Unit 5: Bonding and Intermolecular Forces

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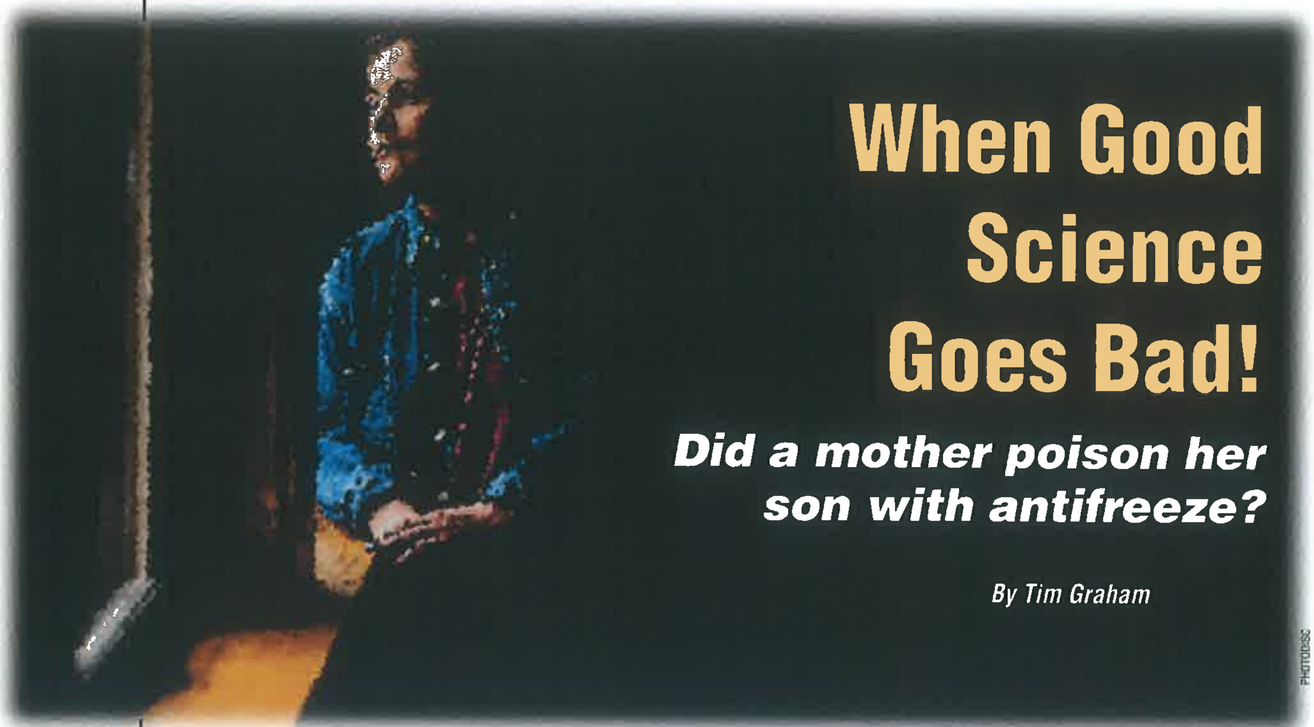
Mystery Matters



PHOTODISC

When Good Science Goes Bad!

Did a mother poison her son with antifreeze?

By Tim Graham

Every mother's worst nightmare began for Patricia Stallings on Friday, July 7, 1989. Her 4-month-old son, Ryan, took his bottle just before bedtime but soon vomited. This set in motion a series of events that would forever change the lives of the Stallings family.

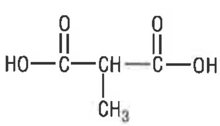
By Sunday morning, it was obvious that Ryan was quite sick. His breathing was labored and he couldn't keep any food down. Patricia loaded Ryan into the car and rushed to a local St. Louis hospital. After three days of testing, doctors concluded that Ryan's illness was due to high levels of ethylene glycol found in his blood. Ethylene glycol is a primary component of automobile antifreeze/coolant (See *ChemMatters*, October 1996). Ryan was too young to have drunk the toxic liquid on his own … someone must have poisoned him! So, on July 17, 1989, the Missouri Division of Family Services took custody of Ryan. It wasn't long before Patricia became the primary suspect in the poisoning of her son.

Early in September, Patricia was granted supervised visits during which she was allowed to feed Ryan a bottle. Three days after one of these visits, Ryan was again hospitalized. This time his condition was much worse and doctors were unable to save him. Ryan Stallings died on September 7, 1989. Patricia found out about Ryan's death the next day when she was arrested and charged with murder. Patricia spent the next seven months in jail while prosecutors built their case against her.

The mounting evidence was damning: a gallon of antifreeze was found in the basement of the Stallings's home, two independent labs confirmed the presence of ethylene glycol in Ryan's blood serum, and postmortem analysis of Ryan's brain tissue confirmed the presence of calcium oxalate crystals, all consistent with ethylene glycol poisoning. Patricia Stallings was convicted of 1st-degree murder in the death of her son and sentenced to life in prison.

But here's where the story takes an interesting twist. Three months after Ryan's death, Patricia Stallings learned she was pregnant! Her second son, David Jr., born five months after Ryan's death, was taken by Family Services and placed into foster care. A few weeks later, David Jr. experienced seizures, vomiting, and lethargy ... the very same symptoms that his brother Ryan had suffered previous to his death. But experts at a different hospital diagnosed David Jr. with rare metabolic disease known as methylmalonic acidemia, or MMA, and were able to treat him. It would be this diagnosis that would ultimately unravel the conviction against Patricia Stallings.

What is MMA? Methylmalonic acidemia is an inherited illness that inhibits the body's ability to metabolize protein correctly. Most babies are diagnosed with the disease only after they get sick. MMA results from a deficiency of enzymes responsible for the metabolism of **methylmalonic acid**. When a sufferer of methylmalonic acidemia eats too much protein (mother's milk and baby formula are high in protein), the capacity to digest and use the protein overloads the deficient enzyme system. Too little dietary protein triggers the body to break down its own protein, which can also overwhelm the enzyme. The disorder is potentially life threatening, but once the condition has been diagnosed, careful monitoring of diet along with a prescribed medical regimen can minimize the symptoms.



