CHEMMATTERS

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Teacher's Guide

About the Guide

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

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

Patrice Pages, *ChemMatters* Editor, and Terri Taylor, CM Administrative 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

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Student Questions

The Captivating Chemistry of Candles

1. What is the source of paraffin wax?
2. What is the general formula for alkanes?
3. Is paraffin a pure substance?
4. What role does the wick play in the burning of the candle?
5. What is capillary action?
6. Name the three parts of a candle flame. State their locations within the flame, their colors, and their approximate temperatures.
7. What makes a candle flame luminous?
8. On the basis of what you read in the article, comment on the following statement: "All candle flames are conical in shape."
9. What is the secret ingredient in those trick candles that don't stay extinguished, and how does it work its magic?

Hindenburg: Formula for Disaster

1. What was the length of the Hindenburg?
2. In what state did the Hindenburg disaster take place?
3. According to the article, what was the color of the flame as the Hindenburg burned?
4. Name the reactants in the thermite reaction.
5. Give the full name of the NASA scientist who advanced the incendiary paint theory discussed in the article.
6. Why was the Hindenburg filled with hydrogen gas rather than helium?

How the Cookie Doesn't Crumble … and Other Sweet Chemistry Secrets

1. What are two factors that affect the consistency of a cookie as it bakes?
2. How can a baker assure he/she produces a flat, crisp cookie?
3. What two ingredients can a baker use to assure a high, cake-like cookie?
4. What is the chemical name for baking soda? What is its formula?
5. Why does baking powder with only water added cause cookie dough to rise, while baking soda requires the addition of an acid in order to work?
6. What two substances make up gluten?
7. What two substances are responsible for giving cookie dough its structure?
8. List 3 reasons for using sugar in cookie recipes.
9. Why do bakers use weights instead of volumes to measure quantities of dry ingredients?
10. Explain the difference between a formula and a recipe.

The Solid Facts About Trans Fats

1. What is the function of fats and oils in plants and animals?
2. What is the difference between a fat and an oil?
3. Translate the word "triglyceride" in chemical terms.
4. What is meant by a saturated bond in a carbon-containing compound?
5. What is the difference between a saturated and an unsaturated bond in carbon-carbon bonding?
6. What is the difference between a monounsaturated fat and a polyunsaturated one?
7. What is the physical state (solid, liquid, gas) of a saturated fat? Of an unsaturated fat? For each type of fat, what is the source—plant or animal?

8. What happens to fat molecules that makes them rancid?
9. What is meant by the process called “hydrogenation”?
10. What is the difference, structurally, between an unsaturated fat that has undergone complete hydrogenation and one that is only partially hydrogenated?

Beyond Hydrogen: The New Chemistry of Fuel Cells

1. What are two compounds that might be used to produce hydrogen?
2. How many carbon atoms are there in a methanol molecule?
3. How many carbon atoms are there in an ethanol molecule?
4. What atmospheric gas can be converted into methanol using a fuel cell?
5. What main part of a fuel cell is made out of a polymer?
6. What metal is found in both the anode and cathode of most fuel cells?
7. At which electrode does oxidation take place in a fuel cell?
8. At which electrode does reduction take place in a fuel cell?
9. Fuels are oxidized in fuel cells. What substance is reduced in a fuel cell?
10. What type of ions pass through the membrane between the anode and the cathode?
11. Very little of the chemical energy released from the fuel used in a fuel cell is released as heat. In what form is the fuel’s chemical energy released?

Answers to Student Questions

The Captivating Chemistry of Candles

1. **What is the source of paraffin wax?**
   Paraffin is obtained via the distillation of crude oil, or petroleum.
2. **What is the general formula for alkanes?**
   The general formula for alkanes is C_nH_{2n+2}.
3. **Is paraffin a pure substance?**
   Paraffin is not a pure substance; it is a mixture of several different heavier hydrocarbons. As a typical average, it can be represented by the formula, $C_{25}H_{52}$.
4. **What role does the wick play in the burning of the candle?**
   The wick serves as the fuel delivery system in the candle, a pipeline through which the liquid wax can flow from the puddle at the top of the candle to the flame.
5. **What is capillary action?**
   Capillary action is the process by which a liquid can travel through an open tube (even if really small), against the force of gravity, due to the cohesion of the liquid molecules (attraction to each other) and the adhesion of the liquid molecules to the walls of the tube (attraction to surrounding, different molecules).
6. **Name the three parts of a candle flame. State their locations within the flame, their colors, and their approximate temperatures.**
   This table shows the information requested in the question.

	Name	Location	Color	Temperature
1	Main reaction zone	Base of flame	Blue	Up to 1400°C
2	Dark zone	Inside the flame	Dark (?)	800°C
3	Luminous zone	Outside, top	Yellow	~1200°C

7. **What makes a candle flame luminous?**
   Unburned carbon particles are heated to incandescence. They are not burning, just heated to the point of glowing.
8. **On the basis of what you read in the article, comment on the following statement: "All candle flames are conical in shape."**
   The statement is only true for candle flames on Earth (or anywhere affected by gravity). All candle flames that are affected by gravity are conical in shape due to convection currents set up when the warm, less dense air rises above the flame, drawing in cooler, denser air at the bottom. But in space, under zero gravity or microgravity, convection does not occur because all the air is equally dense (based on mass, not weight) and there is no rising or rushing in to take the place of the rising air. Then candle flames take on a spherical shape as oxygen in the surrounding air gets to the fuel at the same rate from all directions.
9. **What is the secret ingredient in those trick candles that don't stay extinguished, and how does it work its magic?**
   The secret ingredient to magic candles is magnesium. Magnesium ignites at temperatures as low as 430°C, so glowing embers of a candle are sufficiently hot to ignite the magnesium. The burning magnesium produces enough heat to reignite the remaining wax vapors in the candle.

Hindenburg: Formula for Disaster

1. **What was the length of the Hindenburg?** *The Hindenburg was 804 feet long.*
2. **In what state did the Hindenburg disaster take place?** *New Jersey is the site of the Hindenburg disaster.*
3. **According to the article, what was the color of the flame as the Hindenburg burned?** *The flame color as the Hindenburg burned was yellow.*
4. **Name the reactants in the thermite reaction.** *The reactants of the thermite reaction are aluminum and iron oxide*
5. **Give the full name of the NASA scientist who advanced the incendiary paint theory discussed in the article.** *Addison Bain is the scientist who advanced the incendiary paint theory.*
6. **Why was the Hindenburg filled with hydrogen gas rather than helium?** *The Hindenburg was filled with hydrogen rather than helium because the U. S. had most of the world's supply of helium and was unwilling to supply Germany because the U. S. was wary of Hitler's activities. [Although not specifically mentioned in the article, hydrogen's density is about half that of helium, so it has more lifting force, volume for volume.]*

How the Cookie Doesn't Crumble … and Other Sweet Chemistry Secrets

1. **What are two factors that affect the consistency of a cookie as it bakes?**
   The consistency of a cookie as it bakes is affected by the spread and rise.
2. **How can a baker assure he/she produces a flat, crisp cookie?**
   A baker produces a flat, crisp cookie by using butter or another low melting point shortening so that the fat melts early in the baking process, allowing the dough to spread out as it bakes, producing a flat cookie.
3. **What two ingredients can a baker use to assure a high, cake-like cookie?**
   A baker uses a fat with a low solid fat index (SFI) because it will trap air in it as the dough is kneaded, and he uses baking powder or baking soda and an acidic liquid to generate carbon dioxide gas bubbles. Both the air and the carbon dioxide gas bubbles trapped in the dough will expand as the dough is baked at high temperatures, thus ensuring a porous cookie.
4. **What is the chemical name for baking soda? What is its formula?**
   The chemical name for baking soda is sodium bicarbonate (or sodium hydrogen carbonate in today's terminology), and its formula is $NaHCO_3$.
5. **Why does baking powder with only water added cause cookie dough to rise, while baking soda requires the addition of an acid in order to work?**
   Both baking powder and baking soda cause cookie dough to rise by producing carbon dioxide bubbles. The CO_2 *in both reactions is the result of the base, sodium bicarbonate (baking soda), reacting with (neutralizing) an acid. One of the ingredients in baking powder is an acid. Baking powder is made of baking soda and an acid—usually potassium hydrogen tartrate, although that can vary. Baking soda requires acid from an outside source, sour milk or buttermilk, for example.*
6. **What two substances make up gluten?**
   Glutenin and gliadin are the two substances that make up gluten.
7. **What two substances are responsible for giving cookie dough its structure?**
   Gluten and eggs both contain proteins that give cookie dough its structure.

8. **List 3 reasons for using sugar in cookie recipes.**
    1. *The first and most obvious reason is that sugar adds sweetness to the recipe, which makes the cookie taste better.*

    The other two reasons both center on the fact that sugar is hygroscopic.

    2. *As sugar absorbs water from the cookie dough, it prevents gluten from using those water molecules as it builds its structure within the dough. Less structure results in a tenderer cookie.*
    3. *The water molecules attracted to the sugar remain there after baking and help keep the cookie tasting moister for longer periods of time.*
    4. *Sugar molecules continue to attract moisture from the air, also making it taste moister longer, thus lengthening its shelf life. (This answer may have been incorporated into number 3, since that's the way it was handled in the article.)*
9. **Why do bakers use weights instead of volumes to measure quantities of dry ingredients?**
    The quantity of the ingredient is what's truly important. The volume of a dry ingredient can change depending on the way it is handled, whether it's "fluffed up" or tamped down. The weight always gives the same quantity, which results in the same quality of product every time, barring other variables.
10. **Explain the difference between a formula and a recipe.**
    A formula is just a list of the ingredients in the process, while a recipe is the list of ingredients <u>and</u> the set of directions one uses to complete the process.

The Solid Facts About Trans Fats

1. **What is the function of fats and oils in plants and animals?**
    Fats and oils are molecules for the storage of energy.
2. **What is the difference between a fat and an oil?**
    A fat is solid at room temperature and an oil is liquid.
3. **Translate the word "triglyceride" in chemical terms.**
    Tri- means three and refers to the three fatty acids that bond to one glycerol molecule (glyceride backbone) at each of three –OH groups on the glycerol molecule.
4. **What is meant by a saturated bond in a carbon-containing compound?**
    A saturated bond is one in which a carbon atom is bonded to the maximum number of hydrogen atoms possible, hence saturated. This means all the carbon-carbon bonds are single bonds.
5. **What is the difference between a saturated and an unsaturated bond in carbon-carbon bonding?**
    In carbon-to-carbon bonding, if there is but one single bond between the two carbon atoms, it is saturated. If there is a double bond between the two carbon atoms, then it is possible to add additional hydrogen atoms to each of the carbon atoms, which translates to the idea of unsaturated bonds.
6. **What is the difference between a monounsaturated fat and a polyunsaturated one?**
    In a monounsaturated fat, there is one unsaturated C-C bond. In a polyunsaturated fat, there are many unsaturated C-C bonds.
7. **At room temperature, what is the physical state (solid, liquid, gas) of a saturated fat? Of an unsaturated fat? For each type of fat, what is the source-plant or animal?**

A saturated fat is a solid at room temperature and is found in animals. An unsaturated fat is a liquid and is found in plants.

8. **What changes occur in fat molecules that make them rancid?**
   Unsaturated fat molecules that are of the cis-form more easily react with oxygen in the air, which in turn causes them to break apart into smaller molecules, many of which have unpleasant smell and taste properties.
9. **What is meant by the process called "hydrogenation"?**
   "Hydrogenation" is the process whereby hydrogen atoms bond to unsaturated carbon atoms under high pressure and in the presence of a metal catalyst, such as nickel.
10. **What is the difference, structurally, between an unsaturated fat that has undergone complete hydrogenation and one that is only partially hydrogenated?**
    Complete hydrogenation means all unsaturated carbon bonds are saturated through the addition of hydrogen atoms. Partially hydrogenated molecules contain some unsaturated carbon bonds after other unsaturated bonds have taken on enough hydrogen to become saturated.

Beyond Hydrogen: The New Chemistry of Fuel Cells

1. **What are two compounds that might be used to produce hydrogen?**
   Water and methane are two compounds that might be used to produce hydrogen.
2. **How many carbon atoms are there in a methanol molecule?**
   A methanol molecule contains one carbon atom.
3. **How many carbon atoms are there in an ethanol molecule?**
   An ethanol molecule contains two carbon atoms.
4. **What atmospheric gas can be converted into methanol using a fuel cell?**
   Carbon dioxide from the atmosphere can be converted to methanol using a fuel cell.
5. **What main part of a fuel cell is made out of a polymer?**
   The membrane is made of polymer.
6. **What metal is found in both the anode and cathode of most fuel cells?**
   Platinum is found in both anodes and cathodes of most fuel cells.
7. **At which electrode does oxidation take place in a fuel cell?**
   Oxidation in fuel cells takes place at the anode.
8. **At which electrode does reduction take place in a fuel cell?**
   Reduction in fuel cells takes place at the cathode.
9. **Fuels are oxidized in fuel cells. What substance is reduced in a fuel cell?**
   Oxygen is reduced in a fuel cell.
10. **What type of ions pass through the membrane between the anode and the cathode?**
    Cations or positively-charged ions pass through the membrane.
11. **Very little of the chemical energy released from the fuel used in a fuel cell is released as heat. In what form is the fuel's chemical energy released?**
    The chemical energy of the fuel cell is released in the form of electrical current.

ChemMatters Puzzle: DOUBLE or NOTHING

In this puzzle, there are TWO possible answers to each clue, so if you think you're done after one, think again! We've filled in the letters both words SHARE. Your task is to find at least two words that match the clue, all from the world of chemistry.

> Here's an example: A period 4 transition metal: CO_ _ _ _
> The answers would be Copper and Cobalt.

See how well you can do with these thirteen. And if at first you DO succeed, then try, try again!

1. A transition metal that doesn't end in "ium" _ I _ _ E _
2. An alkaline-earth metal _ A _ IUM
3. An apparatus commonly used in labs _ L _ _ _
4. A particle found in a neutral H-2 atom _ _ _ _ _RON
5. A nuclear particle present in a hydrogen isotope _ R _ TON
6. An unsaturated hydrocarbon with 2 C atoms ETH_NE
7. A sugar with 5 carbon atoms _ _ _ OSE
8. Category of element grouping in periodic table NO_ _ _ _ A _
9. The giving or gaining of electron(s) _ _ _ _ _ TION
10. A form of oxygen found in nature O _ _ _ E
11. A measure of mass (not necessarily metric) _RAM
12. Suffix used when a polyatomic ion contains one or more oxygen atoms. _ TE
13. A unit in electro-magnetism derived from a scientist's name _ _ _ T

Answers to DOUBLE or NOTHING

1. nickel , silver
2. radium , barium
3. flask , clamp , plate (as in well plate)
4. electron , deuteron
5. proton , triton
6. ethene , ethyne
7. ribose , xylose
8. nonmetal , noble gas
9. oxidation , reduction
10. oxide , ozone
11. gram , dram
12. ate , ite
13. watt (from James WATT) , volt (from Alessandro VOLTA)

NSES Correlation

National Science Education Content Standard Addressed

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**Question From the Classroom**	**The Captivating Chemistry of Candles**	**Hindenburg: Formula for Disaster**	**How the Cookie Doesn't Crumble**	**The Solid Facts about Trans Fats**	**Beyond Hydrogen: The New Chemistry of Fuel Cells**
Science as Inquiry Standard A: and abilities to do scientific inquiry.	✓			✓		
Science as Inquiry Standard A: about scientific inquiry.	✓		✓	✓	✓	
Physical Science Standard B: of the structure and properties of matter.	✓	✓	✓	✓	✓	✓
Physical Science Standard B: of chemical reactions.		✓	✓	✓	✓	✓
Physical Science Standard B: of interaction of energy & matter.		✓				✓
Science and Technology Standard E: about science and technology.		✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of personal and community health.					✓	
Science in Personal and Social Perspectives Standard F: about natural resources.		✓				✓
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.			✓		✓	
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.		✓	✓	✓	✓	✓
History and Nature of Science Standard G: of science as a human endeavor.			✓	✓		
History and Nature of Science Standard G: of the nature of scientific knowledge.		✓	✓			✓

History and Nature of Science Standard G: of historical perspectives.		✓	✓		✓	✓

Anticipation Guides

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

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

The Captivating Chemistry of Candles

Me	Text	Statement
		1. Candles were first used in the 1800s.
		2. Paraffin, used to make almost all candles, comes from petroleum.
		3. Paraffin is a compound.
		4. Wax can come from animals, vegetables, or minerals.
		5. Candle wicks are treated with flame-retardant solutions.
		6. Paraffin wax must be in the vapor state to travel up the wick.
		7. Paraffin wax may burn in the vapor, liquid, or solid state.
		8. Burning paraffin wax produces carbon dioxide gas and water vapor.
		9. In the hottest region of the candle flame, temperatures reach about 800 °C.

		10. The bright yellow color of the candle flame is produced by glowing carbon particles.
		11. Candles burn aboard the space shuttle much like they do on Earth.
		12. Trick birthday candles that re-ignite contain magnesium in their wicks.

Hindenburg: Formula for Disaster

Me	Text	Statement
		1. The Hindenburg airship exploded.
		2. The Hindenburg was larger than four Goodyear blimps combined.
		3. The Hindenburg was designed to use helium, not hydrogen.
		4. Hydrogen burns with a yellow flame.
		5. The Hindenburg was painted with a mixture similar to what is found in sparklers and the Space Shuttle’s Solid Rocket Boosters.
		6. The Hindenburg was struck several times by lightning before the fateful day that it was destroyed.
		7. Solid rocket fuel burns quickly compared to H_2 gas.
		8. The Discovery Channel’s “Myth Buster” series concluded that the fire on the Hindenburg was caused by burning hydrogen.

How the Cookie Doesn’t Crumble…and Other Sweet Chemistry Secrets

Me	Text	Statement
		1. Fats with higher melting points spread sooner in the baking process.
		2. In baking, sugar and fat are creamed together to create air bubbles.
		3. Baking soda must be mixed with an acid in order for the dough to rise.
		4. Just a little baking soda is needed to make cookies.
		5. Cookies get their structure from fats.
		6. In addition to making cookies sweet, sugar helps make cookies moist.
		7. Commercial bakers measure ingredients by volume.

