Question From the Classroom

By Bob Becker

Q: Our chemistry teacher told us that when a candle burns, it's really the wax that's burning. I always thought that it was the wick that burns and that the wax is just there to make it burn slowly. Who's right?

A: To be sure, the wick does burn, but the vast majority of light and heat given of from a candle comes from the combustion of the wax, so I'd have to rule in favor of your teacher on this one. To be completely accurate, it's actually the wax vapors that are burning. Here's how it works:

When you light the wick of a candle, the heat and light radiate out in all directions: some of the heat radiates down and melts a small portion of the wax around the base of the wick. The wax used in candles is not a single compound, but a mixture of long, straight-chain hydrocarbon compounds—generally in the range of $C_{20}H_{42}$, $C_{21}H_{44}$, etc. Once the wax is melted, these molecules are free to move about, and being attracted to the molecules of string that make up the wick, they tend to soak up the wick by a process known as capillary action. This is the same way that water is absorbed by a paper towel. As the wax soaks up the wick, the heat from the flame causes it to vaporize; this allows the wax to mix with the oxygen in the air and burn.

"Burn" in chemistry means to react exothermically with oxygen.

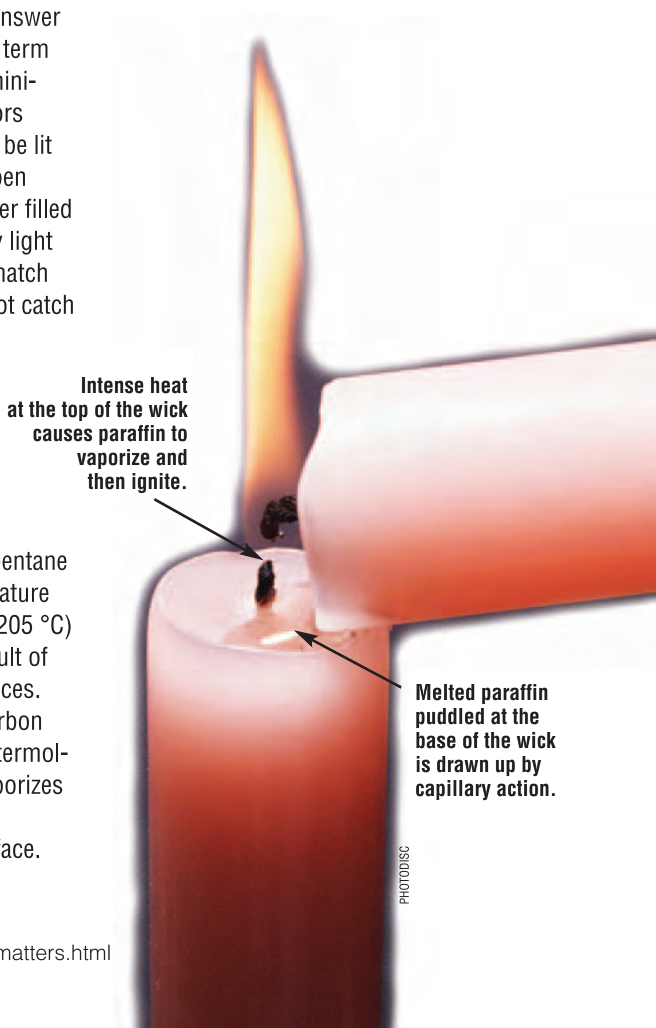
The flame actually serves many purposes: First, it melts the wax of the candle, so that it can be "wicked up" the wick, and then it vaporizes that wax so that it can mix thoroughly with the oxygen. Also, the flame creates convection currents around it, which bring fresh air into the mix so that the wax can continue to burn. Also, the flame provides the activation energy for the reaction to take place.

Thus, the flame is a self-sustaining process: the energy released by each hydrocarbon molecule as it reacts with oxygen enables the next molecule to be brought up and burned. This continues until either the wax runs out, the wick runs out, the oxygen runs out, or the cycle is interrupted by a quick burst of air and a resounding chorus of "Happy Birthday to You!"

If it's true that the wax is the main component that is burning, then you may wonder whether or not it is possible to light a candle without the wick. To answer this question, we need to define the term **"flash point"**. Flash point is the minimum temperature at which the vapors above a combustible substance can be lit by an ignition source, such as an open flame. A lit match brought to a beaker filled of liquid pentane would immediately light the liquid on fire. But that same lit match brought to a beaker of wax would not catch it on fire—at least not at normal room temperature. This is odd when you consider that both of these substances are made up of the same elements (carbon and hydrogen), and both are capable of burning. The difference lies in the flash points: The flash point of pentane (–46 °C) is well below room temperature (25 °C), but the flash point of wax (205 °C) is well above it. This is mostly a result of the vapor pressure of these substances. Pentane's very small-chain hydrocarbon molecules result in much weaker intermolecular attractions; thus, pentane vaporizes readily at room temperature, readily enough to sustain a flame at its surface.

