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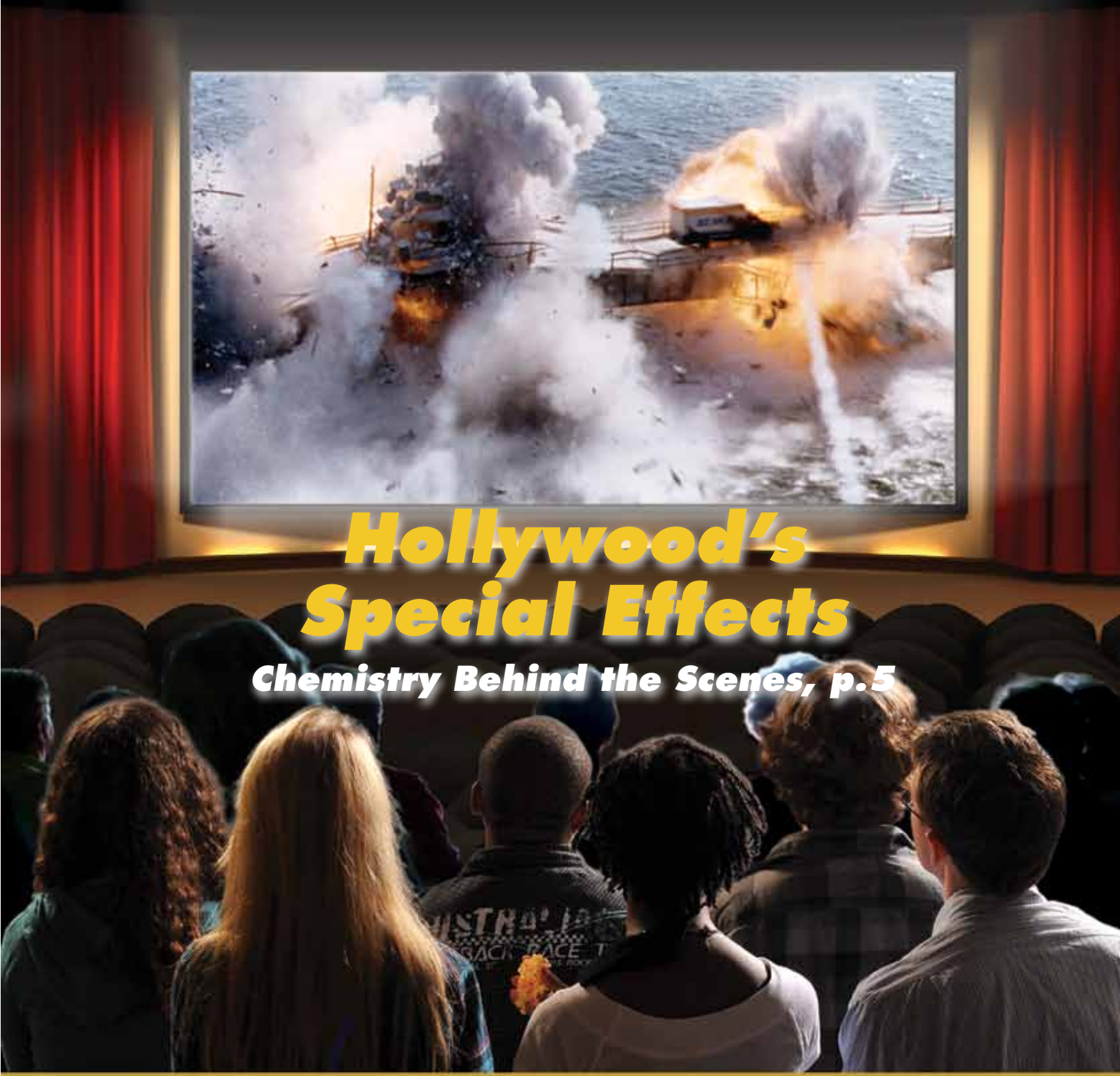
DEMYSTIFYING EVERYDAY CHEMISTRY

DECEMBER 2009



Hollywood's Special Effects

Chemistry Behind the Scenes, p.5

Space Food: Dining 220 Miles Above the Earth, p.11

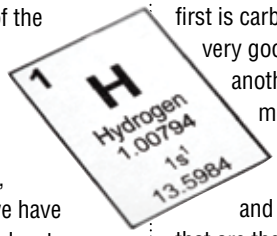
QUESTION FROM THE CLASSROOM

By Bob Becker

Q A classmate recently reported on the element selenium. He said that selenium is an essential mineral in our diets and that humans and other animals could not exist without it. Then, another classmate reported on the element manganese with a similar result. I had never even heard of these two elements. So I was thinking, what would life be like here on Earth without these elements?

A If you consider all of the elements that life depends upon, you may come to the conclusion that we are very lucky to be here at all. The human body contains roughly 40 different elements. For other animals and plants, the list is very similar. But it's easy to assume that if any of these elements were missing from our universe, suddenly our planet would become a lifeless wasteland.

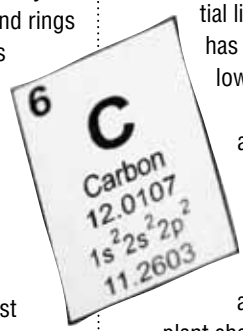
If, right now, all of the manganese and selenium were suddenly taken away, we would all be in a lot of trouble, but that's because we have evolved to take full advantage of the resources available here on Earth.



For example, we depend upon copper, because somewhere in our evolutionary history, this element proved effective in certain biological catalysts that facilitated chemical reactions in our metabolism. We can assume that past organisms that used copper in these catalysts stood a slightly greater chance of survival than those that didn't. So, organisms using copper continued to flourish and pass on their copper-using genes to their offspring. What started out as an evolutionary advantage has become a survival necessity.

But what if copper—or either selenium or manganese—had never been here to begin with? Could life still have evolved? For most of the elements listed below, I think the answer would be yes. If these elements had not existed, animals and plants would have evolved to take advantage of the elements that were available to them.

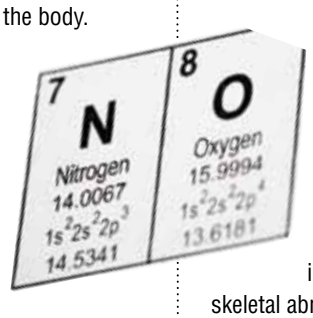
There are a few elements that probably are critical to life. The first is carbon. Carbon atoms are very good at bonding to one another and to other elements, such as oxygen and nitrogen. They do so in chains and rings and intricate arrays that are the building blocks of all organisms.



If there were no carbon on Earth, could silicon, which is just below carbon in the periodic table, fill the void? Silicon has four bonding sites, just like carbon, and it forms a few short chains, but not nearly enough to create the complexity of structures that life processes depend upon. Some science fiction novels have postulated planets populated by silicon-based life forms. Intriguing, yes, but the chemistry just is not there. No other element seems to have the same capacity for life complexity that carbon possesses.

And then there are the elements hydrogen and oxygen. They seem to be indispensable to life. Not just life as we know it, but life of any kind. Not only do they play critical roles in adding to the complexity of carbon-based molecules, but they also combine to make the most unusual compound—water.

Liquid water is vital both as a solvent—in which many of the body's chemicals dissolve—and as an essential part of metabolic processes within the body. No other liquid is known to do it as well. Water is—as far as we know—the only liquid that makes life possible. This is why NASA's policy in its search for potential life on other planets has always been to "follow the water."



Nitrogen would also probably make the short list of elements truly essential to life. Nitrogen plays an important role in plant chemistry, and it serves to bond carbon molecules into long chains known as proteins. So, it is reasonable to assume that a "nitrogen-less" universe would also be a lifeless universe.

How about selenium and manganese (mentioned in the question)? Trace amounts of selenium are essential for the production of enzymes that are found in cells. Selenium deficiency can lead to diseases, such as thyroid disorders, psoriasis (a skin condition), and susceptibility to heart disease and viral infections. Manganese plays a role in the liver, kidneys, and the brain. In experimental animals, manganese deficiency causes impaired growth, skeletal abnormalities, and defects in carbohydrate and fat metabolism.

Beyond carbon, hydrogen, oxygen, and nitrogen, it is hard to say what other elements are essential to life. What experiment could be designed to see what kind of life might have evolved in the absence of any given element? Perhaps these are questions best left to science fiction writers!

ALL ELEMENTS FROM ISTOCK

Correction:

In the October 2009 issue of *ChemMatters*, an error occurred in the caption of Figure 1 (p. 8). The correct caption is: "When light is spread through a prism, it reveals its constituent colors, going from purple to red."

Also, the following reference was omitted by mistake from "Selected references" at the end of the article, "Where Do Chemical Elements Come From," by Carolyn Ruth:

Sagan, C. *Cosmos*; Random House, Inc.: New York, NY, 1980

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Space food needs to be lightweight, compact, and require minimal preparation (given that you can't cook it in space). How do NASA food scientists do it?

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The Vinland Map is either a 13th century map of America that pre-dates Christopher Columbus or a clever fraud. Learn about the scientists who have analyzed the map for the past 50 years and why they have not been able to solve its mystery yet.

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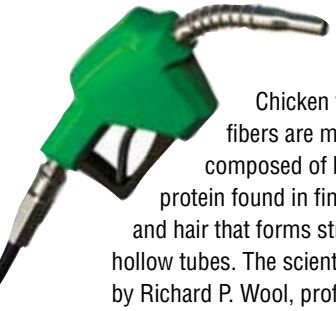
COVER PHOTOGRAPHY COURTESY OF RICHARD RICKITT AND MIKE CIESIELSKI.
Movie screen photo is from the movie *True Lies* (1994) in which a bridge explodes, throwing a truck in midair.



DID YOU KNOW?...

Atomic Bonding: Producing Energy with Chicken Feathers

Scientists in Delaware have discovered that carbonized chicken feathers could be used to store vast amounts of hydrogen, a promising source of energy that may one day replace gasoline in cars.