The Solid Facts about Trans Fats

Me	Text	Statement
		1. Fats that are liquids at room temperatures are called oils.
		2. Unsaturated fats are produced by many animals, particularly mammals.
		3. Unsaturated fats have the maximum number of hydrogen atoms possible bound to carbon atoms.
		4. Fats contain only hydrogen and carbon.
		5.*Trans* fats have a longer shelf life than other types of fats.
		6. “Partially hydrogenated” fats are trans fats.
		7.*Trans* fats contain only single bonds.
		8. Margarine is healthier than butter.

Beyond Hydrogen: The New Chemistry of Fuel Cells

Me	**Text**	**Statement**
		1. Global warming was not foreseen by chemists until the late 20th century.
		2. Hydrogen fuel cells produce water vapor and methanol.
		3. Fuel cells generate much more waste heat than gasoline engines.
		4. Most fuel cells contain platinum catalysts.
		5. Producing hydrogen from hydrogen-containing compounds generates greenhouse gases.
		6. Race cars have used methanol fuel cells for many years.
		7. Methanol fuel cells can produce their own fuel.
		8. Finding new catalysts for fuel cells is a challenge for future chemists.

Content Reading Guides

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

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

The Captivating Chemistry of Candles

Directions: In the chart below, describe each part of a candle and indicate where they are found by drawing a burning candle in the space on the right.

Part	**Chemical Description**	**Drawing**
Flame		
Wick		
Paraffin		

Hindenburg: Formula for Disaster

Directions: In the chart below, compare the different theories explaining how the Hindenburg was destroyed.

Bain's Incendiary Paint Theory (IPT)	
Claims	**Evidence**
Dessler's Theory	
Claims	**Evidence**

How the Cookie Doesn't Crumble…and Other Sweet Chemistry Secrets

Directions: As you read the article, please complete the chart below.

Cookie Ingredient	Chemical Description and Formula (if given)	Purpose in Cookies
Fat		
Baking soda		
Baking powder		
Wheat		
Eggs		
Sugar		

The Solid Facts about Trans Fats

***Directions*:** Please complete each chart below, comparing and contrasting the fats listed. Write the differences in the rectangles to the left, and the similarities in the rectangle on the right.

Fats		**Similarities**
Oils		

Saturated fats		**Similarities**
Unsaturated Fats		

Cis Fats		**Similarities**
Trans Fats		

Beyond Hydrogen: The New Chemistry of Fuel Cells

Directions: In the chart below, compare and contrast hydrogen fuel cells with methanol fuel cells.

	Hydrogen Fuel Cell	**Methanol Fuel Cell**
Membrane		
Anode Catalyst		
Cathode catalyst		
Chemical reactions		
Advantages		
Disadvantages		

The Captivating Chemistry of Candles

Background Information

More on the history of candles

The Egyptians are often credited with using the first candle by 3000 B.C., but their version consisted of burning the cores of reeds that had been soaked in animal fat. While these used animal fats as the fuel, the torches did not have a wick, and are therefore sometimes not considered true candles.

The Romans are credited with developing the first true candle, using rolled papyrus soaked repeatedly in melted tallow or beeswax. They used them to light their homes, for nighttime travel, and for religious ceremonies.

Early Chinese candles used rice paper as their wick, and the wax consisted of indigenous insects and seeds mixed together. Japanese candles used wax extracted from nuts, and in India, candle wax came from the fruit of cinnamon trees.

In religious ceremonies, candles have been traced back to as early as 165 B.C., to the first Jewish celebration of Hanukkah, the Festival of Lights. There are also Biblical references to candles.

Native American Indians are known to have burned oily fish (aptly called candlefish) in the crooks of tree branches (removed from the tree, of course).

Candle development remained relatively unchanged for many centuries, depending on rendered animal fat (tallow) as the fuel, and plant fibers as the wick. Burning tallow produces lots of smoke, soot and smells. A vast improvement came sometime during the Middle Ages when beeswax was first used as a candle fuel. This wax burns much cleaner with a somewhat sweet odor. They were kept for special occasions, especially religious observances, however, because they were much more expensive, so much so that only wealthy people could afford them.

Candle-making became a business for many in Europe during this time. The chandlers, as they were called, traveled from house to house and made candles on-site from the animal fat that the households saved for just that occasion.

I'm sure you've heard of bayberry candles, but did you know that the original bayberry candles were made by women right here in the United States in Colonial times? And that they were made completely of the wax from bayberries? Unfortunately, once again, the process is tedious and the candles' popularity waned.

It was whaling in the 18th century that brought about the next great change in candle-making. Spermaceti, a wax from whale oil, became abundant as more whales were killed. This wax burned with a clean flame and didn't smell bad. It also burned hotter, and was harder than tallow or beeswax, so it didn't soften during hot summers. The first "standard" candles were made from spermaceti. Whale oil was also used as a high-grade lubricant, used primarily for steam engines in trains. Whaling brought many species of whales close to extinction.

Luckily (for the whales, especially), a U.S. patent had been granted in 1850 to distill paraffin from coal, and thus paraffin became commercially available for candle production. Very shortly thereafter, in the 1850s, petroleum came along (think Colonel Drake and the first oil wells drilled in Titusville, PA) and provided both high-grade oils for engines, and paraffin that was used as a new fuel source for candles. Paraffin candles quickly replaced spermaceti candles, and the whale hunting business immediately declined.

Within a few years of the commercial availability of paraffin, stearin (a combination of stearic acid and glycerol) was added to paraffin to give it greater structural strength. The formulation of candles has not changed much since then, except for aesthetic changes—colors and smells and such.

With the distillation of petroleum and the subsequent abundance of kerosene as a lamp fuel, candles quickly faded in popularity as the light source of choice. From that point on, they were used primarily as decoration.

Much of the history of candles above was adapted from the National Candle Association, at http://www.candles.org/. The National Candle Association (NCA) is a trade group that oversees the candle industry in the U.S. It deals with trade issues, fire safety, and regulatory issues for all its members. It has been instrumental in combating a glut of candles from China by lobbying for the imposition of tariffs on Chinese candles, beginning in 1985, at 54%, and then again in 2003, at 108%.

It has also been instrumental in mounting a safety campaign, the goal of which is to make candle-burning in the home a safer experience. As candles became much more widely popular in the mid- to late-1990s, the association voluntarily called for the industry-wide labeling of all candles with safety precautions, and increased the fire-safety of glass containers for candles. They also initiated a consumer safety education program to alert people to the dangers of leaving lit candles unattended.

Until the mid-1970s, it had been common practice among candle manufacturers, to use lead in the core of candle wicks when necessary to maintain a straight wick, particularly in smaller votive candles which become liquefied quickly. Recognizing the problems associated with lead in the environment, the NCA called for the elimination of lead from candle wicks from all candles manufactured and distributed by its member companies at that time, more than 30 years before the government mandated such a move (2003). They also requested that all American candle-makers adopt such a policy several years before it became a federally mandated requirement. Today's candles requiring a stiff wick use tin or zinc as their cores.

More on the candle (and its history) in chemistry classes

In the early 1960s, the image of the burning candle became immortalized in chemistry labs with the development of the Chemical Education Materials Study, or Chem Study, a National Science Foundation sponsored chemistry curriculum designed to combat the perceived superiority of the Soviet scientific regime after the launch of Sputnik, the first satellite ever sent into space by man. The textbook for this curriculum was Chemistry: An Experimental Science, by W. H. Freeman and Company. The Chem Study curriculum was designed to make scientists or engineers out of America's students. It was an inquiry-based curriculum long before the term inquiry entered pedagogical circles.

In a report titled, "The Laboratory in Chemistry Education", Avi Hofstein of the Weizmann Institute of Science states, "During the major curriculum reforms in science education in the early 1960s, practical work in science education was used to engage students in investigations, discoveries, inquiries, and problem-solving activities." In other words, the laboratory became (at least in the minds of science educators and curriculum developers) the center of science teaching and learning. For example, George Pimentel editor of the Chem Study project (summarized by Merrill & Ridgway, 1969) suggested that "…the laboratory was designed to help students gain a better idea of the nature of science and scientific investigation by emphasizing the discovery approach." This report can be found at http://www.uoi.gr/cerp/2004_October/pdf/06HofsteinInvited.pdf.

The burning candle became the icon of the Chem Study project, and a full-page close-up photograph of the top of a burning candle and its flame was placed on the first page of the first edition of the textbook, opposite the first page of chapter 1. The caption under the photograph states, “THE CANDLE—ILLUMINATING CHEMISTRY”.

The first experiment in this curriculum involved a candle and matches, and that’s all. Students had to observe the candle, before it was lit and during and after the burning process, and record as many observations as they could. The goal of the experiment was to help students become keen scientific observers, and to set the stage for all the remaining laboratory investigations to follow. So if you use a similar experiment in your classes today, you have the Chem Study collaborators to thank for it.

A later experiment contained several extensions to the simple observations, including testing the products of the candle’s burning with cobalt chloride paper (for water) and with limewater (for carbon dioxide). The experiments are found in the Laboratory Manual for Chemistry: An Experimental Science, the original laboratory manual that accompanied the Chem Study textbook. The manual was also published by W.H. Freeman and Company. The manual is now out of print, but you may be able to access a copy from a more experienced teacher in your school, or from a teacher at a school near you. An online search for the title at
http://www.google.com/products?hl=en&q=Chemistry+An+Experimental+Science+Laboratory+Manual,+W.H.+Freeman&um=1&ie=UTF-8&sa=X&oi=product_result&resnum=1&ct=title
found several booksellers who have used copies of the lab manual available for prices ranging from $2.95 to $6.95 (plus shipping), which is right around the new book price for the manual when it was first distributed, back in the 1960’s.

Although the original candle experiment may not be immediately available to you, the experiment by the author of the article, Brian Rohrig, at the end of this section of this Teachers Guide will give you some of the flavor of what the original experiment was trying to accomplish with students.

The Chemical Education Materials Study project also produced an extensive teacher’s guide for the book. It included very detailed curriculum notes for the text, instructions for the teacher for all the experiments, and also tests for each chapter. Most textbook companies do this routinely today with their teacher ancillary materials, but such was not the case in the 1950’s and ‘60’s. Chem Study was the first group to see the need for this extensive ancillary material to help teachers.

In addition to the teacher materials, the project also produced a series of chemistry films to accompany the textbook. These films also showed the candle in the opening frames, with the Chem Study logo superimposed over the burning candle. Many teachers today still use the Chem Study series of 16mm films (now revised and edited to VHS or DVD).

Most of the “standard” high school chemistry textbooks of today owe much of their content and approach to the original Chem Study curriculum. Many of the original Chem Study experiments are still the basic labs used in high school chemistry textbooks and classrooms today.

There doesn’t seem to be much of the original documentation online anywhere (after all, Chem Study preceded the internet by several decades), but you can get a little sense of what it tried to accomplish if you access this site: http://www.x98ruhf.net/ruhf.pdf and read the early parts of chapter 2, which deals with the effects of Sputnik on American schools, and the goals of the major science curriculum projects funded by the National Science Foundation at that time.

If you’re interested in reading more (hard copy) about the Chem Study project, Richard Merrrill and David Ridgway published a book called The Chem Study Story that summarizes the entire project, from start to finish. The book is out of print, but it can be obtained from numerous online book sale sites. You can find a one paragraph abstract about the book here:
http://www.uoi.gr/cerp/2004_October/pdf/06HofsteinInvited.pdf.

The original films from the Chemical Education Materials Project are housed in the collections of the Chemical Heritage Foundation, and the Foundation also has copies of The

Chem Study Story, Chemistry: An Experimental Science, and Laboratory Manual for Chemistry: An Experimental Science. You can access the web site at www.chemheritage.org and click on "Library" on the top row toolbar to see their holdings. You cannot, however view the actual book, only the call numbers and title.

More on paraffin

Paraffin is the chemical term for all straight-chain hydrocarbons, from methane, CH_4, on up. They all have the general formula, C_nH_{2n+2}. Paraffins are all straight chain hydrocarbons. If branched, they are known as isoparaffins. Paraffin wax exists as a solid because of its large molecular size ($C_{20}H_{42}$ and larger), which results in increased van der Waals forces along the surfaces of the paraffin molecules. Increased molecular interactions result in increased attractions between molecules, making it more difficult to pull them apart. Smaller molecules, like methane, ethane and propane, CH_4, C_2H_6, and C_3H_8, respectively, are gases at room conditions due to very small van der Waals forces, while larger molecules, like hexane and octane, C_6H_{14} and C_8H_{18}, are liquids at room conditions. See Demonstrations and Lessons, below, for more information.

Connections to Chemistry Concepts

1. **Organic chemistry**—Paraffins are straight chain alkanes. This might be a good way to segue into smaller alkanes—also used as fuels.
2. **Physical/chemical properties—**the properties of the various fuels used for candles make them more/less desirable as a candle.
3. **Homologous series and phase—**The phase of a straight-chain organic alkane compound relates to the number of carbon atoms in its formula.
4. **Burning, combustion—**The burning process, especially in the candle, is not easy to understand. There is a lot going on there that students can't see, and therefore don't believe is happening.
5. **Thermochemistry—**Burning is an exothermic reaction.
6. **Flame temperatures—**The article mentions that a candle flame ranges from 800 (the "dark" part of the flame) to 1400oC (the blue part of the flame), while the temperature of a Bunsen burner flame (always a blue color, once adjusted properly), for example, approaches 1600oC.
7. **Chemical equations—**Combustion reactions are one of the (typically) five types of reactions discussed in an introductory chemistry course.
8. **Polar and nonpolar substances—**Capillary action results from the forces that arise from the interactions of these substances.
9. **Light and electronic structure—**The incandescence of the heated carbon particles in the candle flame is related to the electronic transitions they undergo.
10. **Metals (in trick candles)—**Most students think metals don't burn.
11. **Chemical safety—**burning candles (in the lab or at home) can be a safety hazard if precautions are not taken. For a complete list of safety rules concerning the burning of candles, visit the National Candle Association's safety rules web page: http://www.candles.org/safety_rules.html.

Possible Student Misconceptions

1. **"The wick in the candle is really the only thing burning. The wax is just there to slow down the burning process (or to support the wick)."** *No, the wax is burning, it's just that it is wax vapors that are burning, and we can't see the vapors. The burning process is much more complicated than meets the eye. See Bob Becker's response to just this question/misconception in "Questions from the Classroom", on p. 2 of the February 2005 issue of ChemMatters. He answers a student's question—what actually burns in the candle flame? Access the article at* http://membership.acs.org/C/Chicago/statefair/CD-2006/Chemmatters/2005_2_smpissue.pdf
2. **"All candles are made of the same material." Or, "Candle wax is candle wax."** Although the vast majority of candles are made off paraffin, the article also mentions beeswax candles. And the history of candles above cites many different fuels that have been used for candles over time. See Demonstrations and lessons below for a description of a demonstration of an edible candle.
3. **"Candle flames are really hot."** *Actually, that's not a misconception—just not complete enough. While it's true that a candle flame is hot enough to start other things burning, a candle flame is cool relative to the flame of, say, a Bunsen burner or an acetylene torch. Everything's relative.*
4. **"When a candle burns clean (no visible soot), it's not making any pollution."** *Actually, since candles produce carbon dioxide, and scientists now believe that carbon dioxide produced by man is at least partially responsible for global warming, carbon dioxide can be considered a pollutant in the burning of a candle.*
5. **"Isn't the top of the flame the hottest? That's where I burn my finger."** *As stated in the article, the hottest part of the flame is the bottom portion, the blue part of the flame. Here the burning process produces only carbon dioxide and water vapor. In the cooler parts of the flame, other products are present; e.g., elemental carbon and possibly unburned wax vapors. The elemental carbon collects as soot*

Demonstrations and Lessons

1. This NASA site for grades 9-12 students discusses the need for fire prevention in space. Following the article is a series of experiments—one of which is about burning a candle, that gives both a student and a teacher page describing a basic set of mini-experiments to do with a burning candle to answer many questions about the process of burning; one on : http://www.nasaexplores.com/show2_912a.php?id=01-064&gl=912. Unfortunately, several internal reference links are no longer valid, although the experiment remains workable without them.
2. This NASA site provides a ready-made experiment for students to simulate a candle flame in microgravity: http://quest.nasa.gov/space/teachers/microgravity/9flame.html. The site includes student instructions, data tables, and teacher notes about the activity. The activity can also be done as a teacher demonstration. Another site that lists a ready-made student activity is at the Exploratorium: http://isaac.exploratorium.edu/~pauld/activities/freefall/freefallcandle.html. A NASA site with more detail about how to construct a more permanent structure to test conditions in microgravity can be found here: http://microgravity.grc.nasa.gov/mini/minit.htm. This activity could also be done as a student project. Thus these web sites have also been listed in the Student Project section below.
3. For students who think all candles are made out of paraffin, check out Terrific Science's web site for a description of how to make an edible candle out of an apple and an almond. The site

also has a short video showing a demonstrator eating her candle after burning it. The site: http://www.terrificscience.org/movies/pdf/illuminating_demo.pdf. Here's another site, Doing Chemistry, by David Brooks at the University of Nebraska-Lincoln, that does the same thing with a potato and nut. This site is a complete package, with student data page for the experiment/demonstration, teacher instructions to make the candle, hazards, hints, disposal, and a video series that shows you the complete construction process. Find it at: http://dwb.unl.edu/Chemistry/DoChem/DoChem008.html. This is a very worthwhile site to bookmark for lots of demonstrations. This demonstration is usually used early in the year to help students to differentiate between observations and inferences. They infer that since the candle is burning it must be made of candle wax (based on their previous experiences). The subsequent observation that it is edible disproves their inference (unless the teacher is just plain crazy, as they have suspected all along anyway).