Below a certain temperature (–46 °C), pentane's vapor pressure becomes low enough that it would not catch fire. Wax, on the other hand, is made up of much longer-chain hydrocarbon molecules, and thus, it has considerably stronger intermolecular forces, strong enough to make it a solid at room temperature. This gives wax a very low vapor pressure, way too low to sustain a flame at its surface.

Above its flash point (205 °C), however, the wax molecules will evaporate a sufficient extent to sustain a flame, and it would be possible to burn a wax candle without the aid of a wick



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TEACHERS!
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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

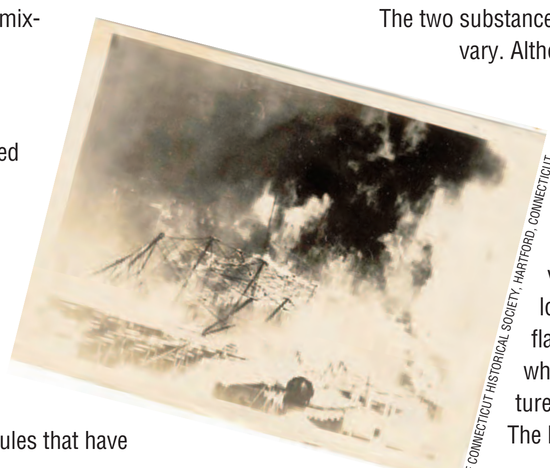
To understand waterproofing, you need to understand water. As you know, water molecules are composed of two atoms of hydrogen and one atom of oxygen. Because of the different characteristics of the oxygen and hydrogen atoms, the area of the water molecule near the oxygen atom is slightly negatively charged, 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.



THE CONNECTICUT HISTORICAL SOCIETY, HARTFORD, CONNECTICUT

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

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.

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

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 firebombing 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?

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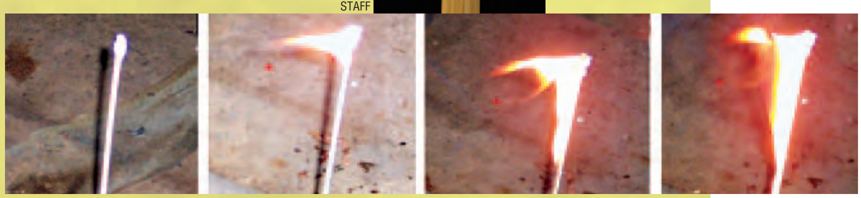


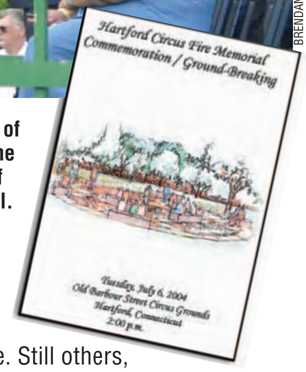
Similar to napalm, when a small amount of the tent waterproofing agent is ignited; it rapidly drips and spreads a sustained fire down a stick.

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.

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.


BRENDAN RIMETZ

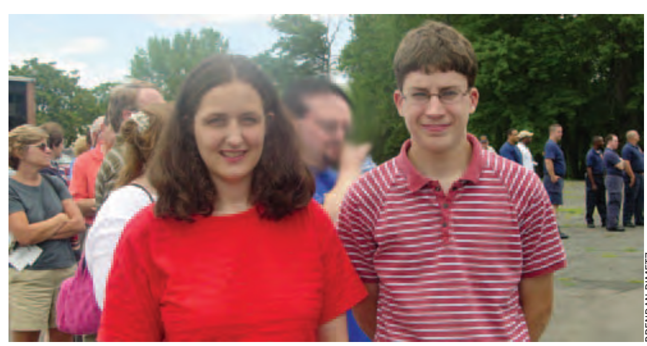


Mayor Perez of Hartford at the dedication of the memorial.

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 Great Hartford


BRENDAN RIMETZ

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.

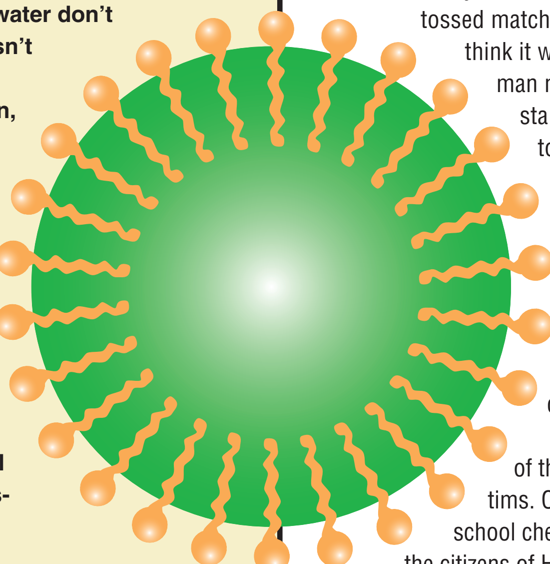
FURTHER READING

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.

ChemShorts

Ice spikes

Talk about your strange, yet ordinary things—ice spikes are real oddities. It's even possible you've seen them in a freezer near you! They grow out of ice cube trays, forming curious-looking peaks up to 5 cm high.

