



December 2006 Teacher's Guide

About the Guide	3
Student Questions	4
Answers to Student Questions	5
Puzzle: Chemistry Drop-outs	7
Answers to Puzzle: Chemistry Drop-outs	8
Content Reading Guide	9
National Science Education Content Standard Addressed	9
Anticipation Guides	10
Corn—the A'maiz'ing Grain	10
Sticky Situations: the Wonders of Glue	11
Unusual Sunken Treasure	12
Thermometers	13
The Race for Iodine	14
ChemMatters December 2006 Reading Strategies	15
Corn—The A'maiz'ing Grain	16
Sticky Situations: The Wonders of Glue	17
Unusual Sunken Treasure	18
Thermometers	19
The Race for Iodine	20
Corn—the A'maiz'ing Grain	21
Background Information	21
Connections to Chemistry Concepts	25
Possible Student Misconceptions	26
Demonstrations and Lessons	27
Suggestions for Student Projects	27
Anticipating Student Questions	28
Websites for additional Information	29
Sticky Situations: The Wonders of Glue	31
Background Information	31
Connections to Chemistry Concepts	36
Possible Student Misconceptions	36
Demonstrations and Lessons	36
Student Projects	37
Anticipating Student Questions	37
Websites for additional Information	37
Unusual Sunken Treasure	39
Background Information	39
Connections to Chemistry Concepts	41
Possible Student Misconceptions	42
Demonstrations and Lessons	42
Student Projects	43
Anticipating Student Questions	44
Websites for Additional Information	44
Thermometers	45
Background Information	45
Connections to Chemistry Concepts	51

Possible Student Misconceptions.....	51
Demonstrations and Lessons.....	52
Suggestions for Student Projects.....	53
Anticipating Student Questions.....	53
Websites for additional Information.....	53
The Race for Iodine	56
Background Information.....	56
Connections to Chemistry Concepts.....	61
Possible Student Misconceptions.....	61
Demonstrations and Lessons.....	61
Student Projects.....	62
Anticipating Student Questions.....	62
Websites for additional Information.....	63

About the Guide

William Bleam, Donald McKinney, Mark Michalovic, and Ronald Tempest, TG Editors, created the teacher's guide article material.

bbleam@verizon.net

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

coopers@hendry.k12.fl.us

Terri Taylor, CM Administrative Editor, and Carl Heltzel, Editor, coordinated production and prepared the MS Word and PDF versions of the Guide.

chemmatters@acs.org

David Olney created the puzzle. djolney@rcn.com

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 *ChemMatters* issues from 1983 to 2003.

The 2006 *ChemMatters* Print Index can be purchased for \$12 and covers all issues from 1983 to 2006.

Purchase information can be found online at:

<http://chemistry.org/chemmatters/cd3.html>

Student Questions

Corn-the A'maiz'ing Grain

1. What is the meaning of "Frankenstein" in terms of science?
2. What is meant by "Franken-food"?
3. How are gene changes made in the DNA of plants?
4. What is meant by the term "pharming"?
5. What is the difference in composition between corn syrup and high fructose corn syrup (HFCS)?
6. What is meant by E85?

Sticky Situations: the Wonders of Glue

1. What parts of fish are used to make glues?
2. What is the chemical name of the family of compounds that are found in Superglue?
3. Why might you *not* want a glue to set instantly?
4. What metal is found in mussel glue?
5. Why doesn't Superglue stick to the inside of its own tube?
6. What kind of intermolecular forces allow a gecko's feet to "stick" to walls and ceilings?
7. What kind of polymer is found in Gorilla Glue?

Unusual Sunken Treasure

1. Which type of alcohol on board the Jönköping turned out to be of no value to the salvage crew?
2. Which gas law refers to the solubility of a gas changing with the pressure over the solution?
3. Define still wine.
4. List two examples of nucleation sites.
5. Name two types of quality hardwoods found underwater that may no longer be available to woodworkers today.
6. How do anaerobic bacteria help to improve the quality of submerged wood?

Thermometers

1. Why would a person feel cold in the thermosphere?
2. What was the boiling point of water as measured using the Römer temperature scale?
3. What temperature did Fahrenheit use for body temperature?
4. On the initial scale that Celsius set up, what was the freezing point of water?
5. All bulb thermometers operate on what principle in science?
6. Why is the infrared thermometer unique?

The Race for Iodine

1. Name three elements discovered by Humphry Davy.
2. What is the chemical name for laughing gas?
3. Who discovered the gas law known as Charles' Law?
4. What does the Greek word "*iodē*" mean?
5. What was the prevailing definition of an element in the early 1800's?
6. Who published the first paper naming iodine an element?

Answers to Student Questions

Corn-the A'maiz'ing Grain

1. What is the meaning of "Frankenstein" in terms of science?
Frankenstein is a synonym for "science out of control".
2. What is meant by "Franken-food"?
Franken-food is a negative term used by critics of genetically modified plants and their food derivatives, implying reckless and unconcerned scientific research that produces "monster" biological creations.
3. How are gene changes made in the DNA of plants?
Parts of the nuclear genetic material, DNA, that is found in the cells of living things, is cut at specific places using special enzymes called restrictive enzymes (produced by bacteria that use them for crippling the nucleic acids of viruses). The fragments of DNA are attached to "bullets" of certain metals such as gold or tungsten and forced into the DNA of plant cells, adding some new characteristic to that plant.
4. What is meant by the term "pharming"?
"Pharming is the contraction of two words, pharmaceuticals or drugs and farming. Plants are modified to produce specific chemicals useful in the pharmaceutical industry, such as vaccines against specific diseases including hepatitis B, measles, polio, and various types of diarrhea.
5. What is the difference in composition between corn syrup and high fructose corn syrup (HFCS)?
Corn syrup contains more glucose than fructose; glucose is not as sweet as fructose. Through concentrating processes, the percent of fructose in corn syrup is increased, compared with glucose, hence the term High Fructose Corn Syrup (HFCS). HFCS, with a higher proportion of fructose is sweeter than regular corn syrup.
6. What is meant by E85?
The E stands for ethanol and the 85 represents the % by volume of the alcohol when mixed with gasoline.

Sticky Situations: the Wonders of Glue

1. What parts of fish are used to make glues?
Glues can be made from the skin, bones, and swim bladders of fish.
2. What is the chemical name of the family of compounds that are found in Superglue?
Cyanoacrylates are found in Superglue.
3. Why might you *not* want a glue to set instantly?
Sometimes you have to move around and adjust the positions of objects that you are gluing together after they have been glued.
4. What metal is found in mussel glue?
Iron is found in mussel glue.
5. Why doesn't Superglue stick to the inside of its own tube?
Acidic stabilizers are added to Superglue to keep it from setting until it is outside of the tube and exposed to moisture in the air.
6. What kind of intermolecular forces allow a gecko's feet to "stick" to walls and ceilings?
Van der Waals forces allow gecko feet to stick to surfaces.
7. What kind of polymer is found in Gorilla Glue?
Gorilla Glue contains polyurethanes.

Unusual Sunken Treasure

1. Which type of alcohol on board the Jönköping turned out to be of no value to the salvage crew?
The cognac
2. Which gas law refers to the solubility of a gas changing with the pressure over the solution?
Henry's Law
3. Define still wine.
Still wine is wine with no fizz.
4. List two examples of nucleation sites.
Imperfections in the glass bottle, dust, or other deposits are all examples of nucleation sites.
5. Name two types of quality hardwoods found underwater that may no longer be available to woodworkers today.
Red birch, red oak, hard maple, beech, and white pine
6. How do anaerobic bacteria help to improve the quality of submerged wood?
The anaerobic bacteria eat the hemicellulose in the cell walls, allowing minerals from the water to enter the cells and crystallize there.

Thermometers

1. Why would a person feel cold in the thermosphere?
Because there are so few molecules in the thermosphere
2. What was the boiling point of water as measured using the Römer temperature scale?
60°
3. What temperature did Fahrenheit use for body temperature?
96°
4. On the initial scale that Celsius set up, what was the freezing point of water?
100°
5. All bulb thermometers operate on what principle in science?
Thermal expansion.
6. Why is the infrared thermometer unique?
It can measure temperatures at a distance.

The Race for Iodine

1. Name three elements discovered by Humphry Davy.
Any three from: sodium, potassium, magnesium, calcium, strontium, and barium
2. What is the chemical name for laughing gas?
Nitrous oxide
3. Who discovered the gas law known as Charles' Law?
Joseph-Louis Gay-Lussac
4. What does the Greek word "iode" mean?
Purple
5. What was the prevailing definition of an element in the early 1800's?
A substance that couldn't be broken down into simpler substances
6. Who published the first paper naming iodine an element?
Gay-Lussac.

Puzzle: Chemistry Drop-outs

Below are eleven clues that identify eleven famous chemists, men and women. To make things interesting, we have “dropped out” of each clue two letters, replacing them with an asterisk. Those missing letters are the letters that make up the chemist’s initials, (but not necessarily in order). A few clues have three asterisks, indicating a hyphenated name.

For example, consider this clue:

“She was the wife and valued col*eague of “the f*ther of *odern chemistry”.

The missing letters are L,A, and M. The clue identifies Marie-Anne Lavoisier.

We hope you don’t drop out of tackling this puzzle!

1. His *cid-ba*e theory preceded that of Bronsted, Lowry and G.N. Lewis.
2. Her X-*ay studies helped Watson and Crick *ormulate their model of DNA.
3. He developed a catalytic process to synthesize ammonia *rom the elements N and *.
4. She was co-discoverer (with Fritz Hahn) of the *echanism for nuc*ear fission.
5. He was the winner of TWO Nobe* *rizes although one wasn’t for Chemistry!
6. He developed (at Oberlin College) a c*eap way to extra*t Al from Bauxite.
7. The given name of the chemist *hose temperature scale sets the boiling point of wa*er to be 373.15 degrees
8. She shared a Nobel Prize in 1935 for pro*e*ts in artific*al transmutations of elements.
(Extra hint: her mother was a famous chemist too!)
9. His *as *aw pro*ects that $V_1/n_1 = V_2 / n_2$ for gases at the same T and P.
10. This influentia* chemist made important contributions to acid-base theory, bondin*, and thermodynamics.
11. His X-ray studies led *im to the concept of atomic nu*ber.

Answers to Puzzle: Chemistry Drop-outs

Answers:

1. Svante Arrhenius
2. Rosalind Franklin
3. Fritz Haber
4. Lise Meitner
5. Linus Pauling
6. Charles Hall
7. William Thompson (Lord Kelvin)
8. Irene Joliot-Curie, daughter of Marie Curie
9. Joseph Gay-Lussac
10. Gilbert (Newton) Lewis
11. Henry Moseley

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	Thermo- meters	The Race for Iodine	Unusual Sunken Treasure	Corn—The A”maiz”ing Grain	Sticky Situations
Science as Inquiry Standard A: about scientific inquiry.	✓	✓	✓	✓	✓
Physical Science Standard B: of the structure and properties of matter.	✓	✓	✓	✓	✓
Physical Science Standard B: of chemical reactions.		✓	✓	✓	✓
Physical Science Standard B: of motions and forces.					✓
Physical Science Standard B: of interaction of energy & matter.	✓			✓	
Life Science Standard C: of matter, energy, and organization in living systems.				✓	✓
Science and Technology Standard E: about science and technology.	✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of personal and community health.	✓	✓		✓	✓
Science in Personal and Social Perspectives Standard F: of 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.

Corn-the A'maiz'ing Grain

Me	Text	Statement
		1. “Corn” refers to the same grain all over the world.
		2. A meal of corn, beans, and squash provides all the amino acids that human beings need to be healthy.
		3. Indirectly, the average American eats about two pounds of corn daily.
		4. In the United States, genetically modified foods are always labeled.
		5. Genetic modification requires knowledge of chemistry to cut and paste DNA molecules with restriction enzymes.
		6. All new cars in the United States can use a fuel mix of 15% ethanol and 85% gasoline.
		7. Every energy conversion consumes more raw energy than is produced in the form of fuel.
		8. Corn syrup is sweeter than sucrose.

Sticky Situations: the Wonders of Glue

Me	Text	Statement
		1. Mussels use iron from the surrounding water to help form a cross-linked framework so that they can adhere to rocks.
		2. Fish glue was patented in the 1950s.
		3. Collagen obtained from hooves, hides, and bones of animals is broken down into a glue that is used in woodworking.
		4. Geckos secrete a gluey substance to help them stick to vertical surfaces.
		5. A glue similar to Superglue was first used on battle wounds in the Iraq War.
		6. Superglue requires water to cure quickly.
		7. Superglue and Gorilla Glue contain the same kind of polymers.
		8. Some glues work by transferring electrons, creating opposite charges on different surfaces.

Unusual Sunken Treasure

Me	Text	Statement
		1. The pressure and cold water at the bottom of the Baltic Sea helped preserve the champagne that was on the sunken ship.
		2. Oxygen can react with ethanol, making acetic acid.
		3. The bubbles in champagne are filled with oxygen.
		4. As bubbles rise in a glass of champagne, they contract.
		5. Champagne has more protein than other sparkling beverages.
		6. Lumber being salvaged from the bottom of the Great Lakes has a different chemistry than wood that has not been submerged in water.

Thermometers

Me	Text	Statement
		1. Thermometers measure the heat contained in a substance.
		2. During the 1700s there were almost 35 different temperature scales in use.
		3. Fahrenheit shared how he determined the reference points for his thermometer with other scientists.
		4. The Centigrade and Celsius temperature scales are identical, but Celsius has been the official designation since 1948.
		5. Absolute zero has been attained in a few laboratories in Europe.
		6. Most thermometers, including alcohol and mercury thermometers as well as Galileo's thermometer, work according to the principle that substances expand when heated and contract when cooled.
		7. Infrared thermometers can only be used to determine the surface temperature of objects.
		8. A pop-up timer for a turkey contains the same alloy as a pop-up timer for steak.
		9. NASA helped develop a thermometer that can be swallowed, allowing temperature measurements inside the human body.

The Race for Iodine

Me	Text	Statement
		1. Because of his interest in electricity, Napoleon worked for a while in the lab of Alessandro Volta, the inventor of the battery.
		2. Sodium and potassium were discovered using electricity from a battery.
		3. Gay-Lussac discovered Charles' Law.
		4. Riding in a helium balloon, Gay-Lussac found that air at high altitudes has a different composition than air at sea level.
		5. The name for iodine was derived from the color of its vapor.
		6. Davy and Gay-Lussac knew that all atoms of the same element are the same.
		7. Scientific discoveries are seldom influenced by the world outside the lab.
		8. Humphry Davy and Joseph-Louis Gay-Lussac were great friends even though they were scientific rivals.

ChemMatters December 2006 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

Notes:

“Unusual Sunken Treasure”

Be sure your students know the meaning of the word “adsorbed” before reading, otherwise they may assume it has the same meaning as “absorbed.”

Adsorb: to collect and hold (a gas or liquid) on the surface of a solid.

Absorb: to take in; soak in or up.

Websters II New Riverside Dictionary, revised edition. Houghton Mifflin Co., Boston, New York, 1996.

Corn—The A”maiz”ing Grain

Directions: As you read, complete the chart below to compare genetically modified corn (GMC), ethanol, and high fructose corn syrup (HFCS).

	GMC	Ethanol	HFCS
Uses			
Advantages			
Disadvantages			
How is this substance produced from corn?			

Sticky Situations: The Wonders of Glue

Directions: As you read, complete the chart below that compares different types of glue.

