



October 2005 Teacher's Guide

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Puzzle: ChemWeb

In keeping with this issue's theme "The Joy of Toys", we offer CHEM WEB.

Chem Web is a student-centered non-competitive game, created by Larry Lemmert, a now-retired chemistry teacher at Neenah H.S. in Wisconsin some years back. Larry shared it with teachers at a Woodrow Wilson Summer Institute at Princeton University in 1989, and it has spread from there. It is adaptable to a wide range of chemical studies, but the one we're showing here treats environmental chemistry.

The instructions for students is in the grid below. One possible web (from Larry) is shown on the answer page, but perhaps you can do better. Remember, there is no single "correct" solution !

Here are some suggestions /extensions for classroom use.

1. Feel free to add or subtract terms as you wish. Store sets in envelopes for future use.
2. After 15–20 minutes have teams view and critique other group's webs, encouraging them to verbalize their reasoning. Doing so is in fact the chief virtue of the game when it unleashes student insight, creativity, and sometimes humor.
3. Have the class vote on which web does the best job of linking terms.
4. Build a class consensus web, with a leader manipulating a large-sized set of squares with magnetic tape backing that can be manipulated on a blackboard/whiteboard for all to see at once..
5. Perhaps a programmer-savvy student could create a computer version in which the user moves squares about on the screen to set up various connections (as in solitaire card games).

CHEM WEB can be adapted to other areas of chemistry, such as HISTORY of chemistry, or REDOX ideas (including cells) or ORGANIC chemistry(family relationships, isomers, etc). Teachers and second-year students should not find it too difficult to come up with 30+ related terms in such areas. Happy web-bing !!

Print this page on heavy-stock paper or tagboard, and cut out squares along dotted lines.

cave formations	car AC systems	freon	limestone	carcino-genic	chromium	heavy metals
building materials	sand	CFC's	ozone depletion	u.v. light	CaCO ₃	lead
perchlor-ates	quartz	calcite	O ₃	photo-chemical smog	SiO ₂	car batteries
explo-sives	NO ₃ ¹⁻	NO _x gases	air pollution	SO _x gases	SO ₃	H ₂ SO ₄
NH ₄ ¹⁺	plant fertilizers	carbonated water	H ₂ CO ₃	SO ₂	sulfur in coal	CH ₄
ground-water pollution	PO ₄ ³⁻	carbon dioxide gas	green-house effect	acid rain	fossil fuels	hydro-carbons
<p>Team's task is to assemble a web in which tiles set side by side, either vertically or horizontally, should be closely allied, diagonal ones somewhat less so. Your goal is to get every tile into the web and to be able to rationalize the linkages chosen.</p>						

Puzzle Answers

Here is one possible web created by Larry Lemmert using the environmental terms on puzzle page.

	car AC systems	freon		carcino-genic	chromium	heavy metals
		CFC's	ozone depletion	u.v. light		lead
perchlorates			O ₃	photo-chemical smog		car batteries
explosives	NO ₃ ¹⁻	NO _x gases	air pollution	SO _x gases	SO ₃	H ₂ SO ₄
NH ₄ ¹⁺	plant fertilizers			SO ₂	sulfur in coal	
ground-water pollution	PO ₄ ³⁻			acid rain	fossil fuels	hydro-carbons
				H ₂ CO ₃	carbon dioxide gas	green-house effect
				carbonated water		CH ₄
			calcite	CaCO ₃		
			cave formations	limestone		
				building materials	sand	quartz
					SiO ₂	

Content Reading Guide

National Science Education Content Standards As a result of activities in grades 9–12, all students should develop understanding	Kitty Litter	Liquid Crystal Displays	Drinking Bird	Golf Balls	QFTC
Science as Inquiry Standard A: of abilities necessary 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 conservation of energy and increase in disorder.			✓	✓	
Physical Science Standard B: of interaction of energy & matter.		✓	✓		
Science and Technology Standard E: about science and technology.	✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of personal and community health.	✓				
Science in Personal and Social Perspectives Standard F: of 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.

Liquid Crystal Displays

Me	Test	Statement
		1. Liquid-crystal displays use a huge amount of energy.
		2. Liquid crystal molecules are long, linear, and polar.
		3. Only a few types of liquid crystals have been developed.
		4. Light emitted from liquid crystals is polarized.
		5. On a color display, only 3 subpixels (red, green, and blue) are needed for each pixel.
		6. Red and green light makes yellow light.
		7. Plasma televisions use LCD displays.
		8. Light for LCD displays is provided by tiny infrared tubes.
		9. It is now possible to show two different images simultaneously on one LCD.

The Amazing Drinking Bird!

Me	Text	Statement
		1. The tail feathers on the drinking bird are just for decoration to make it look more like a bird.
		2. The liquid inside the drinking bird is water.
		3. The space above the liquid in the drinking bird is filled with air.
		4. If the temperature remains constant, the concentration of vapor above the liquid is also constant.
		5. Evaporation is a cooling process because it requires bond breaking.
		6. When vapor pressure in the bottom bulb of the bird is greater than the vapor pressure in the top bulb, the liquid is forced into the top bulb.
		7. A “hand boiler” and a drinking bird operate on the same physical principles.

Kitty Litter Chem

Me	Text	Statement
		1. Kitty litter has been around for at least 200 years.
		2. Most kitty litters today are made of clay minerals.
		3. Sodium-rich bentonite and calcium-rich bentonite perform equally well at absorbing moisture.
		4. Silica gel crystals in kitty litter absorb water, then allow it to evaporate.
		5. Most kitty litters are not biodegradable.
		6. Adsorption and absorption have the same meaning.

There is Chemistry in Golf Balls!

Me	Text	Statement
		1. There are fewer than 10 types of golf balls available to the public.
		2. The first golf balls were made of feathers inside a leather pouch.
		3. Golf ball cores have been made of air, metal, mercury, cork, and elastic.
		4. A given golf ball has the same elasticity no matter how hard it is struck.
		5. If the golf ball is in contact with the club for a longer time, the momentum transfer is greater, so the ball will go farther.
		6. Golf balls are hardest on the inside.
		7. All golf balls today have two layers in addition to the core.
		8. Dimples help the golf ball go higher and twice as far compared to nondimpled golf balls.

Reading Strategies

These matrices and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words. 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

Vocabulary students need to know prior to reading the articles:

- **Kitty Litter Chem:** cation, valence, sequester
- **Liquid Crystal Displays:** nematic
- **The Chemistry of Golf Balls:** polybutadiene (also how to pronounce it)

Also, the **physics teacher** at your school will probably enjoy this issue immensely, and may have materials to share that will help your students understand how the science described in these articles affects their everyday lives.

Liquid Crystal Displays

LCD	Materials used	Advantages
Past		
Present		
Future		

The Amazing Drinking Bird

Complete the chart below explaining how the drinking bird works.

Steps	Why?
<i>Wet bird's head</i>	
<i>Bird dips head</i>	
<i>Bird becomes upright</i>	
<i>Repeat!</i>	

Kitty Litter Chem

Compare and contrast the types of kitty litter using the chart below.

Type of Kitty Litter	Materials used	Advantages
Traditional		
Clumping		
Plant-based		

There's Chemistry in Golf Balls!

In the chart below, describe how chemistry makes the advantages you list possible.

	Advantages	Chemistry involved
Golf balls in history: 1. 2. 3. 4.		
Today's Golf Balls		
Elasticity		
Deformation		
Dimples		

Liquid Crystal Displays

Background Information

More on Liquid Crystal History:

Liquid crystals were discovered in Germany by Austrian botanist Friedrich Reinitzer in the late 1880's. Reinitzer was studying the chemical makeup of plants, and in his study he found that cholesteryl benzoate, $C_{34}H_{50}O_2$, had two melting points, not one as most solids do. At 145 and 5°C the solid changed into a cloudy fluid, and not until it was heated to 178.5°C, did the cloudy fluid become the expected clear liquid. In 1888, Reinitzer showed his results to German physicist Otto Lehman, an expert in crystals, who concluded that this represented a new kind of compound. Lehman first introduced the term "liquid crystal" to describe the cholesteryl benzoate's phase between 145.5°C and 178.5°C.

The discovery of this "liquid crystal" phase created controversy in the scientific community since the traditional three phases of matter—solid liquid and gas—were well-established by this time. Over the next 15 years the idea of liquid crystals was not universally accepted. (Note: You can use this development to illustrate to students the changing and tentative nature of scientific knowledge. As new evidence is uncovered in science, models and concepts are changed, often slowly and often with much controversy.)

By 1904, however, Merck Chemicals was already producing chemicals that exhibited liquid crystal properties. Some examples included methylammonium, dimethylammonium, and trimethylammonium oleate. In part because these molecules were being produced by Merck, the existence of the liquid crystalline phase was commonly accepted by the 1920's. For a while there was a lot of research on the molecules themselves, but virtually none on how to apply their properties. The liquid crystal situation remained dormant for more than 30 years.

In the late 1950's and early 1960's the hunt began for ways to apply the crystals for practical uses. James Fergason, then working at the Westinghouse Research Labs in Pittsburgh, established the first American team researching uses for liquid crystals. A second team was headed by George Heilmeier at RCA. In 1968, Heilmeier unveiled an early version liquid crystal display with the major drawback that it required a temperature of 80°C to operate properly.

Meanwhile, having moved to Kent State University's Liquid Crystal Institute, Fergason discovered the "twisted nematic (TN) crystal effect" that led to LCD's. He patented the use of LC's in a display in 1968, and in 1971 patented the nematic LCD. Fergason began his own company to produce the display, and his first customer was the Gruen Watch Company, which first used LCD's in their watches in place of light emitting diode technology. Fergason holds 125 U.S. patents and more than 500 foreign patents.

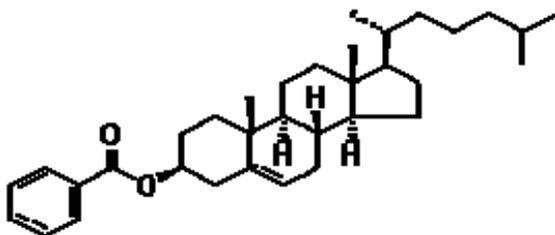
The development of liquid crystals was also greatly influenced by the work of French physicist, Pierre-Gilles de Gennes in the 1960's. Originally interested in magnetic substances and superconductors, he discovered similarities between these and liquid crystals. He was awarded the Nobel Prize in Physics in 1991 for his work on liquid crystals.

More on Liquid Crystals (Microscopic)

Although the chemical composition of liquid crystals is not discussed in the article, and although the composition of the crystals is not absolutely essential for students' understanding of LCD's, the molecules should not be considered "anonymous". For your background and information, here are a few examples of molecules that exhibit liquid crystalline properties.

Most liquid crystal molecules are synthetic organic compounds of moderate size. Liquid crystal molecules have strong dipoles or at least can be easily polarized. The molecules are much longer than they are wide. If the length of the molecule is, for example, 30 Å, then its width would be on the order of 5 Å. This allows them some degree of order. Most molecules used in LCD's have a two, three or four ring-type core consisting typically of aromatic or cyclohexyl rings. These rings may be attached directly to each other or through intermediate groups of atoms. Other groups like alkyl-, alkoxy-, fluoro- or carboxyl may be added at the terminal para- position in the core. For a more complete description of liquid crystal molecule shapes, with graphics, see <http://invsee.asu.edu/nmodules/liquidmod/shape.html>

As mentioned in the section on History (above), cholesteryl benzoate was the first molecule discovered to have liquid crystalline properties. The structure of cholesteryl benzoate is:



Also mentioned in the history section are methylammonium, dimethylammonium, and trimethylammonium oleate.

In the 1960's liquid crystal molecules were synthesized. Among these were p-methoxybenzylidene-p'-butyloxyaniline (MBBA), groups of symmetrically and asymmetrically substituted phenylbenzoates, azoxy compounds like p-methoxy-p'-n-butylazoxybenzene.

In the 1970's, when LCD's were beginning to employ twisted nematic crystals, molecules like substituted cyanobiphenyls, phenylcyclohexanes (PHC's) and cyclohexylcyclohexanes (CCH's) brought stability at room temperature, improved switching times, and better optical display qualities to the technology. The emergence of cyanobiphenyls was of primary importance since they were well suited for the twisted nematic liquid crystal displays in use today.

Currently MBBA is still used in twisted nematic liquid crystal displays as is p-decyloxybenzylidene p'-amino 2-methylbutylcinnamate (DOBAMBC). Currently about 60% of all nematic liquid crystals are produced by Merck-Japan.

These are shown only as specific examples. It should be worth noting to students that these molecules are used in LCD's because of specific properties exhibited by the molecules. It is always worth noting to chemistry students the relationship between molecular properties and uses for the compound.

The article suggests that there are more than 50,000 known liquid crystal molecules. In most LCD's the liquid crystals are not a single kind of molecule but a precisely controlled mixture of as many as 20 molecules in order to get the right properties.

According to Merck-Japan, the largest producer of liquid crystals:

- Liquid crystals are not acutely toxic.
- A few can be an irritant, corrosive or sensitizing, but this can be avoided by limiting the concentration of such liquid crystals in the mixtures that are typically used for LCD's.
- LC's are not mutagenic in either bacteria or mammalian cells.
- They are not suspected of being carcinogenic.
- They are not harmful to aquatic organisms.

optical properties like birefringence and index of refraction. The two main sub-phases relevant to a discussion of LCD's are the nematic phase and the smectic phase.

Nematic Phase

Nematic liquid crystals are the types of crystals used in most LCD's. Nematic crystals are most similar to true liquids in that the molecules are in motion but remain ordered in orientation. Chiral molecules (see below) in the nematic phase often arrange themselves in a twisted orientation. These are the liquid crystals used in LCD's because the twist causes polarized light (see More on Polarized Light, below) to be rotated 90° within the LCD. The term nematic comes from the Greek *nema*, which means thread.

Smectic Phase

Students can think of the smectic phase as layered nematic crystals. Within the layers (or planes), molecules can move, but they cannot move from layer to layer. Molecules in the smectic phases still exhibit the "parallel" orientation seen in nematic crystals. The smectic phase is most like the solid phase.

Students might be familiar with the fact that true crystalline solids interact with light in interesting ways. Since liquid crystals share some properties with true solids, they might be expected to interact with light as well. In fact, this is one of the underlying ideas behind LCD's. Some of the topics you could consider with students that are relevant to both true crystals and to liquid crystals are:

Refractive Index is the ratio of the velocity of light in air to the velocity of light through a transparent material.

Birefringence is the difference in value between the highest and lowest refractive indices in a doubly refractive (anisotropic) material. Many liquid crystals exhibit birefringence.

Dispersion is the ability of a crystal to separate light into its component colors. Under some circumstances (not in LCD's) liquid crystals exhibit this ability.

Other interactions between light, electricity and crystals include photoelectric cells and transistors. Although not directly related to LCD's they are further examples of the ways in which molecules and energy interact in useful ways.

More on Liquid Crystal Displays

The following schematic diagram shows the "layers" involved in making a LCD. Each of the principal parts is labeled to allow you to see the sequence of parts involved. The drawing is not to scale and is not meant to show what a LCD looks like. It is only meant to help you follow the sequence of events in a LCD.

Liquid Crystal Display "Layers"

Light Source

A - Polarizing Filter (polarizer)
B - Glass Substrate
C - Transparent Electrodes
D - Alignment Layer
E - LIQUID CRYSTALS
F - Alignment Layer
G - Color Filters (Pixels)
H - Glass Substrate
I - Polarizing Filter (analyzer)

Eye

Note that in this diagram the light is traveling from the top of the diagram to the bottom.

