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EVERYDAY CHEMISTRY

OCTOBER 2005

OH, THE JOY OF TOYS!

Discover Chemistry in the Amazing Drinking Bird

national chemistry week

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OCTOBER 16–22, 2005

The Joy of Toys

national chemistry week

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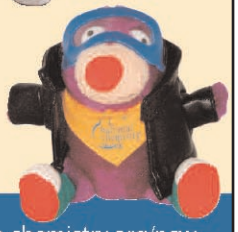
Meg A. Mole Doll

Avogadro with Jacket



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ChemMatters®

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PHOTOS COURTESY OF ERICK SWARTZ

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Correction:
David Holzman (not Holtzman) was the author of our February 2005 article "Water of Life".

TEACHERS!

FIND YOUR COMPLETE TEACHER'S GUIDE FOR THIS ISSUE AT www.chemistry.org/education/chemmatters.html.

Question From the Classroom

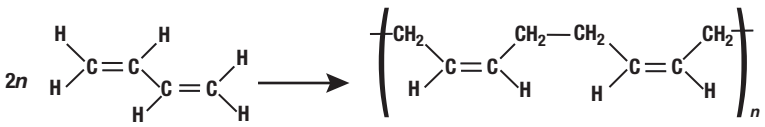
By Bob Becker

Q: What makes a Superball so super?

A: The original Superball "fact sheet" published by Wham-O in 1965 said the Superballs were made of an exotic new compound called "Zectron". That sounds pretty futuristic and high tech, but it means nothing to a chemist. The patent for Superballs, however, filed by its inventor Norman Stingley in that same year, lists as its main ingredient a well-known polymer known as *polybutadiene*, a name that *does* mean something to chemists. The prefix "but-" means a four-carbon chain. The "-ene" ending means double bond, and "di-" means two. So "butadiene" means a four-carbon chain with two double bonds: $CH_2{=}CHCH{=}CH_2$

Finally, the prefix "poly-" means that many of these butadiene molecules are strung together. The stringing together (aka: "polymerization") of these butadiene units starts with a free radical—a molecule with an unpaired electron, and hence an open bonding site. The way a polymer chemist represents the overall reaction is:

Addition Polymerization



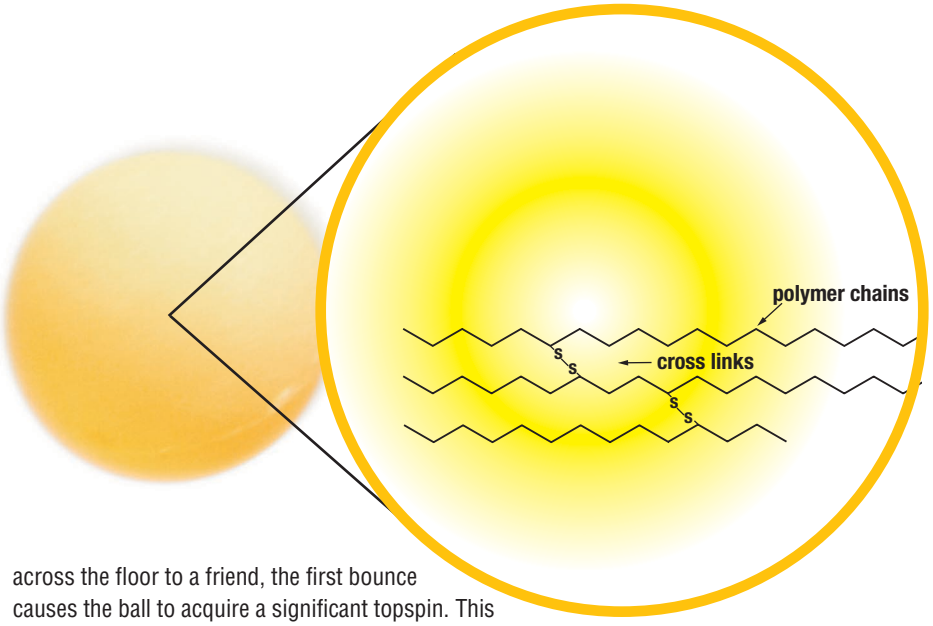
The "n" represents a large number, often in the thousands. The fact that there are still double bonds in the polymer chains is very important, for it allows the polymer chains to be "vulcanized." Vulcanization is a process discovered and patented by Charles Goodyear in 1839. Rubber at that time was very limited in its uses. In the summer time, it got soft and gooey, and in the winter time it became hard and brittle. Goodyear discovered that if you added sulfur to the rubber, and subjected it to heat and high pressure, it made an all-weather rubber that remained flexible and resilient year-round. The sulfur atoms form little bridges between the polymer strands (at the double-bond locations) which kept the strands from sliding past one another at high temperatures or contracting into knots at low temperatures.

Apparently, when polybutadiene is vulcanized at a temperature of 160 °C and a pressure of 70 atm (according to Stingley's patent), it creates a cross-linked polymer with a resilience of 92%. This meant that if you dropped a Superball from 100.0 cm onto a hard surface, it would bounce back to about 92.0 cm, then 84.6 cm, then 77.9 cm, and so on, always bouncing to about 92% of its previous height. When many elastic substances are distorted, they regain their original shape, but in the process, some of the energy that went into distorting the substance is lost as heat. If it didn't, you could theoretically produce a Superball that would bounce forever (ignoring air resistance). Anyone who has played squash or racquetball is familiar with how the ball heats up the more it is bounced. Vulcanized polybutadiene only loses 8% of its energy to heat per collision, and therefore bounces back with 92% resiliency. This was much more than any bouncing ball manufactured at that time.

This alone was impressive, but it alone would not have made the Superball the hottest selling toy of the mid-1960s. A second remarkable property of Stingley's "Zectron" was its high coefficient of friction. Try pulling a Superball across a smooth surface, and you will appreciate this effect. When bounced

SUPERBALL FACTOID

As a promotional item, Wham-O once built a giant Superball, which was accidentally dropped out of a 23rd floor hotel window in Australia. It shot back up 15 floors, then down again into a parked convertible car. The car was totaled, but the ball survived the "test" in perfect condition.



across the floor to a friend, the first bounce causes the ball to acquire a significant topspin. This topspin then propels the ball with remarkable speed on the second bounce, making it nearly impossible to catch. This high coefficient of friction also allowed for all kinds of tricks, the most famous of them being the under-table bounce: If the ball is bounced off the floor so that it hits the underside of a table, the aforementioned topspin makes the ball rebound straight back to the thrower. If you have never seen this, give it a try.

In the vulcanized rubber of a Superball, polybutadiene strands are partially cross-linked with sulfur atom bridges. These bridges keep the strands from sliding past one another at high temperatures or contracting into knots at low temperatures and make the ball very resilient.

Challenge:

Can you match these toys with the years they first hit the stores?

___ Frisbee	A) 1945
___ Hacky Sack	B) 1948
___ Hula Hoop	C) 1955
___ Slinky	D) 1958
___ Slip 'n Slide	E) 1965
___ Superball	F) 1983

Find the solution on back page.

