. Carbon monoxide binds to hemoglobin much more strongly than oxygen—about 200–250 times more strongly. There are four binding sites on each hemoglobin molecule. Although carbon monoxide only binds to one of the four sites, forming a molecule called carboxyhemoglobin, this changes the shape of the molecule. The other three sites now actually bind to oxygen so strongly that the oxygen no longer is released to the cells, so the victim slowly asphyxiates from lack of oxygen.

5. Why didn't the mother suffer from carbon monoxide poisoning even though she was breathing the same air as the rest of her family and the baby inside her was suffering from carbon monoxide exposure?

   The carbon monoxide the mother breathed was transported across the placenta and was binding to the fetus's hemoglobin. Because fetal hemoglobin has a greater affinity for CO than maternal hemoglobin, the level of carboxyhemoglobin in the mother's bloodstream remained at relatively low levels even while the levels in the fetus's bloodstream had reached dangerous levels.

6. What is the standard therapy for carbon monoxide exposure? How rapidly can the levels of carboxyhemoglobin in the affected person's blood be expected to decrease?

   Simply allow the affected person to breath either normal air or air that contains supplemental oxygen, depending on the severity of the symptoms. Patients who breathe normal air can expect the levels of carboxyhemoglobin in their blood to decrease by about half every 320 minutes. If they breathe 100% oxygen, the half-life is reduced to about 80 minutes.

7. How does a hyperbaric oxygen chamber work to help victims of carbon monoxide poisoning recover?

   In a hyperbaric chamber, oxygen is administered to the patient at high pressures—perhaps about three atmospheres or so. Henry's Law states that the solubility of a gas in a liquid is directly proportional to the pressure of the gas above the surface of the liquid, so at the higher pressures, more oxygen can be dissolved into the patient's bloodstream. This can reduce the half-life for carboxyhemoglobin reduction to about 23 minutes.

Water of Life

1. Explain why the fact that ice is less dense than water may be a critical property for living things.

   Because ice is less dense than liquid water, the ice that forms on top of a body of water, such as a lake, in winter, remains on top rather than sinking to the bottom. If, like most substances, the solid form of water were denser than the liquid form, then the ice would sink. This would form an insulating layer separating the frigid lake waters from the warmer earth below while continuing to expose liquid water to the cold air above. It is very likely that the entire body of water could freeze solid over the course of the winter, leaving no refuge for living things that depend on liquid water. And during the summer months, the melting ice would form an insulating layer of water on top of the lake, so the lake might not even fully thaw.

2. How does the boiling point of H_2O compare to that of similar compounds H_2S and H_2Se? What accounts for this unusual property?

   The boiling point of H_2O is 100 ^oC, much higher than the boiling points of the similar compounds H_2S (-60.7 ^oC) and H_2Se (-41.4 ^oC). This unusually high boiling point is caused by the hydrogen bonds that water molecules form with each other. These strong attractive bonds make it difficult to separate water molecules from each other, which means it takes a high temperature to turn the liquid into a gas.

3. How does water affect the folding patterns of proteins?

   Proteins are made of long chains of amino acids. Amino acids have side chains, which may be charged, polar, or electrically neutral. The charged and the polar side chains form hydrogen bonds of varying strengths with water, but the neutral ones do not. This means that water causes proteins to fold in such a manner that the charged and polar amino acids are on the protein's surface.

4. Explain how the properties of water are critical to the construction of cell membranes.

Cell membranes are typically made of two layers of compounds called phospholipids. each phospholipid has a polar "head" and two nonpolar hydrocarbon tails. Water on either side of the cell membrane draws the polar heads of each layer, while the nonpolar hydrocarbon tails attract each other, holding the two layers of the membrane together. Water basically keeps the cell from falling apart.

5. What are some arguments that ammonia, $NH_{3+,}$ might possibly be able to function as the basis for a life system in a manner similar to the way that H_2O functions as the basis for ours?

   There is a whole system of organic and inorganic chemistry that takes place in ammonia. Ammonia actually dissolves most organic compounds as well or better than water, and in addition, ammonia is capable of dissolving many elemental metals such as sodium, magnesium and aluminum directly into solution. Many other elements, such as iodine, sulfur, selenium and phosphorus are also somewhat soluble in ammonia with only minimal reaction. And ammonia is also capable of forming hydrogen bonds and supports acid-base chemistry.

6. What are some arguments that NH_3 probably would not be able to function as the basis for a life system?

   Ammonia is much less polar than water and would be far less effective in holding cell membranes together. It also has a much lower boiling point, -33 ^oC. Since life process are very temperature dependent, life processes might occur far too slowly in an ammonia solvent system. If a planet had a much greater atmospheric pressure than Earth, ammonia might be able to be a liquid at temperature closer to that found on Earth because melting and boiling points vary with pressure, but any planet that contained ammonia very likely would also contain even more water, since nitrogen is not as common as oxygen. In addition, ponds or lakes filled with liquid ammonia might freeze solid in winter, since solid ammonia is denser than liquid ammonia.

7. Why might alien beings find it inconceivable that a life form could exist in an atmosphere that contained significant concentrations of oxygen?

   Oxygen is actually quite toxic in many respects. It is highly reactive, and our bodies expend a great deal of energy protecting us from its ravages.

Question from the Classroom

1. Where does most of the heat and light given off by a burning candle come from?

   The combustion of the wax.

2. What is candle wax actually made of?

   Candle wax is not a single compound, but a mixture of long, straight-chain hydrocarbon compounds—generally in the range of $C_{20}H_{42}$ to $C_{21}H_{44}$.

3. Describe the process that occurs when a candle is burning.

   The paraffin wax melts, and the molecules are soaked up the wick by a process known as capillary action. As the wax soaks up the wick, the heat from the flame causes it to vaporize. This allows the wax to then mix with oxygen from the air and burn.

4. Describe four different purposes achieved by the flame.

   (1) The flame melts the wax.
   (2) It vaporizes the wax so it can mix with the oxygen and burn.
   (3) It creates convection currents around the candle so fresh air can be brought into the mix to burn more wax and keep the flame going.
   (4) It provides the activation energy for the reaction to take place.

5. What is meant by the "flash point" of a substance?

   Flash point is the minimum temperature at which the vapors above a combustible substance can be lit by an ignition source such as an open flame.

6. Explain why a lit match that is brought close to a container of liquid pentane will immediately ignite the pentane, but the same thing will not happen if it is brought close to a container of candle wax.

   It has to do with the relative flash points of the two materials. Even though both pentane and candle wax are hydrocarbons, and therefore made of only carbon and hydrogen, the flash point of pentane (-46 ^oC) is well below room temperature (25 ^oC), while the flash point of wax (205 ^oC) is well above it. The important thing is the relative vapor pressures of the two substances. Pentane evaporates readily at room temperature, so there are plenty of vapors to ignite when the match is brought close to the container of liquid. But wax is a solid at room temperature and there are very few vapors present to ignite.

7. How could you ignite candle wax without using a wick?

   Heat the wax above its flash point of 205 ^oC. At this temperature the wax molecules will evaporate to a sufficient extent to sustain a flame, and it would be possible to burn a wax candle without the aid of a wick.

Content Reading Guide

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**More Than Blue**	**The Silent Killer**	**The Great Hartford Circus Fire**	**Water of Life**	**Question from the Classroom: Candles**
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 conservation of energy and increase in disorder			✔		✔
Physical Science Standard B: of the interaction of energy and matter.		✔	✔		✔
Life Science Standard C: of the cell.	✔	✔		✔	
Life Science Standard C: of the behavior of organisms.	✔				
Life Science Standard C: of matter, energy, and organization in living systems.		✔		✔	
Science and Technology Standard E: about science and technology.	✔	✔	✔	✔	✔
Science in Personal and Social Perspectives Standard F: of personal and community health.	✔	✔	✔	✔	
Science in Personal and Social Perspectives Standard F: of natural and human-induced hazards.		✔	✔		
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 and complete the second column. In the space under each statement, cite information from the article that supports or refutes your original ideas.

More Than Blue

Me	Text	Statement
		1. Chemical imbalances in the brain are sometimes involved in depression.
		2. Neurotransmitters help brain cells communicate with each other.
		3. Serotonin, a chemical often lacking in brain cells of depressed people, can be taken in pill or capsule form.
		4. Drugs that inhibit the enzyme monoamine oxidase can decrease serotonin levels.
		5. Serotonin levels can be increased by allowing cells to reabsorb serotonin.
		6. Some drugs used to treat depression may increase self-destructive behaviors in teens.
		7. Vigorous exercise and eating carbohydrates and proteins increase brain serotonin levels.

The Silent Killer

Me	Text	Statement
		1. Carbon monoxide (CO) is easily detected by human senses.
		2. Carbon monoxide can be produced wherever carbon-containing fuels are burned.
		3. Carbon monoxide attaches to the hemoglobin in your blood, depriving cells of oxygen.
		4. People who have been overcome by CO simply need to be in fresh air to recover.
		5. In a CO detector, CO is changed to CO_2.
		6. CO poisoning is easy for emergency room staff to diagnose.
		7. Adult hemoglobin has greater affinity for CO than fetal hemoglobin.
		8. A hyperbaric oxygen chamber may have oxygen gas at a pressure of 3 atmospheres.

The Great Hartford Circus Fire

Me	Text	Statement
		1. The Hartford circus fire started in the flamethrower's dressing room.
		2. A mixture of gasoline and paraffin was used to waterproof the circus tent used at Hartford.
		3. Paraffin can burn at room temperature.
		4. Napalm, used in wartime, burns very quickly.
		5. Water that firefighters used helped to spread the Hartford circus fire.
		6. If several coats of milk paint are applied to bare wood, it can become water resistant.
		7. The cause of the Hartford circus fire was a carelessly tossed cigarette.
		8. All of the victims of the Hartford circus were eventually identified.

Water of Life

Me	Text	Statement
		1. The most abundant elements in the universe, in order, are oxygen, hydrogen, and helium.
		2. Water has many unique, life-friendly properties.
		3. Water molecules pack together in octagonal units when freezing.
		4. Hydrogen bonding causes water to have an unusually high boiling point compared to similar molecules.
		5. Water helps protein molecules fold into the correct shapes so they can work properly.
		6. Ammonia is a polar molecule that dissolves most organic compounds better than water does.
		7. The melting and boiling points of substances depend only on the temperature.
		8. The amount of oxygen in our atmosphere is less than it was millions of years ago.

Reading Strategies

These content frames 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. 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

More Than Blue

Complete the chart below comparing monoamine oxidase (MAO) inhibitors, serotonin reuptake inhibitors (SSRIs), and tricyclics.

	MAO Inhibitors	SSRIs	Tricyclics
How they work			
Side effects			
Structure			

The Silent Killer

	Carbon Monoxide
What is it?	
Where is it produced in the home?	
Why is it a problem?	
How can it be detected?	
Who is most at risk for CO poisoning?	

Water of Life

Compare water and ammonia in the chart below.