A and I are polarizing filters with their planes of polarization at right angles. Light from the source is polarized in one plane at A. No light would emerge from the analyzer (I) without the effect of liquid crystals.

B and H are glass plates which act as the “bread” for the LCD “sandwich.”

C is a layer of transparent electrodes which re-orient the liquid crystals to control the degree to which light emerges from the analyzer (I).

Layers D and F are each thin polymer films, usually polyimide, that acts as the director to align the liquid crystals. Layer D aligns the liquid crystal molecules to match the polarizing filter A. **Layer F** aligns the liquid crystal molecules to match the analyzer (I). This produces the “twist” in the twisted nematic crystals (E).

Layer E is made up of the nematic liquid crystals, which guide the polarized light through a 90° rotation when the electric current (C) is off so that the light will pass through the analyzer (I) to make the display appear bright. When the current is on, the crystals align with the electric field (as opposed to their “twisted” state) and no light passes through the analyzer.

Layer G is a sheet of color pixels. Each pixel is composed of three sub-pixels, one red, one green and one blue. Light that emerges from this layer is colored light.

Alternately, you can make a transparency of or paste the image from this page http://sharp-world.com/sc/library/lcd_e/s2_3_1e.htm into a PowerPoint slide for viewing by the class.

For a complete description of a liquid crystal display and how to construct one see <http://plc.cwru.edu/tutorial/enhanced/files/lcd/tn/tn.htm>

For a complete explanation (with diagrams) of how LCD's operate see http://sharp-world.com/sc/library/lcd_e/s2_1_1e.htm.

The major advantages of LCD's are:

- the display is compact, which permits flat-panel designs that have become so popular
- the compact display allows for portability
- LCD's use much less power than other displays
- fast switching speed (ms-ms)
- the display is brighter and easier to watch under normal room conditions
- a wide viewing angle
- average lifespan of up to 60,000 hours

More on Polarized Light

Most ambient light is not polarized. As light rays travel out in all directions from a source, we can think of the ray as having a field around it. The field has both a vertical and a horizontal component, and both are essential for the light to travel.

A polarizing filter polarizes light due to the chemical makeup of the filter. Polarizing filters are made up of long molecules that line up and are stretched across the filter. When unpolarized light strikes the filter, the waves vibrating in the same plane as the molecules are absorbed. The part of the light vibrating perpendicular to the planes of the molecules can pass through. The

polarization axis of a filter is actually perpendicular to the plane of the molecules which make up the filter. A polarizing filter can be thought of as a picket fence with openings in the fences corresponding to the polarization axis.

As light is passed through a polarizing filter only the light waves vibrating in the same plane as the polarization axis can pass through, and this emerging light continues to move in the same plane. Remember the picket fence analogy, above. This type of polarization is called linear polarization. The light emerging from a single polarizing filter is less intense than the incoming light.

If light passes through two polarizing filters whose polarization axes are at right angles, the light emerging from the first filter will be absorbed by the second filter and no light will emerge. Polarizers like these are used in LCD's. The first filter is called the polarizer and the second filter is called the analyzer.

In addition to polarization using filters, light can be polarized by refraction as the light passes through a medium, by refraction and by light scattering. For an explanation of polarization, involving an animation, see http://www.colorado.edu/physics/2000/polarization/blocking_light.html

More on Pixels and Subpixels

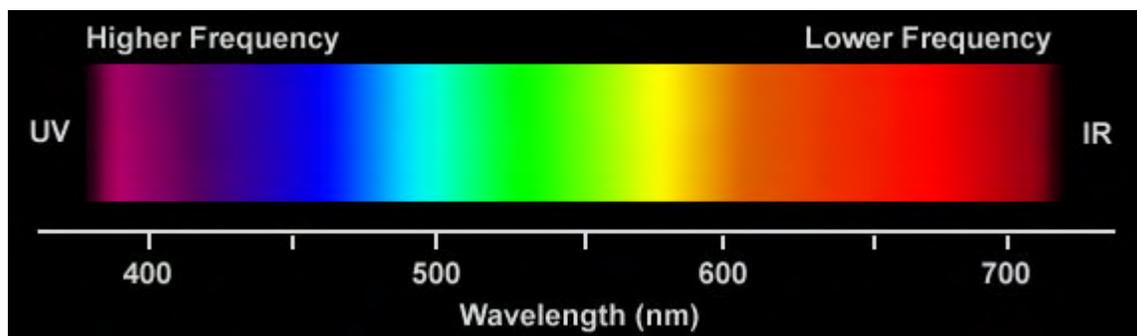
In a liquid crystal display images are formed by turning light on and off in tiny sections of the display called pixels (picture elements). When the electric field in the LCD is turned on the light arriving at a specific pixel is turned off (because the twisted crystals untwist). When the electric field is turned off the light is turned on. This on-off process is called "addressing." In active matrix LCD televisions addressing may require as many as 2.4 million transistors to turn the light on and off in a large display.

Each pixel is actually a trio of sub-pixels—one red, one green and one blue. The primary colors are generated from the white light source in the LCD by means of color filters. The color, hue and intensity of each sub-pixel can be manipulated in a LCD to produce nearly 17 million colors.

For a photo of a pixel see this page from Sharp http://sharp-world.com/sc/library/lcd_e/s1_5e.htm

More on Primary and Secondary Colors

The human eye is capable of seeing electromagnetic radiation with wavelengths between 400 and 700 nanometers. This part of the spectrum is called the visible spectrum.



The human eye resolves color by means of cone cells in the eye that are sensitive to red (about 580 nm), green (about 540 nm), and blue (about 450 nm) light. Each of the cone cells actually responds to a range of wavelengths of light. Depending on the combination of wave lengths of incoming light, the eye "sees" different colors.

It is logical, then, that colors in a LCD color display are based on three primary colors, **red**, **green** and **blue**. The three sub-pixels in each pixel in the LCD transmit these three primary colors. By mixing these colors in myriad combinations, the nearly 17 million color combinations mentioned above can be obtained. In a LCD the colors are produced by addition.

The basic rules of color by addition are these. Adding the three primary color light wavelengths produces white light. Adding red light to blue light produces **magenta**. Adding blue to green produces **cyan**. And adding red to green produces **yellow**. Magenta, cyan and yellow are called complimentary or secondary colors. The Oregon Museum of Science and Technology has an interactive web page at <http://www.oms.edu/visit/tech/colormix.cfm> that allows students to mix colors by addition and see the results. The color displays in a LCD are produced by addition. Students often confuse color by addition with the rules of color by subtraction, which apply for paints and inks (in which adding all the primary colors produces black).

More on Plasma Displays

Phosphorescence, like fluorescence is initiated by UV light. Students may have seen minerals fluoresce when they are exposed to UV light. In the case of fluorescence the phenomenon ceases when the UV light is turned off. If a substance phosphoresces, however, it continues to give off radiation even after the UV source is turned off.

In the case of phosphorescence the substance absorbs light and electrons in the substance are excited to a higher energy level. In the process the spin of the electron is changed (it moves to a "triplet" or metastable state) and it requires a longer time period for it to return to ground state. These substances give off light for longer periods of time than do substances that fluoresce.

Substances that exhibit this phosphorescent behavior are called phosphors. In a plasma display there are phosphors within each pixel that emit red, green or blue light. Thousands of substances are developed to act as phosphors. An example of a green phosphor used in plasma displays is zinc sulfide with copper or aluminum added. Europium oxide and yttrium compounds are often used as red phosphors. Blue phosphors include cobalt-activated zinc sulfide.

Connections to Chemistry Concepts

A discussion of liquid crystal displays would fit naturally during a study of phases of matter and phase transitions. The existence of the liquid crystal phase of matter will be a new topic for many students, who are used to the traditional solid-liquid-gas phases.

If organic chemistry is included in your course, this is another place to bring up liquid crystals and their display applications.

Liquid crystal displays provide you with an opportunity to explore with students the relationships between science and technology.

Liquid crystals could be used to discuss energy and entropy relationships.

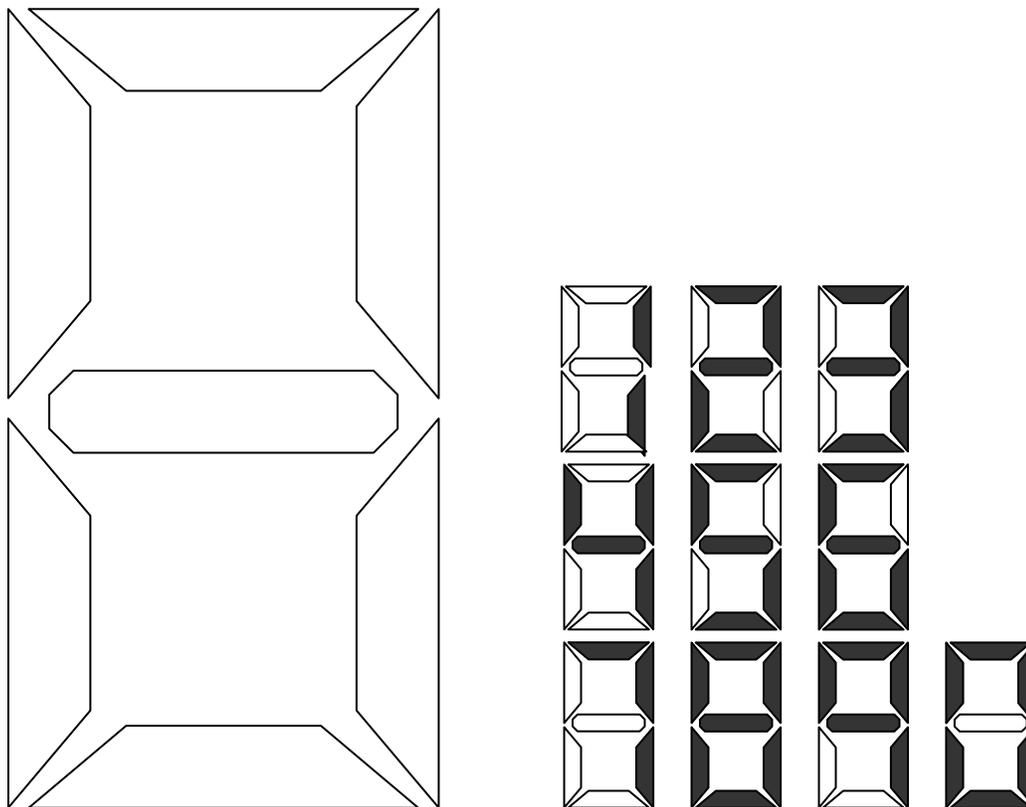
Possible Student Misconceptions

The topic of this article, although very interesting, is not one encountered in typical high school chemistry classes. It is much more likely that students will read this article with curiosity rather than with misconceptions. As students read the article, these misconceptions may arise, however.

1. All electronic devices operate like a traditional television.
2. The only phases of matter are solids, liquids and gases (and possibly plasma, if students are familiar with this 4th phase of matter).

Demonstrations and Lessons

1. On an overhead projector, demonstrate the arrangement of molecules in various liquid crystal phases. Since order in liquid crystals is typically in two dimensions, this will be an effective demonstration. You might provide written instructions to student to do their own arrangements on their desks or lab tables. Use toothpicks (the thicker "cocktail: toothpicks work well) or Popsicle sticks or wood splints. You could also have the students themselves take on the role of liquid crystal molecules and arrange themselves as nematic or smectic molecules.
2. If you have a sample of a liquid crystal, place it between two polarizing filters, placed at right angles to each other. Light passing through the first filter will also pass through the second filter as long as it also passes through the liquid crystal.
3. Students can see for themselves that the LCD on a calculator or watch involves polarized light by rotating polarizing film in front of the calculator or watch display. Polarizing sheets can be purchased from Edmund Scientific, 101 E. Gloucester Pike, Barrington, NJ 08007; Stock No: A71,942; Tel. (609) 573-6250. The online version of the Journal of Chemical Education has slides here <http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA5/MAIN/1ORGANIC/ORG09/TRAM09/B/COMMONITEMS/0262529/THUMBS.HTM> that illustrate this.
4. Remove a LCD from a calculator or watch. Use a 9-volt battery or static electricity to regulate the display. Instructions for this activity are here: <http://olbers.kent.edu/alcomed/Newsletters/Newsletters.shtml>
5. Any experiment in which light passes through a solid substance: refraction, prism etc or a solution (milk in water, for example): Ask the question, "What happens when light passes through solids and liquids?"
6. Build a working LCD. Complete directions are here: http://olbers.kent.edu/alcomed/Sam_Net/August94/Tallmadge_High.html
7. Use liquid crystal thermal sheets for three different temperature ranges, cut into 3" x 6" rectangles (each group should get three sheets total—one sheet of each kind) to show cholesteric liquid crystal phase changes.
8. Use the old-fashioned segment display system, next page, to show how to create the numbers from one through ten in a display. See http://sharp-world.com/sc/library/lcd_e/s2_2e.htm for more details.



Suggestions for Student Projects

1. Make a large version of a liquid crystal display and label the parts. See <http://electronics.howstuffworks.com/lcd4.htm> or here for a good diagram to work from http://sharp-world.com/sc/library/lcd_e/s2_3_1e.htm.
2. Build a model of twisted nematic liquid crystals as they exist in a LCD. Use a thin wooden dowel as the “director” and small thin elongated units like toothpicks or sections of pipe cleaners as the liquid crystals. The “crystals” can be glued in place around the “director” so that the top “molecule” and bottom “molecule” are at right angles to each other.
3. Research the polarization of light by means other than the polarizing filters used in LCD’s. The methods are reflection from a non-metal surface, refraction and dispersion.
4. Research the legend of the Viking Sunstone as an interesting application of polarized light in nature.
5. Research the ability of animals to see and utilize polarized light.

Anticipating Student Questions

1. What is a polar molecule? A molecule is polar if electrons in the molecule are unequally distributed. If a highly electronegative atom combines with an atom of a different element which has a relatively low electronegativity to form a diatomic molecule, ions are formed.

- Since the anion has an excess of electrons and the cation has a deficiency, the electrons are not distributed equally. This will be a polar molecule. In molecules with covalent bonding, the unequal distribution may be less noticeable but present all the same.
2. Are polar molecules magnets? No. In the article polar molecules are compared to magnets because in both cases the unlike ends will attract.
 3. What are polarizing films? See "More on Polarized Light."
 4. What is a nematic crystal? See "More on Liquid Crystals (Macroscopic)"
 5. What are primary and secondary colors? See "More on Primary and Secondary Colors."

Websites for Additional Information

For still more on the history of liquid crystals, and two computer games that illustrate the principles behind them see this site from Nobelprize.org (both games require Flash 6):
http://nobelprize.org/physics/educational/liquid_crystals/history/

For an excellent tutorial on liquid crystals see Case Western Reserve's Polymer and Liquid Crystal site here: <http://plc.cwru.edu/>

For another tutorial on liquid crystals, including helpful graphics, see <http://invsee.asu.edu/nmodules/liquidmod/welcome.html>

For beautiful microphotographs of liquid crystals see <http://www.mc2.chalmers.se/pl/lc/engelska/gallery/gallery.html>

Probably the most inclusive web site on liquid crystals is this one from Kent State University Liquid Crystal Institute at <http://olbers.kent.edu/alcomed/dhtml1.html>

For an explanation of LCD's from HowStuffWorks, see <http://www.howstuffworks.com/lcd.htm>

For a good tutorial on polarized light see <http://www.physicsclassroom.com/Class/light/U12L1e.html>

For more activities from The Exploratorium on polarized light see <http://www.exploratorium.edu/snacks/iconpolarization.html>

For interactive tutorials (requires Java) on polarized light and LCD see <http://micro.magnet.fsu.edu/optics/lightandcolor/polarization.html>

To read more technical information about addressing in LCD's see <http://www.ercservice.com/learning/what-is-tft-lcd.html>

For a great deal more on color mixing, some of which is technical, see <http://www.handprint.com/HP/WCL/color5.html#primmix>

For an extended comparison of plasma and LCD TV's along with newer technologies mentioned in the article, see http://www.audioholics.com/techtips/specsformats/displays_LCD_vs_Plasma3.html

A complete explanation, with diagrams, of how a plasma TV works, see <http://www.plasmatvscience.org/theinnerworkings.html>

The Amazing Drinking Bird!