4. You can do a very simple demonstration about combustion by holding a beaker over a lit candle and slowly lowering the beaker until it extinguishes the flame. The discussion that follows focuses on what caused the flame to go out – build up of CO_2 or lack of oxygen? It's interesting to ask students to individually choose one of the two and offer evidence to support it. Which one actually causes the flame to go out? Or is it something else altogether? Many mini-experiments can be designed to test the hypotheses.
5. A typical demonstration that is done in many chemistry classes is the one in which a burning candle is placed in a container with a shallow pool of water in it. A beaker is then placed (inverted) over the candle and set down in the water, and students watch as the water level rises into the beaker as the candle flame goes out. The water typically rises about one-fifth of the way up the beaker. The erroneous conclusion some teachers make is that this is proof the air is one-fifth oxygen (which was supposedly used up during the burning process). This web site debunks that myth and explains what actually happens, and shows an apparatus that avoids the pitfalls of the aforementioned demonstration: http://www.physics.umd.edu/deptinfo/facilities/lecdem/services/demos/demosi1/i1-64.htm. The site also shows how to use this demonstration effectively in classes.
6. There are experiments that focus on the relative melting points or boiling points of various alkanes in the homologous series. Here is an example from Vernier's *Chemistry with Computers*, Experiment 9, "Evaporation Rates of Alcohols". It uses probes to detect changes in temperature as various alkanes and alcohols evaporate from the tip of the temperature probes. Students plot temperature changes vs. time to see which liquid evaporate most quickly, and then relate that to the strength of intermolecular forces. Find it at http://education.ti.com/educationportal/activityexchange/download_file.jsp?cid=US&fileurl=Science%2FChemistry%2F3778%2F3778.pdf.
7. Another activity that is based on data given in the text can be found at http://dwb.unl.edu/calculators/activities/BP.html. This is another page from David Brooks' web site at the University of Nebraska-Lincoln. The activity was taken from the ACS *ChemCom* textbook. The activity contains 3 parts and deals with the first ten straight-chain alkanes in the homologous series. Students plot a graph of boiling point vs. number of carbon atoms to help them derive the relationship between boiling point and size of molecules. In the last activity they investigate isomerism and its effect on boiling point and try to explain how isomerism affects intermolecular forces.
8. To help students better understand the burning process, you might want them to experiment with the various parts of candles to see what is actually burning. A simple set of activities to get students to think about candle's burning process can be found at http://home.earthlink.net/~ssbeaton/labhints.html#candlelab. Students try burning just wax, just string (representing the wick), toothpick for a wick, etc.
9. You might want to show students that it is only wax in the vapor phase that burns by actually performing the demonstration that the author alludes to. Light the candle and allow it to burn for

awhile, until you can see the glowing ember on the end of the wick. Have a lit match ready, and blow out the candle. Quickly place the match in the smoke stream above the wick, being careful not to actually touch the wick. The candle will mysteriously relight due to the vapors still coming off the hot wick. Since the match didn't actually touch the wick, wax in the vapor phase is the only logical explanation for the reignition.

Brian Rohrig, the author of the candle article, also offers this suggested procedure for students, a possible replacement for the old Chem Study introductory candle experiment:

Candle Discovery Lab: Observations on a Burning Candle

Light a candle.

Make 100 observations (that's right—100!) about your burning candle.

After you have written your observations, draw your candle flame in color. Look carefully at your candle flame to make sure you have included all colors present.

After you have made your observations and drawn your diagram, answer the following questions:

1. What is the purpose of the wax in a candle?
2. Does the size of the candle affect the size of the flame?
3. Would your candle still burn if held upside down?
4. What phases of matter are present within a burning candle flame?
5. What is the purpose of the wick?
6. If the wick were replaced with a wood splint, would the candle still burn?
7. Why is the wick not consumed in a burning candle?
8. Why are there different colors within a candle flame?
9. Does the color of a candle determine the flame color?
10. Why is the region above a candle flame hotter than the region next to or underneath a candle flame?
11. Would a candle work in the absence of gravity, even though adequate oxygen was available?
12. Will two candles directly next to each other burn faster than if they were separated?
13. What would you observe if a burning candle was placed on a balance?
14. Why is liquid wax transparent, while solid wax is opaque?
15. Why does a candle flame have a conical shape?
16. When the candle is blown out what color is the smoke? Why is the smoke this color?
17. What three factors must be present in order for the candle to burn?
18. Where does wax go as the candle burns?
19. What prevents the entire candle from melting while it burns?
20. What must happen to the wax before it can burn?

Student Projects

1. You might want to have students research the history of lead cores in candle wicks, and then follow that up with research on the tin and zinc cores used in today's solid-core wicks, with particular focus on studies dealing with the safety of burning these metals in candles. They could start their search here: http://www.braidway.com/Breaking%20News/Lead%20Info.htm. Keep in mind, however, that this site is run by Atkins & Pearce, a prominent wick-manufacturing company. They might also check out http://www.leadfreecandles.org/, a letter from the American Lung Association, and discuss the relevance of this letter in the lead-core wick argument. Both the above sites were listed as links on this site: http://www.leadfreecandles.org/.
2. Students might be interested in experimenting with candle flames during free fall. They can begin looking at this Exploratorium site for ideas: http://isaac.exploratorium.edu/~pauld/activities/freefall/freefallcandle.html, or this NASA site: http://quest.nasa.gov/space/teachers/microgravity/9flame.html. For more details on how to construct a drop tower mechanism, see http://microgravity.grc.nasa.gov/mini/minit.htm. These sites have also been cited in the Demonstrations and Lessons section, if you would prefer setting it up as a demonstration or classroom student experiment.
3. Students might be interested in researching candles and their effect on global warming. They could determine experimentally how much carbon dioxide is produced by a typical (?) candle, do research to discover how many candles (order of magnitude here?) are burned annually, and determine how much candle-burning contributes to the CO_2 greenhouse gas problem and climate changes.

Anticipating Student Questions

1. **"How can they use a fish as a candle?"** *The candlefish is very oily. When dried, the water is gone, but the oils remain. The oil serves as a great fuel.*
2. **"What happens to the wax when a candle burns?"** *As described in the article, the solid wax is melted by the heat of the flame. The melted liquid wax is carried up the wick by capillary action until it reaches the area of the flame. There it gets so hot that it vaporizes (boils). As a gas, it instantaneously mixes with the oxygen of the air. The heat is sufficient to break bonds between the carbon and hydrogen atoms and between the carbon and other carbon atoms, and then bonds between the hydrogen and oxygen atoms, and between the carbon atoms and oxygen atoms reform, thereby releasing lots more heat to continue the process. Some of the carbon atoms are left unburned. These heat up to the point of incandescence—they're so hot they glow; that's candle light.*
3. **"I've heard that some wicks are made of lead. Is that true?"** *Wicks used to contain lead to help support the wick in candles which tend to get very hot and have large liquid pools of wax (like votive candles), but the federal government no longer allows lead to be used for wicks because lead in wicks vaporizes from lead wicks and gets into the air which people breathe. Today, zinc is used instead.*
4. **"Why does a candle get shorter as it burns, if the wick is the only thing burning?"** *The wick isn't the only thing burning—it's not even the major thing burning. The wick is merely the site where burning of the fuel—the wax—takes place. As the wax burns away, there is literally less of the candle left; hence, it gets shorter.*
5. **"What is it about large molecules being sluggish that makes them form a solid?"** *It isn't really just that they're sluggish, so much as that they have lots of surface atoms that can interact with surface atoms on other molecules. This causes greater intermolecular*

> *attractions, resulting in stronger forces holding the molecules to one another, making it harder to separate the molecules from one another. The extra force requires more energy, thus making their melting and boiling points higher. At room temperature, therefore, they are more likely to exist as solids.*

References

Faraday, Michael. *The Chemical History of a Candle.* The Viking Press: NY, 1960.

Websites for Additional Information

The references below all can be found on the *ChemMatters* 20-year CD, obtainable from ACS for $25 (or a site/school license for $99) at this site: http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccurriculum%5Ccmprods.html#CDsite.

A student's view of the Chem Study classic experiment involving observing a candle can be found here: "The Phantom Flame", Kelly Stuart, *ChemMatters*, October, 1990, p. 13.

A story about John Dalton's discovery of color-blindness that occurred because of his observations of the apparent changing color of flowers in candlelight vs. in daylight can be found here: "THE BACK BURNER: John Dalton's First Paper and Last Experiments", Derek A. Davenport, *ChemMatters*, April, 1984, p. 14.

A segment of this article deals with the changing color of a gem in daylight vs. in candlelight: "The Color of Gems", William S. Harwood, *ChemMatters*, December, 1988, p. 7. This article also shows the spectrum of candlelight vs. that of sunlight, to help explain the difference in appearance of various colored objects under different lighting conditions.

The September 2001 issue of *ChemMatters* contains an article on pages 10 and 11, entitled, "Carbon Dioxide: A Pourable Greenhouse Gas", by Bob Becker. This experiment for students describes how to produce carbon dioxide from vinegar and baking soda and then to contain it in a very simple 2-L soda bottle apparatus to use for other investigations, including observing what happens to a candle lowered into the CO_2.
For more information on CO_2's role (and that of other gases as well) in the greenhouse effect and on Earth's climate, check out "Life in a Greenhouse", Helen Herlocker, ChemMatters, October 2003, pp. 18-21. Actually, the entire October issue is dedicated to atmospheric chemistry.

A sidebar ("The First Atmospheric Modeler?") in another article in the *ChemMatters* October 2003 issue, "Beefing Up Atmospheric Models", by Kevin McCue, pp. 25-28, focuses on Svante Arrhenius, the first scientist to predict an atmospheric temperature increase due to increased carbon dioxide emissions.

The following more recent *ChemMatters* article can be directly accessed online:

“Questions from the Classroom”, by Bob Becker, in the February 2005 issue of *ChemMatters*, answers a student’s question—what actually burns in the candle flame? Lots of kids think it’s only the wick that burns, and Bob addresses this misconception. Access the article at http://membership.acs.org/C/Chicago/statefair/CD-2006/Chemmatters/2005_2_smpissue.pdf.

More sites on the history of the candle

The National Candle Association, a trade group, gives a brief history of the candle at http://www.candles.org/about_history.html.

Wikipedia gives a fairly concise history of the candle at its web site: http://en.wikipedia.org/wiki/History_of_candle_making. No citations are given.

A web site containing Michael Faraday’s “Chemical History of a Candle” can be found at http://www.fordham.edu/halsall/mod/1860Faraday-candle.html. This site contains text only.

Another site that houses the entire book of Faraday’ candle observations can be found at Bartleby.com’s Great Books Online, at http://www.bartleby.com/30/7.html. This web page is the first chapter of the book. Click the “next” button to see each succeeding chapter. This site includes Faraday’s diagrams that accompanied his original work.

Or you can download a copy of Faraday’s book for free from Project Gutenberg, at http://www.gutenberg.org/etext/14474. Click on one of the download buttons at the lower right. This version, too, is text only.

More sites on observations of a candle

This site contains over 100 observations of the burning candle: http://boomeria.org/labschem/candleobserv.html.

More sites on candle flames in microgravity

This NASA video clip from experiments done on the MIR space station shows how a candle flame behaves in microgravity: http://microgravity.grc.nasa.gov/combustion/video/cfm_mir_broad.mov.

Here is a close-up photo of a candle burning in microgravity, from Wikipedia: http://en.wikipedia.org/wiki/Image:Candlespace.jpg.

This NASA still photograph compares a candle burning normally on earth with one burning in microgravity: http://microgravity.grc.nasa.gov/combustion/graphics/candles_compare_lg.jpg.

For a very detailed description of candle flames in microgravity aboard shuttle flights and the Mir space station, see: http://zeta.lerc.nasa.gov/cqa/r1.htm.

If students (or you) really get "into it" and want to see more, NASA has a whole series of downloadable short video clips that show different aspects of combustion in microgravity at: http://microgravity.grc.nasa.gov/combustion/web/video_collection.htm.

Discover magazine ran an article describing some of Paul Ronney's work at NASA on tiny fireballs burning in microgravity. You can access the article, "The Physics of Fire", by Robert Kunzlg, from the January, 2001 issue, at: http://discovermagazine.com/2001/jan/featphysics/?searchterm=microgravity%20combustion.

This NASA site contains a description of the experiments in NASA's microgravity drop tower in Ohio at which Paul Ronney first discovered flame balls (before they experimented on them in space, or even in the zero-gravity airplane flights). It also contains several video clips that can be accessed at the end of the article. Find it at: http://microgravity.grc.nasa.gov/combustion/web/Floating%20Flame%20Balls.htm.

More sites on trick candles

This site describes how a trick birthday candle works, from "HowStuffWorks": http://www.howstuffworks.com/question420.htm. It includes a video clip close-up of a candle on a cupcake that illustrates the magnesium sparking in the candle.

This isn't exactly a trick candle, but here's a patent from the U.S. Patent Office for a wind-resistant candle: http://patft.uspto.gov/netacgi/nph-Parser?u=%2Fnetahtml%2Fsrchnum.htm&Sect1=PTO1&Sect2=HITOFF&p=1&r=1&l=50&f=G&d=PALL&s1=6652269.PN.&OS=PN/6652269&RS=PN/6652269. This site gives the entire text of the original patent, and if you click on the "Images" button, you'll see the patent applicant's drawings that accompanied the application.

YouTube has many videos on trick candles. Here's one that shows a birthday cake and a young girl trying to blow out her candles. A sparkler on the cake burns down and goes out, but the candles just keep on burning! http://www.youtube.com/watch?v=oL9UE3r4OeQ&NR=1

More sites on the burning process in a candle

This site gives another view of the background about the candle burning process, http://www.sfsite.com/fsf/2000/pmpd0008.htm. Although it is a science fiction site, the description of burning is very accurate. The article, "Playing with Fire" is narrated in a light-hearted style, in the context of investigating a candle burning as one dines in a restaurant. The authors of the article have some connection to the Exploratorium. Skip the first two sections and scroll down to the section, "Read this by Candlelight" to get to the meat of the article. It is probably not a good site to which to direct students, however, as the second part of the experiment involves making a flaming alcoholic concoction (why I do not know).

Hindenburg: Formula for Disaster

Background Information

More on hydrogen

Hydrogen is the most abundant element in the universe. It makes up about 90% of all matter by mass. Its low density and high flammability are its two most important properties, especially so for this article. It burns with a pale blue flame which is nearly invisible, another fact that plays an important role in this article. Its heating value is more than double that of most fuels like natural gas and propane.

Properties

Colorless	
Odorless	
Tasteless	
Flammable	
Boiling Point	–252.7°C
Melting Point	–259.2°C
Density	0.0899 g/L
Flammable range in air (by volume)	4.0-75%
Enthalpy of combustion	–286 kJ/mol
Expansion Ratio	1:848

The U.S. produces about 9 million tons of hydrogen per year, enough to power more than 5 million homes. Most of it is produced in just three states—California, Louisiana and Texas. Elemental hydrogen cannot be isolated from natural sources, so it is produced chemically from hydrogen compounds. About 95% of all hydrogen is produced by a process called steam reforming of natural gas (CH_4). In the first step in this process, steam is passed through the natural gas to produce hydrogen and carbon monoxide:

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

A second step produces more hydrogen by exposing the CO to additional steam:

$$CO + H_2O \rightarrow CO_2 + H_2$$

Some hydrogen is also produced by electrolyzing water.

Hydrogen can be used as an energy fuel, both as a primary fuel for rockets (as liquid hydrogen) and in fuel cells. NASA is the largest user of fuels cells, which are the electrical sources for spacecraft. In industry, hydrogen is used in refining, metal treating and in food processing. For more on fuel cells, see the article in this edition of *ChemMatters*.

In 1671, Robert Boyle reported the results of a reaction between dilute acids and iron filings in which a flammable gas was produced. The gas was hydrogen. Nearly a century later, Henry Cavendish recognized the gas to be a distinct element and that it produced water when burned. In 1783, Lavoisier reproduced Cavendish's work and named the gas hydrogen.

Also in 1783, the Montgolfier brothers achieved the first manned hot air balloon flight, and about 10 days later Jacques Charles flew in a balloon filled with hydrogen. Both flights occurred in Paris. By the 1790's hydrogen was being used in balloon flight on a regular basis.

More on helium

Most students will not know that helium is the second most abundant element in the universe, second only to hydrogen. It is created by the alpha decay of heavier elements and diffuses into the atmosphere where it then escapes into space at roughly the same rate at which it produced. Thus, its concentration in the atmosphere at sea level is about 5.25 ppm. Some of the helium produced by nuclear decay in the earth's crust, however, is trapped in relative high concentrations in natural gas deposits. Its modern method of production is by separating it from natural gas by fractional distillation.

Properties

- Colorless
- Odorless
- Tasteless
- Very insoluble in water
- Density 0.178 g/L (at 20°C)
- Melting Point –272.2°C
- Boiling Point –268.9°C
- Heat of fusion 5.23 kJ/mol
- Chemical reactivity—inert

As the article states, the reason that the Hindenburg was filled with hydrogen rather than the more desirable helium was that the United States held most of the world's supply of helium. Research done at the University of Kansas just prior to World War I showed that helium could be extracted from natural gas deposits, most of which were in the U.S. southwest, primarily in Texas. Between the World Wars, the United States developed large scale helium production methods by fractional distillation, and by the late 1930's the helium supply was a U.S. monopoly. Germany, therefore, had to resort to hydrogen for its dirigibles. Between 1915 and 1940, the price of helium dropped from about $2500/cubic foot to about 1.5 cents/cubic foot.

According to the Bureau of Land Management (which is responsible for helium production in the United States), "The United States government became interested in helium during World War I." The Army valued it as a safe, noncombustible alternative to hydrogen for use in buoyant aircraft.

"In 1925 Congress created a Federal Helium Program to ensure that helium would be available to the government for defense needs. The Bureau of Mines constructed and operated a large helium extraction and purification plant just north of Amarillo, Texas, that went into operation in 1929. From 1929 to 1960 the federal government was the only domestic producer of helium.

"During and after World War II the demand for helium increased. In response, Congress passed amendments to the Helium Act in 1960. The amendments provided incentives for private natural gas producers to strip helium from natural gas and sell it to the government. The Secretary of the Interior was given authority to borrow money from the U.S. Treasury to buy helium. Some of this helium was used for research, NASA's space program, and other applications, but most was injected into a storage facility known as the Federal Helium Reserve. The 1960 amendments required the Bureau of Mines to set prices on the helium it sold that would cover all of the helium program's costs and repay its debts.

"Federal demand for helium did not live up to post-war expectations, and by the 1990's private demand for helium far exceeded federal demand. The 1996 Helium Privatization Act redefined the government's role in helium production. The Bureau of Land Management was made responsible for operating the Federal Helium Reserve and providing enriched crude helium to private refiners."

The Federal Helium Reserve, located near Amarillo, TX, supplies 40% of the U.S. demand and 35% worldwide. As of the date of this publication, there is a severe shortage of helium. Part of the shortage has been created by increasing demand, but much of it is due to delays in bringing new helium refining plants online in Qatar and Algeria and maintenance problems in U. S. plants.

