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Teacher's Guide
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About the Guide

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Student Questions

Glass: More Than Meets the Eye

1. Name the two most often used methods of glass analysis.
2. What two substances are added to silica as glass is made?
3. What does the term “amorphous” mean?
4. What does the index of refraction measure?
5. What is the important ingredient in bullet-proof glass?
6. What are the two types of glass fractures?

Chemistry Builds a Green Home

1. List 3 energy-saving devices or characteristics of a “Near-Zero-Energy Home”.
2. How does using cement siding and “studs” (or wall supports) save energy when compared with using wood materials for the same functions?
3. What additional energy-saving characteristics are used in the New Mexico “Vision House 2006” that are not listed for the “Near-Zero-Energy Home”?
4. How do low-emissivity (Low-e) windows reduce heat gain in a house?
5. What property of foam insulation reduces the amount of heat from leaving a house?
6. What role do the wood fibers play in plastic lumber?
7. List two advantages of using plastic lumber rather than regular lumber.

Sick Buildings: Air Pollution Comes Home

1. Name three major indoor air pollutants.
2. What does the abbreviation “SBS” stand for?
3. What is the half-life of radon-222?
4. Give two other names for formaldehyde.
5. What is the name given to the complex that forms when carbon monoxide combines with hemoglobin?

The New Alchemy

1. How are elements heavier than iron formed?
2. What was the first element discovered to be radioactive?
3. What are the three main kinds of radiation that radioactive materials give off?
4. What particles are found in the nucleus of the atom?
5. What does the atomic number of an element signify?
6. How did Ernest Rutherford turn nitrogen into oxygen?
7. What is one element formed when uranium nuclei are split?

MSDS: Passports to Safety?

1. What does the acronym OSHA mean?
2. In what year did OSHA establish the Hazard Communication Standard?
3. List the three requirements of the Hazard Communication Standard.
4. If the Hazard Communication Standard does not apply to state and local government, why do students in high schools need to be aware of MSDSs?
5. Are all MSDSs equally accurate?
6. Is OSHA responsible for enforcing consistency and accuracy in their MSDSs? Explain.
7. Who probably produces/provides the best MSDSs?

Answers to Student Questions

Glass: More Than Meets the Eye

1. Name the two most often used methods of glass analysis.
   determination of density and index of refraction
2. What two substances are added to silica as glass is made?
   s*odium carbonate and calcium oxide*
3. What does the term "amorphous" mean?
   m*olecules arranged in a random fashion, much like those of a liquid*
4. What does the index of refraction measure?
   how much an object bends light
5. What is the important ingredient in bullet-proof glass?
   a polycarbonate layer
6. What are the two types of glass fractures?
   r*adial fractures and concentric fractures*

Chemistry Builds a Green Home

1. List 3 energy-saving devices or characteristics of a "Near-Zero-Energy Home".
   Energy-saving devices in a "near-zero energy home" include 1) photovoltaic panels for generating electricity, 2) low-e windows, 3) heat pumps for cooling and heating, 4) solar heating of domestic water, and 5) judicious siting of the house relative to the sun.
2. How does using cement siding and "studs" (or wall supports) save energy when compared with using wood materials for the same functions?
   Cement siding and "studs" save energy compared to wood materials because the thinner cement devices allow for more insulation both on and between the studs.
3. What additional energy-saving characteristics are used in the New Mexico "Vision House 2006" that are not listed for the "Near-Zero-Energy Home"?
   Advantages of the New Mexico "Vision House 2006" over the "Near-Zero-Energy Home" include using the residual heat of the earth to heat the home through a heat pump arrangement. Additionally, low-e windows are standard in the "Vision House".
4. How do low-emissivity (low-e) windows reduce heat gain in a house?
   Low-e windows reduce heat gain by reflecting transmission of solar IR radiation back out of the window, while allowing the visible light to enter. Heat within the house is reflected back into the house when it reaches the window as IR, reducing heat losses in winter.
5. What property of foam insulation reduces the amount of heat from leaving a house?
   The property of foam insulation that reduces the amount of heat from leaving a house is the foam's use of trapped air as an insulator. Since the air is a poor conductor of heat and is unable to move, this reduces or eliminates convection currents that would move heated air to a cooler location and result in the subsequent loss of thermal energy.
6. What role do the wood fibers play in plastic lumber?
   Wood fibers act as a binder to the plastic, giving more strength to the mixture because of non-directional composite "fibers" or strands.
7. List two advantages of using plastic lumber rather than regular lumber.
   Advantages of using plastic lumber instead of regular lumber include taking advantage of two materials, recycled plastic and reused sawdust, thus saving energy in the manufacturing process; and no preservatives are needed for the plastic wood, unlike regular wood.

Sick Buildings: Air Pollution Comes Home

1. Name three major indoor air pollutants.

Any three from this list: radon, formaldehyde, biological contaminants, lead, asbestos, carbon monoxide, secondhand smoke, household products and combustion by-products.

2. What does the abbreviation “SBS” stand for?
   Sick Building Syndrome.
3. What is the half-life of radon-222?
   3.8 days
4. Give two other names for formaldehyde.
   Either methanal, methylene oxide, or formalin
5. What is the name given to the complex that forms when carbon monoxide combines with hemoglobin?
   Carboxyhemoglobin

The New Alchemy

1. How are elements heavier than iron formed?
   Elements heavier than iron are formed in supernovae.
2. What was the first element discovered to be radioactive?
   Uranium was the first element discovered to be radioactive.
3. What are the three main kinds of radiation that radioactive materials give off?
   The three kinds of radiation are alpha particles, beta particles, and gamma rays.
4. What particles are found in the nucleus of the atom? *Protons and neutrons are found in the nucleus.*
5. What does the atomic number of an element signify? *The atomic number tells you the number of protons in the nucleus of an atom.*
6. What did Ernest Rutherford do to turn nitrogen into oxygen? *Rutherford fired alpha particles into the nuclei of nitrogen atoms.*
7. What is one element formed when uranium nuclei are split?
   Barium is one element formed when uranium nuclei are split. Krypton is another.

MSDS: Passports to Safety?

1. What does the acronym OSHA mean?
   OSHA stands for the Occupational Safety and Health Administration.
2. In what year did OSHA establish the Hazard Communication Standard?
   OSHA established the Hazard Communication Standard in 1986.
3. List the three requirements of the Hazard Communication Standard.
   The three requirements of the Hazard Communication Standard are:
   a. *Chemical manufacturers and importers must evaluate the hazards of the chemicals they produce or import.*
   b. Prepare labels and material data safety sheets (MSDS) to convey the hazard information to their customers.
   c. All employers with hazardous chemicals in their workplaces must have labels and MSDSs for their exposed workers and train them to handle the chemicals safely.
4. If the Hazard Communication Standard does not apply to state and local government, why do students in high schools need to be aware of MSDSs?
   Students in high school need to be aware of MSDSs because most states have enacted similar legislation or have endorsed the OSHA legislation.
5. Are all MSDSs equally accurate?
   No, accuracy varies a great deal from one company’s MSDS to another’s. That is part of the reason for the 2004 study report.
6. Is OSHA responsible for enforcing consistency and accuracy in their MSDSs? Explain.
   No, OSHA is not responsible for enforcement. In their original legislation, OSHA leaves it to the individual manufacturers to ensure accuracy of their MSDSs.
7. Who probably produces/provides the best MSDSs?
   Laboratory chemical suppliers probably write the best MSDSs.

Puzzle: Elements Galore

Instructions:

In the ladder below are spaces for inserting the letters in the names of fourteen elements. One letter in each name is given, so as to spell out the phrase ELEMENTS GALORE. The blanks shown are where you are to insert the remaining letters. As an aid, we've listed at the bottom a clue for each name used, sorted by the number of letters in that name(but otherwise in no special order).

For example, the first element has four letters in its name, the second of which is E. Of the five elements with just four letters in its name, NEON and LEAD match such a placement, but clue c, "glows red when excited" under 4 letters selects NEON as the answer. (Notice none of those three clues describes lead.)

You may prefer to begin with the clues, match them to its element, then fill in the ladder.

```
          _ E _ _
      _ _ _ L _ _ _
          _ E _ _ _
      _ _ _ M _ _ _ _
          _ E _ _ _ _
        _ _ N _
        _ _ T _ _ _ _
        _ _ S _ _ _
      _ _ _ G _ _ _ _
          _ A _ _ _ _
        _ _ L _
          _ O _ _ _
        _ _ R _ _ _ _
_ _ _ _ _ _ E _ _ _ _
```

4 letters

a. used to galvanize steel _ _ _ _
b. a metal almost twice as dense as lead _ _ _ _
c. glows red when excited _ _ _ _

5 letters

d. its electron configuration ends in $5p^6$ _ _ _ _ _
e. used in "doping" semi-conductors _ _ _ _ _

6 letters

f. the heart of organic molecules _ _ _ _ _ _
g. was discovered in the sun before on earth _ _ _ _ _ _
h. most active alkali metal in water _ _ _ _ _ _

7 letters

i. most positive oxidation potential _ _ _ _ _ _ _
j. a liquid at room temp _ _ _ _ _ _ _
k. the <u>other</u> liquid at room temp _ _ _ _ _ _ _

8 letters

l. filaments in light bulbs _ _ _ _ _ _ _ _
m. extracted from bauxite ore _ _ _ _ _ _ _ _

11 letters _ _ _ _ _ _ _ _ _ _ _

n. the newest of the elements; (It's name was adopted by IUPAC in 2004.)

Answer to Puzzle

ANSWER	clue letter
N**E**ON	c
GAL**L**IUM	k
X**E**NON	d
ALU**M**INUM	m
H**E**L**I**UM	g
Z**IN**C	b
L**IT**HIUM	i
CE**S**IUM	h
TUN**G**STEN	l
C**A**RBON	f
GO**L**D	b
B**O**RON	e
ME**RC**URY	j
ROENTG**E**NIUM	n

Content Reading Guide

National Science Education Content Standard Addressed

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**Sick Buildings**	**The New Alchemy**	**MSDS**	**Chemistry Builds a Green Home**	**Glass: More Than Meets the Eye**
Science as Inquiry Standard A: about scientific inquiry.	✔	✔	✔	✔	✔
Physical Science Standard B: of the structure of atoms.	✔	✔			
Physical Science Standard B: of the structure and properties of matter.	✔	✔	✔	✔	✔
Physical Science Standard B: of chemical reactions.	✔		✔		✔
Physical Science Standard B: of motions and forces.					✔
Physical Science Standard B: of interaction of energy & matter.		✔			
Life Science Standard C: of matter, energy, and organization in living systems.	✔				
Earth and Space Science Standard D: about the origin and evolution of Earth System.	✔	✔			
Earth and Space Science Standard D: about the origin and evolution of the universe.		✔			
Science and Technology Standard E: about science and technology.	✔	✔	✔	✔	✔
Science in Personal and Social Perspectives Standard F: of personal and community health.	✔		✔	✔	✔
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✔	✔	✔	✔	✔

Science in Personal and Social Perspectives Standard F: of environmental quality.	✔		✔	✔	
Science in Personal and Social Perspectives Standard F: of natural and human-induced hazards.	✔		✔	✔	✔
History and Nature of Science Standard G: of science as a human endeavor.	✔	✔	✔	✔	✔
History and Nature of Science Standard G: of the nature of scientific knowledge.	✔	✔	✔	✔	✔
History and Nature of Science Standard G: of historical perspectives.	✔	✔	✔	✔	✔

Anticipation Guides

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

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

Material Safety Data Sheets: Passports to Safety?

Me	Text	Statement
		1. Baking soda is a base also known as bicarbonate of soda.
		2. Beeswax is a mixture of hydrocarbons and esters containing between 20 and 40 carbon atoms per molecule.
		3. MSDSs were mandated by the federal government about ten years ago.
		4. Schools and small businesses do not need to have MSDSs available for workers or students.
		5. MSDSs contain very explicit information that is easily understood by laypersons.
		6. In the past, OSHA checked the quality of MSDSs sent out by chemical suppliers.

Glass: More Than Meets the Eye

Me	Text	Statement
		1. Ultraviolet light is often used to examine physical properties of glass.
		2. The flotation method for determining the density of glass is more accurate than finding its mass and volume separately.
		3. Some glass is less dense than water.
		4. There are only about 100 different types of glass, and the FBI hs a database of their refractive index values.
		5. Different glass samples having the same density and refractive index have the same chemical composition.
		6. Most glass is made of silicon dioxide.
		7. A radial fracture from a bullet hole will always terminate in cracks from previous fractures.
		8. Exit holes from bullets are always larger than entrance holes.
		9. There is no way to tell if a light bulb was on or off when the bulb broke.

Chemistry Builds a Green Home

Me	Text	Statement
		1. Green homes contain indoor greenhouses for growing plants.
		2. Sustainable materials promote prosperity while protecting the Earth.
		3. Most of the waste produced by the residential construction industry comes from new home construction.
		4. Trapped air in foam is a good insulator.
		5. The top three meters of Earth's surface varies widely in temperature, by more than 40°C.
		6. There are window coatings available that can admit daylight but block ultraviolet and infrared radiation from the sun.
		7. Wheat straw can be used to make kitchen cabinets that look just like wood.
		8. About one-fourth of the polyester carpet in the United States is made from recycled plastic.

		9. Old polyester carpet can be recycled.

Sick Buildings: Air Pollution Comes Home

Me	Text	Statement
		1. Some homes have air that is more polluted than outdoor air, largely due to energy conservation measures.
		2. Radon was not recognized as an indoor air pollutant until a nuclear power plant worker set off plant alarms in the mid-1980s.
		3. Radon gas contamination cannot be corrected in homes.
		4. Formaldehyde is found in clothing and food as well as building materials.
		5. Mold can grow on dirt and soap scum, but chlorine bleach kills it.
		6. Your bed probably has hundreds of dust mites.
		7. Carbon monoxide binds more readily to hemoglobin molecules than oxygen does.

The New Alchemy

Me	Text	Statement
		1. All naturally occurring elements are made in stars during their life cycles, before they become supernovae.
		2. The first artificial transmutation changed nitrogen into oxygen.
		3. No stable element has ever been transformed into a radioactive isotope.
		4. Protons make better projectiles for nuclear bombardment than neutrons.
		5. The first nuclear fission was accomplished while trying to make element 93.
		6. To produce neptunium, U-238 captures a neutron to become U-239, which forms Np-239 by beta decay.
		7. Two transuranium elements were discovered in nuclear fallout from nuclear weapons testing in the 1950s.
		8. Seaborg's actinide hypothesis changed the layout of the Periodic Table, inserting elements following actinium into a second rare earth row.

Reading Strategies

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

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

Glass: More Than Meets the Eye

As you read, describe each property of glass and tell how it can be used by forensic scientists to gather information.

Property	**Description**	**Usefulness in forensics**
Thickness		
Density		
Refractive Index		
Chemical Composition		
Elasticity		
Filament clues		

Chemistry Builds a Green Home

As you read, please cite examples of how green homes can be environmentally friendly. You should be able to find at least three examples for each "R."

	Green Home Examples
Reduce	
Reuse	
Recycle	

Sick Buildings—Air Pollution Comes Home

As you read, complete the chart regarding indoor air quality.

Contaminant	Sources	Hazards	How can you protect yourself?
Radon			
Formaldehyde			
Molds and Biological Pollutants			
Carbon Monoxide			

The New Alchemy

As you read, please complete the chart below giving details of how people have created new elements.

People	Date	Accomplishment & Significance	How was it done? Include the nuclear equation, if applicable.
Ernest Rutherford			
Irene Curie-Joliot and Fredrick Joliot			
Enrico Fermi, Lise Meitner, and others			
Edwin McMillan			
Glenn Seaborg and his group			

Material Safety Data Sheets: Passports to Safety?

As you read, please complete the diagram below regarding MSDSs.

Why do we need them?	What are some problems associated with their use?
How and when should you use them?	What is being done to make them better?

MSDS

Background Information

The article focuses on two related areas – composition and properties of glass and the way glass is analyzed forensically. The Teachers Guide provides background information for both topics.

More on the Composition of Glass

Because glass is used in so many different ways, there is no one chemical composition for each glass sample. There are thousands of different glass compositions. However, there are three categories of substances in all glass – formers, fluxes and stabilizers. The most common former is silicon dioxide, SiO_2, in the form of sand. Other possible formers include B_2O_3 and P_2O_5. The former makes up the bulk of the glass.

Fluxes change the temperature at which the formers melt during the manufacturing of glass. Substances commonly used as fluxes include sodium carbonate, Na_2CO_3, and potassium carbonate, K_2CO_3.

Stabilizers strengthen the glass and make it resistant to water. Calcium carbonate, $CaCO_3$, is the most frequently used stabilizer.

The raw materials for making glass are all oxides. So the composition of any sample of glass can be given in terms of the per cent of each oxide used to make it. For example, the glass used to make windows and bottles has the following approximate composition:

Silica – SiO_2	73.6 %
Soda – Na_2O	16.0 %
Lime – CaO	5.2 %
Potash – K_2O	0.6 %
Magnesia – MgO	3.6 %
Alumina – Al_2O_3	1.0 %

Note that the magnesia and alumina are present as impurities.