Background Information

More on Evaporation and Condensation:

In order to understand the ideas related to change of phase and vapor pressure as they apply in this article, students should review the kinetic-molecular theory of matter. This review will remind students that in all phases of matter molecules are in constant random motion. As a result of this motion, molecules have kinetic energy, which can be shown by the equation:

$$\text{K.E.} = \frac{1}{2} mv^2$$

The equation could be used to calculate the kinetic energy of a single molecule. However, the molecules in a sample of a matter have a range of kinetic energies with some molecules moving faster and some moving more slowly. The conventional method of indirectly measuring the kinetic energies of all the molecules in the entire sample is by measuring the temperature of the sample and assuming that this represents the average of all these energies.

A range of intermolecular attractions constrain molecular motion in liquids (see below). These attractive forces are London dispersion forces, dipole-dipole interactions and hydrogen bonding. Each of these forces is relatively weak compared to *intramolecular* covalent or ionic bonds, but each is strong enough to influence the motion of molecules in solids and liquids. So the intermolecular forces hold molecules together and limit their motion.

In liquids the molecules are free to move around in a limited way, and in gases the molecules move independent of each other (in ideal gases). The process in which a liquid undergoes a phase change to a vapor is called vaporization. If the process takes place at or near room temperature, we tend to call the process evaporation, even though a liquid can evaporate over a wide range of temperatures.

If we look at evaporation at the molecular level, we can focus on the surface of the liquid, which is where evaporation occurs. Molecules on the surface of the liquid are in motion, like all liquid molecules, and they have a range of kinetic energies. They are also held together by one or more of the intermolecular forces. Energy must be added to the molecules in order to overcome these intermolecular forces, so evaporation is, therefore, an endothermic process. In the case of a liquid at ambient temperature, the added heat is drawn from the immediate environment in contact with the liquid. Because of this, we say that evaporation is a cooling process. A better statement of the phenomenon is that an evaporating liquid cools its surroundings.

The amount of energy needed to evaporate a given liquid depends primarily on the relative strength of the intermolecular forces between its molecules (See Information on Intermolecular Forces). The stronger those forces, the greater the energy required to change to the vapor phase. The weaker the forces, the less energy required. Liquids that evaporate easily are called volatile liquids. The more easily a liquid evaporates the more easily a vapor forms above the liquid. Eventually, in a closed container, the vapor and the liquid reach a dynamic equilibrium (see Information on Vapor Pressure). The pressure of the vapor at equilibrium is commonly called the vapor pressure of the liquid, and it is the most common measure of a liquid's volatility. So liquids with high vapor pressures evaporate easily, and thus are volatile. Liquids with lower vapor pressures evaporate less easily and have low volatility (see Information on Vapor Pressure for a table of selected liquid vapor pressures).

It should be noted that in the drinking bird article, there is actually discussion of the evaporation of two liquids—both water and methylene chloride. With the bird at room temperature and at rest, the methylene chloride, like any liquid, evaporates into the bulb that forms the bird's head. It is, however, evaporating water that triggers the bird's behavior. When the bird is initially dipped into the glass of water, the water is absorbed into the felt covering the bird's head. As this water evaporates, it cools the glass "head" and the bobbing ("drinking") process begins.

More on Vapor Pressure:

The methylene chloride in the drinking bird is a volatile liquid, which means that molecules of the liquid can easily gain sufficient energy to overcome the intermolecular forces between the molecules, thus entering the vapor phase. In the drinking bird the evaporation of methylene chloride is made easier as a result of the manufacturer's evacuating most of the air in the system. As more and more methylene chloride molecules leave the liquid surface and become a vapor, they begin to exert pressure above the liquid surface inside the upper bulb of the drinking bird. The concentration of gas molecules increases (and so does the pressure) until at some point the concentration reaches a maximum. Under these circumstances, any gas molecules striking the surface of the liquid result in those molecules returning to the liquid. At this point, the rate of evaporation equals the rate of condensation, and the system in the drinking bird is in a dynamic equilibrium. The pressure exerted by the vapor at this point is called the vapor pressure.

If we think about this dynamic equilibrium in terms of LeChâtelier's Principle we know that a change in conditions will affect the equilibrium. If we heat a liquid in equilibrium with its vapor, the system will attempt to absorb heat. Since evaporation is an endothermic process, more liquid will evaporate and the vapor pressure will rise. (On the molecular level, heating the system makes molecules move faster, thus giving the liquid molecules more energy to break free and become vapor. The vapor molecules are also moving faster due to the increased temperature. Both of these changes lead to an increase in vapor pressure.) Thus, vapor pressure depends on the temperature of the system.

Dipping the bird so that the felt on its head is saturated with water creates a change in conditions within the bird. The water evaporating into the outside air cools the bird's head. This causes all of the vapor molecules to slow down, lowering the temperature of the methylene chloride vapor in the bird's head and allowing some of the vapor to condense. This reduces the vapor pressure of the methylene chloride, thus shifting the equilibrium within in the bird.

The decrease in vapor pressure means that the vapor pressure in the bottom of the bird is greater than the vapor pressure in the top half. The now-greater pressure at the bottom forces liquid from the bird's abdomen to rise in the central tube, since the bottom of the tube is below the liquid level and this effectively seals off the two halves of the bird, preventing the two vapor pressures from equilibrating with each other. As the liquid rises in the tube, the bird's center of gravity shifts toward its head and the bird dips to take another "drink." As the bird tips forward and the liquid moves along the bottom of the now-horizontal tube, gases (methylene chloride vapor) can move from one half of the bird to the other, and pressures in the top and bottom bulbs can equalize. No force (vapor pressure) is now working on the liquid in the tube (except gravity), and the liquid in the top bulb falls back into the bottom bulb, tipping the bird upright. Meanwhile, the water evaporating from the bird's head cools the top bulb and the process begins again.

The drinking bird operates as a heat engine, since there is a temperature differential between top and bottom bulbs created by the evaporating water.

More on Intermolecular Forces

Primarily, the intermolecular forces holding the molecules of the liquid together determine vapor pressure for a liquid. Intermolecular forces (van der Waals forces) account for nearly all of the physical properties of a substance, including boiling point and heat of vaporization. There are

three types of intermolecular forces in liquids. They are (in order of increasing strength) London dispersion forces, dipole-dipole interactions, and hydrogen bonds. The relative energies of intermolecular forces is much less than covalent or ionic bonding energies. The following chart gives an approximation of the relative strengths in kJ/mol:

Covalent bonds	100–1000
Hydrogen bonds	10–40
Dipole-dipole	0.1–10
London forces	0.1–10

While covalent bond energies range from 150 to 800 kJ/mol, the energy required to overcome intermolecular attractions are usually less than 40 kJ/mol. For example, it takes 464 kJ/mol to break the H–O bonds *within* a water molecule and only 41 kJ/mol to break the bonds *between* water molecules. The energy required to vaporize a liquid is the energy needed to break these intermolecular attractions.

London dispersion forces (one of the three forces that are, in aggregate, known as van der Waals forces) arise from temporary charges that arise in non-polar molecules involving atoms with larger number of electrons. Dipole-dipole interactions (the second type of van der Waals forces) are electrostatic forces created by the partial positive and negative charges within neighboring molecules that exhibit some degree of polarity. Hydrogen bonds (the last of van der Waals forces) are the best known of the three and are the attractions between a polar covalently bonded hydrogen atom in one molecule and an electronegative atom with one (or more) nonbonding pair(s) of valence electrons in a neighboring molecule. Hydrogen bonding occurs most often in covalently bonded molecules involving nitrogen, oxygen, fluorine and chlorine.

Methylene chloride exhibits covalent (and polar covalent) bonding, contains hydrogen and chlorine and is a slightly polar molecule. We would expect methylene chloride to exhibit dipole-dipole interactions and London dispersion forces. Since the hydrogen atoms are not attached to the chlorine, but to carbon instead, there is almost no chance of hydrogen bonding occurring. This is because there is not a strong dipole between carbon and hydrogen in CH_2Cl_2 , so the hydrogen is not strongly electropositive, seeking an electronegative site on another molecule. However, since we know that methylene chloride is a volatile liquid, and has a relatively high vapor pressure (and low boiling point and heat of vaporization), the strength of these intermolecular forces must be relatively weak.

More on methylene chloride:

The drinking bird depends on the properties of methylene chloride, CH_2Cl_2 , also known as dichloromethane or methylene dichloride. According to the Halogenated Solvents Industry Alliance, Inc., “methylene chloride is a widely used chemical solvent with a diverse number of applications. It was introduced as a replacement for more flammable solvents over 60 years ago. Methylene chloride is commonly used in paint removers and industrial adhesive formulations. It also is employed in the production of flexible urethane foams, pharmaceutical products, and plastics, as a cleaning agent for fabricated metal parts, and as an extraction solvent.

“Methylene chloride is a member of a family of saturated aliphatic halogenated compounds. It is a colorless, volatile liquid, completely miscible with a variety of other solvents. It is produced in the United States by The Dow Chemical Company and Vulcan Materials Company. Total U.S. demand for the chemical in 2000 was estimated at about 200 million pounds (90,740 metric tons) of which about 35 million pounds (15,880 metric tons) was imported. About 100 million pounds (45,370 metric tons) were exported.”

The most important of its properties is its vapor pressure (see More on Vapor Pressure). The molecule is slightly polar. Among its properties are:

- Appearance: Clear, colorless liquid
- Odor: Chloroform-like odor
- Solubility: 1.32 gm/100 gm water @ 20°C

Specific Gravity: 1.318 @ 25°C
Molecular Weight: 84.93 g/mol
Boiling Point: 39.8°C (104°F)
Melting Point: -97°C (-143°F)
Vapor Density (Air=1): 2.9
Vapor Pressure: 46.7 kPa @ 20°C (68°F)

Note especially the relatively high vapor pressure of methylene chloride compared to these liquids below (note also the slight difference in temperature conditions for the table below compare to the properties of methylene chloride given above). The liquid inside the drinking bird, as noted in the article, must have a high vapor pressure in order for the effect to work.

Substance Vapor Pressure (kPa @25°C)

H ₂ O _(l)	3.1691
CH ₃ OH _(l)	16.8511
C ₂ H ₅ OH _(l)	7.8279
C ₆ H ₆ _(l)	12.6893
Hg _(l)	0.2460

When methylene chloride is used in the drinking bird a red or blue dye is added to it for a colorful effect.

Safety Note: The liquid is harmful if swallowed, inhaled or absorbed through skin. When using the liquid directly, you should use goggles and shield, lab coat and apron, gloves and a fume hood.

Uses: Methylene chloride has many uses apart from the drinking bird. The pharmaceutical industry uses methylene chloride as a reaction solvent and for isolation and purification. Paint strippers are typically 70-90% methylene chloride with other solvents added. It is used in aerosols to reduce flammability. Other uses include metal degreasing, production of foams, in the processing of polyurethanes and polycarbonates and as a refrigerant.

Methylene chloride is the liquid used in "bubble lights" for Christmas trees. Because the liquid has a high vapor pressure (and, therefore, a low boiling point) it will boil easily. (Note that this, too, is a vapor pressure phenomenon.)

The article mentions that the drinking bird appeared on *The Simpsons*. It also appeared briefly in the opening scene of the movie *Alien*. The discussion on the following web site provides an incorrect explanation of how the bird functions. <http://www.slipups.com/items/11797.html>

References:

Frank, David L., "The Drinking Bird and the Scientific Method", *Journal of Chemical Education*, 50 (3) March 1973, 211.

Vermulapalli, G.K., "A Discourse on the Drinking Bird," *Journal of Chemical Education*, 67 (6) June 1990, 457-458.

Brouwer, Henry, "Work Done by a Chemical Reaction," *Journal of Chemical Education* 73 (4) April 1996, 354-355.

Connections to Chemistry Concepts

1. The chemistry concepts related to this article are:
 - a. Vapor pressure equilibrium and Le Châtelier's principle.

- b. Phase change and the related thermodynamics. The drinking bird operates because of the relationship between the evaporation-condensation cycle and the heat involved in these changes.
 - c. Evaporation and rate of evaporation—the key step in the operation of the bird is the evaporation of water from the bird’s head, which lowers the temperature inside the bird’s head.
 - d. Intermolecular forces—these forces determine all or nearly all of the physical properties of substances.
 - e. Properties of liquids and gases
2. There are several concepts in the article that relate primarily to physics but are relevant to the chemistry in this article.
- a. Work
 - b. Heat engine
 - c. Center of Gravity

Possible Student Misconceptions

1. Vapor pressure depends on factors other than temperature.
2. Evaporation and boiling are the same.
3. Perpetual motion machines are possible.
4. The bird actually drinks!

Demonstrations and Lessons

1. You can demonstrate the effect of sudden changes in vapor pressure by bringing a small volume of water to a boil in a soda can. Holding the can with forceps, thrust it mouth first into a reservoir of cool water. The can will collapse.
2. Students can feel for themselves that evaporation is an endothermic process by placing several drops of isopropyl alcohol on the back of their hand and allowing the alcohol to evaporate. Water may also be used, but it will evaporate more slowly. Students will not notice the cooling effect on their hands as much as they do for alcohol.
3. Activity #2, above, can be done quantitatively by folding a 4 cm square of paper towel and wrapping it around the bulb of a lab thermometer (alcohol thermometer only for safety). Secure the paper towel around the thermometer with a small rubber band. Dip the paper towel in isopropyl alcohol, let the excess drip off, and record the temperature of the system every 15 seconds. Repeat using water instead of alcohol. This activity can also be done using temperature probes.
4. Try using water of different temperatures in the beaker for the bird to drink.
5. Try getting the bird to operate in a closed system, like an inverted fish tank.
6. Try heating (or cooling) each end of the bird with a light source, such as a heat lamp. Predict before the experiment, then do the experiment and observe the results. Discuss any discrepancies between predictions and observations. Be careful – too much heat could cause the bird to burst from much-increased vapor pressure.
7. Try number 6 above after painting the bird’s “bottom” black. (Or use magic marker.) For a description of this process, see http://www.scitoys.com/scitoys/scitoys/thermo/solar_bird/bird.html

Suggestions for Student Projects

1. Students can research the way in which a refrigerator or air conditioner works as an application of evaporation and condensation.
2. Students can research the process of evaporative cooling.

