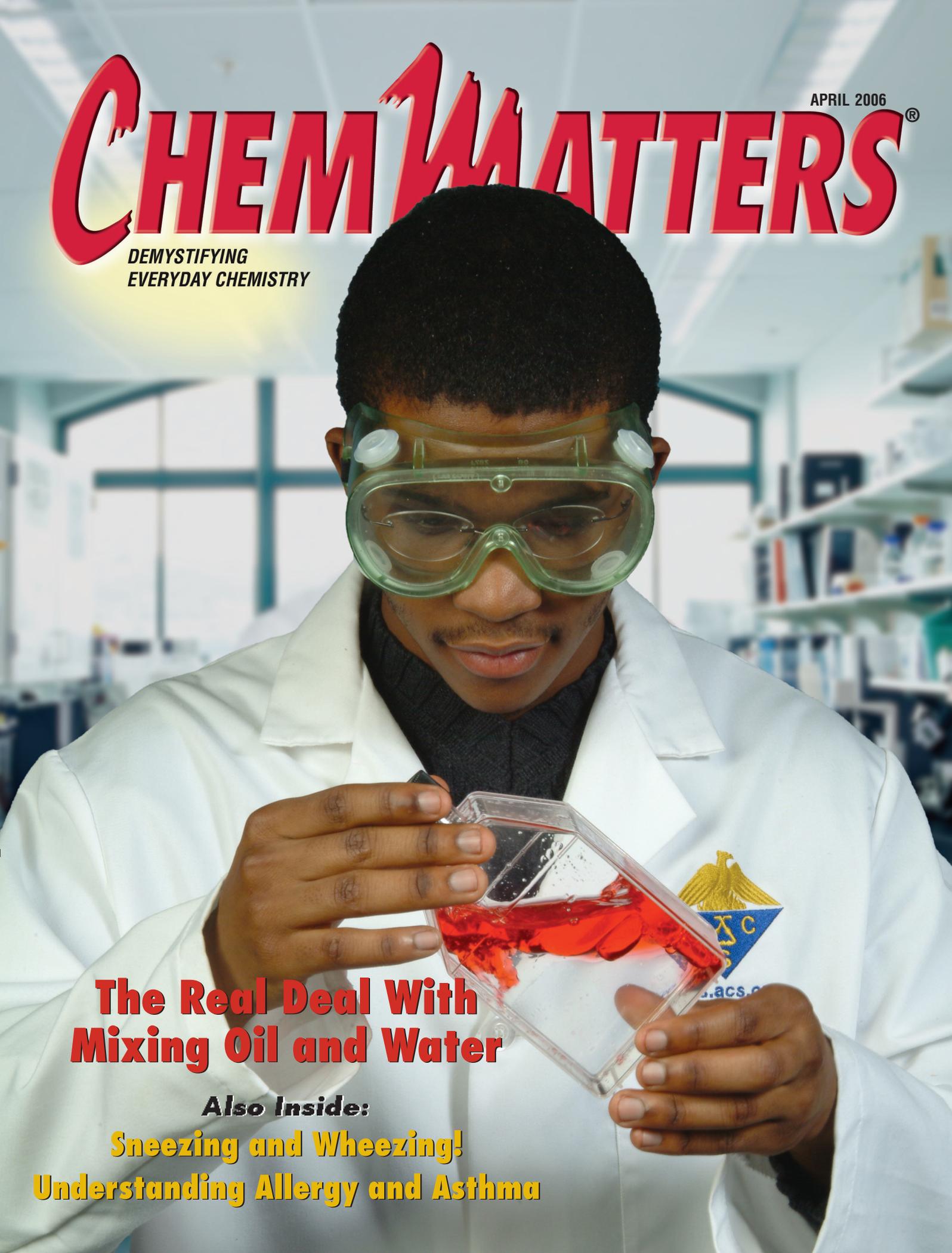


CHEM ¹MATTERS[®]

APRIL 2006

DEMYSTIFYING
EVERYDAY CHEMISTRY



**The Real Deal With
Mixing Oil and Water**

Also Inside:

**Sneezing and Wheezing!
Understanding Allergy and Asthma**

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Question From the Classroom

By Bob Becker

Q: Why do water and oil not mix? I always thought it was because oil was less dense than water, but my teacher said that water molecules would rather stick to other water molecules, and oil molecules would rather stick to other oil molecules, and that's why they don't mix. He says "like dissolves like". Which one of us is right?