According to the Corning Museum of Glass web site (http://www.cmog.org/default.asp) there are six basic types of glass based on composition: "Nearly all commercial glasses fall into one of six basic categories or types. These categories are based on chemical composition. Within each type, except for fused silica, there are numerous distinct compositions.

"Soda-lime glass is the most common (90% of glass made), and least expensive form of glass. It usually contains 60-75% silica, 12-18% soda, 5-12% lime. Resistance to high temperatures and sudden changes of temperature are not good and resistance to corrosive chemicals is only fair. Flat glass and container glass is this type.

"Lead glass has a high percentage of lead oxide (between 20% and 80% of the batch). It is relatively soft, and its refractive index gives a brilliance that may be exploited by cutting. It is somewhat more expensive than soda-lime glass and is favored for electrical applications because of its excellent electrical insulating properties. Thermometer tubing and art glass are also made from lead-alkali glass, commonly called lead glass. This glass will not withstand high temperatures or sudden changes in temperature.

"Borosilicate glass is any silicate glass having at least 5% of boric oxide in its composition. It has high resistance to temperature change and chemical corrosion. Not quite as convenient to fabricate as either lime or lead glass, and not as low in cost as lime, borosilicate's cost is moderate when measured against its usefulness. Pipelines, light bulbs, photochromic glasses, sealed-beam headlights, laboratory ware, and bake ware are examples of borosilicate products.

"Aluminosilicate glass has aluminum oxide in its composition. It is similar to borosilicate glass but it has greater chemical durability and can withstand higher operating temperatures. Compared to borosilicate, aluminosilicates are more difficult to fabricate. When coated with an electrically conductive film, aluminosilicate glass is used as resistors for electronic circuitry.

"Ninety six percent silica glass is a borosilicate glass, melted and formed by conventional means, then processed to remove almost all the non-silicate elements from the piece. By reheating to 1200°C the resulting pores are consolidated. This glass is resistant to heat shock up to 900°C.

"Fused silica glass is pure silicon dioxide in the non-crystalline state. It is very difficult to fabricate, so it is the most expensive of all glasses. It can sustain operating temperatures up to 1200°C for short periods."

More on Properties of Glass

Glass combines some properties of crystals and some of liquids but glass is distinctly different from both. Glass is rigid like a crystal but the molecules that make up glass are arranged randomly like liquids. In general glass is formed by melting crystalline substances and then cooling the liquid before the molecules can form a crystal. Glass does not have a specific melting point but softens over a range of temperatures.

According to the Corning Museum of Glass, the properties of glass include:

- Mechanically Strong – Glass has great inherent strength and is weakened only by surface imperfections, which give everyday glass its fragile reputation. Special tempering can minimize surface flaws.
- Hard surface – Glass resists scratches and abrasions. (Because the composition can vary, so can the hardness. On average the hardness of glass is about 5.5 on the Moh's scale)
- Elastic – Glass "gives" under stress – up to a breaking point – but rebounds exactly to its original shape
- Chemical corrosion-resistant – Glass is affected by few chemicals. It resists most industrial and food acids.
- Thermal shock-resistant – Glass withstands intense heat or cold as well as sudden temperature changes.
- Heat-absorbent – Glass retains heat, rather than conducts it. Glass absorbs heat better than metal.
- Optical Properties – Glass reflects, bends, transmits and absorbs light with great accuracy.
- Electrical Insulating – Glass strongly resists electric current. It stores electricity very efficiently.

More on Glass Manufacturing

The raw material that is the largest component of glass is silica sand or silicon dioxide, SiO_2. Glass is formed by melting the SiO_2 and then cooling the melt before crystals can form. However, the melting temperature of the silica is about 1700^{o}C, and at that temperature the liquid phase is very viscous. Sodium oxide, Na_2O, is added to the silica in the form of sodium carbonate in order to lower the melting temperature. In the heating, CO_2 is driven off the leaving Na_2O. The sodium carbonate serves as a flux in glass making. In order to stabilize the glass product, add strength to the product and make it resistant to water, calcium carbonate ($CaCO_3$) is added. Again, in the heating, CO_2 is driven off leaving CaO as the stabilizer in the glass. Broken glass, called cullet, may also be added to the mix. Other compounds may be added (see "Additives and Color"). There are many formulations for glass. This paragraph is based on the common soda-lime glass.

To see a seven minute video on modern glass manufacturing (produced by Pittsburgh Plate Glass) see http://www.webcastgroup.com/client/start.asp?wid=0870801051775

To see a flow chart of modern glass manufacturing see http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s15.pdf

More on Additives and Color

Color can be added to glass as a result of impurities in the substances used to make the glass. Color can also be added by dissolving one or more metal oxides, by dispersing a colloid throughout the mix or by suspending pigments to create opaque areas. Most common is the solution of metal oxides into the mix. Some common oxides and the colors they produce in glass:

Oxide	**Color**
Iron	green, brown
Manganese	amethyst
Cobalt	deep blue

Gold	red
Antimony	white
Copper	light blue
Lead/antimony	yellow

To see examples of colored glass see http://www.blm.gov/historic_bottles/colors.htm#Aqua

More on Glass as Evidence

The following reference material is presented as part of this Teacher's Guide because students are interested in all aspects of forensics. This part of the Teachers Guide might be used in an activity in which students are asked to "process" a crime scene involving glass. In addition, students may be interested in a career as a chemical technician, in which proscribed steps are required for a specific process. You might want to use this article as a way to introduce students to careers as chemical technicians. For more on this see http://pubs.acs.org/cen/science/83/i17/8317sci2.html .

The article refers to FBI databases for refractive indices. In fact, the FBI has a set of procedures for the analysis of glass. The FBI recommends the following steps for the analysis of glass as crime scene evidence.

1. **Review definitions and map out a plan of analysis**. The FBI definition of glass is "...an inorganic product of fusion that has cooled to a rigid condition without crystallizing." For the analytical methods the FBI recommends, see below.
2. **Collect, handle, and identify the evidence**.
3. **Make your initial examination.** If possible, you'll want to determine the color, fluorescence, surface features, curvature, and thickness of the glass.
4. **Examine fractures.** Are they radial or concentric? Crater or hackle? A fracture match is an absolute means of identification.
5. **Now measure the density of the sample.** Density tells you something about the composition and thermal history of the glass.
6. **Measure the refractive index of the evidence.** Refractive index is the most commonly measured property in forensic glass analysis. It can give you the same information as density, but you only need a very small piece of glass. Testing both density and refractive index tells you more than just checking one or the other.
7. **Determine major, minor, and trace elements in the glass**. These methods are destructive methods so the FBI recommends measuring density and refractive index first (both methods are destructive). You can use scanning electron microscopy, X-ray fluorescence spectrometry, inductively coupled plasma-optimal emission spectrophotometry, inductively coupled plasma-mass spectrometry, laser ablation-inductively coupled plasma-mass spectrometry, or atomic absorption spectrophotometry.

The FBI specifies additional specific protocols for each of the numbered steps**.** Click on the links at http://www.fbi.gov/page2/dec04/lab122204.htm to see the protocols. *This is an extensive resource on glass analysis.*

More on Patterns of Breakage

The article describes a crime scene in which an intruder flees by diving through a window. Glass fragments are often connected to a crime scene because many thieves enter a building by breaking the glass in a window. Most crime scene glass originates in windows, automobile headlights or containers. Forensic scientists know that glass fractures in two basic patterns—radial fractures and concentric fractures.

If an object like a rock is thrown at a window the window will fracture first in a radial pattern. That is the breaks will radiate from the point of contact but on the opposite side of the glass from the point of contact. Glass will be propelled outward away from the point of contact as a result. However, concentric fractures also then develop. They are breaks that form in a circular pattern around the point of contact. Think of a spider web. The radial fractures extend out from the center of the web ad concentric fractures connect the radial fractures. Most important is the fact that concentric fractures form on the same side of the as the point of contact and this causes some of the breaking glass to be propelled toward the person throwing the rock. This glass is called backscatter, and it might be found in the clothes or hair of the person who threw the rock originally. The glass can be scattered backward as far as ten feet.

More on Analysis by Density

The FBI procedure for identifying glass by the **density gradient method** includes the following:

"The method involves placing, in a vertical glass tube, a liquid containing a gradient of density. The gradient is such that the density at any level is less than that at any level lower in the tube and greater than that of any level higher in the tube. When glass fragments are introduced to the column, each will become suspended in the liquid at the level that is the same density as that glass fragment. Fragments of different density will settle to different levels in the column.

"Gradient tubes are usually 25cm to 45cm in length and 6mm to 18mm in diameter. A heavy liquid, such as 1,4 dibromobenzene or bromoform, is mixed with a lighter liquid, such as bromobenzene or ethanol, in varying proportions to form a density gradient. For most purposes, about five layers of liquids are used. The bottom layer of the density gradient tube consists of heavy liquid only. The second layer consists usually of three parts of the heavy liquid to one of the light. The third consists of equal mixtures of heavy and light liquids. The fourth layer is made of three parts light liquid and one part heavy liquid. The top layer consists of light liquid only. Each layer is added to the prior very slowly using a pipette so as to not allow mixture at the interface. The bottom layer is typically about a quarter of the total height of the column. The second, third, and fourth layers should each be about half the height of the first layer. The top layer should be the same height as the bottom layer. The gradient tube should stand overnight before being used so that the liquids will diffuse into each other to form a gradient."

The FBI **sink/float method** of determining density involves "involves suspending glass fragments in a density solution within a constant temperature bath. If two or more fragments are suspended, their densities are the same." There are several adaptations of this method, several of which permit the determination of a numerical value for the density. For more on this method see http://www.fbi.gov/hq/lab/fsc/backissu/jan2005/standards/2005standards8.htm

More on Analysis by Index of Refraction

As the article describes, refraction is the bending of light as it passes from on medium to another. The path of light is bent in various media because the light travels at different speeds in different media. The index of refraction of a substance measures the degree to which the light is bent in a medium. Every substance has its own index of refraction, which is defined as the ratio of the speed of light in a vacuum to the speed of light in that medium. For a somewhat longer explanation of index of refraction see http://acept.asu.edu/PiN/rdg/refraction/refraction.shtml

The FBI protocol on using refractive index for glass indicates that "Refractive index is the most commonly measured property in the forensic analysis of glass. Refractive index is a function of the composition and thermal history of the glass. Several methods for measuring refractive index, along with their advantages and limitations and the procedure for laboratory annealing, are presented in this guideline." For the protocols see http://www.fbi.gov/hq/lab/fsc/backissu/jan2005/standards/2005standards9.htm

More on Trace Analysis of Glass

One of the simplest "low-tech" methods of glass analysis is to try to reconstruct the original glass surface by fitting larger fragments together like a jigsaw puzzle. When glass breaks the impact leaves characteristic ribs or "heckle" marks on the edge of the break. These are helpful in reassembling the fragments. For FBI procedures and definitions see http://www.fbi.gov/hq/lab/fsc/backissu/jan2005/standards/2005standards7.htm

Another simple method results from the fact that glass surface develops unique scratches and abrasions from repeated wear and tear. For example, the glass windshield of a car might develop tell-tale scratches from wiper blades with embedded grit or other minute objects. These patterns can be used to reconstruct the windshield.

The FBI procedures for trace element analysis say that "the concentrations of certain elements in glass serve to chemically characterize its source. The concentrations of several elements are intentionally controlled by the manufacturers to impart specific end-use properties to a particular glass product, and in some instances can be used to identify the product type of a recovered glass fragment. However, even individual glass objects that have major element concentrations within the manufacturer's acceptable ranges display variations that can be measured and provide useful points for a forensic comparison. Glass manufacturers generally do not control the concentrations of trace elements, except as needed to impart color or to keep them below levels that would impart undesirable physical or optical properties to the glass. The differences in concentrations of manufacturer-controlled elements or uncontrolled trace elements may be used to differentiate sources when the variation among objects exceeds the variation within each object. Element concentrations may be used to differentiate among glasses made by different manufacturers, glasses from different production lines of a single manufacturer, specific production runs of glass from a single manufacturer, and in some instances individual glass objects produced at the same production facility." http://www.fbi.gov/page2/dec04/lab122204.htm

Specific methods of instrumental analysis permit forensic chemists to determine the per cent of each element present in a sample of glass. These methods include scanning electron microscopy-energy dispersive X-ray spectrometry, energy dispersive X-ray fluorescence spectrometry, inductively coupled plasma-optical emission spectrophotometry, and inductively coupled plasma-mass spectrometry.

More on Laminated Glass

Laminated glass is simply two panes of glass which sandwich a layer of vinyl. Polyvinyl butyral (PVB) is the most common laminate used today. PVB is a polymer resin produced in the reaction between polyvinyl alcohol and butanal. The PVB is bonded by heat and pressure to the two panes of glass. In addition to preventing shards of glass from scattering in case of breakage (which is mentioned in the article) other advantages of laminated glass include safety, sound reduction, reduction of heat gain in applications like cars, and reduction of UV radiation.

More on Plexiglas

Plexiglas is not glass at all, but a synthetic thermoplastic polymer first developed by chemists at Rohm & Haas. Its chemical name is polymethyl methacrylate (PMMA). It is sold as Plexiglas, Acrylite and Lucite. It is less dense than glass, does not shatter, is easily shaped, transmits visible light readily and does not block UV radiation.

More on the History of Glass

The origins of glass making are obscure but may date to as early as 5000 BC when sailors, carrying soda ash as cargo on their ships, landed on a beach and used the blocks of soda ash on which to rest their cooking vessels. The heat produced soda glass. Useful glass object like bottles were used in Egypt and Babylon as early as 1500 BC. Glassblowing became an art around 250 BC and within 150 years glass began to replace metals as status symbols in the Roman culture.

Flat glass began to be produced in the 13th century but it was not until the early 1800's that flat glass could be produced at reasonable cost for everyday use in windows. In 1883 Pittsburgh Plate Glass Company became the first successful manufacturer of plate glass in the United States.

Glass was first produced in America in about 1608, when settlers in the Jamestown, Virginia, colony set up a glass-melting furnace. The first attempt to establish a glass-making factory by the London Company, employing artisans recruited from Germany and Poland, was not very successful. A second factory staffed by Italian glass workers was also unsuccessful.

Until the early 20th century, glass was made by hand in America, making glass products a luxury. In 1903, Michael Owens invented the first automated glass bottle-blowing machine.

Connections to Chemistry Concepts

1. Phases of Matter – There is still some debate about the phase of glass. Most definitions classify it as an amorphous solid. This topic often arises from students when discussing phases of matter.
2. Properties of Matter – Glass has properties that we assume but often do not think about. For example, it is a relatively hard substance, but because it is brittle, the hardness is often overlooked. The article could provide examples of properties of a unique form of matter as well as properties used to identify substances.
3. Chemistry and Color – This article can be an introduction or application of the color produced by metal ions and their compounds.

4. Forensic Chemistry – This is an area that many students relate to currently. It could be introduced as a "current events" type article.
5. Methods of Analysis – If you include in your course any material that teaches students what the term "analysis" means in chemistry, this article is a very appropriate resource.

Possible Student Misconceptions

1. **"Glass flows."** Because glass is often discussed in terms of its similarity to liquids, many people still believe the old tale that "glass flows," especially in old windows where the bottom of the pans seem thicker than the tops. Glass is, in fact, made up of molecules that are tightly held by their chemical bonds. The panes that seem thicker at the bottom were probably made that way in the early days of flat glass manufacturing. For more see http://www.cmog.org/index.asp?pageId=745
2. **"Glass is glass."** Glass is such a common substance in our environment that we do not often consider its range of properties and, therefore, differences in different types of glass.
3. **"Plexiglas is a special form of glass."** – Plexiglas is a synthetic polymer and not glass at all (see More on Plexiglas)

Demonstrations and Lessons

1. For a lab procedure that requires students to analyze glass fragments see http://web.umr.edu/~maryrr/Outreach/StuMaterialsForensics.doc . Always observe safety procedures when dealing with glass.
2. Another lab on glass fragment analysis: http://www.teachersfirst.com/lessons/forensics/glass-lab.html
3. A case study on glass as evidence is presented here along with a lab procedure for glass analysis. This activity is intended for college level students but may be adapted for high school students. http://course1.winona.edu/jfranz/Broken_Glass_Case.htm
4. Commercial kits on glass fragment analysis can be purchased from suppliers. One example: http://www.sciencekit.com/category.asp_Q_c_E_595431
5. This site has a complete crime scene scenario, including glass analysis: http://library.thinkquest.org/04oct/00206/index1.htm
6. A lab procedure for analyzing glass using density and refractive index: http://www.ncsu.edu/kenan/fellows/2002/pligon/forensics/labs/GlassLab.html
7. From the Corning Museum of Glass, a procedure for making glass in the lab: http://www.cmog.org/index.asp?pageId=737
8. An outline of a procedure to determine the index of refraction of glass can be found here http://online.cctt.org/physicslab/content/Phy1/labs/refraction/indexglass.asp
9. Two lab activities are outlined as part of the article.

Suggestions for Student Projects

1. Students might be assigned these, and other, glass-related topics for research:
   History of glass
   Glass in America
   Colored glass
   Stained glass
   Safety glass
   Mirrors
   Glass and art
   Glass blowing
2. Student might be asked to bring in to class different kinds of glass to examine.