	Uses	Properties	Chemistry involved
Mussel glue			
Fish glue			
Hide glue			
Gecko stickiness			
Superglue			
Gorilla glue			

Unusual Sunken Treasure

Directions: As you read, complete the chart below explaining how each topic is addressed in the reading.

Topic	Describe each term and explain how it relates to the “sunken treasure”
Henry’s law	
Boyle’s law	
Fermentation	
Gas solubility	
Buoyancy	
Anaerobic bacteria	

Thermometers

Directions: In the chart below, compare different the temperature scales described in the article.

	Romer	Fahrenheit	Celsius	Kelvin
Freezing point and how it was determined				
Boiling point and how it was determined				
Interesting facts about or uses of the temperature scale				

Directions: In the chart below, compare and contrast different types of thermometers.

Type of Thermometer	Materials used	Principle of operation	Where used
Bulb			
Bimetallic strip			
Infrared			
Pop ups			
Galilean			

The Race for Iodine

Directions: As you read the article, compare and contrast Davy and Gay-Lussac in the chart below. Record their differences in the top part of the chart and their similarities in the bottom section. Use bullets for each new idea.

Humphry Davy	Joseph-Louis Gay-Lussac
Similarities	

Background Information

This article focuses on corn, including the genetically modified (GM) form as a food source, along with derivative products of corn, such as high fructose corn syrup and ethanol from corn fermentation. The author shows how ubiquitous corn is in products that are consumed daily by Americans. The article is written with a slant by the author which suggests that the concerns of people about GM products are without good scientific evidence. This article provides a good opportunity for students to evaluate the scientific veracity of the major points in the article. As you will notice in the accompanying references for additional information, there are legitimate concerns about the testing and application of GM products.

One of the major concerns has to do with the interaction of these GM plants with the total environment that includes other plants, insects, and soil, as well as farmers/harvesters. In 2003, GM crops were planted in 18 countries on 170 million acres. Besides the insect- and herbicide-resistant plants (soybeans, corn, cotton and canola) that were cultivated, there were rice strains with increased iron and vitamin A to counter chronic malnutrition and dietary deficiencies. There are also sweet potato varieties that resist a virus that could decimate this important food staple in Africa. In addition, plants along with animals are viewed as sources of pharmaceutical precursors or products including vaccines, antibodies, anticoagulants, specific proteins, enzymes and hormones.

The second concern has to do with the many ramifications of GM plant products in the world economy, in particular with the dynamics of agricultural economics. How does the growing and marketing of GM products affect the local farmer, the local, national and international markets. If seeds from GM plants are not able to be planted in the second season, does this make the farmer, particularly those in developing countries, dependent on the company which produced the seed? Farmers in these countries often keep some of the seed for the next season's planting. Another issue related to the production of ethanol from corn is the competition between using this grain for food vs. fermentation into a biofuel. As always, market forces drive the issue in terms of need and price. There are other pathways that limit the use of corn-derived ethanol in favor of food from corn. There are alternatives to using corn for a biofuel such as the cellulosic part of plants as in switchgrass, poplar trees and even the corn stalks themselves (most grain plants have been developed from grass ancestors). Then there are the so-called biodiesel fuels made from oils that, again, can be supplied by a variety of non-grass plants including soybeans and peanuts, as well as palm fruit. But again, the issue is the balance between the use of these plant products for food vs. fuel. The concerns then for the introduction of more productive plants include the effect on the world market of sufficient quantities of food for human consumption. (a recent short article about this issue is found in *Fortune magazine, August 28, 2006; p. 36*)

Another issue in farmer economics is the effect of market price of a particular product. For instance, the recently developed GM cotton that is insect resistant has reduced the cost of growing the crop since less (14%) insecticide is used. With an actual increase in cotton production in China, using insect-resistant cotton crops, the cotton is sold for a lower price that harms farmers who are not using the GM cottonseed. But obviously the choice of higher profits

through increased production and lower costs through reduction in insecticides (and better farmer health) as well as labor input are a double bonus.

There still remain ecological issues that must be studied when GM crops are introduced. For instance, the development of cotton that is insect resistant – in this case to moths whose larval stage is called a boll worm that is found in crops around the world – always has the potential to create insects that are resistant to an insecticide, even one that is biologically produced (deadly crystals from a bacterium) rather than “chemically” produced as with the infamous DDT insecticide. In the case of the insect-resistant cotton, farmers plant some non-insect resistant crops in order to dilute out the insect genes that have evolved as resistant to the GM cotton’s “insecticide”. That is, the insecticide-resistant moth mates with an insect on the non-GM cotton that is not resistant, diluting out the resistant gene in the mixing. Unfortunately, it seems to be a fact that there is still better protection against insects using insecticides along with GM cotton crops rather growing GM crops without spraying. Another issue with spraying of course is the killing of beneficial insects, including those that actually control destructive insect pests. So, reducing insecticide use through the growth of insect-resistant GM plants is desirable. But after ten years, there is a cumulative 100 million global hectares under cultivation without any biologically evolved insecticide-resistant insects.

Another issue in the production of GM plants is the genetic introduction of various allergenic traits, both contained in the food that is consumed as well as plant allergens on the surface that affect the farmer or farm worker who harvests the crop.

An excellent reference that deals with the many important questions about GM issues is found at the WHY files from the University of Wisconsin at:

(http://whyfiles.org/240GM_1/index.php?g=2.txt)

Another reference that deals with the many issues through the written opinions of a collection of experts in the field is found at the PBS website for Frontline, <http://www.pbs.org/wgbh/harvest/>. This site is particularly useful for the teacher as it includes lesson plans and related references, particularly if students are to research the issues and the controversies. It is easy to have undocumented opinions on the ideas behind genetic engineering. Presenting evidence for a particular position is an excellent exercise for students in a science classroom. And the topic of GM foods lends itself very well to engaging students in the activity of searching for documented evidence (and their source!) to support a particular argument or “slant”.

A visual outline of biotechnology – where it comes from as well as what it leads to – is found at the Access Excellence teacher website, <http://www.accessexcellence.org/RC/VL/GG/biotechnology.html>. This site also has a variety of activities, including lab exercises in genetics, along with excellent diagrams for showing genetic transfer techniques involved in producing genetically modified organisms. For instance, cutting genetic material (DNA) using so-called restrictive enzymes is nicely illustrated at the Access Excellence site at <http://www.accessexcellence.org/RC/VL/GG/restriction.html>

Additional references that raise important questions about monitoring of GM crops can be found at the website of the Union of Concerned Scientists

(http://www.ucsusa.org/food_and_environment/genetic_engineering/). Contents at this site include

- Genetic Engineering Basics
- Alternatives to Genetic Engineering
- Risks of Genetic Engineering
- Pharmaceutical & Industrial Crops

- Government Oversight of GE Crops
- Resources (Agricultural Biotechnology on the Web)

Another useful reference along the same lines is the AgBioForum found at <http://www.agbioforum.org/v8n23/v8n23a15-brookes.htm>.

GM product benefits and controversies are summarized at the website of the US Dept. of Energy Office of Science, Biological and Environmental Research (Human Genome Project) at http://www.ornl.gov/sci/techresources/Human_Genome/elsi/gmfood.shtml.

The United Nations has been dealing with the worldwide issues of GM crops. Both the UN's World Health Organization (WHO) and the Food and Agriculture Organization (FAO) have websites that deal with the fundamental ideas behind the development of GM plants as well as the various issues of concern that need monitoring. Twenty questions on genetically modified foods can be found at the WHO site, <http://www.who.int/foodsafety/publications/biotech/20questions/en/ind>.

The FAO site that discusses the potential of biotechnology as well as the cautions to be observed is found at http://www.fao.org/WAICENT/OIS/PRESS_NE/PRESSEENG/2000/p and <http://www.fao.org/biotech/stat.asp>.

High Fructose Corn Syrup presents another interesting science issue for students to investigate. First there is the basic chemistry of sugars – the disaccharide sucrose from cane sugar is a molecule made of two sugars, glucose and fructose, that are linked into one molecule, sucrose. Our bodies split (hydrolyze) the sucrose into the glucose and fructose, using the enzyme, sucrase. The sweetness of sucrose is dependent on the fructose part of the molecule rather than the glucose, which by itself tastes less sweet than fructose. The corn-derived high fructose syrup is a mixture of the separate glucose and fructose molecules. But the mix is produced from the starch of the corn seeds. The starch is essentially a polymer made from glucose molecules. Several enzymes are involved in the hydrolysis of the starch into individual glucose molecules. But then another enzyme, glucose isomerase, changes some of the glucose into fructose. Fructose and glucose differ at the first and second carbon where the double bonded oxygen is found as part of an aldehyde group on carbon one of glucose but is at the second carbon of fructose as a ketone carbonyl group. Otherwise carbons 3-6 are the same in both sugars. The fructose is concentrated in the mix by passing the glucose-fructose combination through a liquid chromatography column. The fructose concentration is now 92%. But this fructose concentration is remixed with glucose to a 55/42 blend of fructose to glucose. Explanations plus references for this manufacturing process are found at http://www.en.wikipedia.org/wiki/High_fructose_corn_syrup.

Additional commentary on the issue of HFCS's role in the overweight problems of Americans is provided by a newspaper article that presents both sides of the issue (<http://www.sfgate.com/cgi-bin/article.cgi?file=chronicle/archive/2004/>). There are clearly a number of interacting factors that contribute to overweight in the population. From the physiological standpoint, a mix of separated fructose and glucose as in HFCS is more readily absorbed in the digestive system than sucrose that requires more time to be enzymatically broken down. Second, fructose that is more readily converted to fat by the liver increases triglycerides (simple lipids) in the bloodstream. And triglycerides are associated with cholesterol production. Third, fructose does not stimulate the production of insulin (from the pancreas) nor the hormone leptin (from fat cells). Both of these chemicals stimulate the brain areas that control appetite. Lack of these chemical signals means appetite is not under control. In addition, some research suggests that fructose does not suppress the production of another hormone, ghrelin, which is responsible for increasing hunger and appetite. Some of these interactions with fructose suggest that weight gain may involve fructose in specific ways, that it is not simply a matter of too many calories from a variety of sources. However, the overall picture receives agreement from different investigators that the major problem is simply people consuming too much refined sugar, regardless of source. A lot of food contains added fructose and consumers do not know it. People should be provided the information on food labels as to how much sugars of various kinds are being added to packaged foods with the percentage of daily value. But will people read the labels?

The cultivation of corn for ethanol production of gasohol is a growing industrial activity, complete with political overtones (Congressional legislation for subsidies to farmers in the Midwest). There are currently two different approaches to the production of ethanol-conversion of cornstarch to sugars and subsequent fermentation and ethanol production from the fermentation of the cellulose in a wide variety of plants, from cornstalks to trees.

Starting with corn, the starch contained in the individual kernels has to be hydrolyzed into separate glucose molecules through either an acidic solution or enzymatic activity. The enzymatic approach is preferred. Once the sugars are freed up, it is a matter of allowing fermentation to take place in essentially anaerobic vats. Yeast organisms that supply the enzymes to convert glucose to ethanol and carbon dioxide (an exothermic reaction, producing the energy for cellular activity) eventually are killed by the rising ethanol concentration that limits the amount of ethanol that can be produced to about 12% by volume. In order to increase the ethanol concentration to something like 95%, distillation is utilized.

The production of cellulosic ethanol depends upon the cellulose that is found in woody plants such as poplar trees and switchgrass. One of the advantages of producing ethanol from cellulose is that the entire operation reduces greenhouse gases. Ethanol fermentation uses fossil fuels to keep the process warm. In cellulosic ethanol production, heat is produced by burning the lignin from the non-fermentable part of the plant that supplies the cellulose. Since the carbon dioxide emitted in the burning of the lignin comes originally from the carbon dioxide absorbed by the plant during its growth, the total carbon dioxide in the atmosphere is more or less unchanged. And the use of cellulose would mean that the competition between corn as fuel and corn as food would be significantly reduced. The goal is to depend less on food-based fuels.

An additional advantage of using something like switchgrass is that it can be grown on marginal lands and does not require pesticides. Corn production also has higher energy costs because it requires fossil fuel-based fertilizers as well as the fuel costs for spreading pesticides and cultivating the corn rows.

A number of articles on the subject of biofuels including biodiesel can be found both in government, academic and journalistic sources. Some of them include the following:

- “The Rise of Renewable Energy”, Daniel M. Kammen; Scientific American, Sept. 2006, pp.84-96 (contains good visual statistics)
- “How to Beat the High Cost of Gasoline Forever”, Fortune magazine, Feb. 06,2006 at <http://cnnmoney.printhis.clickability.com/pt/cpt?action=cpt&title=Ho>
- From the government department of Energy Efficiency and Renewable Energy, “Renewable Diesel Fuel; Biodiesel” at http://www.eere.energy.gov/biomass/renewable_diesel.html
- The US Dept of Energy’s Biomass program gives a good overview of ethanol production from corn and cellulose at http://www.eere.energy.gov/biomass/printable_versions/ethanol.html
- A more extensive treatment of the chemistry and manufacturing steps in ethanol production from a variety of plant materials is found at <http://www.eia.doe.gov/oiaf/analysispaper/biomass.html>
- A realistic evaluation of the economic, environmental, and energetics of ethanol production is found in a short study from the Proceedings of the National Academy of Sciences (PNAS) at <http://www.pnas.org/cgi/content/abstract/103/30/11206?maxtoshow=>
- Three decades of ethanol production in Brazil using sugar cane is found at USA Today archives: http://usatoday.com/money/world2006-03-28-brazil-ethanol-cover_x.html

Connections to Chemistry Concepts

1. Fermentation Equation – $C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$
2. Enzymes – as biological catalysts (protein based), enzymes accelerate the rate of a biochemical reaction and are sensitive to temperature and pH of the system. Enzymes are 1 to 10 million times more efficient than inorganic catalysts. They are highly selective of the substrate medium.
3. Molecular structure – Both starch and cellulose are polymers of one molecule, glucose. Yet their chemical and physical properties differ because of the orientation in space (linkage) of the glucose units. Specific enzymes are required for hydrolysis and dehydration of starch and cellulose.
4. Polymers (starch, cellulose) – As mentioned in #3, starch and cellulose are examples of polymers that are formed from individual units of glucose under enzymatic control in the dehydration reaction. The type of linkage between the glucose units determines if the polymer is cellulose or starch. (Poly)lactic acid is another polymer from starch (corn, sugar beets, wheat). The structural unit (or monomer) is lactic acid, produced by fermentation of dextrose, a sugar processed from starch.
5. Dehydration – This type of reaction involves the removal of a water molecule from two reacting molecules. In the case of starch or cellulose, it is the basis for linking glucose units to form either starch or cellulose. The reverse of dehydration is **hydrolysis** in which water breaks a bond to oxygen. With an enzyme, this is the basis for breaking apart both starch and cellulose molecules into individual glucose units that can then be used in fermentation. Such is the basis for certain plant-derived plastics (e.g., (poly)lactic acid) becoming biodegradable.