A: A lot of people learn that oil floats on water because it is less dense, and they interpret this to mean that oil and water do not mix because oil is less dense. Its low density is what makes the oil end up on top of the water as they separate, but it's not what prevents the two liquids from mixing in the first place. For a better explanation, I have to side with your teacher on this one: The inability of water and oil to mix (also known as immiscibility) is a direct result of intermolecular "preferences", but it turns out that what your teacher is saying has a common misconception in it as well.

Before we get to that misconception, though, let's talk "polar". Not quite as in "north pole" but as in diametric, or in plain English, opposite ends. Molecules are held together by covalent bonds consisting of pairs of shared electrons. If one of the atoms in the bond pulls the electrons more strongly, that tends to attract the electrons toward its end of the molecule. This gives that electron-rich end a partially negative charge (δ^-) and the other end—the atom end where the electrons have made themselves scarce—a partially positive charge (δ^+). These attractions are known as dipole-dipole attractions. Particularly strong dipole-dipole forces are present among molecules where hydrogen is bound to an atom with a very strong pull on the shared electrons (namely, nitrogen, oxygen, and fluorine), and go by the name "hydrogen bonds". Water is an example of a molecule that forms hydrogen bonds. This is significant because it makes water molecules very sticky to one another with the (δ^-) end of one molecule attracted to the (δ^+) end of a neighboring molecule.

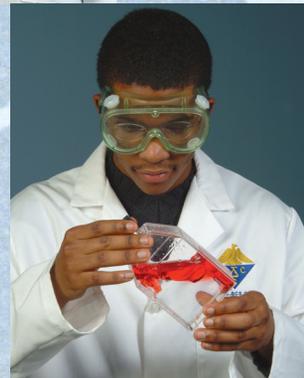
But what about the oil? The bonds within an oil molecule consist of pairs of electrons that are shared pretty equally between the participating atoms. The result? Because there are no (δ^-) and (δ^+) ends, these bonds are nonpo-



MIKE CIESIELSKI

lar and the molecule overall is considered to be nonpolar as well. There is, however, random movement of the electrons within these molecules, and this can lead to temporary lopsidedness in their charge distribution and produce momentary δ^+ and δ^- portions of the molecule. These, in turn, can lead to very weak attractive forces known as induced dipole-induced dipole, or London forces. Because hydrogen bonding in water contributes a substantial amount of cohesive energy, over and above the London forces present, water is a liquid, whereas other molecules of similar size but lacking water's polarity, such as methane, ethane, fluorine, or carbon dioxide, are gases at room temperature.

And now for the misconception: your teacher's explanation makes it sound as though the immiscibility of oil and water is one of mutual agreement and that there is no attraction existing between a water molecule and an oil molecule. Some teachers go as far as to say that oil and water molecules repel one another. In fact, the term often applied to nonpolar substances such as oil is "hydrophobic", which means "water fearing." The truth is that an oil molecule is very attracted to a water molecule—even more than it is to another oil molecule. Because the water molecule has a fixed polarity (a permanent dipole), it is much more capable of inducing a temporary dipole in a nearby oil molecule than is another nonpolar oil molecule. The (δ^+) end of the water molecule attracts the electrons in the oil molecule

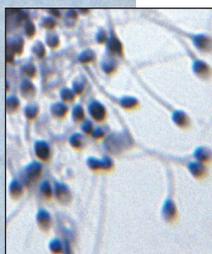


up close to it and this creates a (δ^-) end right there next to the water's (δ^+) end. Likewise, the (δ^-) end of the water molecule repels the electrons in the oil molecule to the far side, and this creates a (δ^+) end right there next to the water's (δ^-) end. These are known as dipole-induced dipole attractions, and they are significantly stronger than the induced-dipole-induced dipole attractions acting between two neighboring oil molecules.