LIQUID CRYSTAL DISPLAYS

By Lois Fruen

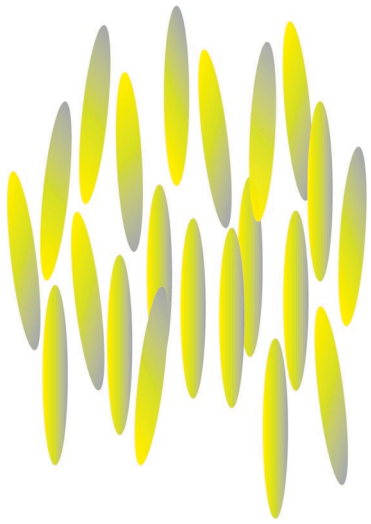
Do you enjoy photo- and instant-messaging with your friends, watching fast-action sports on a widescreen TV, playing fast-action games on a Game Boy, or viewing DVDs? If so, your fun is made possible by LCDs.

LCDs, or liquid-crystal displays, are everywhere; they are in cell phones, laptop computers, games, MP3 players, and all manner of electronic devices. They are thin and lightweight and are run on little power. But what is it about liquid crystals that make all this possible?

Order in disorder

The name *liquid* crystal sounds like an impossible contradiction. Liquids can flow and crystals are solid. How can there be a liquid crystal? In a normal crystal, the molecules have an orderly arrangement. In a liquid, the molecules are jumbled and disordered. Liquid crystals, on the other hand, have molecules that can flow, but that also have an orderly arrangement.

There are several types of liquid crystals, but all of them contain molecules that are linear and polar. Linear molecules have atoms arranged generally along a line, so they are considerably longer than they are wide. A polar molecule is one in which the electrons are distributed unevenly, leaving certain regions with a slight positive electrical charge and other regions with a negative charge. The charges make the ends of the molecules behave somewhat like the poles of a magnet, and the molecules are attracted to each other. If the molecules have a suitable shape, they will line up. No permanent attachments are formed between molecules, so the material does not solidify.



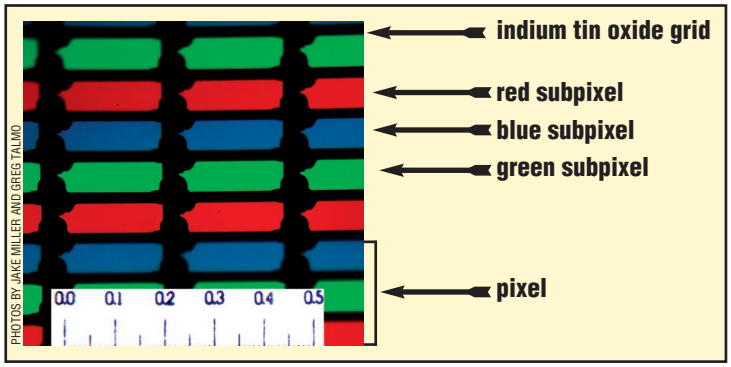
Liquid crystals are often composed of long molecules with a dipole moment typically parallel to the long axis. The molecules of nematic, or threadlike, liquid crystals do not occupy fixed positions. However, they tend to lie parallel to one another, each pointing in the same direction.

Liquid crystals are typically long, thin organic molecules that change orientation in an electric field. The most common type of liquid crystal is the nematic liquid crystal. More than 50,000 different liquid crystals are known.

Pixels and subpixels

The real secret behind a flat-screened LCD television or fast-action handheld game screen is the liquid crystals that are sandwiched between the polarizing films. To unlock that secret, we need to investigate how polarizing films work. The films are positioned at 90-degree angles to each other so that light polarized by the first film is blocked by the second. This results in a black spot.

If the top polarizing film is rotated 90 degrees, light passes through both.



Three successive subpixels—one red, one green, and one blue—make up the pixels of your display screen. The subpixels shown are about 0.20 mm wide.

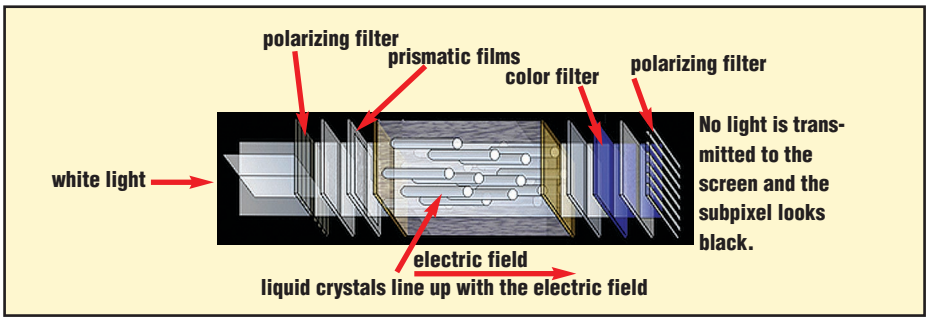
Because it's impractical to physically rotate the polarizing films, chemists have synthesized nematic liquid crystals that rotate polarized light in response to voltage changes. The ultimate role of the liquid crystal and polarized film combination in an LCD is to quickly block or allow light through a subpixel.

What is a subpixel? If you take a really close look at an LCD screen, you will see individually colored regions called subpixels. Three successive subpixels—one red, one green, and one blue—make up a pixel on your display screen.

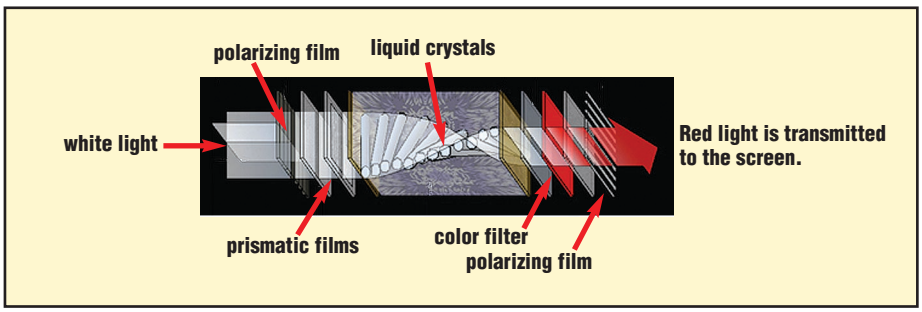
An elaborate series of electronic transistors and capacitors are deposited onto glass plates. Color filters are added in alternating primary colors of red, green, and blue. A transparent indium tin oxide layer is deposited on top of the transistors, which serves as an electrode for each of the glass plates. The top and bottom plates are then glued together leaving a small hole to a gap where the liquid crystals are filled using a vacuum process. Very large-sized monitors and LCD TVs use more sophisticated manufacturing processes. Finally, the glass plates with the liquid crystals and electronic components are sandwiched between the two polarizers that are oriented at 90-degree angles to each other.

When voltage is applied to this blue subpixel, the nematic liquid crystal molecules untwist and line up with the electric field, letting polarized light through to the second polarizer that absorbs the light. No light is transmitted to the screen so the subpixel looks black.

When the voltage to a subpixel is off, the nematic liquid crystals relax back to their original twisted state. Incoming polarized light follows the twist of the liquid crystal molecules, rotating 90 degrees, enabling it to pass through the color filter and on through the second polarizer. With a red filter, red light is transmitted by the subpixel.