Methylmalonic acid

A new trial

Six months after her conviction, Patricia was granted a new trial by the state of Missouri. The toxicology lab at St. Louis University provided samples of Ryan's blood serum and it was determined that Ryan had also suffered from MMA. But would this new information be enough to exonerate Patricia Stallings? The original laboratory work had found ethylene glycol present in Ryan's blood serum. Since experts concluded that there could be no mistaking any of the metabolic products of MMA with ethylene glycol, there was not sufficient evidence to reverse the decision.

Patricia's case soon gained national exposure when it aired on an episode of the NBC television series, "Unsolved Mysteries." One of the viewers of this episode was Dr. William S. Sly, a professor of Biochemistry/Molecular Biology at St. Louis University. Both Sly and a colleague, Dr. James Shoemaker, had been following the case in the news media. They were convinced that a compound called propionic acid was misidentified as ethylene glycol.

Was the blood test correct?

The laboratories that did the original analytical work relied on a technique known as GC-MS. GC-MS is actually a combination of two technologies: the gas chromatograph and the mass spectrometer. The gas chromatograph is a device for separating a mixture of compounds according to their relative attractions to a material called an adsorbent. In chromatography, the adsorbent is known as the stationary phase. Typically, the adsorbent is silica or alumina gel lining the column inside the machine. The sample is injected into a stream of carrier gas (known as the mobile phase) inside the machine where it goes through the column that is heated by an oven. The separations occur on the column. The separated compounds in the mixture pass by a detector, which causes a signal to be emitted.

This signal is sent to a recorder, which prints a chromatogram, which records the relative retention times and amounts of the compounds present in the mixture. After separation on the column in the GC, the materials then pass through to the mass spectrometer. In this machine the materials are fragmented in the presence of a strong magnetic field. Fragments of the materials are then analyzed according to their molecular weight. The results can be compared against a database library of known compounds and their fragmentation patterns.

The combination of information about the physical properties of the compounds (as measured by its retention time) and its chemical composition (as measured by its mass spectrum) is extremely powerful, almost like measuring a fingerprint. GC-MS is practically a "gold standard" for the identification of compounds; it is extremely rare that two different compounds will have both the same retention time and the same mass spectrum. For example, not only do propionic acid and ethylene glycol differ in their retention time by 33 seconds on a standard column, but their mass spectra look completely different. You would think, as the experts testified in the second trial, that there would be no possibility of confusing them!

But Sly and Shoemaker were not so sure. After all, the accuracy of the results depends on the technicians' skill in interpreting the data. It is easy to deceive oneself about the identity of a compound present in a complex mixture such as blood, particularly if one expects to find ethylene glycol. So Sly and Shoemaker applied a *qualitative* test that would give a yes-or-no answer less subject to interpretation. One such test uses a simple colorimetric method. Periodic acid (H_5IO_6) oxidizes ethylene glycol to formaldehyde, which then is reacted with a chemical called Purpald (4-amino-3-hydrazino-5-mercapto-1,2,4-triazole). A purple-colored complex forms if ethylene glycol is present. The pair of scientists was able to secure a sample of Ryan's blood and their additional tests confirmed their suspicions. Propionic acid, expected in the blood serum of a person suffering with MMA, was indeed misidentified as ethylene glycol by both laboratories involved in the original testing. Sly and Shoemaker were so certain of their conclusions that they sent samples doped with propionic acid to seven independent commercial laboratories for analysis. In fact, three of the seven labs misidentified the propionic acid as ethylene glycol. It would seem that few analytical labs, employing only GC-MS techniques, are capable of making a reliable determination when it comes to ethylene glycol!

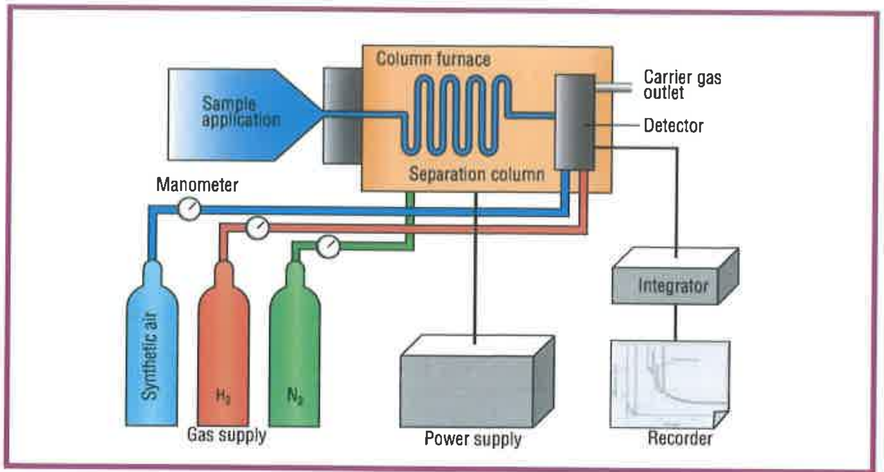
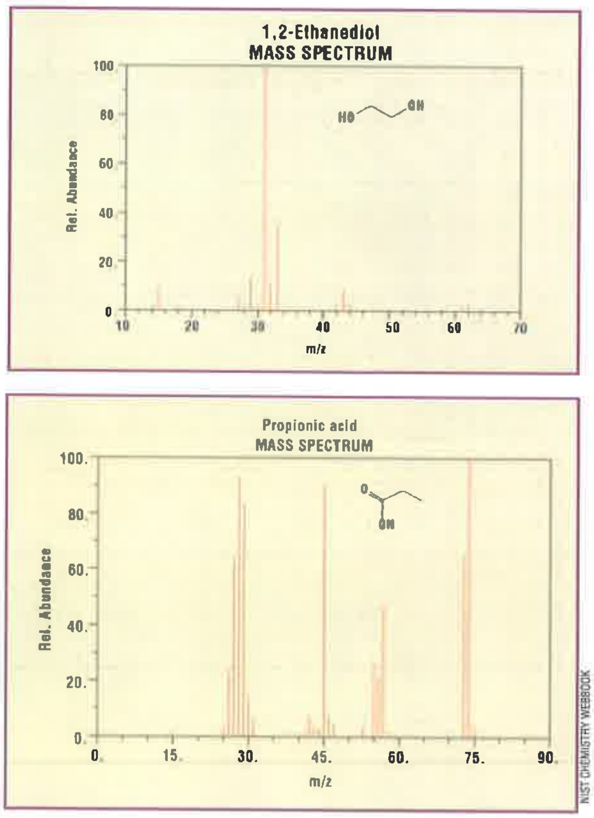


Diagram of a gas chromatograph. Mixtures of compounds injected into the GC are separated by their relative attraction to a stationary material in the separation column. The separated (or partially separated) compounds then pass through a detector, and their signal is recorded.