What this means is, if you were an oil molecule, you would much rather surround yourself with water molecules than with others of your own kind. If that's the case, why then do oil and water not mix? If it were up to the oil, they would. But it turns out that the dipole-dipole attractions described above are so much stronger than dipole-induced dipole, that it is really the water molecules that are calling the shots. Water molecules are far too attracted to their own kind to ever allow any oil molecules to come in-between. In short, water molecules are very cliquish. They will allow other polar molecules such as ethanol or ammonia to enter their exclusive company, but a nonpolar molecule: no way! The only molecules that would associate with nonpolar molecules would be other nonpolar molecules.

So even though it's true: oil and water don't mix, it is hardly by mutual agreement. A really impressive illustration of this discrepancy occurs when a drop of water is placed on a nonpolar surface such as wax paper. The drop of water beads up into a sphere barely touching the wax paper. One can almost visualize the water molecules all gathering together in their exclusive club, not wanting to associate with those lowly wax molecules at all! But when the tables are turned, and a drop of nonpolar liquid is placed on a polar surface, such as occurs when a drop of motor oil falls onto a wet pavement, a very different outcome is observed. Rather than beading up into a tiny sphere, the oil drop spreads out into an infinitesimally thin layer—this is what causes the cool concentric rainbow patterns. In this arrangement, each oil molecule is in minimum contact with other oil molecules, for which the attractions are so weak, and in maximum contact with the much more attractive water molecules.

In this way, like does dissolve like: Polar substances dissolve other polar substances, and nonpolar dissolve nonpolar, but for polar substances, it's a matter of preference and for nonpolar ones, it's more a matter of settling for what you can get! ▲



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The Dog Ate My Homework

and Other Gut-Wrenching Tales

By Michael Tennesand

WANTED!



"Midge"

**Reward for Recovery
of \$180 Missing Cash**

**You'd love Midge.
She's your ordinary,
fun-loving dalmatian
with a great
personality and one
bad habit. She loves
the taste of money,
paper money!**

The crime

Recently, Midge's owners Kit and Steven were serving as hosts for a favorite singer/songwriter, an old acquaintance who was in town for a local concert. Things went well until the door to the guest bedroom was left ajar. Under normal circumstances the open door would not have been a problem, but for lovable Midge, it was a doorway to opportunity. There, on the bedside table was \$180 in cash and a check. So tempting! Not to mention delicious!

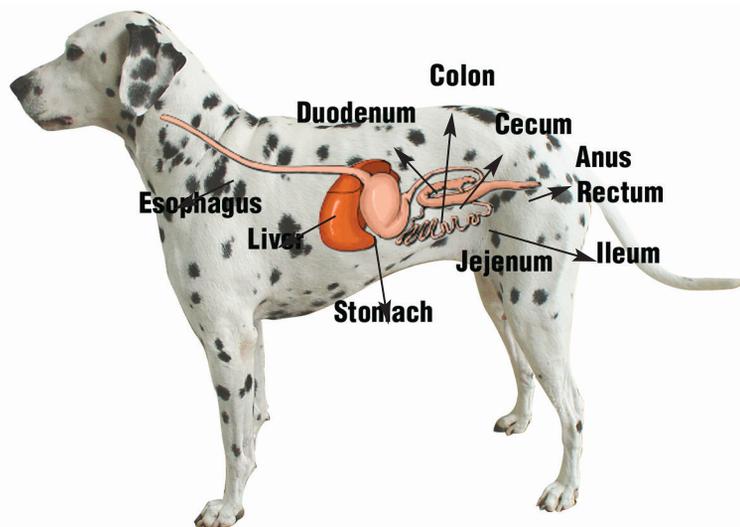
When the break-in was finally discovered, all that was left was a few shreds of the check. No sign of the \$180 cash. Thus, the wait began. For Kit and Steven, walking the dog took on an entirely new sense of pur-

pose. Picking up after Midge required an additional close inspection to see if any of the bills made it through her digestive system intact. The project gave "money laundering" a whole new meaning. Gross? Definitely. But luckily, there was some good chemistry working in favor of retrieving the cash.