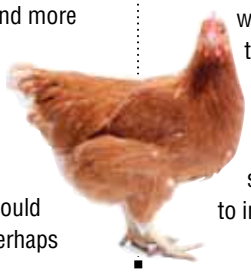
Chicken feather fibers are mostly composed of keratin, a protein found in fingernails and hair that forms strong, hollow tubes. The scientists, led by Richard P. Wool, professor of chemical engineering at the University of Delaware in Newark, had been investigating how the feathers could help improve the performance of electronic circuits. The feather tubes could be used to carry electrons faster along a printed circuit, they thought. But they noticed that the feathers were not stiff enough, so they heated them to strengthen the bonds between the carbon atoms in the keratin. The end result was stronger and more porous feathers.

Then, Wool and colleagues realized that the spongy structures of these carbonized feathers could absorb as much or perhaps more hydrogen than two other materials—carbon nanotubes or metal hydrides—being studied for their hydrogen storage potential.

The scientists looked at chicken feathers because they are very cheap. "It actually costs the poultry industry money to get rid of these feathers, so they are basically for free," Wool says.

"Using carbonized chicken feathers would only add about $200 to the price of a car," Wool adds. "By comparison, making a 20-gallon hydrogen fuel tank that uses carbon nanotubes could cost $5.5 million; one that uses metal hydrides could cost up to $30,000."

Hydrogen has long been held out as a clean energy alternative to oil, natural gas, and coal. But it is very difficult to store and transport—as a pressurized gas it takes up about 40 times as much space as gasoline; as a liquid it needs to be kept at extremely low temperatures.



Wool estimates that it would take a 75-gallon tank to go 300 miles in a car using carbonized chicken feather fibers to store hydrogen. He says his team is working to improve that range.

—Doug Dollemore

ALL PHOTOS FROM ISTOCK

Atomic Structure: Is Air Pollution as Bad as Cigarette Smoke?

A previously unrecognized group of air pollutants could have effects similar to harmful substances found in tobacco smoke, Louisiana scientists say. Inhaling these pollutants may expose people to up to 300 times more harmful chemicals than from smoking one cigarette, they say.

Harmful air pollutants called free radicals are atoms, molecules, or fragments of molecules that are highly reactive and damage cells in the body. They form during the burning of fuels or in chemical reactions with other molecules in the air. The reason they are so harmful is that they contain unpaired electrons, so they try to pair these lone electrons by "stealing" electrons from neighboring atoms or molecules. These atoms or molecules then become free radicals, and they steal electrons, as well. This can go on with hundreds or thousands of atoms or molecules, similar to a chain reaction that can seriously damage cells containing these atoms or molecules.

Most of the currently known free radicals exist for less than 1 second, so they don't cause damage for too long. In contrast, the newly detected pollutants, called persistent free radicals, form on fine particles emitted by smokestacks, automotive exhaust pipes, and household chimneys, and can linger in the air and travel great distances.



ISTOCK

"Persistent free radicals can stay in the air indefinitely, so you are never going to get away from them," says Barry Dellinger, a chemist who led the team of scientists who made this discovery at Louisiana State University in Baton Rouge.

Also, persistent free radicals are similar to harmful chemicals found in cigarette smoke, so they may act on the body the same way cigarette smoke does on people who smoke. This could help explain the long-standing medical mystery of why nonsmokers develop tobacco-related diseases, such as lung cancer.

Once persistent free radicals are inhaled, Dellinger suspects that they are absorbed into the lungs and other tissues where they contribute to the damage to cells and DNA.

Dellinger stresses that additional research is necessary before scientists can link airborne persistent free radicals to medical conditions such as lung cancer.

—Doug Dollemore

HOLLYWOOD'S SPECIAL EFFECTS

How Did They Do That?

By Diana Lutz

JOE VISKOCIL

Special effects in movies are not all done with computers. Fake snow, artificial skin, and big explosions: They can look like the real thing!

These days, many special effects are done with computers. The fire-spewing Balrog that the wizard Gandalf fights in *The Lord of the Rings*, the Watcher in the Water, Gollum and the Orc armies at the Battle of Helms Deep are all computer-generated. But computer-generated effects have limitations and many films still mix old-fashioned physical effects with the trendy computer-generated ones.

Physical effects are usually based upon one simple idea: A material or event is substituted for another, usually one that is less messy, expensive, or dangerous than the real thing. Snow that won't melt might be made out of paper and creature skin that sags like real skin out of latex. Small blasts might substitute for full-scale explosions. But the basic fiddle, or cheat, is only part of the story. The illusion is helped by tricks of the trade, often ones known only to practitioners, and it is this unique knowledge that gives physical effects their sometimes astonishing realism.

Special effects experts use a wide range of chemicals. Snow blanketing the ground might be made of paper or wood pulp, and falling snow from ash or foam. Makeup experts combine either liquid latex or silicone with other chemicals to create a patch of skin that is either thick and leathery or soft and wrinkly. To make explosions or fires, they use miniature models, which they blow up or burn.

Fake snow

One of the paradoxes of fake snow is that it is better than the real thing. According to Richard Rickitt, author of *Special Effects: The History and Technique*, once snow is trampled, it can't be restored, so snow shots can be repeated just once or twice, after which a movie crew needs to move to a new location.

Darcey Crownshaw, founder and managing director of Snow Business, one of the leading suppliers of movie snow, says that real snow is unpleasantly cold and wet. His company sometimes covers real snow with "warm artificial snow that actors can snuggle into like being in a down quilt," he says.

But snow is also one of the hardest of all natural substances to fake. "Movie makers have tried an astounding variety of substitutes over the years," Rickitt says. In the 1930s, one popular recipe was a mixture of shavings of a soft, white mineral called gypsum and bleached cornflakes.



SNOW BUSINESS

Snow technicians use dry foam for this falling snow effect that will be part of a commercial for Waitrose, a supermarket company in the United Kingdom.

Snow Business, whose headquarters is located in a 17th-century water mill in the English countryside, makes more than 170 types of snow. Depending upon the special effect that a movie director wants, the area that must be covered, the length of the shoot, and the budget, snow can be made with different types of materials, including paper, rice or potato starch, plastics, foam, and Epsom salts (magnesium sulfate).

In all these cases, the final product must look like snow and, if necessary, must drift, clump, and melt like snow. This is sometimes tricky and not always done successfully. In one recent movie, Crownshaw noticed snow with "edges," which was actually cheap cotton wadding that was laid down "straight off the roll;" and, in another movie, a car was sliding through "wet snow" that clearly looked like detergent suds. "Bad snow"—as Crownshaw describes it—calls attention to itself, distracting the viewer from the story the movie is telling.

But looks aren't everything. Movie snow, particularly products used on location, must be environmentally friendly. Many of Crownshaw's snows are made of recycled materials, and the company is

careful to use "self-clearing products" in sensitive outdoor locations, such as a cellulose powder that can be hosed down easily or a foam that evaporates within a few hours.

Crownshaw's signature product is paper snow. But there is more to it than you might think. If you try to make snow by cutting up paper, you get confetti. Because the paper "flakes" have straight edges, they don't fall right and, once on the ground, blow about like dry leaves. Snow Business's paper snow is torn rather than cut, so the edges are ragged. The torn edges make the snow flakes tumble as they fall, and, once on the ground, clump and drift like real snow.



From the film *The Day After Tomorrow* (2004), this image shows frozen arctic effects.



Artificial snow used on movie sets.

ALL SNOW PHOTOS BY SNOW BUSINESS

Paper snow is made in huge machines called hammer mills—literally hammers attached to a rotating shaft—that expel the paper through fine screens, shredding it rather than cutting it. "On a typical run, we make 20 tons of snow, and we make about 500 tons of snow every year," Crownshaw says.

Another Snow Business product is a polymer similar to the one found in disposable diapers. A polymer is a large molecule made up of repeating small molecules known as monomers. The granules in a diaper are polymers called sodium polyacrylate that readily absorb water. Sodium polyacrylate is made of repeating units of the monomer [CH_2-CH(COONa)].

The sodium polyacrylate polymer is actually a combination of two polyacrylate polymers linked together like the rails of a railroad track (Fig. 1). Hanging off these "rails" are carboxyl groups (-COOH) in which the hydrogen atoms are replaced with sodium atoms (-COONa). When the polymer comes into contact with water, the sodium detaches, creating two ions, carboxyl (COO^-)—still attached to the chain—and a free sodium ion (Na^+).

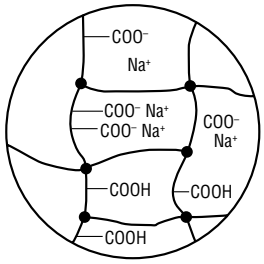


Figure 1. When sodium polyacrylate is in contact with water, it unravels, releasing sodium ions (Na^+).



Taken on the set of *The Chronicles of Narnia, The Lion, the Witch, and the Wardrobe* (2005), this shot shows winter effects created by the company Snow Business.

The carboxyl ions repel one another, widening the polymer coil. Water moves into the polymer from the outside to dilute the free sodium ions. Once the water is inside the polymer, it attaches to the chain by hydrogen bonding, where the hydrogen atoms in water are attracted to the oxygen atom in the carboxylate ions. The polymer swells, but the links between the two chains prevent it from dissolving; instead, it forms a stiff gel.

If you mix diaper granules with water, what you get looks more like ice than snow, Crownshaw says. So his team developed a polymer that swells even more, picking up 4,000 times its weight in water rather than the 800 times, which is more typical of diaper granules.

Artificial skin

The main problem with making artificial skin is that we are intimately familiar with how real skin wrinkles and moves, along with its translucency and flaws. Anything that is not quite right about artificial skin—such as a visible blend line at its edge—immediately tips us off and destroys the illusion.