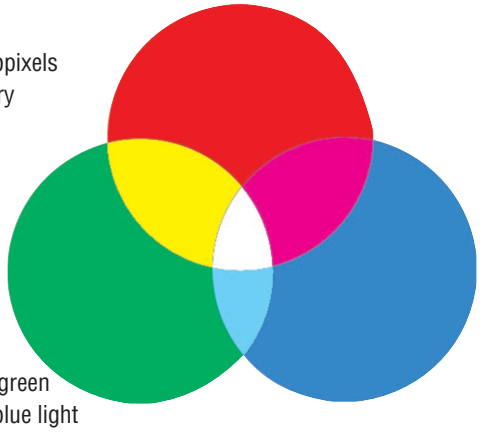


When voltage is applied to the blue subpixel, liquid crystal molecules line up with the electric field. This alignment lets polarized light through to the second polarizer that absorbs the light. This causes the subpixel to look black.



The voltage is off at this red subpixel. In this case, polarized light follows the twist of crystals, rotating 90 degrees to pass the red color filter and on through the second polarizer.

Mixing light from various subpixels in a given pixel produces secondary colors. Red and green produce yellow light. Blue and green make cyan, and red and blue result in magenta light. When combined, light from all three subpixels in a single pixel produces white light.



When mixed, red and green light makes yellow light, blue and green light produces cyan, and red and blue light gives magenta. When combined, red, green and blue produce white light.

By varying the voltage that regulates the positions of the liquid crystals, shades of color can be produced. Today, a typical 12- or 15-inch laptop screen has 1024 pixels across and 768 pixels from top to bottom, which means there are 2,359,296 subpixels on the screen that can produce millions of shades of color.

Quicker and brighter

A big problem with LCD technology used to be "switching speed". Switching speed is the time it takes nematic liquid crystal molecules to switch from twisted to aligned state and back. Historically, liquid crystal switching times were about 25 milliseconds. Improvements to the liquid crystal molecules themselves as well as changes to the electronic driving schemes have reduced switching times to 8 milliseconds and less. Faster switching times have eliminated the washed-out visual smears that plagued action video gamers and DVD enthusiasts who did not like shadow trails on fast-paced scenes.

In addition, LCD displays haven't always been so vibrant and bright. Newer displays on portable game players and laptops often include one or two brightness-enhancing films in the subpixel. What are they? To understand them, it helps to learn a little more about the tiny fluorescent tube in devices that provides the light and ends up going through the subpixel.

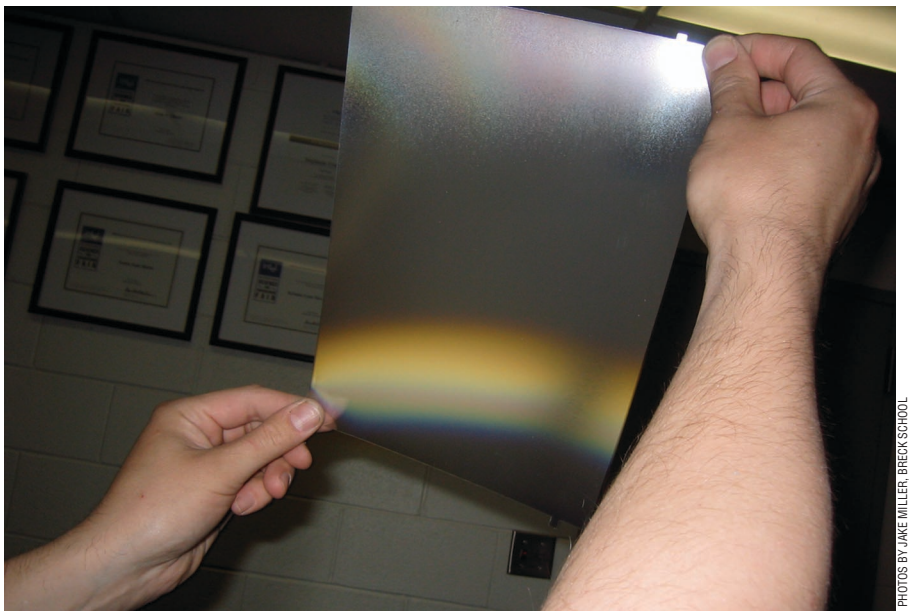
When switched on, gas in the fluorescent tube gives off ultraviolet (UV) light with short wavelengths between 365 and 366 nm. When the UV light strikes a fluorescent coating on the inside of the glass tube, it excites electrons in the fluorescent coating that return to "ground" state, emitting longer wavelengths of visible light ranging between 380 and 760 nm. Chemists have carefully selected coatings that emit red, green, and blue light, which collectively appears white to the eye.

The white light from the fluorescent tube enters the screen along one edge of the light guide and is scattered by thousands of white dots on the backside of the backlight panel, directing the light toward the viewer. Brightness-enhancing prismatic films refract the

Plasma displays

An increasingly popular choice among widescreen enthusiasts are the new plasma televisions. Unlike LCD displays, plasma displays do not use liquid crystals or a backlight. Instead, the display panel on a plasma TV is made up of thousands of tiny phosphorescent cells that are sandwiched between two plates of glass. The glass plates and the electrodes between them act as capacitors and separate the current that activates the phosphorescent cells. The phosphorescent cells are filled with neon, xenon, or argon gas and are coated with different phosphorescent chemicals called phosphors. Color is produced on a plasma screen when atoms of the gas in the tubes are excited by electric current and emit UV light, which excites electrons in the phosphors. When the electrons in the phosphors return to ground state, they give off red, blue, or green light, depending on the phosphor. Colored light from the phosphorescent cells is mixed to produce a full range of colors. Like LCD displays, a pixel on a plasma display is capable of producing white light when all three subpixels—red, blue, and green—are activated. Shades of color are produced by varying the current flow to the subpixels. Plasma displays produce a bright image that looks good from all angles.

NEC PLASMA SCREEN



PHOTOS BY JAKE MILLER, BRECK SCHOOL

Brightness-enhancing film: Note the prismatic effect.

light into a smaller viewing cone to further increase the brightness of the display.

The refracted light enters a polarizer that contains long inorganic polyiodide ions lined up lengthwise. Light that is oriented at right angles to the iodine molecules passes through, while light oriented in the direction of the axis of the molecules is absorbed, cutting the brightness of the screen display in half. New light-enhancing films reflect light back to the backlight panel that would have been absorbed by the polarizer. This reflected light is then rescattered back toward the polarizer. These enhancement films, in combination with prismatic films, increase the brightness of a typical LCD screen by more than a factor of 2, reclaiming light that would have been lost. This makes your laptop or cell phone display much brighter and easier to see. The same brightness-enhancing films are used in many of the newest LCD TVs. You may want to perform your own investigation by visiting your local department or electronics store. If you look closely, you will be able to determine which TVs have brightness-enhancing films and which do not. ***Hint:*** look for the "Vikuiti" label on the TVs.

New technology

LCD displays are changing fast. One of the newest types is called LCOS, which stands for liquid crystal on silicon. What makes LCOS unique is the very high resolution that can be achieved. LCOS displays use reflected rather than transmitted light, which passes through the liquid crystals twice on its way from the light source to the viewer. A typical LCOS panel can produce an image that reproduces the quality of a plasma HDTV. LCOS displays are so small that they do not use subpixels and color filters. In one type of LCOS, light is filtered through a spinning color-wheel. Liquid crystal switching is coordinated with the spinning color wheel, which moves too fast to see. A more sophisticated LCOS uses a system of prisms to split light source into red, green, and blue components and then recombines them by another prism to create the composite likeness.