<table>
<tr><td>H_2O</td><td>NH_3</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Similarities</td></tr>
<tr><td colspan="2">Write a sentence explaining why some astrobiologists are interested in comparing these two compounds.</td></tr>
</table>

The Great Hartford Circus Fire

Circus Tent Fire

Personal tragedies	Waterproofing problems
Firefighting problems	How some of these problems have been solved for today's tents

The Great Hartford Circus Fire

Background Information

An earlier fire

The article mentions the unusual difficulties the circus faced because of shortages created by WWII. These shortages took many forms. Engines needed to pull the trains carrying the vast quantities of equipment, animals, and people of the circus were in short supply. Key experienced personnel were off fighting the war, and it was difficult to hire the large number of workers in each town required to set up and take down the big top. Some of the “little people” had been requisitioned by the war industry to work in tight spaces on aircraft assembly lines. The circus was designed to run like clockwork, and usually did, but during this period delays became increasingly commonplace.

On Aug. 4, 1942, about two years before the Hartford fire, the circus was playing Cleveland. Around 11:30 am, just before lunch, a fire broke out in the menagerie. As workers rushed to the scene they could hear the elephants, tied to the ground by stakes, trumpeting. The fire quickly spread as burning pieces of canvas fell and ignited the straw and hay contained in the animals’ habitat.

Despite the smoke and flames, the highly trained and disciplined elephants refused to move until their trainer came. He and his men bravely entered the flaming compound, freed the elephants from their shackles and directed them to tear their stakes out of the ground, which they did. At his command, they marched out in a line, each using his trunk to grab the tail of the elephant in front. Some were so horribly burned that flesh hung from their bodies, yet they left as directed and without stampeding.

Other animals made it out, but many didn’t. Some escaped, but were so badly burned that they had to be put down. The camels and big cats took the worst of it. The final toll consisted of four elephants, all thirteen camels, all nine zebras, five lions, two tigers, two giraffes, two gnus, two white fallow deer, two Ceylon donkeys, one axis deer, one puma, one chimpanzee and one ostrich.

There were no human fatalities, but it was an omen of what was to come.

The Hartford fire

Two shows had been scheduled for July 5, 1944, but the matinee had to be cancelled. The circus arrived late and couldn’t be set up in time. Missing a show was considered to be a bad omen in the superstitious world of the circus.

As the article points out, the big top that was set up for the evening performance had been waterproofed with a mixture of paraffin and gasoline. Incredibly, it had required eighteen thousand pounds of paraffin and six thousand gallons of gasoline to complete the job. The paraffin had been melted in cauldrons and then thinned with the gasoline. It was then spread onto the canvas with brooms.

Although setting up a performing circus required numerous arrangements with the town of Hartford, none of these involved the Hartford Fire Department. No inspections were required or requested, and the Fire Department later would testify that neither memory nor records gave any indication that protective measures had ever been provided in the past.

The evening show went off without a hitch. The highest applause was saved for the famous Wallendas high wire act, while clowns that included Emmett Kelly, perhaps the most famous clown the world has ever known, entertained the crowd and helped them to forget the hardships and deprivations brought on by the war.

July 6, 1944 was hot and humid. There was a good crowd for the matinee performance. Pictures taken that day appear to indicate that some ushers, in an effort to make a few extra dollars, had added extra chairs to many rows. This could be done by overlapping the legs of the chairs so a few more could be fit in and then charging customers who wished to improve their seating arrangements.

The number of people in attendance that day has never been established with certainty. At a later commissioner’s hearing, the circus vice president presented an attendance figure of 6,789 (a number that obviously ignores significant figure rules). The head usher estimated that about 6,000 people were present.

Some testified that the performance was a sellout. Others said that there actually were sections with half-empty rows. It is almost certainly safe to say that somewhere between 4,000 and 10,000 people were at the performance that day. The official capacity of the tent supposedly was 9,160, but more could easily have been fit in. An accurate attendance figure will never be known, but photographs taken that day and testimony from eyewitnesses seem to indicate that perhaps around 8,700 people had come to see the show—about 5,500 in the grandstand and perhaps 3,200 in general admission seats, called the “blues”.

The show started at 2:23 pm, eight minutes late.

For the first warm-up act, a man dressed in a lion suit ran out. He was quickly followed by a dozen girls dressed in skimpy, by 1944 standards, “lion tamer” costumes. In a reversal of roles, the “lion” produced a whip and proceeded to put the “tamers” through some acrobatic tricks. It was a prelude to the real lion tamer acts, of which two performed at the same time.

As soon as the big cats were done performing, attention shifted to the famous Wallendas and their high wire act.

The fire began on a sidewall behind the southwest blues. It went unnoticed for a few seconds. As is typical in such situations, eyewitness accounts conflict. Some said it was only about the size of a silver dollar. Others said it was the size of a baseball or basketball, or larger. They disagreed on its shape. The only thing upon which there was agreement was that initially it was small and most people were not aware of its existence.

Numerous studies (including some videotapes) of people’s reactions to the beginning of a natural disaster such as a fire have shown conclusively that there is a strong tendency to initially ignore the peril. People tend to continue to go about their normal activities of the moment. They will often even look at the fire yet somehow the obvious danger will fail to register. Perhaps most of us can recall the horrible fire that took place at the Station nightclub in West Warwick Rhode Island on Feb. 21, 2003 and the news footage showing patrons still enjoying the band Great White and ignoring the growing flames for several seconds after the fire begins to rage out of control.

One police detective testified, “I remained silent, hoping that no one else would notice the flame before it was extinguished, as I had no doubt that it would at that time. I had every confidence it would be put out.”

Others noticed it as well. One girl asked her mother if the tent was supposed to be on fire. One person, returning to the bleachers after purchasing some refreshments, did yell “fire,” but even then most of the spectators continued to watch the Wallendas rather than respond to the growing threat.

The fire had started on a sidewall, not the roof of the tent. The sidewalls of the big top were not treated with the waterproofing, so they were not as flammable. Fire buckets were kept under the stands in case a dropped cigarette should ignite any grass under the seats.

Three ushers from the north side cut behind the blues and grabbed the fire buckets. There were four buckets, each filled with four gallons of water.

All four buckets were thrown at the fire, but had no effect. The fire was at about eye level, perhaps a yard wide and five feet high by that time. The ushers then tried to pull down the sidewall.

It was too late. The flames had reached the roof.

While some people began to try to exit, many others still failed to react. Some thought it must be part of the show. They were at a circus to enjoy themselves and be entertained. They couldn’t immediately switch from that mood and anticipation and grasp the reality that was about to engulf them. Others assumed that some circus employee would certainly arrive to put out the fire so their day of fun wouldn’t be spoiled.

The band had been playing a quiet waltz as the Wallendas built their pyramid on the high wire. Now they stopped, then switched to “The Stars and Stripes Forever.” Playing this song was designed to alert circus employees that a serious problem existed. The Wallendas stopped their act and began to break down their pyramid and exit. One of their bikes fell to the sawdust below.

By now the flames had reached the roof and the horrible reality of what was happening set in.

During the fire at the Station in Rhode Island, most of the people in the panicked crowd rushed to exit the same way they entered, ignoring other exits towards the sides of the stage. Psychologists tell us that this is typical behavior in a panic situation. It is also usual for some people to become completely individualistic and antisocial—an “every man for himself” reaction. This behavior can then spread through the crowd. People will often fight to get towards an exit chosen by a few individuals, ignoring other, better options. And as happened in the Station fire, many will run to try and exit the same way they came in, often passing several easier exits along the way.

Many nearest the flames bolted. The lucky ones were in the lower seats and made the choice to quickly run towards the performer’s entrance. Those who hesitated were trampled by panicked and terrified people coming down from higher seats. Some tripped and got caught in the spaces between the seats only to be crushed by the growing stampede. Others remained frozen, just sitting there as if nothing was happening. Psychologists refer to this as “collective disbelief.”

The fire reached the top of the centerpole and then split in three different directions. The announcer at center stage urged people not to panic and instead to leave in an orderly manner, but he was silenced as the power went out.

For those near the top, the best chance was to exit over the back. Some shimmied down poles. Some children jumped into the arms of people outside who tried to catch them. Some adults held the sidewall so children could slide down the wall like a chute. As in many life-and-death situations of this type, there were many stories of people pushing and attacking others so they could escape and many stories of individuals bravely risking their own lives and chances of escape to try and assist others who were weaker or for some other reason unable to make it out by themselves.

The band continued to play the “Stars and Stripes” over and over again. Ushers continued to urge people not to panic. Many rushed children to safety and then returned to try and save more, while some circus employees smashed people’s cameras, trying to prevent photographs from being taken.

Some children who had escaped but could not locate their parents rushed back into the fire.

Some of the big cats were still in the chutes through which they exited after each performance. Panicked people tried to exit over the top of the chutes. Some attendants tried to stop them. Fathers urged their children to ignore the attendants and continue. One woman fell and dropped a child, whose arm dangled into the chute. His arm was clawed by a cat still in the chute.

The Wallendas headed for the performer’s exit, but quickly realized that it was too crowded with people. They climbed over a cage that lined the exit. Herman Wallenda later stated that this was easy for them to do—they were performers. But the general public was not capable of exiting that way.

The band continued to play.

The heated paraffin from the big top not only burned, it also melted and rained on the people inside like napalm, badly burning many.

As the top burned violently, it was as if the people were inside a broiler. Most were not burned by direct flames. Instead, they were literally cooked by the heat from the flames above.

Many in the crowd soon began to realize that they could never escape out the exits, so they ran back to the top of the seats and jumped. The jump was only about 10-12 feet, but that was sufficient to cause many injuries to both the jumpers and the brave souls trying to catch them. Some slid down poles, tearing the skin off their hands and arms. Some broke their ankles, and unable to move, suffered more severe injuries as others jumped and landed on top of them.

Many escaped by simply squeezing under the sidewalls, but in some spots the walls were tied down so tightly that that was impossible. Men and boys, some inside, some already out, opened up small knives and tried to cut holes in the sidewall to allow people to slip through.

The fire continued to rage and the tent collapsed on those still trapped inside. Several survivors stated that they would always be haunted by the horrible screams of the animals inside being burned alive.

There were no animals inside. They had all been led to safety.

The first signal box came in at 2:44 pm. Three Engine Companies and two Truck Companies rushed to the scene. Soon more alarms sounded and more men and equipment sped towards the fire.

Engine Company 7 arrived first, but was blocked from getting as close as it wanted. They were forced to lay about 1000 feet of hose from a hydrant in order to try and fight the fire.

The scene inside was horrendous beyond description. Oddly enough, some survived simply because they had been the first to fall, and the mass of horribly burned bodies on top of them had sufficiently shielded them from the flames to at least keep them from dying on the spot.

In most fires, the most common cause of death is asphyxiation. Victims are overcome by smoke. They typically lapse into unconsciousness and subsequently breathe in extremely hot air and/or poisonous gases produced by the fire. This causes the release of large quantities of fluid into the person’s lungs. Death is caused either by asphyxiation or drowning.