Anticipating Student Questions

1. What does the term volatile mean? Volatile is a term applied to any liquid which evaporates easily at or near room temperature. (See Background Information)
2. What are intermolecular forces? (see More on Intermolecular Forces)
3. What is a dynamic equilibrium? When two opposing processes take place at the same rate, the processes are in equilibrium. For example, this article says that the liquid in the drinking bird evaporates until enough vapor is produced for it to begin to condense. When the rate of evaporation and the rate of condensation (the two opposing processes) are equal, there is no net macroscopic (visible) change in the system and the system is in equilibrium. The equilibrium is referred to as dynamic because at the molecular level changes *are* taking place (evaporation and condensation) even though it seems like nothing is happening.
4. If water is evaporating from the bird's head, as the article describes, the head should be getting lighter, shouldn't it? Why does it get heavier [as it apparently must, since the bird tilts forward]? It is true that the mass of water on the bird's head gets less as the water evaporates, but that is not the most important aspect of the evaporation. As the water evaporates, the glass making up the bird's head is cooled (see More on Evaporation) and the cooled gas inside the bird's head slows down and condenses back to liquid. This reduces the vapor pressure in the head and allows liquid from the bottom bulb to flow into the head (because the vapor pressure at the bottom pushes the liquid up) and make it heavier, causing it to dip.
5. There's an example of a drinking straw in the article. If "science never sucks," why does the liquid in the straw rise up the straw when I suck on the end of the straw? What you do is remove air from the top of the straw (you create a low-pressure area – almost a vacuum). If there's little or no air in the top of the straw above the liquid, the liquid is pushed up the straw to fill that space.
6. What pushes it up? The pressure exerted by the gases that make up the air around the straw.
7. But isn't air pressure acting downward on the liquid in the glass (the glass that the straw is in)? Why does the liquid go up? Because a liquid transmits any force applied to it in all directions throughout the liquid (think water balloon). So the downward force of air pressure is transmitted through the liquid and acts in an upward direction at the lower end of the straw. The liquid takes the "path of least resistance".

Websites for additional Information

For still more on cooling by evaporation, see <http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/sweat.html>

For an article from the *Journal of Chemical Education* on the drinking bird as a heat engine, see <http://www.jce.divched.org/cgi-bin/JCE/jce-idx.pl?type=goto&volume=67&issue=6&page=457> and also see <http://ppm2002.lci.kent.edu/PAPERS/DBPublished.pdf> .

For still more on heat engines in general, see <http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heaeng.html> and <http://www.taftan.com/thermodynamics/HENGINE.HTM> .

For still more on intermolecular forces see: <http://learning.mgccc.cc.ms.us/science/chemistry/CHE1214Chap13handouts.PDF> and http://en.wikipedia.org/wiki/Intermolecular_force#Dipole-Dipole_Interactions

For more on Christmas tree bubble lights, see http://www.oldchristmaslights.com/1946_1950_2.htm

Still more information on methylene chloride can be found at <http://www.dow.com/webapps/lit/litorder.asp?filepath=gco/pdfs/noreg/100-06358.pdf&pdf=true> and http://www.1-electric.com/articles/Methylene_chloride

More on Center of gravity:
http://van.hep.uiuc.edu/van/qa/section/Making_Stuff_Move/Balance/901568953.htm and
<http://online.cctt.org/physicslab/content/phyapb/lessonnotes/centermass/centerofmass.asp>

Still more on the Drinking Bird:

There are dozens of web sites that feature the drinking bird. Among the more interesting of these are:

<http://nicholnl.wcp.muohio.edu/DingosBreakfastClub/DippyBird/DrinkingBird1.html> (This one has a separate clickable movie that shows the angle of the bird's head with each successive sway back and forth.), and <http://www.backstreet.demon.co.uk/oddstuff/drinkingbirds/drinkingbirds.htm>

For more on the story of Daniel Reynolds and his giant drinking birds see <http://www.drinkingbirds.com/>

The original drawing for the patent for the bird can be found at <http://l2.espacenet.com/dips/bnsviewer?CY=gb&LG=en&DB=EPD&PN=US2402463&ID=US+++2402463A1+I+>

Kitty Litter Chem

Background Information

Introduction

According to the American Pet Products Manufacturers Association 2005 survey:

- There are approximately 77.6 million owned cats in the United States.
- Thirty-four percent of U.S. households (or 35.4 million) own at least one cat.
- One half of cat-owning households (51%) own one cat; the remaining own two or more.
- On average, owners have two cats (2.2).
- Slightly more female cats are owned than male cats.
- Sixteen percent of owned cats were adopted from an animal shelter.
- Cat owners spent an average of \$113 on veterinary related expenses in the past 12 months.
- Eighty-four percent of owned cats are spayed or neutered.

This suggests that there is a significant market for pet products, including cat litter.

General Information about Clays

Both fuller's earth and bentonite are varieties of clay. The United States Geological Service provides this general data about clay production and prices. Data for fuller's earth and bentonite, the clays discussed in the article, are highlighted.

Domestic Production and Use: In 1995, clays were produced in most States except Alaska, Delaware, Hawaii, Rhode Island, Vermont, and Wisconsin. The leading 90 firms supplied 25% of the output, and about 203 firms provided the remainder. Together, these firms operated about 983 mines. Estimated value of all marketable clay produced was about \$1.8 billion. Major domestic uses for specific clays were estimated as follows: kaolin--55% paper, 8% kiln furniture, 6% fiberglass, 4% grogs, and 4% paint; ball clay—30% floor and wall tile, 13% pottery, and 24% sanitary ware; fire clay—69% grogs, calcines, and firebrick; bentonite—25% foundry sand bond, 21% drilling mud, and 18% iron ore pelletizing; fuller's earth--75% absorbent uses and 12% insecticide dispersant; and common clay--50% brick, 27% cement, and 14% lightweight aggregate.

Salient Statistics--United States:	1991	1992	1993	1994	1995
Production, mine:					
Kaolin	9,550	8,740	8,830	8,770	9,490
Ball clay	784	854	911	1,050	975
Fire clay	474	383	459	458	412
Bentonite	3,310	2,950	2,870	3,290	3,540
Fuller's earth	2,320	2,410	2,480	2,640	2,500
Common clay	24,600	24,900	25,300	25,900	29,700
Total	41,020	40,200	40,900	42,200	46,600
Imports for consumption	35	41	39	36	39
Exports	4,000	4,160	4,150	4,620	4,505
Consumption, apparent	37,060	36,100	36,600	37,600	42,100
Price, average, dollars per ton:					
Kaolin	96	107	107	116	115
Ball clay	43	42	2	43	49

Salient Statistics--United States: (Con't)	1991	1992	1993	1994	1995
Fire clay	28	27	25	26	26
Fuller's earth	100	100	92	93	108
Common clay	5	5	5	5	5
Bentonite	37	39	36	41	58

More about Fuller's Earth

Fuller's earth is a nonplastic clay material that gets its name from its earliest use. In southwestern medieval England, garment workers, called fullers, rubbed the powdered clay into woolen garments to absorb dirt body oils like lanolin. The clay was then shaken out of the clothing and the garment fluffed in the process called "fulling." At the time, the clay was considered so valuable that England prohibited its exportation.

Fuller's earth had been used as a cleaning agent for centuries. In the Old Testament book of Malachi there is a reference to a "fuller's soap," which may be a reference to a type of fuller's earth. In the first century AD, Mt. Vesuvius erupted near Pompeii, and centuries later archeological digs uncovered what may have been a factory in which fuller's earth was produced. Fuller's earth is thought to be formed in nature by chemical changes in volcanic ash or tuff, and a location near a volcano would likely find deposits of fuller's earth.

Fuller's earth is primarily alumina (Al_2O_3), silica (SiO_2), iron oxides, lime (CaO), magnesia (MgO), and water, but the exact composition can vary greatly. The clay is not very chemically active. It may be white, light brown, olive or blue in color. Most of this clay is mined in southeastern states. The clay is surfaced mined then crushed and dried as part of the processing prior to use. Georgia and Florida are the leading producers. Georgia accounts for about 26% of the U.S. clay production. Decatur County in Georgia describes itself as the nation's leading producer of fuller's earth. Since 1907, fuller's earth has been mined near the city of Attapulgus (pop. 492) in Decatur County, giving rise to the name *attapulgitite*, one of the two primary forms of fuller's earth mined in the United States. The other is *montmorillonite*, which is named for a town in France.

The United States Geological Service provides this summary of fuller's earth **production for 2003**:

"Fuller's Earth.—In 2003, 16 companies produced fuller's earth (attapulgitite and montmorillonite varieties) from 45 pits in 11 States. Production of fuller's earth was reported by producers to be 3.60 Mt valued at \$346 million. This tonnage probably includes crude ore and stocks (more information can be found in the "Montmorillonite" portion of the "Production" section in this report). The fuller's earth deposits grade from attapulgitite-rich in Florida to montmorillonite-rich further northward in Georgia. Only those clays with attapulgitite as the major clay component are classified as attapulgitite. These basically are the gellant-grade fuller's earths in Florida and the southernmost part of Georgia. Going northward into Georgia, the attapulgitite content of the fuller's earth declines, and montmorillonite becomes the dominant clay present. This is classified under montmorillonite although it contains minor to trace amounts of attapulgitite.

"The attapulgitite variety of fuller's earth was mined from eight pits in the Florida Panhandle and southwestern Georgia. Only Engelhard in Iselin, NJ, and Zemex Corp. in Toronto, Ontario, Canada, mined attapulgitite in the United States at yearend 2003. An unspecified portion of the production by Engelhard was sold by ITC, Inc. under the terms of a U.S. Department of Justice agreement, making, in essence, three producers of attapulgitite. Attapulgitite production was 244,000 t valued at \$29.9 million. Georgia led in the production of attapulgitite, followed by Florida.

"Production of the montmorillonite variety of fuller's earth was 3.36 Mt valued at \$316 million. Some of the reported production probably was crude ore and some probably had not entered into commerce by year end. Actual sales of montmorillonite probably were about 2.9 Mt rather than 3.36 Mt. Montmorillonite was produced, in decreasing order of tonnage, in Georgia, Mississippi,

Missouri, Virginia, Illinois, California, Florida, Tennessee, Kansas, and Texas. Production increased in Georgia, Illinois, and Virginia.”

The United States Geological Service reported these **principal uses for fuller’s earth in 2003** (listed in descending order of tonnage):

- **pet waste absorbents**
- oil and grease absorbents
- portland cement manufacture
- pesticides
- animal feed
- drilling mud
- clarifying and decolorizing
- filtering of oils and greases

USGS also breaks down United States usage by the two varieties.

Montmorillonite is the dominant form of fuller’s earth used in the U.S., and its uses parallel those for all fuller’s earth:

- **pet waste absorbents**
- oil and grease absorbents
- Portland cement
- pesticide carrier
- animal feed
- clarifying, decolorizing
- and filtering of oils and greases

Attapulgite accounts for only about 7% of fuller’s earth usage (244,000 tons in 2003) Major uses for attapulgite in 2003 were much more diverse than montmorillonite:

- drilling mud
- **absorbents**
- fertilizer carrier
- asphalt emulsion
- animal feed
- gypsum products
- paper coating
- miscellaneous filler and extender applications
- paint
- miscellaneous refractory
- textile
- clarifying, decolorizing, and filtering of mineral oils and greases
- asphalt tile
- ceramic floor tile
- cosmetic, medical, pharmaceutical applications
- adhesives.

An interesting note: *Attapulgite* was until recently, used in Kaopectate as the binding agent for toxins (replaced by bismuth subsalicylate).

FULLER’S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE(Metric tons)

Use	2002	2003
Absorbents: Oil and grease absorbent	409,000	353,000
Pet waste absorbent	1,580,000	2,400,000

Use	2002	2003
Animal feed	81,500	113,000
Fertilizers	139,000	49,600
Fillers, extenders, binders (2)	58,800	53,200
Filtering, clarifying, and decolorizing		
Animal, mineral, and vegetable oils and		
Greases	63,300	66,200
Pesticides and related products	102,000	134,000
Miscellaneous	264,000	408,000

Data are rounded to no more than three significant digits; may not add to totals shown.

(2)Includes adhesives, asphalt emulsions(2003), asphalt tiles, gypsum products, medical, pharmaceuticals and cosmetics, paints, paper coating (2003), textiles, and other unknown uses.

More about Bentonite

Bentonite is a plastic clay rock composed essentially of smectite minerals formed by geologic changes in igneous material, usually a tuff or volcanic ash. The term "smectite" refers to non-metallic clays primarily composed of hydrated sodium calcium aluminum silicate with individual crystal size less than 2 µm. Some properties of bentonite:

General formula: $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$

Shape: monoclinic

Hardness (Mohs): 1.5-2.0

Typical Surface area: 0.09–1.80 m²/cm³

pH: 8.5–10.5

Specific gravity: 2.6

Typical Per Cent Composition (wt.) = SiO₂= 61.3 and Al₂O₃= 19.8

Common names for bentonite include montmorillonite or sodium montmorillonite ("sodium bentonite" or "Wyoming bentonite") and swelling bentonite ("Western bentonite"). The name originates from its discovery near Fort Benton, USA. Sodium bentonites are characterized by high swelling, high liquid limit and high thermal durability.

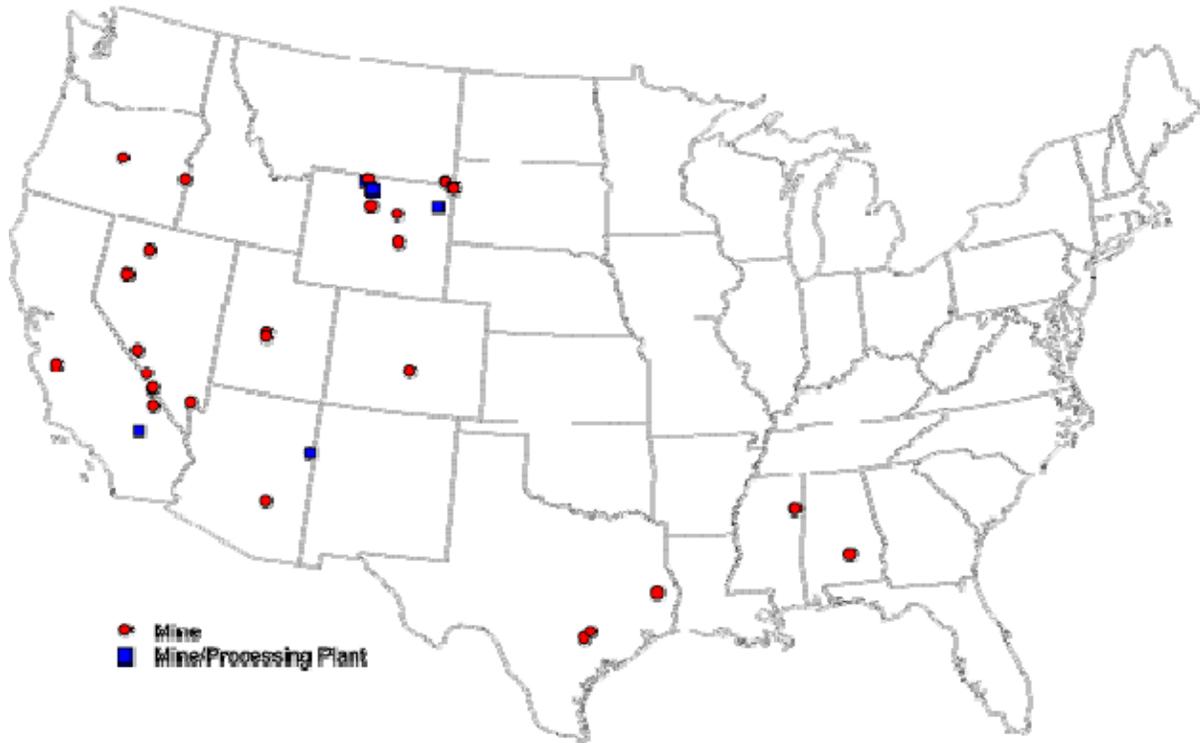
The most common form of bentonite is calcium bentonite, which has a much lower swelling capacity than the sodium form. The sodium form, therefore, is the form of choice for clumping kitty litter. The bentonite crystal absorbs as much as 10 times its weight in water and as it does so the crystal swells up to 18 times its original volume. This is because the structure of bentonite is like two playing cards in a deck. As water is absorbed, the playing cards move away from each other, causing the swelling.