Most uses of helium depend on its low density, low boiling point or its inertness. In addition to uses in lighter-than-air craft, helium is used as a protecting gas in arc welding processes. It is used as a coolant for superconductors and MRI instruments, nuclear reactors and in cryogenic research. It is used as a carrier gas for gas chromatography and in helium-oxygen diving systems. Silicon and germanium crystals as well as optical fibers can be produced best in a helium atmosphere. NASA uses the gas as a pressurizer for liquid fuel rockets. Less than ten per cent goes to fill helium party balloons.

More on buoyancy

The article states that the hydrogen filling the Hindenburg has a density of 0.08988 g/l. The surrounding air has an approximate density of 1.24 g/l. The article says that this difference in densities is what causes hydrogen-filled bladders to float in air. The simplest method of teaching students about buoyancy in a chemistry course is, in fact, to compare densities. Students have probably been taught that a balloon filled with helium floats in air because the density of helium is less than the density of the surrounding air. This “method of densities” is most easily shown using liquids—in a density column demonstration, for example.

Both hydrogen and helium are used in dirigibles and blimps because of their negative buoyancy in air, which means they float in air. The buoyancy of a ship like the Hindenburg is due to the fact that the hydrogen that fills its bladders weighs less than the air displaced by the craft. Objects placed in a fluid displace an equal volume of the fluid. The displaced fluid exerts an upward-acting buoyant force on the object. Gravity exerts a downward-acting force on the object (the object’s weight). If the buoyant force is greater, the object will float. If the object’s weight is greater, the object sinks in the fluid.

Buoyant force on an object in a fluid can be calculated in the following way:

$$F_{(buoyant)} = (d)(V)(g)$$

Where d = density of the fluid
V = volume of the object
g =9.8 N/kg

Note that the volume of the object and the volume of the displaced air are equal. The strengths of the opposing forces (buoyancy and gravity) are determined by the mass (or weight) of those equal volumes, but that means we are comparing the density (mass over volume) of the object with the density (mass over equal volume) of the fluid. So if the density of the *object* is greater, the object sinks in the fluid. If its density is less than the fluid’s, the object floats in the fluid.

The object in the case of this article is the Hindenburg, which is filled with hydrogen gas. The fluid is the surrounding air. Since hydrogen’s density is so much less than that of the surrounding air, the hydrogen floats, taking, of course, the structure of the Hindenburg with it. It is interesting to note that the buoyant force in this case is sufficient to “float” not only the hydrogen and the bladders that contain it, but also the weight of the Hindenburg’s frame and skin.

From a chemistry vantage point, you may want to relate this to Avogadro’s Law. If we compare two gases of equal volumes, we know from the law that there are equal numbers of molecules in each sample. Therefore, the gas with the lower molecular mass will be lighter than the other. In this article, you can think about the “lighter” gas being either helium or hydrogen and the “heavier” gas being air (actually a mixture of gases).

More on lighter-than-air transport

As mentioned above, in 1783, the Montgolfier brothers achieved the first manned hot air balloon flight, and about 10 days later Jacques Charles flew in a balloon filled with hydrogen.

Both flights occurred in Paris. By the 1790's hydrogen was being used in balloon flight on a regular basis. The first balloon flight in America took place in Philadelphia in the 1790's and reached a height of nearly a mile.

A word about terminology is in order here. There are several types of lighter-than-air crafts. The earliest type, as described above, is *hot air balloons*. These balloons were filled with air, which was then heated by some means. The air expands (according to Charles' Law) and its density decreases causing the balloon to rise in the atmosphere. By regulating the degree of heating and by regulating the craft's ballast, the balloon's altitude can be regulated.

During the 1800's hot air balloons were replaced with gas-filled balloons. Although other gases like natural gas were used, hydrogen became the gas of choice in this time period. Remember that helium was not isolated until the late 1890's. The hydrogen was produced using metal-acid reactions. During the Civil War and World War I, hydrogen balloons were used as observation posts. These balloons were steerable and so were properly called blimps or dirigibles. Lighter than air gas balloons that can be steered are usually called blimps.

The term dirigible is often used synonymously with the term blimp, but dirigibles often have a rigid structure, while blimps do not. Among the best known rigid airships were those designed by Ferdinand Adolf August Heinrich Graf von Zeppelin founder of the Zeppelin Airship Company in Germany. The Hindenburg was a Zeppelin airship.

More on the Hindenburg disaster

During World War I, Germany had used zeppelins in bombing raids over Europe. Most of the fleet was destroyed, however. After World War I, Germany again began building zeppelins. The Hindenburg (officially the LZ 129 Hindenburg) was one of two completed in 1936. The other was LZ 130 Graf Zeppelin II. Both were over 800 feet long, just a little shorter than the Titanic. As the article describes, it contained 7,062,000 cubic feet (211,890 m^3) of hydrogen in 16 bladders that provided over 110 tons of lifting force.

The frame, which was made of duralumin, was covered with cotton fabric that had been "doped" with the acetate-iron oxide-aluminum gelatin coating. The coating was intended to both keep the hydrogen from leaking and to reflect infrared and ultraviolet rays which would damage the skin and heat up the hydrogen. This was necessary because, according to Charles' Law, the confined hydrogen would expand excessively as a result of being heated by the sun. Such expansion threatened to rupture the bladders and put the Hindenburg at risk of fire. Duralumin is an alloy of aluminum containing 94% aluminum, 4% copper and 1%.magnesium with possible trace amounts of manganese and silicon. The ship was powered by four 16-cylinder diesel engines.

The article focuses on the cause of the accident and chemistry's ability to determine which of the substances and conditions were to blame. The article cites the possibility of 1) lighting from the storm the Hindenburg passed through, 2) sabotage, 3) an electrical problem within the craft or by a buildup of static electricity, and 4) the incendiary paint theory, which highlights the role of acetate-iron oxide-aluminum coating. One other possible cause that has been advanced was sparks from the engine exhaust emitted when the engines were put in reverse for the landing,

More on "incendiary paint theory"

The chemical factors cited in the discussion of the incendiary paint theory include the flammability of hydrogen, reactions rates, flammability of the doping layer, electrostatic charge, and the stoichiometry of the doping compounds. From these factors it does not seem possible to come to a definitive conclusion about the cause of the disaster. However, students should understand that chemistry and its tools can be used to analyze a situation, even one as far in the past as the Hindenburg. They should also understand that chemistry and other sciences can legitimately seek answers for questions such as, "What caused the Hindenburg fire?"

Questions like this have answers, even though it might not be possible for chemists to find that answer 70 years after the fact. But this is the kind of question that is within the realm of science.

It is also interesting to note for students that scientists always operate in a context. For example, Addison Bain became interested in the Hindenburg because he was the program manager for NASA's Hydrogen Program and then a founding member of the National Hydrogen Association. Founded in 1989, NHA is a trade association with membership from "the automobile industry; the fuel cell industry; aerospace; federal, state, and local government; energy providers; and many other industry stakeholders."

On its website NHA says that it "is leading the transition from a fossil fuel-based energy infrastructure to a hydrogen-based one. Since its inception, the National Hydrogen Association, through its members, has guided the hydrogen community's efforts to create a shared vision for the hydrogen energy infrastructure." Efforts to move hydrogen to the forefront of the energy discussion have always been hampered by the specter of its flammability, and the Hindenburg epitomizes that problem. Bain's efforts to debunk hydrogen as the culprit in the fire are not surprising when viewed in this context. Both the legitimate science and the context must often be taken into account when we decide about cases like this.

More on flame colors

The color of the flame produced as the Hindenburg burned is one of the factors in the incendiary paint theory. Hydrogen burns with a nearly invisible flame, while the Hindenburg produced a yellowish flame color. Flame colors are the result of atomic emission spectra, which are unique to each element. The emission spectra are related to electron energy levels and are often used in chemistry classes to provide evidence for electron energies. This is another connecting point to the chemistry curriculum. Each element has a unique atomic spectrum, which can serve as an indicator of the presence of that element. The spectra in the visible range are sometimes identifiable by the naked eye. The visible flames are not, in fact, colors of single frequency but are a blend of colors, made up of multiple frequencies, which students can view through a diffraction grating. Some typical visible flame colors:

Element	**Color**
Copper	Blue-Green
Potassium	Violet
Iron	Yellow
Lithium	Red
Strontium	Crimson
Calcium	Orange
Barium	Yellow-Green

Connections to Chemistry Concepts

1. **Combustion**—Depending on how you include combustion reactions in your course, this article can provide a starting point for discussion. Students likely have heard or read about the Hindenburg, and the article could give you a good entry point for combustion.
2. **Oxidation-Reduction**—The discussion of the incendiary paint theory of the Hindenburg disaster includes reference to the thermite reaction, an oxidation-reduction reaction. Even if you do not perform the demonstration, you could take students through the redox of this reaction as an example.
3. **Stoichiometry**—The article evaluates the merits of the incendiary paint theory partially on the point of view expressed by A.J. Dessler that the aluminum-iron oxide stoichiometry

needed for the reaction was not present in the Hindenburg. You can refer to his paper here: http://spot.colorado.edu/~dziadeck/zf/LZ129fire.pdf. Students rarely think about stoichiometry in the context of a real world situation. This would be an excellent time to provide such an example.

4. **Reaction Rate**—The article mentions reactions rates, directly or indirectly, several times. Since this is the critical factor in the incendiary paint theory, you can easily connect the article to rates. Also, the article states that the Hindenburg did not explode but rather burned rapidly. But the article never makes the distinction between rapid burning and exploding. In general, chemical reactions are explosive when 1) the reactants—primarily gases—are confined and 2) the volume of the products is significantly greater than the volume of the reactants. For example, in the combustion of hydrogen $2H_2 + O_2 \rightarrow 2H_2O$, there are three moles of reactants and two moles of products. The volume of this system decreases and would not, of itself, result in an explosion, even if the reactions occurred in a rigid container. However, the heat of the reaction could be sufficient to cause the volume of gases to expand, thus leading to an explosion.
5. **Properties**—It may be interesting for students to discuss the way in which the properties of elements (like hydrogen and helium) and compounds are the basis for uses of the substances. The article provides the simple examples of hydrogen and helium. Both are less dense than air and so are useful in lighter-than-air craft. But the fact that hydrogen is flammable makes it the less desirable gas for this use. You can cite similar examples.
6. **Atomic Spectra and Flame Colors**—See “More on flame colors” above.
7. **Gas Laws**—The need for the Hindenburg’s aluminum-iron oxide coating on its skin was to reduce the effects of the sun’s heating the hydrogen inside. This is a direct example of Charles’ Law at work. In addition, you could bring in Avogadro’s Hypothesis as you discuss the buoyancy concept. Since equal volumes of hydrogen (or helium) and air have the same number of molecules and since the masses of the molecules in the volume of air weigh more than those in the hydrogen, the volume of hydrogen will rise in air, giving hydrogen its lifting power.

Possible Student Misconceptions

1. **“So the Hindenburg floated because it was lighter than gravity, right?”** *No, it floated because it was less dense than the air around it, and the air gave it lift. Many students have difficulty with the concept of buoyancy. For a brief description of this topic, see “More on buoyancy”, above.*
2. ***“I saw the video clip of the Hindenburg burning on TV. It sure looked like an explosion.”*** *It is not always clear what distinguishes an explosion from rapid combustion. The article mentions that the Hindenburg did not actually explode but does not explain. There are a variety of factors involved in this distinction, but the two most important factors are pressure and temperature. In general, an explosion is the result of increased pressure in a closed container. If we have a combustion reaction, we would look at the equation for the reaction and determine if an increase in pressure results. That would happen under either of two circumstances. First, if the number of moles of products in the combustion were greater than the total number of moles of reactants, then the closed system would experience an increase in pressure and possibly explode. Second, if the reaction is exothermic, as combustion reactions are, the temperature of the system would increase, leading to an increase in pressure and possible explosion. In the case of the Hindenburg, hydrogen would burn, and in that combustion reaction the number of moles of products is less than the number of moles of reactants. And in the atmosphere, the temperature of the*

system might not rise significantly because the reaction would be taking place over a larger surface area where the heat would dissipate quickly. And as soon as burning began, holes erupted in the skin of the blimp, resulting in the escape of the gases that might potentially have built up to create pressure. With no pressure, there is no explosion.

3. ***"All fires burn with yellow flames—look at the Hindenburg, for instance, and fireplace fires."*** *In the article the color of the fire in the Hindenburg is mentioned as an important factor in deciding the cause. If you have not covered atomic emission spectra at this point in the course, students may not understand that flame colors can be "markers" for individual elements. Refer to "More on flame colors", above, as well as your textbook. Also, sodium imparts an unusually intense yellow color to flames, and it is almost ubiquitous in fuels (such as firewood). So indeed most flames look yellow because of the presence of sodium; only in cases with rather pure liquid or solid fuels (e.g., Bunsen burners' gas flames) does the intrinsic color of the flame show rather than the yellow color imparted by adventitious sodium.*

Demonstrations and Lessons

1. For more on a density column see http://www.exo.net/~donr/activities/Five-Layer_Density_Column.pdf.
2. Another very convenient laboratory scale experiment follows Boyle's early synthesis of hydrogen, the reaction of iron filings with dilute sulfuric acid.

   $$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$
3. With extreme caution and the necessary safety precautions, you could demonstrate the thermite reaction. The setup, safety precautions and a Quicktime video of the demonstration are here: http://www.ilpi.com/genchem/demo/thermite/index.html#demo. Also see the February, 2002 edition of *ChemMatters*, page 14.
4. Have students make their own hot air balloons. See *ChemMatters*, April, 2002. This issue includes directions for making a hot air balloon.
5. With the necessary safety precautions, you could either demonstrate the production and burning of hydrogen gas using a metal-acid reaction or have students perform the activity in the lab. Students can see for themselves how hydrogen burns.
6. Students might perform a lab that demonstrates the flame colors for some of the elements. There are many procedures for this kind of lab. One such procedure from NASA is here: http://imagine.gsfc.nasa.gov/docs/teachers/lessons/xray_spectra/student-worksheet-flame.html.

Student Projects

1. You could have students look up the molecular masses of a list of common gases you provide to them and ask them to determine which ones could be used in a blimp. Note that the average molecular mass for air = 28.97 amu. One such list of gases can be seen here: http://www.reference.com/search?q=lighter%20than%20air. The acronyms **HAHAMICE** (**H**ydrogen, **A**mmonia, **H**elium, **A**cetylene, **M**ethane, **I**lluminating Gases [natural gas], **C**arbon **M**onoxide, **E**thylene or **4H MEDIC ANNA** (**H**ydrogen, **H**elium, **H**ydrogen Cyanide, **H**ydrogen Fluoride, **M**ethane, **E**thylene, **D**iborane, **I**lluminating Gases, **C**arbon Monoxide, **A**cetylene, **N**eon, **N**itrogen, **A**mmonia) are often used to remember common lighter than air gases. Not all such gases are represented here, however. You might also ask students to list those than would be undesirable for use in blimps, and ask them to explain why.

2. Students can go to this site http://www.chemheritage.org/EducationalServices/webquest/blimp.htm and complete the WebQuest on hydrogen and helium that appears there.
3. Of the original documents related to the incendiary paint theory, only Dessler's rebuttal is readily available. However, there are several sympathetic summaries of Bain's research findings. Students could be asked to read these and decide for themselves which theory of the Hindenburg disaster they believe. You can use these documents:
Bain's Theory
http://www.clean-air.org/hindenberg.htm
http://www.esdjournal.com/articles/blame.htm
http://www.aps.org/publications/apsnews/200007/hindenburg.cfm
http://query.nytimes.com/gst/fullpage.html?res=9A05EFD81230F935A35756C0A961958260&sec=&spon=&pagewanted=print
Dessler's Rebuttal http://spot.colorado.edu/~dziadeck/zf/LZ129fire.pdf
Experimental Data from a Neutral Third Party
http://www.sas.org/tcs/weeklyIssues/2004-12-17/project1/index.html

Anticipating Student Questions

1. **"So, what is the difference between rapid burning and an explosion?"** *There are many reactions that occur rapidly. However, the term "explosion" is usually reserved for a reaction between confined gases in which the number of moles of products is greater than the number of moles of reactants. In that case the pressure of the system will increase and that pressure may be sufficient to compromise the container, resulting in an explosion. In addition, many such reactions are also exothermic, also causing an increase in pressure in a closed container. This would also contribute to an explosion. The combustion of hydrogen is exothermic but the number of moles of products is less than the number of moles of reactants. So the hydrogen in the Hindenburg would only burn rapidly. Also, in an explosion, the oxidizer and fuel need to be intimately mixed--there isn't time to bring one into the other. In the Hindenburg, the hydrogen could only burn at the surface of the cells where it came into contact with air. This would preclude an explosion.*

2. **"I thought hydrogen burned with a blue flame—almost invisible. What's with the yellow flame people saw when the Hindenburg burned?"** *It's obvious from the reports that other substances were burning besides hydrogen. The envelope of the blimp was flammable, for instance. If just hydrogen were burning, the flames would have been almost invisible.*

References

"Cartesian Divers – Squeeze Play," *ChemMatters*, February, 2001, pp. 4-6

"Hydrogen and Helium", *ChemMatters*, October, 1985, pp. 4-7.

"The Back Burner", *ChemMatters*, October, 1985, pp. 14-15.

"How The Right Professor Went Up in the Wrong Kind of Balloon", *ChemMatters*, December, 1983, p. 14.

Websites for Additional Information

More sites on the production of helium in the United States

http://center.acs.org/landmarks/landmarks/helium/production.html

More sites with information on hydrogen

http://hydrogen.pnl.gov/cocoon/morf/hydrogen/article/103
http://www.hydrogenassociation.org/general/factSheets.asp
http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/fcm01r0.pdf

More sites on the Hindenburg

Find information about the Hindenburg on the web site of a TV production about the craft at http://www.vidicom-tv.com/tohiburg.htm.

More on the Hindenburg, including photos of its construction and the accident are here: http://www.pbs.org/wnet/secrets/html/e3-about.html.

More on the construction of the Hindenburg can be viewed here http://www.nlhs.com/hindenburg.htm.

More sites on airships

Information about modern airships can be found at http://ntl.bts.gov/lib/000/500/575/823108.pdf.

Information about the history of airships can be found here: http://www.channel4.com/history/microsites/H/history/a-b/airships3.html.

More sites on blimps

A slide show of the construction of the Goodyear blimp can be found at http://www.goodyearblimp.com/basics/building/building.html.

HowStuffWorks provides information on the structure of a blimp at http://travel.howstuffworks.com/blimp1.htm.