The chemistry of digestion

At the most fundamental level, the biological processes of digestion and metabolism are all about the breaking and making of chemical bonds.

Basically, digestion consists of breaking food down into molecules small enough to diffuse through the thin walls of blood ves-



The digestive system of a dog.



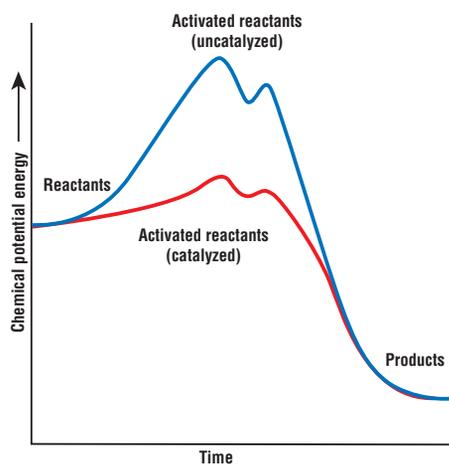
ACS STAFF

sels. After transport through the body, they cross over into tissues where they are absorbed and used by living cells.

Food is primarily composed of large biomolecules such as proteins, fats, and carbohydrates. The “breaking down” of food is the breaking of chemical bonds that hold the molecules of the food together. After the molecules of food are broken down into small enough pieces for cells to absorb them, they are either consumed completely for fuel or reassembled into new polymers and other molecules, according to the body’s own blueprint.

The process of breaking bonds in food includes a number of key steps. Except for animals like pythons who swallow their food whole, the process of digestion usually begins with a physical phase. Chewing breaks the food into smaller pieces, thereby exposing more surface area, which accelerates the process of digestion.

Next, most animals have some sort of specialized sac or pouch, such as a stomach, where serious digestion gets under way. In humans, a strong acid secreted by the stomach helps break down tough connective tissues and activates a set of biological catalysts called enzymes. Like all catalysts, enzymes greatly accelerate the rate of chemical reactions without being used up in the process. A single enzyme molecule can catalyze a reaction thousands of times. But that is not to say that an enzyme is able to catalyze thousands of different reactions. In fact, most enzymes catalyze single specific reactions.

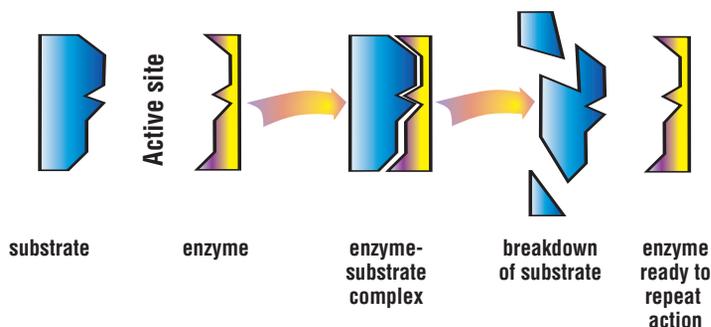


The red line in this graph shows the lower activation energy in a catalyzed reaction.

Enzymes lower the activation energy, the energy required to start the reaction, by securing the reactants in a geometrically favorable position. Held this way, the molecules react with little initial energy—less than if they had to rely on random collisions to bring them together. Once bonded, they are released, and the enzyme is free to act again.