High-quality skins and prosthetics—which can be anything from fake jowls to pointy ears—are custom-fitted to the actor who will wear them. The first step is to make an exact copy of the actor's face or body part,

KNB EFX



Two mold makers from KNB EFX fill a silicone mold with fiberglass to make a life cast for an actor. Wrinkled skin or bite marks will be sculpted on this cast later.

called a life cast. Then, the jowls or ears are sculpted in clay on the life cast. The clay parts are duplicated in a flesh-like material, such as whipped latex, that is then glued onto the actor to transform his or her appearance.

Depending upon how the special effects artist wants the prosthetic to look and move, it can be made of whipped latex, gelatin, or silicone. *The Chronicles of Narnia*, a series of fantasy movies about Narnia, a place where animals talk, magic is common, and good battles evil, provides examples of special-effects work with all three materials.

The makeup for the films was done by KNB EFX, a special effects studio in Hollywood, Calif., famous for its work on horror and science-fiction movies. The studio won the 2006 Academy Award for makeup in the first *Chronicles of Narnia* movie, which included nearly every mythological creature ever invented.

Howard Berger—the "B" in KNB—says that the studio relied heavily on latex for *The Lion,*

the Witch, and the Wardrobe (the first installment in the series), then shifted to gelatin for *Prince Caspian* (the second installment) and is planning to rely mainly on silicone for the third installment, *The Voyage of the Dawn Treader.*

The basic ingredient in latex foam is liquid latex, the milky white sap of the rubber tree that is a dispersion of long-chain polymers in an aqueous medium. A foaming agent and a curing agent are mixed into the latex. The foaming agent is essentially a soap that helps the latex form bubbles, and the curing agent is a mix of chemicals that links the polymer chains in the latex. When heated, the curing agent transforms the liquid latex into a flexible solid.

After all of the ingredients are added, the syrupy latex is tipped into a mixer and whipped into a foam. The amount of time spent whipping the foam greatly affects its consistency, Rickitt says.



ISTOCK

Special effects are used to create a virus appearance on hands.

Small bubbles produce dense and heavy foam, while large bubbles create light and flexible foam. A heavy foam might be used for a large creature, such as a Minotaur—a mythical monster with the head of a bull and the body of a man—whose skin is thick and leathery. Light foam would be used to create a facial appliance or a skin that looks soft and wrinkly.

Once the latex is whipped, a gelling agent is added to the mix, which clears the soap from the latex before the foam is cured. The latex is injected into a mold, which is then left to sit for 15 minutes so that the gelling agent can set the foam, and then the mold is baked in an oven for 1–2 hours to turn the gel into a sponge.

The oven's heat activates the curing agent, which allows the latex molecules to bind with each other. As a result, the latex molecules cannot move independently anymore, and the latex goes from liquid to solid.

Latex is an ideal material for artificial skin because it has a fine enough structure to reproduce frown lines and wrinkles, and is pliable enough to pick up movements of the facial muscles. But its color on film depends upon the lighting conditions on set, a complication that led Berger and his team to switch to silicone for the upcoming movie, *The Voyage of the Dawn Treader.*



KNB EFX

An employee of KNB EFX prepares molds that will be filled with silicone. Once the silicone sets, it is peeled from the molds and glued to an actor's face.

Silicone is a polymer that has a silicon-oxygen backbone (…-Si-O-Si-O-Si-O-…) with organic side groups—such as methyl [-CH_3], ethyl [-C_2H_5], and vinyl [–CH=CH_2]—attached to the silicon atoms.

"Silicone comes in the form of a greasy cream like soft petroleum jelly," Rickitt says. "Unlike foam latex, you don't bake silicone to solidify it. Instead, you use a chemical catalyst that hardens the silicone by linking the silicone polymer molecules together."

The catalysts speed up the curing of silicone by quickly building bridges between silicone molecules. Transition metals such as platinum and tin tend to be good catalysts because they readily accept and release electrons, which are then available to participate in chemical reactions.

For example, if the polysilicone has vinyl groups, then a small molecule with at least two silicon-hydrogen (Si-H) groups is added and the platinum catalyst catalyzes the addition of the silicon-hydrogen groups across the carbon-carbon double bonds (CH = CH_2) (Fig. 2).

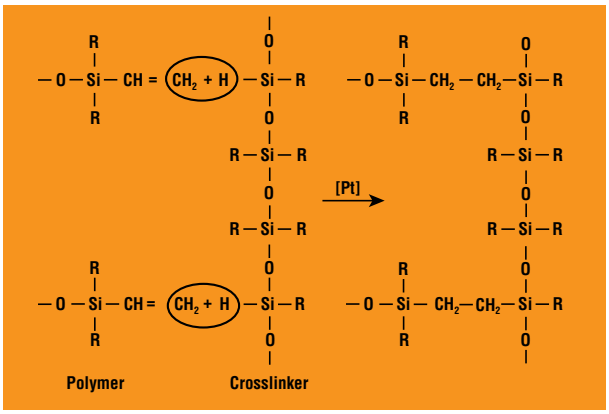


Figure 2. Curing of silicone by attaching silicon-hydrogen (Si-H) groups.

JOE VISKOCIL



By igniting black powder in the presence of gasoline, special effects artist Joe Viskocil makes it seem like a fireball is engulfing a house.

Explosives and fires

When it comes to explosions, flames, or other similar effects used in the entertainment industry—also called pyrotechnic special effects—the problem is to create an illusion of towering fires and shattering explosions by the safest possible means. One of the best ways to do this is to blow up a miniature building or truck rather than a full-sized one.

Special effects expert Joe Viskocil, who has spent nearly 40 years blowing up miniatures, is not a fan of big explosions. Sometimes, he says, directors who are trying to outdo one another ask him for bigger, more dramatic explosions. He says, "I have two words for you: *Twilight Zone*." During filming in 1983, a big pyrotechnic effect caused a low-flying helicopter to spin out of control and crash, killing an actor and two child



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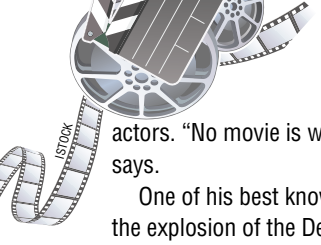

actors. "No movie is worth a life," Viskocil says.

One of his best known special effects is the explosion of the Death Star in *Star Wars Episode IV: A New Hope*. Producer and director George Lucas planned to animate the explosion; in fact, the cartoons for the animation had already been drawn. "It looked cool, very colorful, very weird, but still like an animation," Viskocil says. So, he decided that a physical effect would work better. But what would an explosion in space look like?

RICHARD RICKITT



Joe Viskocil prepares a scene from the movie *True Lies* (1994) in which a bridge explodes. The bridge and the truck were actually miniatures, and the explosives were set off by the truck as it crossed the 40-feet long bridge. The resulting explosion is shown on the cover of the magazine.

He reasoned that since there is no air and no gravity in space, the explosion should be perfectly spherical and not lopsided or squashed. To get a perfectly symmetric effect, he put the camera on the ground and filmed straight up.

A cardboard container of black powder mixed with titanium shavings was suspended from the studio's ceiling. Black powder is a mixture of sulfur, potassium nitrate (KNO_3), and charcoal—a black substance made mostly of carbon, along with other chemicals, and resulting from the heating of wood. When the black powder ignited, sparks and debris were propelled toward the camera as if travelling outward in the vacuum of space. The technique was so successful that it has been copied many times since then.

In 1997, Viskocil won the Academy Award for the special effects in *Independence Day*, a science-fiction film about an alien invasion of Earth. When the death ray from the alien spaceship hits the White House, a fireball rips downward through the building, which then explodes. The White House in the movie was a plaster model 6 feet high by 12 feet wide. "Many movie miniatures are plaster, because plaster shatters into nice chunks that are believable as masonry or concrete," Viskocil says.

Viskocil emphasizes that he has licenses to work with and transport explosive materials; that he prepares all special effects carefully, conducting many tests and checks; that he has a crew of people who watch his back; and that he calls off shots if anything seems even slightly amiss. He would be devastated, he said, if anyone were to be injured trying to imitate an effect he had described.



RICHARD RICKITT

Joe Viskocil's Death Star explosion for *Star Wars* (1977). The camera is on the floor, looking up at the explosion.

The end of film?

Viskocil and other special effects experts say that they are living on borrowed time. "We're dinosaurs," Viskocil says. "The computer has taken over the movie business. Eventually there won't be any film, which is an incredibly sad state of affairs for an art form that is now more than 100 years old."

Perhaps not surprisingly, Viskocil says he is not impressed by computer-generated effects. "The first *Star Wars* was all done with models with real explosions, and none of those were color corrected or computer enhanced," Viskocil says. "What you saw, is what we actually shot. The last three *Star Wars* used a minimum amount of special effects. So, a lot of the explosions and other effects look to me like cartoons." After a moment, he adds, "The old movies had heart, and the computer-generated ones are sterile. That's the way I see it, at least. There is no magic to it any more."

Might he be right? Viskocil makes this observation about his craft, "Commercials on TV are now so saturated with color they look completely fake. The grass is unnaturally green and the sky artificially blue. The producers just take crayons out, in essence, and color everything as brightly as possible." Once Viskocil points this out, you begin to understand—at least a little—what he means by heart.



RICHARD RICKITT

Joe Viskocil (extreme right) prepares a miniature version of the White House for destruction in *Independence Day* (1996).

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Diana Lutz is a science writer in Madison, Wis. This is her first article in *ChemMatters*.





The Science of Snowflakes

Crystals from the Clouds

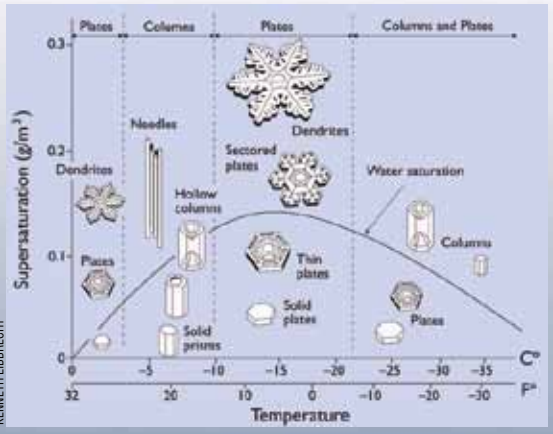
By Andrea Hazard

Snow crystals come in an incredible variety of shapes, including wide flat plates, long thin columns, and branched snow stars. These natural wonders have fascinated scientists, photographers, and snowflake enthusiasts, who have been studying how these crystals form and grow for more than a century.