6. Alcohols – These organic molecules are important solvents and fuels, including the trihydroxy glycerol that can form larger lipid molecules by reacting with fatty acids. Biologically, fat can be considered a “fuel”.
7. Gasohol – This is a blend of an alcohol, usually ethanol, with gasoline, from 15% by volume to 85%. Because of the size of the alcohol molecule, less energy is produced per molecule in the burning process compared with octane, the major molecule in the mixture, gasoline. However, CO₂ emissions are lower. Depending on the design of the engine fueled by gasohol, there may be lower miles per gallon and reduction in power available in acceleration.
8. Gasoline – This mixture of various chemicals has the hydrocarbon octane as the predominant reactant. Octane is isolated from petroleum by the distillation process, the same as used to concentrate ethanol produced by fermentation.
9. Exothermic Reaction – This type of reaction is basic to fuels. The potential energy of chemical bonds in the reactant fuel such as ethanol exceeds the potential energy of the chemical bonds formed in the products such as carbon dioxide and water. The excess energy becomes heat energy, the driving force behind kinetic energy (mechanical) of a machine. Or, in biological systems, the ‘excess” energy is transferred (bond making) into other molecules as potential energy through enzyme-regulated chemical reactions. The production of ethanol in fermentation (an anaerobic reaction) is an inefficient exothermic reaction (in yeast cells) compared with the “combustion” of glucose in aerobic biochemical systems.
10. Biodiesel – This fuel is a mixture formed with plant derived oils rather than petroleum-based oils. Since the oils are from a renewable source (corn, soybeans), there is unlimited supply. However, the total production of crops for these oils is limited by available land and the competitive needs of these same crops for human and livestock needs. These oils cannot replace petroleum as a diesel fuel source (estimates suggest a maximum of 14% replacement).
11. DNA (Deoxyribonucleic Acid) – This extremely large molecule, found in the nuclear material of living cells, is the information storage unit of all life (except viruses). This molecule depends upon hydrogen bonding in order to have its double helix structure “opened”, after which it is chemically copied to be inserted in new cell nuclei. Portions of DNA that control a particular characteristic are inserted into cells of plants that are being modified or changed, i.e., genetically modified plants (GM). The transfer is often done through certain bacteria that normally “infect” cells through the transfer of portions of the DNA in rings called “plasmids”.

Possible Student Misconceptions

1. **“If a single gene from a tomato plant is inserted into an egg cell from a pig, the developing pig will sprout some part of the tomato plant, like a stem or fruit.”** Inserting a gene from one organism into a completely different one usually runs the risk that the gene will never be expressed in the first place. Second, a gene’s expression in a different type of cell, if possible, would be restricted to a single trait, rather than a series of traits that, in combination, would be required to produce a fruit or stem or leaf.

2. **“Distillation is the process that makes alcohol, such as methanol or ethanol.”** Distillation is a process for isolating alcohol from the water solution produced by fermentation. Distillation is able to separate the alcohol from the water because the boiling point of the alcohol is lower than water. When the boiling point of the alcohol is reached, the alcohol vaporizes while the water remains behind as a liquid.

Demonstrations and Lessons

1. Isolation of DNA from strawberries and peas using liquid detergent, onion using cold salt water (see www.Accessexcellence.org and <http://gsic.genetics.utah.edu> for references on lab procedures).
2. Testing the herbicide “Roundup^R” (available at garden centers) against GM soybeans that resist the herbicide vs. non-GM soybeans or other garden plants of the dicotyledon variety (tomato, green bean, pea); compare with monocotyledon plants such as grass and corn. (an excellent reference with background information on how genetic techniques are used to create GM food plants along with lab exercises is found in “*Your World-Biotechnology and You*”, Vol. 10, Issue #1 from the Biotechnology Institute, 1524 W. College Ave., Suite 206, State College, PA 16801 (www.BiotechInstitute.org))
3. Set up the fermentation process. Test for products including CO₂ (with limewater) and alcohol (boiling point, solubility of sugar or iodine in ethanol vs. water’s solvent properties, flammability)
4. Measure energy content of several fuels or precursors to fuels such as olive oil, canola oil along with ethanol or methanol using simple calorimetry (water as heat absorber).
5. Enzymatic conversion (amylase) of starch to glucose using commercial amylase or student saliva; testing presence of either starch or glucose with iodine solution and Benedicts solution, respectively. You can show enzymatic conversion by bean or pea seed halves on starch agar plates; test for starch and sugar as above. You can destroy seed enzyme by heating (illustrating limiting optimal temperature range for enzymatic catalysts vs. inorganic catalysts, such as platinum, that can operate over a very wide temperature range).

Suggestions for Student Projects

1. Debates (see topics in #2 below)
2. Research projects on
 - GM plants as pharmaceutical producers vs. animals; what determines the choice of plants? Animals?
 - European (European Union) attitudes toward GM food products vs. those of USA; regulations on each continent
 - Alternatives to corn as a fuel (ethanol) source; advantages of cellulose rather than starch as source of glucose for fermentation.
 - Comparing methanol with ethanol as a fuel; advantages and disadvantages; sources of methanol and ethanol

- Comparing ethanol with biodiesel as a fuel; what are the starting materials for biodiesel; what are the advantages of making and using biodiesel vs. ethanol
 - The ethical issues related to producing GM plants and animals
3. Run the fermentation process.
 - As a chemical reaction, what factors influence the rate of the reaction?
 - How would you test for products in the reaction (CO₂, ethanol)?
 - What is the role of yeast cells? Are catalysts (enzymes) involved?
 - What is the effect of temperature on the rate of the reaction? What is the range of temperatures possible for the reaction? What minimum and what maximum temperatures are possible?
 - What substrates are used?
 4. Do studies on the factors that effect the activity of an enzyme (a catalyst) – refer to the website “Access Excellence” (<http://www.accessexcellence.org/AE/ATG/data/released/0074-genNelson/index.html>) The lab listed is “Catalase Lab- A bio ENZYME Activity Laboratory”.
 5. Hydrolysis of starch – use of acidic solutions vs. enzymes. Source of amylase enzyme for starch hydrolysis is either a commercial product or human saliva. Need tests for starch (KI solution) and glucose (Benedict’s solution)
 6. Reverse of hydrolysis of starch to form glucose is dehydration of glucose to form starch. This is an enzyme-based reaction. The source of the enzyme, phosphorylase, is found in potatoes. There are standard lab manuals available that list various necessary procedures including a variety of chemicals needed. Evaluating the various factors that affect the rate of reaction are found in the reference #4 listed above.

Anticipating Student Questions

1. **“Why does the fermentation of sugars produce only 12% ethanol rather than 100%?”** Since the alcohol is an excretion product from yeast cells, the yeast cells are eventually poisoned by their own alcohol at a concentration of 12% by volume.
2. **“Why can sugar cane be used directly in the fermentation process but cornstarch requires several processing steps before fermentation?”** Sugar in the form of disaccharides (sucrose) or monosaccharides (glucose) is required for fermentation by yeast. The crushed sugar canes have the sucrose available for fermentation while starch from the corn kernels must first be changed (with enzymes and/or acids) from starch, a polysaccharide of linked glucose units, into individual glucose molecules through hydrolysis.
3. **“Will a gene inserted into a wheat plant to produce an anticoagulant affect coagulation in my body if I consume the wheat product?”** There is that possibility though it depends upon whether or not the wheat plant has actually produced the anticoagulant itself or some kind of precursor that must be further processed chemically in the pharmaceutical manufacturing process. But this is one of the concerns with transgenic plants – contamination of the environment that could mean genetically affecting other plants or mixing in with processed plant material (i.e., food products) because of contaminated processing/ packaging equipment.

4. **“Why is alcohol mixed with biodiesel fuel if both are fuels?”** Biodiesel, like petroleum-derived diesel fuel can be too viscous to be injected in a diesel engine cylinder. This is especially true when air temperatures drop toward the freezing mark. Alcohol reduces the viscosity enough for free flow of the diesel fuel as well as adding additional energy units (Joules) to the fuel mix.
5. **“Why is ethanol found in the laboratory unsuitable for drinking, if ethanol is found in alcoholic drinks?”** Ethanol found in the laboratory is usually of very high concentration, about 95% (close to what is called 200 proof)). Drinking such concentrated alcohol could be fatal at small volumes. To prevent people from drinking the alcohol, other chemicals such as methanol or acetone are added to give a bitter taste that also would cause vomiting. This treated alcohol is called ‘denatured’ alcohol.

Websites for additional Information

Twenty questions on genetically modified Foods (from the World Health Organization) www.who.int/food_safety/publications/biotech/20questions.en.ind

Discussion of potentials and dangers of biotechnology from the Food and Agriculture Organization of the UN:
www.fao.org/WAICENT/OIS/PRESS_NE/PRESSENG/2000/p

A handy listing of benefits and controversies about GM products as well as additional links: www.ornl.gov/sic/techresources/Human_Genome/elsi/gmfood.shtml

An overview of agricultural biotechnology is found at the American Chemical Society’s “*Science in Focus*”:
www.chemistry.org/portal/resources/ACS/ACScontent/government/agriculture0801.pdf

The impact of genetically modified organisms on human health at
<http://ohioline.osu.edu>

Biotechnology Institute (Penn State); www.BiotechInstitute.org

Roundup Ready^R Soybeans, www.roundupready.com/soybeans/rrechnology.htm

Illustrations of how genes are inserted into plants is found at
<http://learn.genetics.utah.edu/features/gmfoods/>

An example of an investigation into problems created by insect-resistant plants and their effect on beneficial insects, such as the Monarch butterfly is found at:
www.ars.usda.gov/is/br/btcorn/

A view from industry about biotechnology is found at www.bio.org/foodag/faq.asp. Compare reference #10 with GMO Compass, a website that is the work of independent science journalists in Europe. One example of reporting on the importance of keeping biodiversity in the midst of introducing essentially monoculture

crops such as corn or soybeans is found at www.gmo-compass.org/eng/safety/environmental_safety/166.biodiversity_threatened

A summation of the global economic and environmental impact of GM crops from 1996-2004 is found at www.agbioform.org/v8n23/v8n23a15-brookes.htm

The Union of Concerned Scientists has a useful website for promoting a variety of concerns about genetic engineering and the role of the federal governmental agencies in monitoring both the products developed before use as well as their dispersal in the environment. Some of the topics include:

- Genetic Engineering Basics
- Alternatives to Genetic Engineering
- Risks of Genetic Engineering
- Pharmaceutical & Industrial Crops
- Government Oversight of GE Crops
- Resources

Find it at www.ucsusa.org/food_and_environment/genetic_engineering

The “Why Files” at the Univ. of Wisconsin are an excellent source of information on many science topics including Genetic Engineering: <http://whyfiles.org>

A website that serves as a link to many other websites in biotechnology is the Internet Public Library at www.ipl.org/div/subject/browse/sci36.05.00/

The basics of genetic biotechnology for developing animals that produce (“secrete”) various pharmaceutical and non-pharm products is well explained (and illustrated at the Genetics Science Learning Center, <http://learn.genetics.utah.edu/features/pharming/>

A brief study on the need for more detailed permits for companies that want to plant GM crops and the need for more careful monitoring of the dispersal of pollen, seed and plant parts (environment contamination) is found at the Center for Science in the Public Interest, http://cspinet.org/new/200406021_org.html

Ramifications for health, environment, and wildlife concerning the expanded production of palm oil production in SE Asia is found at <http://cspinet.org/palmoilreport/index.html>

A source of data (graphs, charts, maps) on the extent of GM crops in the USA is found at the Pew Initiative on Food and Biotechnology, <http://pewagbiotech.org/resources/factsheets/display.php3?FactsheetID=1>. Their home page on Food and Biotechnology lists many other topics: <http://pewagbiotech.org/>

Another reference that tries to present a balance between concerns and accomplishment with GM foods is found in the **Scientific American**, April, 2001, “Genetically Modified Foods: Are They Safe?- The Risks on the Table” by Karen Hopkin.

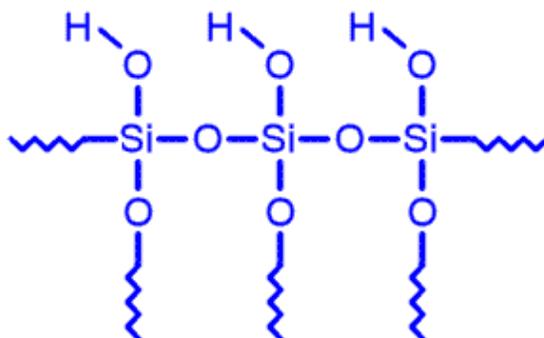
Background Information

The Science of Surfaces

Adhesives join surfaces, and much of the chemistry that makes adhesives work happens at surfaces. Since the surfaces of objects that are to be glued are similar to the surface of a drop of water, it can help to consider the chemistry of a water drop's surface. A water molecule is very polar, thanks to its strongly polar covalent bonds and asymmetrical shape. In liquid water, the partial positive and negative charges are stabilized by the partial negative and positive charges on neighboring water molecules. However, a water molecule at the surface of a drop only has neighboring water molecules on one side. The part of the water molecule facing out into the air has no neighboring molecules to provide stabilization. The side of the molecule facing out will experience electrostatic attraction drawing it into the interior of the molecule.

A surface water molecule is in a higher energy state than a molecule in the interior of a water drop. This difference in energy is called the *surface energy*. Electrostatic forces are constantly pulling on surface water molecules, pulling them into the interior of the molecule where they would be more stable. The surface of a drop of water is a dynamic place, with surface molecules constantly being pulled into the interior of the drop, with interior molecules being shoved to the surface to take their places.

This gives rise to the phenomenon of surface tension. The drive of surface molecules into the interior of the drop means a water droplet will be most stable when it has the fewest possible water molecules at the surface; that is, when it has the lowest surface-to-volume ratio. Of course, the drop has the lowest surface-to-volume ratio when it takes the shape of a sphere.



Schematic of silanol groups on the surface of a piece of glass.

Suppose now that the drop of water is falling as rain, and happens to land on the windshield of a car. Glass is a complex and fascinating material (see *ChemMatters*, October 2006). It is an extended solid, made up primarily of an extended three-dimensional network of covalently bonded silicon and oxygen atoms. The surface of glass is made up of silanol groups, hydroxyl groups bonded to silicon atoms. The oxygen-hydrogen bond in the silanol group is of course very polar, and the silanol groups can form hydrogen bonds with water molecules.

When a water drop lands on a glass windshield, the water molecule on the surface of the water drop on the side that lands face down on the glass will suddenly find themselves in a different chemical environment than the surface molecules on the other side of the water drop.

The water molecules on the surface of the drop touching the glass form strong hydrogen bonds with the silanol groups on the surface of the glass.

This hydrogen bonding stabilizes the partial positive and negative charges on the water molecule. The water molecules that form hydrogen bonds with the silanol groups in the glass are no longer in the high state of energy of surface molecules. Rather, the water molecules at the glass-water interface are energetically comparable to interior water molecules.

Since contact between water and the glass stabilizes surface water molecules, the water drop is most stable when as many surface molecules as possible are in contact with the glass. For this reason, a raindrop will spread across a glass windshield, maximizing contact and minimizing surface energy. This general principle that maximizing contact between surfaces minimizes surface energy is very important for understanding how adhesives work, as we'll learn more fully later on.

A drop of any liquid will display a surface energy. The difference in energy between surface molecules and interior molecules varies with the polarity of the molecules and the strength of the intermolecular forces that act between those molecules. A very polar molecule like water that forms strong hydrogen bonds will have a high surface energy. A non-polar substance that exhibits only weak van der Waals forces will have a much lower surface energy (and a lower surface tension).

Surface energy is a property of solids as well as liquids. In a solid object, the molecules on the surface are not stabilized by interactions with neighboring molecules, just as in liquids. Also as in liquids, the surface energy depends on the polarity of the material. A polar surface like glass has a high surface energy, while non-polar materials, like most plastics, have low surface energies. However, a solid object can't easily assume the shape of a sphere or spread across a glass surface to minimize surface energy, since definite shape is one of the defining properties of a solid. So the molecules on the surface of a solid just remain in a higher state of energy relative to its interior molecules.