Enzymes can also work to break bonds. In this case a single molecule fits with the enzyme in such a way that one particular bond is stressed. This stress lowers the energy requirement for breaking the bond.

Because the interactions between the enzyme and the substrate molecules are totally dependent on shapes, each reaction requires its own enzyme. Virtually all of the

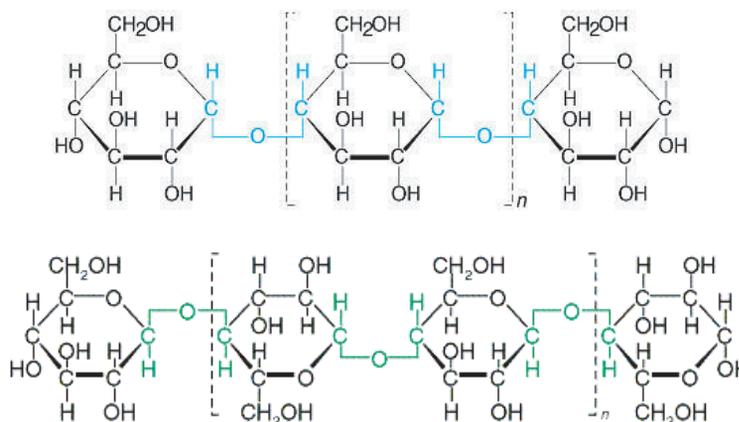


The lock and key model of enzyme action.

This is easier to understand once you understand how enzymes work. In what is often called the “lock and key” model, enzymes participate in chemical reactions based on the shape and structure of the reactants. An enzyme can join reactants (often called substrates) together by offering adjacent surface features where the reactants can fit. In this case, the enzyme makes it much easier for bonds to form in a reaction that is already energetically favorable.

chemical reactions that occur in living cells rely on one or more enzymes to allow them to occur at a useful rate. Just like each lock requires a key with just the right shape, each chemical reaction requires an enzyme with the right shape.

And all of this explains why Kit and Steven were optimistic about seeing their \$180 again, even after it had been subject to Midge’s digestive process and the accompanying onslaught of enzymes.



The only difference between starch top and cellulose bottom is the way the ring-shaped glucose molecules are connected (blue-colored bonds).



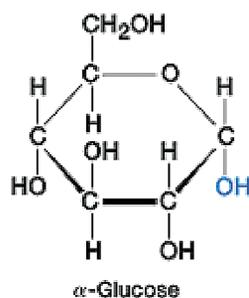
The paper currency is clearly intact after passing through the dog's digestive system.

Cellulose—defying digestion

The enzymes found in humans and other animals allow them to digest and metabolize many, but not all, biomolecules. Cellulose is one example of a molecule that defies digestion in many animals. This is an interesting exception because cellulose, a structural material found in plant cell walls, is made up of the same glucose subunits as digestible starch. Glucose is a simple sugar that provides fuel for most organisms. But the slight difference in the way the glucose molecules are hooked together in starch, compared with how they are hooked together in cellulose makes a big difference in their digestibility. Humans and many other higher animals have the enzyme required to break the bonds in starch, releasing glucose. But because the shape of the linkage is different in cellulose, the same enzyme will not work. In fact, where cellulose is concerned, humans do not have an enzyme that will work. Neither do dogs. Which brings us back to Midge.

Paper money is made of cellulose in the form of very high-quality cotton and linen fibers. This cellulose not only resists the chemical processes that are a part of digestion, but also withstands the mechanical breakdown—chewing and shredding—that is part of the digestive process.

As it turns out, most humans eat a fair amount of cellulose in the form of fruits and vegetables. Although we cannot digest it, the cellulose serves as roughage or fiber that gives food bulk and keeps it moving through the digestive system. In the end, all of the undigested material ends up being eliminated as feces.



Glucose is fuel for most organisms and the building block for both starch and cellulose. Humans (and dogs) can break down starch into glucose but not cellulose.

The end ...