Snow crystal research began in 1885 when a photographer named Wilson Bentley perfected a process for photographing snowflakes before they melted. He took pictures of more than 5,000 snowflakes, and never found two alike.

Then, in 1930, Japanese physicist Ukichiro Nakaya grew the first man-made snow crystals. He showed that the temperature and humidity affected how the crystals grew. For example, at a temperature of –2 °C, the crystals grew short and wide, while at –5 °C, they grew tall and thin. At low humidity, the crystals were small. At high humidity, they grew larger and formed complex branches.

SNOW CRYSTAL PHOTOGRAPHS BY KENNETH LIBBRECHT



KENNETH LIBBRECHT

Figure 1. Nakaya's snow crystal morphology diagram shows that the shape of a snow crystal depends upon temperature and humidity.

Nakaya summarized his findings in the diagram shown in Fig. 1. For the first time, it was possible to predict the shapes of snow crystals based upon the surrounding temperature and humidity.

For the past half-century, scientists have made interesting discoveries about what snow crystals are made of, how they grow, and why they come in so many shapes.

How snow crystals form and grow

A snow crystal forms when liquid water crystallizes onto a small particle of dust. Then, the crystal grows in different directions when molecules of water vapor bind to it. But no matter what shape the crystal comes in, the water molecules always arrange themselves to form hexagons—plane figures with six equal sides and six equal angles.

Scientists have shown that the hexagonal structure of snow crystals results from two properties of the water molecule. First, water is a polar molecule, which means that its oxygen atom has a somewhat negative charge and its two hydrogen atoms each have a somewhat positive charge (Fig. 2a). This is because the oxygen atom partially pulls the electrons that it shares with the hydrogen atoms away from the hydrogen atoms. So, these atoms are left with a slightly positive charge. As a result, the oxygen end of the water molecule is partially negative and the hydrogen end is partially positive. A molecule that has two poles is called a polar molecule.

The other interesting property of a water molecule is that the bonds that connect the oxygen and hydrogen together form an angle of 104.5°. Because of this geometry and the fact that water molecules are polar, when these molecules bind to each other, they naturally form a series of hexagon-like structures that are connected to one another (Fig. 2b). These hexagons can grow in width and stack atop one another, forming a hexagonal prism (Fig. 2c). The prism has smooth, flat surfaces called facets. The side surfaces are called prism facets, and the top and bottom surfaces are called basal facets.

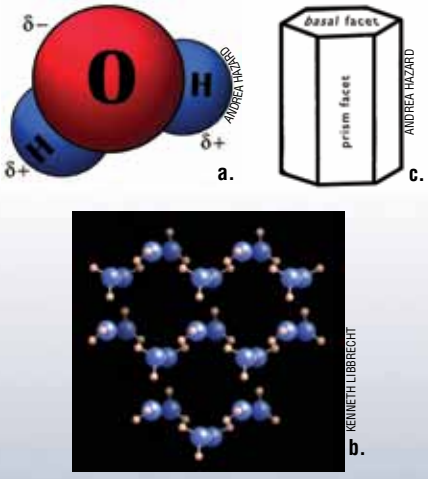


Figure 2. a. Water molecule; b. molecular structure of a snow crystal; and c. the basic shape of a snow crystal is a hexagonal prism, with six prism facets and two basal facets.

An ice crystal contains rough surfaces, with dangling, unbonded water molecules. Water molecules from the air readily attach to these rough surfaces, which thus grow relatively quickly. Unlike these rough surfaces,



the facet planes tend to be smoother, with fewer dangling bonds. Water molecules cannot so easily attach to these smooth surfaces, so the facet surfaces advance more slowly. After all the rough surfaces have grown out, what remains are the slow-moving facet surfaces.

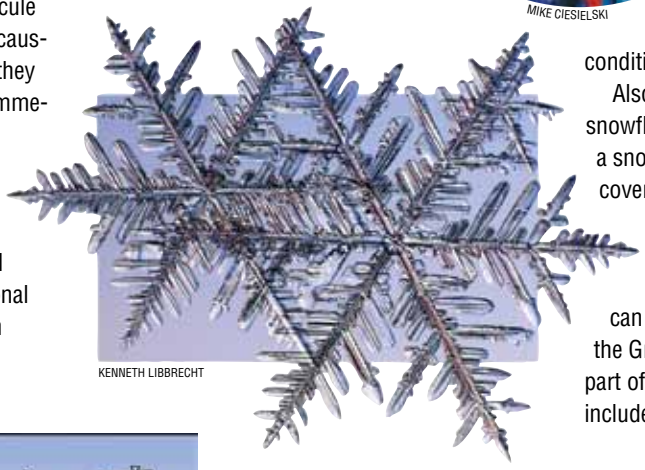
Branched snow stars

Environmental conditions can sometimes cause snow crystals to deviate from a basic hexagonal shape and form branched snow stars instead. A branched snow star forms when a growing snow crystal depletes water vapor from the surrounding air. The crystal can no longer grow until more water molecules float into its vicinity.

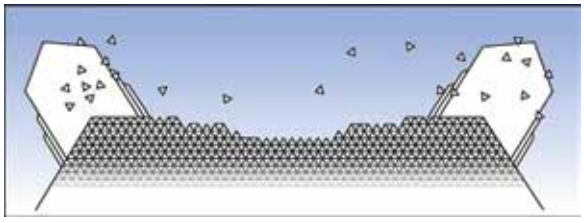
Because the edges of the crystal stick out a bit more than the faces, there is a slightly greater chance that a drifting water molecule will crystallize onto an edge than a face, causing the edges to grow faster (Fig. 3). As they grow, the branches keep a hexagonal symmetry and faceted surfaces.

But the most stable crystal structure is a simple hexagon. So, after a certain period of time and with enough water vapor, the shape of these branched snow crystals reverts to a simple hexagonal prism—the dominant crystal structure in snow banks.

SNOW CRYSTAL PHOTOGRAPHS BY KENNETH LIBBRECHT



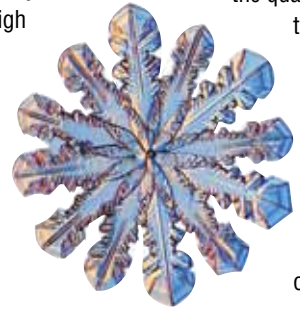
KENNETH LIBBRECHT



KENNETH LIBBRECHT

Figure 3. Rough surfaces (right and left) have more dangling water molecules than smooth surfaces (middle area), so rough surfaces more readily attract water molecules.

Branching only occurs under conditions of high humidity, as can be seen in Nakaya's diagram (Fig. 1). This is because high humidity favors rapid growth that depletes water vapor from the crystal's surroundings. At very high humidity, branches can form on branches, resulting in complex crystals.



Plates versus columns

As the temperature decreases from 0 °C to subfreezing temperatures, the crystal shape switches back and forth between plates and columns. Kenneth Libbrecht, a physicist at the California Institute of Technology in Pasadena, who has been studying snow crystals for the past 12 years, believes the chemistry at the crystal's surface may explain this odd temperature dependence.

Snow crystals are coated with a thin layer of water molecules called a "quasi-liquid" layer, because it is neither solid nor liquid, but something in between. Libbrecht believes that the snow crystal's temperature dependence is due to the presence of impurity molecules on the crystal's surface that interact with the quasi-liquid layer. "The ice surface is likely covered with impurity molecules, even in very clean air," Libbrecht says. "Our studies have shown that the interaction of these impurity molecules with the quasi-crystal layer affects how the crystal grows. But how this happens is still being investigated."

Not only temperature, but other environmental conditions—such as humidity—give rise to the variety and complexity of snowflake shapes. "As a growing snow crystal drifts through the atmosphere, it encounters many different conditions of temperature and humidity," Libbrecht says. "A crystal that starts out in conditions that favor branching may drift into conditions that favor plate formation on the tips of the already formed branches, and then new conditions may arise that lead to even more shape diversity. In short, the complex atmospheric conditions can give snow crystals a seemingly infinite variety of shapes."



MIKE CIESIELSKI

A new look at snowflakes

If you are lucky—or unlucky—enough to live in a snowy region, go out into nature's laboratory, catch snow crystals on your gloves and think about atmospheric conditions that formed them!

Also, if you want to keep a record of a snowflake, you can make a snow fossil. Let a snowflake fall on a cold glass slide and cover it with superglue. When the glue dries and the flake melts, you have a snow fossil. Visit http://snowcrystals.com for more ice crystal experiments you can try at home, even if you don't live in the Great Lakes region or the northeastern part of the United States. This Web site also includes photo galleries of snowflakes.

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Andrea Hazard is a writer and illustrator who lives in Danby, N.Y. This is her first article in *ChemMatters.*

SPACE FOOD

By Kathy De Antonis

Eating in space goes as far back as John Glenn's first orbit around the Earth in 1962. Given the magnitude of his accomplishment, not much attention was paid to the food that he ate, a paste that he squeezed into his mouth from what looked like a toothpaste tube. It was nutritious for sure, but not very appetizing.



NASA

The National Aeronautics and Space Administration (NASA) has come a long way in its effort to provide a variety of appetizing foods for its astronauts in space. Based upon extensive studies by food scientists working closely with astronauts, different types of foods are now prepared and packaged to make them last longer and taste better and to make them easier to transport in space.

Vickie Kloeris, a NASA food scientist, leads a team of food scientists, engineers, dietitians, and technicians who work at the Johnson Space Center in Houston, Texas, on testing and making many different foods for astronauts.