Anticipating Student Questions

1. **"Is glass a solid or liquid?"** It is a solid. The Corning Museum of Glass says that glass is a "homogeneous material with a random, liquid-like (non-crystalline) molecular structure. The manufacturing process requires that the raw materials be heated to a temperature sufficient to produce a completely fused **melt**, which, when cooled rapidly, becomes rigid without crystallizing."
2. **"If glass is so hard and strong, why does it break so easily?"** Glass is both elastic and brittle. Glass can be deformed and it will return to its original shape, but the surface forces and stresses in glass make it brittle. See http://www.cmog.org/index.asp?pageId=715 for more.

Websites for additional Information

Corning Museum of Glass site, http://www.cmog.org/default.asp, has many resources for teachers regarding glass. Click "For Teachers" and then click "Online Resources."

The National Heisey Glass Museum site also has resources for teachers, especially about colored glass. http://www.heiseymuseum.org/resources/colors.htm

Chemical & Engineering News publishes a series of articles called "What's That Stuff?" For the article on glass see http://pubs.acs.org/cen/whatstuff/stuff/8147glass.html

For a five-page article from the *Journal of Chemical Education* on glass see http://www.chihuly.com/pressroom/pdfs/JCE_77_p812.pdf

For more on glass colors and how they are produced see this site from the U.S. Bureau of Land Management http://www.blm.gov/historic_bottles/colors.htm#Aqua

For the complete FBI glass analysis procedures, see http://www.fbi.gov/page2/dec04/lab122204.htm and http://www.fbi.gov/hq/lab/fsc/backissu/jan2005/index.htm

For more on the history of glass see http://www.glassonline.com/infoserv/history.html

Chemistry Builds a Green Home

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Background Information

This article is about energy conservation through the design of the home and in the actual building of the home. The construction of an energy efficient home (or "green" home) starts with the actual design, a deliberate use of strategies that include site orientation of the home relative to sun, construction using modular units that are more efficiently manufactured and of more consistent quality, integrated efficient energy-transforming devices (heat pumps fine tuned to solar panels, solar panels for hot water, solar-produced electricity through photovoltaic cells), low-emittance (low-E) windows, and judicious use of insulating materials.

In building the home, some energy savings are possible through

- reusing building materials and/or
- using recycled materials.

Energy conservation in the design of the green home includes

- reducing energy usage for cooling and heating through insulating materials and low-emittance windows (low-E),
- using efficient energy transforming devices such as heat pumps, solar heated panels (air and water), and photovoltaics
- orienting the home for maximum solar gain in winter, reducing solar gain in summer by judicious planting of deciduous trees.

More on reusing building materials

In the reusing of building materials, organizations and companies exist such as the Portland Cement Association (www.cement.org/tech/cct_aggregates_recycled.asp). that promote and provide for reprocessing of various construction materials. After slabs of concrete that have been removed from highways or dismantled buildings have been processed by breaking and crushing, the concrete aggregate as it is called is ready for reuse directly, without any further processing. Applications include general bulk fills, bank protection, fill for drainage structures, road construction (underlay), noise barriers and embankments.

The crushed concrete can also be used as aggregate when new concrete is made from cement. Sand and stone, among other things, are added to give "structural" durability to cement (the cement is the binder). This mixture is called concrete. For instance, recycled concrete aggregates that replace natural rock pass the same tests for quality and strength as required of conventional aggregate, i.e., natural rock. Higher porosity of recycled concrete aggregate requires more water when used in the cement mix. But the effect of different combinations in the mix and their effect on the final concrete product have been tested. There are all kinds of materials that can be mixed in with the cement in addition to the aggregate from recycled concrete.

More on using recycled materials

One organization that promotes recycled materials and alternative construction techniques can be found at Toolbase Services and their Green Building program, www.toolbase.org/ToolbaseResources/level3.aspx?BucketID=2&CategoryID=17
This is a very extensive resource for builders, contractors and those who remodel dwellings. For a builder who selects a particular choice of building material (let's say, precast concrete panels for a solar home), the site not only describes how the panels are used and their ease of implementation, but also how they function in creating energy savings for heating and cooling,

what their initial and operational costs are, what field evaluations have concluded, and U.S. code acceptance when using these materials.
Under the general category of concrete construction, there are myriad categories of materials, from "autoclaved aerated concrete" to "spray-applied concrete walls" with construction guides, best practices, performance reports, field evaluations, questions and answers and web links.

If you go to the home page, you will find a variety of categories for technical information – building systems (appliances, floors, landscaping, electrical, etc), home building topics (energy efficiency, green building, land use, zero energy homes), design and construction guides, construction methods, technology inventory, field evaluations, and newsletters. In essence, this site is **very** extensive in terms of explaining all aspects of the building trade when it comes to energy-saving techniques and materials as well as the rationale for choosing the listed alternatives versus traditional building practices. This is especially important when trying to have builders and contractors switch from techniques they are most comfortable with, and when they cannot afford to make costly mistakes in adopting new ways to build.

More on existing "green homes"

The Department of Energy (DOE) at Oak Ridge Tennessee is actively involved in helping with the design and promotion of what is called the Near Zero Home (NZH). An outline of the DOE's goals can be found at their website, www.ornl.gov/ornlhome/print/press_release_print.cfm and at Solar Today, www.solartoday.org/2005/may_une05?ZEh.htm. An important consideration for these homes is that they make more use of solar to generate electricity, so that homeowners can reduce their electricity consumption from the public grid and add their excess electricity to the electric company's generating capacity, with compensation (electric meter runs backwards as a type of credit).

More on insulating materials

The choice of insulating materials, including the sealing of outside walls and joints, depends many times on synthetic materials rather than natural materials for many reasons, including cost and moisture resistance or water-impermeability. An insulator, in contrast with a conductor of heat depends on the properties of non-metallic materials, as is true when thinking about electrical conductors and electrical insulators. The characteristics of thermal conduction are based on that of electrical conduction – electrons that are freer to move in metallic substances compared with non-metallic. On the other hand, insulation material will sometimes contain reflective material (metallic) for preventing or reducing transmission of infrared (IR), which would be heat escaping from a home. And the reflective material on a wall surface would face into the house, the source of heat loss. That is the same principle for the reflective surface of the low emittance (low-E) window glass. Reflectivity, like conductivity, depends upon "loose" electrons, electrons that can easily move within a collection of metallic atoms, the so-called "sea of mobile electrons".

More on low-emittance windows (low-e)

The use of the sun as an energy source for homes is as simple as providing enough windows that face along an arc from southeast through south to southwest. These windows have to perform in two ways – transmit light, including infrared (IR), into the house during the cooler months of the year, and reduce light transmission, in particular IR and ultraviolet (UV), in the warmer months. The window must also reduce losses of heat as IR, from within the house. There are different types of windows of low emittance (low – e) for use in different climates (think California vs. Maine). The basic construction of these windows depends upon two things – a layer of gas between two layers of glass, and coatings of reflective metallic oxides on the glass. The idea behind the layer of gas is to use a substance of low thermal conductivity, an

insulator. The choice of gas is based on its density because you want to have minimal movement of the gas within the space – otherwise more heat within the space will be transmitted from the outer glass surface to the inner (summer) or vice versa (winter) through convection. Air can be used but the gas of choice is argon – a compromise between cost and density. The density factor affects how easily the confined gas is able to move about in the space – higher density means less convection and less conduction. Krypton, which is more dense than argon, is also used but it is more expensive. The depth of the space is also critical – too much space allows for more convection. Too thin a space means less insulation. Restricted space means more difficulty for the gas to move. The space between the glass layers using argon is 11-13 mm; for krypton optimum spacing is 9 mm. Melding cost savings and density is accomplished by using a mix of argon and krypton.
http://www.efficientwindows.org/lowe.cfm
http://www.bobvila.com/HowTo_Library/Understanding_Low_e_Window_Coatings--A2077.html

The metallic oxide coating on low-E windows is applied both to the outside glass layer to act as a reflective mirror outward while a second metallic coating is placed on the inside glass layer facing into the house to reflect back IR (heat related) escaping from the house interior. Depending on climatic conditions, low-E windows have different characteristics regarding transmission of visible light, IR and UV. One is called the U-factor and refers to extent of heat loss. The other is called Solar Heat Gain Coefficient (SHGC). Windows for Florida, for example, should have a U-factor of 0.7 (for high heat loss) and a SHGC of 0.35 or lower. In Maine, the numbers are: a U-factor of 0.3 or less and a SHGC as high as possible. The specifics of these choices is given in more detail at http://www.efficientwindows.org/lowe.cfm

More on heat pumps

One of the more recent ideas for producing heat energy through a heat pump is to connect the heat pump to a heat source in the ground at a depth which is constant at 55°F. Either the soil itself or contained water, as in a well, can be used as a heat source. The pipes in the soil or water deliver the heated medium (usually water) to a heat pump which operates the same way as a refrigerator or air conditioner. The heat in the piped water is lost to a cooler fluid in the heat pump's circulation pipes.

You can feel the same kind of heat that is given off by a refrigerator or an air conditioner when it cools warmer air inside the refrigerator or in a room. This happens when a gas is compressed into a liquid (which heats up), then allowed to expand. Expansion of the liquid into a gas causes cooling in the environment; thermal energy is taken from the environment to expand the gas (increase in potential energy). Think of how it feels when water or, better yet, alcohol evaporates on your skin. There is a cooling sensation because thermal energy of your skin causes evaporation of the liquid by increasing the potential energy of the water or alcohol molecules

The piped water cools when it loses thermal energy to the cool gas in the heat pump. When the gas returns to be compressed back into a liquid, more heat is produced (the reverse of a liquid expanding into a gas). Some of the heat is transferred from the hot liquid in the heat pump's circulation pipes to the room air of the house (think of the back of your refrigerator). The cooled water is returned to the earth where transfer of additional heat will take place because the soil is warmer than the returning fluid. See "How Refrigerators Work" at http://home.howstuffworks.com/refrigerator.htm.
In addition, diagrams of heat pumps with earth heat sources (geothermal) can be found at www.fujitaresearch.com/reports/solarpower/html and http://www.geoexchange.org/pdf/GB-034.pdf.

More on solar heated panels (air and water)

If a house is equipped with an array of solar panels for heating air or water, light passes through glass (a 'greenhouse") and is absorbed on the dark surface of copper pipes that are coated with something like chromium oxide, which is black. The visible light (along with IR and some UV) is converted to heat and transferred by conduction through the metal to a circulating liquid, usually non-toxic propylene glycol which has a higher boiling point and density than water (though water is used in climates where freezing does not occur). Heat exchange between the propylene glycol and water in a tank occurs in copper tubing or fins. For warmer climates, water in a storage tank can be circulated to the solar panel, heated and returned to a storage tank with continuous cycling of the water between the tank and the solar panels.
www.azsolarcenter.com/technology/solarh20.html

For space heating, solar panels can be used to directly heat air rather a liquid http://www.solar-components.com/SOLARKAL.HTML. The heated air can also be passed through some kind of heat storage material such as water or stone for heat retrieval later. Ideally, one can "fine tune" a heat pump to extract heat from solar heated air. The fine tuning is meant to have the heat pump operate in very narrow heat range and not requiring back up of resistance heating (electrical) for the colder winter temperatures. The alternate is to heat water or propylene glycol in a solar system that would circulate though a hot "water" heating system in the house. But the cost of this kind of arrangement (more solar panels vs. those needed for hot water) usually does not justify this kind of system.

More on photovoltaics

Photovoltaic panels for generating electricity are nearly competitive with electricity generated the usual way (steam or water turbines). This is especially true in rural areas where new homes are built and new power lines have to be established. Then too, increasing the number of photovoltaic panels added to appropriately sited homes will collectively reduce the amount of oil and coal (and carbon dioxide emissions) used for making steam to generate the same amount of electricity.

Photovoltaic cells operate on the principle that light absorption at certain frequencies will displace electrons in the right material (the photoelectric effect). Photovoltaic cells are made in two layers. One layer of predominantly silicon has mixed in with it ("doped") some arsenic. Arsenic has 5 valence electrons and silicon has 4. With these two elements mixed together in a crystalline lattice, there are 9 electrons between two atoms, an excess of electrons (think of the octet rule) or mobile electrons. A second layer of primarily silicon with some doping by aluminum or gallium means that the octet rule is not satisfied and there is a deficiency of electrons (7 total between a silicon and an aluminum or gallium) or "holes".
As a result, electrons from the Si/As layer move to the Si/Al or Si/Ga layer, which makes the two layers charged (positive and negative). With such a situation, adding light of enough energy displaces the electrons that have migrated to the Al or Ga side (which has become negative from the extra electrons). The displaced electrons will migrate toward the positive layer containing the arsenic (it lost electrons to the Al or Ga layer initially). This means that a current is generated if an electrical conductor connects the two layers in the right way. View an animated version of this activity at http://j.solarhomes.com/photo-voltaic.html. A more technical reference is found at
www.howstuffworks.com/solar-cell.htm/

With the generation of the electricity, there has to be a storage system of special batteries. Entire photoelectric system packages are available for installation. If a home is completely independent of outside electrical service, then the home system has a backup generator powered by propane or natural gas.

Connections to Chemistry Concepts

1. Metals and non-metals – preventing heat loss either as thermal conduction or infrared radiation (IR) depends upon use of non-metallic materials (silica-based glass wool, carbon-based Styrofoam®) for reduced thermal conduction and metallic reflective materials to reduce IR losses. Metals are also important in the exchange of heat as in solar collectors and heat pumps.
2. Phase changes – necessary for thermal energy transfer in the operation of heat pumps ("refrigeration cycle" equivalent).
3. Potential and kinetic energy – changes in these energies occur in the transfer of energy from one source to another as in heat pumps, solar heating, and geoexchange of heat from the ground to a heat pump. Phase change salts such as sodium acetate with additives undergo changes in potential energy for both storage and release of solar energy.
4. Specific heat and heat capacity – these properties of matter determine which materials are most effective as storage materials for solar-produced heat; also important for heat transfer in solar collectors.
5. Photoelectric effect – production of electricity in a photovoltaic cell depends upon this effect by which light energy is transformed into electrical energy.
6. Metals, metalloids, non-metals – all three categories of elements necessary for the operation of a solar photovoltaic cell.
7. Octet rule – basis for creating movement of electrons from one part of a photovoltaic cell (electron number exceeds octet rule) to another (electron number less than octet rule).
8. Electromagnetic radiation (EMR) absorption and reflection – both visible (light) and invisible EMR, such as IR, are absorbed by solar collectors and photovoltaic cells and reflected by low-E windows, Metallic backing on wall insulation reflects radiating heat as IR back into the house, preventing heat loss from the house interior.
9. Polymers – these large molecules that are carbon-based are useful as insulation material.

Possible Student Misconceptions

1. **"Potential energy and kinetic energy are really the same thing."** Students need to understand the difference between potential energy and kinetic energy and their relationship to thermal energy and temperature. Phase changes in which temperature does not change but thermal energy is either absorbed or lost can be difficult to understand if students do not have a model for atomic/molecular behavior when a substance is undergoing a temperature change vs. a phase change.
2. **"Cold comes into the house from the outside in the winter time."** When dealing with the idea of energy transfer, students need to understand the basic laws of thermodynamics, that heat energy moves from an environment with a higher temperature to that of a lower temperature. Insulation does not act to keep out cold from a house in the winter, but rather it prevents heat transfer from the warmer house to the colder environment. Likewise, thermal transfer by some "heating" device such as a heat pump, in which outside air of 55°F is to be used to heat a room at 65°F would occur by

the cooling of that outside air (to an even lower temperature) by the heat pump, giving up its heat to the room (refrigeration cycle, air conditioner with heat expelled).

3. **"A green home means lots of green plants growing everywhere."** No, green in this sense simply means that it is environmentally friendly – it doesn't waste Earth's resources.

Demonstrations and Lessons

1. To distinguish between heat energy and temperature, you can do a simple demonstration to heat two different volumes of water from the same starting temperature to the same final temperature, using two identical heat sources that are constant and are timed. (identical candles, electric heaters). Students will observe that it takes a longer heating time to get the container with more water to the same temperature as the one with less water. Alternatively, if you heat both containers for the same length of time, students will observe that, even though the same amount of heat was added to both containers, the one with more water had a smaller temperature increase than the one with less water.
2. To show the energy changes involved with a phase change, the simplest idea is to have students measure the temperature of a beaker of ice cubes periodically as the ice melts. The beaker of ice could be placed in a larger beaker of warm water that also has a thermometer to show the temperature change of the warm water. Why does the temperature of the warm water bath change while that of the beaker of ice does not? Where is the thermal energy absorbed by the ice? Distinguish between thermal and potential energy in the two systems.
3. Another simple demo to show thermal changes with a phase change is to completely melt sodium acetate in a test tube, with immersed thermometer. Allow the liquid to cool to room temperature. Adding a few crystals of the sodium acetate will cause an immediate crystallization with a dramatic rise in temperature. Sodium acetate, which is a hydrate, melts at 58 ^{o}C. With continued heating, the chemical dehydrates at 120 ^{o}C, forming a solution. When the solution cools to room temperature, it becomes a supersaturated solution. When some crystals of sodium acetate are added, the sodium acetate is able to condense around these seed crystals as well as rehydrate. This condensation occurs with a reduction in potential energy; the same is true for addition of water to the sodium acetate formula units. This reduction or loss in potential energy is transformed into thermal (kinetic) energy. You can relate thermal changes to what is happening at the molecular level in terms of distance between molecules and potential energy changes (dissolved sodium acetate crystallizing to the solid state and the bonding of "free" water molecules to the sodium acetate crystal).