This is just the beginning. Scientists, engineers, and chemists around the world are developing new ways to use liquid crystal molecules. At a recent conference in Boston, a company demonstrated an 84-inch diagonal LCD TV. Others envision displays that might be rolled up to the diameter of your pencil. Others are working to engineer displays that use no battery, but rather are powered by the same microwave transmissions that transmit information to your cell phone.

You can expect future displays to be both smaller and much larger. And they will be brighter, sharper, and cheaper, thanks to chemistry.

SHARP CORPORATION

Two-way viewing angle LCD. This new LCD from Sharp Corporation sends the light from the backlight to the right and the left, making it possible to show two different images at the same time. Reflecting the LCD in a mirror shows that one user sees a TV show, while another sees an Internet homepage. One possible application is a car display that shows the driver a map, while the passenger watches a movie on DVD.

Lois Fruen teaches chemistry at the Breck School in Minneapolis, MN. Her most recent article "Cleopatra's Perfume Factory and Day Spa" appeared in the October 2004 issue of *ChemMatters*.

The Amazing Drinking Bird!

By Brian Rohrig

The drinking bird is a mesmerizing little science toy that has fascinated young and old for more than 50 years. It is also known as the happy bird, the dippy bird, the happy dippy bird, and other variations on this same theme. It looks like a bird and will bob up and down as it appears to drink out of a glass of water. As long as it can reach the water, it will bob up and down indefinitely. The drinking bird consists of two elongated glass bulbs that are connected by a straight glass tube extending well into the interior of the bottom bulb. The only way any substance can pass between the two bulbs is through this narrow glass tube. The top bulb is covered with a porous feltlike material that also makes up the beak. On top of the head is a plastic top hat, which is only for decoration. Taped to the bottom chamber are tail feathers, which help it to maintain balance. The whole thing is suspended from plastic legs, with a horizontal piece of metal that acts as a pivot, allowing it to bob up and down.

Inside, the drinking bird is a highly volatile liquid known as methylene chloride (CH_2Cl_2). Since methylene chloride is colorless, coloring must be added to enhance the visual effect. This liquid is also highly volatile, meaning it evaporates rapidly due to weak intermolecular bonds in the liquid state. Its boiling point is 39.7 °C (103.5 °F), and its vapor pressure at room temperature is 46 kilopascals (compared to only 3 kPa for water). Methylene chloride is somewhat toxic, so if a drinking bird breaks, care must be exercised in cleaning it up. Methylene chloride is commonly used as an industrial cleaner, degreaser, and paint remover.

After the methylene chloride is added by the manufacturer, most of the remaining air is then vacuumed out. Because a near vacuum now exists within the bird, the highly volatile liquid readily evaporates until the space above the liquid is saturated with vapor. At this point, a dynamic equilibrium is established within the bird between the liquid and the vapor above it. Once equilibrium is established, anytime a molecule evaporates, another molecule will condense, resulting in an overall constant amount of vapor within the bird as long as the temperature stays constant.

To activate the drinking bird, his head is dipped into a glass of water, and he is then set upright in such a position that when he tips his beak, he will be able to reach into the glass of

ALL PHOTOS BY MIKE CIESIELSKI; BIRDS COURTESY OF TEACHERSOURCE.COM

water. Once the head is wet, a strange thing immediately begins to happen. Like magic, the fluid begins to rise upward into the head, until his head fills with liquid. The head then becomes top heavy as the center of gravity of the bird is raised. The bird then topples over, takes another drink. As the bird tips over, the liquid flows back to the bottom bulb, restoring the low center of gravity. The bird resumes its upright position, beginning the whole process all over again.

To understand what makes the fluid rise within the bird, think about what happens whenever your own head gets wet. As long as the relative humidity is not 100%, the water will immediately begin to evaporate. And evaporation always causes cooling, because it is an endothermic process. That's why you sweat when you get hot; it's not the sweating itself that cools you, but rather the evaporation of the sweat from your body. Any phase change that requires bond breaking will be endothermic, because energy is required to break bonds. This energy is drawn from the surroundings, thereby causing the temperature of the surroundings to decrease.

Because water evaporates from the head of the bird, the head immediately begins to cool. This is the most crucial point in understanding how the drinking bird works. If you could cool the head another way, the drinking bird would work just the same. When the head begins to cool, some of the vapor within the head will condense into tiny droplets of liquid. A similar process occurs at night when water vapor condenses out of the air as it cools, forming dew on the ground. Because some of the vapor condenses within the top chamber of the bird, there is now less vapor pressure in the top bulb. Less vapor means less pressure. But the vapor pressure within the bottom bulb has not changed. Because the vapor pressure in the bottom bulb is now greater than the pressure in the top bulb, the liquid is forced upward into the top chamber. (Don't say the liquid is sucked up into the top chamber—science never sucks!) Once the bird tips over, vapor from the bottom travels to the top until the pressure in both spheres equalizes and the bird begins the process all over again.

To understand how this pressure differential can cause the fluid within the bird to rise, consider what happens when you use an ordinary drinking straw. When you suck fluid up into the straw, you are creating a region of reduced pressure within the straw. Because outside air pressure is greater, it pushes downward on the surface of the fluid, forcing it up the straw.

Not only is the drinking bird educational, but it can also provide hours of entertainment. Many science museums feature displays of drinking birds. No science classroom would be complete without one. The amazing drinking bird has even appeared in a 1995 episode of *The Simpsons*, where Homer positions a drinking bird in front of his keyboard to help monitor the controls at the Springfield nuclear power plant. The artist Daniel Reynolds spent a small fortune and several years developing an art exhibit comprising a whole flock of giant 6 1/2 feet tall drinking birds, each weighing 3,000 times more than an original drinking bird. They had to be made with a special vacuum attachment in order to work properly.

There are many variations on the drinking bird. They come in a variety of styles and sizes. There is even a drinking giraffe! The very popular, but falsely named "hand-boiler" is nothing more than a drinking bird that is stripped down to the bare essentials. It works either by cooling the top or warming the bottom.

The next time you need a unique gift for the person who has everything, consider a drinking bird. A quick search on the Internet will reveal a plethora of sources. They especially make great gifts for science teachers!

Additional experiments you can perform with the drinking bird:

1. Place a gallon-size freezer bag over an operational drinking bird. He will almost immediately stop drinking. Can you explain why?
2. Have a drinking bird "drink" hot water and then ice-cold water. Which will make the bird drink faster?
3. Have the bird "drink" a liquid with a higher evaporation rate than water, such as rubbing alcohol. Does the drinking bird drink faster?
4. Instead of cooling the head, heat the body, either with your hand or a heat lamp. Does the drinking bird work?
5. If you have a spare drinking bird that you don't mind disfiguring, paint the top bulb silver and the bottom bulb black. Place in a sunny windowsill and watch it bob up and down! No water required.

Brian Rohrig is a chemistry teacher at Jonathan Alder High School in Plain City, OH. His article "There's Chemistry in Golf Balls!" also appears in this issue.