Bentonite deposits formed 100 million years ago as volcanic ash dropped into inland seas, forming a sediment on the bottom. This sediment was slowly altered into bentonite. The deposits are rocklike in nature and usually extracted by quarrying. In the processing plant the bentonite is dried until its moisture content is about 10%. It is then granulated and packaged for sale.

The United States Geological Service offers this information about the **production of bentonite:**

In 2003, 24 companies produced bentonite from approximately 105 pits in 11 States. About 3.94 Mt valued at \$177 million of bentonite was sold or used (table 5). Production of nonswelling bentonite was 238,000 t valued at \$9.84 million. Alabama led all States in the production of nonswelling bentonite, followed by, in descending order of tonnage, Mississippi, Arizona, Nevada, California, and Colorado. Production of swelling bentonite was 3.70 Mt valued at \$167 million.

Wyoming still led all States in the production of swelling bentonite, followed by Montana, Utah, Texas, California, Oregon, and Nevada.



Bentonite locations in the United States (resourcescommittee.house.gov/.../bentonite.html)

The United States Geological Service offers this information about the **uses of bentonite**:

Sales and use were estimated to be 3.94 Mt. Major domestic markets for bentonite were **pet waste** (987,000 t), drilling mud (790,000 t), foundry sand (763,000 t), and iron ore pelletizing (530,000 t). Total sales (domestic and exports) of bentonite were approximately 989,000 t for foundry sand bond (about 92% was swelling bentonite), 993,000 t for **pet waste absorbent** (more than 99% was swelling bentonite), 847,000 t for drilling mud (essentially all swelling bentonite), and 597,000 t for pelletizing iron ore (all swelling bentonite).

“Data for other bentonite markets were concealed to avoid disclosing company proprietary data. However, swelling bentonite accounted for more than 90% of the bentonite sold for absorbents, animal feed, civil engineering, drilling mud, foundry sand, miscellaneous chemical manufacture applications, pelletizing iron ore, waterproofing, and water treatment and more than 70% of the bentonite sold for miscellaneous filler and extender applications. More than 60% of the bentonite sold for clarifying, decolorizing, and filtering of oils and greases was the nonswelling variety. Nonswelling bentonite was used mainly for desiccant, ink, pesticides, pharmaceuticals, and plastic applications.

“The major domestic markets for swelling bentonite, in decreasing order, were **pet waste absorbents**, drilling mud, foundry sand, iron ore pelletizing, and sealing and waterproofing. Major export markets for swelling bentonite, in decreasing order, were foundry sand, iron ore pelletizing, and drilling mud applications. The major domestic uses for nonswelling bentonite, in descending order of tonnage, were foundry sand bond; miscellaneous absorbents; clarifying, decolorizing, and filtering of oils and greases; animal feed; miscellaneous refractory products; miscellaneous

fillers and extenders; drilling mud; water treatment; pet waste absorbent adhesives; and sealing and waterproofing.

BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE1
(Metric tons)

Use	2002	2003
Domestic:		
Absorbents:		
Pet waste absorbents	899,000	987,000
Other absorbents	W	W
Adhesives	2,100	5,610
Animal feed	42,400	52,400
Ceramics (except refractories) ²	W	W
Drilling mud	762,000	790,000
Filler and extender applications ³	45,700	41,300
Filtering, clarifying, decolorizing	127,000	W
Foundry sand	762,000	763,000
Pelletizing (iron ore) ⁴	536,000	530,000
Miscellaneous refractories	W	W
Miscellaneous ⁵	117,000	378,000
Waterproofing and sealing	269,000	W
Total	3,560,000	3,550,000
Exports:		
Drilling mud	59,200	57,200
Foundry sand	244,000	226,000
Other ⁶	106,000	108,000
Total	408,000	392,000
Grand total	3,970,000	3,940,000

W Withheld to avoid disclosing company proprietary data; included with "Domestic, miscellaneous."

1. Data are rounded to no more than three significant digits, may not add to totals shown.
2. Includes catalysts and pottery.
3. Includes asphalt tiles (2003), cosmetics, ink, medical, miscellaneous fillers and extenders applications, paint, paper coating, paper filling (2003), pesticides and related products (2003), pharmaceuticals, and plastics.
4. Excludes shipments to Canada. Total sales in North America were 603,000 metric tons (t) in 2002 and 600,000 t in 2003.
5. Includes chemical manufacturing, heavy clay products, and other unknown uses.
6. Includes absorbents, fillers and extenders, miscellaneous refractories, pelletizing, and other unknown uses.

See *Websites for Additional Information*, below.

More about the Clay Mineral Group

Source: <http://mineral.galleries.com/minerals/silicate/clays.htm>

The clay minerals are a part of a general but important group within the **phyllosilicates** that contain large percentages of water trapped between the silicate sheets. Most clays are chemically and structurally analogous to other phyllosilicates but contain varying amounts of water and allow more substitution of their cations. There are many important uses and considerations of clay minerals. They are used in manufacturing, drilling, construction and paper

production. They have great importance to crop production as clays are a significant component of soils.

It is the physical characteristics of clays that more so than the chemical and structural characteristics define this group:

- Clay minerals tend to form microscopic to sub microscopic crystals.
- They can absorb water or lose water from simple humidity changes.
- When mixed with limited amounts of water, clays become plastic and are able to be molded and formed in ways that most people are familiar with as children's clay.
- When water is absorbed, clays will often expand as the water fills the spaces between the stacked silicate layers.
- Due to the absorption of water, the specific gravity of clays is highly variable and is lowered with increased water content.
- The hardness of clays is difficult to determine due to the microscopic nature of the crystals, but actual hardness is usually between 2 to 3 and many clays give a hardness of 1 in field tests.
- Clays tend to form from weathering and secondary sedimentary processes with only a few examples of clays forming in primary igneous or metamorphic environments.
- Clays are rarely found separately and are usually mixed not only with other clays but with microscopic crystals of [carbonates](#), [feldspars](#), [micas](#) and [quartz](#).

Clay minerals are divided into four major groups. These are the important clay mineral groups:

The Kaolinite Group

This group has three members ([kaolinite](#), [dickite](#) and [nacrite](#)) and a formula of $Al_2Si_2O_5(OH)_4$. The different minerals are polymorphs, meaning that they have the same chemistry but different structures (polymorph = many forms). The general structure of the kaolinite group is composed of silicate sheets (Si_2O_5) bonded to aluminum oxide/hydroxide layers ($Al_2(OH)_4$) called [gibbsite](#) layers. The silicate and gibbsite layers are tightly bonded together with only weak bonding existing between the **s-g** paired layers.

Uses: In ceramics, as a filler for paint, rubber and plastics and the largest use is in the paper industry that uses kaolinite to produce a glossy paper such as is used in most magazines.

The Montmorillonite/Smectite Group

This group is composed of several minerals including [pyrophyllite](#), [talc](#), [vermiculite](#), [sauconite](#), [saponite](#), [nontronite](#) and [montmorillonite](#). They differ mostly in chemical content. The general formula is $(Ca, Na, H)(Al, Mg, Fe, Zn)_2(Si, Al)_4O_{10}(OH)_2 \cdot xH_2O$, where x represents the variable amount of water that members of this group could contain. Talc's formula, for example, is $Mg_3Si_4O_{10}(OH)_2$. The gibbsite layers of the kaolinite group can be replaced in this group by a similar layer that is analogous to the oxide [brucite](#), $(Mg_2(OH)_4)$. The structure of this group is composed of silicate layers sandwiching a gibbsite (or brucite) layer in between, in an **s-g-s** stacking sequence. The variable amounts of water molecules would lie between the **s-g-s** sandwiches.

Uses: Are many and include a facial powder (talc), filler for paints and rubbers, an electrical, heat and acid resistant porcelain, in drilling muds and as a plasticizer in molding sands and other materials.

The Illite (or The Clay-mica) Group

This group is basically a hydrated microscopic [muscovite](#). The mineral **illite** is the only common mineral represented, however it is a significant rock forming mineral being a main component of shales and other argillaceous rocks. The general formula is $(K, H)Al_2(Si, Al)_4O_{10}(OH)_2 - xH_2O$, where x represents the variable amount of water that this group could contain. The structure of this group is similar to the montmorillonite group with silicate layers sandwiching a gibbsite-like layer in between, in an **s-g-s** stacking sequence. The variable amounts of water molecules would lie between the **s-g-s** sandwiches as well as the potassium ions.

Uses: A common constituent in shales and is used as a filler and in some drilling muds.

The Chlorite Group

This group is not always considered a part of the clays and is sometimes left alone as a separate group within the phyllosilicates. It is a relatively large and common group although its members are not well known. These are some of the recognized members:

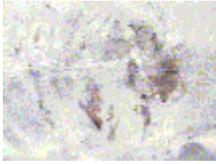
- **Amesite** $(Mg, Fe)_4Al_4Si_2O_{10}(OH)_8$
- **Baileychlore** $(Zn, Fe^{+2}, Al, Mg)_6(Al, Si)_4O_{10}(O, OH)_8$
- **Chamosite** $(Fe, Mg)_3Fe_3AlSi_3O_{10}(OH)_8$
- **Clinochlore (kaemmererite)** $(Fe, Mg)_3Fe_3AlSi_3O_{10}(OH)_8$
- **Cookeite** $LiAl_5Si_3O_{10}(OH)_8$
- **Corundophilite** $(Mg, Fe, Al)_6(Al, Si)_4O_{10}(OH)_8$
- **Daphnite** $(Fe, Mg)_3(Fe, Al)_3(Al, Si)_4O_{10}(OH)_8$
- **Delessite** $(Mg, Fe^{+2}, Fe^{+3}, Al)_6(Al, Si)_4O_{10}(O, OH)_8$
- **Gonyerite** $(Mn, Mg)_5(Fe^{+3})_2Si_3O_{10}(OH)_8$
- **Nimite** $(Ni, Mg, Fe, Al)_6AlSi_3O_{10}(OH)_8$
- **Odinite** $(Al, Fe^{+2}, Fe^{+3}, Mg)_5(Al, Si)_4O_{10}(O, OH)_8$
- **Orthochamosite** $(Fe^{+2}, Mg, Fe^{+3})_5Al_2Si_3O_{10}(O, OH)_8$
- **Penninite** $(Mg, Fe, Al)_6(Al, Si)_4O_{10}(OH)_8$
- **Pannantite** $(Mn, Al)_6(Al, Si)_4O_{10}(OH)_8$
- **Rhipidolite (prochlore)** $(Mg, Fe, Al)_6(Al, Si)_4O_{10}(OH)_8$
- **Sudoite** $(Mg, Fe, Al)_{4-5}(Al, Si)_4O_{10}(OH)_8$
- **Thuringite** $(Fe^{+2}, Fe^{+3}, Mg)_6(Al, Si)_4O_{10}(O, OH)_8$

The term [chlorite](#) is used to denote any member of this group when differentiation between the different members is not possible. The general formula is $X_{4-6}Y_4O_{10}(OH, O)_8$. The X represents either aluminum, iron, lithium, magnesium, manganese, nickel, zinc or rarely chromium. The Y represents either aluminum, silicon, boron or iron but mostly aluminum and silicon.

The gibbsite layers of the other clay groups are replaced in the chlorites by a similar layer that is analogous to the oxide [brucite](#). The structure of this group is composed of silicate layers sandwiching a brucite or brucite-like layer in between, in an **s-b-s** stacking sequence similar to the above groups. However, in the chlorites, there is an extra weakly bonded brucite layer in between the **s-b-s** sandwiches. This gives the structure an **s-b-s b s-b-s b** sequence. The variable amounts of water molecules would lie between the **s-b-s** sandwiches and the brucite layers.

Uses: No industrial uses.

Some minerals listed above (specifically chlorite, pyrophyllite and talc) as belonging to one of the clay groups are often excluded by some mineralogists. Usually the reason is that their crystal size and character do not consistently conform to those parameters that define a clay. Such minerals are listed here more for their structural similarities, however all three minerals are quite often found associated with and do behave like clays occasionally.



The Mineral Montmorillonite

Source: <http://mineral.galleries.com/minerals/silicate/montmori/montmori.htm>

- **Chemistry:** $(\text{Na, Ca})(\text{Al, Mg})_6(\text{Si}_4\text{O}_{10})_3(\text{OH})_6 \cdot n\text{H}_2\text{O}$, Hydrated Sodium Calcium Aluminum Magnesium Silicate Hydroxide
- **Class:** [Silicates](#)
- **Subclass:** [phyllosilicates](#)
- **Group:** The [Clays](#) and also The [Montmorillonite/Smectite Group](#).
- **Uses:** as a drilling mud and as a water clogging agent in soil.
- [Specimens](#)

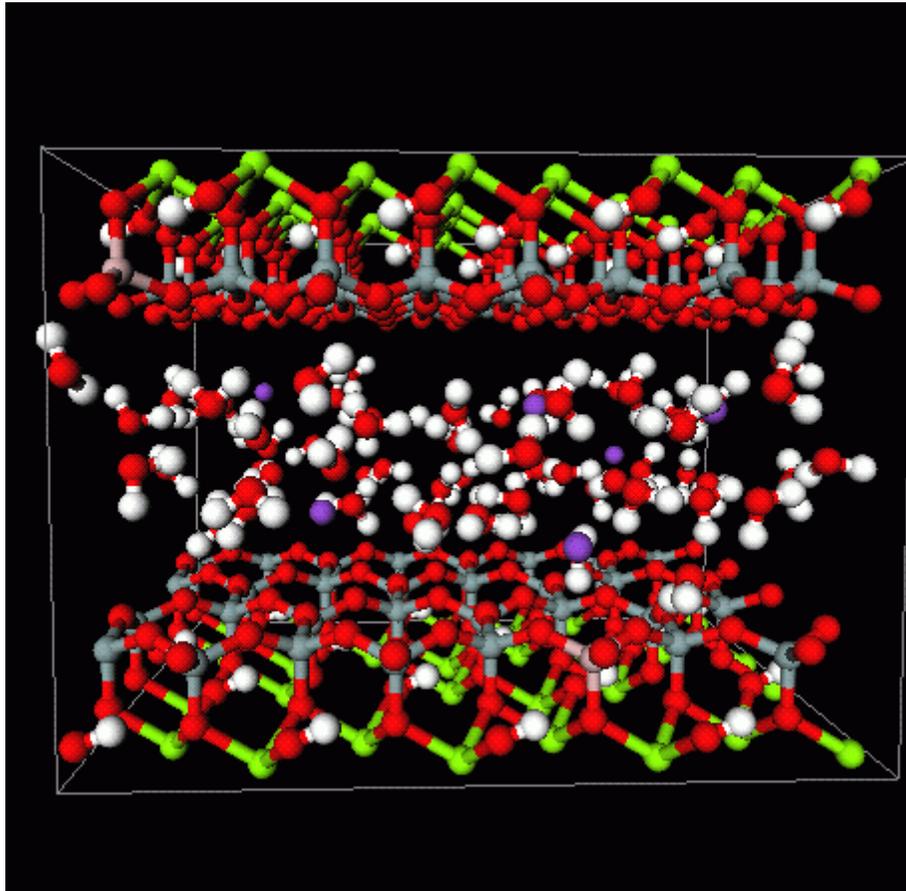
Montmorillonite is a member of the general mineral group the [clays](#). It typically forms microscopic or at least very small platy micaceous crystals. The water content is variable, and in fact when water is absorbed by the crystals they tend to swell to several times their original volume. This makes montmorillonite a useful mineral for several purposes. It is the main constituent in a volcanic ash called bentonite, which is used in drilling muds. The bentonite gives the water greater viscosity ("thickness" of flow), which is very important in keeping a drill head cool during drilling and facilitating removal of rock and dirt from within a drill hole. Another important use of montmorillonite is as an additive to soils and rocks. The effect of the montmorillonite is to slow the progress of water through the soil or rocks. This is important to farmers with extended dry periods, engineers of earthen dams or levees, or perhaps to plug up old drill holes to prevent leakage of toxic fluids from bottom levels to higher aquifers used for drinking water.