One of the main challenges for NASA food scientists is to make these foods tasty, so they try different recipes and keep the ones that work best. It is a lot of work, but you need to keep the astronauts happy, especially if they have to stay in space for months or years on end!

Meeting astronauts' nutritional needs

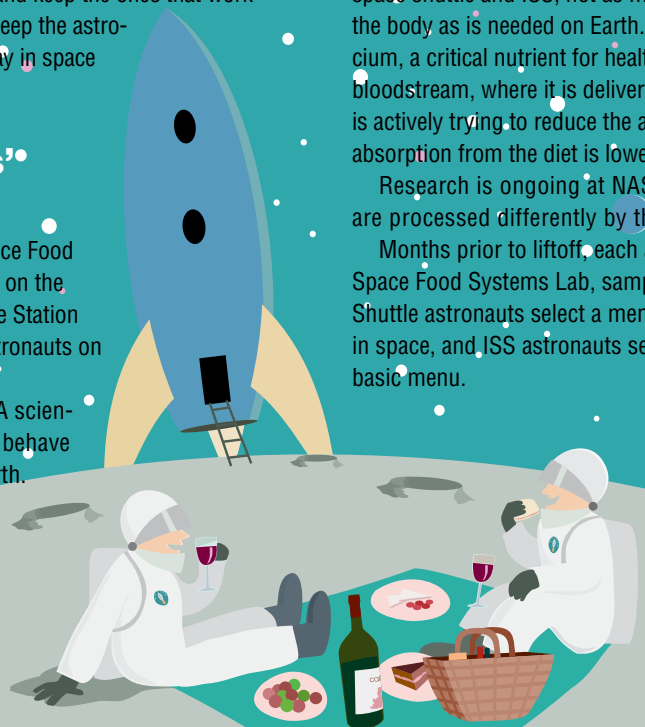
At the Johnson Space Center, the Space Food Systems Laboratory develops food used on the space shuttle and the International Space Station (ISS) and is working on ways to feed astronauts on longer trips in the future.

An interesting finding made by NASA scientists is that some nutrients in the body behave differently in space than they do on Earth. For example, astronauts don't need as much iron in microgravity. In the body, iron is found in the blood. In microgravity, the body does not need as much blood, so it reduces the total volume of blood by destroying red blood cells as soon as they are produced, leading to about 15% less blood in the body than on Earth. The iron that is bound to these red blood cells is released and stored elsewhere in the body. An excess of iron in the body can be harmful, so dietary intake of iron is reduced in space to help reduce the amount of extra iron in the body.

Likewise, astronauts are prone to bone loss during extended missions in space because the body senses that the skeleton is not required for support in flight as it is on Earth. In the low gravity of the space shuttle and ISS, not as much bone mass is needed to support the body as is needed on Earth. When people eat food containing calcium, a critical nutrient for healthy bones, calcium is absorbed into the bloodstream, where it is delivered to the bones. But because the body is actively trying to reduce the amount of bone, the rate of calcium absorption from the diet is lower in space than on Earth.

Research is ongoing at NASA to learn more about how nutrients are processed differently by the body in space and on Earth.

Months prior to liftoff, each astronaut spends some time in the Space Food Systems Lab, sampling an assortment of space foods. Shuttle astronauts select a menu for every meal that they will eat while in space, and ISS astronauts select food items that complement their basic menu.



ISTOCK

Eating in space is no picnic, but it would be cool to have a picnic on the moon!

What is space food like?

The Space Food Systems Lab faces many constraints when producing space food. Food must be lightweight, compact, and require minimal preparation. Also, the food must be well preserved, so it does not spoil in space in the absence of refrigerators or freezers. Even food consistency is considered. Crumbly foods don't work well in space because small particles will float in near-zero gravity and potentially get into the workings of the spacecraft.

To take all these restrictions into account, scientists at the Space Food Systems Lab have come up with different categories of food. For example, soups, casseroles, and scrambled eggs are "freeze-dried." After they are prepared, water is almost entirely removed prior to packaging, making these foods lighter to carry and more compact. Once astronauts are in space, they add water back to these foods before eating them.


NASA

Some foods, such as tuna, are "thermostabilized," that is, they are heat-processed after they are packaged. Other foods, such as some meats, are irradiated after they are cooked and packaged. Thermostabilization and irradiation are ways of sterilizing food so that it can be stored in the absence of refrigerators and freezers. Unlike freeze-dried food, these two types of food do not require the addition of water and are edible as is.

Salt and pepper are also modified for use in space. They cannot be shaken over food because the particles will float away. So, salt is dissolved in water and pepper is mixed with oil.

Does it taste good?

Bill Daley, a food critic at *The Chicago Tribune*, ventured to answer that question. He sampled and critiqued a dozen space food rations that were delivered to him as they would be delivered to astronauts in space. He quickly realized the challenges that astronauts face in eating a simple meal.


NASA

The serving-size portions were delivered in plastic pouches, each labeled with preparation instructions, such as how much water to add or how long to warm it. He was unprepared for the awkwardness of rehydrating freeze-dried foods by injecting water into the pouches with a 60-milliliter syringe and reheating thermostabilized food pouches in a warm water bath. These are cooking techniques that chefs don't frequently use here on Earth.

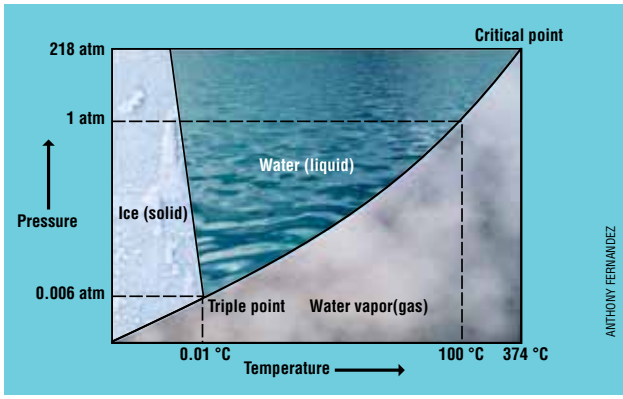
Daley was surprised to find he needed a pair of scissors among his utensils. He found it to be a critical tool—and astronauts use scissors during every meal to open their food pouches. Fastened to each pouch is a Velcro disk, which is of no use here on Earth, but in space, it is critical for fastening the pouches to a tray so they don't float.

Once he worked past the preparation, Daley found that most of the foods did not meet his standards. "Space food isn't restaurant cooking; it's not even takeout. If anything, it's more along the lines of a frozen dinner—but you get bigger portions from the frozen-food aisle." That said, he was satisfied by some things. "I particularly enjoyed the dried peaches, because of their intense flavor and a satisfying, chewy texture," he says.

Freeze-drying food

Freeze-drying is probably one of the most fascinating ways of preparing space food. This process not only removes as much water as possible from a given food but also preserves it for as long as possible.

Food spoils when microorganisms, such as bacteria, feed on the matter and decompose it. Bacteria may release chemicals that cause disease or may just release chemicals that make food taste bad. Bacteria need water to survive, so if you remove water from food, it won't spoil. Freeze-dried foods can be stored for years and then be restored with just a little water.



ANTHONY FERNANDEZ

Figure 1. Water can take the form of solid, liquid, or gas, depending upon different values of temperature and pressure.

Freeze-drying is different from dehydration, which involves heating food in dry air until the moisture is gone. But dehydration usually doesn't remove more than 90% of the water, so bacteria can still grow. Freeze-drying more successfully removes a much higher percentage of the water. Typically, the foods have less than 3% of the remaining water, and the food's composition remains otherwise unchanged.

Freeze-drying relies on a natural process, called sublimation—the conversion of frozen water present in foods directly to gaseous water. Depending upon the surrounding



MIKE CIESIELSKI

temperature and pressure, water can exist as a solid, a liquid, or a gas. By varying the temperature and pressure, it is possible to see water go from one of these forms to another.

The temperatures at which water goes from solid to liquid (melting), liquid to gas (boiling), and solid to gas (sublimation) vary with the surrounding pressure (Fig. 1). There is one value of temperature and pressure (0.006 atmosphere of pressure and 0.01 °C)—called the triple point (Fig. 1)—for which water coexists at equilibrium as a solid, a liquid, and a gas. At any pressure below 0.006 atmosphere, liquid water cannot exist and ice is converted directly to water vapor—that is, it sublimes—when heated.

The process of freeze-drying takes advantage of this property, as follows: First, the temperature is reduced below 0 °C until all water present in a given food is frozen solid. Then, pressure is reduced below 0.006 atmosphere, and the food is slowly warmed to a temperature above the freezing point. With time, the water sublimes and is drawn away by vacuum. Over many hours—sometimes even days— 97% or more of the water is removed, leaving the freeze-dried food.

Rehydrating freeze-dried food

Aboard the space shuttle, water is produced by battery-like devices, called fuel cells, which also provide electricity. Each space shuttle is powered by three fuel cells that are tucked beneath the cargo bay. Each one weighs about 225 pounds and is 45 inches long, 15 inches wide, and about 14 inches high.

Like a standard battery, a fuel cell converts energy produced through chemical reactions

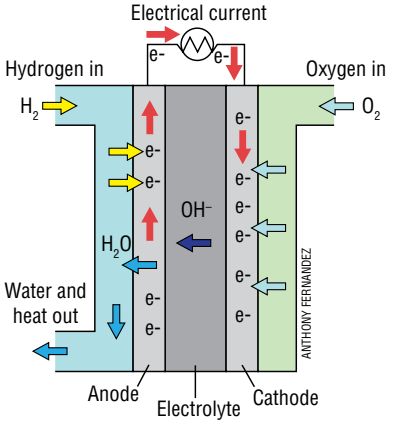


Figure 2. Schematic representation of what happens in fuel cells used on the space shuttle.


NASA

into electricity. In a battery, the chemical reactants are limited to what is contained inside; so, once they are consumed, the battery runs out of power. In contrast, a fuel cell can continue working as long as the chemical reactants are added to the cell from the outside. A byproduct of the chemical reactions occurring in a fuel cell is water vapor, which can be condensed into liquid water and stored.