Under the right conditions, ice spikes grow as water freezes in an ice cube tray. Put a tray in the freezer, and you will notice that freezing begins at the edges of the tray. As surface freezing moves in from the edges, a small hole can be left at the top of each cube. At the same time, the bottom and sides of the cube are also freezing. As you know, when water freezes, it expands and becomes less dense. The pressure from the expanding ice forces the remaining unfrozen water up through the hole. It eventually forms a spike.

You've never seen them? The reason could be related to the purity of your water. According to research mentioned on the Web site SnowCrystals.com, the presence of even small amounts of NaCl can reduce spike production.

SNOWCRYSTALS.COM

So how do you make your own ice spikes? Buy some distilled water and fill up your ice trays. If you can't make ice spikes after a few tries, consider raising the temperature of your freezer to just below freezing. Your freezer might be too cold to allow the formation of spikes.

ACS STAFF

Pulse oximetry

If you've visited someone at the hospital recently, you might have seen a clip attached to their finger with a red light coming out of it. The clip is actually a probe attached to a monitor that gives pulse rate, as well as the percentage of oxygenation of the blood—important information for a doctor to know from moment to moment. This noninvasive method is known as pulse oximetry.

How does it work? The probe shines two wavelengths (650 and 805 nm) of light through the finger, earlobe, or foot of the patient and detects how much of the light is absorbed. Hemoglobin—the oxygen-carrying protein in blood (see "The Silent Killer" in this issue)—absorbs light at different wavelengths depending on whether oxygen is attached to it. Measuring the absorption of light at two wavelengths enables a computer processor to quickly calculate the percentage of hemoglobin saturated with oxygen. If oxygen saturation falls below a predetermined level, say 90%, an alarm bell sounds to alert medical staff.

The red glow comes from a probe attached to a baby's foot. Pulse oximetry allows doctors to continuously monitor percent blood oxygenation.

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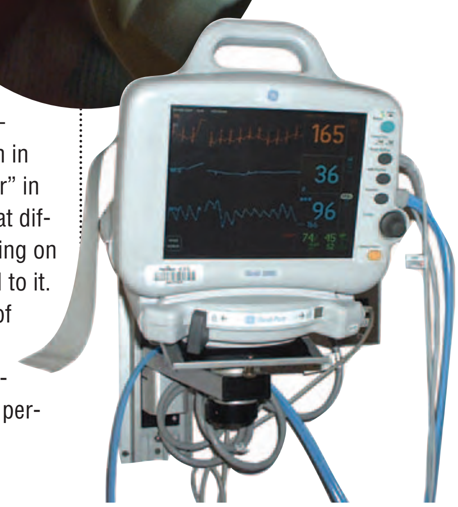
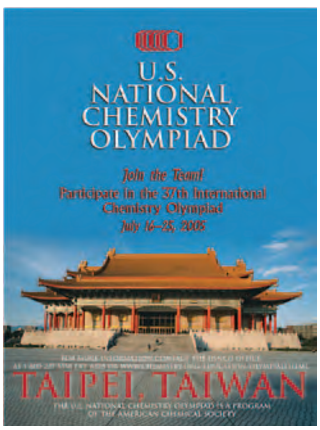


Chem.matters.links

The 37th International Chemistry Olympiad—Tapei, Taiwan

Do you have what it takes to be a *chemistry* Olympian? Each year, over 200 of the best high school chemistry students, their mentors, scientific observers, and guests from more than 60 countries gather in July for a 10-day chemistry competition called the International Chemistry Olympiad (IChO).

The competition includes both a five-hour exam of basic knowledge and problem solving and a five-hour laboratory practical. The level of difficulty of the challenge is on a par with mid-level college chemistry courses. Medals are awarded based on of the total exam scores from both sections with the top students winning gold, silver, and bronze medals.



The U.S. team has performed well at the international event. In 1999, the team placed first and won the top gold medal; in 2000, a member of the U.S. team won the top individual gold medal.

How will the top U.S. students be selected in 2005? As the result of a selection process that may include examinations, science fairs, or teacher's recommendations, 800 students representing 125 of the local sections of the American Chemical Society (ACS) will be chosen to take the U.S. National Chemistry Olympiad examination in March.

On the basis of their performances on the qualifying exam, twenty of the nation's top high school chemistry students will be selected to attend a 10-day study camp to be held in June at the U.S. Air Force Academy in Colorado Springs, CO.

At the camp, students will take part in an intensive study program that includes organic, inorganic, analytical, and physical chemistry. During the two weeks, the camp directors will observe student performances related to laboratory work, teamwork, and basic knowledge. At the end of the camp, four finalists and two alternates will be selected to represent the United States at the 37th International Chemistry Olympiad in Taipei.

Want to try out for the team?

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

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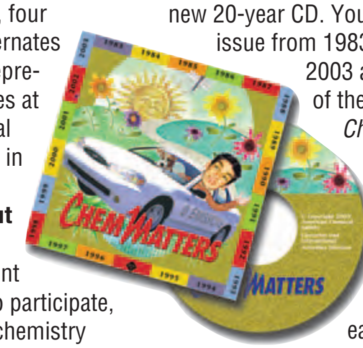

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