NIST CHEMISTRY WEBBOOK

The mass spectra of ethylene glycol and propionic acid look completely different. You would think, as the experts testified in the second trial, that there would be no possibility of confusing them.

Prosecutors, now a bit more uncertain about Patricia's guilt, had to take a new look at the mounting evidence that suggested that Stallings might be innocent. They decided to consult with a world-renowned genetics expert from Yale University named Dr. Piero Rinaldo. Rinaldo agreed with Sly and Shoemaker's findings and concluded that Ryan's symptoms were due to MMA and not ethylene glycol poisoning. The original tests run on Ryan's blood were also scrutinized and found to be insufficient to condemn a person to life in prison.

What about the calcium oxalate crystals?

Rinaldo also concluded that Ryan's death might have been the result of his treatment for ethylene glycol poisoning. The treatment, an ethyl alcohol drip, while appropriate for most patients suffering from ethylene glycol poisoning, was totally inappropriate for a patient with MMA.

Once ethylene glycol has entered the bloodstream, an enzyme called alcohol dehydrogenase (ADH) breaks it down into several organic acids, one of which is oxalic acid. In an attempt to rid the body of a potentially harmful chemical, the enzyme makes the situation worse. Oxalic acid reacts with calcium ions in the blood to produce the insoluble salt, calcium oxalate. It is this substance that does much of the damage to organs like the brain and kidneys.

But ethanol treatment for ethylene glycol poisoning must be carefully monitored because of the unpredictable behavior of ethanol when subjected to the human body. In small children, especially ones vulnerable because of poor health, ethanol can prove to be just as harmful as it is helpful. Excess ethanol exposure is known to increase the precipitation of calcium oxalate resulting in a calcium deficiency in the blood (hypocalcemia). This may well explain the crystals found in Ryan's brain tissue post-mortem.

Faced with the new evidence collected by the two very determined chemists, prosecutors for the state of Missouri dropped all charges against Patricia Stallings. Patricia's conviction was overturned, and she was released from prison 14 months after her nightmare began.

Tim Graham teaches chemistry at Roosevelt High School in Wyandotte, MI. His most recent article, "Scanning Electron Microscopy Solves a Mystery!", appeared in the December 2003 issue of *ChemMatters*.