In a fuel cell that is used on the space shuttle, electricity is produced via two reactions that occur simultaneously near two conducting materials, called anode and cathode (Fig. 2). Hydrogen gas (H_2) is delivered to the anode and oxygen gas (O_2) is delivered to the cathode. Near the anode, hydrogen reacts with hydroxide ions (coming from the cathode) to produce water and electrons:

$$H_2 + 2\ OH^- \rightarrow 2\ H_2O + 2\ e^-$$

Near the cathode, oxygen reacts with water and the electrons to produce hydroxide ions (OH^-):

$$O_2 + 2H_2O + 4e^- \rightarrow 4\ OH^-$$

The hydroxide ions then move to the anode, and the cycle starts again. The electrons that are produced at the anode are routed into an electrical circuit that powers the shuttle.

The net result of the two reactions, called oxidation (at the anode) and reduction (at the cathode), is water:

Anode	$2[H_2 + 2\ OH^- \rightarrow 2\ H_2O + 2\ e^-]$
Cathode	$O_2 + 2H_2O + 4e^- \rightarrow 4\ OH^-$
Net Reaction	$2H_2 + O_2 \rightarrow 2\ H_2O$

Taken together, the fuel cells can produce up to 25 pounds of water per hour, which is more than enough to meet the astronauts' needs.


NASA

Space food of the future

In the future, NASA is looking to send astronauts to outposts on the moon and Mars. Although the target for liftoff for the moon mission is not until 2020, efforts are already under way at the Space Food Systems Lab. Scientists in the Advanced Food Technology group, led by NASA food scientist Michele Perchonok, are developing foods that are "nutritious, good tasting, and provide variety for a 3-year mission."

The biggest challenge for these future missions is a food's shelf life. "For an initial trip to Mars, you will need products that have a 5-year shelf life," Kloeris says. The only foods that have currently shown such a long shelf life are a few thermostabilized foods, which is not enough to provide a balanced diet, Kloeris says.

Perchonok and her team are looking at ways to improve packaging materials that will provide a better barrier to water and oxygen—which can cause food to spoil. This way, the shelf life for many current food items can be extended. Another area of research is to develop ways to transport some foods—such as wheat berries and soybeans—in bulk to reduce the amount of packaging materials used and to minimize waste.

"A 1,000-day mission to Mars for a crew of six will need about 10,000 kilograms if we went with our packaged food system," Perchonok says. "If we can save on that by growing some items, by bringing some items up in bulk, it will be a lot easier."

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Kathy De Antonis is a science writer who lives in Old Saybrook, Conn. This is her first article in *ChemMatters*.



BEINECKE RARE BOOK AND MANUSCRIPT LIBRARY, YALE UNIVERSITY

The Vinland Map

The Vikings' Best Kept Secret

By Linda Zajac

Square sails billowed in the mist, as a great Viking ship carved its way past icebergs and ocean swells. In the open wooden boat, the Vikings ventured farther across dangerous uncharted waters, risking their lives to discover what lay beyond the setting sun. On the horizon, a new land of barren rock and glaciers rose from the sea.

The Vikings reached shore at the northern tip of Newfoundland, now part of Canada. On shore, they were chilled by an ocean breeze that swept through tall thick grasses on knobby green hilltops. On this lush green cove by the bay, the Vikings made their home.

But over time, the location of this historic Viking landing was lost. **In 1953,** Norwegian explorer Helge Ingstad visited a Viking settlement site in Greenland, sparking a burning desire to find a landing site in North America. He scoured the northeastern coast of Newfoundland, searching for possible sites.

Finally, **in 1960,** he spotted ridges in the grass, the remains of an ancient colony. He was unsure whether the site had been settled by Eskimos, American Indians, or Vikings. From 1961 to 1968, Ingstad led seven expeditions to unearth the ruins of a Viking settlement at L'Anse aux Meadows in Newfoundland. Archaeologists uncovered cooking pits and charcoal kilns, houses, and hearths. Later, scientists and scholars bitterly debated whether these brave explorers left a map of their voyage.



SHUTTERSTOCK

In 1957, a faded world map was discovered in Europe. It appeared to be drawn by the Vikings and cast doubt about whether Columbus knew of its existence. If authentic, it was proof the Vikings were the first to set sail for the New World. Scrutinized and disputed for nearly half a century since its discovery, that map is now locked safely in a vault at Yale University's Beinecke Library, New Haven, Conn.

One man's treasure changes history

The map first surfaced in Geneva, Switzerland, when Laurence Witten, an antique book dealer from New Haven, browsed through soiled and water-stained books that an Italian book dealer, named Enzo Ferrajoli, had offered him.

Witten spent hours examining the *Tartar Relation,* an account by Italian traveler and Franciscan monk Friar John de Plano Carpini of his mission to the empire of the Mongols (or Tartars) in Central Asia from 1245 to 1247. Although the slim volume, which contained a crude map, had been carelessly patched and rebound with a modern binding, Witten fell under its spell.

Other customers interested in purchasing the *Tartar Relation* had doubts about whether the map belonged with the manuscript. There was no record indicating where the book came from. Worms had chewed through the manu-

script and map, but the holes didn't align. Despite the uncertainty, Witten paid $3,500 for the book.

On thin crisp folded parchment, in fine Latin script, the map detailed the voyage of the Vikings who sailed from Greenland to Vinland, a fertile land with vines. Vinland is thought to represent the Baffin Islands, Labrador, or Newfoundland, all parts of Canada. The Vinland Map is the only known map of a Viking voyage. In 1957, it was a sensational find.

The following year, at his home in Connecticut, Witten leafed through the dilapidated binding of another medieval manuscript. The *Speculum Historiale*, a Mirror of History, was like an encyclopedia for the Middle Ages. It contained portions of French Dominican Friar Vincent of Beauvais' history of the world from creation to the time it was written in the 15th century.

Witten noticed striking similarities to the *Tartar Relation*. Both manuscripts were written in two columns of Gothic cursive. He recognized a watermark he had seen in the *Tartar Relation*, a bull's head wearing eyeglasses. "My heart began to pound," Witten wrote.

With a ruler, he carefully measured where worms had chewed through the map and manuscripts. The wormholes in the *Tartar Relation* were in the same spots as the holes at the end of the *Speculum Historiale*. When Witten compared the wormholes in the map to those at the front of the *Speculum Historiale,* he was shocked—they perfectly aligned. Like a puzzle snapping into place, Witten realized that, at one time, the manuscripts and the map were bound together as one.



He concluded that the *Speculum Historiale* was sandwiched between the Vinland Map and the *Tartar Relation* and that the map was drawn to illustrate a portion of the *Speculum Historiale.* In a stroke of good fortune, Witten had stumbled upon the missing manuscript. Now, he was certain the Viking Map was real.

He immediately contacted the curator at Yale University's library. Yale assembled a team of scholars who painstakingly researched the map's authenticity. **In 1965,** Yale stunned the nation by announcing that the Vinland Map was the only map of America produced prior to the voyage of Columbus. Some scholars wondered whether Columbus knew of the map before setting sail.

A close look at the ink

The authenticity of the manuscripts was not questioned, but some scholars and scientists had concerns about the map. Greenland was drawn with striking accuracy. On all other medieval maps, Greenland is shown as a peninsula, but on the Vinland Map, it is an island.

In 1967, the ripple-edged map was flown to the British Museum for an exhibition. While it was there, A. D. Baynes-Cope, a scientific officer at the museum, examined it under a microscope. Under ultraviolet light, the inks in the manuscripts were black against a glowing fluorescent background. This is typical of inks made by crushing larval growths, or galls, on oak trees to create gallotannic acid which is used to make medieval iron-gall ink. But the ink in the map behaved differently. "The ink was unlike any other ink we had encountered in authentic medieval documents, and no explanation could be found for this," Baynes-Cope wrote.

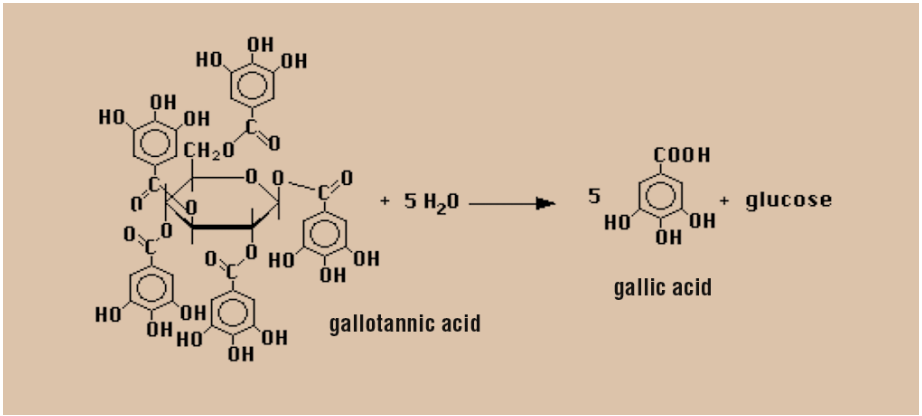
In 1972, McCrone Associates, Inc., in Chicago, Ill., analyzed the map using new scientific techniques. With a tiny drop of rubber cement at the end of a fine-tipped needle, Anna Teetsov, a senior research microscopist from McCrone Associates, delicately plucked 29 ink samples from the map and viewed them under a microscope. Teetsov reasoned that the map was "double inked"—drawn first in yellow, then in black. After hundreds of years, the ink in medieval documents leaches into the parchment fibers to produce a yellow stain. She assumed that the map was drawn first in yellow ink, redrawn with black ink, and then most of the black ink was chipped away.

In the yellow ink, Teetsov, along with Walter McCrone, a chemical microscopist and founder of McCrone Associates, expected to find titanium dioxide (TiO_2), a brilliant white paint pigment that naturally occurs in three mineral forms: rutile, brookite, and anatase. With a transmission electron microscope, which uses a beam of electrons instead of light, they noticed small rounded crystals.