In light of this, why don't solid objects stick to each other? Part of the reason is that not some surfaces have lower surface energies than others, and have less need of the stabilization that contact with another surface would provide. But what about high-energy surfaces like that of glass?

The answer to this question is that even surfaces that appear very smooth to the touch can be, on the microscopic level, very rough, pitted and wrinkled and covered in ridges. This means that when two solid objects with flat surfaces are brought into contact, there may not be a whole lot of actual contact between the two surfaces. Most of the surface molecules in the two objects never come close enough to have the kind of stabilizing interaction that would make the surfaces stick. Sometimes, if the two surfaces are polished smooth enough, they would stick without the help of any adhesive, especially if the surface is polar, like that of glass. This can be observed by simply stacking two clean microscope slides one on top of the other. Try to pull them apart, and you will feel a noticeable adhesion between the two slides.

What Makes Glues Sticky?

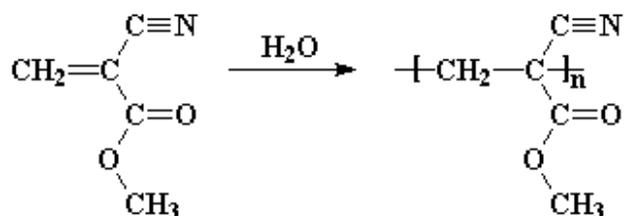
Adhesives join together solid objects much more strongly than the forces arising from the surface energy of the solids would. How does this happen? The answer lies in the fact that most adhesives are applied as liquids, only becoming solids later by some means or another. As a liquid, an adhesive can flow into all the pits and crevices in a surface of the solid object (called the substrate). Contact between the adhesive and the substrate is maximized, and surface energy is minimized. In this manner, the adhesive adheres to both substrates and joins them together.

Electrostatic forces and surface energy aren't the only factors affecting adhesion. The mechanical interlocking between an adhesive and a rough substrate surface increases

adhesion, too. Model airplane glues work in a completely different manner. Such glues use solvents that dissolve small amounts of plastic on two surfaces that are to be joined. When brought together, the polymer solutions on the surfaces co-mingle. When the solvent evaporates, the dissolved plastic from both surfaces solidifies together, joining the surfaces.

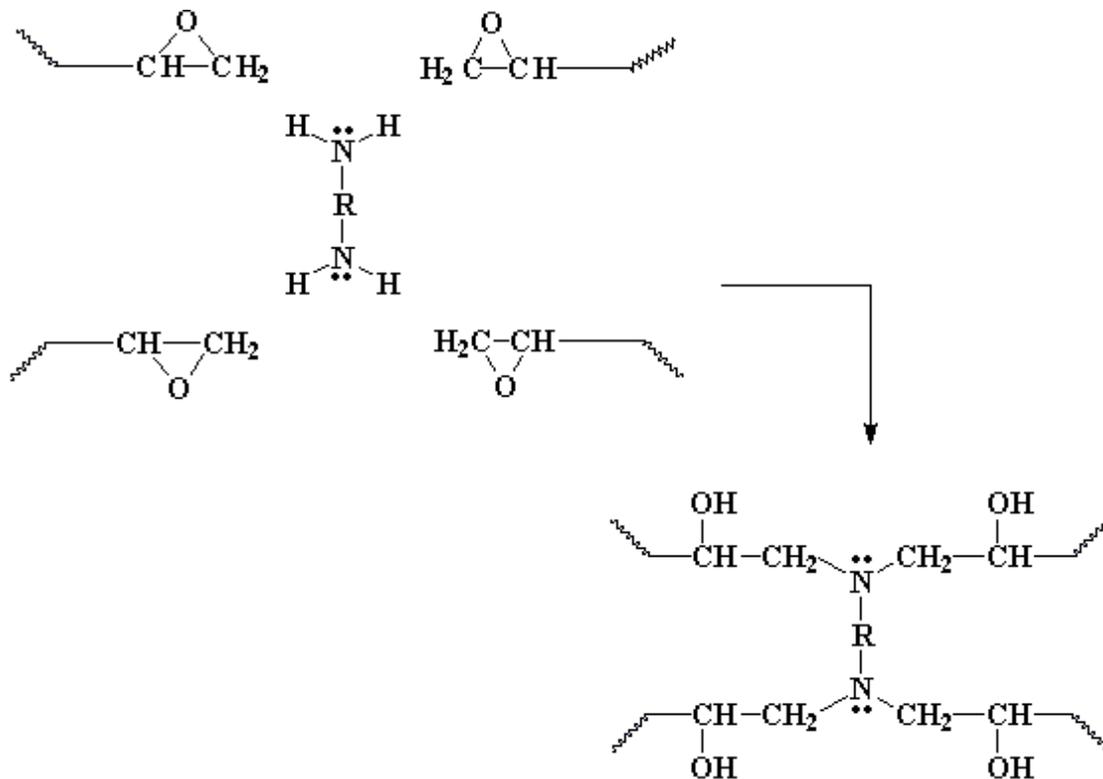
Curing

The adhesive does need to solidify, or cure, before adhesion can become permanent. (Water can be a very good adhesive if it is cold enough to solidify between two substrates, say, a tongue and a flag pole, for example.) Different adhesives solidify by different means. The water in the example of a tongue and a flag pole solidifies by undergoing a simple phase change, freezing, with no chemical change taking place. White glue also cures by means of a physical change. White glues are aqueous solutions of either a milk protein called casein, or a synthetic polymer called poly(vinyl acetate). As the white glue dries, water evaporates from white glue leaving solid casein behind.



Polymerization of methyl cyanoacrylate. (Note: Cyanoacrylate adhesives are often made from larger alkyl cyanoacrylates, as large as octyl cyanoacrylate.)

Other adhesives solidify by means of chemical changes. "Super" glues solidify when small molecules of a cyanoacrylate undergo polymerization to form a polycyanoacrylate. Two-part epoxy adhesives also cure by means of chemical reactions. In a two-part epoxy, one part is a relatively short-chain polymer, while the other is an amine that reacts with the polymer molecules, joining them into a three-dimensional crosslinked network.



The curing of an epoxy resin to create a material with polar hydroxy groups and amine groups

Since surface energy makes adhesives stick to their substrates, it helps if the adhesive has a high surface energy. This means that polar substances often make good adhesives. Cyanoacrylates adhere well because they contain extremely polar nitrile groups. Likewise, epoxy adhesives have polar amine groups that can form hydrogen bonds, leading to good adhesion. Polyurethane adhesive also get extra adhesion from the polar urethane groups they contain.

This is not to say that all adhesives must be polar substances. Some hot melt glues used in glue guns, are made of non-polar polymers like polyethylene. Such adhesives adhere solely because of van der waals forces.

Polymers, Adhesives, and Mechanical Properties

Many adhesives are either polymers or monomers that polymerize while curing. Polymers are long, chain-like molecules that contain thousands of atoms. Polymers are formed by chemical reactions that join together small molecules called monomers. Sometimes these giant molecules are covalently joined together to form three-dimensional networks of macroscopic proportions. Such networks are called crosslinked polymers. Both crosslinked and uncrosslinked polymers are commonly used as adhesives.

Cyanoacrylate "super" glues, epoxies, polyurethanes, and polyethylene hot melt glues are just a few examples of adhesive polymers. There are many reasons polymers make good adhesives. Polymerization is a very handy curing mechanism in many cases, as monomers are often liquids, while the polymers they form are usually solids. In other cases, a liquid polymer will become a solid when it is crosslinked. Epoxy adhesives cure in this way.

Also, polymers can be made with a wide variety of properties for different applications. One of the most important reason polymers make good adhesives is their good mechanical properties. On top of being sticky, an adhesive has to be able to stand up to physical wear and tear. In regular use an adhesive is subjected to the same mechanical forces and stresses as the substrates it holds together. If the adhesive can't mechanically hold up to these forces, it will fail under use.

Polymers are not only strong, but they are often tough, that is, they can absorb energy by deforming instead of breaking. They are often elastic as well, meaning they can return to their original shapes after deforming. This kind of resilience is necessary in many applications.

Substrate Considerations

The chemical and physical properties of the substrate also affect adhesion. On the chemical side, a polar substrate will adhere to an adhesive more strongly than a non-polar one will. Materials like wood or paper contain polar bonds in their molecules, so they tend to take adhesives better than materials like plastics, which tend to have mostly non-polar bonds in their molecules. With regard to physical properties, a rough or porous surface generally will adhere to an adhesive better than a smooth one. This is because a rough or porous surface has more effective surface area than a smooth surface on an object of the same dimensions. Since there is more surface area for the adhesive to adhere to, the secondary forces acting between the adhesive and the substrate will be greater.

Plastics are difficult to join with adhesives because they tend to have low surface energies, since they are often made of non-polar molecules. For this reason, plastics are often joined with adhesives that work by dissolving and joining small amounts of plastic at the surface, as described above.

Oddly, metals tend to have high-energy surfaces, but they can be difficult to join with adhesives. Metals have high-energy surfaces because metals are electron deficient. But being electron deficient also makes metals very reactive. A solid piece of just about any metal will usually have a microscopically thin coating of oxide on its surface. While the metal itself may have excellent mechanical properties, metal oxides are often weak or brittle. Even if an adhesive sticks to the oxide coating, the oxide coating can easily shear off from the metal, separating the metal from the adhesive. For this reason, metals are usually sanded to remove the oxide coating before adhesives are applied.

Additional Historical Background

Adhesives have been used for thousands of years. Many good adhesives can be found in natural materials, and indeed scientists are still finding them in creatures like mussels and barnacles. Ancient Egyptians made collagen-based glues from the skins of animals. Hide glues are still preferred for bonding wood in certain artisanal applications like crafting fine musical instruments and furniture. Many ancient peoples used glues made from the skins and bones of fish.

The biggest revolution in adhesives came with the development of synthetic polymers in the early 1900s. Many polymers were found to have adhesive properties. Epoxy resins were first prepared by Swiss chemist DeTrey Frères in 1936, and CIBA AG (now part of Novartis) introduced the first epoxy adhesives in 1946. A scientist at Tennessee Eastman Co first

discovered that cyanoacrylates could make strong adhesives in 1951, and the first “super” glue was brought to market in 1958.

Connections to Chemistry Concepts

1. Intermolecular forces – adhesion arises from hydrogen bonding, dipole-dipole interactions, and van der Waals forces.
2. Chemical bonding – covalent bonds, especially polar covalent bonds, give rise to the intermolecular forces responsible for adhesion.
3. Polymers and polymerization – many adhesives are polymeric.
4. Thermodynamics and stability – adhesion driven by energetic stability with respect to the intermolecular forces acting at the interfaces between adhesives and substrates.

Possible Student Misconceptions

1. **“Adhesives form chemical bonds with substrates.”** With most common adhesives, adhesion is due to secondary forces, not actual chemical bonds. Chemical bonds may be formed within the adhesive during curing, like the bonds that form between cyanoacrylate monomers when “super” glue cures, but chemical bonds usually do not form between adhesives and substrates in most applications with which students will have had first-hand experience.
2. **“All adhesives cure by the same mechanism.”** There are many different ways that adhesives cure. Some cure when a solvent evaporates, others cure by solidification upon cooling, while others cure by polymerization, or the crosslinking of a polymer. Both physical and chemical changes can be involved in curing. However, since most students are used to talking about glues “drying,” they may puzzle as to how mussel adhesive can cure under water. It is important for students to realize not all adhesives cure by “drying.”

Demonstrations and Lessons

1. A Sticky Situation: The Chemistry of Everyday Glues and Adhesives – a week-long class investigation in which students experimentally study the bonding capabilities of common adhesives on various substrates, and also research competitions on the internet
<http://www.chemed.org/Downloads/2004LP/StickySituation.pdf>
2. Glue from Milk – lab activity in which students convert the milk protein casein into a usable adhesive. The activity also pays attention to the environmental principles of green chemistry. It has been created by Greening Schools.
<http://www.greeningschools.org/docs/GluefromMilk.pdf>
3. Stick-O-Meter – this lab activity is designed for middle school students, but can be made more sophisticated for the high school level by adding variables such as different substrates and substrate surface roughening; from Zoom, WGBH Boston and PBS Kids.
<http://pbskids.org/zoom/activities/sci/stickometer.html>

Student Projects

1. Students could choose a particular adhesive and prepare a report describing its chemical composition, how it cures, the nature of its adhesion, common uses, and if possible some historical information.
2. Students could investigate and prepare reports on unexpected uses for adhesives, such as:
 - bonding of automobile structural components
 - bonding surgical sutures
 - civil engineering
 - food
 - forensic science
 - non-lethal weapons
 - pest control
 - space flight

Anticipating Student Questions

1. **“Why are some glues stronger than others?”** This can be hard to answer, because a glue that bonds one substrate strongly might bond another one weakly. However, in general, we can say that an adhesive will be strong if it has strong mechanical properties and a high surface energy, usually because it contains polar covalent bonds.
2. **“Why are there different kinds of glues?”** There are many different adhesives partly because many different kinds of substrates need to be joined, and not all substrates bond with all adhesives equally well. Also, sometimes we need to use adhesives that have special properties, like water resistance or extra strength, and other times we don't. If we don't need water resistance, for example, we might want to choose a cheaper adhesive that doesn't resist water just to save money.
3. **“How Do I Unstick My Fingers If I Superglue Them Together?”** Acetone can unstick the fingers of the careless. A complete guide to removing cyanoacrylate adhesives is available at the official Super Glue website:
<http://www.supergluecorp.com/removingsuperglue.html>

Websites for additional Information

Art Fry and the invention of Post-it[®] Notes – story of how a failed adhesive became a success on the backs of little pieces of paper, from 3M.
<http://www.3m.com/about3M/pioneers/fry.jhtml>

Ask the Experts: Is it True That Surgeons Are Now Using Glues and Adhesives to Seal Incisions? What Are These Materials? – from *Scientific American*.

http://www.sciam.com/askexpert_question.cfm?articleID=000AE585-7C1B-1C71-9EB7809EC588F2D7&catID=3

Ask the Experts: What Exactly Is the Physical or Chemical Process That Makes Adhesive Tape Sticky? – from **Scientific American**.

http://www.sciam.com/askexpert_question.cfm?articleID=000E47BD-6690-1C71-9EB7809EC588F2D7&catID=3

Bacteria Make World's Strongest Glue– news story from the Associated Press, hosted by MSNBC, April 19, 2006.

<http://www.msnbc.msn.com/id/12389963/>

Chemists Identify Key Ingredient in Natural “Super Glue.” news article from *Scientific American*, January 13, 2004.

<http://www.sciam.com/article.cfm?articleID=000F3DED-2C2E-1003-AC2E83414B7F0000&sc=1100322>

Gecko-Inspired Adhesive Sticks It to Traditional Tape – news story from *Scientific American*, June 4, 2003.

<http://www.sciam.com/article.cfm?articleID=000C1ED0-F88B-1EDC-8E1C809EC588EF21>

Gecko Tape Will Stick You to Ceiling – news story about a tape which uses gecko-like nanoscopic hairs to achieve adhesion, from *New Scientist*, June 2003.

<http://www.newscientist.com/article/dn3785.html>

Heat Switches New Glue's Stickiness On and Off – news story from *Scientific American*, June 28, 2002.