Kitty Litter Chem

By Amanda Yarnell

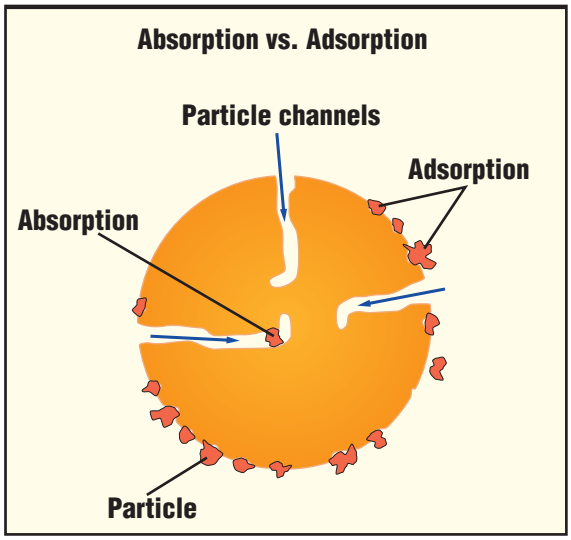
For today's cat owners, cat litter is as much a necessity as cat food. But before 1950, most cat boxes were filled with sand, dirt, or ashes instead of the more convenient superabsorbent litters, to which cat lovers are now accustomed.

Kitty litter got its start when a neighbor frustrated with her cat tracking ashes throughout the house asked a budding entrepreneur named Edward Lowe for some sand. Lowe, whose family owned an industrial absorbents company, convinced her to try clay instead. So Lowe sent the neighbor home with an absorbent clay called Fuller's earth. She loved it and soon would use nothing else in her cat box.

Her enthusiasm spurred Lowe to try to sell the stuff, which he dubbed "Kitty Litter," as a cat box filler. But the local pet store owner was doubtful that anyone would pay money for the product when the alternatives were available for next to nothing. So Lowe began giving it away for free. Soon, he had satisfied customers willing to pay good money for Kitty Litter. By 1990, Edward Lowe Industries was the largest producer of cat box filler in the United States.

The secret to Lowe's Kitty Litter is granulated Fuller's earth. Fuller's earth is actually a catchall term for a chemically diverse set of absorbent clay minerals capable of absorbing their weight in water. Fuller's earth litters naturally provide some odor control by sequestering urine. But if the soiled litter isn't replaced and urine begins to collect at the bottom of the box, bacteria found in feces will convert the uric acid in cat urine into unpleasant-smelling ammonia. Fuller's earth litters can alleviate some of the ammonia odor by trapping the positively charged ammonium ions that are formed when water in urine protonates the ammonia. To improve odor control, cat litter manufacturers use a number of additives, including baking soda to absorb smells, fragrances to mask unpleasant scents, and antibacterial agents to kill odor-causing bacteria.

GETTY IMAGES



ILLUSTRATIONS BY CESAR CAMINERO

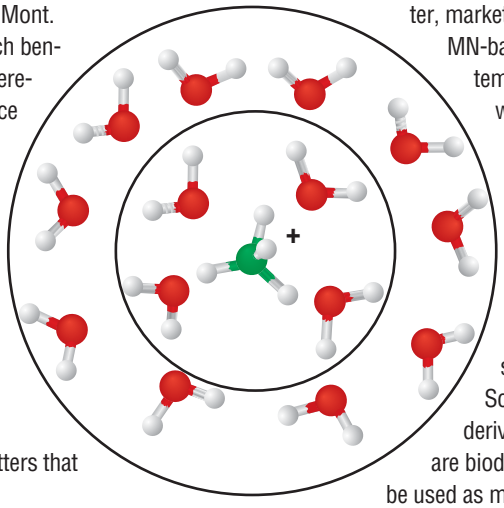
Adsorption and absorption—different phenomena with similar names. Adsorption is the attachment of a molecule to the surface of a solid. Charcoal is an excellent deodorizer because vapor molecules readily adsorb on its surface, and clay soils can adsorb some gas odorants. Absorption is the taking up of a substance into the porous interior of a solid—like a sponge absorbing water.

Traditional clay litters like Lowe's original Kitty Litter still make up about 40% of the cat litter market. But like ashes, dirt, and sand, traditional clay litters must be discarded and replaced fairly often, making cat box cleaning a frequent chore. Unhappy with the inconvenience of traditional litters, biochemist and cat lover Thomas Nelson began investigating alternative clay formulations in the early 1980s. He observed that a certain type of clay called bentonite clumped up in the presence of moisture, allowing waste to be isolated and scooped out, leaving behind clean litter. Today, roughly 60% of the cat litter sold in the United States is of the clumping variety, and most of it is made from bentonite clay.

Bentonite is largely composed of montmorillonite, a clay mineral made up of stacks of SiO_4 sandwiched between two sheets of octahedrally coordinated aluminum, magnesium, or iron. Substitution of lower-valence ions for some of the higher-valence ones in the octahedral sheets creates a negative charge imbalance that traps cations, most often sodium or calcium, between the stacked sandwiches.

The absorption power of various types of bentonite is determined by which cation is present and in what amount. Because sodium ions have a larger hydration sphere than calcium ions do, sodium bentonite can absorb more moisture than its calcium counterpart, explains clay scientist Shobha Parekh of Wyo-Ben, a bentonite mining company in Billings, Mont. Sodium-rich bentonite is therefore the material of choice for clumping cat litter, she says.

Like traditional clay litters, bentonite litters provide some inherent odor control, thanks to their ability to sequester urine and to trap any NH_4^+ produced from urine degradation. Recently, "crystal" cat litters that promise improved odor control have entered the market. The silica gel used to make these crystals is chemically similar to that used in desiccants. The silica gel crystals in such litters are dotted with tiny pores, allowing the crystals to absorb cat urine, then slowly allow the water to evaporate off.



What is a hydration sphere? When dissolved in water, ions hydrate (are surrounded by water molecules electrostatically attracted to them). For positively charged ions like NH_4^+, attraction to the strong partial negative charge on oxygen helps create an inner sphere. The ordered structure of the inner sphere creates, through hydrogen bonding, a region in which the surrounding waters are also somewhat ordered; this is the outer sphere. The number of water around different ions varies.

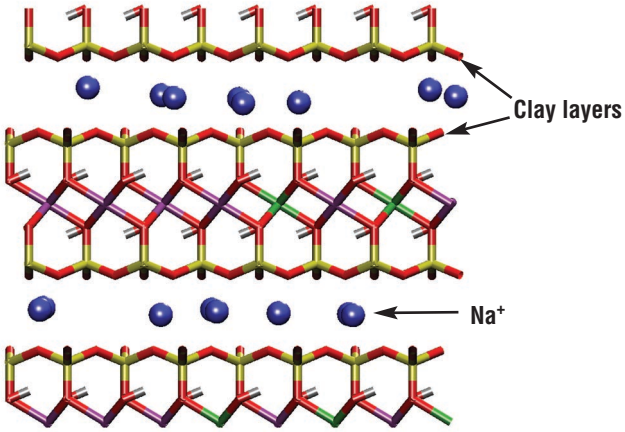
Some cat lovers fear—unnecessarily, cat litter manufacturers say—that their cats might harm themselves by ingesting superabsorbent clay litters if they lick their paws after doing their business in the box. In response, a number of companies are marketing plant-derived alternatives made of wood pulp, corn, wheat—even peanut shells and orange peels.