As a mineral specimen, montmorillonite does not get much consideration. Usually, pure samples of montmorillonite are massive, dull and not very attractive. However, as with all minerals, there are those exceptional specimens that defy the norm. Montmorillonite has been found as attractive pink inclusions in quartz crystals, and these make for interesting specimens.

Physical Characteristics:

- **Color** is usually white, gray or pink with tints of yellow or green.
- **Luster** is dull.
- **Transparency** crystals are translucent and masses are opaque.
- **Crystal System** is monoclinic; $2/m$.
- **Crystal Habits:** never in large individual crystals, usually found in compact or lamellar masses. Also seen as inclusions in quartz as fibers and powder-like masses.
- **Cleavage** is perfect in one direction, basal; not seen in massive specimens.
- **Fracture** is uneven to lamellar.
- **Hardness** is 1-0–2 (can sometimes leave marks on paper)
- **Specific Gravity** is variable from 2.3–3 (average)

- **Streak** is white.
- **Other Characteristics:** crystals expand to many times their original volume when added to water.
- **Associated Minerals** include other [clays](#), [garnets](#), [biotite](#) and [quartz](#).
- **Notable Occurrences:** include sources in France, Italy, USA and many other localities world wide.
- **Best Field Indicators** softness, color, soapy feel, luster and expandability when added to water.



Montmorillonite

Source: <http://www.ill.fr/dif/3D-crystals/images/montmorillonite.gif>

More on Edward Lowe

The originator of cat litter was "Poppy George" Plitt. Plitt graduated from SUNY Delhi College with a degree in agriculture in 1932. His litter was made of wood ashes, which he called Kleen Kitty. In fact, ashes or sand were the most common indoor cat box fillers before World War II. Most cats used backyards and gardens to "do their business."

In the article, Edward Lowe is credited with inventing kitty litter. Here is a little more background on him:

After he returned from a stint in the Navy during World War II, Edward Lowe was selling and hauling sand, gravel and absorbent clay (fullers earth) made by his father's firm. At the time the

clay was used to absorb industrial oil spills. The article describes Lowe's attempts to get people to use the fuller's earth as a cat litter. The "Kitty Litter," as Lowe had named it, was easily able to absorb cat urine and to control the odor. Lowe marketed his product at pet shows, where he cleaned cat boxes in exchange for a booth to exhibit his Kitty Litter. The product caught on and in 1964, Lowe created the Tidy Cat brand to sell his product in grocery stores and super markets. Lowe Industries was unique in that it was the only litter company with a research and development division. Housed in Cape Girardeau, Missouri, the R&D unit looked for ways to improve Kitty Litter and develop new products. Lowe sold the company in 1990. At the time, the company was doing more than \$210 million in annual sales and was the leading producer of cat litter in the United States. The Purina Company now owns Tidy Cat.

Lowe, who today would be called and innovator and an entrepreneur, started the Edward Lowe Foundation in 1985, to assist budding entrepreneurs in developing their business. The Foundation has its headquarters on a 2500-acre estate in Cassopolis, Michigan, donated by Lowe. The Foundation today sponsors programs that bring young entrepreneurs together to share ideas about starting a business. Lowe, who died in 1995, held 67 domestic and foreign patents.

See Websites for Additional Information, below.

More on Thomas Nelson

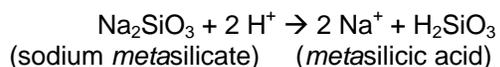
In the article, Thomas Nelson is mentioned as the inventor of clumping litter. Thomas Nelson was a biochemist and professor of medicine at Houston's Baylor College. He also bred Persian cats, and he became dissatisfied with the granulated clay litters on the market. While studying organic chemistry as a graduate student, he investigated the molecular structure of clay. He discovered that some types of clay trapped urea through hydrogen bonding and prevented it from breaking down. He found that clays that were dried but not baked were very absorbent and would form a clump when the cat urinated on them. In 1984, he created the first clumping litter, which was made from bentonite and was marketed as Better Way Cat Litter by a company called Harvest Ventures. By the early 1990's his litter accounted for almost half the litter sold in the country.

More about Alternative Kitty Litters

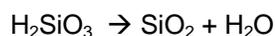
There are a wide variety of non-clay cat litters on the market. Most are made either of silica gel or of biodegradable matter, including newspaper, corn, wheat, wood, and citrus peel. Standards on which these (and clay-based) litters are rated include clumping, absorbency, biodegradability, dust production, "flushability", septic tank safety, and odor.

Silica Gel Litter:

Silica gel, despite its name, is a solid that is chemically unreactive, non-toxic and non-flammable. It is the *non-crystalline* form of silicon dioxide, SiO₂. The crystalline form, sand or quartz, occurs in abundance naturally. Silica gel has a high porosity (about 800 m²/g), which allows it to *adsorb* (not absorb) about 40 times its own weight in water. This property makes it useful as a cat litter. It is made synthetically from sodium silicate, a compound that exists in several forms. Among these forms are sodium *orthosilicate*, Na₄SiO₄; sodium *metasilicate*, Na₂SiO₃; sodium *polysilicate*, (Na₂SiO₃)_n; sodium *pyrosilicate*, Na₆Si₂O₇. All are water soluble and form alkaline solutions. When the silicates are acidified, they reacts with hydrogen ions to form the respective silicic acids (ortho-,meta-, etc.).



Roasting *metasilicic acid* drives off a molecule of water to produce silica gel, SiO₂.



Silica gel is the desiccant of choice, along with montmorillonite clay and Zeolite. It was developed just prior to World War I for use in gas masks. In World War II it was used to keep penicillin dry. It's also in those little bags that come packed with electronic equipment, for example, to keep moisture out. Litter made from silica gel comes primarily in pellet form. The pellets look clear to slightly translucent.

See *Websites for Additional Information*, below.

Plant-based litters:

Among these are litters made from organic waste products like corn, corncob, cornhusks, wheat by-products, wheat grass, beet pulp, oat hulls, and kenaf. In addition to being biodegradable, these litters recycle what might otherwise be unusable material. A brief summary of the properties of these:

- > Ground corncob litter - good odor control, very absorbent, can be flushed
- > Whole kernel corn litter – good absorbency, clumps well, little dust, good odor control
- > Wheat husks and kernels – clumps well, very good odor control, can be flushed and composted
- > Kenaf -- [a plant in the hibiscus family (*Hibiscus cannabinus* L), also related to cotton and okra]. The manufacturer claims the litter to be super absorbent, non-clumping, dust-free, and biodegradable.

The manufacturer of one product mentioned in the article, Swheat Scoop, provided the following information about its wheat-based litter. In a patented process, wheat kernels, classified as #2 secondary wheat-non food grade, are run through a grain cleaning device to remove soybean, corn and sunflower kernels. The wheat grain is then ground in two stages (to increase absorbency), converted to pellets. Soybean oil is added to reduce dust from the litter and the product ground once more. After cooling, the product is sifted and bagged for sale. Fractured wheat starch causes the litter to clump quickly, and a protein enzyme present in wheat controls the ammonia odor from urine. The company lists the following composition for its product:

Ingredient	Percent
Wheat	85.1615
Moisture	14.536
Natural soybean oil	0.0025
Nilecho deodorizing	0.3
Chemicals (a)	

(a) Contains cinnamic aldehyde, amyl acetate, amyl salicylate, d-limonene, and methyl salicylate

Pine and Cedar Sawdust Litter

Unused pine lumber is dried in a kiln and compressed into pellets that absorb many times their weight in moisture before they break back down into sawdust. The wood naturally absorbs ammonia. Small amounts can be flushed, or used litter can be used as biodegradable garden mulch. Cedar is also used to make litter and has similar properties to the pine pellets.

Off-label Uses for Kitty Litter:

There are a wide variety of uses that consumers have found for kitty litter, in addition to its intended use. Some of the more interesting uses include:

- sachet of kitty litter in a sock (for use in a folded tent, for example)
- facial clay mask—

mix equal parts water and unscented 100% clay kitty litter (for detoxifying the skin)

- make a shoe deodorizer by placing kitty litter in panty hose and place in shoes
- absorb oil or paint spills (10 lb bag absorbs a gallon)
- in trunk of car for ballast and for traction in the snow Use the non-clumping variety only. (Note that cat litter manufacturers do not recommend this)

Connections to Chemistry Concepts

1. Crystalline vs. amorphous solids
2. Ions and ion charge—ion exchange
3. surface phenomena—adsorption
4. acid-base chemistry—protonation of ammonia to ammonium ion

Possible Student Misconceptions

1. **Clays are just mixtures of amorphous solids without any specific chemical composition or structure.**
Kaolinite $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
<http://scienceworld.wolfram.com/chemistry/ClayMineral.html>
<http://www.clays.org/eduresources/EduResources.html>
2. **The clay used in making pottery or other crafts is different than the clay used for cat litter.** Students may not relate the clay in cat litter to the clay they are familiar with in crafts class. Potting clay is moist and pliable and cat litter is dry and granular. They are similar in that the chemical compositions of the clays are similar. The difference is that potting clay has high water content. This makes it pliable or plastic so it can be molded. Actually, clays hold water very well by a mechanism called *adsorption*, not *absorption*. Because the clay particles are extremely small, they are closely packed. Water molecules are held in this tightly packed arrangement by adsorption. If the clay is heated, the water evaporates leaving a hard dry anhydrate. This process occurs in a kiln for pottery clay. Clay used for cat litter is also heated to drive off the water, and then the dried clay is granulated.
3. **All kitty litters are alike.** This is common attitude for all consumers, not just students, to have. Many products that consumers buy regularly are seen as identical. Included here are products like soaps and detergents, gasoline, beer, and toilet paper. Manufacturers are aware of this and through their advertising attempt to create “brand loyalty” for their product.

Students who do not own a cat and students who do not clean cat litter boxes at home may not be aware of the chemistry that is associated with cat litter. Although the clays in clay-based litters are similar in structure, there are wide ranges of chemicals that are added in various products. These chemical additives include deodorizers, antibacterials, and fragrances, all of which are chemicals.

Demonstrations and Lessons

1. You can connect this article to acid-base chemistry by testing the pH of ammonia using a paper indicator.
2. Test the ability of baking soda, a common kitty litter deodorizer, to neutralize the ammonia odor from urine. In a fume hood, place a measured mass of household baking soda in a small beaker. Generate ammonia into a larger beaker by placing the inverted

beaker over the mouth of a bottle of concentrated ammonium hydroxide. Test for ammonia using wet litmus. Carefully lower the inverted ammonia beaker over the beaker of baking soda. At regular time intervals, test the larger beaker for the presence of ammonia.

3. Test the “clumping ability” of several clumping kitty litters. Measure identical masses of several clumping kitty litters into separate beakers. To each sample, add the same mass of water. After the water is absorbed, remove the clumped litter and measure its mass. It may also be possible to measure the volume of the clumps. Compare.
4. One of the typical lab investigations in soils science classes is to approximate the composition of a soil sample by adding a sample to water. After the water and sample are shaken thoroughly the mixture is allowed to stand. The heavier sand particles will settle quickly. Clays will take longer to settle, and organic matter will float on the water. You may want to devise a similar procedure using several kinds of clay-based litters and several non-clay litters for comparison.
5. For a lesson showing how short RNA fragments could have been synthesized in the presence of clay catalysts in a prebiotic environment and hints at how life could have emerged, see this site: <http://www.origins.rpi.edu/claycatalyzed.html>.

Student Projects

1. Compare the absorbing ability of several materials used as kitty litter: non-clumping kitty litter (various brands), sand, paper, wood chips, etc. The simplest experimental design: To 250 mL beakers add identical masses (or volumes) of the kitty litter samples. To each sample add measured volumes of water until the sample is saturated. Measure the volume of any unabsorbed water in each sample. Calculate the volume of water absorbed by each kitty litter sample.

2. Have students research the question “Is clumping clay safe for cats and kittens?” Students can begin with these web sites:

Yes, it is safe: <http://cats.about.com/cs/litterbox/a/clumpingclay.htm>

http://www.catsinternational.org/articles/housesoiling/which_litter_is_best.html

<http://www.petfinder.com/journalindex.cgi?path=/public/animalbehavior/cats/1.2.524.txt>

No, it isn't safe: <http://www.thelighthouseonline.com/marina/articles/moredata.html>

<http://www.felinesandfriends.org/content/clumping.htm>

General: <http://answers.google.com/answers/threadview?id=286497>

Suggest to students that they look for scientific evidence as well as personal stories from pet owners. Also, suggest that students visit the web sites of kitty litter manufacturers. The site listed in #3 below may also be helpful.

3. Students can do comparative research on brands of cat litter and their component chemicals on a web site provided by the National Institutes of Health and the National Library of Medicine at <http://householdproducts.nlm.nih.gov/index.htm>. On the home page, click on “Products” then “Pet Care” and follow the links to cat litter. The database gives basic ingredient information, health effects with links to MSDS sheets on

ingredients. Note that the database can be searched by specific ingredient. A student can search for all products in the data based that contain bentonite or silica gel. Links within each page provide for easy comparisons.

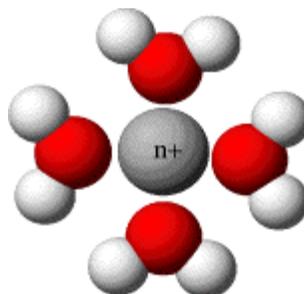
4. There is a reference in the article to cat litter's contribution to the waste stream. Student can research this study done in Oregon to discover how much kitty litter is added to landfills. <http://www.deq.state.or.us/wmc/solwaste/wcrep/ReportWC02AppATableA2.pdf>

Anticipating Student Questions

1. **What is sequestering?** Sequestering is a process in which a chelating agent traps ions, usually cations, chemically so that they cannot react further. In this process, a metal ion binds to two or more ligands. For example, blood hemoglobin is a chelate formed by the bonding of iron to the blood protein. Another example is EDTA (ethylenediamine tetraacetic acid), which can bind to a wide range of metals including calcium, magnesium, iron and lead. Clay minerals, like fuller's earth or bentonite, are often used to sequester unwanted cations during environmental remediation.

See http://www.public.asu.edu/~jpbirk/CHM-115_BLB/ClassNotes/chpt24.pdf

2. **What does "protonation" mean?** It means to add a proton to an atom, molecule or ion. The term is used frequently in discussing the action of acids in producing a hydrogen ion (remember that the hydrogen ion is a single proton). A Brønsted acid is defined as a proton donor. In donating the proton to the Brønsted base the acid protonates the base.
3. **What is a hydration sphere?** "Hydrates. Li^+ , Na^+ and K^+ probably have 4 molecules of water in their first (or primary) hydration sphere, while Rb^+ and Cs^+ probably have 6. The larger the central ion is, the smaller the area of ordering of the water around it, so the effective size of the ions decreases going down the group. This is important in understanding the mobility of the ions, for example down an ion exchange column." http://artsandscience.concordia.ca/facstaff/a-c/bird/c242/notes_ch10-cwp.html



Water molecules around a metal ion in aqueous solution.