This didn’t happen in the circus fire. The big top acted like a chimney, the hot gases exiting out the top. Most victims burned to death. The intensity of the fire was so great that many bodies were burned completely beyond recognition—mothers holding children sometimes being literally fused together. In many cases not even the victim’s gender could be determined.

Identifying the dead was a horrible task. Bodies were taken to a local armory and separated into male, female, and uncertain. Children constituted a separate group. Friends and relatives lined up to try and identify the dead. Often dental charts had to be used. Gold melts at 1,945 ^{o}F (1,063 ^{o}C), and dental fillings even higher, since they are an alloy.

The investigation

Early on, a circus representative was publicly stating that nothing combustible had been used on the circus big top, even though this was in conflict with reports published in the press indicating that the top had actually been coated with flammable waterproofing. Officials from Ringling Brothers stated that the top actually had been treated with a fireproofing material, and although it wasn’t fireproof, it was fire resistant. Robert Ringling was quoted as saying, “Every test we put that through showed that it would resist fire. A fire might endanger some of the equipment but would never endanger human life.”

Later, as stated in the article, the circus would maintain that they were unable to obtain adequate fireproofing materials because they were needed for the war effort.

This position is open to serious challenge. After the Cocoanut Grove fire in Boston, all decorations in restaurants and nightclubs were required to be fireproof. Several different materials had been sanctioned for this purpose and had passed tests. At least two other circuses advertised that their big tops were treated with fireproofing materials. Former Ringling Bros. employees working for these circuses testified that claims that appropriate materials could not be obtained were false. Another circus had failed a burn test the previous June and subsequently had spent $6,000 to flameproof their main tent.

The circus remained closed for a period of time. As the article points out, before they reopened, they fireproofed their tents with Hooper Fire Chief fireproofing. It had been invented in 1936, but evidently was not, in fact, made available to civilians because of wartime priorities, although other materials were available. The first show after the disastrous fire took place on Fri, Aug. 4, 1944 in Akron, Ohio. The weather was terrible—cool and rainy, and there were only about 2,000 people in the audience.

The final totals

The final death toll came to 167 people, 67 of them children under the age of 15. It was concluded that none died from their crush injuries and none from asphyxiation. That may not be completely true, but it does appears that almost all of the victims had burned to death. The number of injured is not known with accuracy. A figure of 487 injured is sometimes presented, but as the article points out, the actual number is probably greater. Many people simply walked or drove home rather than seek medical care.

Six bodies were never identified. Three were children. One, called “Little Miss 1565,” had suffered some burns to her face, but they were relatively minor, which would have made her easily identifiable. Nevertheless, no one identified or claimed her.

Of course thousands of children escaped unharmed, at least physically, and the article presents one of their stories.

Lawsuits and settlements

Of course lawsuits were filed. In Connecticut at that time, the maximum accidental death benefit was only $15,000. The board who determined death benefits did not think that most of the victims were worth that much. They devised a formula that considered the age of the deceased, probable future earning power, and especially for women, education and social responsibilities. Most children were valued at $6,500. A sixty-nine year old woman was only given $5,000, a seventy-five year old woman $5,000.

Those who were alive but terribly injured received more. The largest award was $100,000. The circus took years to pay the claims.

There were also criminal indictments. Six circus defendants were charged with ten counts of involuntary manslaughter. The lawyers representing the circus pleaded “nolo contendere,” which means “no contest.” The defendant basically accepts punishment for the charges but denies any responsibility. It differs from a guilty plea in that it cannot be used against the defendant in another course of action. The circus basically threw themselves on the mercy of the court. Lawyers for the accused evidently expected the judge to dismiss the charges. They argued that a long trial would keep the defendants from being able to prepare the circus for the following season.

The judge didn’t buy it. He found all six defendants guilty. Ringling Bros. was fined $10,000. Sentences for the convicted ranged from six months to 2-7 years.

The circus appealed, and later the sentences were reduced. Five did go to prison for several months. Upon their release they all immediately went back to work with the circus.

The very last claim was paid in 1969.

Final comments

The circus did not return to Hartford until 1975.

A mentally disturbed person, Robert Dale Segee, was arrested six years after the fire occurred. He confessed to setting several fires over the course of several years, including the Hartford fire. At the time of the fire he would have been only fourteen years old. He was sentenced to two terms of 2-20 years, to run consecutively. He served his sentence and was released. Later he maintained that he was innocent and had confessed, as he stated, “If you was hassled as much as I was, you’d tell them anything to get them off your back.” There remain a lot of conflicts surrounding both him and his confession, with no clear proof in regard to his guilt or innocence.

The identity of “Little miss 1565” remained a mystery for many years. Rick Davey, a Hartford arson investigator, became obsessed with solving the mystery. He continued the investigation on his own time. In 1991 he concluded that the girl was Eleanor Cook. There had been three Cook children at the circus. The youngest, Edward, had died in the fire. The oldest, Donald, had escaped. The mother, Mildred Cook, had been told that Eleanor’s body was not at the morgue or armory. The body was “identified” as Eleanor. It was disinterred and reburied in a new white coffin beside her brother Edward.

But according to author Stewart O’Nan, doubts remain. The dental charts don’t match. Eleanor was eight years old, but the teeth of Miss 1565 are those of a much younger child. In addition, the height and weight do not appear to match. The clothes on the girl at the armory did not match the clothes Eleanor had been wearing. O’nan thinks that another badly charred body, #1503, is probably Eleanor Cook, but perhaps neither is. Currently the State Police Forensic Science Lab is reviewing the case.

In 1994, a reunion was held in Hartford. Over 200 people attended. Many brought their old circus programs.

In 1997 both Mildred Cook and Robert Segee died. His home town at the time, Columbus, Ohio, didn’t even run an obituary. The Hartford *Courant* failed to note his passing.

To this day many survivors who escaped unharmed still suffer psychological effects. They stay on the bottom floor of hotels and nervously check where the exits are. The sound of a fire truck can produce high emotional distress. Some are still unable to stand inside of any tent. Others cannot bear to watch a circus. Some say that they have memorized the detailed features of their children’s teeth. Some still have recurrent nightmares sixty years later. They say the memory never goes away.

Connections to Chemistry Concepts

“Paraffin” is not a pure chemical substance. The term refers to the kind of waxy solid that is used to make candles, for example. Being nonpolar, paraffin is not soluble in water, but will dissolve in nonpolar solvents such as gasoline or benzene (see the Teacher’s Guide material for the Dec. 2004 article on Transdermal Patches). It is relatively impervious to most chemical agents, but will burn readily in air. It typically is a mixture of high molecular weight alkanes. Alkanes are saturated hydrocarbons with the general formula C_nH_{2n+2}. In paraffin, “n” typically ranges from about 22-27. Many high school textbooks will use the formula $C_{25}H_{52}$ to represent paraffin in things such as stoichiometry problems.

Possible Student Misconceptions

Students may have heard or read that most fire victims actually are killed from smoke inhalation rather than the fire itself, and may therefore assume that this is the case for the Hartford circus fire. Unfortunately, this is not the case. Virtually all the victims of the circus fire actually burned to death (see *Background Information*).

They may also assume that in the panic, many victims were probably trampled to death rather than being killed by the fire. Again, this does not appear to be the case.

Demonstrations and Lessons

1. A very simple demonstration of the fact that a nonpolar liquid will not “mix” with water and that hydrocarbons (such as the paraffin-gasoline mixture used to waterproof the circus tent) are very flammable can be demonstrated as follows.

   Pour a small amount of hexane (perhaps 2 mL or so) into a 125 mL Florence or Erlenmeyer flask so that its presence is not really visible. Proceed by filling the flask with water—preferably from a faucet—perhaps with some accompanying spiel about how “polluted” the water is in your area.

   After the flask is filled almost to the top, place it on top of the demonstration table, ignite a match, and bring it near the mouth of the flask. The hexane, being less dense than water, will be on top and will ignite.

   Obviously appropriate safety precautions should be taken. Safety goggles should be worn. No students should be in the immediate vicinity of the demo, and most importantly, the bottle from which the hexane was obtained should be well away from the demonstration area.

   This can be followed with a discussion of polar vs. nonpolar molecules, the concept of “like dissolves like,” and the flammability of hydrocarbon molecules.

2. A discussion of the Hartford Circus Fire can be used to introduce or review several chemical principles. Among these are:

   The flammability of a paraffin-gasoline mixture, including perhaps some typical combustion reactions of molecules like $C_{25}H_{52}$ (used to represent paraffin).

   The reason why paraffin is soluble in gasoline, but not in water (like dissolves like).

   The reason pouring water on a paraffin-gasoline fire might act to spread the fire rather than extinguish it (density and “like dissolves like”).

   The reason most victims of the circus fire burned to death rather than dying from smoke inhalation (see *Background Information*)—expansion and relative density of hot air vs. cold air.

   The reason why dental fillings were used to identify many of the bodies that were burned beyond recognition (see *Background Information*).

Connections to the Chemistry Curriculum

There are a number of important chemical concepts and principles that are demonstrated in the events of the Hartford Circus Fire. See *Demonstrations and Lessons*.

Suggestions for Student Projects

1. It would be nice to think that tragedies like the Hartford Circus fire are not likely to occur today because of better safeguards, better regulations and more fireproof materials and sprinkler systems. But as the Station fire in Warwick, Rhode Island on Feb. 21, 2003 demonstrated, disasters or this type are still very possible. Students could research the causes and lapses of good safety procedures that resulted in this fire. Could it have been prevented? Who should be held responsible? What should have been done differently or not done at all? They might also comment on crowd behavior as the disaster began to unfold.

2. Stewart O'Nan's account of the Hartford Circus fire (O'Nan. *The Circus Fire*. First Anchor Books: New York, 2000) is a heartrending and captivating account of a great American tragedy. It operates on many levels. It is a spellbinding narrative of the events that occurred and the reactions of those trapped by the events. It is a "whodunit" mystery of what actually happened and why. It is a study in human psychology and human fallibility when faced with an overwhelming reality. It is a study of the best and worst of human behavior. Students could gain much insight into human nature and the human spirit by studying and reporting on this book.

Anticipating Student Questions

1. How did people behave when the fire was first discovered? What prevented so many from escaping? Did people behave rationally, or was there widespread panic? Did any animals die? Were most injuries caused by the fire or by other causes?

   See *Background Information*.

2. Was the circus at fault for what happened, or was it just an unavoidable accident?

   See *Background Information.*

Websites, Books, and Videos for Additional Information

Some other books related to the Hartford Circus Fire:

A Matter of Degree: The Hartford Circus Fire and the Mystery of Little Miss 1565," by Don Massey and Rick Davey, Willow Brook Press.

The Great Hartford Circus Fire: Creative Settlement of Mass Disasters," legal scholarship on the arbitrated settlement between the circus and survivors, by Henry S. Cohn and David Bollier, Yale University Press, 1992.