And so it was that Kit and Steven, with patience and endurance, were at last able to recover their \$180. Midge, like the goose that laid the golden egg, eventually passed all of the well-chewed bills in her feces.



Photomicrograph of cellulose fibers shows their linear nature.

Maybe you are wondering how animals such as cattle, sheep, deer, and goats thrive on a diet of grass or other cellulose-rich food. Can they digest cellulose when humans cannot? The answer is no. None of these animals

have the enzymes required to digest cellulose. Instead they rely on colonies of microorganisms living in their digestive systems. These simple microorganisms have the correct enzymes to digest the cellulose and to reassemble the products into starches and proteins. From these products, grazing animals acquire their nutrients. The special relationship between these animals and their resident microbes is called symbiosis—two organisms living with each other to the benefit of both.

As for Midge, it was a happy ending for all concerned. With the cash recovered, Midge eventually got out of the doghouse, and the songwriter was even inspired to write a new song to commemorate the entire affair.

So what are the chances—in the extremely rare case that a dog really DID eat your homework—that it might show up again undigested on the front lawn? Not good. The chemical processes that break down cellulose in the paper-making industry leaves a weaker form of cellulose in the product—so weak that there is little likelihood of it making its way through a dog's digestive system.

Better idea? Save to disk! Avoid magnets. But that's another story ... ▲



Michael Tinneland is the Associate Director of Academic Programs at ACS. His most recent article, "What's So Equal about Equilibrium", appeared in the September 2005 issue of *ChemMatters*.

Sneeze and Wheeze

By Roberta Baxter

Nose dripping, eyes and throat itching, and sneezing—allergies are no fun. But wheezing and struggling to breathe? That may be asthma.

All too many of us know the sneezes of allergies and the wheezes of asthma. The American Academy of Allergy, Asthma, and Immunology estimates that 40 to 50 million Americans have allergies, making them the sixth leading chronic disease in the United States. Close to 21 million Americans have asthma, with many of us suffering with both. Allergies are blamed for triggering the majority—close to 70%—of asthma attacks.

Learning how allergic reactions occur is often the key to living with and controlling the misery they create.

Breathe in!

The respiratory system resembles an upside-down tree. The mouth and nose connect with the trachea, which forks into two branches called the bronchial tubes. These tubes split into smaller and smaller passages called the bronchioles ending in the miniature sacs called alveoli. There, oxygen diffuses through the thin walls of the alveoli to be carried by red blood cells through the circulatory system to every cell in the body.

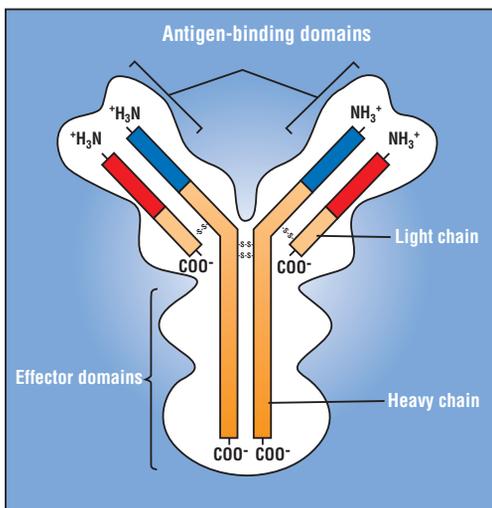


Carbon dioxide, released from cellular metabolism, is transported by the blood to the alveoli to be exhaled from the lungs.

For people with allergies and asthma, environmental conditions often trigger problems that affect the process of breathing. Affecting the cells lining the trachea and bronchioles, these triggers result in “twitchy” over-reactive airways. Although inflammation of the airways may be present even when the person is still breathing normally, a sudden swelling reduces the air flow, causing the all-too familiar wheezing associated with an asthma attack.

Allergy alert!