How the Cookie Doesn’t Crumble … and Other Sweet Chemistry Secrets

Background Information

More on the history of cookies

Crackers, or biscuits, were the more practical and historically older counterpart to cookies. They typically were made of more readily-available, less costly ingredients. They were very simple foods, made from water and a grain paste. They were made for longevity; they were the traveler’s or hunter’s food staple. Crackers were typically baked twice, thereby effectively driving out all water from the dough and rendering them stable and resistant to decay. Thus they were the perfect traveling foodstuff because they wouldn’t spoil. Farmers as early as 10,000 years ago are known to have made crackers or biscuits on hot stones over their fires. These are some of the earliest foods cooked by man. The word biscuit derives from the French biscuit, which means twice-cooked or baked. Typically, the biscuits would be baked in a hot oven until done, and then were left in a cooler oven to complete the dehydration process.

Cooks of the ancient civilizations of the Middle East experimented with the cracker/biscuit recipes to improve their taste by adding ingredients like eggs, cream and butter, and sweetened them with honey and fruit. Later, when it became available, other cooks added sugar. All of these made richer, lighter, sweeter products—and led to what we today call cookies. The information above came from the book, *Cookies and Crackers*, Time/Life Books, 1982, page 5.

The history of specific types of cookies is not easy to ascertain. Early English and Dutch immigrants brought cookies to America in the 1600s. Although the English called them small cakes, or tea cakes, or gave them specific names, such as jumbles or macaroons, the Dutch called them koekjes, or small cakes. The term cookie didn’t become established until the early 1700s, although it was in print as early as 1703.

Ammonia cookies (I hope they taste better than they sound!) comprise a whole group of cookies that used ammonium bicarbonate, an old leavening agent. It can be obtained from hart shorn, a substance obtained from deer antlers (harts horn). The principal use was for smelling salts, as it can produce ammonia, but it also was used as a leavening agent. The carbonate can produce carbon dioxide, just like baking soda’s carbonate. Ammonium carbonate was also known as powdered baking ammonia. The ammonia volatilized off, so any smell would not have lingered in the food product; however, it is that very volatility that also made it lose its leavening strength quickly. Baking soda is more stable and lasts longer.

A great source to help you learn more about cookies and where they came from (and the source of much of the above information) is: http://www.foodtimeline.org/foodcookies.html. The site contains histories of many, many different kinds of foods, so the subject of cookies is only one small part of the huge site. It also provides historical recipes for cookies, such as the original chocolate chip cookie recipe (Mrs. Wakefield’s, from the cookies she made for her guests at her Toll House Inn in the early 1930s), an 1884 recipe for oatmeal cookies, an 1886 recipe for sand tarts, and a 1902 recipe for snicker doodles. The editor of the site is Lynn Oliver, a research librarian for the International Association of culinary Professionals.

Kraft Foods has a consumer web site that contains a timeline of discoveries that include their product line. It begins in the 1700s and goes to the present. According to this timeline, the first cracker was produced in Massachusetts by a baker who made biscuits that made a cracking sound when they were eaten. (Remember that historically, crackers were the predecessors of cookies.)

Animal crackers had been around for a long time, but they, like most other cookies, had been bulk packaged in barrels or large wooden boxes. When P.T. Barnum took his circus on the road (by boat, actually, to England and Europe), bakers in Europe, who had been making animal-shaped cookies for a long time, saw the chance to increase their sales and packaged their animal crackers in boxes with circus designs and marketed them as Barnum's. Back in the U.S., the National Biscuit Company (eventually bought by Kraft) in 1902 first packaged animal crackers as Barnum's Animals in individual boxes, with animals in cages printed on the outside of the box, and the popularity of the cookies sky-rocketed. Did you ever wonder what the string was for on the boxes of animal crackers? The cookies were originally marketed as Christmas gifts, and the string was meant to allow the boxes to be used as Christmas tree ornaments. According to the Barnum organization, P.T. Barnum never made a cent from the sales of these cookies. (For all those who have been dying to know about it, the Oreo® cookie was first marketed by the National Biscuit Company in 1912.) Here's the web site for Kraft Foods: http://www.kraft.com/100/index.html.

More on the history of leavening agents

The Egyptians are known to have used yeast as a leavening agent more than 5,000 years ago. Yeast continued to be used in the succeeding millennia, often in the form of a yeast "starter", where a portion of the batch of dough was kept from each batch and fed flour and water. It was allowed to continue to grow for another week or until it was used again. These starters were grown for long periods of time, even years.

Sodium bicarbonate had been known as a leavening agent for centuries. Baking soda was known as saleratus, from the Latin, sal (salt) and aeratus (aerated). In 1867 James Church marketed baking soda under the name Arm & Hammer.

Double-acting baking powder was first marketed in 1889 by William Wright as the Calumet brand.

By 1880, there were over 42 different brands of baking powder being manufactured and sold in the United States. There was even a significant controversy, leading to court proceedings, about the wholesale substitution of alum for the cream of tartar then (and even today) being used in the baking soda. The *NY Times* article covering the court proceedings can be found at http://query.nytimes.com/mem/archive-free/pdf?_r=1&res=9D04E7DB123FEE3ABC4952DFB467838B699FDE&oref=slogin. It includes testimony by several leading scientists of the day.

Yet another report of the alum controversy in baking powders was reported in 1929 in the Journal of Nutrition. The scientific report, titled, "Do Baking Powder Residues Exert Injurious Effects Upon Growth and Nutrition?" offers laboratory evidence of deleterious effects of alum baking powders on rats in their studies. They were not quite so clear about their effects on humans, however.

More on the chemistry of baking

The average cookie/biscuit has 1-5% water content, while cakes have 15-30% moisture, and breads have 35-45% water content. This is one reason cookies and biscuits resist spoilage; mold needs moisture to grow.

Sodium hydrogen carbonate, $NaHCO_3$, can be used alone as a leavening agent, as it will decompose with heat to produce carbon dioxide. Historically, this is probably how baking soda was first used in baking. The equation below describes the process.

$$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

One problem with this process is that it produces only one half the carbon dioxide it is capable of producing. (The other carbon dioxide molecule remains locked in the sodium carbonate.) This could cause gastric distress, as eating the baked good will cause the sodium carbonate to react with hydrochloric acid in the stomach and produce the remaining CO_2 molecule, where the gas will build up in the digestive tract.

The second problem is that the reaction produces sodium carbonate, a stronger base than sodium hydrogen carbonate. This compound remains in the baked product and gives it a bitter taste, as well as a yellowish color. Thus baking soda by itself is very rarely used in baking recipes.

To avoid producing the base, one must add acid to the reaction to neutralize the system. The equation below typifies this process.

$$NaHCO_3 + H^+ \text{ (acid)} \rightarrow Na^+ + H_2O + CO_2$$

This process is the idea behind baking powder. A weak acid or acid salt is added to baking soda to prepare a mixture that will react when water is added to neutralize the acid/base mixture. The neutralization process produces carbon dioxide, the actual leavening agent. The advantage of using baking powder instead of baking soda is that the baking powder mixture has been prepared stoichiometrically to ensure a 1:1 acid: base reacting ratio, so that the resulting products are neutral. When one uses baking soda (as opposed to baking powder), one must add either sour milk, cream of tartar, or vinegar to serve as the acid, and it is much more difficult to know how much acid is needed (and how much is being added) to precisely neutralize the baking soda base, without having excess of either one after mixing. Baking powder is more certain to result in a neutral pH, and it is therefore preferred over baking soda for most baking applications.

The equation describing the reaction involved when cream of tartar based baking powder produces carbon dioxide is the following:

$HKH_4C_4O_6$	+	$NaHCO_3$	→	$KNaH_4C_4O_6$	+	H_2O	+	CO_2
potassium acid tartrate	+	sodium hydrogen carbonate		potassium sodium tartrate (Rochelle's salt)	+	water	+	carbon dioxide

If tartaric acid were used (it rarely is) instead of potassium acid tartrate, this is the equation representing the reaction:

$H_2H_4C_4O_6$	+	$2\ NaHCO_3$	→	$Na_2H_4C_4O_6$	+	$2\ H_2O$	+	$2\ CO_2$
Tartaric acid	+	sodium hydrogen carbonate		sodium tartrate	+	water	+	carbon dioxide

Stoichiometrically, though, you can see that twice the baking soda is used in the second equation, compared to the first equation, but you also produce twice the amount of carbon dioxide.

Another variety of baking powder uses calcium phosphate. The equation for that reaction follows:

$Ca(H_2PO_4)_2$	+	$2\ NaHCO_3$	→	$CaHPO_4$	+	Na_2HPO_4	+	$2\ H_2O$	+	$2\ CO_2$
monocalcium phosphate	+	sodium hydrogen carbonate	→	calcium hydrogen phosphate	+	sodium hydrogen phosphate	+	water	+	carbon dioxide

And alum based baking powders react according to this equation:

$KAl(SO_4)_2$	+	$6\ NaHCO_3$	→	$2\ Al(OH)_3$	+	$3\ Na_2SO_4$	+	K_2SO_4	+	$6\ CO_2$
potassium	+	sodium	→	aluminum	+	sodium	+	potassium	+	carbon

aluminum sulfate	hydrogen carbonate	hydroxide	sulfate	sulfate	dioxide

The book, Human Foods and Their Nutritive Value, Harry Snyder, the Macmillan Company, 1914, has an entire chapter (Chapter 12) devoted to baking powders. The material can be accessed online via Google's digitized book collection, at http://books.google.com/books?id=ZsUCAAAAYAAJ&pg=PA186&lpg=PA186&dq=composition+baking+powder&source=web&ots=uV3QwiF_e4&sig=LhHbURC5cJI6Tt30vscLy72aACA#PPA186,M1. Chapter 12 begins on page 186 and runs to page 192. Downloading the book takes some time. The chapter on baking powders includes chemical equations describing the various types of baking powders and how they work. The equations above were taken from this source.

There seems to be some disagreement about the amount of baking soda needed to replace baking powder in recipes. The article in this issue says replace each teaspoon of baking powder with ½ teaspoon of baking soda, while the About.com web site, in the article, "Leaveners for Baking, Part 2", at http://homecooking.about.com/library/weekly/aa072197a.htm, says for every two teaspoons of baking powder, use ½ teaspoon of baking soda.
The web site "SlashFood", part of "AOL Food", at http://www.slashfood.com/2006/05/09/baking-powder-vs-baking-soda/ says that, "…if you must substitute for baking powder, the equivalent to 1 tsp of baking powder can be made by combining 3/4 tsp cream of tartar with 1/4 tsp baking soda. This is a 4:1 replacement ratio, and seems more in keeping with the 2:½ ratio than the 1:½ ratio.
The replacement factor may also vary depending on the type of baking powder, single- or double-acting, sulfate-, carbonate-, phosphate-, or alum-based. The equations for each of these baking powders may give us some insight as to why the substitution ratios vary.

Several patents have been granted in the recent past for baking powder formulations. Here are three of them: patent # 5925397, "Leavening Acid Composition Produced by Heating Monocalcium Phosphate at Elevated Temperatures, http://www.patentstorm.us/patents/5925397-claims.html (1999); patent # 6080441, "Leavening Acid Composition", http://www.patentstorm.us/patents/6080441-claims.html; patent # 5773068, "Leavening System and Products There from", http://www.patentstorm.us/patents/5773068.html. This information shows that the baking powder industry is constantly undergoing research to improve their products.

More on proteins in baking—relaxation

The Exploratorium in San Francisco has a short animation on the process of gluten, as described in "The Chemistry of cookies" article. It shows an animated sequence of water molecules reacting with molecules of glutenin and gliadin to form gluten under a simulated magnifying glass. The actual site deals with baking bread, but the same process applies to baking cookies. You can find the animation at http://www.exploratorium.edu/cooking/bread/glutengood1test.html. Click on the "Explore Gluten" magnifying glass in the slice of bread on the right of the screen. To see a magnified image of the holes in a slice of baked bread (which would be similar to those in raised cookies), click on the magnifying glass at "Slice-o-Scope".

More on fats

See "The Solid Facts about Trans Fats" article in the December, 2007 issue of *ChemMatters*, and its accompanying teachers guide pages on this web page.

More on shortenings

The word “shortening” actually has a chemical basis. Fats tend to “shorten” the dough by weakening the gluten network, thus making a softer baked good, which will break more easily and be tenderer.

More on baking as chemistry experiments

Here’s a slogan seen on an apron for sale in a shopping catalog: “Chemistry is just like cooking, only you don’t want to lick the spoon!”

More on definitions

Definition of a cake: “A baked cake has been defined as a cellular structure of air bubbles enveloped in a continuous protein matrix, with swollen starch particles, fat and sugar crystals dispersed randomly as discrete particles throughout the material.”—quoted from “The Chemistry of Cakes” at http://www.margarine.org.uk/pg_app2.htm. How’s that for a scientific definition?

Connections to Chemistry Concepts

1. **Organic chemistry**—Fats and proteins are organic molecules.
2. **Gas laws**—the rising of the cookie dough is at least in part due to the increase of volume in the air/CO_2 bubbles in the cookie dough with increasing temperature as it bakes. About 10% of the entire volume increase is due to the temperature rise; the remaining 90% is due to the leavening agent and water vapor produced at baking temperatures. The baked good doesn’t collapse when the temperature decreases back to room temperature because the gas cells have toughened/hardened and maintain the structure.
3. **Hydrogen bonding**—The properties of macromolecules are often due to hydrogen bonding between molecules.
4. **Hygroscopic**—The hygroscopic nature of sugar is due to hydrogen bonding.
5. **Acid-base chemistry**—Carbon dioxide gas is produced in baking when an acid and a base (usually baking soda, sodium hydrogen carbonate) combine.
6. **Neutralization**—the acid and base neutralize each other in the chemical reaction.
7. **Physical properties**—Melting points (and boiling points) of fats are related to their structures. See “The Captivating Chemistry of Candles” article in the December, 2007 issue of *ChemMatters*, and its accompanying teachers guide pages on this web page for related information on the melting and boiling points of the alkane homologous series, as related to molecular size and structure.
8. **Mixtures**—Cake/cookie batter is a very complex system consisting of ingredients in solution, colloidal dispersion, and suspension.

Possible Student Misconceptions

1. **“Baking soda and baking powder are the same things.”** *No, as the article states, baking soda is a pure substance composed of sodium hydrogen carbonate (baking soda), a base. Baking powder is a mixture of both an acid; e.g., potassium hydrogen tartrate,* $KC_4H_5O_6$ *(tartaric acid) and baking soda. Baking soda alone requires the addition of an acid; e.g., sour milk or vinegar to make the chemical reaction go, while baking powder contains both acid and base already, and only requires water to dissolve the acid and base to make the reaction work.*

2. **"A cookie is a cookie is a cookie."** *Cookies in the U.S are called biscuits in most other parts of the world.*
3. **"Acids and bases are harmful to humans. What are they doing in baking powder—or cookies?"** Students may believe that all acids and bases are strong acids and bases, and that they are only found in chemistry laboratories. You can remind them that they have acid in their own stomachs—and strong acid at that, but it is normally not harmful to us. Many foods contain acids, especially fruits, and we eat them with little or no digestive problems. And they wash with soap, which is basic, and results in no/little harm to them.

Demonstrations and Lessons

1. You might want to do a demonstration to show the difference between baking soda and baking powder, or have the students investigate it for themselves.
2. Students can experiment with regular and double-acting baking powders to attempt to differentiate between the two.
3. To further differentiate between formulas and recipes, as stated in the article, you might want to relate these two to the list of materials, expendables only (aka, the formula) in a typical student experiment, and the procedure (aka, the recipe) they must do to perform the experiment.
4. A cookie experiment you might want students to try involves a quantitative investigation of cookies. Even there's not much hard chemistry here, the math involved makes it (perhaps) more appropriate for a chemistry course. This one might best be aimed at an honors level class—or for college, from which it originates. The experiment involves two parts. The first asks students to determine if Oreos "Double Stuff" cookies really (quantitatively) have twice the stuffing of regular Oreos, and the second part asks students to find the percent composition by weight of the chocolate chips in a specific brand of chocolate chip cookie (you or they can choose). They then do a statistical analysis of their findings in groups—or the whole class. Students must determine their goals, their approach and procedure, and then do the experiment, analyze their results, and report them to their peers. This is very much an inquiry based experiment. Check it out at http://www.lifescied.org/cgi/content/full/5/1/76. Scroll down to "Laboratory Experience", where the experiment is described briefly. A table of past student results is also offered. OK, maybe this wasn't originally a college-level experiment. See http://www.jacksonville.com/tu-online/stories/092907/nec_203511891.shtml) for the results from a 5th grade version of (almost) the same experiment. Still, it's the analysis of the data, and maybe even the experimental design that makes this a high school chemistry level experiment, not just the experimental findings.
5. If you happen to teach a subject in addition to chemistry—like earth science, for instance, you might be interested in this video that shows a paleontologist using pieces of cookies to simulate the re-assembling of fossil pieces into the original skeleton. Students would like it if you actually did the activity because they can eat the experiment! View it at http://krampf.com/experiments/Science_Experiment25.html.
6. A complete set of experiments on the concept of leavening agents, "Baking Sciences: Leavening Logic," awaits you at http://www.kswheat.com/upload/baking%20science%20leavening%20logic.pdf. It originates from the Kansas Wheat Commission. The experiments are really designed for a family and consumer science (formerly home economics) class, but part of it can be done easily in the chemistry lab. The experiments are divided into two parts. The first part tests various leavening ingredients in a typical laboratory setting. The second part then applies these leavening agents to the baking of waffles to see their effects on the final product, which they test by eating (or at least tasting). This second part of the experiment is the part that might better be done in a family and

consumer science (formerly home economics) kitchen than in your lab. Perhaps you could do a joint experiment with that teacher. The first part of the experiment could stand alone, but it seems to be more effective if students can taste their handiwork. The PDF file contains student data tables and questions to be answered by students. It also contains background material, historical connections, and recipes for waffles and for syrups. See “More Sites on leavening agents” in the “Additional Web sites” section for another experiment from the *Journal of Chemical Education*.