Source:

<http://www.corneli.us/webgallery/hydrationsphere.html>

4. **What is a desiccant?** A desiccant absorbs moisture from the air. Silica gel (see *Background*) is the most widely used desiccant in the world today.
5. **Do clays really have a crystal structure?** On a chemical level, clay particles arrange in layers made up of tetrahedral or octahedral crystals bound together by cations, usually either calcium or sodium. Intermolecular forces hold the layers together. These forces arise because clay particles have an excess of negative charges. Therefore, they can attract and hold, or *adsorb*, cations such as ammonium, potassium, calcium, or magnesium.

Websites for additional Information

Clay structures

<http://pubpages.unh.edu/~harter/crystal.htm>

This web site is the best site for structures of clays the editors found. The visuals within the body of the text show specifically why tetrahedral and octahedral structures occur in clays. In addition, the author has included links to Chime rotatable molecular structures for several of the clays under discussion. (You will need to download a [free] copy of Chime to view these structures.) This site is part of a course in the chemistry of soils at the University of New Hampshire, taught by Dr. Robert Harter (who has since retired).

The 3-D images mentioned above can be viewed as “stick”, “ball and stick”, and “space-filling” versions, and they can be rotated at will using the mouse. The images actually come from another web site, the Virtual Museum of Minerals and Molecules. This site contains other images that may intrigue students and can be useful in teaching other topics; e.g., graphite and especially the buckyball, in the [“Quasi-Minerals Gallery](#). This molecule is rather elegant, especially when viewed in the space-filling mode.

http://www.soils.wisc.edu/virtual_museum/soil_smectite/index.html

This is the Chime picture (rotatable) of smectic type clays, of which montmorillonite is one.

<http://www.ill.fr/dif/3D-crystals/vrml/montmorillonite.wrl>

This is the Chime page for montmorillonite. This structure shows up close the positions of the water molecules in between the crystal layers that causes swelling.

<http://www.ill.fr/dif/3D-crystals/layers.html>

This site, Layered Structures, gives background information and structures on the major types of clays. Some clays have links to Parallel Graphics Cortona structures. This is another free download. This system gives more (but different) control over the molecule’s movement, although it seems to give only ball-and stick structures.

<http://www.gly.uga.edu/schroeder/geol6550/CM06.html>

This web site gives detailed information about several different types of clay structures, including differentiation between tetrahedral structures and octahedral structures.

http://www.srs.fs.usda.gov/pubs/ja/uncaptured/ja_barton002.pdf

This site shows models of the tetrahedral and octahedral structures of clays and gives information re: isomorphous substitutions within various clays.

<http://courses.smsu.edu/ejm893f/Mineralogy/atomicstruct.html>

This site deals with Linus Pauling’s 5 rules of ionic substitution and how these rules help to classify minerals

<http://www.tulane.edu/~sanelson/geol211/clayminerals.htm>

This web site gives the structures of various clay types and explains why bentonite and montmorillonite are expanding (swelling) clays. It also describes how Bragg's law and x-ray diffraction are the means by which clay structures are determined.

http://soils1.cses.vt.edu/MJE/CSES3124/VR_exports/intro.html

This site explains the structures of various clays and it gives Quick Time views of the structures that can be manipulated with the mouse to show rotation of the structures. Several of the clay types also have 3-D views, providing the viewer has red/blue 3-D glasses. This editor had difficulty getting a full-screen view of these structures, as a very small screen appeared, and the structure was not centered in this screen.

<http://www.phys.ntnu.no/~fossumj/P2Akademiet/english.htm>

Physical Phenomena in Clays is an English translation of a lecture by a Norwegian physics professor, describing clays and their structure to an audience of radio listeners. Professor Fossum attempts to make the talk livelier by including analogies to the structures; he uses ketchup, for example, as an analogy for the types of movement that can occur within clays when they are mixed with water. This talk may be more easily understood by students than most of the other discussions listed here.

<http://esd.lbl.gov/sposito/OMinteractions.pdf>

This site gives two pages of information re: surface interactions of various clays. It could be used to help explain protonation of NH_3 to NH_4^+ in cat litter.

<http://www.agron.iastate.edu/soilphysics/a577clay.pps#2>

This web site is a PowerPoint presentation of parts of several other sites. It shows the octahedral and tetrahedral structures and discusses the swelling (on a non-scientific basis). It also has a photo of parched and cracked soil, which happened because of swelling and shrinking of the clays in the soil.

<http://www.people.carleton.edu/~bhaileab/mineralogy/MinWeb/ChrystalchemistryLecture.ppt#12>

This site is another PowerPoint presentation, focusing on substances found in the Earth's crust. Data is included showing oxygen to be the most abundant element in substances found in the crust. The show develops the main types of bonding, ionic, covalent, and metallic and secondary, and their roles in forming crystals. It concludes with Pauling's 5 rules of crystal formation, focusing on geometry and radii of ions.

<http://www.uio.no/studier/emner/matnat/geofag/GEO1011/h04/undervisningsmateriale/tilleggspen-sum/Mineralogi.txt4.doc>

One page of this ten-page file discusses clay minerals. The rest deals with tetrahedra and octahedra in mineral structures.

<http://www.glossary.oilfield.slb.com/Display.cfm?Term=clay>

This is a glossary of terms used in oil field exploration, hosted by Schlumberger. It gives a different use for bentonite (montmorillonite), besides kitty litter – namely in drilling mud.

http://www.cite-sciences.fr/english/web_cite/voir/invisibl/droit_fs.htm

This site shows nine different types of material, from steel to hair and concrete. Clay is one of them. When you click on the material, it shows a video ever-greater magnifications of images of

that same material. It is reminiscent of that video, "Powers of 10". The images increase in size to over 18,000,000x – down to the atomic level, where the layers of tetrahedral and octahedral are visible. An audio track describes what the viewer is seeing as the magnification increases to the atomic level.

Hydration Spheres

<http://bell.mma.edu/~jbouch/OS212S00H/sld041.htm>

This site is a pseudo PowerPoint presentation describing the chemistry of water. Slides 14 – 18 show diagrams of first and second hydration spheres for cations and anions.

As an aside, slides 3 and 4 in the above presentation offer an interesting intro to hydration spheres and their decrease in entropy. These two slides show what happens when a specific amount of salt is added to a specific amount of water. The combined volumes are less than expected, due to "electrostriction" – the effect of the hydration spheres on the sodium and chloride ions.

<http://www.wou.edu/las/physci/ch412/ppt2.htm>

For a discussion of thermodynamics and precipitate formation based on hydration spheres, see the above web site.

Miscellaneous

For more information on smectites see: <http://pubs.usgs.gov/of/of01-041/html/docs/clays/smc.htm>

For more information on bentonite see:

http://www.aquatechnologies.com/info_bentonite_clay.htm

http://www.ima-na.org/about_industrial_minerals/bentonite.asp

http://www.iied.org/mmsd/mmsd_pdfs/064_murray.pdf

<http://www.taunton.com/finegardening/pages/g00012.asp>

This site is an article from a gardening magazine discussing the benefits and problems with clay soil. It mentions swelling properties and sodium vs. calcium ions in swelling clay but, as you might imagine, it treats these ideas in a "surface" manner. Nonetheless, it shows students that there is a real-world consequence of the swelling structure of clay.

http://www.naturesbodybeautiful.com/about_calcium_bentonite.htm

This is a commercial site, selling calcium bentonite clays for personal beauty care (mud baths)

For videos on Lowe's life see <http://edwardlowe.org/index.peer?page=FDNfounders>

To read an article about the brothers who first developed silica gel cat litter see:

<http://www.entrepreneur.com/article/0,4621,300831,00.html> (Note that there is a typographical error in the article. The year in which the brothers began their company is 1997, not 1977)

There is Chemistry in Golf Balls!

Note—There is an error on page 16 and 17 concerning the coefficient of restitution. The coefficient of restitution is equal to the *square root* of (bounce height/drop height). The ratio of heights gives the fraction of kinetic energy that is returned after a bounce.

Background Information

The article describes briefly the history of golf balls and what they were made of. A theme that you can develop with students as they read this article is the way in which chemistry has allowed us to develop and use new materials throughout history, and those new materials have, in turn, changed the way we live. Many students will be able to relate to this idea through sports. It can be seen in many sports like baseball (wooden bats vs. aluminum bats), tennis (lighter, stronger racquets), sailing, fishing, hang-gliding, flying, biking, snowboarding and skiing to name a few. In fact, any sport that requires participants to wear protective equipment has changed in terms of participant safety as a result of advances in materials science.

More on Golf ball history

Wood—the early balls were probably hardwoods like elm, boxroot and beech. Balls made of elm and beech were imported from Holland in the late 15th century. The Dutch were playing *colf*, a primitive form of golf, much before the game was being played in Scotland. Elm is classified as a medium to hard wood. It has a density of 0.50 g/cm³ and is a medium strength wood. Beech wood is hard with good resistance to wear. It has a density of 0.64 g/cm³. (Note that wood density is often given as specific gravity, and that moist wood data seems to be for the wood with 12% moisture content.) For comparison, here are the specific gravities of several woods: Balsa .16, Western Yellow Pine .51, Poplar .45, Cherry .58, White Oak .76, Maple .72

Featherie—The feather-stuffed golf ball was in use by the early 1600's and lasted into the mid-19th century—usually bull's hide—The "feathery" had two differences from the balls preceding it. Firstly, wooden balls could seldom be propelled more than 100 yards whereas distances of more than twice that could be easily achieved with the "feathery". The cost of a "feathery" was twelve times the price of the old boxwood ball and about the same as a wooden club. It made golf far too expensive for the ordinary man - with the result that **each featherie cost as much as 4 shillings** (a considerable amount of money in the 19th Century). Nor was the featherie a durable ball, and in wet weather a golfer would be required to carry about 6-8 featherie balls with him.

More About Natural vs, Synthetic Rubber

Natural rubber is a natural polymer, polyterpene, found just inside the bark (cambium) of the rubber tree, *Hevea brasiliensis*. This form of rubber is called latex. The rubber tree grows naturally throughout the tropics and is also grown on plantations in Southeast Asia, Malaysia and Indonesia. The sap is collected from the trees, and when exposed to air and heating, the natural polymer is formed. The natural rubber monomer is 2-methyl-1, 3-butadiene (isoprene), with the monomers arranged as *cis*-isomers, which gives the rubber its elasticity (see More on Isoprene). A few percent of other materials, such as proteins, fatty acids, resins and inorganic materials are found in high quality natural rubber. Natural rubber is produced by masticating (grinding) the latex, adding vulcanizing agents, plasticizers and fillers before it is shaped and molded for various uses.

Natural rubber has been known for a long time, but was not widely used until the discovery by Charles Goodyear of vulcanization, which involves heating the rubber in the presence of sulfur to produce a more elastic substance by cross-linking of the polymer chains. Although Germany produced synthetic methyl rubber, a polymer of 2, 3-dimethyl-1, 3-butadiene, during World War I,

it was not until World War II that synthetic rubber was produced in large quantities. Currently 75% of the rubber used in the U.S. is synthetic. The figure is 65% worldwide. (See *Websites for Additional Information*, below.)

Buna-S and Buna-N are the dominant synthetics. Buna-S is a copolymer of 1, 3-butadiene and styrene. Buna-N is a copolymer of 1, 3-butadiene and acrylonitrile. A synthetic rubber virtually identical to natural rubber is made by polymerizing isoprene. Other synthetic forms of rubber include:

Neoprene (polychloroprene)— used for heavy-duty applications

Ethylene-propylene rubbers—used for automobile parts, hose, electrical insulation, and footwear.

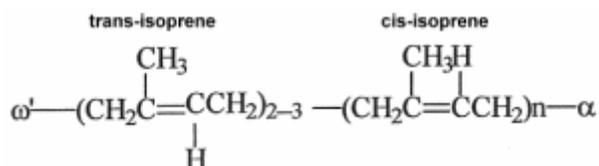
Urethane elastomers (spandex)— replaced rubber in elasticized materials. Other uses range from airplane wheels to seat cushions.

Silicone rubbers (organic derivatives of inorganic polymers like dimethylsilanediol)— used in wire and cable insulation

(See *Websites for Additional Information*, below.)

More about Gutta-Percha

Gutta-percha is one of several forms of natural rubber along with caoutchouc, balata and chicle. Gutta-percha comes from the gutta-percha tree (*Palaquium gutta*). Both caoutchouc and gutta-percha are polyterpenes, polymers of isoprene. In fact, all natural rubbers are polyterpenes consisting of isoprene molecules linked into loosely twisted chains. The monomer units along the carbon chains are in a *cis* arrangement. This isomer gives rubber its highly elastic character. However, in gutta-percha the isoprene molecules are bonded in a *trans* configuration leading to a crystalline solid at room temperature. The polymer rubber chains have a molecular weight of more than 1 million.



The "guttie" golf ball, introduced in 1848, had a solid gutta-percha core. Gutta-percha continued to be the primary golf ball component until the early 20th century when it was replaced by synthetic rubber.

(See *Websites for Additional Information*, below.)

More About the Haskell Ball

The so-called Haskell ball had a core of natural rubber. The core was wrapped in rubber thread and then encased in gutta-percha. This ball was adopted in 1901 after a successful trial at the British and U. S. Opens. After W. Millison invented the thread winding machine, Haskell balls were mass-produced and therefore more affordable.

(See *Websites for Additional Information*, below.)

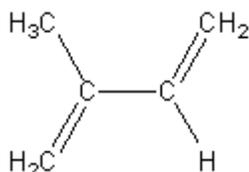
Standardization: On January 1, 1932, the United States Golf Association, following 1930 standards set by the British Golf Association for a slightly smaller ball, established standardization of golf ball weight and size. The weight was set at a maximum of 1.620 oz., and diameter not to be less than 1.680 in. Later, after testing apparatus was developed to measure velocity, a maximum velocity of 250 feet per second was added by the USGA.

Only in 1972, when Spalding introduced the first two-piece ball, the Executive, was the basic Haskell design improved upon.

The Synthetic Rubber Ball The more than one dozen major classes of synthetic rubber are made of raw material derived from petroleum, coal, oil, natural gas, and acetylene. Many of them are copolymers, i.e., polymers consisting of more than one monomer. By changing the composition it is possible to achieve specific properties desired for special applications. Common general-purpose elastomers are *cis*-polybutadiene and *cis*-polyisoprene, whose properties are close to that of natural rubber. Elastomers are just substances that can be stretched and they will return to their original shape without being deformed.

More on Polyisoprene

The systematic name for isoprene is 2-methyl-1,3-butadiene. As a monomer – a single molecule - it is a colorless liquid and is highly flammable. The isoprene monomer's structure looks like this:



Other properties of isoprene include:

Formula C₅H₈ (first determined by Michael Faraday)

Molar Mass 68.11 g/mol

Density 0.681 g/mL

Melting Point -145.95 °C

Boiling Point 34.07 °C

Vapor pressure, kPa at 20°C: 53.2

When it polymerizes into a long chain of these monomers to make **polyisoprene**, however, the polymer that forms behaves much like a molecular solid—flexible and low-melting. Joseph Priestley gave the name “rubber” to the natural substance since it erased pencil marks by rubbing.

Vulcanization can also change its properties. For example, adding a small amount of sulfur to the rubber causes the sulfur to bond the polymer chains together, linking the chains and thus limiting their ability to move freely, and increasing the rubber's hardness and heat resistance. This is an example of crosslinking.

(See *Websites for Additional Information*, below.)

More on Polybutadiene

The systematic name for *butadiene* is 1,3-butadiene. It is a colorless liquid and is highly flammable. Other properties include:

Formula C₄H₆

Molar Mass 54.09 g/mol

Density 0.64 g/mL

Melting point -108.9°C

Boiling point -4.4°C

Vapor pressure: 121.3 kPa at 20°C

It can be polymerized to give the polymer polybutadiene.

(See *Websites for Additional Information*, below.)