Allergy actually comes from a word meaning “altered state”, implying that something is going very wrong. What happens to body cells when they undergo allergic reactions? The story starts with the body’s immune system, a system designed to recognize and react to foreign matter. The immune system responds to the presence of foreign matter and defends the body in a number of ways. One type of response involves the creation of a hostile environment through conditions such as fever and or swelling. Another type of response involves the production of antibodies. Antibodies are glycoproteins (proteins that have a small car-



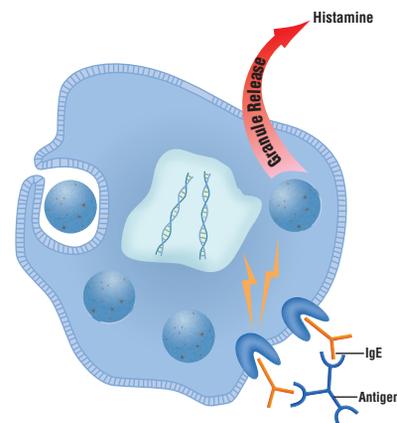
Antibodies are glycoproteins that bind and recognize antigens (foreign matter) and facilitate their removal.

bohydrate component). These large molecules bind and recognize specific antigens and facilitate their removal from the body via a complex series of steps. These harsh conditions make it difficult for bacteria and viruses to survive within the body. Normally, this is a good thing. The immune system protects you from the disease threat of bacteria and viruses. But, for allergy sufferers, the system becomes too much of a good thing, and that’s *bad*. Allergy sufferers often react violently to otherwise benign foreign

substances such as pollen, dander, dust, and mold spores. Put another way, the allergic person’s immune system reacts to false alarms.

A substance that causes an allergic reaction is called an *allergen*. With exposure to allergens, an allergic person develops unique antibodies to those allergens in much the same way that we develop a resistance to disease organisms. Pollen allergy, often called hay fever, is the most common type

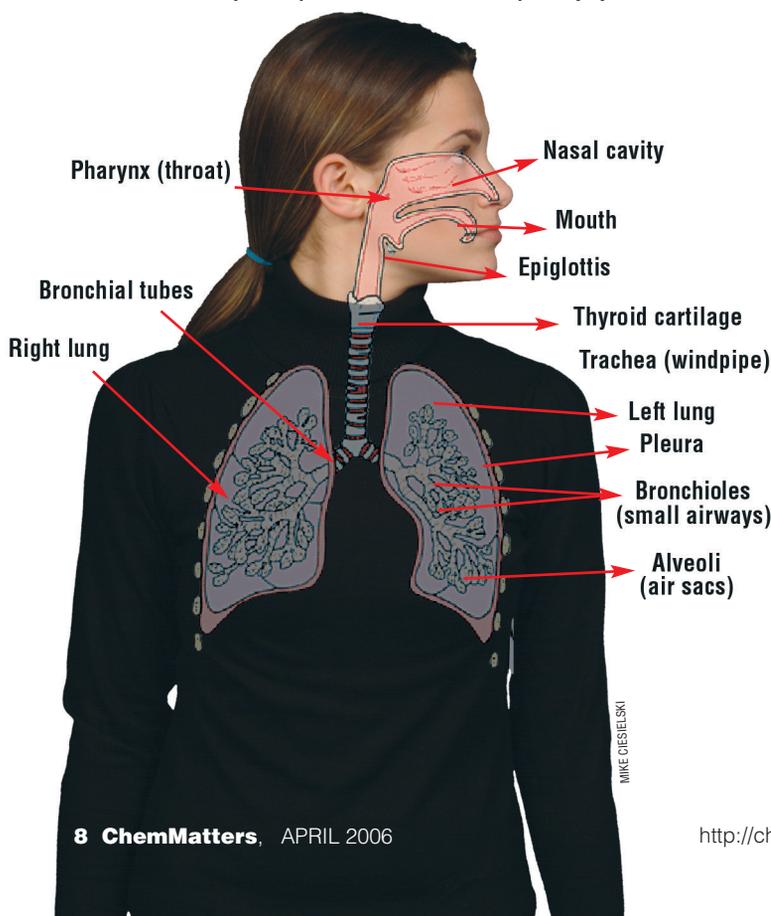
of allergy. The antibodies involved in the allergic response are called immunoglobulin E (IgE) antibodies. In allergy-prone individuals, during primary exposure to the allergen, specific IgE antibodies are produced. These antibodies have a unique chemical composition that is complementary to the shape and chemical features of the allergen. These antibodies bind to receptors on the surface of mast cells—cells of the protective immune system found in the tissues lining the nose, bronchial tubes, gastrointestinal tract, and skin. During the body’s second (and subsequent) exposure to the allergen, the allergen is introduced to these mast cells—bound antibodies, and it sticks tightly to the antibody’s binding site by virtue of its shape and chemical composition. That’s when the allergy cascade begins.