7. Here is another curriculum teaching unit for high school teachers on leavening agents, this one from the Food and Science family and consumer science program from the Utah State Board of Education: http://www.uen.org/Lessonplan/preview.cgi?LPid=1184. The site includes pre-assessment, lab activity, and follow-up assignment. Although the site is for family and consumer science teachers, this particular segment on leavening agents is treated rather as a chemistry experiment/lesson.
8. An experiment to determine and compare melting points of fats can be found at the British Nutrition Foundation site, http://www.nutrition.org.uk/upload/Comparison%20of%20melting%20point%20of%20fats.pdf. The activity is the normal capillary tube melting point experiment, nothing fancy.
9. This site has a baking activity related to stoichiometry: Students bake biscuits, varying the amounts of ingredients to see the effect on the product. There isn’t much in the way of calculations, however; it’s mostly in the appearance/taste of the product. Find it at http://www.learner.org/channel/workshops/chemistry/support/act5_a1.pdf.
10. This web site offers a student experiment in which student groups analyze different brands of baking powder. They assume the roles of analysts in a consumer research organization. They must design, conduct, draw conclusions about, and report on their own experiment. The class must agree on one experimental design to provide standardization of results. This is a great example of an industry-based inquiry lab. Find it at http://www.instruction.greenriver.edu/Kmarr/POGIL%20STUFF%20TO%20SHARE/1_Good%20Inquiry-Based%20Chem%20Labs/140_Lab%207_Baking%20Powder%20Stoichiometry.doc.

Student Projects

1. Students might investigate how to best preserve cookies by looking at the investigation at the American Chemical Society Chicago Section’s “Chem Shorts for Kids” site: http://membership.acs.org/C/Chicago/ChmShort/CS03.html. This site contains a series of activities for students. Check out the “Food Wraps” section, the December activity, by scrolling all the way to the bottom of this page.
2. Students may be interested in an experiment to test which chocolate chip cookies is “the best”. There’s not much strict chemistry in the experiment, but students must design their own experiment, perform the experiment, follow it through to a conclusion, and report their results, just as they would for any other science experiment. See http://www.dartmouth.edu/~chance/teaching_aids/cookie.html and then click on “Cookie Rating Activity, Grinnell College 1994” for some ideas about how to set up the student experiment. Also included on the original site is the *Consumer Reports* chocolate chip cookie report from 1993. Part 1 is the data and rankings of thirty-five different brands of cookies; part 2 is the comments on each of the cookie brands. Properties tested include: product type (hard or soft, fresh-baked or packaged); “sensory score” (all the way from 96 down to 3); and then, per 30-g serving, the following: number of cookies, number of calories, grams of fat, number of fat calories, and cost. Further research has shown that this experiment was (originally?) done on a much simpler level by

nursing departments at colleges as an attempt to encourage student research in nursing: http://www.hsc.mb.ca/nursing/contents/projects/completed/The%20Great%20Canadian%20Cookie%20Experiment.pdf. One caution about the experiment: make sure students don't have allergies to cookie contents before they do the taste tests. There are also a number of sites online (blogs, mostly) that report the findings of various experiments the cooks/bakers have done. One in particular describes her findings when she experiments with changing variables in the baking of the perfect snicker doodle cookie. Students can check it out at http://jennarator.com/archives/cat_experiments.php. This particular blogger experimented with these variables: types of flour—bleached vs. unbleached, butter vs. shortening, and baking soda vs. baking powder. This person seems to be rather scientific about the experiments themselves, but ultimately it comes down to what cookie her sample samplers liked best—rather subjective, unfortunately. You might ask students to analyze/critique the experiments with respect to the attention paid to specific scientific methods.

3. You could have students do a similar taste test comparison of regular and "low-fat" cookies. They could research the fat content of specific brands of regular and low-fat cookies and judge (via survey, perhaps) the taste vs. fat content decrease vs. cost vs. health concerns to see if it makes sense to purchase and consume the low-fat variety.
4. As many baking/cooking web sites might have articles related to the topic of cookies, it might be interesting to ask students to do online searching to find inaccuracies in the articles they read there. They could then, after clearing it with you, write those online authors with their comments and corrections to the errors. One such example of an error is found at this site on the "Helium—Where Knowledge Rules" web site: http://www.helium.com/tm/314020/baking-power-sodium-bicarbonate. The article, "All about Baking Soda and Baking", mentions that baking powder contains baking soda, acid, and "starch gas". One could write the author of the article to correct the misconception, but that requires that one join the site.
5. It might be an interesting student project/experiment to investigate the claim in the article that one needs to replace each teaspoon of baking powder with ½ teaspoon of baking soda when one substitutes an uncalled-for acid for a neutral liquid in the recipe.
6. You might get students involved to report on the fast-food trans-fat discussion. Several fast-food chains have banned trans-fats. KFC, Kentucky Fried Chicken, was even sued in 2006 by the CSPI, the Center for Science in the Public Interest. Students can start their research here: http://www.bfeedme.com/lawsuit-trouble-for-kfc-over-cooking-oil/, or here: http://www.chicagobusiness.com/cgi-bin/news.pl?id=22655. WebMD even weighs in on the controversy at http://www.webmd.com/diet/news/20061030/kfc-to-fry-chicken-without-trans-fats. Here's the online copy of the original complaint filed against KFC: http://news.findlaw.com/nytimes/docs/transfat/hoytkfc61306cmp.html.

Anticipating Student Questions

1. **"Wait, I don't understand. Doesn't a cup of flour (for example) always weigh the same?"** *This would be true for liquids (over narrow temperature ranges), but not for solids. The mass of a liter of water is always 1 kg, but the mass of a cup of flour can vary a lot, depending on how much the flour has been "fluffed up" or tamped down. Solid powders have lots of air space trapped in them, and tamping the powder forces the particles to move closer together and this squeezes out air. Since the particles occupy less volume, their density increases. This could be a big problem if the recipe requires, say, 8 ounces, which is normally one cup—but tamping the contents may squeeze an extra ounce of solid into the same volume.*

Liquids typically have very little air trapped among the liquid molecules; hence their volumes tend to remain very constant, even when shaken a little. Another example of this phenomenon, with solids, is boxes of cereal or crackers. A statement frequently appears on the boxes, saying that the contents of the box may have settled upon shipping, but that the box was packed by weight, not by volume. This is to alert consumers that the box may not be full when it is opened due to settling in transit, but assures them that they are getting all they paid for, as the contents are sold by weight.

2. **"Why don't cookies spoil?"** One reason is t*he low water content of cookies (1-5%) is too low for mold to grow. Bread contains 35-45% water. Molds love that!*

References

The reference below can be found on the *ChemMatters* 20-year CD, obtainable from ACS for $25 (or a site/school license for $99) at this site: http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccurriculum%5Ccmprods.html#CDsite.

"Leavening: How Great Cooks Loaf", by Melissa Rudolph, a chemistry student at the time, on pages 4-5 of the April, 1996 issue of *ChemMatters*, discusses the various ways bakers have to make baked goods rise.

Websites for Additional Information

More sites on the history of cookies

We would be remiss if we didn't mention Girl Scout Cookies®. For the complete history of Girl Scout Cookies®, see http://www.girlscouts.org/program/gs_cookies/cookie_history/.

More sites on cookie experiments

Here's another example of the student-designed chocolate chip cookie experiment: http://www.dartmouth.edu/~chance/course/Syllabi/97Dartmouth/chance-section2.html. The site contains the syllabus and contents of a course on chance in math. Scroll down to the October 23 class, or search (<control-f>) for the word "cookie". This experiment is very simple, but very student-based. It is a good example of a true inquiry experiment.

Here's a blog about "A Mean Chocolate Chip Cookie": http://www.megnut.com/2007/05/a-mean-chocolate-chip-cookie. The blogger reports receiving 26 chocolate chip cookie recipes when she asked fellow bloggers for their recipes for the best chocolate chip cookie ever, so she calculated the averages of all the ingredients and procedures, including average temperature. She made that recipe to get her mean (mean—average, get it?) chocolate chip cookie. She changed all the amounts to decimal equivalents to do her calculations on an Excel spreadsheet.

The following web site provides "The Chemist's Recipe for Chocolate Chip Cookies": http://www.psc.edu/~deerfiel/Jokes/cookie.html. The entire recipe uses only scientific terms to describe all the ingredients, the (laboratory) apparatus, and the procedure. The recipe was originally published in *Chemical and Engineering News*, June 19, 1995, p. 100. This web page also provides a somewhat scathing review of the article from another scientist. The exchange is rather humorous.

More sites on the chemistry of baking

The New Zealand Baking Industry Research Trust (BIRT) web site contains information on the chemistry of baking bread. It states what specific reactions are happening at specific temperatures within the baking oven. The text also contains two electron photomicrographs showing gluten's role in forming the structure of bread. You can find the "Science behind Bread Making" site at http://www.bakeinfo.co.nz/school/school_info/breadmaking.php#science.

The New Zealand Institute for Crop and Food Research has a very complete web site on the chemistry of baking at http://www.nzic.org.nz/ChemProcesses/food/6D.pdf.
It includes discussion of the major ingredients in baking and the role each plays in making the final baked product, and a flow chart that lists many major types of baked goods and the ingredients in each. The flow chart shows how baked goods differ in their ingredients. The site also includes a description of a few of the tests that are done in the laboratory to determine quality of raw ingredients used by bakeries, including stoichiometric titrations of baking soda and baking powders by addition of sulfuric acid and measuring CO_2 production, and atomic absorption spectroscopy to determine metallic ion concentrations in the ingredients.

This site, Cookies-in-Motion.com, has several sections dealing with baking powders, fats, gluten, how sugar affects cookies, etc. The gluten button shows a sketch of how glutenin and gliadin combine to form gluten. This is one of the sites referenced in the article. Access it at http://www.cookies-in-motion.com/.

More sites on leavening agents

The Journal of Chemical Education has a classroom activity on testing the effects of leavening agents on the quality of biscuits. JCE Editorial Staff (2000) "Flat as a Pancake? Exploring Rising in Baked Goods," *Journal of Chemical Education*, Vol. 77, No. 10, pp: 1264A-1264B and supplements1-3. This is also available at JCE Online, as a title or an abstract only, or if you subscribe to the Journal, you can access the entire activity at http://www.jce.divched.org/Journal/Issues/2000/Oct/PlusSub/V77N10/p1264A.pdf

More sites on fats

A site that provides more information—and structures of many fats in our diet can be found at this site: http://www.omega3sealoil.com/Chapter2.html. Its contents must be taken in the context of the author, who is a medical doctor who is espousing the benefits of omega 3 fats in our diet, especially seal oil's omega 3 fat. Nevertheless, the content of this chapter is rather straightforward and factual.

This site is actually a question-and-answer format from an experienced chef. The question on this page focuses on a student doing a science fair project who needs information about the differences between butter and margarine. The chef responds in great detail. He includes melting temperatures of various butters (yes, plural) and margarines. Find it here: http://www.ochef.com/864.htm.

Baking 911.com has a page containing all you could ever possibly want to know about fats, from a baking perspective (not necessarily a scientific one). Find information at http://www.baking911.com/pantry/fats.htm.

NSTA provides a look into fats on the nanoscale level in an article from the December, 2006 issue of *The Science Teacher, at* http://www3.nsta.org/main/news/stories/science_teacher.php?news_story_ID=53014. The article includes a table of melting points of various fats and fatty acids, and it shows structures to differentiate between cis and trans unsaturated fatty acids.

The Solid Facts About Trans Fats

Background Information

More on Categories of Lipids

Lipids or fats can be grouped according to source, structure, and use. One scheme is as follows:

- Waxes are *esters of long-chain fatty acids and long chain alcohols.*
- Triglycerides are triesters of long-chain fatty acids and glycerol (a three carbon chain).
- Complex lipids comprise cell membranes. Complex lipids include two subgroups, phospholipids and glycolipids. Phospholipids are esters of phosphoric acid, utilizing long-chain fatty acids, glycerol and phosphoric acid. Glycolipids are lipid molecules that contain carbohydrates, usually simple sugars such as glucose and galactose
- Steroids are lipids found in plants and animals. Steroid molecules are derived from the same basic three ring (benzene) structure, phenanthrene, to which is attached a saturated five carbon ring, cyclopentane. The ring structures are saturated compared with the phenanthrene from which they are derived. Steroid molecules are formed from this nucleus by adding hydrocarbon chains, functional groups or introducing carbon-to-carbon double bonds into one or more of the cyclohexane rings. Steroid molecules that contain a hydroxyl group (-OH) and no carboxyl (-COOH) or aldehyde (-CHO) groups are called *sterols*. Cholesterol, a waxy solid, is a sterol found only in animals. Cholesterol provides rigidity to cell membranes (think also of plaques and increased rigidity in blood vessels due to deposits of cholesterol in the vessel walls).

More on Foods, Fats, and Health

Although the article is focusing on one type of fat relative to health issues, there is obviously a concern about the content of individual diets' effect on body weight, blood levels of such things as cholesterol (both high density and low density lipoprotein), and possible development of diabetes, particularly in younger people. Although fat is a major source of calories (kilocalories or large "C" calories), the concern is not only how much fat is in the diet but also the type of fat with regard to health issues, particularly related to long-term cardiovascular health. Looking at the categories of fat, one has to distinguish between saturated and unsaturated fats as well as the presence or absence of the *cis-* and *trans-* forms of unsaturated fats. A good source of basic information in the realm of nutrition and trans fats can be found at the website of the Food and Drug Administration (FDA), http://www.fda.gov/default.htm, http://www.cfsan.fda.gov/~dms/qatrans2.html#s4q3, and http://www.fda.gov/FDAC/features/2003/503_fats.html. This last URL gives lots of detailed information about major sources of trans fats for American adults as well as a chart listing the more common foods, their fat content (total fat, saturated fat, trans fat), cholesterol, and daily value (%) for saturated fats.

A second article that provides data on fat content of various common foods is found in the December, 1989 *ChemMatters* titled "Oil Changes", pp.7-9. Another *ChemMatters* article, "Fast Fats", is found in the February, 1990 issue, pp.13-15. Useful charts are provided that show the fat content of the more popular foods ordered at the fast food places such as Wendy's, Burger King, and McDonald's. Another reference article on the basics of fats and health is found in the *ChemMatters* article, "Fats – Fitting Them Into a Healthy Diet", October, 2000, pp.6-8. Back issues of *ChemMatters* can be found on the CD, *ChemMatters*, Version 3.0 and can be purchased at http://acswebapplications.acs.org/portaltools/shopper/productDetail.cfm?prod_cd=1-CMCD3.

The September, 2007 issue of *Scientific American* is a special issue on diet, health, and the food supply. Some of the topics include "Feast and Famine: the Global Paradox of Obesity and Malnutrition", which states that there are more people in developing countries who are overweight than hungry! The question is then raised as to how the poorest countries are going to fight obesity. It could be the starting point for a class discussion about obesity. Additional articles of interest include some of the more recent ideas about obesity and the role of the brain, in particular the hypothalamus, and feedback mechanisms involving a hormone-like chemical called leptin which, when released by fat tissue, can reduce appetite and energy expenditure once the leptin reaches the brain. Are there malfunctions of leptin production that contribute to the obese situation of some individuals? Some of the articles are available at the *Scientific American* website, http://www.sciam.com/issue.cfm?issueDate=Sep-07. Other articles in that issue are available only through electronic subscription. Perhaps your library has the electronic subscription. Another reliable source of health information for understanding trans fats is found in the Mayo Clinic electronic health newsletter at www.mayoclinic.com/health/trans-fat/CL00032. The article of interest is titled *"Trans Fat: Avoid This Cholesterol Double Whammy".*

Another interesting aspect of obesity and secondary diabetes (that results from obesity in some people) is the existence of what is called the "slow gene" in the general population and certain groups in particular, such as Native Americans. This gene seems to be an inheritance from ancestors who in their time experienced very uncertain food supplies (particularly non-agrarian, hunter groups). Natural selection produced a gene that essentially reduced the rate of metabolism of food in order to "spread out" the availability of the digested food over a period of time during which there might not be additional food consumption. This gene remains in the DNA of some people today but complicates things because it continues to keep metabolism slower than for those without the gene. With more food available compared with the prehistoric times of hunting and gathering, people with the slow gene are essentially "stockpiling" the excess food not metabolized into usable energy. This stockpiling takes the form of converting unused calories into storage as fat.

On the commercial front, there is scientific response to the search for alternatives to trans fat-containing food. Archer Daniels Midland (ADM) company, along with Novozymes, have developed an enzymatic method to produce a line of zero- and reduced- trans fat oil used in food processing. The product line is called NovaLipids. In order to avoid the conversion of the *cis*- isomer to the *trans*- isomer of an unsaturated fat undergoing hydrogenation, the new process starts with fully hydrogenated oil, then "inter-esterifies" it with unhydrogenated oil. In the process, sodium methoxide (a catalyst) along with the enzyme, lipase, is used to cut and randomly exchange the positions of the three fatty chains of the various triglycerides in oils (p. 4, http://pubs.acs.org/cen/science/83/print/8326sci1.html). This inter-esterification avoids formation of the unwanted trans fats. Additional manufacturing procedures deal with eliminating some of the by-products that are not needed or wanted. The sodium methoxide is also used in another important application, the production of biodiesel fuel from plant oils. It is used to initiate transesterification in the biodiesel manufacturing process. One important consideration in its usage is that it must operate in a near-zero water environment. Otherwise, in the presence of water, the triglycerides present will react to form soap, an unwanted by-product.

Although the emphasis of this article is trans fats, there are two interesting topics that rely on the use of fats of the triglyceride type—soap /detergent production and the development of explosives! In the case of making soap, a chemical reaction in the category of esterification (synthesizing an ester) uses fatty acids (from animals) and the trihydroxy alcohol, glycerol, to form the ester. The ester is then broken apart in the presence of an alkali solution such as sodium or potassium hydroxide to form the salt of the fatty acid (and the by product of glycerol once again). The solid formed is the soap. This process is called "saponification". The root word is *"sapo"*, Latin for soap. The Italian word for soap is *sapone.* The choice of the alkali determines the "hardness" of the soap; sodium produces a harder soap, potassium a softer soap (as in liquid hand soaps). Soap production has a long history, perhaps second in time after the fermentation of grapes! Soap making has its origins in ancient Babylon around 2500-2800 BC. (see also http://inventors.about.com/library/inventors/blsoap.htm)

Students can make soap in the lab. Some may want to duplicate the process used by the early settlers to this country in which the alkali solution was made in crocks with wood ash soaking in water for several days. Several references to soap making, from the historical to the "do-it-yourself" include:
"Saponification is 'Clean' Chemistry", http://www.chemistry.org/portal/a/c/s/1/printit.html?id=5db3b51ae2cd11d6f6b6ed9fe800100
"What is Saponification?"
http://www.realhandmadesoap.com/folders/FAQ/what_is_saponification.htm
"How Does Soap Clean?", from About.com: Chemistry at
http://chemistry.about.com/library/weekly/aa081301a.htm?p=1
This reference also includes additional links to topics related to soap including molecular structures.