   Sodium acetate is used in heat pads. A video clip of a working heat pad can be found at http://static.howstuffworks.com/mpeg/q290.mpg. Sodium acetate has also been used in the walls of homes for solar/thermal storage. The cycle of dissolving (becoming liquid) (solar heating) and crystallizing (solidifying) (thermal release into the home) degrades over time unless certain additives (certain salts and some polymers) are added to the sodium acetate to keep it from layering (crystals sink to the bottom of the acetate solution).
4. To illustrate kinetic energy changes and their relationships to thermal energy, you can demonstrate the effect of doing work (increase in kinetic energy) on confined air by accelerating the air using a plunger-like device called a fire syringe. It is no different than using a bicycle pump, except that the air is confined. This fire syringe can be

purchased from major school science equipment suppliers. This is a glass tube with a metal plunger. Inserting a small piece of loose cotton or "frayed" paper at the bottom of the tube, followed by a rapid push on the plunger, ignites the cotton or paper. Pushing the plunger down accelerates the air molecules which means they are moving faster and are at a higher temperature (you have added energy to the particles, you have done some work). The hotter air molecules ignite the cotton or paper in the syringe. Although there is obviously a decrease in the volume of the air and a corresponding decrease in the potential energy of the air molecules, this energy change is not the main contributor to the ignition of the paper or cotton.

5. The photoelectric effect (photovoltaic) can be demonstrated with an electroscope that has a strip of zinc metal (newly sanded) wrapped over the "bulb" of the electroscope. Charge the electroscope through the zinc strip, using standard electrostatic charging methods (a plastic strip or rod is rubbed with fur; the plastic charges the zinc when touched). The leaves of the electroscope now should be repelling each other. Now shine an ultraviolet source directly onto the zinc strip. The leaves should slowly lose their repulsion and the gap between them should close as the electroscope discharges due to the ultraviolet light photons forcing electrons off the zinc.
6. The behavior of different materials upon exposure to a light source (reflection, absorption, transmission) and subsequent heating to various degrees can be done through an experiment documented in:
   NSTA "Science Teacher", Idea Bank, Nov.1996, Vol.63, #8, p.60
   See complete description of experiment below under student projects
7. Specific heat and heat capacity (related to solar thermal storage) can be done through standard experiments using a variety of materials actually used in thermal storage – water, rock, propylene glycol (compare with metals!)

Suggestions for Student Projects

1. Students can build a non-silicon photovoltaic cell using copper plates in a salt solution. Instructions for construction can be found at:
   http://www.thesolarguide.com/solar4scholars/make-a-solar-cell.aspx
2. Instructions for construction of a solar air heater can be found at: http://www.solar-components.com/SOLARKAL.HTML
3. Students can duplicate, in simple terms, the idea behind energy conversions in a fuel cell. Set up an electrolysis-of-water apparatus, using carbon electrodes and a small beaker (100ml) of water (acidified for conduction). After some minutes of electrolysis, disconnect the power source (a nine volt battery) and attach a micro-ammeter. There should be an indication of current flow (amperage) because the hydrogen and oxygen are recombining to form water. Among many other technical problems to be overcome is the fact that a fuel cell requires a cheap source of hydrogen (think solar-based) electrolysis of water. The whole issue of fuel cells is worth a student's literature search.
4. Students can measure, through temperature changes, the different behaviors of conducting, insulating and reflective materials using a light source, a digital thermometer placed on a vertical piece of Styrofoam, then covered with various single layers of material (white paper, aluminum foil, saran wrap, dark paper). For a fixed period of time, students measure temperature as it changes. Data can be graphed for each material, time vs. temperature. (see National Science Teachers Association publication, "The Science Teacher", Nov. 1996, Vol. 63, #8, p. 60), www.nsta.org

Anticipating Student Questions

1. "**What's the difference between kinetic energy and potential energy?"**
Kinetic energy is energy possessed by a moving object. If we are dealing with atoms and molecules, temperature is directly related to kinetic energy. An increase in temperature means an increase in the kinetic energy of those particles. Potential energy is best described as energy of position. In order to increase the distance between atoms or molecules, energy must be added. If the distance between particles decreases, then their potential energy decreases. A useful analogy is to think of masses that move away from or toward the earth. To move a mass further from the earth, an input of energy is needed – there is an increase in the potential energy of the mass. For that same mass to move closer to the earth, the mass gives up some energy of position, potential energy.
2. **"What's the difference between kinetic energy and thermal energy?**
Kinetic energy, energy of motion of atoms, molecules and ions, is directly related to temperature. An increase in temperature correlates with an increase in kinetic energy of particles and vice versa. All matter has thermal energy. The more thermal energy a substance has, the greater the motion of its atoms and molecules. An increase or decrease in thermal/heat energy of a system can result from a change in the kinetic or potential energy of particles. As heat energy, it flows across a conducting boundary from a system at higher temperature to a system at lower temperature.
3. **"What is the difference between temperature and heat?**
Temperature is a measure of molecular motion. Heat is a form of energy that flows across a conducting boundary from the higher temperature to the lower temperature. Temperature is stated in units of ^{o}C or K while heat is stated in units of joules or kilojoules.
4. **"Can I make a green home out of 100% recycled materials?"**
It is possible but probably not practical. A combination of recycled and reused material is more likely. Energy savings are dependent on the energy expenditures of the builder who looks for and collects materials for reuse.
5. **"What is a low-emittance (Low-e) window?"**
A low-e window is one that is designed to reduce what is called radiative heat flow. Thermal radiation refers to the transfer of thermal energy in the form of infra red (IR) which is electromagnetic radiation (EMR) just beyond visible red. A "heated" body emits IR which can be detected with special instruments as well as special photographic film. Night vision goggles and binoculars are electronic devices that can detect IR . A low-e window is designed to reduce this IR radiation, hence heat loss, from the warm side of a double paned window (the pane of glass closest to the house interior). Through the use of reflective coatings the IR is reflected or redirected back into the house. The heat associated with summer sunlight is also controlled the same way. A reflective metallic coating on the outer pane of glass reflects the IR of sunlight back out, away from the house.
6. **"How is it possible for air at 35^{o}F, that is drawn into a heat pump outside a house, to heat the interior of the house that is at a temperature of 75^{o}F?"**
The heat pump operates like a refrigerator or air conditioner. Since the air at a temperature of 35^{o}F has to contain heat energy, it is a matter of removing some of that heat energy. This is done as in a refrigerator (see referenced materials in this teacher guide) which means that the refrigerator's so called compressor mechanism that compresses a gas into a liquid which causes heating due to both an increase in kinetic

as well as a decrease in potential energy. When this pressurized liquid is allowed to expand in another part of the refrigerator or heat pump, the gas cools the environment because the change in physical state from liquid to gas requires thermal energy from the environment. The cooled gas circulates and heat from the 35 ^{o}F air moves to the cold gas.
When this gas returns to the compressor, the gas becomes a liquid, with subsequent heating again. But this time the heat energy is greater because of the addition of thermal energy from the air to the cold refrigerant gas. As the recycling of the refrigerant repeats itself, some of the heat of the hot liquid is transferred into the interior of the house (there is always heat loss from the hot liquid refrigerant through coils that are exposed to the house interior, as with a refrigerator).]

Websites for additional Information

How does a solar photovoltaic system produce electricity? See www.thesolarcenter.com/learnmore/howsolarworks.cfm or www.howstuffworks.com/solar-cell.htm/printable

Interseasonal solar storage (in the earth) and recovery: www.fujitaresearch,com./reports/solarpower.html

Solar storage in ponds with salt gradients; ACS ChemMatters, 1989*

How a solar hot water system works: www.azsolarcenter.com/technology/solarh20.html

Animated model and chemistry of photovoltaic electricity: http://jc-solarhomes.com/photo-voltaic.htm

Heat pump operation (with images) and thermal extraction from underground: http://www.geoexchange.org/pdf/GB-034.pdf

Fiberglass – chemistry, properties, formation. This reference provides lots of useful information about the manufacturing process of glass wool that differs from the making of glass which has been done for more than a thousand years. Most of us do not know how raw materials from the earth are converted into the products we encounter every day, from an automobile tire to a cardboard cereal box. Students can use this article to learn more about the chemical and physical behavior of silica (glass and quartz). They can compare these properties of glass with those in silica-based photovoltaic solar panels. http://en.wikipedia.org/wiki/Fiberglass

Energy Education Resources: Two sites with many links to other sites involved with general energy education topics are www.eia.doe.gov/kids and http://www.eia.doe.gov/bookshelf/eer/kiddietoc.html. Even though the term “kid” is in both sites’ url, the information contained on the two sites ranges from K-12 and beyond.

“Wind, Water, Fire and Earth – Energy Lessons for the Physical Sciences”, National Science Teachers Assoc. (NSTA), 1986, ISBN # 0-87355-046-3, www.nsta.org

The history behind the design of the fire syringe in the 19^{th} C. and its operational concept as the basis for Rudolf Diesel's engine design of the same name.
http://physics.kenyon.edu/EarlyApparatus/Thermodynamics/Fire_Syringe/Fire_Syrin

"Smart Windows", ACS ChemMatters, Oct. 1999, p. 7*

Solar storage transport in "Solar Chemistry", ACS ChemMatters, Feb. 1991, p.4*

"Recycle PET", ACS ChemMatters, Oct. 1994, p.8*

Development of extremely low density insulating materials is found in "When Good Ideas Gel", ACS ChemMatters, Dec. 1992, p. 14*

* (NOTE: articles from past issues of ChemMatters can be accessed from a CD that is available from the American Chemical Society for $25. The CD contains all ChemMatter issues from 1983 to 2003. Purchase information can be found online at http://chemistry.org/chemmatters/cd3.html

Sick Buildings: Air Pollution Comes Home **Edition:** October 2006

Background Information

The article lists these nine specific sources of indoor air pollution: radon, formaldehyde, biological contaminants, lead, asbestos, carbon monoxide, secondhand smoke, household products and combustion by-products, and it describes in detail the first four on that list. In this Teachers Guide there are additional details on all nine pollutants. Much of this material was taken from EPA sources.

More on indoor air quality

According to the EPA, major sources of indoor air pollution include:

- **combustion sources** such as oil, gas, kerosene, coal, wood, and tobacco products
- **building materials and furnishings** as diverse as deteriorated, asbestos-containing insulation, wet or damp carpet, and cabinetry or furniture made of certain pressed wood products
- **products for household cleaning and maintenance**, personal care, or hobbies
- **central heating and cooling systems** and humidification devices
- **biological contaminants** like bacteria, molds, mildew, viruses, animal dander and cat saliva, house dust mites, cockroaches, and pollen
- **outdoor sources** such as radon, pesticides, and outdoor air pollution

An EPA publication says, "The relative importance of any single source depends on how much of a given pollutant it emits and how hazardous those emissions are. In some cases, factors such as how old the source is and whether it is properly maintained are significant. For example, an improperly adjusted gas stove can emit significantly more carbon monoxide than one that is properly adjusted.

"Some sources, such as building materials, furnishings, and household products like air fresheners, release pollutants more or less continuously. Other sources, related to activities carried out in the home, release pollutants intermittently. These include smoking, the use of unvented or malfunctioning stoves, furnaces, or space heaters, the use of solvents in cleaning and hobby activities, the use of paint strippers in redecorating activities, and the use of cleaning products and pesticides in housekeeping. High pollutant concentrations can remain in the air for long periods after some of these activities.

"If too little outdoor air enters a home, pollutants can accumulate to levels that can pose health and comfort problems. Unless they are built with special mechanical means of ventilation, homes that are designed and constructed to minimize the amount of outdoor air that can "leak" into and out of the home may have higher pollutant levels than other homes. However, because some weather conditions can drastically reduce the amount of outdoor air that enters a home, pollutants can build up even in homes that are normally considered "leaky."

Also according to the EPA (http://www.epa.gov/iaq/pubs/insidest.html#IAQHome1) there are three basic strategies for improving indoor air quality in your home:

"Source Control

Usually the most effective way to improve indoor air quality is to eliminate individual sources of pollution or to reduce their emissions. Some sources, like those that contain asbestos, can be sealed or enclosed; others, like gas stoves, can be adjusted to decrease the amount of emissions. In many cases, source control is also a more cost-efficient approach to protecting indoor air quality than increasing ventilation because increasing ventilation can increase energy costs."

"Ventilation Improvements

Another approach to lowering the concentrations of indoor air pollutants in your home is to increase the amount of outdoor air coming indoors. Most home heating and cooling systems, including forced air heating systems, do not mechanically bring fresh air into the house. Opening windows and doors, operating window or attic fans, when the weather permits, or running a window air conditioner with the vent control open increases the outdoor ventilation rate. Local bathroom or kitchen fans that exhaust outdoors remove contaminants directly from the room where the fan is located and also increase the outdoor air ventilation rate."

"Air Cleaners

There are many types and sizes of air cleaners on the market, ranging from relatively inexpensive table-top models to sophisticated and expensive whole-house systems. Some air cleaners are highly effective at particle removal, while others, including most table-top models, are much less so. Air cleaners are generally not designed to remove gaseous pollutants."

More on "Sick Building Syndrome"

Although this article is about indoor air in homes and sick building syndrome usually refers to office buildings or schools, the same ideas apply to homes. Another difference is that sick building syndrome usually refers only to short term immediate symptoms and not to the longer term problems associated wit the presence of radon, for example,

According to the U.S. Department of Energy (DOE), improving buildings and indoor environments could reduce healthcare costs and sick leave and increase worker performance, resulting in an estimated productivity gain of $30 billion to $150 billion annually. The DOE further estimated the potential decrease in adverse health effects from improvements in indoor environments to be 10 percent to 30 percent for infectious lung disease, allergies and asthma; and 20 percent to 50 percent for Sick Building Syndrome symptoms. For the United States, the corresponding annual healthcare savings plus productivity gains are:

$6 billion to $19 billion from reduced lung disease,
$1 billion to $4 billion from reduced allergies and asthma,
$10 billion to $20 billion from reduced Sick Building Syndrome symptoms,
$12 billion to $125 billion from direct improvements in worker performance unrelated to health. http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=327043

The term "sick building syndrome" (SBS) is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be widespread throughout the building. In contrast, the term "building related illness" (BRI) is used when symptoms of diagnosable illness are identified and can be attributed directly to airborne building contaminants.

In sick building syndrome, occupants complain of symptoms associated with acute discomfort, e.g., headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odors.
The cause of the symptoms is not known. Most of the complainants report relief soon after leaving the building.

The following have been cited causes of or contributing factors to sick building syndrome. Many of them are mentioned in the article:

Inadequate ventilation: In the early and mid 1900's, building ventilation standards called for approximately 15 cubic feet per minute (cfm) of outside air for each building occupant, primarily to dilute and remove body odors. As a result of the 1973 oil embargo, however, national energy conservation measures called for a reduction in the amount of outdoor air provided for ventilation to 5 cfm per occupant. In many cases these reduced outdoor air ventilation rates were found to be inadequate to maintain the health and comfort of building occupants.

Chemical contaminants from indoor sources: Most indoor air pollution comes from sources inside the building. For example, adhesives, carpeting, upholstery, manufactured wood products, copy machines, pesticides, and cleaning agents may emit volatile organic compounds (VOCs), including formaldehyde. Environmental tobacco smoke contributes high levels of VOCs, other toxic compounds, and respirable particulate matter. Research shows that some VOCs can cause chronic and acute health effects at high concentrations, and some are known carcinogens. Low to moderate levels of multiple VOCs may also produce acute reactions. Combustion products such as carbon monoxide, nitrogen dioxide, as well as respirable particles, can come from unvented kerosene and gas space heaters, woodstoves, fireplaces and gas stoves.

Chemical contaminants from outdoor sources: The outdoor air that enters a building can be a source of indoor air pollution. For example, pollutants from motor vehicle exhausts; plumbing vents, and building exhausts (e.g., bathrooms and kitchens) can enter the building through poorly located air intake vents, windows, and other openings. In addition, combustion products can enter a building from a nearby garage.

Biological contaminants: Bacteria, molds, pollen, and viruses are types of biological contaminants. These contaminants may breed in stagnant water that has accumulated in ducts, humidifiers and drain pans, or where water has collected on ceiling tiles, carpeting, or insulation. Sometimes insects or bird droppings can be a source of biological contaminants. Physical symptoms related to biological contamination include cough, chest tightness, fever, chills, muscle aches, and allergic responses such as mucous membrane irritation and upper respiratory congestion. One indoor bacterium, Legionella, has caused both Legionnaire's Disease and Pontiac Fever.

More on sources of indoor air pollution mentioned in the article

The following sections give brief profiles of the four major indoor air pollutants mentioned in the article. Much of this information is taken directly from the EPA.