For example, Swheat Scoop litter, marketed by Detroit Lakes, MN-based Pet Care Systems, relies on natural wheat enzymes to neutralize litter box odor, while wheat starches trap moisture and clump firmly for easy scooping. In addition to being safe to eat, Swheat Scoop and other plant-derived alternative litters are biodegradable and can be used as mulch or even flushed down the toilet. Swheat Scoop founder Mike Hughes estimates that more than 160,000 tons of nonbiodegradable cat litter end up in municipal solid-waste landfills each year.

Despite this vast array of choices—both clumping and nonclumping litters made of clay, silica, and plant-derived alternatives—most cat lovers still think that cleaning the litter box stinks.

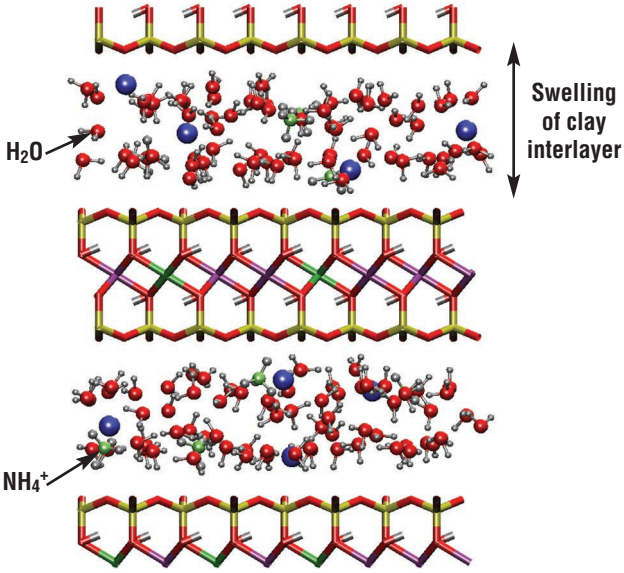
Kitty Litter—The Molecular Vision

Dry Kitty Litter



In dry cat litter, sodium ions are trapped between clay layers, but the clay still has an overall negative charge. When a cat urinates on the litter, the clay soaks up water (and NH_4^+), and it swells, softens, and clumps. The primary driving force for this adsorption is the hydration of the Na^+. Extensive hydrogen bonding to and between the clay layers also helps to trap odor (ammonia smell) and wetness.

Wet Kitty Litter



These are atomistic models of sodium montmorillonite before water adsorption and after water adsorption (O in red, H in gray, Na in blue, N in green, Si and Al in yellow, octahedral cations in purple and green).

MODEL CREDIT: E. J. M. HENSEN (EINDHOVEN UNIVERSITY OF TECHNOLOGY) AND T. J. TAMBACH (UNIVERSITY OF AMSTERDAM).

Amanda Yarnell is a writer on the staff of *Chemical and Engineering News* at the American Chemical Society. This article was adapted from Yarnell, A., What's that Stuff?, *Chemical and Engineering News*, April 26, 2004, p. 26.

THERE'S CHEMISTRY IN GOLF BALLS!

By Brian Rohrig

There are only so many modifications you can make to a tennis ball or a baseball, but golf balls are constantly changing. Since Americans spend $650 million per year on golf balls, there is much financial incentive for manufacturers to try to find a ball that will go just a little farther and straighter. Today, there are well over 90 different types of golf balls available to the public! Once you hit the ball, the laws of physics govern what happens to it. But the composition of the golf ball itself is due to amazing advances in materials science that are firmly rooted in chemistry.

Golf balls have come a long way since the first wooden ones were made in the 15th century on the east coast of Scotland. These inefficient wooden balls were used until the mid-seventeenth century, when the "featherie" was introduced. The featherie was made from a spherical leather pouch that was soaked in a solution of alum. It was then filled with "a top hat full" of wet goose feathers that were softened by boiling. The feathers expanded as they dried while the leather shrunk. The result was a very hard ball. It was painted white to make it more visible. At best, these balls could travel from 150–175 yards, which was twice the distance that the wooden balls could travel. But the high price of these first golf balls made the sport inaccessible to the common man. A single golf ball could be more expensive than a club!

More chemistry is packed into a golf ball than any other piece of athletic equipment.

In 1848, the gutta-percha golf ball was introduced. Gutta-percha is the dried rubber-like sap of the sapodilla tree from Malaysia. When this sap is heated to the temperature of boiling water, it develops the consistency of putty, allowing it to be fashioned into a solid ball. When cooled, it becomes a very hard sphere. These balls could be inexpensively produced. They could easily be reheated and reshaped if they became deformed. As a result of these affordable balls, golf became increasingly popular. As these balls became nicked up from use, they traveled much farther. Eventually, these "guttie" balls were intentionally made with rough surfaces, becoming the forerunner of today's dimpled golf ball.

In 1898, a Cleveland, OH golfer named Coburn Haskell produced a one-piece golf ball with a rubber core that is considered the forerunner of the modern golf ball. The solid rubber core was wrapped in rubber thread that was then enclosed within a gutta-percha pouch. These balls could be mass-produced, further lowering their cost. The Goodrich Company came out with a pneumatic ball in 1906, which had a compressed air core. Since gases expand when heated, these balls would sometimes explode! Other manufacturers experimented with cores of metal, mercury, or cork.

In 1932, the United States Golf Association standardized the mass and size of all golf balls, which has remained constant up to the present day. The weight cannot be greater than 45.93 grams (1.620 ounces) and the diameter cannot be less than 42.67 mm (1.680 inches). Golf balls pretty much look the same now as they did in the 1930s. But what goes on inside the ball is another story.

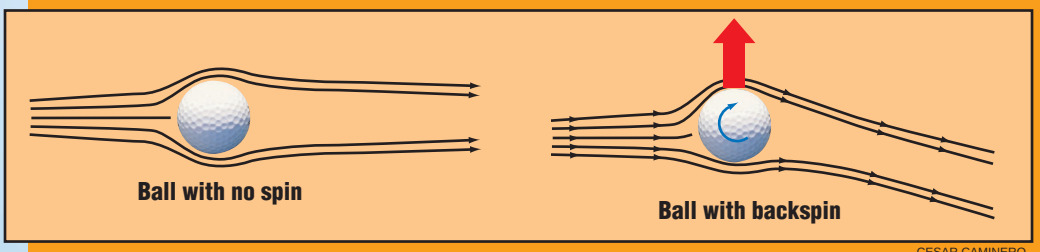
The key to a good golf ball is its ability to be both soft and elastic. Older golf balls accomplished this by having a hard elastic core surrounded by a layer of rubber windings that looked like rubber bands. The elastic core is the most important component. Elasticity is very important, since the ability of the ball to spring back quickly is crucial to achieving maximum distance. The elasticity of any substance is measured by something called the coefficient of restitution (CoR). The CoR is simply a measure of how bouncy a ball is. If a ball is dropped from a height of 1 meter, and it bounces back 60 cm, then its coefficient of restitution is 0.6. If it bounced back 70 cm, its CoR would be 0.7 at this particular velocity. If a ball were perfectly elastic, when dropped it would bounce back to its original height. An object like a Superball has a coefficient of restitution that is close to 1. When dropped on a hard surface, it nearly bounces back to its original height. A piece of clay on the other

MIKE CIESIELSKI

What's in *your* golf ball? Both of these modern golf balls have an outer layer of Surlyn. If you look closely at the bottom ball, you will see an additional ring for the softer inner core. The manufacturer claims this design reduces spin and helps the ball fly in a straight path.