More on Polymer Crosslinking

Vulcanization of rubber is just a process in which a vulcanizing agent is added to the polymer to promote crosslinking between the polymer strands by means of covalent bonds.

Other crosslinking agents are organic peroxides, dicumyl peroxide, t-butyl peroxide, azo compounds, and azobisisobutyronitrile, and a group including zinc acrylate, zinc methacrylate, magnesium acrylate, magnesium methacrylate.

(See *Websites for Additional Information*, below.)

More on the Modern Ball

From Golf Digest:

<http://www.golfdigest.com/gfw/gfwequip/index.ssf?/gfw/gfwequip/gfw200409golfballs.html>

“Ten years ago, choosing a golf ball was simple. They came in two basic varieties: hard, two-piece distance balls for the average high-handicappers and softer, wound three-piece "spin and feel" balls for pros and better players. The better-player balls didn't go as far off the tee, but the players who used them didn't mind because they hit the ball plenty far enough, preferring to have the ability to spin and work the ball on their short shots. Distance balls were notoriously difficult to stop around the greens, but the average weekend players who used them didn't care. They preferred getting those extra yards off the tee, and besides, they weren't very good at finesse shots anyway.”

From Golf Tips magazine at

<http://www.golftipsmag.com/content/buyersguide/2003/balls/balls02.html>

According to Dean Snell, Senior Director of Golf Ball Research And Development at TaylorMade-Adidas Golf, many of the performance benefits can be traced to advanced core designs and materials. “In the past, designers tried to make ball cores larger and softer, but the materials available caused them to be slow, meaning they didn't create much velocity at impact. But in recent years, new formulations and materials have allowed us to make much larger, lower-compression cores, which don't suffer any loss of velocity. This combination creates golf balls that feel soft, but create a tremendous amount of speed potential and distance.”

In regard to some of the specifics involved in material advances, Snell adds that the base formulation of rubber used for golf ball cores, called polybutadiene, in itself doesn't produce the desired distance characteristics. But when materials like cobalt, neodymium, nickel or others are added to the core formulation, there are nearly endless possibilities for golf ball performance.

When it comes to golf ball cover technology, according to Snell, almost the same thing can be said. “Covers have come a long way since the original hard Surlyn covers and non-durable synthetic balatas. Urethane obviously has allowed for the creation of balls that can provide all-around performance. However, the new formulations of Surlyn are probably just as important. Many of the golf balls from which the recreational golfer most benefits feature some type of Surlyn blend, and they definitely don't feel hard like they used to.”

A personal survey of 21 balls from 10 of the top companies (published in the web version of Golf Tips magazine at <http://www.golftipsmag.com/content/buyersguide/2003/balls/balls02.html>) reveals the composition of golf balls in use to day. Most balls have a polybutadiene core and a urethane cover. (Note that the “mid-layer” column does not add up to 21 because some of the balls surveyed had two-piece construction.)

Core

Mid-layer

Cover

Polybutadiene (15)
Rubber (4)
Muscle Fiber (2)

Tungsten ionomer (6)
Blended polymer (2)
Rubber (2)
High Acid Magnesium (1)
HPF Polymer (1)

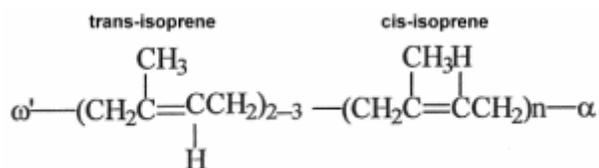
Urethane (12)
Surlyn (5)
Softane (1)
Spintane (1)
Fusablend (1)
Spintack (1)

(See *Websites for Additional Information*, below.)

More on Cis-Trans Isomers

Isomers are molecules that have the same composition but a different arrangement of atoms with the molecules. If you want to illustrate isomers for students, using molecular models is a big help as students try to visualize isomerism. As you know, there are several types of isomers—structural isomers (now called constitutional isomers) and stereoisomers. Cis-trans isomers fit into the stereoisomer group. In stereoisomers the atoms are arranged in the same order in the molecule, but have a different arrangement in space. This is typically the result of the molecule having a double bond that prevents internal rotation of atoms.

In the section above on gutta-percha, cis-trans isomers are shown. Note the double bond in the isoprene. One carbon involved in the double bond has a methyl group attached to it and the other carbon has a hydrogen attached. In the cis isomer the methyl group and the hydrogen are both located on the same side of the molecule. In the trans isomer the methyl group and hydrogen are on opposite sides of the molecule.



Isomers usually have different physical properties as well as chemical properties. For example, look at the melting and boiling points of the stereoisomers:

	Melting Point(°C)	Boiling Point (°C)
cis-1,2 dichloroethene	-80	60
trans-1,2 dichloroethene	-50	48

As to chemical properties, we can note that if a biologically active molecule has stereoisomers, only one isomer usually exhibits the biological activity.

Connections to Chemistry Concepts

Materials science
Organic chemistry
Polymers
Cis-trans isomers
Structural formulas
Chemical bonding

Possible Student Misconceptions

1. All polymers are synthetic. In fact, natural polymers existed when (and probably even before) life began on earth. Man has been able to synthesize polymers for only about 100+ years. Natural polymers get less “press coverage” precisely because they are

natural. All living things have polymers in them. Students probably think of plastics when they hear the word polymers, but in fact, there are many other types of polymers, as elastomers, films, coatings and adhesives.

2. Dimpled balls travel more slowly and don't go as far because they are rough; smooth balls would travel faster and farther. The author has explained why this is not true.
3. Golf balls are made of one material throughout. Again, this idea is dispelled in the article.
4. Bernoulli's Principle only works on airplanes (if they've had physics already). Bernoulli's Principle works on any object which is subjected to differences in fluid velocity on top compared to that on the bottom of the object – golf balls included.

Demonstrations and Lessons

1. Determine the CoR for several golf balls: Students can determine an approximate coefficient of restitution for a golf ball by dropping the ball vertically from a specific height (1.0 meter, say) and measuring the height of the first bounce. Run at least three trials for each ball and find the average. Have students compare brands of golf balls.

An article from the online version of Golf Digest about the importance of CoR appears here http://www.golfdigest.com/features/index.ssf?features/golfs_gr_y0nollfc.html

Detailed calculations for CoR can be found here <http://carini.physics.indiana.edu/E105/cor.html>

2. Have students bring in several brands of golf balls. Cut the balls in half and have students compare the insides.
3. Calculate the maximum density of a USGA approved golf ball. The information students will need is included in the article.
4. Compare size, weight and density of a golf ball and a baseball. The USGA says that "The (base) ball should be a sphere formed by yarn wound around a small sphere of cork, or rubber, or similar material covered with two stripes of white horsehide or cowhide, tightly stitched together. It shall weigh not less than 5 nor more than 5 1/4 oz avoirdupois and measure no less than 9 nor more than 9 1/4 inches in circumference." For information on baseballs see: <http://pubs.acs.org/cen/whatstuff/stuff/7713scit3.html>
5. The "featherie" golf ball was made using a "gentleman's top hat" full of goose feathers. **What volume would the typical top hat of the mid-1800's hold?** An average men's hat size is 7-1/4, which corresponds to a circumference of 58.0 cm (22 3/4 inches). Top hats varied somewhat in height, but 17.8 cm (7 inches) was typical. Since we are asking about the volume of a cylinder, we find that $r = 9.24$ cm and $h = 17.8$ cm. The volume, therefore, would be 4770 cm³ or 4770 mL or 4.77 L. This means that 4.77 L of goose feathers were stuffed into a leather pouch with an approximate volume of 40 mL.

Directions for making a top hat at <http://turf.lib.msu.edu/1920s/1923/230380.pdf>

6. Plot Drive Distances To see the effect of modern golf materials, here are the average drive lengths of the top 10 leading drivers on the PGA tour since 1989 (from http://www.pgatour.com/stats/2003/r_101.html) Have students graph this data and compare the drive lengths with those mentioned in the article for earlier types of balls:
Wooden Ball – 75–85 yds
Featherie – 150–175 yds
Gutta-Percha 170–190

Year	Drive (yards)	1991	277.8	1993	277.9
1990	277.3	1992	275.5	1994	278.9

1995	281.1	1998	288.5	2001	296.4
1996	283.3	1999	291.2	2002	295.1
1997	286.7	2000	289.9	2003	305.4

It might be interesting to ask students to hypothesize the reason for the continuing increase in drive length over the years. Better golf balls is one reason, so is better golf clubs – using graphite, for example. Scientific study of the golf swing using technology might also contribute to the increased distance. Besides these possible explanations, are golfers getting better? More muscular? Starting their game earlier (as in childhood)? Could they be on steroids? Would steroids help golfers as they do for baseball players?

Suggestions for Student Projects

1. In the lab, students can make a superball, like the one mentioned in the article. You will need for each student (or group of students) 20 mL of sodium silicate (water glass) solution, 5-10 mL ethyl alcohol, a small paper cup for each liquid, a stirring rod and paper towels. Students should wear plastic gloves so that the sodium silicate does not come in contact with their skin. Add the alcohol to the sodium silicate and stir. Students can mold the resulting polymer in their hands to shape a ball. They should try to gently press the polymer into a ball. It may crumble, but they can put the pieces back together and remold it gently. Wet the ball occasionally if necessary. The polymer that is formed is a silicate polymer with the ethyl groups providing the crosslinking. Here's a reference for you. It contains a teacher version (appearing first) and a student version.
http://www.lyochem.com/html/social/explore_experiment/pdf/t7/super_ball_v3_0.pdf
2. Make a latex rubber ball (Dave Katz) <http://www.chymist.com/Rubber.pdf>
3. Test “Happy” and “Unhappy” balls
<http://www.physics.bcit.ca/demos1103/DMP/DMP06.htm>
4. Refer students to the following ACS article
<http://pubs.acs.org/cen/whatstuff/stuff/7713scit3.html> and then compare the composition of a golf ball to a baseball.
5. This web site has a unit of lab activities related to polymers that students can do
http://www.grc.nasa.gov/WWW/K-12/Summer_Training/Magnificat/Polymer_Project.html
6. Golf by the numbers: Every golf ball has a set of numbers on it. What do the numbers mean? Students can investigate these numbers and relate their answers to the article. The following web sites provide answers
http://golf.about.com/cs/beginnersguide/a/bfaq_numberonb.htm
<http://www.leaderboard.com/GLOSSARY BALLNUMBERS>
<http://www.golfballs101.com/golf-ball-numbers.aspx>
<http://www.golf.vonabercron.com/knowledge.htm>

Anticipating Student Questions

1. What is materials science? From LaborLawTalk, at http://encyclopedia.laborlawtalk.com/Materials_science, “**Materials science** includes those parts of chemistry and physics that deal with the properties of materials. Materials science encompasses four classes of materials, the study of each of which may be considered a separate field: metals, ceramics, polymers and composites.”

2. What is alum? Alum is actually a group of compounds having similar composition – aluminum [metal] sulfates. The alum they used to make the featherie was likely aluminum potassium sulfate, or aluminum ammonium sulfate, as these two are very common alums, both of which were already in use in the tanning industry at the time of featherie production.
3. Does elasticity have anything to do with stretchiness? Elasticity is the ability of a material to regain its shape when a force/load has been removed. In the case of the golf ball, the force is an inward force (or compression) as the club hits the ball. It's a deformation that we can't see because it happens so fast, and the golf ball rebounds (almost) to its original shape. In the case of a rubber band, though, the force is a stretching force and as we pull on the band, we can see the rubber band deform as it gets longer. But when we release it, the rubber band returns (almost) to its original shape and the deformation disappears.

Websites for Additional Information

Natural vs. Synthetic Rubber

For still more on natural rubber see <http://www.infoplease.com/ce6/sci/A0860822.html>.

To read a brief history of rubber production, see <http://www.beyonddiscovery.org/content/view.txt.asp?a=203#Summary>

For an article by David Katz and an accompanying lab on making latex rubber, see <http://www.chymist.com/Rubber.pdf>

Gutta-Percha

For a long article on gutta-percha including its part in golf ball history see <http://www.altcorp.com/AffinityLaboratory/guttahistory.htm>

The Haskell Ball

For still more on Haskell's "bounding billie" ball see <http://www.uh.edu/engines/epi1716.htm>

Polyisoprene

For even more on polyisoprene see <http://www.pslc.ws/macrogcss/isoprene.html> . The Polymer Science Learning Center is housed at the University of Southern Mississippi. This is an excellent site for all things polymer.

Polybutadiene

For even more on *polybutadiene* see <http://www.pslc.ws/macrogcss/pb.html> . The Polymer Science Learning Center is housed at the University of Southern Mississippi. This is an excellent site for all things polymer.

To read an article on synthetic rubbers and their history and development, available on line from the *Journal of Chemical Education* (Kauffman, George B., *Elastomers II: Synthetic Rubbers*, 68, 1991, 217) see <http://search.jce.divched.org:8081/JCEIndex/FMPro?-db=jceindex.fp5&-lay=wwwform&combo=rubber&-find=&-format=detail.html&-skip=13&-max=1&-token.2=13&-token.3=10>

Polymer Crosslinking

For a more detailed explanation of crosslinking, see <http://www.pslc.ws/macrog/xlink.htm> at the University of Southern Mississippi's Polymer Science Learning Center.

The Modern Ball

This web article contains cut-away diagrams of modern golf balls:
<http://www.golfdigest.com/gfw/gfwequip/index.ssf?/gfw/gfwequip/gfw200409golfballs.html>

Diagrams also appear here:

<http://www.golftipsmag.com/content/buyersguide/2003/balls/balls02.html>

This commercial site from Precept, makers of golf balls, gives useful answers to FAQ's about materials making up golf balls at http://www.preceptgolf.com/products/golf_ball_faq.html#q2

This site relates the composition and structure of balls to the aerodynamics of the game:

<http://www.golf.vonabercron.com/knowledge.htm>

Golf Ball History

For good histories of the golf ball, see:

<http://www.golfballmuseum.co.uk/index.html> The Golf Ball Museum in England provides many details in the history of the ball.

http://www.usga.org/aboutus/usga_history/1894_1910.html The USGA provides a history that includes golf ball milestones.

http://www.golfeurope.com/almanac/history/golf_ball.htm This page from GolfEurope has good illustrations of the balls mentioned in the article.

<http://library.thinkquest.org/10556/english/high/history/hist05.htm> This Thinkquest page also has illustrations.

<http://www.titleist.com/technology/evolution.asp?bhcp=1> This commercial site from Titleist, not only has a history of the golf ball but also has a section (see right hand navigation bar) on the principles of aerodynamics that are discussed in the article.

To view a clickable list of the 88 patents that have been awarded for inventions/processes involving the golf ball since 1790, visit the US Patent Office at (this is all one web site address):

<http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&p=1&u=%2Fnetatml%2Fsearch-bool.html&r=0&f=S&l=50&TERM1=260%2F998.14&FIELD1=ORCL&d=pall>

Aerodynamics of the Golf Ball

For an excellent "short course" on the science of golf balls, which emphasizes the physics of the game, see http://www.preceptgolf.com/new_index.html# and click on "Products" then "Golf Balls" and then "The Science of Golf Balls."

For physics of the golf ball and aerodynamics:

http://ffden-2.phys.uaf.edu/211_fall2002.web.dir/josh_fritts/swing.html

For a complete guide to the physics of golf from a physics professor see http://ffden-2.phys.uaf.edu/211_fall2002.web.dir/josh_fritts/index.html

These articles emphasize the importance of the dimples on a golf ball. Read more about the role of dimples here:

<http://wings.avkids.com/Book/Sports/instructor/golf-01.html>

<http://science.howstuffworks.com/question37.htm>