Masters of Illusion, Mary-Ann Tirone Smith, Warner Books, 1994. This is a novel based on the circus fire.

Videos:
The Wrath of God: Fire Under the Big Top. This is one of the "Wrath of God" documentaries of disasters that appears periodically on the History Channel. A videocassette of the 50 minute program can be purchased at HistoryChannel.com.

Connecticut Public Television has also produced a program entitled, "The Hartford Circus Fire of 1944." It is rebroadcast periodically, but unfortunately is not available for purchase.

For some additional information and photographs:
http://www.hartfordhistory.net/circusfire.html
http://www.informationblast.com/Hartford_Circus_Fire.html

The above site contains some information that is in conflict with some information contained in O'nan"s book. The material in this Teacher's Guide was obtained from the book, as the author's research appears to have been both deep and thorough. There is, of course, no way to accurately judge the validity of some of the statements made in regard to the fire.
While one might question the pro-circus bias for the following site, it does contain several good photographs taken during the fire.
http://www.historybuff.com/library/reffire.html

More Than Blue

Background Information

Definition of Clinical Depression

As might be suspected, diagnosing a condition like clinical depression is not as clear cut as diagnosing something like a broken bone, acne, blocked arteries or a specific type of cancer. As the article points out, everyone is depressed at many points in their lives, often for understandable reasons. There is no sharp dividing line between “normal’ bouts of temporary depression (the “blues”) and clinical depression. The article doesn’t present a specific definition of clinical depression, but rather states that depression “becomes a problem” when “it interferes with your normal day-to-day activities.” But “becoming a problem” really isn’t an adequate criteria to label something as clinical depression. The loss of a loved one, for example, can often result in a temporary period of grief and depression that would certainly be expected to interfere with normal day-to-day activities but wouldn’t be classified as clinical depression because of its obvious and understandable cause and the reduction in severity with time. People can and do “get over” normal bouts of depression. Most of us probably do it several times over the course of our life.

One accepted definition of clinical depression is: *a state of depression and anhedonia* (loss of interest in life) *so severe as to require clinical intervention*.

Understandably, the phrase “so severe as to require clinical intervention” will be interpreted differently by different individuals. Nevertheless, it is clear that many people suffer extended bouts of depression whose symptoms are so severe that they become debilitating to the point where clinical intervention is necessary if they are going to have a good chance to recover in a reasonable period of time.

Sometimes clinical depression is defined as depression whose severity reaches levels that meet criteria that are generally accepted by clinicians. Once again, this is somewhat ambiguous, but this may involve a state of depression that lasts more than two weeks and is so severe that it interferes with daily living.

In an effort to shed more light on exactly how clinical depression is diagnosed, I contacted a former student who is now a practicing psychiatrist. The following question was posed:

“Internet sources indicate that clinical depression is defined as ‘a state of depression and anhedonia so severe as to require clinical intervention. But how does one determine when it has reached that state?”

His response was:

The formal diagnosis of depression for a psychiatrist has to fulfill criteria laid out in the DSM-IV-TR (Diagnostic and Statistical Manual, Fourth Edition). There are nine potential criteria and a diagnosis of major depression requires five of them present for at least two weeks. One criterion that must be present is either depressed mood or anhedonia. The others are things like appetite changes, changes in sleep, energy, concentration, or suicidal thoughts.

Most depression is diagnosed by non-psychiatrists, for example primary care doctors. There it’s more art than science, but does generally rely on the same criteria. A few key factors that usually catch the attention of any doctor are depressed mood, crying, suicidal thoughts, and impairment of function at work or at home.

As you may know, a number of more “objective” instruments have been developed to diagnose and monitor the progress of treatment. One commonly used is the Beck Depression Inventory (BDI). The patient answers about 20 questions indicating symptom severity on a 0-3 scale, and the scores are summed. Another common tool is the Hamilton Rating Scale for Depression (HAM-D).

Approximately 5% of the population of the United States will experience a depressive episode that will require psychopharmacological treatment. A number of studies put the average age of onset in the late 20s. Women are about twice as likely as men to undergo treatment, although this discrepancy is shrinking and is no longer present after menopause. The greatest danger comes from suicide. Some estimates put the suicide rate for patients whose symptoms are severe enough to require hospitalization at about 15%.

Different subgroups of clinical depression

Clinical depression has been subdivided into a number of subgroups. Included among them are:

affective disorder, emotional disorder, emotional disturbance, major affective disorder—these refer to any mental disorder that does not appear to be caused by some detectable organic abnormality of the brain but still involves a major disturbance of emotions.

agitated depression—a state of clinical depression marked by significant irritability and restlessness.

anaclitic depression—a severe and progressive depression in infants who have lost their mother and for whom no suitable substitute was obtained.

dysthymia, dysthymic depression—this refers to mild but chronic depression—a person who seems to always be in a “bad mood” and has been that way for years.

melancholic depression, endogenous depression—a state of depression that does not appear to be related to any obvious cause.

exogenous depression, reactive depression—a state of depression that has an obvious cause, but the depth and duration of which is more severe than might be considered a normal reaction to the event(s).

major depressive episode—a state of depression that has all the classic symptoms, such as anhedonia, lethargy, sleep disturbance, despondency, morbid thoughts, feelings of worthlessness and perhaps even attempted suicide, but for which there is no known organic dysfunction.

neurotic depression—a term used for any state of depression that is not psychotic.

psychotic depression—a state of depression so severe that the person loses contact with reality and is severely functionally impaired.

retarded depression—a state of depression marked by extreme lethargy.

What causes depression?

No specific cause has yet been identified, but a number of different factors appear to play a part. Included among there are:

Heredity—there is some evidence that there may be a genetic link to the tendency to suffer from depression.

Physiology—Changes or imbalances in chemicals which transmit information in the brain—the neurotransmitters, as discussed in the article.

Psychological factors—This includes things such as low self-esteem and/or self-defeating or distorted thinking. There is a cause vs. effect question here, i.e., which came first, the distorted thinking or the depression? But it has been established that sufferers who can correct their thinking patterns can show significant improvement in both their mood and their self-esteem.

Early experiences—If one suffers trauma early in life, one is much more likely to suffer from severe depression later in life. Trauma can include things such as the loss of a parent, abandonment or rejection, neglect, chronic illness and severe physical, psychological or sexual abuse.

Life experiences—Loss of a spouse or family member, financial difficulties, including the loss of a job, divorce, long term stress, etc.

Medical conditions—some medical conditions can contribute to depression. Included are hepatitis and mononucleosis. Some medications such as birth control pills and steroids can also precipitate bouts of depression.

Alcohol and other drugs—including tranquillizers, sleeping medications and narcotics.

Post-partum depression—About 10% of new mothers experience some form of depression after childbirth. The most common time of onset is about three months after delivery. About 0.2% of new mothers have symptoms so severe that they include hallucinations or delusions.

Living with a depressed person—A person living with a depressed person is more likely to become depressed themselves.

Treatment of clinical depression
As the article points out, there is no one way to treat clinical depression. Individuals differ, and their reaction to and the success of any particular treatment scheme will vary. There are two main modes of treatment, medication and psychotherapy, often employed together. Although not mentioned in the article, another treatment alternative involves the use of electroconvulsive therapy.

Approaches using medications
The article does a very good job of presenting the three major kinds of medications used to treat clinical depression, namely the Serotonin Reuptake Inhibitors (SSRIs), MAO inhibitors and the tricyclics.

The use of Selective Serotonin Reuptake Inhibitors (SSRIs), such as fluoxetine (Prozac), paroxetine (Paxil), sertraline (Zoloft) and nefazodone (Serzone) currently constitutes the most commonly used treatment involving medication. As the name suggests, these pharmaceuticals operate by reducing the reuptake of serotonin by nerve cells. This leaves higher serotonin levels in the brain. Since lower levels of serotonin have been connected to depression, raising these levels often leads to a lessening of the condition. One advantage attached to the use of SSRIs in place of other medications is that they typically have fewer side effects than the tricyclics or the MAO inhibitors, although side effects can include drowsiness, dry mouth and decreased sexual performance.

The Monoamine Oxidase Inhibitors (MAOIs) are often prescribed if the use of SSRIs proves to be ineffective. As the article points out, there can be serious side effects if the patient consumes too much food containing tyramine. These potentially serious and possibly fatal side effects have resulted in SSRIs largely replacing the use of MAOIs in the treatment of depression. A new MAOI has recently become available. Moclobemide (Manerix) is classified as a reversible inhibitor of monoamine oxidase A (RIMA). Its use does not demand that the patient follow a special diet.

As pointed out in the article, the oldest group of chemicals used to treat depression are tricyclics such as amitriptyline and desipramine, but their use has decreased because of the more serious side effects attached to their use and the availability of better alternatives. These side effects can include increased heart rate, drowsiness and memory impairment.

There also is a newer group of pharmaceuticals called Selective Norepinephrine Reuptake Inhibitors (SNRIs) such as venlafaxine (Effexor) and rebosetine (Edronax). These work by maintaining a constant level of noradrenaline in the brain while also acting upon serotonin. Fewer side effects have been connected to their use and they appear to have a positive affect on both concentration and motivation. One negative is that discontinuation of the drug appears to be associated with withdrawal symptoms.

Occasionally other types of medications may be used for particular patients. These may include tranquillizers and sedatives, antipsychotics and lithium, but the potential addiction issues as well as several serious possible side effects generally limits their use to treat depression.

Psychotherapy
Psychotherapy is often used in conjunction with medical approaches. The goal is to help the patient both understand the problems that are contributing to his/her condition and then take steps to resolve these problems. Psychotherapy can be done in either a group or individual setting. While only a licensed psychiatrist can prescribe medication, psychotherapy (or counseling) can be administered by a number of different health care professionals such as psychiatrists, psychologists, social workers or psychiatric nurses.

Some of the goals of psychotherapy are to help the patient make changes in his/her thinking patters, to deal with relationship issues and to gain insight into the factors that are contributing to the depression and learn ways to deal with them. They also help the patient deal with relapses.

Different approaches can be used. *Cognitive therapy* focuses its efforts on how patients think about themselves and their relationships to the rest of the world. It tries to get them to correct negative thought patterns, improve their self-image, develop better interpersonal skills and reduce stress. *Behavioral therapy* is based on the idea that behaviors are learned. It tries to replace ineffective and destructive behaviors with better and more effective alternatives. *Supportive therapy* focuses on getting people to discuss their problems, and then share information, ideas and strategies for coping while providing emotional support.

Electroconvulsive therapy
As the name suggests, this type of therapy involves subjecting the patient to convulsive electrical shocks. It employs short bursts of carefully controlled electrical current. These bursts induce an artificial epileptic seizure.

Unfortunately, this type of therapy conjures up a very repulsive and negative image in the minds of most people, which may be largely due to the way the therapy was performed and misused in the past as well as its portrayal in movies such as “One Flew over the Cuckoo’s Nest.”