More on radon (Rn)

Sources: Earth and rock beneath home; well water; building materials.

Health effects: No immediate symptoms. Estimated to contribute to between 7,000 and 30,000 lung cancer deaths each year. Smokers are at higher risk of developing radon-induced lung cancer.

Levels in homes: Based on a national residential radon survey completed in 1991, the average indoor radon level is 1.3 picocuries per liter (pCi/L). The average outdoor level is about 0.4 pCi/L.

Steps to reduce exposure:

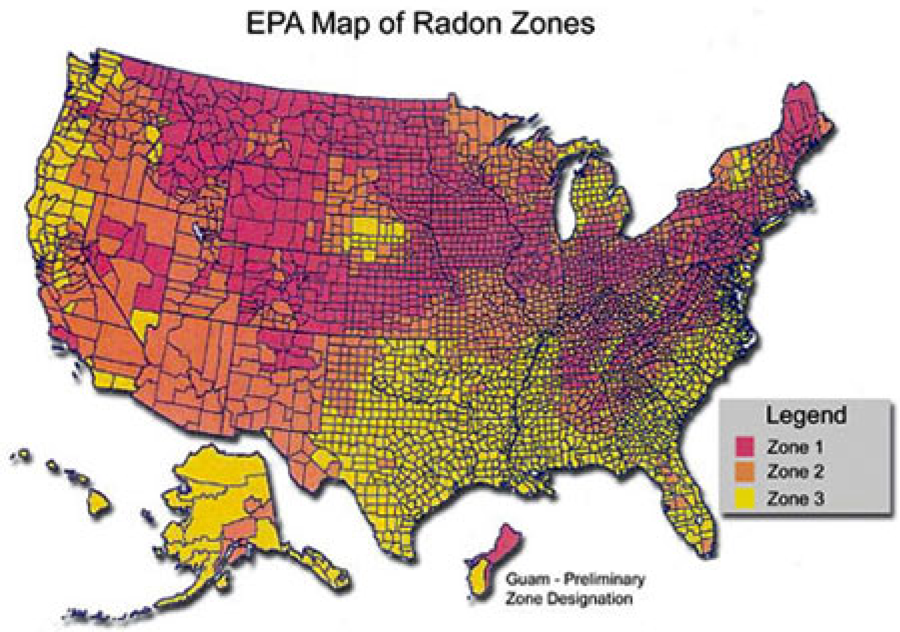
- Test your home for radon. It's easy and inexpensive.
- Fix your home if your radon level is 4 picocuries per liter (pCi/L) or higher.
- Radon levels less than 4 pCi/L still pose a risk, and in many cases may be reduced.

Properties:

State at room temperature: Gas
Density [211K] : 4400 kg m^{-3}
Crystal Formation: Face centered cubic
Melting Point : 202 K
Boiling Point : 211 K
Thermal Conductivity [300K] : 0.00364 W $m^{-1}K^{-1}$
Heat of:

Fusion: 2.7 kJ mol^{-1}
Vaporization: 18.1 kJ mol^{-1}
Does not react with air
Slightly soluble in water 230 cm^3 kg^{-1} at 293 K
Reacts with fluorine to form radon (II) fluoride, RnF_2.

The EPA provides a map which shows where radon levels are elevated in the U.S. Zone 1 has a high concentration and Zone 3 has low concentrations.



From: http://www.epa.gov/radon/zonemap.html

More on formaldehyde (HCHO)

Sources: Pressed wood products (hardwood plywood wall paneling, particleboard, fiberboard) and furniture made with these pressed wood products. Urea-formaldehyde foam insulation (UFFI). Combustion sources and environmental tobacco smoke. Durable press drapes, other textiles, and glues.

Health effects: Eye, nose, and throat irritation; wheezing and coughing; fatigue; skin rash; severe allergic reactions. May cause cancer. May also cause other effects listed under "organic gases."

Levels in homes: Average concentrations in older homes without UFFI are generally well below 0.1 (ppm). In homes with significant amounts of new pressed wood products, levels can be greater than 0.3 ppm.

Steps to reduce exposure:

- Use "exterior-grade" pressed wood products (lower-emitting because they contain phenol resins, not urea resins).
- Use air conditioning and dehumidifiers to maintain moderate temperature and reduce humidity levels.
- Increase ventilation, particularly after bringing new sources of formaldehyde into the home.

According to OSHA (http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=PREAMBLES&p_id=923), the chemical "formaldehyde" is a colorless, pungent gas at room temperature with an approximate odor threshold of about 1 ppm. While the term "formaldehyde" is also used to describe various mixtures of formaldehyde, water, and alcohol, the term "formalin" more precisely describes aqueous solutions, particularly those containing 37 to 50 percent formaldehyde and 6 to 15 percent alcohol stabilizer. Most formaldehyde enters commerce as formalin. Alcoholic solutions of formaldehyde are available for processes that require low water content. Paraformaldehyde, a solid, also serves as a source of formaldehyde gas. Formaldehyde gas per se is not available commercially.

Formaldehyde has four basic uses: as an intermediate in the production of resins; as an intermediate in the production of industrial chemicals; as a bactericide or fungicide; and as a component in the formulation of end-use consumer items. The manufacture of three types of resins: urea-formaldehyde, phenol-formaldehyde, and melamine formaldehyde, accounts for about 59 percent of total consumption An additional seven percent is consumed in the production of thermoplastic acetal resins. About one-third is used in the synthesis of high volume chemical derivatives, including pentaerythritol, hexamethylenetetramine, and butanediol. Two percent is used in textile treating and small amounts of formaldehyde are present as preservatives or bactericides in consumer and industrial products, such as cosmetics, shampoos and glues.

Some products prepared from formaldehyde contain unreacted formaldehyde residues which may be released from the product over its useful life. One example is urea-formaldehyde resin. Urea-formaldehyde resin is a generic name that actually represents an entire class of related formulations.. Urea-formaldehyde resins are also used in decorative laminates, textiles, paper, and foundry sand molds

Formaldehyde destroys bacteria, fungi, molds, and yeast. Its commercial importance as a fungicide is probably its greatest use as a disinfectant [Ex. 70-2]. Because of its bactericidal properties, formaldehyde is used in numerous cosmetic preparations.

More on biological pollutants (molds, etc.)

Sources: Wet or moist walls, ceilings, carpets, and furniture; poorly maintained humidifiers, dehumidifiers, and air conditioners; bedding; household pets.

Health effects: Eye, nose, and throat irritation; shortness of breath; dizziness; lethargy; fever; digestive problems. Can cause asthma; humidifier fever; influenza and other infectious diseases.

Levels in homes: Indoor levels of pollen and fungi are lower than outdoor levels (except where indoor sources of fungi are present). Indoor levels of dust mites are higher than outdoor levels.

Steps to reduce exposure:

- Install and use fans vented to outdoors in kitchens and bathrooms.
- Vent clothes dryers to outdoors.
- Clean cool mist and ultrasonic humidifiers in accordance with manufacturer's instructions and refill with clean water daily.
- Empty water trays in air conditioners, dehumidifiers, and refrigerators frequently.
- Clean and dry or remove water-damaged carpets.
- Use basements as living areas only if they are leak-proof and have adequate ventilation. Use dehumidifiers, if necessary, to maintain humidity between 30-50 percent.

According to the EPA, Molds are part of the natural environment. Outdoors, molds play a part in nature by breaking down dead organic matter such as fallen leaves and dead trees, but indoors, mold growth should be avoided. Molds reproduce by means of tiny spores; the spores are invisible to the naked eye and float through outdoor and indoor air. Mold may begin growing indoors when mold spores land on surfaces that are wet. All molds require water to reproduce.

Molds produce allergens (substances that can cause allergic reactions), irritants, and in some cases, potentially toxic substances (mycotoxins). Inhaling or touching mold or mold spores may cause allergic reactions in sensitive individuals. Allergic responses include hay fever-type symptoms, such as sneezing, runny nose, red eyes, and skin rash (dermatitis). Allergic reactions to mold are common. They can be immediate or delayed. Molds can also cause asthma attacks in people with asthma who are allergic to mold. In addition, mold exposure can irritate the eyes, skin, nose, throat, and lungs of both mold-allergic and non-allergic people.

More on carbon monoxide (CO)

Sources: Unvented kerosene and gas space heaters; leaking chimneys and furnaces; back-drafting from furnaces, gas water heaters, woodstoves, and fireplaces; gas stoves. Automobile exhaust from attached garages. environmental tobacco smoke.

Health effects: At low concentrations, fatigue in healthy people and chest pain in people with heart disease. At higher concentrations, impaired vision and coordination; headaches; dizziness; confusion; nausea. Can cause flu-like symptoms that clear up after leaving home. Fatal at very high concentrations.

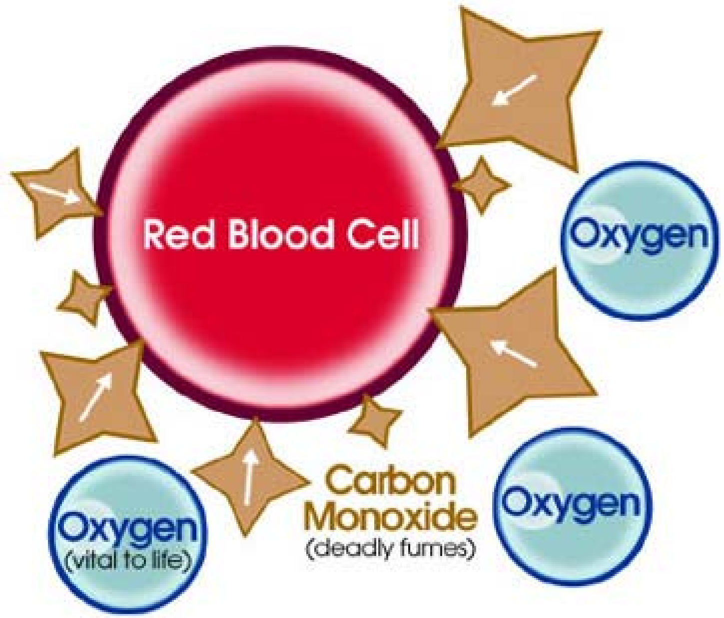
Levels in homes: Average levels in homes without gas stoves vary from 0.5 to 5 parts per million (ppm). Levels near properly adjusted gas stoves are often 5 to 15 ppm and those near poorly adjusted stoves may be 30 ppm or higher.

Steps to reduce exposure:

- Keep gas appliances properly adjusted.
- Consider purchasing a vented space heater when replacing an unvented one.
- Use proper fuel in kerosene space heaters.
- Install and use an exhaust fan vented to outdoors over gas stoves.
- Open flues when fireplaces are in use.
- Choose properly sized woodstoves that are certified to meet EPA emission standards. Make certain that doors on all woodstoves fit tightly.
- Have a trained professional inspect, clean, and tune-up central heating system (furnaces, flues, and chimneys) annually. Repair any leaks promptly.
- Do not idle the car inside garage.

Carbon monoxide (CO) is a colorless, practically odorless, and tasteless gas or liquid. It results from incomplete oxidation of carbon in combustion. Burns with a violet flame. Slightly soluble in water; soluble in alcohol and benzene. Specific gravity 0.96716; boiling point -190^{o}C; solidification point -207^{o}C; specific volume 13.8 cu. ft./lb. (70^{o}F). Auto ignition temperature (liquid) 1128^{o}F. It is usually classified as an inorganic compound.

The article describes the CO-blood interaction. A non-technical diagram illustrating this interaction, from the Center for Disease Control:



Since CO molecules bond with hemoglobin more easily than oxygen does, the body is prevented from taking up the needed oxygen.

From: http://www.nlm.nih.gov/medlineplus/carbonmonoxidepoisoning.html

Other sources of indoor air pollution The article focuses on four major pollutants. This section provides information on other major indoor air pollutants.

More on Lead

Sources: Lead-based paint, contaminated soil, dust, and drinking water.
Health effects: Lead affects practically all systems within the body. Lead at high levels (lead levels at or above 80 micrograms per deciliter (80 ug/dl) of blood) can cause convulsions, coma, and even death. Lower levels of lead can cause adverse health effects on the central nervous system, kidney, and blood cells. Blood lead levels as low as 10 ug/dl can impair mental and physical development.
Steps to reduce exposure:

- Keep areas where children play as dust-free and clean as possible.
- Leave lead-based paint undisturbed if it is in good condition; do not sand or burn off paint that may contain lead.
- Do not remove lead paint yourself.
- Do not bring lead dust into the home.
- If your work or hobby involves lead, change clothes and use doormats before entering your home.
- Eat a balanced diet, rich in calcium and iron.

More on Asbestos

Sources: Deteriorating, damaged, or disturbed insulation, fireproofing, acoustical materials, and floor tiles.
Health effects: No immediate symptoms, but long-term risk of chest and abdominal cancers and lung diseases. Smokers are at higher risk of developing asbestos-induced lung cancer.

The most dangerous asbestos fibers are too small to be visible. After they are inhaled, they can remain and accumulate in the lungs. Asbestos can cause lung cancer, mesothelioma (a cancer of the chest and abdominal linings), and asbestosis (irreversible lung scarring that can be fatal). Symptoms of these diseases do not show up until many years after exposure began. Most people with asbestos-related diseases were exposed to elevated concentrations on the job; some developed disease from exposure to clothing and equipment brought home from job sites.

Levels in homes: Elevated levels can occur in homes where asbestos-containing materials are damaged or disturbed.

Steps to reduce exposure:

- It is best to leave undamaged asbestos material alone if it is not likely to be disturbed.
- Use trained and qualified contractors for control measures that may disturb asbestos and for cleanup.
- Follow proper procedures in replacing wood stove door gaskets that may contain asbestos.

More on Cigarette Smoke

Sources: Cigarette, pipe, and cigar smoking.

Health effects: Eye, nose, and throat irritation; headaches; lung cancer; may contribute to heart disease. Specifically for children, increased risk of lower respiratory tract infections, such as bronchitis and pneumonia, and ear infections; build-up of fluid in the middle ear; increased severity and frequency of asthma episodes; decreased lung function.

Levels in homes: Particle levels in homes without smokers or other strong particle sources are the same as, or lower than, those outdoors. Homes with one or more smokers may have particle levels several times higher than outdoor levels.

Steps to reduce exposure:

- Do not smoke in your home or permit others to do so.
- Do not smoke if children are present, particularly infants and toddlers.
- If smoking indoors cannot be avoided, increase ventilation in the area where smoking takes place. Open windows or use exhaust fans.

More on volatile organic compounds (VOC’s)

Sources: Household products including: paints, paint strippers, and other solvents; wood preservatives; aerosol sprays; cleansers and disinfectants; moth repellents and air fresheners; stored fuels and automotive products; hobby supplies; dry-cleaned clothing.

Health effects: Eye, nose, and throat irritation; headaches, loss of coordination, nausea; damage to liver, kidney, and central nervous system. Some organics can cause cancer in animals; some are suspected or known to cause cancer in humans.

Levels in homes: Studies have found that levels of several organics average 2 to 5 times higher indoors than outdoors. During and for several hours immediately after certain activities, such as paint stripping, levels may be 1,000 times background outdoor levels.

Steps to reduce exposure:

- Use household products according to manufacturer's directions.
- Make sure you provide plenty of fresh air when using these products.
- Throw away unused or little-used containers safely; buy in quantities that you will use soon.
- Keep out of reach of children and pets.

- Never mix household care products unless directed on the label.

More on pesticides

Sources: Products used to kill household pests (insecticides, termiticides, and disinfectants). Also, products used on lawns and gardens that drift or are tracked inside the house.
Health effects: Irritation to eye, nose, and throat; damage to central nervous system and kidney; increased risk of cancer.
Levels in homes: Preliminary research shows widespread presence of pesticide residues in homes.
Steps to reduce exposure:

- Use strictly according to manufacturer's directions.
- Mix or dilute outdoors.
- Apply only in recommended quantities.
- Increase ventilation when using indoors. Take plants or pets outdoors when applying pesticides to them.
- Use non-chemical methods of pest control where possible.
- If you use a pest control company, select it carefully.
- Do not store unneeded pesticides inside home; dispose of unwanted containers safely.
- Store clothes with moth repellents in separately ventilated areas, if possible.
- Keep indoor spaces clean, dry, and well ventilated to avoid pest and odor problems.

More on Combustion Pollutants

Sources: Fireplaces, woodstoves, and kerosene heaters. Environmental tobacco smoke.
Health effects: Eye, nose, and throat irritation; respiratory infections and bronchitis; lung cancer. (Effects attributable to environmental tobacco smoke are listed elsewhere.)
Levels in homes: Particle levels in homes without smoking or other strong particle sources are the same as, or lower than, outdoor levels.
Steps to reduce exposure:

- Vent all furnaces to outdoors; keep doors to rest of house open when using unvented space heaters.
- Choose properly sized woodstoves, certified to meet EPA emission standards; make certain that doors on all woodstoves fit tightly.
- Have a trained professional inspect, clean, and tune-up central heating system (furnace, flues, and chimneys) annually. Repair any leaks promptly.
- Change filters on central heating and cooling systems and air cleaners according to manufacturer's directions

Connections to Chemistry Concepts

1. **Properties of elements and compounds** – You could use this article to discuss properties of elements (like radon) and compounds like formaldehyde or carbon monoxide.
2. **Uses of elements and compounds** – Many of the polluting substances are present in a consumer product. This might provide an opportunity to focus on uses of substances.