A useful summary about soap synthesis with good molecular models (in color) is found at the Elmhurst College Chemistry Department website:
http://elmhcx9.elmhurst.edu/~chm/vchembook/554soap.html
There are various references to making soap in the lab or kitchen. One such reference on procedure is found at: http://www.chem.latech.edu/~deddy/chem122m/L06U00Soap122.htm

Lets turn now to a completely different story about the use of one fat component, glycerol. This time the trihydroxy alcohol when reacted with nitric acid (and sulfuric acid), rather than fatty acids as in soap synthesis, produces a compound in which each hydroxyl group (-OH) is replaced by $-NO_2$ to form nitroglycerine, an unstable and violent explosive. This substance was first discovered by the Italian chemist, Ascanio Sobrero (1812-1888). Because of the later use by Alfred Nobel of Sobrero's nitroglycerine for munitions manufacture, Sobrero was shocked and dismayed about its becoming a weapon of mass destruction (compared with earlier weapons!) and was ashamed to admit to being its discoverer. But Nobel went on to find ways to stabilize pure nitroglycerine (his brother and a number of coworkers were killed in the lab experimenting with the explosive). He eventually used a special Swedish clay called *kieselguhr* that changed the liquid nitroglycerine into a paste. This product, called *dynamite* could now be formed into stable rods of various sizes for inserting into drilling holes in quarrying or mining operations. In present day, dynamite used in the USA is composed of nitroglycerin, ammonium nitrate and sodium nitrate (two other explosives), wood pulp (replacing the clay) and a trace of calcium carbonate to neutralize traces of acids that might form in storage. In later years, after earning huge profits from the war machines, Nobel created the Nobel Prizes after reading his pre-mature obituary in which he was remembered only as the person who created death and destruction through his explosives. (Equations for the synthesis of nitroglycerin and background on Alfred Nobel can be found at :
http://www.ch.ic.ac.uk/rzepa/mim/environmental/html/nitroglyc_text.htm.

Connections to Chemistry Concepts

1. **Cis-trans isomers**—These occur in molecules of the same molecular formula but different geometric arrangements of groups attached next to each other; if across from each other, then it is a *trans* arrangement; if adjacent, then it is a *cis* form. (Note that this is only possible in structures that have groups like carbon-carbon double bonds which cannot rotate easily; different geometric arrangements in straight-chain compounds containing only carbon-carbon single bonds would not normally be isomers since they could interconvert by rapid rotation around the single bonds.) Because of these different isomeric structures, the molecules possess different physical and chemical properties. In the case of *cis* and *trans* fats, there are different properties due to the shape of the molecules ("bent" vs. "straight").
2. **Hydrogenation**—This is the process of adding hydrogen atoms (with a metal catalyst and high pressure) to a molecule with double or triple bonds reduces or eliminates these bonds, creating single bonds. The molecule has gone from an unsaturated to a saturated molecule. In the case of fats, that is usually not desirable in terms of health; unsaturated molecules are preferred.
3. **Catalyst**—These substances increase the rate of a reaction without themselves undergoing change (or are regenerated). The metal nickel is an important catalyst in the hydrogenation process for fats and oils.
4. **Oxidation**—Oxidation is a category of chemical reaction in which an element or compound loses electrons due to the presence of an oxidizing agent, such as oxygen, that is an electron acceptor. In the case of fats, this is the process whereby some fat molecules are broken up into smaller units, producing what is known as rancidity.
5. **Double bond**—Double bonds are chemical bonds in which two atoms share two pairs of electrons. In the case of double or triple bonds for organic molecules, the bond is considered unsaturated and additional atoms such as hydrogen can be added (bonded) producing a different molecule. The difference in such properties between saturated and unsaturated molecules is especially important for health reasons in the case of fats and oils.
6. **Saturated**—These molecules contain all single bonds between carbon atoms. They do not allow for additional bonds through the addition of an element such as hydrogen.
7. **Unsaturated**—Molecules of this type all contain carbon-carbon bonds that are double or triple bonds. These molecules can accept additional elements such as hydrogen, reducing the number of double or triple bonds. This process of accepting additional hydrogen atoms changes the physical characteristics of fats and oils.
8. **Monounsaturated**—These molecules contain only one double bond in the chain of carbon atoms.
9. **Polyunsaturated**—Molecules of this type contain multiple double or triple bonds in a carbon chain. The more unsaturated a fat, the healthier it is as a food product. It is also more likely to be a liquid rather than a solid at room temperature since the fat most likely has many *cis* double bonds which create bent molecules that cannot pack as closely as *trans* double bonds that tend to be tubular for stronger intermolecular forces because of closer packing.
10. **Triglycerides**—This is the name given to the ester formed between fatty acids (three or tri-) and glycerol, the tri-hydroxy alcohol. Triglycerides are the molecules of fats and oils.
11. **Fatty Acids**—These organic molecules are acids because of their functional group known as the carboxyl group, -COOH. It is this end of the acid molecule that reacts with the hydroxyl end(s) of an alcohol such as glycerol to form an ester such as a triglyceride or fat, depending on the length of the fatty acid.
12. **Polarity of molecules**—Polar molecules have regions where electrons are shared unequally between atoms, thus creating regions of excess negative or excess positive charge. These regions can interact with the complementarily charged regions of other polar molecules, which in turn can interact with other polar molecules. Non-polar molecules have symmetrical distribution of bonding electrons about any two nuclei within the molecule, hence no regions of partial negative or positive "charge". These two types of molecules

determine, among other things, solubility between two or more different types of molecules. Fats, as very large carbon-based molecules, tend to be non-polar and will not mix in something like water that is polar. In order for mixing to happen, one has to introduce something called a "soap" that, as a large molecule, has both polar and non-polar ends. Since "like" dissolves "like", the non-polar fat binds to the non-polar end of the soap molecule and the polar end of the soap bind to the polar water, hence "dissolving". On the other hand, fats can dissolve in other non-polar solvents such as gasoline or carbon tetrachloride (used to be used in dry cleaning, dry meaning without water!).

Possible Student Misconceptions

1. **"You can eliminate cholesterol in the blood by not eating cholesterol-containing food"** *The body synthesizes cholesterol all the time because it is needed to form other chemical compounds needed by the body. So ingestion of food that is without cholesterol will not eliminate cholesterol in the body.*
2. **"Because fat is a storage form for food, it contains less energy per gram than carbohydrates in metabolism."** *Actually, fat is the most concentrated form of energy compared with carbohydrates and proteins (the least). Fat provides 9 kcal of energy per gram and carbohydrates provide 4 kcal per gram.*

Demonstrations and Lessons

1. Students can Isolate fat from milk (see *ChemSource*, Food & Chemistry[FOOD] unit, Volume II, p. 15-21; http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccurriculum%5Cteachres.html.
2. You can demonstrate the amount of water in regular, light and "extra light" margarines. See "Light Margarine, Paying More for Less", an activity found on p.22-23 of the FOOD unit above in *ChemSource*.
3. You can demonstrate the solubility of oils (fats) in polar and non-polar solvent.
4. Synthesize soap from a fatty acid and glycerol (Esterification, Saponification).
5. Test chemical properties of soap—suds, dispersion, pH, "scum" production in hard and soft water, etc.
6. Have students read food labels for fats of every category (refer to the *Chemical Matters* article, "Oil changes", Dec. 1989, pp 7-9; also "Fats, Fitting them into a Healthy Diet", Oct., 2000, pp. 6; "Fast Fats", Feb. 1990, pp. 13-15). What is listed? Any olestra? Hydrogenation?
7. Have students investigate the esterification process; make aromatic esters rather than soap. Use molecular models to illustrate the dehydration reaction.
8. Use molecular models to illustrate *cis-trans* arrangements; translate molecular formulas (partial structural formulas) into 3-D models.
9. Compare different organic alcohols in terms of viscosity (effect of size of molecule, number of –OH groups per molecule (mono-, di-, tri-hydroxy alcohols). Account for differences in terms of intermolecular bonds (hydrogen bonding)
10. Investigate weight and diet; fat vs. calories (what vs. how much); BMI (Body Mass Index) calculation as homework (not in class to protect student's self-esteem); read food container labels of common foods that individuals eat to determine: type of food categories, specific fat categories, and % of daily totals ingested—"what vs. how much (calories)".

Student Projects

1. Students can investigate all aspects of olive oil production; virgin vs. extra virgin.
2. See # 3,4,5,9 in Demos/Lessons above.
3. Students can design an experiment to determine the length of time for rancidity to begin with a variety of fat-containing foods such as nuts, butter products, margarine products (those with and without trans fats). What conditions delay onset of rancidity? (temperature, degree of exposure to air)
4. Students can investigate and compare the chemistry of soap and detergent synthesis.

Anticipating Student Questions

1. **"How can the fat food flavoring called Olestra not provide either calories or fat molecules for our body's use ?"** *Olestra is a fat substitute that tastes like a fat but is indigestible. It cannot be metabolized in the body because it is unable to be absorbed from the digestive system into the bloodstream to be carried to body cells to be metabolized (cellular "digestion"). Like real fat, olestra is synthesized from fatty acids of cottonseed or soybeans but uses sucrose rather than glycerol to form a type of "triglyceride" . The resultant molecule (an "ester") has as many as 6-8 fatty acids attached to the hydroxyl (–OH) groups of the sucrose which is more than the three of glycerol. The olestra molecule is a larger molecule than a triglyceride and is not digested by enzymes in the digestive system. Therefore it passes out of the intestines undigested and is unabsorbed because the molecule is too large to pass into the blood vessels (capillaries) of the digestive tract.*
2. **"If fats are insoluble in water, how is it possible for fat to be absorbed into the blood stream since blood is primarily water ?"** *Fats, either saturated or unsaturated, are made soluble in blood by first dissolving in the digestive tract through the use of a biological detergent called bile, which is produced in the liver and stored in the gall bladder. The mixing (emulsifying) of the detergent with the fats allows for the non-polar end of the detergent to interact with the non-polar end of the fat (the fatty acid end) while the polar end of the detergent bonds with the polar end of the fat (the glyceride ends) just as regular soaps and detergents would do when you wash greasy dishes with soap or detergent. Once the fat is emulsified in the digestive "juices", it can be broken apart by hydrolysis (water and enzymes) to yield water soluble fatty acids, glycerols, soaps or mono- and di-glycerides which are then small enough and soluble enough to pass through the intestinal wall into the blood stream, although it is not clear what form the digested fat takes in passing through the intestine. Lipids are found in the blood stream but are in the form of lipoproteins that are soluble. This is important because lipids are needed in various locations of the body including the liver and the brain.*
3. **"What is the difference between a soap and a detergent?"** *A soap and a detergent are similar in terms of their synthesis, each undergoing what is known as an ester-forming (esterification) reaction in which fatty acids bonds to the -OH (hydroxyl) group of a trihydroxy alcohol called a glycerol in the case of a soap. The fat so formed is reacted in an alkaline solution (sodium or potassium) to form a soap, which is the salt (sodium or potassium) of the original fatty acid. In the case of a detergent, a fat, oil or some other long-chain hydrocarbon reacts with some chemical such as an inorganic acid (sulfuric acid) or ethylene oxide in the presence of an alkali (sodium or potassium hydroxide as in soap). The detergent formed contains chemicals called surfactants which result from the addition of the alkali to the acid-derived molecule first formed in the "esterification reaction". It is these surfactants that, depending on their chemical composition, enable the detergent to operate in a variety of water conditions (such as hard water) compared with regular soap. See the following sites for more information: http://inventors.about.com/library/inventors/blsoap.htm and*

http://chemistry.about.com/gi/dynamic/offsite.htm?site=http://vm.cfsan.fda.gov/%7Edms/cos%2D215.html.

4. **“Aren’t all fats bad?”** *There are both “good” and “bad” fats. Our bodies need fat for a variety of purposes, including synthesizing cell membrane structures, hormones, nerve tissue, and body insulation against temperature changes, among other things. Saturated fats and trans fats have bad effects on cholesterol levels (cholesterol is needed by our bodies but too much is not good), while polyunsaturated fats and monounsaturated fats have good effects on cholesterol levels.*
5. **“Cholesterol is a fat—how is it related to trans fats?”** *Cholesterol levels are affected by trans fats. There are two kinds of cholesterol, low density lipoprotein (LDL) which transports cholesterol throughout the body and high density lipoprotein (HDL) which picks up excess cholesterol in the blood and takes it back to the liver. High levels of LDL build up in the walls of the arteries, making them hard and narrow. Trans fats elevate LDL and reduce HDL rather than the reverse. It is thought that trans fats also elevate blood levels of triglycerides, which in high levels may create the same effects on the blood vessels as that from LDL. Trans fats may also increase the rate of inflammation by damaging the cells that line the blood vessels. Inflammation may contribute to formation of fatty blockage in heart blood vessels.*
6. **“How much fat (% of total daily calories) should be consumed per day?”** *Guidelines suggest that no more than 30% of your daily calories should come from fats of every kind. And only 7 % of the daily calorie total should come from saturated fats. Monounsaturated fats (from plant oils) along with what are known as omega-3 unsaturated fatty acids (from fish and nuts) should be the major source of fat-derived calories in the 30% total. The % of daily requirements (calories) that are provided by saturated and unsaturated fats in a specified portion of a particular food is found on the labels of food containers. You need to determine the number of calories required by your body which can be approximated by consulting reference charts in which your life style (demands) and physical size (height and weight) determine average caloric needs.*
7. **“If cholesterol is bad, should you avoid all cholesterol-containing food?”** *The body needs cholesterol for synthesizing a variety of cholesterol-based molecules, including steroidal compounds such as the sex hormones. The body synthesizes cholesterol. So, zero consumption of cholesterol in food will not eliminate cholesterol found in the blood stream. But the quantity of cholesterol or even trans fats ingested effects the total blood levels of cholesterol. So limiting cholesterol- and trans fat- containing foods is desirable.*

References

A reference that all teachers might consider for their professional library is the *Sourcebook* 2.1 from the ChemSource Project. It is available from the American Chemical Society at the following web address: http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccurriculum%5Cteachres.html.

Websites for Additional Information

More sites on Soaps and Detergents

This site, http://inventors.about.com/library/inventors/blsoap.htm, gives a wonderful history about the commercial development of soaps, beginning back in the 19th C. Do you realize that liquid soap was first developed in 1865? And how did Ivory soap come to be the floating soap? Some of the soaps may not be familiar to students these days but again the history of their commercial development is interesting. For good illustrations, with equations and with color "3-D" models of important molecules in the synthesis of soap and the various types of detergents, refer to the following websites from Elmhurst College chemistry department:
http://elmhcx9.elmhurst.edu/~chm/vchembook/554soap.html and
http://elmhcx9.elmhurst.edu/~chm/vchembook/558detergent.html.

For a different and less technical discussion of soap and detergent synthesis and the chemistry behind the reactions, refer to
http://www.cleaning101.com/sdalatest/html/soapchemistry1.htm

More sites on Fats

For an interesting history of the development of margarine that began in the 19th C., refer to http://pubs.acs.org/cen/whatstuff/print/8233margarine.html. We tend to think of modern issues related to technology as having a recent history. But a lot of good commercial chemistry was happening more than a century ago, with and without health hazards identified later. But the identification of the hazards still depends on additional chemistry! The next two sites, again from the Elmhurst College chemistry department, nicely illustrate the hydrogenation process with molecular structures in color. These structures will make good overheads or LCD-projected illustrations for the classroom. The olestra molecule is very clearly a large molecule that, because of its size and geometry, resists chemical interaction with solvents and enzymes; hence it is excreted without being chemically "digested" to smaller molecules that can be absorbed into the blood stream.
http://elmhcx9.elmhurst.edu/~chm/vchembook/558hydrogenation.html (hydrogenation with good molecular structures in color)
http://elmhcx9.elmhurst.edu/~chm/vchembook/558olestra.html (molecular structure of olestra)

For discussion purposes and for student activities related to the frequency and amounts of various lipids in foods, the following websites provide handy references in chart form:
http://elmhcx9.elmhurst.edu/~chm/vchembook/550lipids.html This site shows an organizational chart for different classes of lipids.

http://elmhcx9.elmhurst.edu/~chm/vchembook/552triglycerides.html This site shows structural formulas in color of triglycerides and a chart to summarize % fatty acids in each.
http://elmhcx9.elmhurst.edu/~chm/vchembook/551fattyacids.html This site provides fatty acid structural formulas and charts showing the amount of saturated and unsaturated fatty acids, both from plant and animal sources in various common foods.

The Federal Government's FDA (Food and Drug Administration) has a very useful website that includes a section on how to read labels on food containers to determine the amount of fat content present (all categories). Refer to:
http://www.cfsan.fda.gov/~dms/transfat.html .

Another reference from the FDA that deals specifically with trans fats provides a series of questions that people might ask. In addition, there are charts listing a variety of common foods with the % trans fat present. Find it here:
http://www.fda.gov/FDAC/features/2003/503_fats.html. Again, this might prove a useful

reference for students who are into investigating the extent to which trans fats occur in a variety of food categories (including diet programs!).

In case there is a need to delve into the basics of bonding in organic molecules and to illustrate the specific molecules in the fatty acid and lipid categories, the following websites provide user-friendly illustrations for students and teachers alike.
http://www.accessexcellence.org/RC/VL/GG/chemBonds1.html (good basic diagrams of organic molecules with bonding illustrated)
http://www.accessexcellence.org/RC/VL/GG/fattyAcids1.html (more diagrams and structural formulas of fatty acids and lipids)
http://www.accessexcellence.org/RC/VL/GG/fattyAcids2.html (part II of diagrams and structural formulas of fatty acids and lipids)

Finally, for the student who has had biology, she might want to check out where lipids (as phospholipids) fit into the structure of the cell membrane. There are interesting chemical and structural issues with the cell membrane as a selectively permeable membrane—how do water soluble and partially soluble molecules pass across a membrane that contains lipid and non-lipid structural elements?
http://elmhcx9.elmhurst.edu/~chm/vchembook/553bilayer.html The site shows structural formulas of phospholipids and their position in cell membrane diagrams.