DIMPLES AND SPIN—
The physics of golf ball flight

Probably the most unique aspect of a golf ball is its dimpled surface. A typical golf ball usually will have anywhere from 300 to 500 dimples, with shallow dimples often alternating with deeper dimples. Dimples may be of various shapes, from circular to hexagonal to triangular. Dimples were officially introduced in 1908 by the Spalding Company, but it was well-known for many years that a roughed up golf ball went farther.



CESAR CAMINERO

How does it work? As the ball travels, it pushes the air out of the way, leaving a region of reduced air pressure behind the ball, known as a turbulent wake. Think of a boat traveling through the water. As the boat pushes water aside, a wake is created behind the boat. The same thing happens as a golf ball travels through the air. Because the wake is essentially a region where air has been pushed away, there is a partial vacuum behind the ball. Air will rush in to fill this partial vacuum. As a result of air rushing in to fill this partial vacuum behind the ball, drag increases on the ball and the ball slows down.

However, with a dimpled ball, the tiny dimples on the surface of the ball create turbulence in the boundary layer—the thin layer of air surrounding the ball. This turbulence is in the form of little vortices or eddy currents all along the dimpled surface of the ball. Air becomes trapped along the surface of the ball, causing air to flow farther down around the ball before it separates to form the wake. Because less air is displaced, more air can flow directly around the ball, decreasing air resistance. The size of the wake behind the ball is greatly decreased. With a smaller wake, there is less drag and the ball travels farther.

If a golf ball is hit properly, it will spin as it moves through the air. The spin should be such that the top of the ball is moving toward you (away from the direction the ball is going) and the bottom of the ball spinning away from you. This is known as backspin and is imparted to the ball by the grooves on the head of the club when hit squarely. When a ball has backspin, the air that is moving over the top of the ball is moving in the same direction as the air that flows over the top of the ball, causing the air along the top to move faster than the air underneath the ball. According to Bernoulli's principle, the faster the air moves, the less pressure it exerts. Because the air is moving faster over the top surface of the ball, there is less pressure on the top and more pressure underneath. This increased pressure under the ball produces lift, keeping the ball in the air longer and allowing it to travel farther. Dimples help to produce lift because they increase airflow around the ball, maximizing lift. End result—a dimpled golf ball will go twice as far as a nondimpled golf ball.

hand, has a CoR close to zero, since it does not bounce back at all.

The greater the CoR of a golf ball, the farther it will go when struck. A large CoR represents a ball that is traveling very fast when it leaves the tee. A typical golf ball will have a CoR of approximately 0.8 when struck at 20 mph and a CoR of around 0.6 when struck at 100 mph. This does not mean that balls struck at 20 mph will go farther, but rather that less energy is lost at lower speeds than at higher speeds. If the collision between ball and club was perfectly elastic, then 500-yard drives would be the norm! Watch out, Tiger Woods!

Interestingly, it was the development of the Superball that led to many advances in the golf ball. Superballs are made with polybutadiene, a synthetic rubber with a very large CoR. However, by itself polybutadiene is too soft to be used in golf balls. The key is that the rubber must be vulcanized, which means that the polymer strands must be partially cross-linked by a substance, which can add to the double bonds in the polymer. Using vulcanized rubber, the CoR of golf balls could be made even greater.

Elasticity is only one aspect of a golf ball, however. The golf ball must also deform significantly during the millisecond of contact between ball and club. This deformation is too brief to witness with the naked eye but can be witnessed using high-speed photography. At the moment of contact, the ball flattens considerably, losing as much as one-third of its original diameter. This deformation is only possible because the bonds between molecules within a golf ball act like tiny springs that can be stretched and then snap back into place.

This flattening of the golf ball greatly increases the amount of time the club is in contact with the ball. If the club is in contact with the ball for a larger period of time, you have delivered a greater impulse to the ball. A greater impulse means that more of the momentum of the club will be transferred to the ball. That is why it is so important to follow through with your swing. In order to maximize the time of impact between a golf ball and club, the ball must deform when hit. The greater the time of impact between the club and ball, the farther the ball will go.

One material by itself cannot give both optimal deformation and elasticity. Older three-piece golf balls met this challenge by being composed of a hard elastic core that would bounce back quickly. A hard elastic core, however, does not deform very much during impact with the club. That is why there was a second layer of rubber windings around the core. It was this middle layer that deformed during contact, while the core provided the elasticity. This middle layer looked like little rubber bands. The ball would then be covered with balata, a nonelastic natural rubber obtained from the latex of South American rubber trees. These "rubber band" balls are no longer manufactured today.

Try this with a golf ball:

1. Determine the density of a golf ball. Use the formula D = M/V. Find the mass using a balance. To find the volume, use water displacement, or use the formula $V = 4/3\pi r^3$. Because you probably know what happens if you hit a golf ball into a body of water, the density you arrive at should be greater than that of water, which is 1 g/ml. You can buy floating golf balls at a novelty shop. These are made with a hollow core. If you can find one, determine its density using the same method.
2. Determine the coefficient of restitution of various golf balls as well as other types of balls (like the Superballs on page 4). Drop each from a height of 1 meter and measure the distance it rebounds. If the ball rebounds 50 cm, its coefficient of restitution is 0.5 at that velocity.

MIKE CIESIELSKI

The more modern 2-piece golf balls are composed only of a large core and a thin cover. If the core were made of only one material, it would be impossible to be both soft and elastic. Therefore, the core of the ball is made up of progressively softer layers, with the harder layers on the inside. The two-piece balls can then effectively mimic the 3-piece balls in terms of both temporary deformation when struck and elasticity.

All golf balls today essentially have a core surrounded by either one or two layers. The core is always composed of some combination of rubber compounds. Some lower-end balls also have a fluid-filled sphere at the center of the core. Today, nearly all golf balls are covered with a synthetic outer layer, replacing the natural balata covers. Higher-end balls are typically covered with a synthetic rubber such as urethane or a combination of rubber compounds. Lower-end balls typically use Surlyn, which is a synthetic thermoplastic polymer. Thermoplastics soften upon heating.

The next time you go golfing (or watch it on TV), think of all the wonderful chemistry that has gone into the humble little golf ball. A big reason that records are continually being broken in golf, as well as many other sports, is because of improved technology. Understanding a little about the science of golf will obviously not make you into the next Tiger Woods, but it can't hurt your golf game.

Brian Rohrig is a chemistry teacher at Jonathan Alder High School in Plain City, OH. His article "The Amazing Drinking Bird!" also appears in this issue.

Interview With a Chemist

Christen Brownlee talks with a chemist whose mission is to save lives in the event of a chemical, biological, or radiological attack.

PHOTO COURTESY OF ERICK SWARTZ

Erick Swartz

Research Scientist for CBIRF

What is CBIRF?