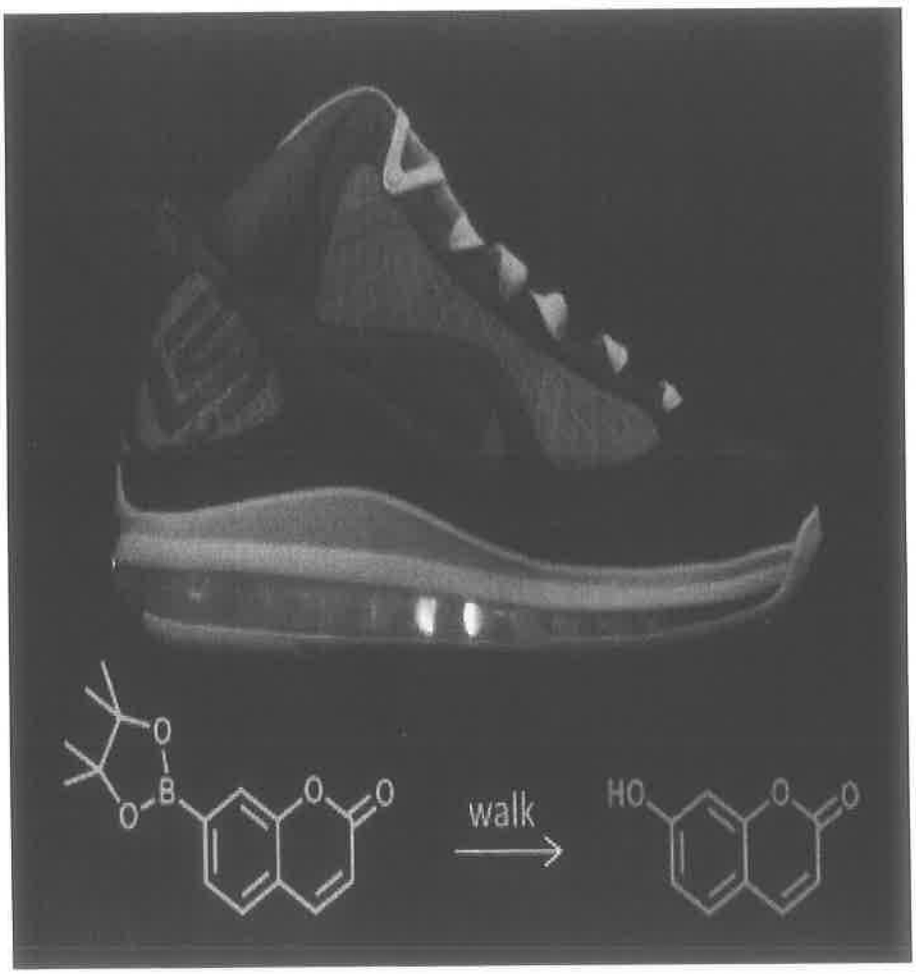
ScienceNews for Students

Chemistry

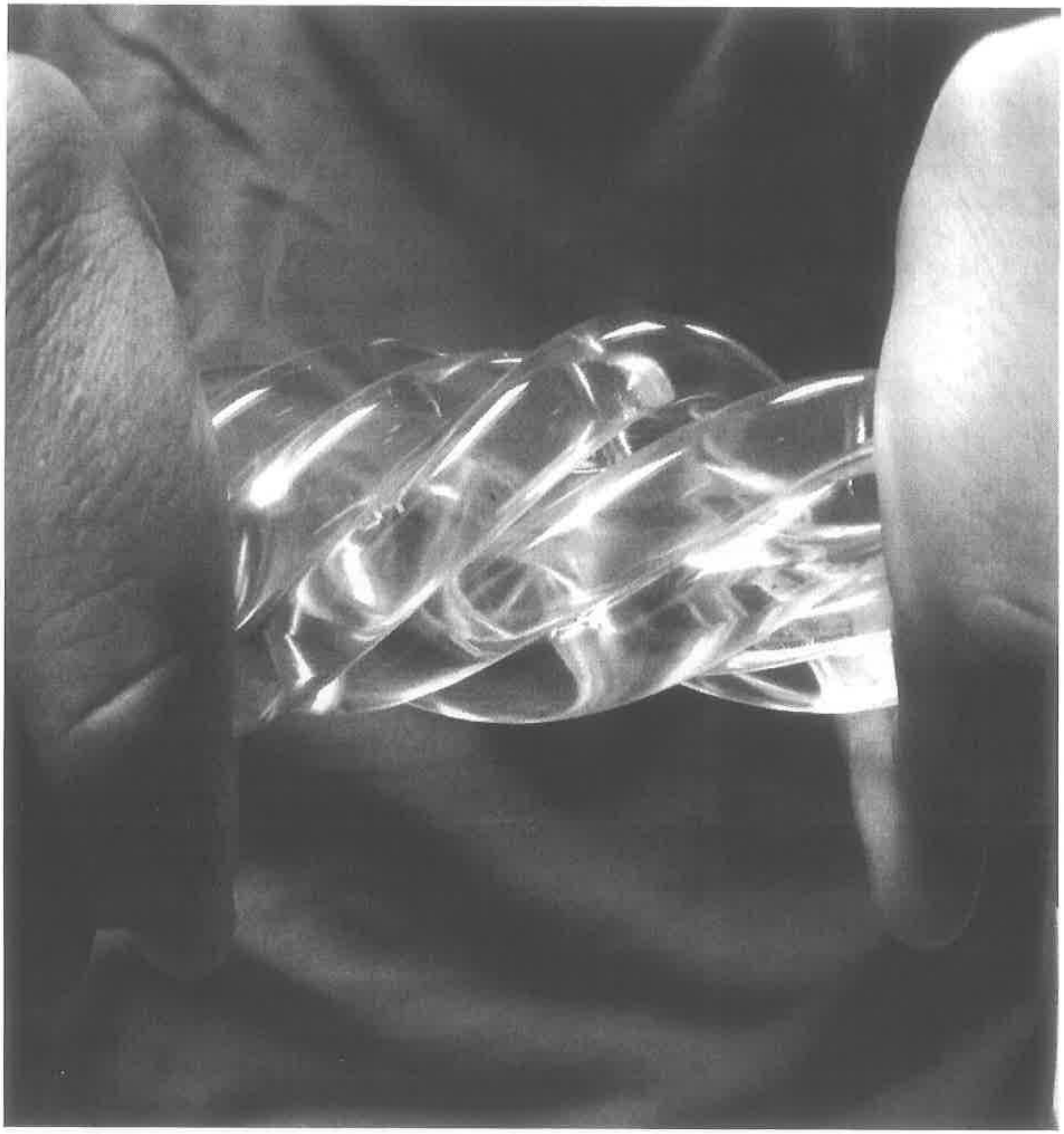
Squeeze power

Under pressure, plastics produce energy

By Stephen Ornes 2:18pm, March 27, 2012



The blue glow in the sole of this shoe shows a chemical reaction at work.
H. T. Baytekin and B. Baytekin



Northwestern University scientists report that squeezing plastic may be a way to harvest energy from an unusual source.
H. T. Baytekin and B. Baytekin

The “lightning shoe,” looks like an ordinary Nike LeBron sneaker. But it hides a secret that isn’t revealed until the sneaks have been for a 30-minute walk. Then, a liquid solution inside the sole begins to glow an eerie blue.

The engineers at Northwestern University in Evanston, Ill., who designed the new glow technology aren’t in the shoe business. Nor is their lightning model slated to hit stores in the near future. Rather, the researchers used this project as an example of a way to get energy from an unexpected source.

molecule A group of atoms held together by bonds.

electron A subatomic particle with a negative charge. Electrons act as the carriers of electricity.

physical chemistry The area of chemistry that uses the techniques and theories of physics to study chemical systems.

Further Reading

R. Ehrenberg. "Polymer power drives tiny reactions." *Science News*. March 12, 2012.

S. Ornes. "An energy lesson from panda poop." *Science News for Kids*. Sept. 14, 2011.

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Source URL: https://student.societyforscience.org/article/squeeze-power

ChemHistory

The Great Hartford Circus Fire

By Brendan Rimetz

Fire has the ability to mystify and amaze us and also scare and horrify us. It can heat our homes and cook our food, but it can also kill us. It is uncontrollable and unforgiving when not properly controlled, and it can spread with overwhelming speed when conditions are favorable. An unforgettable display of the power of fire took place in my hometown of Hartford, CT, on July 6, 1944.

It was a hot summer day in the southern end of Hartford, and the Ringling Brothers and Barnum & Bailey Circus was in town for two shows, which were to be held under the big top.

The show began eight minutes late at 2:23 pm on that fateful day. Minutes later, a flame leapt up from a side wall and quickly began to burn the tent.

The fire started out small, but as it gained oxygen and fuel, it grew to the point where it could be seen clearly by the audience. At first, many thought it was just part of the show and did not realize that it posed a life-and-death situation until it hit the roof and began to spread rapidly.

People began to panic and rush for the exits. Because the walkways around the tent were narrow, they became crowded and chaotic. Animal chutes also blocked many exits, and once people realized this, they had to turn around back into the bedlam. Within minutes the whole roof was engulfed in fire and the main support poles began to give

ALICE LINDE MAZUR

way and collapse on the people below. The melted burning pieces of canvas fell and stuck to people's skin.