<http://www.sciam.com/article.cfm?articleID=000BCB39-8DE8-1D1B-8B07809EC588EEDF>

An Introduction to Surface Science – online resource from Dr. Roger M. Nix, Department of Biological and Chemical Science, Queen Mary University of London

<http://www.chem.qmul.ac.uk/surfaces/scc/>

The Macrogalleria – comprehensive and accessible information on polymer chemistry from the University of Southern Mississippi.

<http://www.pslc.ws/mactest/index.htm>

Stick It To 'Em – news story from *Popular Science* about an adhesive harpoon being tested by the Los Angeles police department for catching fleeing autos in car chases.

<http://www.popsci.com/popsci/whatsnew/73415ef7dfa1c010vgnvcm1000004eecbccdrcrd.html>

Background Information

More on the Jönköping

The Jönköping was built in Sweden in 1896. It was a relatively small (20 m) two-mast wooden-hulled ship. She was essentially a trading vessel and had made nine successful voyages in 1916 before this fateful one. The German U-boats sunk many ships, but they reserved their torpedoes for larger, steel vessels. The hole in the hull of the Jönköping is much too small to have been made by a torpedo, as students might think (and was originally reported by news sources). Typically, small vessels as this wooden-hulled ship were not considered worthy of a torpedo, as these arms were relatively expensive and in short supply. The Jönköping was reportedly sunk by a dynamite charge left onboard after the German U-boat crew had boarded the vessel and determined that it was carrying contraband and had to be sunk. (If a torpedo had been used, the ship would have been a mass of wooden splinters (and shards of glass bottles), not an intact ship.)

More on salvage operations

It seems that the discovery of elements (see this current issue of *ChemMatters*, “The Race for Iodine”) is not the only place there is competition. Two salvage teams competed for the spoils of the Jönköping. See <http://www.abc.se/~m10354/uwa/champ-en.htm> for a reporter’s story of the 1998 event, which involved divers from one of the two competing teams to switch sides – for a sum, of course. The ship was eventually brought up from the sea bottom intact, and the cargo was off-loaded. The plan had been to raise the ship, tow her to shore, and then to restore her as a museum, even though the ship itself is of a fairly common type, and there are several others just like the Jönköping still in service. This site also provides photos of the ship and some of its cargo. (According to the one photo, the “small hole in the hull” appears to be about 3 feet wide by 4 feet high.) After the raising, however, it was determined that the ship was too damaged and the decision was made to allow her to sink to the bottom for a second time, this time permanently.

Another account of the salvage, this time a first-hand account by Peter Lindberg, the salvage project leader, can be found at <http://www.centic.biz/pages/jonkoping.html>. Most of the above-mentioned report matches Lindberg’s very closely. Lindberg gives a very detailed account of the entire project to salvage the Jönköping but, interestingly, makes no mention of the clash between the two salvage teams, nor the wiring of individual bottles of the champagne to prevent their “blowing their tops”.

More on carbonation – and Priestley

Joseph Priestley is credited with the discovery of the carbonated beverage. Living close to a beer brewery, he was able to experiment with the gas produced by the fermentation process. One of the things he discovered (besides the fact that the gas is heavier than air, and that it extinguishes flames and kills mice), was that adding some of the gas to stirred water made the water taste slightly sour and refreshing. Although he didn’t know it was carbon dioxide at the time (he called it “fixed air”), he is still given credit for discovering the phenomenon. He published a treatise on the process, an online copy of which can be found at

the Chem Team's "Classic Papers" web site on Priestley at <http://dbhs.wvusd.k12.ca.us/webdocs/Chem-History/Priestley-1772/Priestley-1772-Start.html>.

More on Henry's Law

The concentration of carbon dioxide in the champagne is proportional to the atmospheric pressure inside the closed bottle, consistent with Henry's Law. That's why champagne bottles are made of such thick glass, and why they have the inversion in the bottom – both designed to withstand the increased internal pressure inside the bottle.

More on Boyle's Law

For an animated illustration of Boyle's Law, see this NASA site: <http://www.grc.nasa.gov/WWW/K-12/airplane/aboyle.html>. Also see number 3 in "Demonstrations and Lessons", below for a lesson involving this simulation. Or to simulate the syringe experiment yourself (or your students) and collect data and plot a graph of P vs. V, or 1/P vs. V, see http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/boyles_law_graph.html

More on the chemistry of champagne

From the BBC comes the report that the effects of the alcohol in bubbly champagne are felt more quickly than those of "still", or non-bubbly wines with the same alcohol content. See the report at <http://news.bbc.co.uk/1/hi/health/1719780.stm>. (You might not want to share this information with students, however.)

A site that seems to offer a thorough coverage of the problems of (college-level) student drinking (of alcohol) can be found at <http://www.chemcases.com/alcohol/alc-01.htm>. This site covers the psychological as well as the physiological aspects of the effects of alcohol on the body. (This might be a good site to send students to if they seem to be enjoying the article on alcohol too much.)

More on underwater logs

Historically, floating logs on waterways was the mode of transport of choice, since it required no extra energy source, like horses or trains or trucks. But the longer a log sits in the water, the more water-logged it becomes. It has long been known that hardwoods sink much faster than softwoods, so frequently loggers would rig rafts of pine logs (softwood) and transport the hardwood logs on these rafts. Logging mills using this system of transporting the logs anticipated a loss of 10-15% of their logs due to becoming water-logged and sinking, or breaking up of the rafts. Thus there would seem to be a rather large source of logs at the bottom off those waterways. Companies trying to find these underwater logs use a process called side scan sonar to detect them. This process gives a 3-dimensional picture of what lies on the bottom of lakes, etc. Superior Water-Logged Lumber Company was formed in 1992 and this company has led the way in retrieving sunken logs. They anticipate no shortage of sunken logs in the foreseeable future.

The reason trees become water-logged in the first place is that the water gets into the cells and replaces oxygen in them. That of course increases the density of the logs and eventually causes them to sink. The flip side of the swap of water for oxygen is that the tree cells now have no oxygen in them to aid in decay, so the logs are very well preserved. Thus the quality of these logs is at least as good as logs felled today – and frequently better. Water apparently leaches out resins and gums from the wood, resulting in better resonance of the wood when used to craft musical instruments.

One problem the water-logged tree company encountered was that the sunken logs are more susceptible to air and sun damage than normal trees. Another problem discovered is that these trees cannot be allowed to freeze, or they will literally explode, much like a can of soda left in the freezer – and for the same reason. The water-filled cells will all freeze and expand until the wood explodes. Thus, in cold-weather locations, these logs must be carefully and continuously heated to avoid freezing (at least until the water is removed). For more of this story, see <http://home.flash.net/~falline/ocrSalvage.htm>.

One source of underwater logs that was not discussed in the article is the forests of trees that were submerged when dams were built, not only in this country, but abroad as well. The number of dams greater than 15 meters high has increased seven-fold since 1950. Frequently, the trees left behind and submerged undergo no further degradation over time, other than increased water content. That can be kiln-dried out over time. Triton Logging, a private company has developed a remotely-controlled underwater logging apparatus, the Sawfish, that can cut down and float trees to the surface at the rate of about 12/hour. The quality of the wood is equivalent to that of a newly felled tree on land. The article cited below talks about this wood as being “sustainable” in the environmental sense, but it’s not clear how that term applies here, as no new tree will grow underwater to replace the one removed. See the article at <http://www.ehponline.org/members/2004/112-15/innovations.html>. A pdf file of the same article can be accessed at <http://www.ehponline.org/members/2004/112-15/EHP112pa892PDF.pdf#search=%22underwater%20logs%22>.

Most of the companies doing the underwater logging operations have been able to get the needed permissions from the local governmental agencies, because this process is seen as a positive thing for the environment. The companies actually keep the environment safer by cutting the underwater trees, rather than pulling them up out of the muck, thus avoiding the mud and silt redistribution that would occur otherwise. One company though is facing a tougher problem. The Underwater Timber Salvage company wants to pull up logs from the bottom of Lake Coeur D’Alene in Washington. Logging went on in that area for a long time, so there are plenty of logs sunk in that area. The problem here is that mining also occurred here for more than 100 years, and the residues from the mining processes have settled over the logs. Local agencies fear that the mud stirred up by the log retrieval will wash downstream into the Spokane River, carrying toxic substances along with it. The company proposed only bringing up 100 logs to “test the waters” to see if that would really disturb the silt all that much. More information can be found at <http://www.spokesmanreview.com/news-story.asp?date=121101&ID=s1068779>.

Connections to Chemistry Concepts

1. Gas laws:
 - a. Henry’s Law – carbon dioxide concentration in solution is proportional to gas pressure in the “head space” of the closed bottle
 - b. Boyle’s Law – bubble size varies with depth/hydrostatic pressure
2. Nucleation sites – bubble formation requires these, as does precipitation from a supersaturated solution
3. Gas solubility (carbonation) – as related to gas laws
4. Distillation – as a way to purify alcohols – or other liquids
5. Organic chemistry – alcohols as functional groups
6. Chemical equations – the fermentation process
7. Limiting reagents – fermentation reactants
8. Reaction rates – what factors affect fermentation

- Density – the sunken logs only sank because their density became greater than that of water
- biopolymers – cellulose and hemicellulose are examples of polymers in living organisms

Possible Student Misconceptions

- “It can’t hurt to drink a little champagne as a way to celebrate.”** Champagne has an alcohol content around 12%, higher than most wines. (Besides, it’s still against the law for underage drinkers.)
- “All wood floats.”** Wood that floats does so because its density is less than that of water. Some types of wood are very dense – more dense than water – and hence sink in water. Mahogany is an example of such a dense wood.
- “These underwater logs can’t be good for much, because wood kept underwater will rot away to nothing.”** Students’ experiences with wet wood usually are limited to wood exposed to air, and in that atmosphere, decay happens quickly. Decay usually only happens if bacteria have an oxygen source as well as the nutrient wood. Water doesn’t contain much (elemental, gaseous) oxygen, so underwater decay is extremely slow. Actually, in a log which is partially submerged, the underwater part will be much better preserved than the part sticking up out of the water.
- “Logs can’t sink! They’re all wood, and all wood floats.”** See the section above, **More on Underwater Logs.**

Demonstrations and Lessons

- Demonstrate Boyle’s law by observing bubbles rising through water in a long tube; e.g., a burette, eudiometer, or tall graduated cylinder. Bubble size/volume should increase as the bubbles rise through the water. Bubbles of hydrogen, for example, can be generated using a piece of magnesium and some hydrochloric acid. Note that this is a different reason for volume increase (pressure decrease and Boyle’s Law) than that given in the article for bubble size increasing in the champagne; this increase was due to accumulation of carbon dioxide molecules coming out of solution and diffusing into the already formed bubbles, thus making them larger.
- To demonstrate a simulation of Boyle’s Law, the site, http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/boyles_law_graph.html allows you to choose your own volumes of gas in a syringe and it illustrates the appropriate pressure and records both on a data table. Then it plots a graph for you of P vs. V, and then if you choose, 1/P vs. V.
- Another Boyle’s Law simulation/self-guided experiment for students is located at http://www.iit.edu/~smart/martcar/lesson3/Boyle_s_Law/Field_Trip/field_trip.html. This site makes use of the NASA site listed earlier in this guide.
- Demonstrate how much carbon dioxide is contained in a typical 12-ounce can of soda by pouring it into a bottle and then attaching a large deflated balloon to the open top of the bottle. After shaking, the balloon will fill (part way) with released

CO₂. Alternatively, you can do the same thing with the bottle of soda, except in place of the balloon you can attach firmly a piece of rubber tubing and lead that to an inverted graduated cylinder full of water in a sink of water and quantitatively measure the amount of CO₂ produced. You can also do this microscale. See <http://mattson.creighton.edu/SodaWater/SodaWater.html> for a description of the procedure. This site also contains other experiments, including one that replicates Priestley's carbonation of water experiment. (All these demonstrations involve Boyle's Law.)

5. You could use fermentation as a way to introduce or experiment with reaction rates, variables, and limiting reagents.
6. A series of 14 experiments on the topic of fermentation, one of the Unilever biotechnology guide series, can be found at <http://www.ncbe.reading.ac.uk/NCBE/PROTOCOLS/fermentation.html>. A full-color student version and teacher version pdf file can be downloaded from the site. (I got error messages when I tried to do the download.)
7. If you don't like the direction this is headed, with fermentation producing alcohols, you might want to consider the fermentation of cabbage into sauerkraut. See <http://www.splammo.net/foodaplmicro/applkraut.html> for background on the process, as well as directions for students to make their own "kraut".
8. An experiment from the *Journal of Chemical Education* (by the author of this article, Brian Rohrig) dealing with the stoichiometry of carbonation in "fizzy drinks" can be accessed (if you're a subscriber) at <http://jchemed4.chem.wisc.edu:8081/JCEIndex/FMPro?-db=jceindex&-lay=wwwform&title=taste&-find=&-format=detail.html&-skip=0&-max=1&-token.2=0&-token.3=25>.

Student Projects

2. Have students research the methods used to move logs across the Great Lakes.
3. Students can research why the champagne bottle is shaped the way it is (with the large inverted bell shape at the bottom).
4. Students could research the fermentation process as a way to assess their understanding of reaction kinetics.
5. Students can research mineralization processes in submerged wood.
6. Students could do lab research involving different types of wood to see if there are differences between softwoods and hardwoods re: rate of water uptake. They could also observe these woods under the microscope to see any differences there. A web site that describes activities like this, as well as other activities, is at <http://www.swst.org/teach/teach2/activities2.pdf#search=%22experiments%20density%20wet%20wood%22>. To speed up the process, you might have students try using cardboard squares instead of wood. The disadvantages are obvious, since they are only simulating the process of water absorption, but the advantage is that it would take much less time for the cardboard to "soak up" than it would for wood.

Anticipating Student Questions

1. **“How could all those bottles be undamaged if the ship was sunk by a torpedo?”** Actually it was not sunk by a torpedo. See “More on the Jönköping” under **Background Information, More on Jönköping**, above.
2. **“Why wasn’t the cognac any good after all those years?”** Apparently, the cognac was sealed in wooden barrels, and over time salty water from the sea was able to penetrate the wood and enter the cognac, making it taste salty.
3. **“What does it take for underwater decay to occur?”** A food source (the wood), aerobic bacteria, and oxygen are all needed for decay. Underwater, oxygen is typically lacking.

Websites for Additional Information

More Sites on the Jönköping

The Jönköping has been dubbed, “the champagne wreck”. See <http://www.abc.se/~m10354/uwa/champ-en.htm>

The Swedish Maritime Law web site at <http://www.juridicum.su.se/transport/Forskning/artiklar/SwMarLaw%203rd%20Ed%2020050801.pdf#search=%22Jonkoping%20schooner%22> does make reference to some misunderstandings about the contract for salvaging the Jönköping. See the last part of item 7.

More web sites on gas laws

An application of Henry’s Law can be found in Like-a-Fish, a company that uses technology to extract air from sea water, based on Henry’s Law. The process is expected to be used for divers and long-term aquatic habitats. The apparatus uses a high-speed centrifuge to lower the pressure inside a small sealed chamber. The air dissolved in the water in the chamber then escapes as a gas, which is then transferred to another container for the diver to breathe. A review of the apparatus can be found at <http://news.bbc.co.uk/2/hi/science/nature/4665624.stm>. The company’s own web site is <http://www.likeafish.biz/>.