3. **Gases and phases of matter** – Most of the indoor air pollutants are gases (there are some particulates), and you might discuss the article from the point of view of gas behavior.
4. **Combustion -** Pollutants related to combustion provide an opportunity to discuss combustion as a chemical change.
5. **Environment** – This is an obvious way to relate chemistry and the environment

Possible Student Misconceptions

1. **"Air pollution only happens outdoors."** Most students associate pollution with the external atmosphere. The reason this article is of interest is that it highlights indoor air pollution, which we think about only in parts and rarely as w hole. For example, students are probably aware of the dangers of second-hand tobacco smoke, a problem that is tacitly associated with the indoors. Students also know about household odors associated with cooking or with pets. This article takes a step back and considers the whole of indoor air pollution.
2. **"Radon is a noble gas, and noble gases don't react."** How can radon be a pollutant?" It is true that radon does not generally react with other substance in the atmosphere, but reactivity is a chemical concept. Radon's danger as a pollutant is that it undergoes nuclear decay, and the decay products are dangerous.

Demonstrations and Lessons

1. The National Safety Council produces a Guide to Indoor Air Quality for Teachers. It is available at http://www.nsc.org/public/ehc/iaq/teachgde.pdf . Although it is designed for students in grades 4-6 some of the activities are adaptable for older students.
2. Students can do lab work to determine the products of complete combustion. Students can conduct their own experiments to monitor the grow of mold: http://www.brown.edu/Departments/Swearer_Center/Projects/PSO/Lessons/mold.htm
3. Some hospitals have instruments that measure the amount of carbon monoxide in exhaled breath. If possible, arrange to have a health care professional come to your class and measure the CO content of students' exhaled breath.
4. Your students could do a lab activity that illustrates the volatility of liquids compared to water. Most volatile liquids are organic in nature. This relates to pollution from VOC's.
5. Commercial vendors sell inexpensive lead test kits. You could purchase a kit and have students learn how to test for lead. Two such vendors: http://www.leadinspector.com/ and http://www.hach.com/hc/browse.parameter.list/PAR053/NewLinkLabel=Lead#PRODCAT0032

Suggestions for Student Projects

1. The National Safety Council produces a Guide to Indoor Air Quality for Teachers. It is available at http://www.nsc.org/public/ehc/iaq/teachgde.pdf . Although it is designed for students in grades 4-6 some of the activities are adaptable for older students.
2. Students (working in teams or as a class) might design and conduct home surveys for indoor pollutants. This could be as simple as counting the number of homes which have been tested for radon or lead or as complex as desired.

3. Teams of students (or individual students) can be assigned to do research on one of the major indoor pollutants. Outcomes might include posters or papers or a brochure that can be distributed to stsudents' families and neighbors
4. Students could organize to raise money to buy CO detector/radon detectors for homes of all classmates or for the elderly in your community.
5. Students might look for mold samples in their homes.

Anticipating Student Questions

1. **"The article says that taking a shower can contribute to indoor air pollution. How is that possible?"** In many places in houses water can leak into hidden spaces under floors or behind walls where molds can grow unseen (see More on Biological Pollutants) and produce dangerous substances in addition to mold spores.
2. **"How does frying meat produce hazardous chemicals?"** Frying meat produces polycyclic hydrocarbons (PCH) and heterocyclic amines (HCA) which are gases that can cause cancer.
3. **"What dangerous chemicals are could be produced from a carpet?"** In the manufacturing of carpets, chemicals are used which may vaporize from the newly installed carpet. These chemicals include toluene, benzene, formaldehyde, ethyl benzene, styrene, acetone and p-Dichlorobenzene.

Websites for additional Information

The EPA's online version of a publication called "The Inside Story: A Guide to Indoor Air Quality" is located here http://www.epa.gov/iaq/pubs/insidest.html

For state-by-state air quality information from the Center for Disease Control see http://www.cdc.gov/nceh/airpollution/indoor_air.htm

Although this article is about air quality in homes, children spend a significant amount of time in school buildings. For a government guide to air quality in schools, see http://nces.ed.gov/pubs2003/maintenance/chapter4.asp#21

For a *ChemMatters* related article on asthma see the April, 2006 edition, page 7. The teachers guide is available on line at http://www.chemistry.org/portal/resources/ACS/ACSContent/education/curriculum/chemmatters/tg/2006_4_tg.pdf

The National Safety Council publishes fact sheets on most of the major indoor pollutants at http://www.nsc.org/EHC/indoor/factshet.htm

Although this article is about home air quality, students might become interested in the air quality in your school. For a kit from the EPA titled "Indoor Air Quality Tools for Schools" see http://www.epa.gov/iaq/schools/tools4s2.html

For more detail on CO and CO poisoning see http://www.nlm.nih.gov/medlineplus/carbonmonoxidepoisoning.html

For an article from ACS on carbon monoxide detectors, see
http://www.chemistry.org/portal/a/c/s/1/feature_ent.html?id=04dd47d40b8211d7f0856ed9fe800100

Background Information

More on stellar nucleosynthesis

As the article indicates, protons and neutrons are joined together in the cores of stars by the processes we call thermonuclear fusion. The extremely high temperatures found in stellar cores are necessary for the formation of nuclei because only at such temperatures do protons collide at speeds high enough to overcome the electrostatic repulsion that would normally drive them apart. Thermonuclear fusion first builds regular hydrogen into higher isotopes like deuterium and tritium, and then into helium. This releases a tremendous amount of energy, because a helium nucleus is much more stable than the simple proton of the hydrogen nucleus. This is thanks to the strong nuclear force, which attracts baryons (protons and neutrons) to each other very strongly.

Note that neutrons are necessary for holding any nucleus together. Being electrically neutral, they bring to the nucleus the attraction of the strong nuclear force, but none of the electrostatic repulsion that protons bring. This means they act as the glue that holds a nucleus together.

Just as hydrogen fuses to form helium, helium fuses to form heavier elements: lithium, boron, carbon; releasing energy at every step of the way until iron nuclei are created, with 26 protons and 30 or so neutrons, depending on the isotope. Fusion cannot create nuclei heavier than iron, because adding more protons to the nucleus at this point makes the nucleus less stable rather than more stable. This is because at this point the electrostatic repulsion of the protons in the nucleus begins to overcome the attraction of the strong nuclear force. Adding more protons to an iron nucleus is something that takes more energy than is normally available in thermonuclear fusion.

The question then begs, where do all those elements heavier than iron come from? Synthesis of heavier nuclei requires a source of energy even greater than that found in the heart of a star. It requires the energy of an exploding supernova. It is thought that most heavy elements were born in the death throes of stars that ended their lives catastrophically billions of years ago. This hypothesis is supported by the fact that "first-generation" stars—those stars formed from the primordial stuff of the big bang—contain mostly lighter elements. Meanwhile heavier elements are usually only found in younger "second-generation" stars—those stars formed from the dust left behind after older stars explode as supernovae.

In recent years, astrophysicists have discovered a process by which heavier elements can form in living stars, called the "slow process"—to distinguish it from the "fast" process of supernovae. It is thought that the slow process can create nuclei as heavy as lead, while supernovae are still thought necessary to create still heavier radioactive nuclei like radium and uranium.

A good online source of information on nuclear fusion is "Fusion—Physics of a Fundamental Energy Source" at http://fusedweb.pppl.gov/CPEP/Chart.html, produced by the Contemporary Physics Education Project.

A really catchy song about thermonuclear fusion is available as an mp3 from Singing Science Records at http://acme.com/jef/science_songs. This version was recorded in the 1950s, but a more modern new wave rendition was recorded live by They Might Be Giants and is available on the album *Severe Tire Damage*.

More on radioactive decay

As discussed above, some atomic nuclei are more stable than others. This is because a number of forces are at play inside the nucleus. Nuclear reactions are driven to bring about these forces into balance. Among the forces at play are the aforementioned strong nuclear force which attracts protons to neutrons; the electromagnetic force, which causes protons to repel each other; and the weak nuclear force, which affects the stability of protons and neutrons themselves. As we've seen, nuclear fusion takes place to make nuclei more stable with regard to the strong nuclear force, but won't take place if it makes the nucleus unstable with regard to the electromagnetic force. Radioactive decay processes also take place against this backdrop of balancing forces.

Alpha decay is driven by the electromagnetic force. If a nucleus has too many protons, the electrostatic repulsion between them will act to drive the nucleus apart. This stress is relieved when a heavy nucleus expels an alpha particle, that is, a helium nucleus. This lowers the number of protons in the nucleus by two, and reduces the repulsive strain on the nucleus. Since the number of protons in the nucleus changes by -2, the atomic number is lowered by 2 and the nucleus becomes one of a different element, two spaces to the left on the periodic table.

For example, the uranium that Henri Becquerel observed is an alpha emitter. Uranium-238 (atomic number =92) decays into thorium-234 (atomic number = 90) by the emission of an alpha particle.

Alpha particles themselves are usually not terribly dangerous, but are stopped by a sheet of paper, or human skin. However, if a radioactive substance that emits alpha particles is ingested into the body, it can increase a person's risk of cancer.

Beta decay is driven by the weak nuclear force. While a discussion of this force is beyond the scope of this guide, it will suffice to say that a proton is more stable with regard to this force than a neutron is. A free neutron floating in space will, in time, decay into a proton, releasing an electron in the process, thereby maintaining cosmic balance in terms of electrical charge. This process is called beta decay, because it emits an electron, also called a beta particle.

Beta decay does not happen to neutrons in common nuclei because were such neutrons to decay, they would make their nuclei less stable with regard to the electromagnetic force. (Remember, it's the neutrons that act as the glue that holds those repulsive protons in the nucleus.) But suppose a nucleus has more than enough neutrons to keep it stable. In that case, it could lose one to beta decay without destabilizing the nucleus. This is why we see beta decay taking place in light isotopes with excess neutrons, like carbon-14 with its abundance of 8 neutrons to its 6 protons. In this case, the nucleus would lose one neutron and gain one proton, turning it into a nitrogen-14 nucleus, a stable isotope. Beta decay also in heavier nuclei.

Like alpha particle radiation, beta particle radiation is most dangerous if the radioactive substance emitting the beta particles is ingested. However, unlike alpha particle radiation, beta particle radiation can cause severe sunburn-like injury to the skin.

Unlike alpha and beta particle radiation, gamma radiation is a form of electromagnetic energy rather than a stream of high-speed particles. Gamma radiation is the most energetic form of electromagnetic radiation. That is, gamma waves have the shortest wavelength and highest frequency of any electromagnetic waves.

Even so, gamma radiation is like alpha radiation in that it is caused by the weak nuclear force. Sometimes when a neutron decays into a proton and an electron (beta particle), some of the energy released is emitted in the form of a gamma photon. (Remember that electromagnetic radiation behaves like waves and like particles.)

Common gamma emitters are moderately-heavy nuclei like cobalt-60, cesium-137, and technetium-99.

Gamma radiation is the most dangerous of all forms of radiation emitted by radioactive materials because they can penetrate the skin. Gamma radiation can cause radiation sickness and some forms of cancer. Lead shielding is the most effective protection from gamma radiation.

A fourth kind of radiation mentioned in the article is positron decay. Like alpha decay, it is driven by the electromagnetic force. Positron decay takes place in nuclei with an excess of protons and in order to reduce the repulsive strain within the nucleus. In this process, a proton decays into a neutron, emitting a positron at the same time. A positron is a small piece of antimatter, and is essentially an electron with a positive charge rather than a negative charge. (This maintains the positive charge the proton had before becoming a neutron.) Positron decay lowers the number of protons in the nucleus by one, thus lowering the atomic number by the same amount, shifting the nucleus one place to the left on the periodic table. For example, radioactive magnesium-23 decays into sodium-23 by positron decay.

As for the positron itself, it will meet with the fate of all antimatter in our matter-laden universe. When antimatter meets ordinary matter, they annihilate each other and are converted into energy. Very quickly the positron will meet an electron in an atom of ordinary matter. The positron and the electron will be annihilated releasing energy in the form of gamma radiation.

The article also mentions a fifth mode of radioactive decay, electron capture. This is also driven by the electromagnetic force, as it reduces the number of protons in a nucleus by one. In this process, an electron is “captured” by a proton in the nucleus, and the two particles become a neutron, in essence. A neutrino, a neutral particle even smaller than an electron, is released at the same time. Also, since the electron captured usually is taken from an inner-core electron shell, electrons in higher shells collapse inward to fill the vacancy. Losing energy, they emit electromagnetic radiation, including X-rays.

More information about these forms of radiation and others can be found on the website “Understanding Radiation” at http://www.epa.gov/radiation/understand/alpha.htm from the U.S. Environmental Protection Agency.

More on nuclear fission

The fission of heavy nuclei is driven by the electromagnetic force, as are several radioactive decay processes. Very heavy nuclei like uranium are greatly stressed by the large number of mutually-repelling protons packed inside. The attraction of protons and neutrons arising from the strong nuclear force is barely enough to hold the nucleus together. A slight nudge, like that provided by a colliding neutron, is enough to make the nucleus split in two. The two nuclei that are produced, having far fewer protons each, are much more stable. What's more, being mutually repulsive thanks to their positive charges, the two nuclei rush away from each other at high speed. The energy of these speeding nuclei is dissipated as heat, the usable energy obtained from fission.

Einstein points the way to just how much energy is released in this process. The atomic mass unit is defined as the mass of a proton, also roughly the mass of a neutron. But in reality, the mass of a proton changes depending on how stable it is in a given nucleus. The less stable it is, the greater its mass. The extra energy required to keep a proton in a less-stable nucleus becomes the extra mass, according to the equation $E = mc^2$. When fission takes place, and all those protons find themselves in more stable nuclei, they are in a state of lower energy. The energy released is the energy of nuclei speeding away from each other. The lost energy also shows up as lost mass, as the protons are now slightly less massive than they were before. All-in-all, the particles in the nucleus of a uranium-235 nucleus lose about 0.2 atomic mass units during the fission process.

Also released in the process are three stray neutrons. These are what make nuclear chain reactions possible, since they can collide with other uranium-235 nuclei, causing them to split, releasing three more neutrons, etc.

More on applications of nuclear transformations

While its obvious that fission has applications in atomic bombs and in the peaceful generation of nuclear power, the applications of other radioactive processes may not be as well known. The discovery of artificial radioactivity by Irène Joliot-Curie and Frédéric Joliot meant that radioactive isotopes of just about any element could be created. This has allowed chemists to use radioactive labeling to follow the courses of individual atoms in chemical reactions, helping them determine many reaction mechanisms. It also helps us follow the course of drugs in the body, by using radioactively-labeled drugs. Since any element can be made radioactive, any drug can be prepared with a radioactive label. Radioactive isotopes of iodine are especially useful for radioactive labeling of drugs, and they are also useful in imaging and in cancer chemotherapy.

Artificial transmutation is also being investigated as a way to convert nuclear waste into less dangerous isotopes. More information about this topic can be found at this website from Oak Ridge National Laboratory: http://www.ornl.gov/info/ornlreview/rev26-2/text/radside1.html.

The artificial elements heavier than uranium are not renowned for their usefulness, but there is an application of a transuranium element that is worth mentioning. Americium is one element that should be found in every home. As all smoke detectors contain a small amount of this radioactive substance. It's radiation ionizes smoke particles, making them easily detected using simple electronics.

More on kinetics of radioactive decay

Radioactive decay processes are of kinetic interest because they follow perfect first-order kinetics, since radioactive decay is an internal process taking place within a single atom, involving no other species reacting with the atom. For this reason the half-life is an inherent property of any radioactive isotope. The kinetics of decay are also not affected by temperature.

More on historical background

Henri Becquerel's discovery of radioactivity and the subsequent investigations of Marie and Pierre Curie (among others) created quite a stir in the scientific circles of the day. This spontaneous transmutation of elements was vehemently rejected by Dmitri Mendeleyev, who thought it as alchemy, not worthy of consideration by modern rational chemists. What's more, he thought it a threat to the fundamentally inviolate nature of his elements that he felt was at the heart of his periodic system. But the joke was on Mendeleyev, for it was through the study of radiation and the structure of the atom that we finally discovered the rational basis for his table.

Meanwhile, others were undaunted and made more shattering discoveries. Rutherford first used alpha bombardment to discover the nucleus of the atom before achieving artificial transmutation. A crucial breakthrough came in the 1930s when James Chadwick discovered the neutron, which was put to use in nuclear bombardment by Enrico Fermi.