Eventually, the tent collapsed on all of those inside. The incredible heat of the fire cremated many of those who were killed. Although many people did survive, and there were many amazing rescue stories, 167 died in total, and over 700 were injured.

How could something like this have happened!?

Gasoline and paraffin

Much of the blame for the rapid spread of the fire and intense heat rests squarely on the choice of waterproofing agent for the tent. Because World War II was still raging and the U.S. military needed as many supplies as they could get, the circus owners weren't granted the use of the safe waterproofing agent they had wanted.The owners would later claim that because there was no other safe, effective means of waterproofing a large canvas, the circus owners had to rely on a mixture of paraffin wax and gasoline to waterproof their tent. Although this mixture had worked well before, it was very flammable and had caught fire many times before the Hartford fire. But if the owners were to hold shows in the rain, to maximize their profits, they had to rely on this flammable mixture.

Waterproofing

To understand waterproofing, you need to understand water. As you know, water molecules are composed of two atoms of hydrogen and one atom of oxygen. Because of the different characteristics of the oxygen and hydrogen atoms, the area of the water molecule near the oxygen atom is slightly negatively charged, and the area near the hydrogen atoms is slightly positively charged. Molecules that have this type of charge separation are called polar molecules. Water's polar nature causes its molecules to bond to each other between their positive and negative ends.

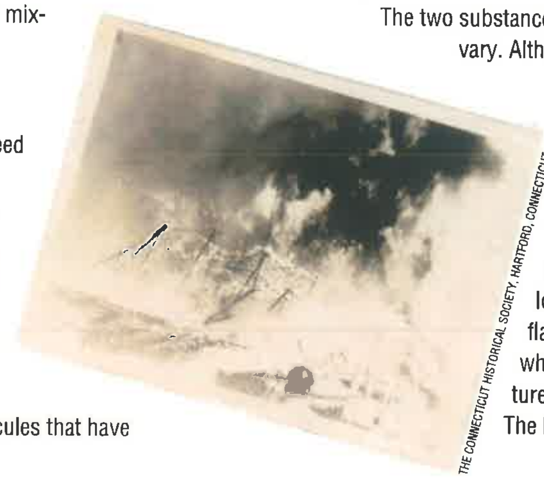
Substances such as gasoline and paraffin wax are hydrocarbons, consisting only of carbon and hydrogen. Because carbon and hydrogen have very similar electronegativities, carbon-hydrogen bonds are nonpolar, and the hydrocarbon molecules do not have positively or negatively charged ends. Water molecules would rather adhere to themselves than to a nonpolar wax surface. This is why water beads up on a waterproofed tent. Paraffin is a great waterproofing agent on its own, but it is normally a solid. Gasoline is used to dissolve paraffin, so that the pasty mixture can be "painted" or spread on the tent.

A bad combination

Because the whole top of the tent was covered in the gasoline and paraffin mixture, it provided a large amount of fuel; up to 800 pounds of paraffin wax and 6000 gallons of gasoline by some accounts.

The two substances are combustible, but their properties vary. Although paraffin is combustible, it needs to be heated to burn. Paraffin wax is the slow-burning fuel that keeps candles burning for hours. But you can drop a cigarette or match next to paraffin and not have it ignite.

Gasoline, on the other hand, is very flammable, which means it has a low flash point and is easily ignited. The flash point is the lowest temperature at which a liquid can form an ignitable mixture in air near the surface of the liquid. The lower the flash point, the easier it is to



THE CONNECTICUT HISTORICAL SOCIETY, HARTFORD, CONNECTICUT

A SURVIVOR'S STORY

My grandmother, 12-year-old Alice Linde was at the circus on the day of the fire. "I went to the fire with my dad, my younger brother, and sisters", she recalls. "We sat up high in the bleachers next to the circus band. While the lion act was just getting over, I looked up over at the reserved seating section of the tent and saw the ceiling on fire. I turned to my dad and yelled "Fire!", and that is when everyone around us looked up and started to panic. My dad sat us calmly in the seats as he looked around. Next, he gave us instructions to exit underneath the bleachers. He dropped us one by one behind the bleachers and told us to head for the nearest exit. I was to hold my 4-year-old sister's hand as we ran toward the exit which happened to be down the hallway of the circus entertainers' dressing rooms. Once outside the door, I turned and realized that it was someone else's hand I was holding and not my sister's. She escaped safely with someone else. All around us were the circus entertainers, some actually naked because they ran out so quickly. My dad quickly found us, and we stood outside to watch. Being only 12 at the time, it was a sad and unforgettable sight to see all the entertainers around crying and frenzied," said Alice, who

ALICE LINDE MAZUR

ignite the material. Gasoline has a flash point of –40 °C and is more flammable than paraffin wax which has a flash point of 204–271 °C.

Gasoline provided the flammable vapor that started the fire and heated the paraffin, which, in turn, ignited and kept the tent burning.

Problems fighting the fire

The reaction that took place in this event is classified as a combustion reaction. In a combustion reaction, a compound or element, in this case, gasoline and paraffin, reacts with oxygen to release energy rapidly in the form of heat and light, hence, the fire. Because the tent was outside and there was plenty of available oxygen, the fire spread quickly.

As mentioned before, gasoline and paraffin are both nonpolar and mix together well, but they don't mix well with polar water. This caused a great setback for those who tried to put the fire out using the fire hoses and dousing the flames with buckets of water. The flaming mixture of paraffin and gasoline simply floated on the water and continued to burn. In fact, the flowing water actually spread the fire around and worsened the situation.

The fire needed to be smothered or cooled, but water could do neither, and modern equipment and fire-fighting foams (see *ChemMatters*, April, 2001) were not available at that time. This made it virtually impossible for the firefighters to extinguish the fire.

A SHOCKING SIMILARITY

The paraffin and gasoline mixture used to waterproof the tent shares some similarities with a notorious substance. Ever heard of napalm? It's best known for its use in bombs during the fire-bombing of Tokyo, Japan, and Dresden, Germany, during World War II, as well as its use during the Vietnam War. The military discovered that traditional bombs, and bombs with just gasoline, explode and burn too quickly to be effective at starting fires on the ground. Napalm was a jellied gasoline formulation originally made from gasoline, naphthalene, and palmitate. It was sticky, highly flammable, but also slow burning. Sound like any waterproofing agent you've just read about?