The gas laws are covered with a slightly different “twist” – for divers – at <http://www.ukdivers.net/science/gaslaws.htm#Boyle's%20Law>.

More sites on champagne

The weekly news publication from the American Chemical Society, *Chemical and Engineering News*, has a feature called, “What’s That Stuff?” The January 5, 2004 issue contained an article on champagne. You can find it at <http://pubs.acs.org/cen/whatstuff/stuff/8201champagne.html>.

More sites on underwater logs

The site dealing with the benefits of underwater logs, cited by the author in the article, <http://www.popularwoodworking.com/features/fea.asp?id=1300>, discusses more of what happens to the logs left underwater for long periods.

Another account of underwater logging with the Sawfish can be found at <http://www.grist.org/news/maindish/2005/08/18/greenemeier-waterlog/>.

Underwater Logging, Inc.'s web site has a lot of photos of the logs they've retrieved: find them at <http://www.underwaterlogging-ltd.com/index.html>.

Most of the cited underwater logging companies are Canadian, but this one is American, situated near Mt. St. Helens: http://www.forestcouncil.org/tims_picks/view.php?id=1116.

Thermometers

Edition: December, 2006

"Where now are your tree-toads, your young love, your early season? Before noon it rains, by three o'clock it hails; before night the bleak storm-cloud of the northwest envelops the sky; a gale is raging, whirling about a tempest of snow. By morning the snow is drifted in banks, and two feet deep on a level. Early in the seventeenth century, Drebbel of Holland invented the weather-glass.

Before that, men had suffered without knowing the degree of their suffering. A century later, Romer hit upon the idea of using mercury in a thermometer; and Fahrenheit constructed the instrument which adds a new [but] distinct terror to the weather. Science names and registers the ills of life; and yet it is a gain to know the names and habits of our enemies. It is with some satisfaction in our knowledge that we say the thermometer marks zero."

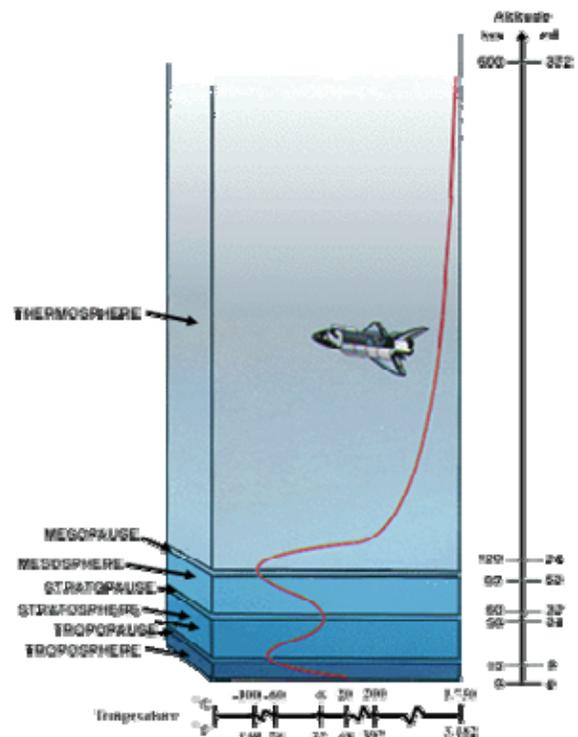
"How Spring Came in New England" by Charles Dudley Warner (1829-1900)

Background Information

More on the thermosphere

The thermosphere is the highest designated layer in the earth's atmosphere, from about 85-200 km in elevation. As you leave the earth you travel (in order) through the troposphere, the stratosphere, the mesosphere, the thermosphere and finally the exosphere before reaching space. The Kaman line, an altitude of about 100 km, is usually recognized as the arbitrary "edge" of space. (see diagram of the atmosphere at the end of this Teacher's Guide).

45



Temperature behaves differently in each layer of the atmosphere. (See the accompanying diagram from NASA. The red line in this diagram indicates temperature.) In the troposphere and mesosphere temperature decreases with altitude, while in the stratosphere and thermosphere temperature increases with altitude.

Because gas molecules in the thermosphere absorb direct radiation from the sun, they travel at high velocities, making the potential temperature in the thermosphere very high. The article refers to this phenomenon. The article notes, however, that the gas molecules are far apart in the thermosphere, so despite the high velocities, few would strike a thermometer placed in the thermosphere. This would cause a person to feel cold.

More on Temperature Scales

The article mentions the large number of temperature scales that have been used at one time in history. In addition to the Réaumur scale, once-used scales include the Newton, Rømer, Delisle (or de l'Isle), Leyden, Dalton, Wedgwood, Hales, Ducrest, Edinburgh and Florentine scales. The number of temperature scales resulted in part from the large number of methods of making thermometers and their composition. In different parts of Europe up to the early 18th century, thermometers were made using local materials and techniques. Since early thermometers were as much curiosities as measuring devices, there was little need for standardization. It was often assumed that a thermometer was good only in the locale in which it was made.

The earliest thermometer was not a thermometer at all. In the late 1600's Galileo designed a thermoscope, which consist of an egg-sized glass with a long neck. The jar was held in a person's hands to warm it and then the open end immersed in water. When the hands are removed water rose in the neck of the container. The experiment demonstrated the changes in air density caused by temperature variations. There were no graduations on this thermoscope and so it simply indicated differences in temperature. Santorio later built a similar instrument in Italy in 1612 but he added markings to show measurable differences in temperature. Both of these early devices relied on the expansion of air and so were subject as much to differences in pressure as temperature. In fact, many of the inventors of early barometers also developed thermometers.

By the mid-1600's liquid sealed-in-glass thermometers like the one invented by the Grand Duke of Tuscany, Ferdinand II were in use. But the use of wine in many of these thermometers through the 18th century meant that they gave inconsistent readings due to the variations in alcohol content.

More on Fahrenheit

In the early 1700's Fahrenheit was the first to use mercury sealed in glass as a thermometer. Even so, wine was still the liquid of choice throughout the 18th century. Fahrenheit's background was as a glassblower and instrument maker. Fahrenheit's use of two fixed points to calibrate his thermometer was a major development based on his desire to make thermometers reproducible, something he achieved at age 28 (in 1714). His work was based on that of Römer (see below). Until this time thermometers were localized in their composition and scales.

Fahrenheit used the ice, salt mixture mentioned in the article and an alcohol thermometer to determine the lowest temperature he could produce. Calling that temperature "zero," he originally assigned the number 4 to the freezing point of water and the number 12 to body temperature. (This twelve-point scale had been suggested in the writings of Sir Isaac Newton.) Later on Fahrenheit divided each of his "degrees" into eight equal divisions (as Römer

had done), producing the now-familiar 32° for the freezing point of water and the erroneous 96° for body temperature. He later on adjusted his scale so that the boiling point of water would have a value of 212° , exactly 180° higher (or the opposite of) the freezing point. Note: some of this history is not totally accepted, in part because Römer's records were destroyed and Fahrenheit probably tried to keep his methods a trade secret.

More on Celsius

As the article describes, in 1742, Anders Celsius, a professor of astronomy, recommended a temperature scale that was somewhat simpler than the one used by Fahrenheit. It is likely that he had been working on this scale for a number of years before, but only published in 1742. Celsius labeled the freezing point of water as 100 degrees and the boiling point of water as 0 degrees, dividing these two accepted reference points into 100 equal divisions. This shift made sense at a time when Europe was moving in the direction of widespread acceptance of metric measures. After his death, Celsius' scale was called the centigrade scale, adopting the prefix for 100. At the same time the scales was reversed to make the freezing point of water 0°C and the boiling point of water 100°C , a more logical system. Other European instrument makers adopted Celsius' design and popularized it after his death.

In fact, Celsius was not the first to devise a temperature scale with 100 degrees. Some sources suggest that Delisle (see below) invented such a scale to measure air temperatures during the solar eclipse in 1724. On this scale 0° was assigned to boiling water and 100° was taken as the temperature in a local basement. Note that the numbers seem to be reversed, as Celsius also did..

In 1887 the International Commission on Weights and Measures adopted "as the standard thermometric scale for the international services of weights and measures the centigrade scale having as fixed points the temperature of melting ice (0°) and the vapor of distilled water boiling (100°) at standard atmospheric pressure"

The name of the centigrade scale was changed to the Celsius scale in 1948. *In 1954* at the 10th General Conference of Weights and Measures, temperature on the Celsius scale is the temperature on the Kelvin scale minus 273.15.

More on Kelvin

William Thomson was a brilliant youth. He attended Glasgow University from the age of 10. He began college studies at age 14, focusing on astronomy, chemistry and natural philosophy (physics). Thomson was especially interested in heat, electricity and magnetism. As part of his study of thermodynamics he proposed in a paper 1848 an absolute temperature scale. He described it this way:

"...The characteristic property of the scale which I now propose is, that all degrees have the same value; that is, that a unit of heat descending from a body *A* at the temperature T° of this scale, to a body *B* at the temperature $(T-1)^{\circ}$, would give out the same mechanical effect, whatever be the number *T*. This may justly be termed an absolute scale, since its characteristic is quite independent of the physical properties of any specific substance."

His work was based on the heat theories of Carnot and Clapeyron. Note that this was about a century after Celsius. Among the titles he received for his work in physics and engineering were Sir William Thomson, Baron Kelvin of Largs, Lord Kelvin of Scotland

More on Other Temperature Scales

Römer In this scale, proposed in about 1700, the zero point was set using either a freezing ice/ammonium chloride solution or snow (Römer's records were burned in a fire). Römer defined the boiling point of water as 60 degrees. The freezing point of water corresponded to about 8° so a Römer degree is a little more than twice a Celsius degree. Römer was a Danish astronomer and was the first to use two reference points in calibrating the scale. Fahrenheit consulted with Römer and eventually used Römer's work in creating the Fahrenheit scale. To convert to the Celsius scale use this formula: $^{\circ}\text{C} = (^{\circ}\text{R}\ddot{o} - 7.5) \cdot 40/21$

Delisle In 1732 Delisle (or de l'Isle or de Lisle) built a thermometer that used mercury as its liquid. He chose his scale using the temperature of boiling water as the fixed zero point and measured the contraction of the mercury (with lower temperatures) in hundred-thousandths. So the numbers on this scale increased with colder conditions. So the melting point for water on this scale was 491.67°.

To convert to the Celsius scale use this formula: $^{\circ}\text{C} = 100 - ^{\circ}\text{De} \cdot 2/3$

Reaumur This scale named after René Antoine Ferchault de Réaumur, who proposed it in 1731. The freezing point of water is 0°Réaumur, the boiling point 80°Réaumur. Réaumur's thermometer used alcohol as the liquid. He assigned the freezing point of water as 0°, and graduated the tube into degrees each of which was one-thousandth of the volume contained by the bulb and tube up to the zero mark. On this scale the boiling point of water was 80°. The scale was used in Europe, especially in France and Germany. It was replaced by the Celsius scale. To convert to the Celsius scale use this formula: $^{\circ}\text{C} = ^{\circ}\text{Ré} \cdot 5/4$ Some historical documents indicated that Reaumur devised a scale based on 100 degrees.

Rankine The Rankine scale corresponded to the absolute temperature scale except that the degrees were Fahrenheit degrees. So the freezing point for water on this scale would be 491.67°R and the boiling point of water would be 671.67°R. This scale was proposed by the Scottish engineer and physicist William John Macquorn Rankine in 1859. To convert to the Celsius scale use this formula:

$$^{\circ}\text{C} = ^{\circ}\text{R} \times 5/9 - 273.15$$

More on Imperial vs. SI Units of Measure

Despite Fahrenheit's temperature scale being widely accepted, the article says that it was replaced by the Celsius scale, which was based on 100 divisions between the freezing and boiling of water. This, of course, was part of the acceptance of the metric system (SI) throughout the world.

By the end of the 18th century, the prefix "centi" had made its way into the metric system, and the metric system gained widespread use in Europe by the 1850's. According to the United States National Institute of Standards and Technology (NIST), "Most Americans think that our involvement with metric measurement is relatively new. In fact, the United States has been increasing its use of metric units for many years, and the pace has accelerated in the past three decades. In the early 1800's, the U.S. Coast and Geodetic Survey (the government's surveying and map-making agency) used meter and kilogram standards brought from France. In 1866, Congress authorized the use of the metric system in this country and supplied each state with a set of standard metric weights and measures.

In 1875, the United States solidified its commitment to the development of the internationally recognized metric system by becoming one of the original seventeen signatory nations to the Treaty of the Meter. The signing of this international agreement concluded five years of meetings in which the metric system was reformulated, refining the accuracy of its standards. The Treaty of the Meter, also known as the "Metric Convention," established the International Bureau of Weights and Measures (BIPM) in Sèvres, France, to provide standards of measurement for worldwide use.

In 1893, metric standards, developed through international cooperation under the auspices of BIPM, were adopted as the fundamental standards for length and mass in the United States. Our customary measurements -- the foot, pound, quart, etc. -- have been defined in relation to the meter and the kilogram ever since. The *General Conference of Weights and Measures*, the governing body that has overall responsibility for the metric system, and which is made up of the signatory nations to the Treaty of the Meter, approved an updated version of the metric system in 1960. This modern system is called *Le Système International d'Unités* or the International System of Units, abbreviated SI."

More on Thermal Expansion

Thermometers in general work due to thermal expansion. When thermal energy is added to a substance, not only does its temperature increase, but the substance expands in all directions. That is, its volume increases. The property that determines this expansion is called the coefficient of volumetric expansion. If a sealed glass thermometer contains alcohol, and both the glass and alcohol are heated, why does the alcohol rise in the thermometer? It's because the coefficient of expansion for the alcohol is greater than the coefficient of expansion of glass, and the alcohol expands at a greater rate. For an excellent article on thermometers and thermal expansion see

http://howthingswork.virginia.edu/supplements/thermometers_and_thermostats.pdf#search=%22liquid%20crystal%22%20thermometer%20uses%22 . The article discusses bimetallic strip thermometers and LCD thermometers as well as bulb thermometers.

More on Modern Thermometers

In addition to the thermometers and temperature scales mentioned in the article there are several methods of sensing and measuring temperature today. A few of these are:

Thermocouple

The thermocouple is a very simply designed temperature sensor. It is made by joining two wires made of different metals. Temperature is measured at the spot where the metals are joined. Because of differences in electron mobility, different metals produce different amounts of current when they are heated. This is called the Seebeck Effect. The differences in current can be calibrated into temperatures. The typical thermocouple is made of a platinum wire and a platinum-rhodium alloy wire. Thermocouple are used in high or low temperature applications like furnaces.

In 1821 Thomas Johann Seebeck discovered the basic principle of a thermocouple. At about the same time, Sir Humphrey Davy discovered that all metals have a positive temperature coefficient of resistance. These two discoveries marked the beginning of the development of the thermocouple.

Bimetallic Strip

These thermometers are made from two different metals which are permanently bonded together. Since different metals have different coefficients of both linear and volumetric expansion, the bimetallic strip will bend in one direction when heated and in the other direction when cooled. One metal expands more than the other and forms the concave part of the bend. The increase in size is small so the motion is expanded by a mechanical pointer that moves over the calibrated temperature scale. Bimetallic strips have a wider span than liquid thermometers, making them ideal for many industrial applications. Coiled bimetallic strips are used in thermostats in residential heating systems, as well as other devices to regulate heat.