ECT was first used in the 1930s. During the 1940s and 1950s, ECT was used to treat severe mental illness. It was often administered to severely disturbed patients residing in large mental institutions. And it was often misused. It was administered for a wide variety of illnesses, many of which did not respond to this type of treatment. It was given in large doses and for extended periods of time. In some cases it harmed rather than helped the patient. It was sometimes used to manage and control unruly patients rather than as a form of therapy designed to help them.

The development of effective psychopharmacological medications and the imposition of judicial and regulatory restrictions designed to prevent abuses greatly diminished the use of ECT. Today it is mainly used in psychiatric hospitals or the psychiatric units of general hospitals. Although there is an ongoing debate as to what type of psychiatric disorders it should be used for, there is a growing concern that the curtailment of this type of therapy may be depriving many patients of what might be an effective treatment method.

First, ECT is no longer administered the way it has been portrayed in the movies. The patient is given a general anesthetic and is asleep during the procedure. Then the drug succinylcholine is administered. This drug temporarily paralyzes the muscles, which is a positive thing, since this means that they will not contract during the treatment. In the traditional treatment two electrodes are placed on the patient, one above the temple of the nondominant side of the brain and a second in the middle of the forehead. A current is applied for about one second. The patient’s seizure activity is monitored with an electroencephalogram (EEG) while his/her heart rhythm is monitored with an electrocardiogram (EKG). During the procedure the patient is ventilated with pure oxygen. The induced seizure typically lasts about 30 seconds to perhaps slightly over a minute. The patient generally awakens from the anesthesia about 10-15 minutes later. Common side effects upon awakening may include some confusion, headache or muscle stiffness. These generally diminish significantly in about an hour. Because the procedure can sometimes produce an increase in blood pressure and/or temporary heart arrhythmia, patients who suffer from hypertension or cardiovascular problems need to be carefully evaluated before undergoing the procedure.

After initial improvement it is common for patients to relapse, so ECT is often readministered at intervals of perhaps six weeks.

The one major problem associated with this treatment is the potential for persistent memory loss. Although most patients return to normal, a small percentage appear to suffer severe loss.

How distressing is it to the patient? One study interviewed seventy-two patients that had undergone the procedure. While some did find the procedure terrifying and/or shameful and others reported persistent memory loss, the majority spoke positively of the benefits. Among the patients who were interviewed, 54% said that a visit to the dentist was more stressful and 81% stated that they would agree to have the procedure performed again.

Is ECT effective, and if so, for what specific conditions? A report on ECT prepared by the National Institutes of Health (NIH) states that studies that have used various controls for comparison, including “sham” ECT (e.g., all of the elements of the ECT procedure except the electric stimulus), the use of MAOIs, tricyclics and other combinations of antidepressants and placebos have demonstrated the efficacy of ECT in the treatment of delusional and severe endogenous depressions. It does not appear to be effective for patients with milder depressions such as dysthymic disorder.

Transcranial magnetic stimulation

Repetitive transcranial magnetic stimulation (rTMS) is currently being studied as a possible treatment for depression. This technique uses a powerful magnetic field to stimulate the left prefrontal cortex. This area of the brain typically shows abnormal activity in depressed individuals. Preliminary studies appear to indicate that its effectiveness parallels that of ECT, but with fewer side effects.

Possible Student Misconceptions

There are a great number of misconceptions that students may have about depression and its treatment. The article should dispel many of them. Included may be things such as:

Depression is normal and never requires medical treatment.

Clinical depression is very rare.

Clinical depression is the same thing as "manic-depressive" or bipolar disorder.

Depressed individuals may threaten suicide, but they rarely go through with it.

Demonstrations and Lessons

1. If your course includes a strong organic component, a careful analysis of the structures and functional groups present in many of the molecules presented in the article could provide either the foundation for a lesson introducing these structural elements and functional groups or an excellent review.

2. There is always an ongoing debate as to whether high creativity is positively connected to mental illness and/or depression. It is easy to have an opinion on the topic and to cite one or two specific examples (Van Gogh always comes to mind), but what is the actual evidence for this view? Many very uncreative individuals suffer from mental illness and/or depression as well. This topic could provide a vehicle for debate designed perhaps not so much to "settle" the question as to analyze the nature of evidence—anecdotal vs. statistical, etc. Such a debate could go far to teach students about the nature and value of different kinds of evidence and argument, especially if students were given an assignment to come prepared for the debate with more than just their opinions.

Connections to the Chemistry Curriculum

Although this article may not connect as strongly to topics typically included in a high school chemistry course, it does tie in nicely to organic structures and functional groups.

Suggestions for Student Projects

1. One means of treating depression involves the use of electroconvulsive shocks (see *Background Information)*. The way in which this therapy was administered and misused in the past, along with its very negative portrayal in movies such as "One Flew over the Cuckoo's Nest" has resulted in many people's rapid and almost reflex rejection of this type of therapy. But the way it is administered today is far different from the way it was administered in the past and the way it has been portrayed in movies. In addition, many studies have shown its effectiveness for some types of depression. Students could prepare and present a report showing how this type of therapy has been portrayed by Hollywood, how it was used and misused in the past, and how the current application differs dramatically, along with a presentation of information relating to some of the studies that support its clinical effectiveness.
2. There has always been an ongoing argument as to whether mental illness and/or depression and creativity are connected. It is certainly true that many creative individuals have suffered from various kinds of mental illness and depression. This issue could be the focus of a couple of different projects. Students could take one specific individual and research both his/her creative achievements and his/her difficulties. Alternately, they could research the arguments and evidence on both sides of the issue.

Anticipating Student Questions

1. Why don't people who claim to be suffering from depression just quit feeling sorry for themselves and get on with their lives? I've done it, why can't they?

   To quote one Website: (http://www.free-definition.com/Clinical-depression.html)

   It is hard for people who have not experienced clinical depression, either personally or by regular exposure to people suffering it, to understand its emotional impact and severity, interpreting it instead as *being similar to "having the blues," or "feeling down." ..clinical depression is a syndrome of interlocking symptoms which goes far beyond sad or painful feelings. A variety of biological indicators, including measurement of neurotransmitter levels, have shown that there are significant changes in brain chemistry and an overall reduction in brain activity. One consequence of a lack of understanding of its nature is that depressed individuals are often criticized by themselves and others for not making an effort to help themselves. However, the very nature of depression alters the way people think and react to situations to the point where they may become so pessimistic that they can do little or nothing about their condition. Because of this profound and often overwhelmingly negative outlook, it is imperative that the depressed individual seek professional help. Untreated depression is typically characterized by progressively worsening episodes separated by plateaus of temporary stability or remission. If left untreated it will generally resolve within six months to two years although occasionally depression becomes chronic and lasts for many years or indefinitely. Treatment can shorten the period of distress to a matter of weeks. While depressed, the person may damage themselves socially (e.g. the break up of relationships), occupationally (e.g. loss of a job), financially and physically. Treatment of depression can significantly reduce the incidence of this damage, including reducing the risk of suicide which is otherwise a common and tragic outcome. For all of these reasons, treatment of clinical depression is seen by many as very useful and at times life saving.*

2. Is a tendency towards depression inherited?

   There does appear to be some individuals whose brain chemistry is predisposed to depression while others appear to be much more resistant, even when they experience the same or similar physical or psychological triggers. Close relatives of people who are bipolar disorder (manic-depressive) are at a higher risk for developing depression than the general population.

3. Are there any other ways to treat depression other than those discussed in the article?

   See *Background Information.*

Websites for Additional Information and Ideas

For additional discussion of serotonin:
http://www.health.uab.edu/show.asp?durki=61541&site=734&return=18687

For a good general discussion of mood disorders:
http://www.surgeongeneral.gov/library/mentalhealth/chapter4/sec3.html

The Silent Killer

Background Information

Dangerous levels of carbon monoxide
As stated in the article, perhaps surprisingly, there are currently no agreed upon standards for carbon monoxide levels in indoor air. What constitutes an unacceptable concentration of carbon monoxide depends, to some extent, on the susceptibility of the individual being exposed. The article also gives some general figures relating carbon monoxide concentrations to physiological effects. Britain's Health and Safety Executive specifies 50 ppm as being an acceptable safety level. At concentrations of about 200 ppm one can expect to develop a slight headache. By 400 ppm widespread headaches can be expected in perhaps 2-3 hours. Above 800 ppm severe symptoms such as dizziness, nausea and convulsions emerge in less than one hour of exposure and unconsciousness and death may follow.

It is possible for neurological effects be become evident even weeks after exposure, even though the exposed person appears to have made a complete recovery.

Carbon monoxide levels in homes are generally low. In homes without gas stoves they typically vary from about 0.5 to perhaps 5 ppm. If properly adjusted gas stoves are present, levels may be in the 5-15 ppm range. Poorly adjusted (but not malfunctioning) stoves may raise levels to around 30 ppm or higher.

According to UL Standard 2034, home carbon monoxide detectors must sound a warning before the following levels are reached:

100 ppm for over 90 minutes
200 ppm for over 25 minutes
400 ppm for over 15 minutes

It might be noted that the "normal" level of carboxyhemoglobin in the blood of people living in cities is less than 1.5%--but is up to 8%-10% in heavy smokers.

Diagnosis of carbon monoxide poisoning.
CO poisoning is not easily diagnosed. Symptoms such as headaches, nausea, dizziness, etc., can easily be confused with other illnesses such as the flu. Diagnosis often depends on knowing the patient's history—how and where did the symptoms arise?

Interestingly, those non-invasive oximeters that we've all seen put on someone's finger to measure oxygen levels in the blood are not useful. They work by emitting light at two different frequencies, 660 and 940 nm. They then measure the difference in absorption of the light as it passes through the person's finger. Unfortunately, carboxyhemoglobin absorbs the same frequency as oxyhemoglobin. If a person's blood contains relatively high concentrations of carboxyhemoglobin, the oximeter will produce essentially the same reading as it would if the substance were oxyhemoglobin.

Carbon monoxide in automobile exhaust—catalytic converters
Modern automobiles are equipped with catalytic converters that are designed to reduce emissions of unburned hydrocarbons, nitrogen oxides and carbon monoxide. Before the introduction of catalytic converters, automobile exhaust could contain significant concentrations of CO, perhaps in the range of 5% or so. But today these emissions have been reduced to only a few hundred ppm when the engine is warm and idling.

The article states that about 2000 suicides are committed in the United States by using the exhaust from automobile engines. At first consideration, the data on the effectiveness of catalytic converters and the number of suicides attributed to the intentional use of automobile exhaust might appear to be in conflict. But this is not the case. Despite the presence of catalytic converters, automobile exhaust is still very dangerous and one should never run an automobile engine in a confined space, such as a closed garage.

Catalytic converters have three characteristics that affect the concentration of carbon monoxide. First, the converter only operates effectively over a narrow fuel/air ratio. Secondly, the converter only operates effectively above a relatively high temperature. Finally, if the converter gets overheated the materials from which it is made can sinter. This results in a longer warm-up time being needed before the converter will function as designed.