STAFF

Similar to napalm, when a small amount of the tent waterproofing agent is ignited; it rapidly drips and spreads a sustained fire down a stick.

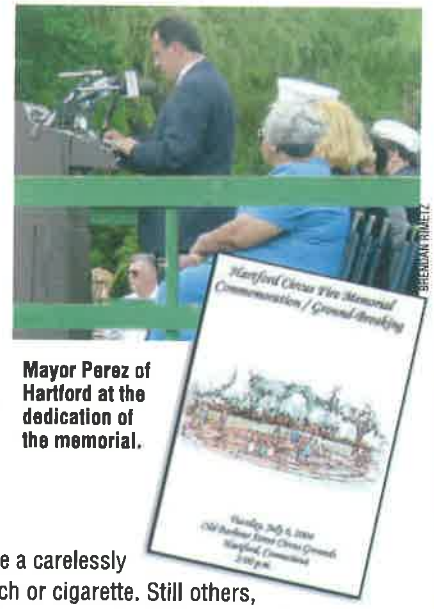
STAFF

The waterproofing agent used on the circus tent was a dangerous combination of gasoline and paraffin. When a quarter-sized dollop ignites, it melts and spreads rapidly.

Aftermath

Immediately after the disaster, Ringling Brothers and Barnum & Bailey Circus announced that it would not use the big top tents until they could be rebuilt and fireproofed. By the time of this announcement, they had already purchased a waterproofing agent that was also fireproof. Hooper Fire Chief fireproofing was purchased by the circus and used to fireproof the side walls of the dressing rooms and sideshow tents. The substance was a thick, milky substance that had been successfully used by the U.S. military to fireproof truck and boat covers. It was advertised as waterproof and resistant to mildew. The advertisements pointed out that "…for nearly a minute a blowtorch was applied to a section of the chemically treated sideshow tent. As the first flames touched the canvas, it began to glow a bright red … . When the flame was removed the glow died out, leaving a blackened charred-edge hole in the fabric.'"

It still would be a long time until Ringling Brothers and Barnum & Bailey Circus would overcome the bad publicity from the fire. After the fire they were sued and ended up paying 10 years' worth of profits to fulfill claims by the victims' families. The company never fully recovered from the fire and its repercussions. Shortly after the fire, it stopped using big tops and tents for the circus shows. Instead, the circus company decided to perform in arenas and stadiums. In 2000, the Ringling Brothers and Barnum & Bailey circus was preparing to tour the United States under a tent for the first time in more than 40 years. Since the fire, Connecticut and many other states have passed fire prevention laws that strictly regulate the way circus tents are constructed.



Mayor Perez of Hartford at the dedication of the memorial.

Many questions remain about how the fire started. To this day, no one is really quite sure about how or where the fire started. Many blame a carelessly tossed match or cigarette. Still others, think it was arson. In 1950, a mentally unstable man named Robert D. Segee claimed he started the fire, but Connecticut investigators were never able to prove that he was in the state that day, and he later recanted. We may never know who or what started this disaster.

The fire is still a very painful memory in Hartford. Almost all of the 167 victims of the fire were eventually identified, yet six remain unidentified to this day.

After 60 years, a monument at the site of the fire will finally be erected for the victims. On July 6, 2004, I joined with my high school chemistry teacher, Ms. Coan, survivors, and the citizens of Hartford to remember The Gr[illegible] Hartford

Brendan Rimetz is a high school junior at East Catholic High School in Manchester, CT. He enjoys writing about chemistry and sports. He would like to thank his chemistry teacher, Mrs. Amy Coan, for all of her assistance.

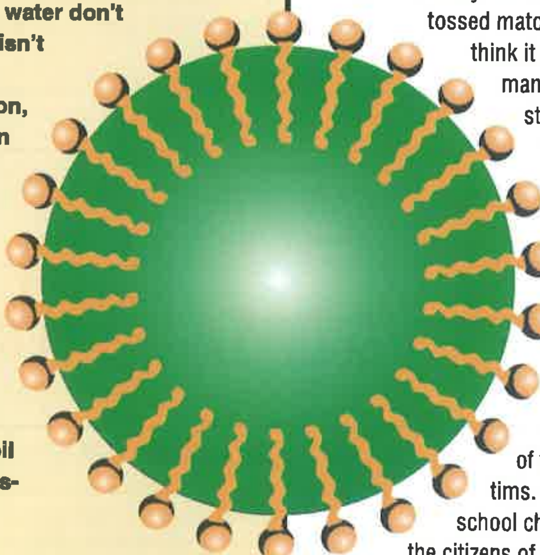
FURTHER READING

O'Nan, Stewart. *The Circus Fire*. First Anchor Books: New York, 2000.

COLLOIDAL DISPERSIONS—OIL AND WATER MIX!?

Instead of dissolving paraffin or some other oil-based waterproofing agent in gasoline, why not dissolve it in water instead? Water is cheap and, most importantly, nonflammable. But is this possible? You've probably already heard that "like dissolves like" or the more common "oil and water don't mix." Sometimes, this helpful rule isn't exactly true.

In the presence of soap solution, oil from your clothing can be drawn into water to form a colloid. A colloid essentially consists of particles of one substance dispersed throughout another. Soap molecules are able to form spherical structures in water, known as micelles, with hydrophobic (water-fearing) tail interiors and hydrophilic (water-loving) head exteriors. A soap micelle, with an oil droplet in its center, can remain suspended in water indefinitely.



A soap micelle, with an oil droplet in the center, can remain suspended in water indefinitely. Without soap, the droplet would merge with others of its kind, making a large pool of insoluble oil.

The difference between a solution and a colloid is somewhat arbitrary. In a solution, the different ingredients dissolve into tiny particles less than 1 nanometer (nm) in diameter. In a typical stable colloid, the particles are larger, up to 100 nm, although they are still invisible without an optical microscope.