Thermistors

Thermistors are electrical thermometers which measure changes in resistance with changes in temperature. Thermistors are made out of semiconductors, which are neither good electric conductors nor good electric insulators. It indicates its temperature by changing its electric resistance. At low temperatures semiconductors are insulators since they have no transitional electrons to carry current. But as the material is heated some electrons break away from atoms and move freely in the material.

Commercial thermistors, such as those found in electronic fever thermometers and other household electronic thermometers, are built out of specialized semiconductors. These semiconductors are designed so that their resistances change dramatically over the ranges of temperatures they are supposed to measure. Properly made thermistors can be very accurate over a considerable range of temperatures.

Infrared Thermometers

Traditional thermometers, like liquid-in-glass thermometers, must be in contact with the substance whose temperature is being measured. It is, however, possible to measure temperature at a distance, and one method is to use an infrared thermometer. IR thermometers are useful if the temperatures are outside the range of traditional thermometers or if the target is moving or too far away.

IR thermometers measure the electromagnetic radiation emitted by an object. All objects emit some type of radiation, and very little of it is visible to the human eye. The sensor in an IR thermometer is able to detect amounts of energy on the order of 0.0001 watt, which produces an electric signal that is amplified and sent to a digital output

At temperatures above 550°C, the eye can see this radiation, even though the radiation can be felt on the skin at lower temperatures. The radiation appears red and then changes to white and then to bluish white. It is interesting to note that early artisans, like metal workers, learned to judge the “heat” of a flame by the colors emitted.

For a complete explanation of the science and use of infrared thermometers, see http://www.raytek-northamerica.com/admin/file_handler/2ae6092f570efab9e577de9b6820919c/1017776674/IR_Theory_RevB_LR.pdf

Phase Change Temperature Sensors

Phase change temperature measurement devices or thermometers take many forms like temperature labels or temperature stickers that have a central white or yellowish dot that turns black when the temperature value printed on the label is exceeded. There are also thermal paints that change color and temperature crayons that melt and become liquid when their specified temperatures are exceeded. These are used as temperature sensors for food products, for example, or in industries where the temperature of high-volume processes cannot exceed a maximum temperature.

Liquid Crystal Thermometers

Liquid crystal thermometers are a layer of liquid crystals sandwiched between two strips of plastic. A liquid crystal has properties between those of a solid and a liquid. A series of numbers are printed on the strip, and those numbers represent the temperature range that can be measured. The liquid crystal behind each number will reflect light only at the temperature indicated. These devices are useful for measuring surface temperatures, including skin temperature. For more on liquid crystals, see the background information in the *ChemMatters* Teacher’s Guide on Liquid Crystal Displays, October, 2005.

http://acswebcontent.acs.org/education/chemmatters/tg/2005_10_tg.doc

Pop Up Meat Thermometers

Students have probably seen the small devices embedded in turkeys and other meats that tell the cook when the meat is completely cooked. The small devices are made of plastic and contain a plastic plunger inside of a compressed spring. The tip of the plunger is anchored in a metal which melts at about 185°F. When the internal temperature of the turkey reaches that temperature, the metal melts and frees the plunger, which then “pops up” to indicate that the meat is done. In a limited way this can be thought of as a temperature sensor.

Connections to Chemistry Concepts

1. Measurement and Units – The article discusses the measurement of temperature, which is typically part of introductory lessons in chemistry. The importance of reference points, units, and scales can be introduced with this article. The concept of measurement as a comparison process can be introduced using the article as well.
2. SI Units vs Imperial Units – You can discuss with students the history of SI units by using the Fahrenheit-Celsius section of this article.
3. Thermochemistry – The article would provide an excellent example as you discuss ideas of heat and temperature and calorimetry.
4. Thermal Expansion - The only place in a typical chemistry course where thermal expansion is discussed is in the section on gas laws. Charles Law describes the thermal expansion of gases. You might extend this discussion to relate it to the liquids and solids mentioned in the article.
5. Change of Phase – The typical reference points used to calibrate thermometers in history have been the freezing and boiling of water. Use of a salt/ice mixture to lower the freezing point to obtain “the lowest possible temperature” is an example of a colligative property.

Possible Student Misconceptions

1. **“The temperature scales of all thermometers are alike.”** Some students may be familiar with only the Fahrenheit scale, but most of your students will have encountered Celsius and perhaps Kelvin in other science classes. It is, however, still confusion for students to see the similarities and differences in the scales, and even more difficult for them to understand that water will boil, for example, regardless of which temperature scale is used on the thermometer measuring the water’s temperature. The number recorded as you measure the temperature depends on which scale is used on the thermometer, but the behavior of the water is the same. Another way to approach the differences in scales is to have students measure the same object using a ruler marked in inches and a ruler

- marked in centimeters. The length of the object is constant, but the recorded numbers depend on the units used.
2. **“Heat and temperature are the same.”** This is not a simple misconception to correct, and it may not be possible to do so. A simplistic way of explaining the difference is to remind students that a thermometer measures (indirectly) the average velocity of the particles that collide with it. If the thermometer were to be placed near the surface of, say, 5.0 L of water and the temperature recorded, you would know only the velocity of the molecules near the thermometer. Since the heat in the water includes the thermal energy of *all* the water molecules, you would have to take into account the mass of the water in order to know something about the heat. For activities to illustrate these ideas, see <http://www.genesismission.org/educate/scimodule/heat/>
 3. **“All thermometers are bulb thermometers.”** Most students think of a bulb thermometer when they think of measuring temperature. See “More on Modern Thermometers” above for brief explanations of other types of thermometers.
 4. **“A thermometer must be in contact with a substance to measure its temperature.”** The article describes infrared thermometers which are remote sensors. Also see “More on Infrared Thermometers” above.
 5. **“All thermometers contain mercury (because they’ve all heard the saying, ”the mercury’s rising).”** The article describes the fact that any liquid can be used in a bulb thermometer, but some liquids are more appropriate than others. Historically mercury was the liquid of choice until recently when its potentially toxic properties became widely known.

Demonstrations and Lessons

1. The article describes a demonstration to illustrate the concept that at higher temperatures molecules move faster. The demonstration involves placing food coloring in water of varying temperature. Students can do this activity. See the article.
2. Have students design a lab to test another statement made in the article about the molecules of gases diffusing faster at higher temperatures.
3. Students can make their own thermometer. Two procedures are here <http://www.allstar.fiu.edu/AERO/Experiment9.htm> and here <http://inventors.about.com/qi/dynamic/offsite.htm?site=http://www.howstuffworks.com/therm.htm>
4. Have students look at a thermometer under a magnifying glass and ask why the tube through the majority of the thermometer is so much thinner than the bulb at the bottom.
5. Lab: “How Low Can You Go?” using salt and ice, create lowest temp possible. For a procedure see <http://www.zoo.utoronto.ca/able/volumes/vol-24/mini.10.readel.pdf#search=%22lab%20%22how%20low%20can%20you%20go%22%22>
6. Design and exercise in which students explore thermometer accuracy vs precision. Both the precision and the accuracy of early thermometers was lacking.
7. For a series of activities that describe the difference between heat and temperature, see <http://www.wvpt4learning.org/lessons/pdf01/heat.pdf#search=%22heat%20vs.%20temperature%22> These are aimed at grades 6-8, but are adaptable.

8. For a lab on measuring temperature, see <http://depts.washington.edu/rural/RURAL/resources/temperature.html>
9. For more background and a lab on liquid crystal thermometers see http://kicp-verkes.uchicago.edu/2003-winter/pdf/ywi2003-liquid_crystals.pdf#search=%22%22liquid%20crystal%22%20thermometer%22

Suggestions for Student Projects

1. Assign students to research any of the people discussed in the article.
2. Research the history of Imperial Units and the development of SI units.
3. Groups of students can be assigned to read the article on the history of temperature scales here: http://www.x98ruhf.net/temperature_lesson.htm and follow directions in the lesson at the end of the article.

Anticipating Student Questions

1. **“How does a “distance” thermometer work?”** See “More on Infrared Thermometers.”
2. **“How do they take high temperatures, like those in a volcano?”** See http://hvo.wr.usgs.gov/observatory/hvo_history_beg.html for an explanation.

References

Daumas, Maurice, (translated and edited by Mary Holbrook), *Scientific Instruments of the Seventeenth and Eighteenth Centuries and Their Makers*, B.T. Batsford, London, 1972.

Middleton, W.E. Knowles, *A History of the Thermometer and Its Use in Meteorology*, Johns Hopkins Press, Baltimore, MD, 1966.

Websites for additional Information

For a brief history of temperature measurement and related calculations see <http://www.chymist.com/Temperature.pdf#search=%22romer%20thermometer%22>

For a NASA website on heat and temperature see <http://www.genesismission.org/educate/scimodule/heat/>

For a comparison of temperature scales see <http://en.wikipedia.org/wiki/Rankine>

For a web site on how thermometers work, see <http://www.madehow.com/Volume-1/Thermometer.html>

For more on the SI system, including history, see
<http://www.unc.edu/~rowlett/units/sipm.html>

For an excellent article on thermometers and thermal expansion see
http://howthingswork.virginia.edu/supplements/thermometers_and_thermostats.pdf#search=%22%22liquid%20crystal%22%20thermometer%20uses%22

For more on IR thermometers see
<http://www.capgo.com/Resources/Temperature/NonContact/NonContact.html#Eye>

For an article from ACS that describes temperature sensing, see
http://www.chemistry.org/portal/a/c/s/1/feature_tea.html?id=c373e900e01081fa8f6a17245d830100

For the complete text of the International Temperature Scale of 1990 (ITS-90) see
<http://www.capgo.com/Resources/Temperature/TempHome/ITS90/TheITS90.html>

For an article and Teacher's Guide on road salt and freezing point depression, see
ChemMatters, February 2006.
http://acswebcontent.acs.org/education/chemmatters/tg/2006_2_tg.doc

For a history of infrared thermometers see <http://www.zytemp.com/tutorial/history.asp>

Image of thermosphere from NOAA



Background Information

More on the Rivalry

When Humphry Davy and Joseph-Louis Gay-Lussac were competing in their studies of iodine in 1813, they had already been rivals for several years. Their rivalry went back as far as 1807, when Davy discovered potassium and sodium via the electrolysis of caustic potash (potassium hydroxide) and caustic soda (sodium hydroxide), respectively. Davy fell ill not long after he published his discoveries, and was out of commission for several weeks while he convalesced. Gay-Lussac began a serious investigation of the two metals along with his friend Jacques-Louis Thenard. The two greatly expanded our knowledge of the chemistry of potassium and sodium. They developed a new way to prepare them that didn't involve electrolysis, making them much easier and cheaper to prepare. While Davy's method required an unwieldy metal-acid battery, Gay-Lussac and Thenard's method required heating the caustic potash or caustic soda in a bent gun barrel with iron filings. They also studied the action of potassium on boric acid, and in the process discovered the element boron.

The next episode in their rivalry came a few years later when Gay-Lussac and Davy both found themselves investigating a greenish gas that had been discovered back in 1774 by a Swedish pharmacist named Carl Wilhelm Scheele. No one was sure of the nature of this gas, but some thought it was a compound of oxygen. The gas was known as "oxymuriatic acid." The two rivals both had reason to doubt conventional wisdom. They both had tried to produce oxygen by breaking down oxymuriatic acid, and both had failed. What's more both had failed to decompose the gas at all. Ever since the time of Lavoisier a practical working definition of "element" was any substance that could not be broken down into simpler substances. By this definition, oxymuriatic acid was showing every sign of being an element.

Gay-Lussac certainly thought so as early as 1809. The thing that stood between him and claiming so publicly was his mentor Claude-Louis Berthollet. A renowned chemist and conservative by nature, Berthollet had a personal connection to oxymuriatic acid, for it was he who discovered that it could be used to bleach fabric very nicely. He also felt very strongly that oxymuriatic acid was a compound, not an element. Owing much of his professional success to the good graces of Berthollet, Gay-Lussac was in no position to go publishing papers that directly contradicted the views of his mentor. So he held his peace, leaving a door wide open for his British rival.

Davy jumped at this chance, and in 1811 he published his conclusion that this gas was in fact an element. Since it was not a compound of oxygen, he concluded the name "oxymuriatic acid" was no longer appropriate, and gave it a new name. He called it "chlorine" from an ancient Greek word for pale green, reasoning that no matter what future scientists discovered, the gas would always be green, and his new name would never become obsolete as "oxymuriatic acid" had.

Having let this one discovery slip through his hands, winning the race to identify iodine as an element must have been especially satisfying for Gay-Lussac. After their row over iodine, the two were never again in direct competition with each other. Gay-Lussac spent the rest of his life in his chemical research, positions of scientific advisory to the French government (at one point even becoming a legislator in the national parliament) and a number of business ventures. He lived to an old age, passing away in 1850. Davy on the other hand spent less and less time in chemical research after this episode. In 1820, he became president of the Royal Institution, and administrative duties consumed most of his attention. Meanwhile his health

began to fail, and he resigned the presidency in 1827 to convalesce. Nevertheless, his condition continued to deteriorate, and he died two years later, at the age of only fifty.

More on Other Accomplishments by Davy and Gay-Lussac

Humphry Davy is best known for his discovery of the metals sodium and potassium using electrolysis. He also discovered magnesium, calcium, strontium, and barium by this method. His first fame had come when he was only 21 years old, when he carried out an in-depth study of the oxides of nitrogen. The numbers Davy measured for the compositions of oxides of nitrogen were used by John Dalton in formulating his atomic theory. Meanwhile, Davy also discovered the physiological effects of nitrous oxide, which he popularized for recreational use in addition to its use as an anesthetic. Later in life, Davy invented a safety lamp that could be used in coal mines without igniting the methane that is often found there.

Joseph-Louis Gay-Lussac earned his first scientific acclaim during his balloon ascents. First planned to measure any changes in the earth's magnetic field with altitude, he also collected air samples high above the earth to measure their composition. It was in trying to perfect a method for making such measurements that he first discovered the simple volumetric combining ratios of hydrogen to oxygen to water vapor when hydrogen and oxygen react to form water. This would in time lead to his discovery of the general law of combining volumes, which states that gases react in simple whole number ratios by volume. While some took this as support for Dalton's atomic theory, Gay-Lussac didn't say as much, at least while Berthollet was alive, since he strongly opposed Dalton's theory. In gas research, Gay-Lussac also discovered the law which describes the relationship between the temperature and the volume of a gas. Later in life Gay-Lussac developed a method for measuring the alcohol content of liquor. To this day, the strength of alcoholic beverages in France is measured in "degrees Gay-Lussac." A degree Gay-Lussac is equivalent to the percent of alcohol by volume in a beverage.

More on Properties of Iodine

Iodine is the only halogen which is a solid at room temperature, fluorine and chlorine being gases while bromine is a liquid. Solid iodine is made of dark-colored crystals which can appear black, or very dark purple or blue, depending on how the light hits them. The crystals melt at 113.7 °C, and boiling occurs at 184.3 °C, though solid iodine will sublime at room temperature, existing in equilibrium with its vapor. The vapor has a purple color, which gives the element its name.