The ensuing discovery of nuclear fission is a story sometimes long and twisting, but fascinating and worth investigating further. A few details are worth pointing out. In1935 Lise Meitner learned from Fermi about the strange results that were observed when he bombarded uranium with neutrons. Meitner tried to replicate his results, and enlisted her old friend chemist Otto Hahn to carry out the separation and identification of the products of the bombardment. Hahn in turn recruited the young chemist to assist him. For three years they had struggled with the puzzle when Meitner was forced to flee the country to escape Nazi persecution. Hahn and Strassmann kept up a surreptitious correspondence with Meitner, now living in Sweden. When Strassmann, looking for radium in the bombardment products found only a radioactive barium isotope, Hahn wrote to Meitner with this strange result. Never before had such a large change in the atomic number of a nucleus been observed. Meitner calculated the balance of forces between repulsive protons and attracting neutrons in the nucleus, and determined that the uranium nucleus was teetering on the verge of destruction, and the slightest nudge could cause it to split. They had discovered nuclear fission. In a bitter twist, only Hahn would be awarded the Nobel Prize for this discovery.

The discovery of fission was made in a Europe on the verge of war, and subsequent nuclear research was consumed in the Manhattan project. It was for the production of bomb material that methods for producing large amounts of plutonium were developed by Glenn Seaborg and others.

Incidentally, Seaborg's actinide hypothesis could have helped Meitner, Hahn,and Strassmann had it been elucidated a few years earlier. One of the reasons they thought they had created several elements heavier than uranium is that most people thought transuranium elements would be transition elements. Since some of the fission products were lighter transition elements, they were mistaken for the supposed transuranium elements which would have fallen directly beneath the true fission products on the periodic table.

After the war, nuclear research was shaped by U.S.-Soviet rivalry even when not applied to weapons research. Researchers in the U.S. Like Glenn Seaborg, Albert Ghiorso, and Darleane C. Hoffman just to name a few were perpetually racing with Soviet teams to be the first to definitively observe new transuranium elements. This led to many priority disputes, and often elements lingered for years unnamed while IUPAC sorted out who had in fact earned the naming rights.

A set of class lessons which covers many of these stories in much greater detail is the ChemCases case study “Nuclear Chemistry and the Community” created by Frank Stettle, and found at found at http://chemcases.com/nuclear/index.htm.

Connections to Chemistry Concepts

1. The structure of the atom – all the processes in this reading reinforce the basic notion of an atom with a nucleus made of protons and neutrons.
2. Isotopes – artificial radioactivity depends on the fact that there are different isotopes of elements. A common element might be stable, but an uncommon isotope of that element might be radioactive. Also, fission reinforces the concept of isotopes because only uranium-235 is fissile, while uranium-238 is not. Also, Ernest Rutherford created less-common isotopes in his transmutations, such as oxygen-17.
3. Radioactive decay processes – the major processes of alpha, beta, and gamma emission are discussed along with the positron decay and electron capture.

4. Nuclear fission – the story of Lise Meitner, Otto Hahn, and Fritz Strassmann is a dramatic way to teach this nuclear reaction.
5. Nuclear fusion – this reaction is necessary for sustaining life on earth and is essential to forming the very elements that make us up.
6. Transmutation and the nature of elements – teaching the processes by which one element is transformed into another reinforces the basic definition of an element, namely a substance made of only one kind of atom, the atoms being distinguished by their atomic numbers, the number of protons in the nucleus.
7. Thermodynamics and stability – all the processes described are driven by energetic stability, with the exception of the slow process and the supernova process which create heavy elements, which must be considered a kinetically-driven process given the stability of the products formed.
8. Fundamental forces – the processes in this reading can reinforce understanding of electromagnetism, specifically electrostatic repulsion, while the strong and weak nuclear forces would likely be introduced for the first time.
9. Nature of science – the story of the discovery of fission shows how science moves in fits and starts, and goes down blind alleys before making discoveries. Even good scientists can be wrong. It also shows how real science is often interdisciplinary, as solving this puzzle required both physicists and chemists.
10. Hypotheses and evidence – it is hypothesized that heavy elements are created in supernovae, and evidence that supports this conclusion is the fact that heavy elements are found mostly in stars formed from the remains of older stars.

Possible Student Misconceptions

1. **"Elements are natural."** In popular parlance the word element is often used to mean anything that is natural or primordial. The idea of artificial elements is sometimes hard for students to get their minds around. This can be an opportunity to reinforce the scientific notion of elements as substances made of only one kind of atom, be they natural or artificial.
2. **"All radiation is electromagnetic energy/All radiation is made of particles of matter."** It should be stressed that alpha and beta radiation on one hand are fundamentally different from gamma radiation on the other. Alpha and beta radiation are streams of high-energy particles of matter, while gamma radiation is electromagnetic radiation, and has no mass.
3. **"Radiation makes objects radioactive."** This one is partly true, in that bombardment with alpha particles is used to create artificial radioactivity in the target substance. However, the distinction between alpha particle radiation and gamma radiation can be lost on some people. This can lead to ungrounded fears of things like gamma-irradiated food. It should be stressed that gamma radiation, while harmful to humans, cannot make our food radioactive.
4. **"Whole particles are converted into energy during fission."** This is a misconception I held personally in high school, so I can only assume others might hold it too. It may have its origins in the three stray neutrons that aren't part of any of the daughter nuclei produced by fission of uranium. I may have somehow thought these neutrons were being transformed into energy. But the truth is that all particles are preserved in fission; they all just have a little less mass each when the process is done.

5. **"Microwave ovens 'nuke' food."** Some may think that a microwave oven uses alpha, beta, or gamma radiation to cook food. In fact, microwaves are a form of electromagnetic radiation that is much less energetic than gamma radiation, with much longer wavelengths and much lower frequencies.

Demonstrations and Lessons

1. Radioactivity and Half-Life Demonstration – this activity provide free online by Carolina Biological Supply demonstrates the concept of half-life using the random probability of coin tosses. http://www.carolina.com/chemistry/experiments/halflife.asp.
2. Nuclear Chemistry and the Community – created by Frank Stettle for ChemCases.com, this activity explores nuclear chemistry from a historical perspective. http://chemcases.com/nuclear/index.htm.
3. Radioactive Background and Detectors – this demonstration from the Institute of Physics uses a Geiger counter to demonstrate that some degree of radiation is all around us and identifies some of the common sources of background radiation. http://www.iop.org/Our_Activities/Schools_and_Colleges/Teaching_Resources/Teaching%20Advanced%20Physics/Atomic%20and%20Nuclei/Radioactivity/page_5479.html.
4. Properties of Radiations – this activity from the Institute of Physics demonstrates the penetrating power of different forms of radiation and shows that beta particles have mass using magnetic deflection. http://www.iop.org/Our_Activities/Schools_and_Colleges/Teaching_Resources/Teaching%20Advanced%20Physics/Atomic%20and%20Nuclei/Radioactivity/page_5480.html.

Using Popcorn to Simulate Radioactive Decay – created by Jennifer Wenner, University of Wisconsin-Oshkosh, this demonstration uses the popping of popcorn as a model for radioactive decay processes. http://serc.carleton.edu/quantskills/activities/popcorn.html.

Student Projects

1. Students could choose a scientist in the reading and prepare a report on his or her life and work. A useful starting place for biographical information on scientists is *Chemical Achievers*, from the Chemical Heritage Foundation: http://www.chemheritage.org/classroom/chemach/index.html.
   Another useful site for biographical information of scientists is the Nobel Foundation's official site: http://nobelprize.org.
2. Students might want to explore and form opinions about the pros and cons of nuclear power. One way to do this is presented in "Nuclear Power in Seaside," a WebQuest activity in which students take on the roles of different parties with an interest at stake in a fictional proposal to restart a mothballed nuclear power plant, and debate the issue from the perspectives of their characters. The activity was created by Keith Nuthall. http://powayusd.sdcoe.k12.ca.us/projects/NUKEWEB/default.htm

3. Students can explore the many uses of radioactive isotopes. One way to allow them to do this is to assign each student a particular radioactive isotope (or let each choose one) and have the students prepare reports describing the uses of their isotope, whether it is naturally occurring or if it is prepared artificially (and how), and any risks associated with its use.

Anticipating Student Questions

1. **"Can we make gold using transmutation?"** Yes we can, but we can't do it cost-effectively.
2. **"Will our sun become a supernova?"** Our sun will eventually die, but it isn't nearly large enough to become a supernova, or even a regular nova. It's thought that our sun has another 5 billion or so years left in it before it becomes a red giant, followed by a stage of contraction to become a white dwarf, after which time it will probably just quietly burn out when it has no more fuel that can be fused into heavier elements.
3. **"Is radioactivity dangerous to me?"** While nuclear waste and nuclear power plants may instill more fear in students, the biggest immediate radiation risk most students will face is radon in the home. Home radon testing might be a worthwhile topic to discuss with your students.

Websites for additional Information

General

Nuclear Chemistry and the Community – this lesson plan explores nuclear chemistry by studying its history; created by Frank Stettle for ChemCases.com.
http://chemcases.com/nuclear/index.htm

Fifty Years from Trinity – this site from the Seattle Times explores many aspects of nuclear chemistry and how it has affected life in the post-war world.
http://seattletimes.nwsource.com/trinity/index.html

The ABC's of Nuclear Science – an oddly named but thorough and useful site from Lawrence Berkeley National Laboratory.
http://www.lbl.gov/abc/

Stellar nucleosynthesis

They Came from Outer Space – his website discusses the creation of heavy elements during a supernova event.
http://www.astrocentral.co.uk/stardust.html

Heavy Metal Stars – this news piece from Spaceflight Now describes the slow process by which heavy elements are created in living stars.
http://spaceflightnow.com/news/n0108/30heavy/

Georges-Henri Lemaitre: Father of the Big Bang – from About.com.
http://space.about.com/cs/astronomerbios/a/lemaitrebio.htm

Discovery of radioactivity

Discovery of Radioactivity – a historical narrative or Becquerel's investigations, from the ChemTeam at Diamond Bar High School.
http://dbhs.wvusd.k12.ca.us/webdocs/Radioactivity/Disc-of-Radioactivity.html.

Transmutation

Rutherford – site dedicated to Ernest Rutherford's life and work, created by John Campbell at the University of Canterbury, Christchurch, New Zealand.
http://www.rutherford.org.nz/

Artificial radioactivity

The Nobel Prize in Chemistry 1935 – the lives and work of Frédéric Joliot and Irène Joliot-Curie, from the Nobel Foundation
http://nobelprize.org/nobel_prizes/chemistry/laureates/1935/index.html

Nuclear fission

The Discovery of Fission – from Moments of Discovery, a detailed narrative of the fission story, with audio clips of the key scientists involved.
http://www.aip.org/history/mod/fission/fission1/01.html

Transuranic elements

Glen Seaborg: His Life and Contributions – comprehensive site from the Lawrence Berkeley National Laboratory.
http://isswprod.lbl.gov/Seaborg/

Material Data Safety Sheets: Passports to Safety?

Background Information

Introduction and General Information about MSDSs

The site http://www.ilpi.com/msds/ contains a list of more than 100 links to websites that provide MSDS (or their equivalent) information. Most of these sites can be accessed for free. The sites are annotated to help you choose the site best suited for your needs. Other sites are listed in the "**Web Sites for Additional Information**", but most are not as extensive as this one.

MSDSs were required for the first time as a result of the Occupational Safety and Health Administration (OSHA) law passed in 1983. In a paper he wrote to the American Chemical Society's 191st National Meeting, Samuel Aaron Kaplan says, in part,

> "…Finally, on Friday, November 25, 1983, in Rules and Regulations of the Federal Register, Volume 48, Number 228, OSHA issued its final regulations. Under this ruling, MSDS's …were required for all shipments of hazardous chemicals leaving the manufacturers work place and from all importers of such on all shipments by November, 1985. Distributors and employers were to comply as of that same date. All employers will be in compliance with all provisions of this section including initial training requirements for all current employees by May 25, 1986."

Although OSHA requires MSDS's for all hazardous substances, it does not specify the format the MSDS should take. There are two major formats of the MSDS that are widely used: one, recognized as the OSHA format, and the ANSI (American National Standards Institute) format. The OSHA format contains the eight main components of the MSDS requirement, while the ANSI format contains all the required OSHA information, plus other useful information, a total of sixteen different sections. The OSHA format contains the minimum information needed to satisfy the OSHA Hazards Communications Standards (see list, below). While the OSHA requirements allow the information to be in almost any order, the ANSI format is a specified sequence of the sixteen sections. Many of the components of the two formats overlap, and OSHA now recommends using the ANSI format, although it does not mandate this format as that requirement would require federal legislation. Most new MSDSs issued today are in the ANSI format, and several other groups recommend using the ANSI format. See http://www.ilpi.com/msds/ref/ansi.html for more information.

The OSHA MSDS requires that the form contain the following components: Identification of the substance, as listed on product label, followed by

I. Manufacturer's Name and Pertinent Information
II. Hazardous Ingredients/Identity Information
III. Physical/Chemical Characteristics
IV. Fire and Explosion Hazard Date
V. Reactivity Data
VI. Health Hazard Data

VII. Precautions for Safe Handling and Use
VIII. Control Measures

The topics listed below, taken from the Cornell MSDS web site (http://msds.ehs.cornell.edu/msdssrch.asp), are the major components of the ANSI format MSDS.

Section 1 - Product and Company Identification	Section 9 - Physical & Chemical Properties
Section 2 – Composition/Information on Ingredients	Section 10 - Stability & Reactivity Data
Section 3 - Hazards Identification Including Emergency Overview	Section 11 - Toxicological Information
Section 4 - First Aid Measures	Section 12 - Ecological Information
Section 5 - Fire Fighting Measures	Section 13 - Disposal Considerations
Section 6 - Accidental Release Measures	Section 14 - MSDS Transport Information
Section 7 - Handling and Storage	Section 15 - Regulatory Information
Section 8 - Exposure Controls & Personal Protection	Section 16 - Other Information

Note that the actual structure of the identified substance is not included in the MSDS form. Section 9, Physical and Chemical Properties, gives information like melting and boiling points, solubility, decomposition temperature, etc., but that section does not contain the structure of the substance (although it does give molecular formula and molecular weight – their term, not ours). From a chemistry teacher's perspective, not giving the structure is one shortcoming of this MSDS format. (This information is also omitted from the other MSDS formats.)

Yet a third format for MSDS sheets is the Workplace Hazardous Material Information System (WHMIS) format. This system seems to be closer to the m9inimal OSHA requirements than the more thorough ANSI content. For more information on this format, see this text at http://www.healthandsafetycentre.org/sc/resources/publications/HStopics/whmis.pdf.

Although the actual *ChemMatters* article focuses on the inconsistencies contained in MSDSs, the form itself can offer lots of "teaching moments" for chemistry classes.

More on hazards

There are two major classifications of hazards: chemical and physical.

- Chemical hazards involve flammability, corrosivity, toxicity and reactivity. For more information on these hazards, see pages 6-12 of the American Chemical Society book referenced in the MSDS article, *Chemical Safety for Teachers and Their Supervisors, Grades 7-12*, found at http://membership.acs.org/c/ccs/pubs/Chemical_Safety_Manual.pdf.

- Physical hazards (page 12 of the Chemical Safety book) include slipperiness, radiation, and very low temperatures resulting in freeze burns (dry ice, for example). Physical hazards unrelated to a particular substance are all those teachers typically try to avoid/prevent in the lab: loose clothing or long hair, horseplay, still-lit but unattended Bunsen burners, etc.

More on triclass dry chemical fire extinguishers

Triclass fire extinguishers are also known as ABC extinguishers. They can be used on any of the three classes of fires – A, B, or C. “A” type fires are those involving paper, trash and cloth or rags. “B” type fires involve flammable liquids, such as gasoline, butane, or alcohols (think, alcohol burners). “C” type fires are electrical fires, as in electrical boxes or electrical cords. ABC dry powder extinguishers primarily use ammonium dihydrogen phosphate (fire extinguisher companies call it monoammonium phosphate), possibly including ammonium sulfate, magnesium aluminum silicate, and silicon dioxide. Information in this section was taken from http://www.imperialinc.com/msds0038940.shtml and http://www.ilpi.com/safety/extinguishers.html.

More on chemical splash goggles

Although this is not the main focus of this article, teachers are often confused about which eye protection is most appropriate for their students. Most laboratory glasses or goggles do conform (and **all** should conform) to the American National Standards Institute ANSI Z87 code for impact resistance. This code should be printed directly on the goggles if they meet the ANSI standard. According to the American Chemical Society book referenced in the article, *Chemical Safety for Teachers and Their Supervisors, Grades 7-12*, there are several different types of safety **glasses** that meet this standard, but do **not** provide sufficient splash protection for the eyes in a chemistry laboratory setting. These glasses, types A, B, C, and D, all provide protection from flying debris. Types B, C, and D provide side shielding of some sort to also protect the eyes from flying debris from the side. Even with this shielding, however, none of these provide sufficient protection from chemicals splashing into the eyes from the side – or even the front – of the face. The authors differentiate between safety glasses and safety goggles.

They state, “There are two types of ‘safety goggles’, types G and H, with no ventilation and with indirect ventilation, respectively. Only these two types are suitable for eye protection where chemicals are used and handled. Both types G and H are equipped with flexible edging so that they fit against the skin and thus protect from both flying fragments and flying splashes of liquid from all directions. Make sure that the type G or H safety goggles you and your students use are marked ‘Z87’.”

Thus it would seem that these authors believe that only safety **goggles**, and **not** safety **glasses**, are the appropriate eyewear for students handling chemicals in a chemistry laboratory. They state again on page 17 in their recommended safety checklist, “Always wear only ANSI Z87-approved safety goggles, type G or H.”