When started cold, an automobile engine uses a high fuel/air mixture to get the combustion process started. This means that for a period of time, the converter will not be functioning. This combination of a high fuel/air ratio along with a non-operating catalytic converter can result in exhaust CO concentrations exceeding several thousand ppm.

The actual concentration of carbon monoxide in automobile exhaust will vary significantly from situation to situation. Starting a cold engine produces much more CO than starting an engine that is already warm. A properly functioning catalytic converter will greatly lower the concentration of CO, but not all catalytic converters operate at optimum efficiency.

Automobile exhaust also contains significant concentrations of carbon dioxide—around 15% or so, and low concentrations of oxygen.

This combination of factors makes it entirely possible to use automobile exhaust to commit suicide, especially if a car is started cold.

Connections to Chemistry Concepts

The structure of carbon monoxide and bonding theories

Since carbon monoxide only consists of two atoms, it obviously must be a linear molecule (the nuclei are arranged in a straight line), but that doesn't address the question of what kinds of bonds exist within the molecule and how we might apply bonding theory to derive a structure that would appear to be consistent with the known properties of the molecule.

The most striking property of the bond between carbon and oxygen in carbon monoxide is probably the exceptionally high value for its bond dissociation energy. It takes approximately 1072 kJ to break one mole of these bonds. By comparison, the amount of energy required to break a mole of bonds between carbon and oxygen in carbon dioxide is only about 799 kJ (still relatively high), and the amount needed to break a bond between carbon and oxygen in a molecule like ethyl alcohol (CH_3CH_2OH) is only about 360 kJ.

Classical bonding concepts suggest that this high value indicates that the bond between carbon and oxygen in carbon monoxide is probably a "multiple" bond, i.e., a "double" or "triple" bond.

The use of molecular models may have one slight unintended consequence in that it may subtly implant in the minds of our students the notion that bonds are "things." To build a model of something like water, we take two spheres representing hydrogen atoms one sphere representing an oxygen atom and then reach for two "chemical bonds," as if we had to go get these bonds if we wanted to make the actual molecule.

Of course bonds are not real "things," so what does the term "double" or "triple" bond imply?

At the introductory level the most commonly taught theories of bonding are the Valence Shell Electron Repulsion theory (with Lewis Dot Structures) and the Valence Bond theory, which introduces the idea of orbital hybridization. These two approaches are "good" in the sense that they are comparatively simple to apply and do a decent job of accounting for experimentally determined properties such as bond energy, bond length and the arrangement of the nuclei in a large number of molecules.

But VSEPR and Valence Bond theory cannot adequately explain many molecules, the oxygen molecule being perhaps the most commonly cited example. In addition, we have to invoke the somewhat artificial notion of "resonance structures" to attempt to explain many molecules and ions that contain equivalent bonds that have properties somewhere between that of single and double bonds. The essential problem is that one basic assumption Lewis made when the theory was formulated was that all covalent bonds involve sharing pairs of electrons, and that simply is not always the case.

A more sophisticated bonding theory called Molecular Orbital Theory utilizes sets of orbitals that encompass the entire molecule. MO theory does a much better job of explaining the structures of molecules. Unfortunately it is much more complex for students to apply, especially for molecules that contain more than two atoms.

To try and present the basic ideas behind MO theory in this Teacher's Guide would be too ambitious, but if you are interested in learning or reviewing some of the basic ideas, a few good Websites to visit might be:
http://www.chem.ufl.edu/~chm2040/Notes/Chapter_12/theory.html
http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch8/mo.html

http://www.ch.ic.ac.uk/vchemlib/course/mo_theory/main.html
http://www.mpcfaculty.net/mark_bishop/molecular_orbital_theory.htm

Back to carbon monoxide.
Students are usually told that a typical and simple covalent chemical bond involves two atoms sharing a pair of electrons in a region between their nuclei. Of course not all chemical bonds involve the simple sharing of pairs of electrons, and later we may discuss resonance structures, where the simple “sharing a pair” notion is inadequate. We may even present molecules such as oxygen, O_2, where Valence Bond theory appears to be unable to explain the known properties of the molecule.

But if we apply simple Valence Bond theory to the carbon monoxide molecule, we can quickly come up with a structure that seems reasonable.

Carbon has four valence electrons ($2s^2$ $2p^2$), while oxygen has six ($2s^2$ $2p^4$), so the Lewis structure for the carbon monoxide molecule contains a total of ten electrons.

Since carbon and oxygen are in the second period of the Periodic Table, we would expect them to satisfy the “Octet Rule,” which means we would try to come up with a structure where both atoms were surrounded by eight electrons.

This can be easily achieved if we from a “triple” bond between carbon and oxygen with oxygen contributing four of the six shared electrons, as illustrated in the Lewis structure shown below.

:C:::O:

This simple model “explains” the properties of carbon monoxide in that it shows a triple bond, which is consistent with the abnormally high bond dissociation of the molecule and also accounts for all the electrons while allowing the model to satisfy the “octet rule”, something that is considered to be a general goal, especially for a molecule consisting of atoms that are in the second period of the Periodic Table.

This is the model that is normally presented in a high school chemistry course.

Valence Bond Theory also tries to describe what kind of orbitals the bonding electrons are utilizing. Like all atoms, carbon and oxygen are assumed to each contain one 2s orbital and three 2p orbitals. Valence Bond Theory “hybridizes” these atomic orbitals to produce molecular orbitals. Hybridization is a mathematical procedure where the equations representing the wave functions of orbitals are added and subtracted to produce new wave functions which then represent new bonding orbitals.

An excellent presentation of the basic concepts underlying orbital hybridization can be found at:
http://chipo.chem.uic.edu/web1/ocol/SB/1-2.htm

To “explain” the bonding in CO, Valence Bond Theory states that the carbon and oxygen atoms utilize a set of sp hybrid orbitals. Two of these orbitals overlap “head on” to form something that is designated as a “sigma” bond, which is represented by the symbol σ̃. The other two sp hybrid orbitals (one on each atom) each contain an unshared pair of electrons.

This leaves both atoms with two p orbitals, each containing one electron. The two p orbitals on each atom are oriented along two axes that are perpendicular to each other (like the “x” and “y” axes) and are parallel to the p orbitals on the other atom. Each of these two parallel sets of p orbitals “overlap sideways” to form what are designated as “pi” (π bonds, which indicates that the electrons are not being shared along a line that runs through the two nuclei, but rather are being shared in regions on both sides of a line drawn through the two nuclei.

It is somewhat difficult to visualize this from a verbal description, but a very nice illustration of this can be found at: http://www.cem.msu.edu/~reusch/VirtualText/intro3.htm

Henry’s Law
The article mentions Henry’s Law in connection with the use of a hyperbaric chamber to treat some victims of carbon monoxide poisoning and goes on to state that the law tells us that the solubility of a gas in a liquid increases when the pressure of the gas above the surface of the liquid is increased.

Henry's Law actually says more than just that the solubility increases as the pressure of the gas above the surface of the liquid increases. It reflects a specific mathematical relationship between the pressure and the "solubility,"—which is somewhat ambiguous, since there are several different units in which solubility can be expressed.

William Henry was an English chemist of the late 18th and early 19th centuries. More specifically, his law states that the solubility of a gas in a liquid is directly proportional to the pressure of the gas above the surface of the liquid. The constant of proportionality is called the Henry's Law constant for that particular gas at that particular temperature, but this constant can and is expressed in different ways.

There is no consistent way in which Henry's Law is stated or in what units the constant is expressed. In a "Noisy Knuckles" article (*ChemMatters, Dec. 2000*), the law was presented in the following way.

$P_{gas} = k_H C$

where k_H is Henry's Law constant for the particular gas being considered.

If we rearrange this expression as

$C = P_{gas}/k_H$, (Equation 1)

it says that the concentration of the gas in solution is *inversely* proportional to the numerical value of Henry's Law constant, that is, the larger the value of the constant, the lower the solubility of the gas in water.

Other sources will present Henry's Law as

$C = k_H P_{gas}$ (Equation 2)

While both forms of the law nicely express the concept that the concentration of a gas in a liquid is directly proportional to the partial pressure of the gas above the surface of the liquid, the second form states that this concentration is *directly* proportional to Henry's Law constant. The difference is minor, but awareness is useful if you are accessing a variety of sources.

Henry's Law constant is sometimes presented as having the units L˙atm/mol. These units are for the law as written in Equation 1, and is equivalent to M/atm, for the second form of the law, as shown below.

1st Form of Law	2nd Form of Law
$P = k_1 C$	$C = k_2 P$
$P/C = k_1$	$P/C = 1/k_2$

$k_1 = 1/k_2$

$$\frac{\text{L} \bullet \text{atm}}{\text{mol}} = \frac{1}{\text{M/atm}}$$

$$\frac{\text{L} \bullet \text{atm}}{\text{mol}} = \frac{\text{L} \bullet \text{atm}}{\text{mol}}$$

The constant, k_H in Henry's Law can be expressed in a number of different units, depending upon what units of concentration and pressure are selected. The accepted SI units are $\text{Pa}/(\text{mol/m}^3)$ for the first form of the law and its reciprocal for the second form. The most commonly used unit is M/atm (for the second form of the law), although popular "Advanced Placement" textbooks show little consistency in the units used.

The k_H constant can even be a dimensionless quantity if it is taken to be the ratio of the concentration of the gas in the aqueous phase divided by the concentration of the gas in the gas phase.

One assumption that must be met for a system that obeys Henry's Law is that the gas does not react with the solvent, or at least does not react to a significant extent. The constant also changes with temperature and is normally given for a temperature of 25 ºC. The law holds best for dilute solutions. As solutions become more concentrated, deviations from the law will emerge.
For more technical information about Henry's Law, consult this Web site maintained by Rolf Sander of the Max Planck Institute for Chemistry (Germany): http://www.mpch-mainz.mpg.de/~sander/res/henry.html

Possible Student Misconceptions

Students may mistakenly think that a carbon monoxide detector is the same thing as a smoke detector or that they function as smoke detectors. This is not the case. Smoke detectors do not detect carbon monoxide, and carbon monoxide detectors do not function as smoke detectors.

Students may have learned that modern automobiles are equipped with catalytic converters and that one of their functions is to reduce the amount of carbon monoxide in the exhaust. This may lead them to the erroneous conclusion that the exhaust from a relatively new car is not dangerous, which is certainly not the case (see *Background Information*).

Demonstrations and Lessons

1. If you are teaching an advanced course with a strong and sophisticated bonding unit, carbon monoxide provides a very interesting molecule with which to compare Valence Bond Theory and Molecular Orbital Theory. Even though Valence Bond Theory produces a simple and "logical" structure for carbon monoxide that looks very good in the sense that it shows a triple bond and satisfies the "Octet Rule," the structure actually has some interesting features. For instance, the highly electronegative oxygen atom ends up with a formal charge of +1, while the less electronegative carbon atom is assigned a formal charge of –1. This is a good chance to discuss the connections (and divergences) between *formal* charges and actual charge distribution. Molecular orbital theory, on the other hand, accounts easily for the "triple bond" character of the molecule (see *Connections to Chemistry Concepts*). This molecule could serve as the basis for a discussion and comparison of these two theories of bonding.