Other properties of iodine include:

- Atomic number 53
- Atomic Mass 126.905 g/mol
- Electronegativity (Pauling) 2.5
- Density 4.93 g/mL (at 20°C)
- Heat of fusion 15.52 kJ/mol
- Heat of vaporization 41.57 kJ/mol
- First ionization energy 1009 kJ/mol
- Number of Isotopes 15

Isotope	Half Life	Decay
I-122	3.6 minutes	electron capture
I-123	13.2 hours	electron capture
I-124	4.2 days	electron capture
I-125	60.1 days	electron capture
I-126	13.0 days	beta
I-127	stable	
I-128	25.0 minutes	beta
I-129	1.57 x 10 ⁷ years	beta
I-130	12.4 hours	beta
I-131	8.0 days	beta
I-132	2.3 hours	beta
I-133	20.8 hours	beta
I-134	52.6 minutes	beta
I-135	6.6 hours	beta
I-136	1.4 minutes	beta

Like the other halogens, elemental iodine exists as a diatomic molecule, I₂. Like other halogens, iodine is highly reactive, and forms similar compounds to other halogens. For example, iodine forms hydrogen iodide (HI) which becomes hydroiodic acid in aqueous solution, and salts like sodium iodide, which are analogous to HCl and NaCl.

Iodine is a solid largely because the bond length in I₂ is longer than the bond length in Br₂, Cl₂, or F₂, and it has a larger more diffuse valence electron cloud. This means the molecule is more polarizable, and even with only van der Waals forces acting between iodine molecules, there is enough intermolecular attraction to make iodine a solid.

While iodine is reactive, it is the least reactive of the halogens, following a trend toward lesser reactivity among the halogens as atomic number increases. With its valence electrons further from the attractive force of the nucleus, the drive to gain an extra electron is weaker in iodine than the other halogens.

More on the Uses of Iodine

The most familiar use of iodine is in iodized salt. Most salt sold in the United States for human consumption has small amounts of potassium iodide added to it. This provides people with the small amounts of dietary iodine needed to prevent goiter, a disease of the thyroid gland that results from iodine deficiency. The added sodium iodide also has the effect of disrupting the cubic crystalline structure of sodium chloride, making table salt crystals appear as randomly-shaped solids rather than cubes as is the case with pure NaCl.

Students may also be familiar with tincture of iodine, which is a solution of KI and I₂ in ethanol. Tincture of iodine is commonly used to disinfect wounds. Another medical use of iodine is in the thyroid imaging. In the body, iodine collects where it is needed and used, in the thyroid gland. If a patient is given a small dose of a radioactive isotope of iodine, like ¹³¹I, the radiation emitted by the radioiodine can be used to make an image of the thyroid which is useful in diagnosing thyroid diseases.

Iodine also is used in old-fashioned black-and-white chemical photography. Silver iodide (AgI) is a light-sensitive compound, and is used to coat black-and-white photographic film.

Exposure to light in a camera causes a negative image to be burned into the silver iodide, which is then developed into a positive image. The manufacture of some printing inks and dyes and some drugs require compounds of iodine.

World Iodine Production (in 1000 grams elemental iodine)

2004	2005		
United States	1,130	1,240	
Azerbaijan	300	300	
Chile	15,600	16,200	
China	550	550	
Indonesia	75	75	
Japan	6,500	7,200	
Russia	300	300	
Turkmenistan	250	300	
World total	24,700	26,200	

World Resources: In addition to the reserve base, seawater contains 0.05 part per million iodine, or approximately 34 million tons. Seaweeds of the Laminaria family are able to extract and accumulate up to 0.45% iodine on a dry basis. Although not as economical as the production of iodine as a byproduct of gas, nitrate, and oil, the seaweed industry represented a major source of iodine prior to 1959 and remains a large resource.

Substitutes: Bromine and chlorine could be substituted for most of the biocide, colorant, and ink uses of iodine, although they are usually considered less desirable than iodine. Antibiotics and boron are also substitutes for iodine as biocides. Salt crystals and finely divided carbon may be used for cloud seeding. There are no substitutes for iodine in some animal feed, catalytic, nutritional, pharmaceutical, and photographic uses.

Source: United States Geologic Survey

<http://minerals.usgs.gov/minerals/pubs/commodity/iodine/iodinmcs06.pdf>

Some iodine-containing minerals include alutarite, found primarily in Chile and iodargyte, found in Colorado, Nevada and New Mexico.

More on Discoveries of the Other Halogens

As described above, chlorine was first discovered in 1774 by Carl Wilhelm Scheele, though its nature was not known until many years later. He produced it through the reaction of manganese dioxide on hydrochloric acid. Scheele was an excellent experimentalist and had tremendous insight into chemical phenomenon. He also discovered oxygen before Joseph Priestley (Scheele called it "fire air") and figured out the nature of combustion before Lavoisier. However, because Sweden was still remote from the scientific centers of Europe at the time, his discoveries were not known in Britain and France until after Priestley and Lavoisier had carried out and published their respective work.

Scheele also discovered hydrogen fluoride, though did not know its nature. Scientists concluded this compound which behaved so much like hydrogen chloride and hydrogen iodide must contain an element similar to chlorine and iodine. Because of the extreme reactivity of fluorine, isolating it proved very difficult. Several chemists were injured and at least two were killed in attempts to isolate fluorine from its compounds over the years. Finally in 1886 Henri Moisson succeeded in isolating fluorine by electrolyzing a solution of hydrogen fluoride and potassium fluoride at cryogenic temperatures. Moisson's isolation of fluorine and subsequent investigation of its properties earned him the Nobel Prize for Chemistry in 1906.

Bromine, was discovered in 1826 by the French chemist Antoine-Jérôme Balard, who succeeded in isolating the element from sea water. It seems there was a race of sorts over bromine, as there was with chlorine. About the time Balard was working to isolate bromine, a German chemistry student named Carl Löwig was also at work. It is possible that Löwig isolated bromine first, but had to delay his investigation of the material, and publication of his results, to take his mid-winter exams. This delay was long enough to let Balard publish his work first.

While bromine was first isolated from seawater, this proved costly as an industrial process for producing usable quantities of the element. In 1889, Henry Herbert Dow developed a method for obtaining bromine by the electrolysis of brine from underground brine wells deep beneath central Michigan. This process greatly increased the availability of bromine, and was also the beginning of Dow Chemical.

A fifth halogen was created in 1940 by Dale Corson and coworkers at the University of California at Berkeley. They bombarded bismuth-209 with alpha particles to achieve a transmutation into astatine. All isotopes of astatine are radioactive, the longest-lived isotope having a half-life of only 8.1 hours. The element currently has no uses.

More on Other Elemental Discovery Disputes

The discovery of iodine certainly wasn't the only elemental discovery with a messy history. Long before helium was isolated on earth, it had been observed on the sun by astronomers. In the 1860s, lines were discovered in the spectrum of sunlight that did not correspond to the spectral lines produced by any known element. A French astronomer named Pierre-Jules-César Janssen and a British astronomer named Norman Lockyer independently concluded a previously unknown element was present in the sun. While they disputed priority at first, upon meeting the two became friends and agreed to share credit for the discovery of helium. Meanwhile, it would not be until 1895 that helium was isolated on earth by Sir William Ramsay.

Vanadium was actually discovered twice. In 1803 a Spanish scientist named Andres Manuel del Rio was collecting mineral samples in Mexico and found what he thought to be compounds of an element never before described by science. Del Rio proposed the name "erythronium" for his new element, but soon backed off from his claim, lacking confidence in the face of criticism. Many years later, in 1831, Swedish chemist Nils Gabriel Sefström showed that the minerals del Rio was investigating really did contain a previously-unknown element, which he named "vanadium."

In the 20th-century there were many disputes over the discoveries of transuranium elements, especially during the Cold War. In several cases, a U.S. team and a Soviet team put forth competing claims for the discovery of the same element. The practical result was that elements remained unnamed for years after being discovered as the disputes awaited resolution, since the discoverers have naming rights. In one case, an element even changed names, as the International Union of Pure and Applied Chemistry (IUPAC) reassigned naming rights for element 105. This element was first named "hahnium" by the U.S. team after nuclear chemist Otto Hahn who co-discovered nuclear fission along with Lise Meitner and Fritz Strassmann. Later when it was decided that a team based in the Soviet Union had simultaneously discovered element 105, naming rights were given to the Soviet team led by Georgy Flerov. They renamed it "dubnium," after the city of Dubna, Russia, where their laboratory was located.

Connections to Chemistry Concepts

1. Elements and compounds – the macroscopic definitions of an element as a substance that can't be broken down and of a compound as a substance that can be broken down are central to understanding the story of iodine.
2. Families of elements in the periodic table – The similarities between chlorine and iodine were readily apparent to Davy and Gay-Lussac. The obvious similarities among some elements led to hypothesizing by many, including Davy, which would ultimately culminate in Mendeleev's development of the periodic table almost sixty years later.
3. Nature of science – The story shows how scientific discoveries involve the work of many people. It also illustrates that scientists can be wrong, as many thought iodine was a compound of chlorine. At the same time, the story shows how science is self-correcting as new information overturns previously-held ideas.

Possible Student Misconceptions

3. **“Gay-Lussac discovered iodine.”** Science is seldom so clean and tidy. Many people's work went into the discovery that iodine is an element – from Bernard Courtois, who first found iodine in seaweed – to Gay-Lussac, who correctly determined it to be an element.
4. **“Gay-Lussac and Davy weren't very smart when they first thought iodine was a compound of chlorine.”** When science history is taught in school at the elementary and secondary level, it is often taught in a smug manner, as is the case when students are taught that Copernicus knew the earth moved around the sun because he was smart and everyone else wasn't. Science is always tentative and discovering new things. What we think we know now can always be overturned should new evidence be uncovered. Gay-Lussac and Davy were only able to conclude iodine is an element after they uncovered evidence that others had not known about, evidence that overturned conventional wisdom. Before the two carried out their investigations, there was no evidence that could rule out iodine being a compound of chlorine. Only further experiments could rule out that possibility.

Demonstrations and Lessons

1. “Iodine Demonstration of Sublimation” – Iodine can be made to sublime using the heat of an overhead projector, while the whole process is projected onto the screen for all to see.
Goldsmith, Robert H. *J. Chem. Educ.* **1995**, *72*, 1132. (This procedure is available online to subscribers to the *Journal of Chemical Education* at <http://144.92.39.64/journal/Issues/1995/Dec/abs1132.html>.)
2. A Solid-Vapor Equilibrium Demonstration – demonstration of solid iodine/iodine vapor using QuickTime video, from Purdue University that shows the degree of sublimation of iodine changing with increasing temperature
http://chemed.chem.purdue.edu/demos/main_pages/14.9.html

How to Perform the Nitrogen Triiodide Chemistry Demonstration – demonstration of by the rapid explosive decomposition of nitrogen triiodide when touched with a feather, Anne Marie Helmenstine, Ph.D., from About.com.

<http://chemistry.about.com/od/demonstrationsexperiments/ht/triiodide.htm> or view a QuickTime movie of the demonstration here

<http://jchemed.chem.wisc.edu/jcesoft/cca/cca0/MOVIES/NI3IOD.html>

Note the required safety precautions. This can be a **very** dangerous demonstration if safety precautions are not followed, as nitrogen triiodide is very unstable. This material should never be touched with bare hands, and should be handled with utmost caution as it can detonate with the slightest touch. Only small amounts of nitrogen triiodide should be made at any given time, and the substance should never be stored. This substance should be moved only while still damp, and should be kept away from heat and sunlight. In addition, the explosion produced in the demo is very loud, so ear protection should be worn as well as eye protection. A safety shield should be used and the demonstration should be done in a fume hood. Also, the iodine produced in the decomposition of nitrogen triiodide is an eye and respiratory irritant.

Student Projects

3. Students could choose a particular halogen and research the history of its discovery, and write papers or prepare presentations based on their research.
4. Students could similarly prepare research reports or presentations about any of the personalities in the story.
5. Students could prepare timeline for the discovery of iodine, based on the article.

Anticipating Student Questions

4. **“Why are we learning about old, dead chemists, anyway?”** The stories of people like Gay-Lussac and Davy show how science takes place in the real world, and they also help us understand the scientific concepts involved, like the nature of elements and the properties of iodine.
5. **“Is science always a competition like this?”** No, sometimes different scientists work together (like in the story of helium described above), but in many other cases scientists do compete against each other. The story of Percy Julian’s synthesis of physostigmine is a good example of scientists in competition. (See *Science Alive!* from the Chemical Heritage Foundation, <http://www.chemheritage.org/scialive/julian/history/5.html>.) In some cases, scientists even use questionable means to gain the edge over competitors, such as the case of Watson and Crick’s unauthorized use of Rosalind Franklin’s X-ray crystallographs of DNA to elucidate the structure of DNA. Sometimes the competition is between scientists of hostile nations, as was the case with Gay-Lussac and Davy, but today the competition is more often between scientists working at rival corporations, racing to invent patentable products.
6. **“Why does the article mention electricity several times?”** The relationship of electricity and chemistry was something new in the early 1800’s, a time when a lot of new ideas were emerging in chemistry. Volta’s invention of “the Pile,” the first working battery, spawned attempts to use this new technology in chemistry.

Among others working on this new field of “electrochemistry,” Humphry Davy used the direct electric current supplied by Volta’s battery to separate compounds of what we know as the alkali metals and alkaline earth metals into their elements, a process not possible with by other means available at the time. Other important experimenters included Ampere in France, Faraday in England and Oersted in Germany. The use of this new technology enabled many new discoveries in chemistry.

7. **“Our chemistry textbooks usually list one discover for things like elements. Why don’t they tell stories like the one in this article?”** As important as stories like this one are to the history of chemistry, chemistry textbooks today do not have space to tell these stories. It is worth remembering that all discoveries is chemistry (and all of science) have a story behind them, and the stories tell of the lives and work of the people involved. The practice of chemistry, in history or today, is not an abstract idea, but a process being carried on by a wide range of people.
8. **“What’s the big deal about history in science? Why do we need to know this?”** A chemistry course is often presented as a set of fixed ideas. By reading about the history of these ideas you can find out how ideas and events in the past are related to each other and to the present. You will also find out about the people involved, and maybe even be inspired to become a chemist.

Websites for additional Information

Dubnium – story which describes some of the competing claims of discovery of transuranium elements by U.S. and Soviet teams, written by Ivo J. Zvara for *Chemical and Engineering News*.

<http://pubs.acs.org/cen/80th/dubnium.html>

Gay-Lussac Museum – official site of the museum in Gay-Lussac’s home town of Saint Léonard de Noblat , featuring online exhibits, animations, and descriptions of Gay-Lussac’s experiments.

<http://apella.ac-limoges.fr/musee-gay-lussac/Gay-Lussac-en.html>

Humphry Davy – biographical sketch, part of *Chemical Achievers* from the Chemical Heritage Foundation.

<http://www.chemheritage.org/classroom/chemach/electrochem/davy.html>

Humphry Davy – a longer biography from the Notable Names Database.

<http://www.nndb.com/people/028/000083776/>

Iodine – well-written piece on the uses and chemistry of iodine by Peter J. Strang from *Chemical and Engineering News*.

<http://pubs.acs.org/cen/80th/iodine.html>

Joseph-Louis Gay-Lussac – biographical sketch, part of *Chemical Achievers* from the Chemical Heritage Foundation.

<http://www.chemheritage.org/classroom/chemach/gases/gay-lussac.html>

“On a Combination of Oxymuriatic Gas and Oxygene Gas” – text of Humphry Davy's paper describing his investigations of chlorine, originally published in *Philosophical Transactions of the Royal Society*, **1811**, 101, 155-162. Hosted by the ChemTeam at Diamond Bar High School.

<http://dbhs.wvusd.k12.ca.us/webdocs/Chem-History/Davy-Chlorine-1811.html>

For a complete discussion of the radiochemistry of iodine, see <http://library.lanl.gov/cgi-bin/getfile?rc000043.pdf>