For a fairly detailed discussion of what the ANSI standards for eye safety mean for you and your students, see Flinn Scientific’s “Goggle Safety” page at http://www.flinnsci.com/Sections/Safety/eyeSafety/goggle.asp

More on the book, *Chemical Safety for Teachers and Their Supervisors, Grades 7-12*

To reference this ACS publication online, go to http://membership.acs.org/c/ccs/pub_1.htm There you can either order a copy free, or order multiple copies for $2.50 each, or click to go to a free pdf version of the booklet. Or go directly to the pdf file at http://membership.acs.org/c/ccs/pubs/Chemical_Safety_Manual.pdf

More on OSHA's hazards communications information

OSHA Report- Hazard Communication in the 21st Century Workplace, March 2004: http://www.osha.gov/dsg/hazcom/finalmsdsreport.html This site gives the complete story of OSHA's work in communicating hazards involved in the chemical industry, including a history of the Hazards Communications.

In an appendix toward the end of the information at this site, in a section titled, **Literature Addressing MSDS Quality**, the site cites a small number of studies that show that workers in the chemical industry (and outside that industry) don't fully understand MSDS documents. This section also cites 11 brief stories highlighting accidents resulting in injuries in the workplace that involved either incorrect or insufficient information on MSDSs that either directly or indirectly caused the incident. References to the actual incident reports are given. These are part of a study done jointly by the EPA and OSHA to test the accuracy and comprehensibility of MSDS documents.

OSHA's hazards communication site: http://www.osha.gov/SLTC/hazardcommunications/index.html This site is a portal to all the hazards communication materials OSHA offers. It also links to the Society for Chemical Hazard Communication and other non-OSHA technical sites

More on the history of MSDSs

The history of MSDSs goes "…back into the dawn of time…" Check out this web site: http://jrm.phys.ksu.edu/Safety/kaplan.html This site claims the MSDS was "around" long before it was called MSDS.

More on "How to Read an MSDS"

As mentioned above, the MSDS typically includes information about 16 major components:

1) Product and Company Identification
2) Composition/Information on Ingredients
3) Hazards Identification Including Emergency Overview
4) First Aid Measures
5) Fire Fighting Measures
6) Accidental Release Measures
7) Handling and Storage
8) Exposure Controls & Personal Protection
9) Physical & Chemical Properties
10) Stability & Reactivity Data
11) Toxicological Information
12) Ecological Information
13) Disposal Considerations
14) MSDS Transport Information
15) Regulatory Information
16) Other Information

There are a number of web sites that are designed to help you understand the information contained in an MSDS. Several good sources are:

http://muextension.missouri.edu/xplor/agguides/agengin/g01913.htm and http://www.denison.edu/sec-safe/safety/msds/_msds.html.

The MSDS HyperGlossary (MSHG) from Safety Emporium contains more than 500 terms and definitions commonly found on MSDSs and other health and safety documents. This site can be used to better understand the details of MSDSs. The HyperGlossary can be found at http://www.ilpi.com/msds/ref/demystify.html.

This site also provides an MSDS "De-Mystifier", a software tool that allows you to cut and paste an MSDS into their site and the "De-Mystifier" then links all the terms in the MSDS with the terms in its HyperGlossary so that they become hot-linked and can be automatically defined for the reader with a single mouse click. This software can be found at http://www.ilpi.com/msds/ref/demystify.html. The site suggests that students and teachers can make their own safety documents and plug them into the de-mystifier to add clarity to their documents.

The same Safety Emporium site has a 7-part quiz to assess a person's understanding of MSDSs and OSHA's Hazard Communication Standard (HCS). The quiz uses many of the tools on the site to familiarize the user with MSDS and OSHA HCS content as it takes the reader through the quiz. Find the quiz at http://www.ilpi.com/msds/quiz/part1.html.

More on supplements to MSDSs – "International Chemical Safety Cards"

Although this item was not mentioned in the article, these cards may be of interest to you and your students. International Chemical Safety Cards have been developed by the International Programme on Chemical Safety, and they have been adapted to the US workforce by NIOSH, the National Institute for Occupational Safety and Health. They are an attempt to interpret the information found on MSDSs in a way that is more comprehensible to workers, rather than just to scientists and engineers in the field. OSHA and EPA joint studies have shown that the information in MSDSs is understandable by only a small percentage of the people for whom they are targeted. The following information was taken from http://www.cdc.gov/niosh/ipcs/ipcscard.html

INTERNATIONAL COUNCIL OF CHEMICAL ASSOCIATIONS (ICCA) Headings of Material Safety Data Sheets	**INTERNATIONAL PROGRAMME ON CHEMICAL SAFETY (IPCS)** Headings of International Chemical Safety Cards
1. Chemical product identification, and Company identification	1. Chemical identification
2. Composition/Information on ingredients	2. Composition/formula
3. Hazards identification	3. Hazard identification from fire and explosion, and from exposure by inhalation, skin, eyes and ingestion Prevention measures (with personal protective equipment)

4. First-aid measures	First-aid measures
5. Fire-fighting measures	Fire-fighting measures
6. Accidental release measures	4. Spillage, disposal
7. Handling and storage	5. Storage 6. Packaging, labelling & transport
8. Exposure controls/Personal measures	See 3. above
	7. Important data:
See 15. below	Occupational exposure limits
9. Physical & chemical properties	See 8. below
10. Stability & reactivity	Physical & chemical dangers
11. Toxicological information	Routes of exposure Effects of short- and long-term exposure
See 9. above	8. Physical properties
12. Ecological information	9. Environmental data
13. Disposal considerations	See 4. above
14. Transport information	See 6. above
15. Regulatory information	See 7. above
	10. Notes
16. Other information	11. Additional information

As you can see from the side-by-side comparison of categories of information above, there are close similarities between MSDSs and ICSCs. It should be noted, however, that MSDSs and the ICSCs are not identical, either in content or intent. The MSDS, is usually much more technically complex and frequently too extensive for use by workers on the job. ICSCs, on the other hand, are simpler and more concise. The ISCS is not meant to replace the MSDS, but is rather designed to be used by workers directly to communicate information on the nature of specific chemicals and the risks they pose to the worker.

To compare the two: here, for example, are the MSDS and the ICSC for mercury:
MSDS (from the J.T. Baker Chemical company:
http://www.jtbaker.com/msds/englishhtml/m1599.htm
ICSC (from NIOSH): http://www.cdc.gov/niosh/ipcsneng/neng0056.html

The ICSC might be a good place to start class discussion of the hazard and safety information available for individual substances.

Connections to Chemistry Concepts

1. Chemical safety – this article gives some credibility to all the safety rules you give students; it's not just their mean old teacher who insists they behave safely.

2. Chemical reactions – picking the right MSDSs for students to investigate could give them some insights into the reactions chemicals might undergo if given the opportunity
3. Physical and chemical properties – MSDSs might give students an insight into what information constitutes a chemical property and a physical property, and the differences between the two types of properties.
4. Periodicity – students could access MSDSs for each alkali metal, for example, to see the reactivity of each and note that they are very similar.

Possible Student Misconceptions

1. **"MSDSs give all the accurate chemical hazards – and remedies – for every chemical."** The quality of information contained in MSDSs varies greatly. Presently there is no one agency responsible for correlating that information, although OSHA is taking an active role in accomplishing this task.
2. **"MSDSs don't affect me – they are only for the chemical industry."** OSHA regulations affect almost all public and private schools. And students, like workers, are entitled to know the hazards involved with the chemicals they're handling.
3. **"All the MSDSs for one chemical are alike, no matter who prepares the sheet."** MSDSs vary widely in their form and content. Compare the following MSDS sheets, all for sodium chloride, table salt: http://www.flinnsci.com/Documents/MSDS/S/SodChide.pdf, from Flinn Scientific, https://www2.carolina.com/webapp/wcs/stores/servlet/msds/888880.pdf from Carolina Scientific, and http://msds.ehs.cornell.edu/msds/siri/files/cgk/cgkvh.html, from Fisher Scientific
4. **"OSHA oversees the production of all MSDSs, so they should all be the same."** Until 2004, no oversight entity existed to check the validity of MSDS sheets.

Demonstrations and Lessons

1. PBS has a 4-day health/chemistry lesson for high school students on chemical hazards in our environment, focusing on chemicals that have been in our environment for a long time, and which have only recently been tested and found to be potentially harmful. The lesson includes viewing selected video clips from the PBS video called "Trade Secrets", from the NOW Series with Bill Moyer. The video must be purchased (unless your library or you already has a copy) from PBS for $29.95 at http://www.shoppbs.org/product/index.jsp?productId=2407949&cp&keywords=Trade+Secrets&y=5&searchId=5711466138&x=38&parentPage=search.
The lesson can be found at http://www.pbs.org/tradesecrets/classroom/health_lesson2.html. After students view clips from the video and discuss their reactions to that, they are assigned to be members of various teams to do research on phthalates in the environment. Teams include medical researchers, people from industry, people from government agencies, citizens' group members, and politicians. The teams then share their information and their views with the other groups.

2. Another lesson for high school students taken from the same PBS video, "Trade Secrets", deals with chemical exposure in students' own environment, especially related to children. Students identify chemical hazards in their own environment, categorize those hazards, and try to find alternatives to the chemicals. They learn from the video why children are so much more at risk to chemical exposure than are adults. This in turn helps them understand the need for vigilance where chemical hazards are concerned. The background reading can be viewed at http://www.pbs.org/tradesecrets/problem/children.html.
3. A lesson designed for middle school level students relating commercial products' contents and their labels to MSDS information can be found at http://www.uwsp.edu/chemistry/polyed/pdf/exercises/label.pdf. The pdf seems to be a draft, as it has many formatting errors. It probably needs to be retyped, but cutting and pasting into a word processing document should be fairly easy. The activity could be upgraded to high school level with proper questioning.
4. A lesson designed to allow students to review chemistry and biochemistry information via real data related to the article, "A Whiff of Danger: Synthetic Musks may Encourage Toxic Bioaccumulation" can be found at http://www.ehponline.org/science-ed/2005/whiff.pdf. The lesson is part of the National Institute of Health Sciences (NIEHS) Community Outreach and Education Program. The self-contained lesson includes student handouts and the website for the above-referenced article, from EHP, *Environmental Health Perspectives*, a monthly peer-reviewed journal on environment and human health. The journal is free online The musk article can be found at http://www.ehponline.org/docs/2005/113-1/ss.html. The lesson is aimed at 11th – 12th grade chemistry students.
5. Another NIEHS, EHP lesson, "Great Lakes – Make the Human Health Connection", can be accessed at http://www.ehponline.org/science-ed/2005/greatlake.pdf. This lesson is designed primarily for grades 10 – 12 biology and health and environment students. It focuses on 4 pollutants found in the Great Lakes –their sources, health effects, possible routes of exposure, and policies designed to minimize exposure.
6. This is not really a lesson, so much as an assignment. The assignment could be given to students requiring that they obtain their own set of MSDSs (from the web sources you provided from this TG) for a specific lab experiment (assigned by you during the year), and you could provide a list of specific items you want to see them summarize from those sheets. Items could include: physical properties of each, chemical properties, hazards they might face as they do the experiment, and potential hazards they might develop later (hopefully, none). I got the general idea from a general organic college course at http://www.mc.maricopa.edu/dept/d43/chm/Giles/Syllabi/236lab_intro.htm
7. After discussing in class the rationale for MSDSs, and after studying the content of an MSDS, you might want to pose to your students the following questions: "How might an employer use the MSDS to make a safer workplace for his employees?" "How might an employer use the MSDS to avoid worker exposure altogether?"
8. A brief lesson which incorporates general lab safety in the classroom with understanding the content of MSDSs can be found at http://www.nasaexplores.com/show_912_student_st.php?id=030108104806. This site contains the student version, and at the bottom of this page you can click to go to the teacher version for ideas about which chemicals to suggest.

9. A paper-and-pencil activity involving MSDSs, titled "Avoiding Chemical Warfare" can be found at http://www.uwsp.edu/chemistry/polyed/pdf/exercises/chem_warfare.pdf. The title seems to refer to what might happen if two household chemicals were mixed.
10. After a lesson involving MSDSs, you might send your students to the computer lab and access the Safety Emporium OSHA and MSDS quiz site at http://www.ilpi.com/msds/quiz/part1.html to assess their comprehension level.

Student Projects:

1. Class discussion about MSDSs and chemical hazards may trigger students desire to research the "really bad" chemicals in our environment. The Environmental Protection Agency (EPA) maintains a list of 31 Priority Chemicals – the "bad guys" – on which it focuses its efforts through EPA's National Partnership for Environmental Priorities (NPEP). NPEP works to reduce these 31 priority chemicals "…found in our nation's products and wastes by finding solutions that eliminate or substantially reduce the use of Priority Chemicals in production or on recovering or recycling these chemicals where they cannot easily be eliminated or reduced at the source." Their website at http://www.epa.gov/epaoswer/hazwaste/minimize/chemlist.htm might be a good place to start students searching for the reasons these 31 chemicals <u>need</u> to be reduced or recovered or recycled from our environment. The fact sheets the EPA provides at this site sometimes don't give enough information to actually tell students what the substance is. (Fluorene, for example is merely listed as an HAP, without giving its actual chemical name or formula.) MSDSs will have the information they need to do, or at least begin, their research.
2. Another possible project involving those bad chemicals might be to research how such a list evolves over time. The ASTDR's CERCLA list (See Websites for Additional Information for more on CERCLA.) is available for each odd-numbered year from 1997 to 2005. Once students have seen which chemicals have been added to or deleted from the list, they could then research why these changes may have occurred. The lists can be accessed at http://www.atsdr.cdc.gov/cercla/#bookmark01.
3. Students may be interested in knowing what hazardous chemicals may be present in the cleaning materials used throughout their home. Then they can determine how to go about "greening their cleaning" – using safer alternatives. They can then prepare and present a report to classmates to effect such improvements. For a list of websites relevant to this topic, see http://www.greeningschools.org/docs/HouseholdChemicalsandAlternatives.pdf

Anticipating Student Questions

1. **"Why do <u>we</u> need to be concerned with MSDSs?"** Students are exposed to chemicals in the laboratory, and awareness of the hazards listed on the MSDS might encourage them to be more careful in their conduct in the laboratory.
2. **"Help! There's so much information on this MSDS. How do I interpret all the information?"** See the section above, **More on "How to Read an MSDS"**

Websites for Additional Information

More Sites with Links to Other MSDS Sites

The Vermont Safety Information Resources, Inc. (SIRI) web site gives http://siri.org/msds/, and the actual SIRI MSDS site at http://www2.hazard.com/msds/index.php provides a source of MSDSs from many different chemical manufacturers, as well as chemical toxicity data from other sites.

MSDSSEARCH is another website that provides links to other MSDS databases. It can be found at http://www.msdssearch.com/DBLinksN.htm.

Flinn Scientific Company has MSDSs available online for all the chemicals they sell (over 1300 MSDSs at present). (Other companies have these also.) Flinn's MSDSs have been written specifically for high school and community college teachers and students. For these MSDSs go to http://www.flinnsci.com/search_MSDS.asp You can probably go to the website of any of your favorite chemical suppliers and find similar MSDSs. On the Carolina website, for instance, you must enter their online catalog and then click on a letter of the alphabet to get a list of the chemicals beginning with that letter. Then when you click on a specific chemical, you get that chemical and then you can click on its MSDS. I was unable to type in the name of a chemical with the term" "MSDS" and go directly to its MSDS on the Carolina site. On the Flinn website home page, there is a "Free MSDS" button at the bottom of the page. Click on it and there is a search bar where you can type in the name of the chemical you seek and get its MSDS immediately. (Or just use the website locator cited above to go to the MSDS page directly.)

www.MSDS.com is a specific website for finding MSDSs for 2.5 million chemicals. It is rather commercial, though, as it identifies companies that provide that chemical. The MSDSs on this site are in pdf format, so they are downloadable and printable. (I was unable to download the pdf files from this site.)

Other sites

Another site to help you and students understand the information found in an MSDS can be found at http://ccinfoweb.ccohs.ca/help/msds/msdsINTGUIDE.html.

The ASTDR, the Agency for Toxic Substances and Disease Registry, also maintains a priority list of hazardous substances that could be used for the research report proposed in the **Student Projects** section of this Teachers Guide. This list, the CERCLA (Comprehensive Environmental Response, Compensation and Liability Act) list, contains 275 chemicals! The list is based not necessarily on substances which are the most toxic. From their website: "It should be noted that this priority list is not a list of "most toxic" substances, but rather a prioritization of substances based on a combination of their frequency, toxicity, and potential for human exposure at NPL sites." The 2005 list (only updated every other year) can be found at http://www.atsdr.cdc.gov/cercla/05list.html.

For a website dealing with locating environmental laws and regulations online, visit http://www.wmrc.uiuc.edu/main_sections/info_services/library_docs/other_pubs/legal_regulatory_info.pdf

*** (NOTE: articles from past issues of ChemMatters can be accessed from a CD that is available from the American Chemical Society for $25. The CD contains all ChemMatter issues from 1983 to 2003. Purchase information can be found online at http://chemistry.org/chemmatters/cd3.html**