   If you would like some information on formal charge, how it is calculated and what it is used for, some good Websites include:
   http://dbhs.wvusd.k12.ca.us/webdocs/Bonding/FormalCharge.html
   http://www.scientia.org/cadonline/Chemistry/bonding/formalcharge.ASP
   http://chemistry.che.georgiasouthern.edu/paulcerp/general/molecule/fc.htm

2. The discussion of the use of a hyperbaric chamber to treat victims of carbon monoxide poisoning can provide a nice vehicle for discussing the solubility of gases in liquids and Henry's Law. This aspect of solubility may sometimes be glossed over, but it has many very practical and significant ramifications. For example, if it weren't for the fact that gases obey Henry's Law, the oceans and other bodies of water would never have absorbed so much of the carbon dioxide that has been released into our atmosphere since the beginning of the Industrial Revolution and the proliferation of vehicles propelled by internal combustion engines. The Lake Nyos tragedy (see the online Teacher's Guide for the Dec. 2000 issue of *ChemMatters*) can be discussed as a dramatic example of what can happen under a set of unusual circumstances.

Connections to the Chemistry Curriculum

This article connects strongly to several important curricular topics, especially theories of chemical bonding, molecular structures, the solubility of gases in liquids, Henry's Law, combustion reactions, stoichiometry, hemoglobin, equilibrium, acids and bases, alkalosis and pH.

Suggestions for Student Projects

1. Even though Valence Bond theory produces a simple and "logical" structure for carbon monoxide that looks very good in the sense that it shows a triple bond and satisfies the Octet Rule, the structure actually has some deficiencies. For instance, the highly electronegative oxygen atom ends up with a formal charge of +1, while the less electronegative carbon atom is assigned a formal charge of –1. Advanced students could learn about the concept of formal charge if it is not included in your curriculum and then prepare a report and/or presentation of how formal charges are calculated and how they can be used to help select from several possible Lewis structures for a molecule. See *Demonstrations and Lessons.*

2. Students might want to research Henry's Law in its detailed mathematical form and present a paper or lesson on his life and work. They could then discuss something like the Lake Nyos tragedy (see *ChemMatters, Dec. 2000*) and how it relates to this law. Alternately, they might discuss how Henry's Law and hyperbaric chambers relate to divers who get the "bends" when ascending too rapidly from a deep dive.

3. The entire topic of how oxygen is transported from the lungs into the bloodstream and then delivered to all parts of the body via hemoglobin is both interesting and complex, and could make for an excellent student report

Anticipating Student Questions

1. The article states that about 2000 suicides annually are connected to the use of automobile exhaust. But modern automobiles have catalytic converters that are designed to significantly reduce the concentration of carbon monoxide in the exhaust, so how is this possible?

   See *Background Information*.

2. Has the increase in vehicular traffic increased the concentration of carbon monoxide in our air to dangerous levels?

   No. Despite increased traffic, the introduction of catalytic converters in the 1970s has reduced CO emissions significantly. Today's passenger cars are capable of emitting 90% less CO over their lifetimes than cars made in the 1960s. But these levels may rise as traffic continues to increase unless even more effective emission controls can be employed.

3. What is the major source of the carbon monoxide that is found in our atmosphere?

   Automobiles. In some urban areas over 90% of all CO emissions may come from automobile exhausts. Other sources include industrial processes, non-transportation fuel combustion and other natural sources. CO levels tend to be highest during the coldest months of the year. Cars emit higher concentrations of CO when the engine is cold (see *Background Information*), and atmospheric conditions where warm air traps pollutants near the ground are more common during colder months.

4. Where should carbon monoxide detectors be placed?

   If your home only has one detector, it is recommended that it be placed in your sleeping area. It is easier to be overcome by CO poisoning when you are asleep than when you are awake and are more likely to be aware of its initial symptoms. If additional protection is desired, detectors can be installed on each level of a multi-level home and in each individual bedroom.

5. What should you do if you discover someone who you think is suffering from carbon monoxide poisoning?

   First, be sure you are safe and do not become overwhelmed yourself. Try to insure that you do not put yourself in a situation where you can be overcome before you can help the other person. Try to insure that there is some ventilation and "fresh air" before you enter an area where the CO level may be extremely high. Then remove the affected person to fresh air. Administer 100% oxygen if this is possible. Call for an ambulance as soon as possible. Check that the person is breathing and perform CPR if required.

Websites for Additional Information and Ideas

A good source of general information about carbon monoxide and carbon monoxide detectors can be found at:

http://www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_ce25.cfm

For more information about automobiles and carbon monoxide: http://www.epa.gov/otaq/consumer/03-co.pdf

You can take a virtual tour of a hyperbaric chamber at: http://www.hyperchamber.com/virtual

Water of Life

Background Information

The general field of exobiology
The National Aeronautics and Space Administration, NASA, contains an Exobiology Branch that conducts research seeking to increase our knowledge of the origin, evolution, and distribution of life in the universe. The questions this branch seeks to answer essentially provide a good explanation of what the field of exobiology is and what it investigates. Some of these questions are:

To what extent did chemical evolution occur in the primitive bodies of the solar system?

How did life originate on Earth, and what role did minerals play?

What evidence exists regarding the early interplay between biological and environmental evolution?

What do molecular fossils tell us about early microbial evolution?

How can the study of contemporary microbes or geochemical samples inform us of past events?

A few very general comments
Of necessity, the article only dealt with some of the basic ideas regarding the essential features and requirements of any system that might support "life" in one form or another. As discussed in the article, here on Earth, life is based on the compound water. Space limitations and content focus precluded also discussing the fact that life on Earth is also based on the element carbon and its unique ability to form complex molecules and polymers. Carbon's uniqueness among elements appears to make it perhaps the only element upon which a life-form could be based. Whether other life systems might be based on an element like silicon or a solvent like ammonia is, of course, a topic for conjecture and debate.

The basics, as presented in the article, make for a nice discussion of some interesting chemistry, but there are obviously much more complex, emotional and controversial questions that could be asked and addressed. The article doesn't deal with one of the major ones—How did life originate on Earth?

If you decide to delve more deeply into the field of exobiology and discuss theories about the origin of life, be prepared to deal with the many controversial aspects that are connected to this topic.

A brief outline of a few of the basic concepts and views regarding how life may have first appeared on Earth
Of course every single one of these statements is open to debate and would be strongly opposed by numerous individuals, some for scientific reasons and others for other reasons. But a cursory summary of some of the major concepts, theories and arguments might include the following:

The Earth is about 4.5 billion years old, give or take perhaps a half-billion years.

We don't have a good fix on when life first appeared on Earth, but the available evidence points to about 3.5 to perhaps 4 billion years ago.

We don't have a clear idea as to what Earth was like 3-4 billion years ago. One of the major unanswered questions that is debated is the nature of Earth's atmosphere at that time. If Earth had a reducing atmosphere made up of substances such as methane, ammonia, hydrogen and water, then experiments such as the Miller-Urey experiment suggest that organic molecules that may have been the precursors to life could have been created by lightning strikes. Whether enough of these kinds of compounds could have been created is debatable, as is the question of how these compounds could then undergo transformation into the much more complex replicating molecules that are required for life to exist.

Because of the problems associated with trying to create requisite molecules on Earth, some argue that the requisite molecules were brought to Earth via meteorites, comets or dust. Studies of objects such as the Murchison meteorite provide evidence that complex organic molecules can certainly be brought to Earth by such objects. But whether enough of them could be brought to Earth to actually start life here is a different question.

Of course if they were brought to Earth, then they had to be created somewhere else, which in turn argues that if this could happen somewhere else, then it could happen on Earth.

Some argue that life may have originated around hydrothermal vents. This mechanism would not require that Earth have any particular kind of atmosphere. Others argue that the high temperatures around these vents would destroy rather than create organic molecules. Others argue that the molecules could be created in a small region between the hot water surrounding the vents and the cold ocean water.

And there are other theories and ideas as well, but a 2,000 page Teacher's Guide for this article didn't seem to be a practical idea.

Arguments against silicon being the basis of a life system
Some have proposed that a life system might possibly be based on the element silicon instead of carbon. However, one can easily make a case that silicon, despite having many properties similar to that of carbon, would not be a likely candidate to form the basis for a life system. A more complete list of arguments could include:

Silicon is nowhere near as versatile as carbon in its ability to bond. While carbon easily forms a great number of different kinds of structures, including long chains with numerous branches, rings, multi-ring chains and molecules that contain double bonds, silicon is very limited. Many analogous structures are unstable and often highly reactive.

Silicon is also much less abundant in the universe.

Silicon compounds also lack chirality, or "handedness." Very few silicon compounds exhibit any handedness at all, and since the biochemical reactions of life are extremely specific, the ability of biomolecules to recognize specific substrates would be extremely limited in a silicon-based world.

Another problem centers at respiratory products. The respiratory product of carbon-based compounds is carbon dioxide, a gaseous substance easily excreted by an organism. The respiratory product of a silicon-based system would be silicon dioxide, a dense, solid material not easily removed from an organism.

Solids that are less dense than their own liquids

The article mentions that ice has the unusual property of floating on liquid water, indicating that the solid form of water is actually less dense than its own liquid. This, of course, is a very unusual property. As a generalization, the density of most solids is around 10% greater than the liquids from which they are made. This is easy to explain. In a solid the particles are expected to be packed more efficiently than they would be in the corresponding liquid, where they are not in fixed positions in a crystal lattice but are relatively free from each other and able to move throughout the entire liquid.

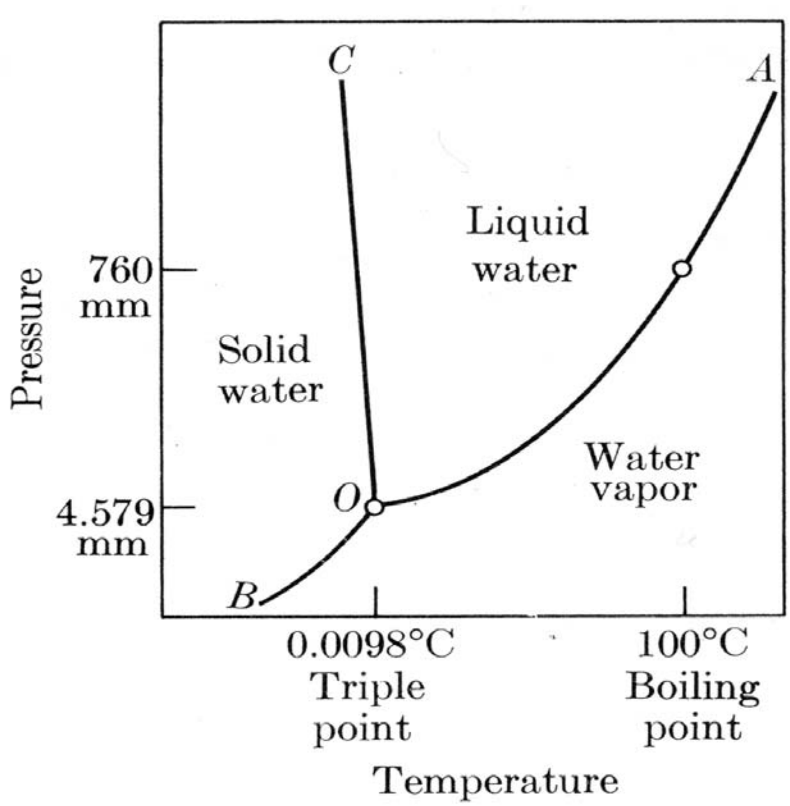
For water, this unusual property has a relatively simple explanation. The formation of hydrogen bonds between water molecules is energetically favorable. When ice forms, two conflicting behaviors compete. It is energetically favorable for the water molecules to get close to each other. They attract each other, and any time things that attract each other are allowed to get closer, this lowers the potential energy of the system, and this is "good."