Milk is a familiar liquid-in-liquid dispersion (emulsion) of protein and fat in water. In fact, before commercial paint was available, people used to paint their houses with homemade formulations of milk, lime ($CaCO_3$), and available pigments. Depending on the number of coats given to bare wood, milk paint can be a very water-resistant coating.

The exact ingredients of Hooper Fire Chief Fireproofing are unknown today, but the description of it as a thick milky substance suggests that it was similar to water-based paint, which is a solid-in-liquid colloid.

NATURAL, BRAIDED, BLEACHED, COLORED, STRAIGHT, AND CURLY HAIR ... Thanks to Chemistry

By Lois Fruen

The way you style your hair can make a bold statement about who you are. There are lots of different styling products that can give you the look you want, and those products are all formulated by chemists. Many of these products also help repair potential damage caused by blow-drying, coloring, and straightening your hair.

Below is an overview of hair products that you can find in your favorite store. You will discover some of the chemicals they contain and how some of them interact with your hair.

Conditioners

To add moisture to hair and smooth the cells on its surface—collectively called the hair cuticle—most people use hair conditioners, which help untangle and improve hair appearance, prevents hair from getting dry and brittle, and makes locks easy to brush.

"Stripped of its natural oils, hair feels dry and raspy," says Anita Grahn, a cosmetic chemist at Aveda Corporation. "This is because strands of negatively charged hair repel each other, causing so-called 'flyaway hair.'"

Hair conditioners usually contain positively charged molecules called quaternary ammonium compounds, such as stearalkonium chloride (Fig. 1), which bind strongly to the hair surface and then act as the new hair surface. Conditioners usually also contain molecules called amino silicones that fill in the splits, cracks, and chips present on the surface of damaged strands.

HEADLINE PHOTOS FROM JUPITERIMAGES

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Both ingredients work together to add weight to the hair, make it easier to comb, and restore the essential oils needed to make hair healthy. A hair strand that was exposed to a conditioner is shown in Fig. 2.

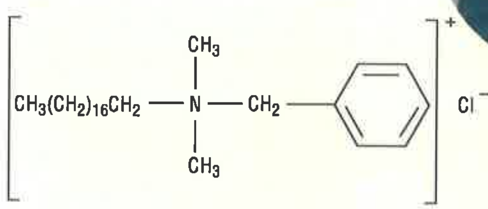

Figure 1. Stearalkonium chloride

COURTESY OF AVEDA

Figure 2. Hair strand with conditioner.

Antihumectants

If your hair frizzes in humid weather, you can use an antihumectant pomade, which contains chemicals free of water.

Substances that repel water often feel oily or greasy, which is unappealing. But most antihumectants are not greasy, yet they repel water. The reason is that most atoms in greasy substances have nonpolar bonds with their neighboring atoms, that is, they share electrons equally. Instead, antihumectants contain a molecule called isopropyl palmitate (Fig. 3), in which some atoms have nonpolar bonds with their neighbors, while other atoms have polar bonds, in which electrons are unequally shared with neighboring atoms. This doesn't make the antihumectant greasy, yet it repels water.

Christine uses an antihumectant to give her hair high gloss and sheen and protect her hair from the heat of her straightening iron.

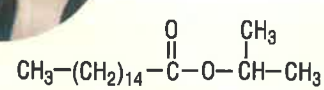

Figure 3. Isopropyl palmitate

In addition to isopropyl palmitate, antihumectants also contain phenyl trimethicone, which acts like a lubricant to add shine and makes hair easier to brush. These ingredients are dissolved in a solvent, such as cyclopentasiloxane, which evaporates readily and prevents the ingredients from feeling heavy or oily.

Styling products

Once your hair is conditioned and defrizzed, you can use one of many styling products. For example, styling gels prevent fine hair from falling flat and make it shine with a substance called a film former that forms a coating around the strands of hair as the gel dries.

In these gels, molecules called polymers, which contain a chain of identical units, make a film that steps in between hair strands, drawing them together. When the gel dries, it forms a firm connection between the hair strands which can be immediately undone by brushing or washing.

ALL STUDENT PHOTOS BY JACOB MILLER. PHOTO OF OSIE BY ACS STAFF

Styling gels are usually used to make hair stand out. This way, you can try to make a Mohawk spike—like the British punk-rock band G.B.H. or *American Idol* finalist Sanjaya Malakar—or a fauxhawk—like the British soccer player David Beckham.

"Some of these styling products are really sticky to start, but they dry down to a nice film," Grahn says.

The chemicals at work in these products have exotic names, such as polyvinylpyrrolidone (PVP) and a molecule called a copolymer made of a chain of smaller molecules called methyl methacrylate, octyl acrylamide, propylene glycol monomethacrylate, butylaminoethylmethacrylate, and acrylic acid (Fig. 4). In the copolymer, some of these molecules are positively charged, while others are negatively charged, making the copolymer soluble in water, so that it can be removed with a shampoo.

You may also want to give your hair a gritty, messy look. You can try a product that uses grit wax, which works by coating

Jan styles his hair with boosters that contain polyvinylpyrrolidone and methacrylate copolymers.

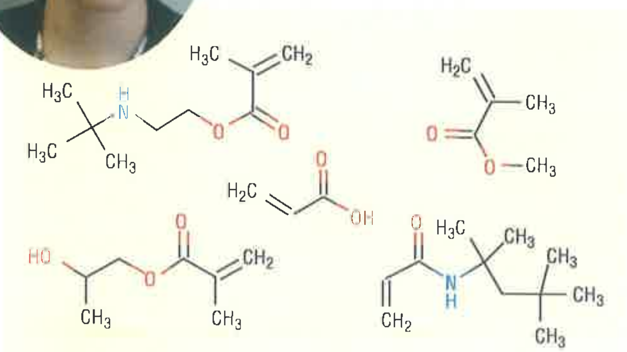

Figure 4. The monomers used to make the copolymer are (clockwise from top right): methyl methacrylate, octyl acrylamide, propylene glycol monomethacrylate, butylaminoethylmethacrylate, and (center) acrylic acid.