The scientists determined that the crystals were anatase, which was available only since 1917. Based upon the evidence, they came to an unfortunate conclusion. "It was a brilliant job of forgery," McCrone said.

Retesting the ink with a blast of protons

But the debate was far from over. **In 1985,** the map and manuscripts were tested at the Crocker Nuclear Laboratory at the University of California, Davis. Using a new method, Thomas Cahill, professor emeritus of physics and atmospheric sciences, and his colleagues retested the ink. They used a technique, called Proton Induced X-ray Emission (PIXE), in which a massive machine called a cyclotron is used to accelerate charged particles called protons. As a beam of high-energy protons is fired at a sample—in this case, the Vinland Map—the protons collide with atoms



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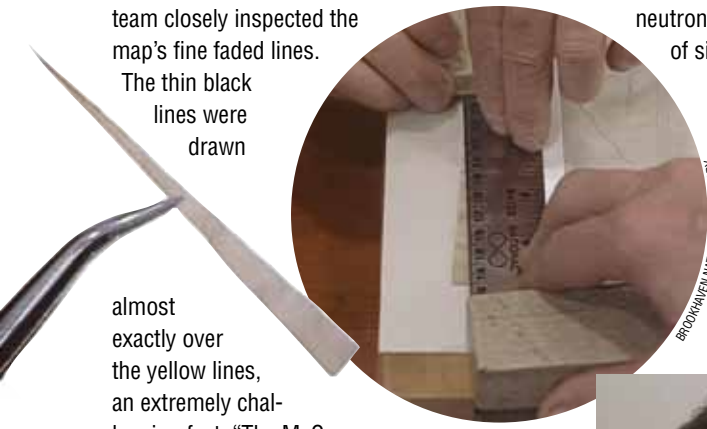
gallic acid + ferrous sulfate heptahydrate ($FeSO_4.7H_2O$) + H_2O → iron-gall ink

In the Midlle Ages, iron-gall ink was made by converting gallotannic acid into gallic acid (first chemical reaction), and then by combining gallic acid with ferrous sulfate heptahydrate and water (second chemical reaction).

in the sample, and X-rays are recorded. X-rays of the elements in the map appeared as sharp peaks and valleys on one graph.

Although Cahill's team found titanium in several spots on the map, roughly one-third of the inked lines that they tested showed no titanium above a minimum detectable limit. They concluded that titanium dioxide was present only in trace amounts in the ink and that it could not be the basis of the yellow ink.

With a microscope, Cahill's team closely inspected the map's fine faded lines. The thin black lines were drawn almost exactly over the yellow lines, an extremely challenging feat. "The McCrone 'double inking' hypothesis was impossible," Cahill said. "Our work argues strongly against the specific McCrone Associates' proof that the map is fraudulent," he wrote in a 1987 paper.



With hope riding high, Yale locked the map securely in a vault. "The insurance was raised to millions of dollars," Cahill revealed.

Dating the parchment

In the 1980s, Garman Harbottle, a retired senior chemist at the U.S. Department of Energy's Brookhaven National Laboratory, Upton, N.Y., and Jacqueline Olin, a retired chemist at the Smithsonian Institution, Washington, D.C., urged Yale to pursue radiocarbon dating to determine the age of the parchment. But this technique destroys the sample.

"We wrote two or three proposals to Yale University to allow the sampling," Harbottle said. "All were shot down." When Harbottle and Olin recruited a radiocarbon expert, Yale finally agreed.



Garman Harbottle examines the Vinland Map.

Radiocarbon dating is a method to estimate the age of an organic material. The parchment is a wafer-thin material made from the skin of sheep, goats, or calves. As living organisms breathe and eat, they consume carbon from the atmosphere. Most of the carbon consumed is carbon-12, an abundant isotope of carbon that contains six protons and six neutrons and does not change over time. Much rarer is carbon-14, a radioisotope of carbon that differs from carbon-12 in the number of neutrons that it contains (eight instead of six).

When a living organism dies, the ratio of carbon-12 to carbon-14 is the same as in the surrounding atmosphere. Over time, carbon-14 decays, that is, it transforms into another element, namely nitrogen-14, which contains seven neutrons and seven protons. After about 5,730 years, half of the carbon-14 decays into nitrogen-14. By comparing the amount of carbon-14 and carbon-12 in an organic material, scientists can determine a radiocarbon date.



Garman Harbottle and Jacqueline Olin slice a strip (inset) from the Vinland Map.

At Beinecke, **in 1995,** Olin sliced a strip from the bottom-right corner. Then, at the University of Arizona, Tucson, the sliver of parchment was snipped into six pieces. Each piece was first soaked to remove contaminants and then burned. Using a special machine, the carbon dioxide gas that was produced was converted to graphite.

Finally, a huge machine called an accelerator mass spectrometer counted all of the carbon-12 and carbon-14 atoms in the graphite sample. Radiocarbon dates for the parchment pieces fell between 1411 and 1468— stunning proof that the Vinland Map parchment was ancient.

Real or fake?

Despite numerous tests on ink and parchment, the controversy continues. One undisputed piece of evidence could be the key to solving the Viking mystery. For Ingstad, a critical piece of evidence linking the Vikings to the settlement site at L'Anse aux Meadows came on the final day of the last expedition.

Kneeling in the ruins of a four-room house and scraping the soil at the edge of a cooking pit, archaeologist Sigrid Kaland suddenly shouted, "I found bronze!" Carefully, Kaland brushed away the dirt. She stared in disbelief at a corroded pin the length of a twist-tie, green and bronze. Clearly, it was a Viking pin used to fasten a cloak. "The best find of all was in truth the final clue," wrote Anne Stine Ingstad, archaeologist and wife of Helge Instad. "We practically exploded in our excitement!"

Ingstad's remarkable discovery of Viking ruins left no doubt that the Vikings were the first to discover the New World. But did they leave a map of their voyage? Like a ring-headed pin lost among the ruins, the identity of the scribe is a key piece of evidence, buried in the past.

More than half a century has passed since the Vinland Map first surfaced. Scientists and scholars still debate whether the map is authentic or a clever forgery. History has left an incredible secret etched in the fine faded lines of this ancient parchment.

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Linda Zajac is a science writer in Vernon, Conn. Her most recent article, "Glowing Proteins with Promising Biological and Medical Applications," appeared in the December 2008 issue of *ChemMatters*.

J. L. Kiappes

Silver Medalist in the 2004 International Chemistry Olympiad


ISTOCK, USNCO ARCHIVES

By Christen Brownlee

How much chemistry do you know? One way to put your knowledge to the test is by competing in the International Chemistry Olympiad. Since 1968, this contest has challenged high school students to see how their chemistry comprehension stacks up against the best minds from around the world. Like the athletic Olympic Games, top finishers in the Chemistry Olympiad win bronze, silver, or gold medals. The top 10% of finishers receive gold medals; the next 20% receive silver; and the next 30% bronze.

The United States has been participating in this competition since 1984, so 2009 is the 25th anniversary—or silver anniversary—of U.S. participation. This anniversary was celebrated at a reception that was part of the 238th National Meeting of the American Chemical Society on August 16–20 in Washington, D.C. Past winners of the International Chemistry Olympiad were present, along with teachers and mentors who helped them prepare for the competition.

I talked with J. L. Kiappes, a silver medalist in the 2004 International Chemistry Olympiad and now a doctoral candidate at the Scripps Research Institute in La Jolla, Calif., and the University of Oxford in the United Kingdom, to get the real scoop on what it's like to take part in this tough—but rewarding—test of chemistry prowess.

How did you become involved with the International Chemistry Olympiad?

I've been interested in chemistry for a long time. I remember making a model of an atom in sixth grade and being intrigued—I thought: This is what I want to do. In my junior year of high school, I took advanced placement (AP) chemistry, and the teacher encouraged all of us to take a scholarship exam. When I was looking for information online about the exam, I ran across information about the Chemistry Olympiad. I learned that to qualify for the U.S. National Chemistry Olympiad—the contest that selects students for the International Chemistry Olympiad—I would need to take a qualifying exam given by local chapters of the American Chemical Society (ACS) across the country. It was too late for me to take the exam that year, so I decided to do it my senior year. I worked with my teacher, going through lots of different AP-level chemistry textbooks to learn as much as I could to prepare for the test.


NADINE SZCZEPANSKI

The 2004 U.S. team (from left to right: Eric Brown, Fan Zhang, Emily Tsui, and J. L Kiappes) won four silver medals at the International Chemistry Olympiad in Kiel, Germany.

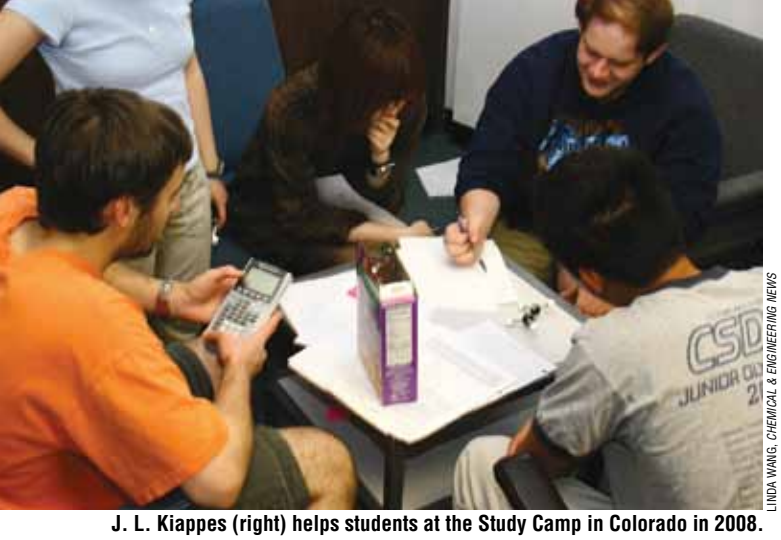
Tell me about the national exam—is it really hard?