But forming hydrogen bonds is also energetically favorable, and in order to maximize the formation of hydrogen bonds, the water molecules must arrange themselves in such a manner that they are not as close together as they might be if these bonds did not form. As it turns out, it is better to sacrifice a bit of "closeness" in order to maximize the formation of hydrogen bonds, so this is what water molecules do when they form the ice crystal lattice.

Although this property is very unusual, it is not unique to water. At least two other substances, bismuth and gallium, exhibit similar behavior.

Connections to Chemistry Concepts

Phase diagram for water
Most high school textbooks present a partial phase diagram for water, as shown below:



Discussion of this diagram typically includes pointing out that the normal boiling point is shown where the line separating the liquid phase from the gaseous phase reaches a value of 760 mmHg for the pressure and 100 ^{o}C for the temperature. Further discussion may involve illustrating how the diagram can be used to determine the boiling point of water at lower or higher atmospheric pressures by locating the pressure on the y axis and finding the corresponding temperature on the x axis.

Then the triple point may be explained as being the only point where the three phases all coexist in equilibrium at a pressure of 4.579 mmHg and a temperature of 0.0098 ^{o}C. This is typically followed by pointing out that the solid-liquid line “slopes upward to the left,” i.e, the line has a negative slope, and this is very unusual. It is a consequence of the fact that ice is less dense than liquid water. When pressure is increased on a system it will favor which ever phase is more dense, and therefore occupies a smaller volume. For water, this is the liquid phase, so at higher temperatures the liquid phase is “favored,” which basically means that the liquid phase will extend to lower temperatures at higher pressures, as illustrated by the slope of the solid-liquid line.

It should be pointed out that the line is almost always drawn out-of-scale. If drawn to scale, it would be difficult to discern that the line really deviated from vertical. The change in freezing point with pressure is very small.

It turns out that the phase diagram for water is actually quite complicated. There are at least eleven confirmed crystalline phases for water and three amorphous phases. The kind of ice and snow that we experience in everyday life is called hexagonal ice, or ice Ih. If you are interested in seeing a phase diagram that shows most of these phases, two good sites are: http://www.lsbu.ac.uk/water/phase.html http://www.es.ucl.ac.uk/research/planetaryweb/undergraduate/dom/ices/ices.

Phase diagram for water and ice skating

Many textbooks and Websites state that the reason a person can skate on ice has to do with the fact that ice is less dense than liquid water and the slope of the solid-liquid line on the phase diagram.

The argument is that the melting point of ice decreases with increasing pressure. When standing on skates, great pressure is exerted by the skate blades. They are sharp, so the entire weight of the person is exerted over a small surface area, therefore high pressure. Since the melting point of ice is lower at higher pressure, this results in the ice melting under the skates so that the skater can glide along on a thin layer of water.

This explanation, although still commonly presented, is not correct.

Interestingly, your Teacher's Guide editor taught this incorrect explanation for many years, even though it was in direct contradiction to personal experience and doubts had existed in my mind from the first time I read it. Doubts first centered around the fact that the slope of the solid-liquid line was actually so vertical that it just seemed improbable that the pressure being exerted on the ice could really make all that much difference. But without any actual data or calculations, well—"It must be correct, it's in all the textbooks."

Furthermore, I noticed that when the temperature was well below freezing in winter the ice on my driveway seemed to be much more slippery than when the temperature was closer to the melting point. Why would this be, since it would appear to be much easier to form a layer of liquid water at the higher temperature? And how is it that little children seem to be able to skate across ice as easily as heavy adults? And why would ice be so slippery in the first place? It is a crystalline solid held together by moderately strong forces. Surely the pressure on the bottom of a broad shoe isn't sufficient to cause it to melt.

Apparently there is always a very thin layer of liquid water on the surface of ice at any temperature that one might find on earth—at least, according to one Website, down to –157 ^{o}C (-251 ^{o}F). It is this always-present layer that we skate on and slip and fall on. It has nothing to do with pressure or the slope of the solid-liquid line. The Feb. 2000 issue of Scientific American had a nice article relating to this phenomenon. They refer to this as "surface melting," whereby the surface of ice is always covered with what is called a "quasiliquid film." This film arises simply because the last few layers of water molecules near the surface do not have as many bonds holding them to the remaining solid. Interestingly enough, this notion dates back at least a couple hundred years.

Possible Student Misconceptions

Students may have read or heard the commonly offered explanation that the reason we can ice skate is related to the slope of the solid-liquid line on the phase diagram for water. Although this explanation is still found in texts and on many Websites, it is not correct. See (*Connections to Chemistry Concepts*).

Students may assume that scientists have a good fix on how life began on Earth. After all, they're scientists—they know everything. That is definitely not the case. There are many conflicting theories and ideas, but no conclusive evidence in favor of any particular view. Perhaps Harvard paleontologist Andy Knoll said it best—"The short answer is we don't know how life originated on this planet."

Demonstrations and Lessons

1. There is a terrific Website at: http://www.pbs.org/wgbh/nova/origins/aliens.html

   It begins by presenting some basic facts about the Milky Way galaxy, giving a couple of very superficial arguments, one pro and one con regarding the possibility of other life in our galaxy, and then asking students:

   Do aliens exist in the Milky Way?

   The student votes "yes" or "no."

   But what makes the site unusual is that no matter which way the student votes, the next screen will contain counterarguments to whatever his/her position is at that point.

   After reading the counterarguments, the student votes again. Once more, no matter which way they vote (it doesn't matter if they decide to change their mind), more counterarguments are presented.

   This continues for several arguments. At the end, a brief summary of all the arguments, both pro and con are presented in table form and the person submits their final vote.

   After submitting their vote, "yes," "no," or "undecided," they are shown the percentages cast by other individuals.

   If you have access to a computer lab, this could make for a fun and interesting activity—perhaps on a day when you need to be absent from school. It should be noted, however, that is not likely to take and entire class period for students to go through the questions, so some additional assignment might be prudent.

2. How likely is it that life might exist somewhere other than Earth? This could make for an excellent debate. There are good arguments on both sides of the question. Students could volunteer or be assigned to both sides of the issue and a debate held. Since the debate is taking place in a science class, some of the ground rules might include that only scientific arguments can be presented (as opposed to philosophical or religious arguments), and that all opinions must be backed by evidence. Indeed, the quality and quantity of the evidence should probably be the cornerstone of the evaluation rubric. Students could also be graded on how well they appear to understand and can explain the scientific information that they cite in their presentations and arguments. The Website cited above can provide some excellent arguments on both sides.

Connections to the Chemistry Curriculum

This article obviously has a strong connection to many topics that are normally included in the typical high school chemistry course. Included among them are the chemistry of carbon and types of carbon compounds, organic chemistry, oxidation, photosynthesis, the structure and properties of water, hydrogen bonding, phase diagrams, density, polarity, the structure and properties of ammonia, and melting and boiling points.

But if you delve deeper into the question of how life began on Earth you will quickly access a debate that gets to the real core of what scientific knowledge and evidence are, how one formulates scientific arguments, and the limitations of our knowledge. Studying and discussing the theories and arguments about how life may have originated on Earth can go far towards teaching students how scientific theories are created, developed, modified and perhaps eventually discarded in favor of newer theories more in agreement with experimental and observational data. The article itself is relatively simple, but the underlying questions are quite profound and complex.

Suggestions for Student Projects

1. The phase diagram for ice is much more complex than the partial and much simpler diagram typically presented in high school texts (see *Background Information*). A good project for advanced and talented students would be to learn about the different types of ice, the complete phase diagram for the substance, and then prepare a paper or presentation on the topic.

2. The entire question of how life might have begun on Earth is extremely complex. There are conflicting scientific theories, ideas and arguments. Able, ambitious and interested students could prepare a paper or presentation comparing and contrasting some of the more popular ideas. If they want to limit the scope of their investigation they might simply deal with the Miller/Urey experiment (see http://www.chem.duke.edu/~jds/cruise_chem/Exobiology/miller.html), recent criticisms regarding whether the implications drawn from the experiment are valid, and subsequent alternate theories based on the experiments of Juan Oro (http://www.sciencedaily.com/encyclopedia/miller_urey_experiment) as well as evidence collected from the Murchison meteorite (http://www.ast.cam.ac.uk/AAO/local/www/jab/astrobiology/murchison.html). A google search will easily turn up many sites besides the ones above that relate to these experiments and events.

3. Two additional theories of how life may have developed on Earth include the notion that life originated not on the surface of early Earth, but instead developed around hydrothermal vents (see *ChemMatters, Dec. 2003*), or deep below partially frozen oceans. Another possible paper or report could focus on examining and critiquing these theories.

4. Aliens have been portrayed in many different forms in movies such as *Close Encounters of the Third Kind* and *Alien*. Students could take one or more of these kinds of movies and evaluate the quality of the portrayal. To what extent does the movie account for the existence and nature of the aliens that are represented? How scientifically reasonable are any explanations presented?

Anticipating Student Questions

1. I've heard that the reason you can skate on solid ice is because ice is less dense than liquid water. Is this correct?

   No. See *Connections to Chemistry Concepts*.

2. Is there life on other planets?

That's an easy question to answer. We don't know. Go to http://www.pbs.org/wgbh/nova/origins/aliens.html for some interesting arguments on both sides.

Websites for Additional Information and Ideas

The field of exobiology is vast and complex. The following Website contains an extensive list of informational sources: http://members.aol.com/gca7sky/life.htm

An excellent outline of many of the important concepts and arguments about how life may have originated on earth can be found in the transcript of an interview of Dr. Stanley L. Miller—half of the duo that conducted the famous Miller-Urey experiment in 1953: http://www.accessexcellence.org/WN/NM/miller.html

Another excellent Website addressing the question: "How Did Life Begin" can be found at: http://www.pbs.org/wgbh/nova/origins/knoll.html