To style his dreadlocks, Osie uses a conditioner and shampoo for dreadlocks. After the hair is twisted, he uses a locking wax that holds the hair in place, and then he dries it with a blow dryer.

$$CH_3-CH(OH)-CH_2(OH)$$

Figure 5. 1,2-propylene glycol.

the hair with powdered starch for separation. But if you prefer lacquered spikes, you can try polyurethane products.

Styling products for dreadlocks can make extremely thick gels in water, helping to wash hair and keep a twisted rope styling. Such products contain a dye called D&C Yellow 11 and a thick oily liquid called 1,2-propylene glycol (Fig. 5).

Frizzy and springy hair benefits from moisturizing products that soften the curls while fighting frizz. Such products contain polyquaternium-11, a molecule that reduces frizz while softening the curls.

Hair dyes

You can also change the color of your hair. You can do it in one of three ways: temporarily, semipermanently, and permanently. Dyes used for temporary hair color contain pigment molecules that are large and, therefore, don't penetrate the cuticle layer. Instead, they coat the cuticle and may be removed by shampooing.

Semipermanent hair dyes deposit color on the hair shaft but don't remove the hair pigments. These dyes contain small molecules that penetrate the hair shaft.

The third type of dyes first removes the hair pigments with a chemical called hydrogen peroxide (H_2O_2). This process is called lightening, since it gives hair a lighter color. Then other chemicals such as *p*-aminophenol (Fig. 6) penetrate the hair and give it a new color.

You can also do highlights, which consist of selecting small or thick strands of hair and giving them a color that is at least two


ISTOCK PHOTO

Mary Ann likes soft, nonfrizzy curls, so she uses products with polyquaternium-11

Emily lightens her hair with products that contain *p*-aminophenol.

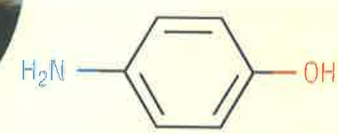

Figure 6. *p*-aminophenol

What Does

Anita Grahn is a cosmetic chemist who works for Aveda Corporation. She uses her degrees in chemistry and biology to formulate new products and to monitor her formulations for quality and safety.

Grahn likes to use for herself the products that she and her team have developed. She likes to give body to her hair, so she uses Pure Abundance, which gives some volume to her hair.

"I designed Pure Abundance to rough up my hair cuticles, which are the cells located on the surface of each hair," she says. "Most hair products are designed to keep cuticles lying flat, but Pure Abundance makes cuticles flare out without damaging them, which gives hair a fuller look."

Madia straightens her hair with phenyl trimethicone and a flat iron.

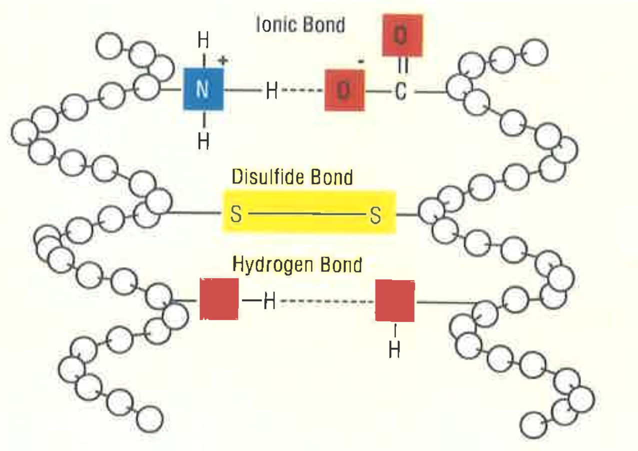

Figure 7. The three main types of bonds between proteins (white chains on right and left) inside a strand of hair: ionic, disulfide, and hydrogen bonds.

Elliot uses hydrogen peroxide to remove his hair pigments before dying his hair with a hair cream, and then he styles his hair with polyvinylpyrrolidone.

shades lighter than the rest of your hair. Hair creams that contain acetic acid, cetearyl alcohol, and a dye called D&C Red 33 can give you funky burnt-orange and pink streaks.

Straightening your hair

Maybe you are looking for straighter hair. You can temporarily straighten your hair with a hot ceramic flat iron that works at temperatures between 170°C and 230°C. The flat iron realigns bonds between proteins inside each hair strand.

Each strand of hair is made up of millions of long chains of proteins cross-linked with each other by three different types of bonds called hydrogen, salt, and disulfide bonds (Fig. 7). When you apply heat to your hair, these bonds are the first to break, but they can easily reform by drying or cooling your hair.

But heat from the iron can also frizz your hair, so be sure to use a defrizzing product. Such products use a variety of silicones, such as phenyl trimethicone, along with cyclopentasiloxane for lightness. All of these chemicals handle the heat of the iron to make hair shiny and leave it soft after straightening.

To permanently straighten your hair, you can use a lotion or cream that relaxes hair curls called a relaxer. This product permeates the protein structure of the hair and weakens its internal bonds, causing the natural curls to loosen out. Some relaxers use potassium hydroxide (KOH), lithium hydroxide (LiOH), or a combination of calcium hydroxide ($Ca(OH)_2$) and a solution of guanidine carbonate.

a Cosmetic Chemist Do?

Anita Grahn, Director of Hair Care Research at Aveda Corporation.

During her 16 years at Aveda, Grahn has prepared a number of the company's most popular hair products, such as Custom Control and Rosemary Mint Shampoo. Her team of eight chemists also has prepared many of the hair products that are sold in Aveda shops, including Be Curly, Brilliant Anti-humectants Pomade, and Hang Straight.

Grahn's team is now working on a new shampoo plus conditioner that will be launched soon. The scientists are also working to find alternatives to petrochemicals that are still used to prepare some products. "My team is currently experimenting with plant waxes that hold hair in place using viscosity," she says.

Grahn also works with many other scientists, including microbiologists who ensure that products are free from bacteria; formulators who find ways to use raw materials in new and innovative ways; perfumers who formulate aromas; color chemists who make products appealing to consumers; and chemical engineers and technicians who test products on hair.
—Lois Fruen

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Lois Fruen teaches chemistry at Breck School in Minneapolis, Minn. Her most recent *ChemMatters* article, "Real of Fake? The James Ossuary Case," appeared in the February 2006 issue.