It's a tough test because it covers so much material. The exam lasts 4 ½ hours and consists of a multiple choice section, an essay section, and two lab practicals. I immediately knew the answer to some of the questions, but there were other questions for which I had absolutely no idea what the answer was. I had to tell myself: What do I know, what can I find out, what's reasonable? As a senior, it was my last year to take the exam, so I really wanted to do well. I was totally wiped out when I finished the test, but I was glad I had done it. It's one of the few opportunities to see how much chemistry you know.

Don't keep us in suspense—how did you do?

A little bit less than a month after I took the exam, I got a call from the local ACS chapter with exciting news: I had earned a spot at the Olympiad Study Camp! Only 20 students who take the national exam are selected for the camp each year to prepare for the international competition. Soon after I learned that I would be going to Study Camp, I received an organic chemistry textbook in the mail from the camp's mentors, along with a letter telling me to start preparing by reading the first eight chapters.

In June, I flew to the U.S. Air Force Academy in Colorado Springs, Colo., where Study



LINDA WANG, *CHEMICAL & ENGINEERING NEWS*

J. L. Kiappes (right) helps students at the Study Camp in Colorado in 2008.

Camp takes place. For 2 weeks, I and the other camp attendees crammed as much chemistry as we could. Every day, we woke up at 7 a.m., ate breakfast together, attended lectures from 8 a.m. to noon, had lunch, and then had lab from 1 p.m. to 5 p.m. At night, there was no computer or television, so we spent time studying more, playing cards and word games, and getting to know each other. It's a very intense experience—you are with the same 19 people all the time, working together on chemistry. Toward the end of Study Camp, there is another qualifying exam—this time to decide who goes on the traveling team to the international competition.

How did you find out whether you'd made the traveling team?

At the end of Study Camp, there's a banquet. Everyone's parents flew in, and all the mentors and professors from the camp were there. It was very nice because it was the first time in 2 weeks that we weren't thinking about studying for the next exam. But getting chosen for the traveling team was on everyone's minds. It was the big elephant in the room. After dinner, everyone gets an award for participating, and then they announce two alternates for the traveling team, and finally, the four members of the traveling team. I'd had a great experience at Study Camp, but I didn't think there was any way I had made the traveling team—but then they called my name as one of the four. I was in such complete shock that my mom had to tell me to get up to join the team! Earning a spot on the traveling team was a huge honor and surprise.

Once you had been selected for the traveling team, what happened next?

Everything happened really quickly—in the few weeks before we left for the international competition—which was in Kiel, a coastal city in northern Germany, that year—I tried to study up on everything I didn't know at Study Camp.

In mid-July, the team met in Washington, D.C., to travel to Germany together. When we arrived in Germany, teams from 60 other countries were all arriving around the same time. We all stayed together at a hostel—a lodging place with dormitory accommodations and shared facilities.

The international competition consists of two 5-hour exams. We all wanted to do well on the exams, but it was also important to live the experience: Imagine being in a different country, with students from around the world who share your interests—it's rare to have an opportunity like this.



JOHN KOTZ

J. L. Kiappes was the scientific observer in the U. S. delegation to the 2007 International Chemistry Olympiad. Shown here are members of the delegation (wearing yellow T-shirts, from left to right: Kara Pezzi, Sofia Izmailov, Justin Koh, Brian Lee, John Kotz, Kenneth Brewer, and J. L. Kiappes) with Russian guide Daria Tsareva (wearing a blue T-shirt).

Tell us about how you received your silver medal.

At the end of the competition, there is a closing ceremony which is a lot like the one at Study Camp. There is a dinner, and then they announce all the awards. Everyone gets a certificate of participation, and then they announce the medals: bronze, silver, and then gold. You don't want to hear your name as long as possible, because everyone's name gets called. The later you hear your name, the better you did. When I heard my name for the silver medal, it was unbelievable! I was incredibly excited.

How has participating in the Chemistry Olympiad changed your life?

I went to Rice University in Houston, Texas, a few weeks after I went to the International Chemistry Olympiad. Participating in this competition prepared me for what some call the culture shock of having to learn so much when you are in college. It also gave me a leg up on my chemistry classes through my junior year of college, since I had been exposed to so much material while preparing for the Olympiad exams.

Also, the National Chemistry Olympiad allowed me to meet and work with exceptional mentors and other students. The relationships that I built during my summer as a student at Study Camp are some of my most rewarding professional relationships and friendships. I am still in contact with all of the mentors and some of the students with whom I spent time in 2004.

The chance to represent the United States at the International Chemistry Olympiad helped me realize what a truly universal language chemistry is. Because of our mutual interest in chemistry, I made lifelong friends from all over the world whom I continue to run into at school and at conferences.

What does it take to participate in the Chemistry Olympiad? What advice do you have for interested students?

The most important thing is being dedicated. Some people have asked me if you need to take college classes to prepare for the exams—you don't. But you need to put in the time to understand chemistry, not just memorize facts. You have to have a real passion for chemistry to do this—you have to think about it a lot, and if it's not something you truly enjoy, you won't be able to stick with it. But if you put in the time to learn and understand it, you'll have a good shot at success.

Christen Brownlee is a science writer in Baltimore, Md. Her latest article "What Uuought to Know About Elements 112–118," appeared in the October 2009 issue of *ChemMatters*.

Interested in competing for the National Chemistry Olympiad?

Here is a chance to test yourself!

By Arden Zipp

The National Chemistry Olympiad is a U.S. competition designed to test students' understanding of chemistry concepts learned in class. For the past several decades, approximately 10,000 students enter local Chemistry Olympiad competitions vying for a chance to compete at the national level. Of those, approximately 1,000 students are selected to take the national exam.

Twenty of the highest-scoring students on the national exam are chosen to spend 2 weeks in a Study Camp at the U.S. Air Force Academy in Colorado Springs, Colo. Based upon their performance on exams and laboratory exercises, four students are selected to represent the National Chemistry Olympiad. These students then represent the United States at the International Chemistry Olympiad, a worldwide competition among high school chemistry students.

Not only do the national exam's questions test students' knowledge of chemistry, but they also test students' logic and creativity. For example, here is a question that appeared on Part II of the National Chemistry Olympiad in 2003:

How many different isomers have the formula $C_4H_{10}O$?

The term "isomer" refers to substances that have the same chemical formula but different structures. In the case of $C_4H_{10}O$, the number of isomers is eight.

Here are four of them. The other four can be found on *ChemMatters'* Web site: http://www.acs.org/chemmatters.

First, the oxygen atom can be inserted into the chain of carbon atoms in one of two ways:

$CH_3CH_2CH_2OCH_3$

or

$CH_3CH_2OCH_2CH_3$

These two molecules are isomers because the oxygen atom is inserted into the carbon chain at different points: In the first molecule, the oxygen atom divides the four carbon atoms into shorter pieces, one with a single carbon atom and the other with three carbon atoms; in the second molecule, the oxygen atom divides the four carbon atoms evenly with two carbon atoms in each segment.

On the other hand, the molecules

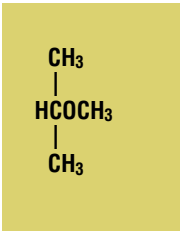
$CH_3CH_2CH_2OCH_3$

and

$CH_3OCH_2CH_2CH_3$

are not isomers because each contains a single carbon atom joined to a 3-carbon chain through the oxygen atom. They are the same!

Other isomers of this type exist. Since the 3-carbon atom chain can be connected to the oxygen atom via either one of the carbon atoms on the end of this chain or through the central one, there is one more isomer:



has a different structure than

$CH_3CH_2CH_2OCH_3$.

So, that's a total of three isomers. These isomers are called ethers, because the oxygen atom is in the carbon chain.

In addition to inserting the oxygen atom in the chain of carbon atoms, it can be part of a hydroxyl (-OH) group, thus creating molecules called alcohols. One such molecule is

$CH_3CH_2CH_2CH_2OH$

This is the fourth isomer.

The other four isomers are at: http://www.acs.org/chemmatters.

If you would like to test yourself with more questions from past National Chemistry Olympiad exams, you can go to: http://www.acs.org/olympiad and click on "Past Exams" on the top left. Enjoy!

If you find yourself answering many questions correctly, you may want to enter the local Chemistry Olympiad competition by contacting the coordinator of your local section of the American Chemical Society or by sending an e-mail message to usnco@acs.org.

Arden Zipp is a Distinguished Teaching Professor at the State University of New York, Cortland, NY, and chair of the American Chemical Society's Olympiad Examinations Task Force, which prepares and grades the U.S. National Chemistry Olympiad.

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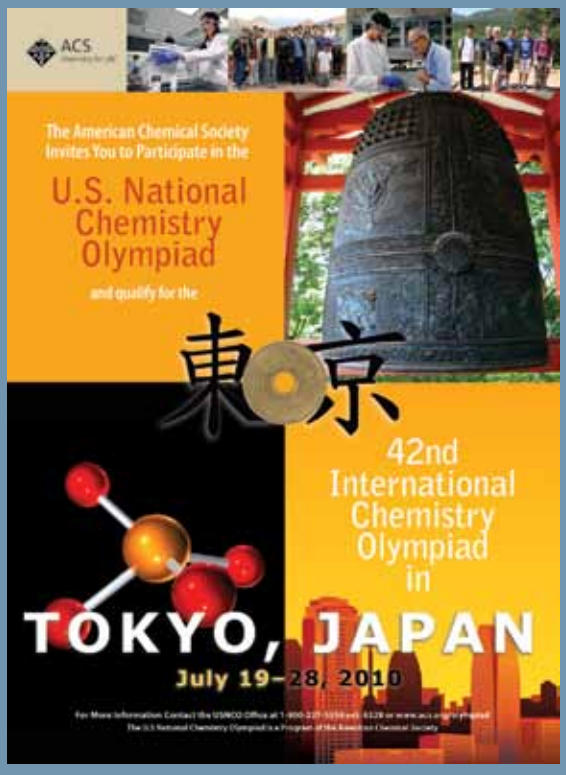

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