Beyond hydrogen: The New Chemistry of Fuel Cells

Background Information

More on the inefficiencies of internal combustion engines

Fuels cells are much more efficient than internal combustion engines, that is, they convert more of the energy available in the chemical bonds of a fuel into useful kinetic energy that actually ends up moving a car down the road. There are three main sources of inefficiency in internal combustion engines. The first is that most of the energy released in an internal combustion engine is released as heat. Some of this heat makes gases in the cylinders expand, pushing the pistons, and ultimately, turning the wheels of the car. However, pushing the pistons doesn't use nearly all the heat produced. When the gases are through pushing, they are sill very hot, and much of the heat is sent out the tailpipe of the car with the hot exhaust gases. What's more, a lot of the heat released doesn't do any useful work at all, but just makes the metal in the engine hot. This is the nature of heat, to flow from hot objects to cold objects, so containing it requires a fight against the second law of thermodynamics. A fuel cell releases most of its energy as electrical current rather than heat, reducing this kind of inefficiency.

The second source of inefficiency is friction. An internal combustion has lots of moving parts. Pistons slide up and down in cylinders, the crankshaft moves in its bearings, and so forth. Every time moving parts move in contact with non-moving surfaces, the moving parts must overcome friction. There is plenty of friction in an internal combustion engine, cutting its efficiency. Fuel cells, on the other hand, have few moving parts, and therefore little loss of energy due to friction.

The third source of inefficiency in an internal combustion engine has to do with the way pistons move. In an internal combustion engine, pistons are constantly moving back and forth, accelerating to very high speeds, coming to a stop, and then accelerating in the opposite direction. When the fast-moving piston comes to a stop, a lot of its kinetic energy is converted to heat rather than being used for work. Some clever designs, like the Wankel rotary engine used by Mazda in several models, eliminate this problem. Needless to say, fuel cells have no pistons and no such energy losses.

More on the drawbacks of methanol

For all their advantages, methanol fuel cells do have two serious drawbacks. The first is a property of the fuel itself. Methanol is much more toxic than gasoline and other alternative fuels like ethanol. In the body, methanol attacks the optic nerve and can cause permanent blindness if ingested in small doses. Larger doses can be fatal.

The second drawback has to do with the operation of methanol fuel cells. Methanol molecules can sometimes pass through the polymer membrane which separates the anode catalyst from the cathode catalyst. The methanol molecules are then oxidized into CO_2 and H_2O, but without producing any useful electrical current. This is called crossover oxidation, and it results in a reduction in the amount of useful energy obtainable from a given amount of methanol fuel.

More on the drawbacks of ethanol

Ethanol fuel cells aren't as efficient as methanol fuel cells because ethanol molecules contain carbon-carbon bonds, which don't oxidize as efficiently in fuel cells as, say, carbon-oxygen bonds do. However, bigger disadvantages may revolve around the production of ethanol. Depending on the source, ethanol may or may not be a "green" fuel. Corn-based ethanol still requires fossil fuel use, once growing the corn, fermentation, and distillation have been taken into account, so the decrease in greenhouse gas emission is much smaller than you would expect. Ethanol from sugar cane is somewhat less energy-intensive to produce. On the other hand, sugar cane ethanol is less energy-intensive to produce. Many other plants are currently being investigated as ethanol sources. Furthermore, the use of corn-based ethanol as a fuel has driven up corn prices world-wide, leading to increased food prices. In February of 2007, there were even street protests in Mexico City over the high price of corn tortillas, a direct result of the use of corn-based ethanol fuels.

More on other fuels

Alcohols aren't the only fuels being considered as alternatives to hydrogen for use in fuel cells. Ammonia, dimethyl ether, and formic acid are also under investigation. In ammonia fuel cells, ammonia essentially acts as a medium for delivering hydrogen to the fuel cell. First, the ammonia is heated to decompose it into hydrogen gas and nitrogen gas. Then the hydrogen gas is oxidized into water as in a normal hydrogen fuel cell. The main advantage of ammonia as a fuel is that it can be liquefied at moderate pressures, and therefore is easier to handle, store, and transport than hydrogen. Dimethyl ether (DME) offers this same advantage. DME is less toxic than methanol, and DME fuel cells don't suffer from crossover oxidation the way methanol fuel cells do. Formic acid also offers the advantages of lower toxicity and reduced crossover oxidation.

There is an important difference between fuel cells that use fuels like ammonia and those that use fuels like formic acid or dimethyl ether. Ammonia is not itself electrolyzed in an ammonia fuel cell. Rather, ammonia is decomposed into N_2 gas and H_2 gas, and the H_2 gas is electrolyzed as in a normal hydrogen fuel cell. Fuel cells that convert their fuels into hydrogen are called *reforming* fuel cells. Formic acid and DME, on the other hand, are themselves electrolyzed in fuel cells. Fuel cells that do not convert their fuels into hydrogen or other substances are called *direct* fuel cells. Ethanol and methanol fuel cells are usually direct fuel cells.

More on fuel cell electrode materials

Traditionally, platinum has been the metal of choice in both the anode and the cathode of polymer-electrolyte fuel cells, regardless of the fuel used. Recently, a new platinum-nickel alloy called $Pt_3Ni(III)$ has been developed which is ten times as catalytically active as platinum alone when used as a cathode material. For the cathode catalyst to work, molecular oxygen from the air must be adsorbed on the surface of the catalyst. However, when platinum cathodes are used, hydroxide ions produced as intermediates in the production of water molecules adsorb tightly to platinum atoms at the surface of the catalyst, blocking those surface platinum atoms. Hydroxide ions adsorb much less strongly on $Pt_3Ni(III)$, meaning fewer surface platinum atoms will be blocked, and more will be available onto which O_2 can adsorb.

The greater catalytic activity increases the efficiency of fuel cells, which is important in the case of methanol fuel cells which already suffer from losses of efficiency due to crossover oxidation.

More on polymer electrolyte membranes

Most experimental fuel cells for automotive use involve polymer electrolyte membrane fuel cells. These are fuel cells in which the electrolyte which separates the anode and the cathode is a thin layer of a special polymer designed to conduct cations, but not electrons. Polymers are giant molecules containing thousands of atoms, usually arranged in a chain-like structure. Many polymers are made up of a main backbone chain, with small side chains of atoms attached to the atoms in the backbone chain. In polymer electrolytes, these side chains contain ionizable groups. Nafion, a polymer often used for making fuel cell electrolyte membranes, is a polymer containing mostly carbon and fluorine atoms, but with side chains containing sulfonate groups, usually with sodium as the counterion. The anionic sulfonate groups are bound to the polymer chain, but cations are freely conducted through the material. This allows the material to conduct hydrogen or other cations between the anode and the cathode.

Other types of materials are used as electrolytes in fuel cells for non-automotive applications. For example, phosphoric acid is used an electrolyte in larger stationary fuel cells. Other stationary fuel cells use solid oxides as electrolyte membranes.

More on the history of fuel cells

Electrochemical cells were invented in the late 1700s. The connection between electricity and chemical reactions provided a fruitful field for researchers of the early 1800s. Scientists like Humphry Davy improved cell designs while using their current to decompose compounds by electrolysis to discover new elements like sodium, potassium, magnesium, calcium, strontium, and barium. Meanwhile, William Nicholson and Anthony Carlisle discovered that water could be decomposed by electrolysis into hydrogen and oxygen. In 1839, Sir William Grove experimented with reversing the process to generate electricity while synthesizing water from hydrogen and oxygen. Even so, it would be another fifty years before the first practical fuel cell was built by Charles Langer and Ludwig Mond in 1889, powered by methane. Francis Bacon worked to develop better fuel cells from the 1930s through the 1950s. Fuel cell development really took off with the birth of the space age, when NASA needed compact and efficient sources of electricity for spacecraft.

Connections to Chemistry Concepts

1. **Oxidation and reduction**—All the reactions that power fuel cells are redox processes, regardless of the fuel involved.
2. **Half reactions**—Fuel cells are a real-world application in which it makes sense to describe the chemical reaction taking place as two half-reactions. In fuel cells, oxidation and reduction take place in different locations. Half-reactions provide a realistic description of the chemistry.
3. **Energy and chemical reactions**—The chemical reactions in fuel cells are necessarily exothermic, just as combustion reactions are exothermic.
4. **Ions**—All fuel cells involve the passage of cations through a membrane while electrons travel separately through a wire to the same destination at the cathode catalyst on the far side of the fuel cell.
5. **Atomic structure**—The nature of atoms as being made of protons, neutrons, and electrons is central to understanding how ions form and convert to neutral molecules again in fuel cells.
6. **Electrochemical cells**—To understand fuel cells, students will apply concepts familiar from other electrochemical cells and reinforce those concepts.
7. **Polymers**—The membrane separating the anode and cathode of a fuel cell is usually made of a polymer electrolyte of some sort.
8. **Catalysis**—The anode and cathode of a fuel cell not only conduct electrons from one side of the fuel cell to the other, but they also catalyze the oxidation of the fuel molecules and the reduction of the resulting ions to form waste products.
9. **Gases and liquids**—The fact that there is a lot of empty space between the molecules of a gas becomes important when the economics of transporting hydrogen need to be evaluated. The fact that liquid fuels have much less empty space in between their molecules makes them more economical to transport.

10. **Atmospheric chemistry**—The carbon dioxide content of the atmosphere is a major concern in this story, not only the fact that human activity is raising atmospheric CO_2 levels, but ironically that CO_2 levels might not be high enough to make methanol production from atmospheric CO_2 feasible.
11. **Surface and interphase chemistry**—In a fuel cell, both oxidation and reduction take place when gas-phase reactant molecules are adsorbed onto the surface of a solid-phase catalyst. A lot of interesting chemistry takes place on surfaces, from sophisticated catalysis to the simple spreading of water on a piece of glass. Even though this topic usually gets little attention in high school chemistry classes, it is important enough that the 2007 Nobel Prize for Chemistry was awarded to German scientist Gerhard Ertl for his work in surface chemistry.
12. **Elements and compounds**—Hydrogen is the most abundant element in the universe, and there is plenty of it on planet Earth—but it is locked up in compounds with other elements, mostly water, and to a lesser extent methane. Obtaining elemental hydrogen, H_2, requires decomposing water or other hydrogen containing compounds.

Possible Student Misconceptions

1. **"Fuel cells burn fuels"** "Burning" implies combustion, which is mechanistically, and kinetically different from the way fuels are oxidized in fuel cells. A major consequence of the different mechanisms of oxidation in fuel cells is that energy is released as electric current rather than heat, as is the case with combustion.
2. **"The electrodes in a fuel cell absorb ions."** The difference between absorption and adsorption is one that high school students may not be familiar with. They should be made aware that adsorption is merely the attachment of molecules or ions to a surface through chemical interaction of some sort, and not the same thing as absorption.
3. **"Hydrogen, methanol, and ethanol are energy sources."** Any fuel is just a means of storing energy. (Even fossil fuels are merely storing solar energy from millions of years ago.) Energy is required to produce hydrogen, methanol, and ethanol. That energy must come from somewhere. The energy used to produce hydrogen, methanol, or ethanol, may be that stored in fossil fuels, or it may come from a renewable source like solar or wind power. Either way, the fuels are only as green as the energy used to produce them.
4. **"Ethanol is non-toxic."** Ethanol is toxic, just not as toxic as methanol. While (most) adults can safely and responsibly consume it is small doses, people have died from ingesting enough of it.

Demonstrations and Lessons

1. The electrolytic decomposition of water can be accomplished using a Hoffman's apparatus or with simpler set-ups using batteries and pencil-lead electrodes. Fuel cells combine hydrogen and oxygen to generate electricity. The reverse process, using electricity to decompose water into hydrogen and oxygen, demonstrates the connection between electricity and chemical transformation, and underscores the thermodynamics of the reactions involved in fuel cells (i.e. producing water releases energy, while converting water into hydrogen and oxygen absorbs energy). What's more, it reinforces the understanding that generating hydrogen for fuel requires energy of some sort.
2. Constructing a simple galvanic cell is another way to reinforce the concept that chemical reactions can produce electricity. Also, there are enough similarities between fuel cells and

galvanic cells that concepts learned in one are applicable to the other, and one can be used to reinforce understanding of the other.

3. You can set up an electroplating apparatus to reinforce the connection between electricity and chemical changes.
4. Simple reforming fuel cells can be made that use HCl and HNO_3 as hydrogen sources. A description and procedure is found in Bilash, Borislaw; Gross, George R.; and Koob, John K., *A Demo A Day: A Year of Chemical Demonstrations*. Batavia, IL: Flinn Scientific, 1995, p. 240.
5. A description of how to build a direct methanol fuel cell for classroom demonstration use can by found in Zerbinati, Orfeo, "A Direct Methanol Fuel Cell," *Journal of Chemical Education*, July 2002, **79(9)**, *829*.
6. A low-cost apparatus for studying gas adsorption on solid-surfaces for use in teaching is described in Macedo, Hugo; Aguiar-Ricardo, Ana ; and Sotomayor, João, "Construction of a Low-Cost Apparatus for Gas Adsorption on Solids, *Journal of Chemical Education*, June 2006, **83(6)**, *915*.

Student Projects

1. Students can research other fuels; they can be assigned fuels, other than methanol and ethanol, which are being investigated for use in fuel cells. Students should investigate the advantages, disadvantages, and potential applications of their assigned fuel. You might choose to have them report their findings as written reports, posters, or class presentations. This project might be done in groups so you don't have to find a different fuel for each individual student in your class.
2. Have a debate/discussion in which students have been assigned to argue for either methanol or ethanol fuel cells as a better alternative for automotive use.
3. Assign students or groups to research and report on other important electrochemical processes, such as aluminum refining, galvanic corrosion protection, the reactions in rechargeable batteries, photovoltaic cells, etc.
4. Assign students or groups to research and report on non-automotive uses of fuel cells. Fuel cells are used in aerospace applications, portable electronic devices, and stationary power sources, among other things. Student reports, in whatever format you choose, should include information about the technical constraints of the application, the fuel used in a particular application, and the limits of the technology used, and outlook for future development.

Anticipating Student Questions

1. **"Why can't water be used as a fuel?"** *Fuels release their energy by reaction with oxygen (which is relatively abundant). Water cannot react further because it is already oxidized as much as it can be. (Any further oxidation with oxygen would consume, not release energy.)*
2. **"Why can't electricity from windmills be transmitted over long distances?"** *Electrical current is the motion of electrons moving through a wire or some other conducting material. Although the copper wire in transmission lines conducts electricity very well, it does resist the flow of electrons a little bit. Overcoming that resistance uses up some of the energy of the moving electrons. The longer the distance the electrons have to travel through the transmission lines, the more energy will gradually be used up overcoming resistance. After a few hundred miles, the flowing electrons will have lost so much energy that they won't*

have enough energy left to do things like turn electric motors or make bulbs light up. For this reason, electric power plants have to be built relatively close to where the electricity they produce will be used.

3. **“Why are we worried about the effect of CO_2 in the atmosphere if it only makes up less than 1% of the atmosphere?”** *Carbon dioxide is a potent enough greenhouse gas that even small amounts can have an effect on global temperatures. Currently CO_2 levels are at about 370 ppm. It’s thought that an increase to only 450 ppm may cause irreversible and possibly catastrophic climate change.*

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McFarlan, A.; Pelletier, L.; and Maffei, N. “An Intermediate-Temperature Ammonia Fuel Cell Using Gd-Doped Barium Cerate Electrolyte,” *Journal of the Electrochemical Society*, 2004, **151**, *A930*.

J.T. Muller, P. M. Urban, and W. F. Holderich, “Electro-oxidation of Dimethyl Ether in a Polymer-Electrolyte-Membrane Fuel Cell,” *Journal of the Electrochemical Society*, 2001, **147**, *4058*.

Jiang, Ruichun; Kunz, H. Russell; and Fenton, James M. “Comparison of Several Research Approaches for Direct Methanol Fuel Cell Membranes,”
Abstract of a paper presented at the 210th Electrochemical Society Meeting, October 29-November 3, 2006, Cancun, Quintana Roo, Mexico.
<http://ecsmeet2.peerx-press.org/ms_files/ecsmeet2/2005/06/01/00021841/00/21841_0_art_file_0_1117673543.pdf>

Jeong, Kyoung-Jin, et al. “Fuel crossover in direct formic acid fuel cells,” *Journal of Power Sources*, 2007, **168 (1)**, *119*.

Stamenkovic, V. R., et al. “Improved Oxygen Reduction Activity on $Pt_3Ni(111)$ via Increased Surface Site Availability,” *Science*, 2007**,** **315**, *493*.

“Mexicans Stage Tortilla Protest,” BBC News Online, February 1 2007.
http://news.bbc.co.uk/2/hi/americas/6319093.stm

Ehsani, Mehrdad. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design*. CRC Press, 2005, p. 17-18.

Websites for Additional Information

More on the History of Fuel Cells

“Collecting the History of Fuel Cells” —an impressive online exhibit from the Smithsonian Institution. http://americanhistory.si.edu/fuelcells/

More on Ethanol as a Fuel

“Green Dreams,” Joel K. Bourne, Jr. This feature story also available in the print edition of *National Geographic* magazine, October 2007, explores the promises and pitfalls of ethanol and biodiesel produced from a variety of plant sources, from corn and sugar cane to switch grass and algae. This insightful and in-depth story looks at the various sources in terms of their environmental, economic, and human impacts.
http://magma.nationalgeographic.com/ngm/2007-10/biofuels/biofuels.html

General Web References

“Fuel Cells”—from the U.S. Department of Energy. This site contains basic information on a wide variety of fuel cells using different technologies and for different applications.
http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html

“Fuel Cells” —video segment from the PBS television series *NOVA ScienceNow*, which originally aired in July of 2005. The segment features a particularly entertaining explanation of how fuel cells work by Tom and Ray Magliozzi, hosts of National Public Radio’s *Car Talk*. The site also includes web extras.
http://www.pbs.org/wgbh/nova/sciencenow/3210/01.html

“How Fuel Cells Work” —from HowStuffWorks. http://auto.howstuffworks.com/fuel-cell.htm

More websites on Teacher Information and Lesson Plans

“Discovering the principle of the fuel cell at home or in school” —An involved student laboratory activity on electrolysis, created by Dr. Martin Schmidt, from Fuel Cells 2000.
http://www.fuelcells.org/ced/career/scienceproject.pdf

“Bonneville Power Administration Energy Efficiency Education Program” —This site features free downloadable curriculum materials on fuel cells and other energy-related topics.
http://www.bpa.gov/Energy/N/projects/fuel_cell/education/index.cfm