CBIRF stands for Chemical Biological Incident Response Force. We're part of the United States Marine Corps. If an individual is in trouble, they dial 911 and the police and fire department come. But what happens if those responders are overwhelmed? CBIRF assists the police and fire departments in dealing with a horrific event, like those resulting from bioterrorism or weapons of mass destruction.

I've worked as a research scientist for CBIRF for a little over a year. I'm actually a contractor for the military, but not a Marine. I've never served in the military a day of my life! I'm the only individual in CBIRF that has not. I just happened to come into this field. Most people in CBIRF are active-duty military or retired military.

What is CBIRF's job when a disaster strikes?

Our mission is to save lives. The idea is to go into a contaminated area and assess the area with equipment that detects chemical or biological contaminants. We're asking ourselves: Which areas are clean and which are contaminated? Once we know the answer, we try to get people out of the contaminated areas safely and swiftly. That may sound simple enough, but the scene could be disastrous. There could be people trapped beneath vehicles or trapped in elevators or under desks.

CBIRF has an hour response time. If called, we get all the equipment rounded up and we leave the base in an hour. We have a second response force that's ready to go in 4 hours if one group of responders isn't enough.

CBIRF is located just south of Washington, DC. Our main focus is protection of the Capitol. If a disaster happens elsewhere, then we have planes and boats that can get us where we need to be a lot faster than cars would.

Where does your work fit in with CBIRF's mission?

If there were a chemical or biological disaster, the Marines can either take me with them as an onsite chemist, or I can stay back in the lab to do some immediate research. I could use the Internet to look up information on the chemicals or biological hazards that are at the disaster site, how dangerous they are to people, and the signs and symptoms of exposure. If I have an idea what chemical or other hazardous sub-

stance is at work, I can tell the Marines which piece of equipment they might use to detect it.

I also make sure pieces of scientific equipment we use to measure and detect chemicals are maintained and calibrated properly. I train the Marines on how to use the instrumentation that they take down to the contaminated area, and I instruct them on the limitations and capabilities of that gear. I like to satisfy my scientist side by trying to figure out new ways to use the equipment more effectively.

Finally, I train the Marines how to handle hazardous situations. I help create scenarios that deal with weapons of mass destruction in chemical, radiological, or biological situations. The Marines' instruction includes some basic chemistry, a little bit of organic and physical chemistry, and lots of analytical chemistry thrown in.

PHOTO COURTESY OF ERICK SWARTZ

Erick Swartz and a marine are working on a portable gas chromatograph–mass spectrometer.

Have you responded to any disasters?

Last year, there was a toxin called ricin that was found in the Senate's mailroom. There were potentially a thousand rooms contaminated with this agent, so we had to send in a large force to clear the area. Our responders had to wear personal protective equipment (PPE), the white outfits that look like space suits. Those can fully protect you from a chemical or biological agent.

I'm trained to respond to incidents in PPE, but during the ricin incident, I needed to stay back in the lab and do research on the toxin. I had to instruct the Marines in how to detect ricin and get it off their PPE, and I served as a resource just in case something else came up.

What are you doing the rest of the time, when there's no disaster?

There's no downtime because we're always in training and preparing for the next incident. Some weeks I'm dedicated to teaching the Marines general chemistry, and other times, we have equipment training. It's important to learn how to use our equipment not only in the lab, but in a real disaster situation, when you're wearing PPE. It's not as easy as it looks!

At least once a month, we actually have disaster training for the Marines where they have to deal with casualties—other Marines who play out a disaster scenario. For example, our Marine actors might be coughing or wheezing like they have symptoms of massive chlorine gas exposure. My job is to make it as realistic as possible. I feed the Marines all the information they would need to respond to this disaster situation, and they have to make decisions on the fly.

What's the best thing about your job? How about the worst?

I absolutely love my job here. The best part is that I'm helping to defend the country in a lifeguard-like fashion so that when something bad does happen, I can help deal with it. The worst part of my job is that I spend a significant amount of time fixing gear, which isn't as exciting as doing real scientific research!

How did you get into this job?

I was always interested in science as a kid—I originally wanted to be a marine biologist because I liked swimming and science so much. But when I went to college, I couldn't get into a marine biology course. I took chemistry instead. Then I fell in love with all the instrumentation! I ended up studying atmospheric chemistry and getting a Ph.D. in physical chemistry. When I finished graduate school, I got a postdoctoral fellowship with the EPA studying air pollution. Then September 11th happened. I had about six weeks studying the air around Ground Zero. Helping with the aftermath of that disaster made me a perfect fit for this job.

If you're interested in chemistry now, the best way to get a job you love is to continue with your studies. Be curious, ask lots of questions, and learn how to take tests well. In my field, you are tested a lot. When you put on PPE and go into a hazardous environment, it's the biggest test of all! Sometimes, the Marines will complain that the exams we administer are hard—but when you're in a contaminated area, that [situation] will be difficult too. If something terrible does happen, we want to be on our best game.

Factoid

Ricin is an extremely toxic protein derived from the castor bean (think castor oil). In a notorious 1978 incident, Bulgarian operatives used a modified umbrella containing a ricin pellet in its tip to inject dissident Georgi Markov. Markov died three days later from just a 0.2-mg dose.

Christen Brownlee is a freelance science writer in Arlington, VA.

Chem.matters.links

The 37th International Chemistry Olympiad—Taipei, Taiwan

59 countries gathered in July for a 10-day chemistry competition called the International Chemistry Olympiad (IChO). Each country sent a team of four top students. The competition included both a five-hour exam of basic knowledge and problem solving and a five-hour laboratory practical. The level of difficulty of the challenge was on a par with mid-level college chemistry courses. Medals were awarded based on the total exam scores from both sections with the top students winning gold, silver, and bronze medals.

The results are in. The USA team won three silver medals and one bronze medal. South Korea won overall first place and Alexey Zeifman from Russian Federation won the top gold medal.

ROXIE ALLEN

Left to right: Scott Rabin (bronze), Allen Cheng (silver), Jacob Sanders (silver), Nicholas Sofroniew (silver).

Want to try out for the team next year?

1. If you are a student who would like to participate, check with your chemistry teacher.
2. If you are a teacher with students interested in the United States National Chemistry Olympiad (USNCO) program, contact your local section of the ACS. If you are not sure whom to contact, find help on the Olympiad web page. Go to www.chemistry.org/education and select the Olympiad link in the High School section. Enrollment deadlines, contact information, and copies of past exams are available at the site.

Celebrate National Chemistry Week

National Chemistry Week is October 16–22 this year. The theme is "The Joy of Toys". The official website is at http://chemistry.org/ncw. On the site you will find an easy formula to make your own "bouncing ball". In addition, the American Chemical Society is sponsoring a poster contest for students in Kindergarten–12th grade. Students are invited to create a poster that will serve as a public service announcement emphasizing the role of science/chemistry in toys for their peers or other age group.

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It is possible that you received this issue as part of our National Chemistry Week promotion. If you have not renewed your subscription yet, it is not too late. Last year, we added multiyear subscriptions so that you can lock in current rates for two or three years.

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Answer to quiz (page 4)

Solution: A) Slinky B) Slip 'n Slide C) Frisbee D) Hula Hoop E) Superball F) Hacky Sack

Tell us what you think

Let us know about the chemistry that counts in your life. E-mail your thoughts and suggestions to chemmatters@acs.org, and we'll use your comment to make future issues even better.

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