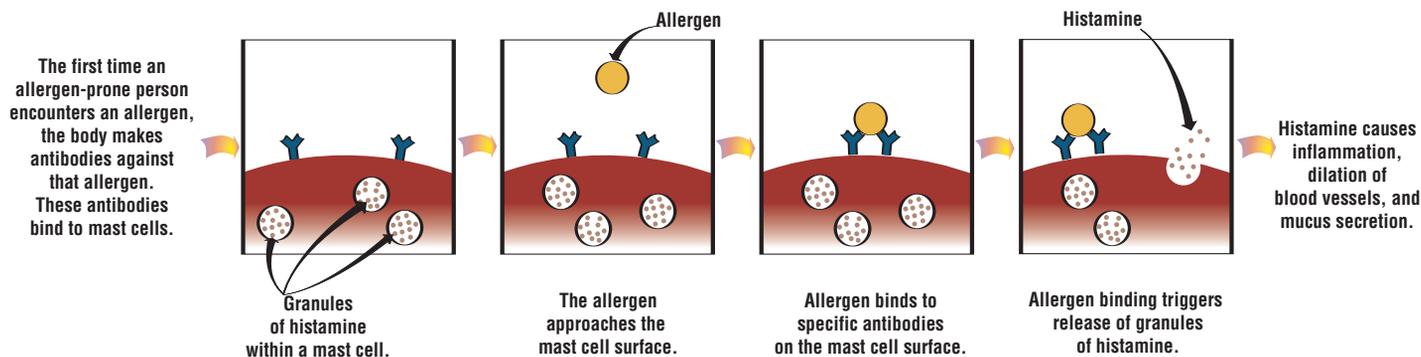


Mast cells, using the antibodies on their surfaces, bind antigens and release chemicals such as histamine.

The engaged mast cell, which now houses the allergen-antibody complex on its surface, explodes, releasing, among others, the chemicals histamine and leukotriene. Histamine and leukotriene irritate the delicate tissues of the nose and throat, causing inflammation. Tiny blood vessels in the nose and throat dilate, fluid leaks out, and swelling occurs in the passages. Excess mucus formation further constricts the passages. Your eyes and throat begin to itch, and your nose alternately drips or blocks up with congestion. Sneezing occurs as an attempt to clear your airways. Over time, the chemicals released into the bloodstream by the mast cell leads to the arrival and activation of more mast cells and other cells important in the immune response.

Major components of the human respiratory system.





Phases of an allergic reaction.

Allergy relief

Doctors recommend avoidance as the first step in allergy control. Some allergens such as foods, drugs, and animal dander can be avoided. But there aren't very effective ways to avoid pollens, spores, and other airborne particles, unless you plan to live in a bubble.

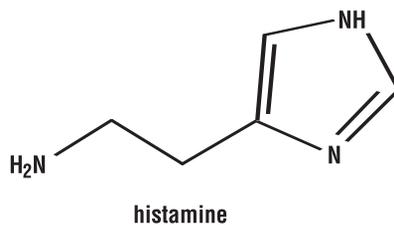
A group of medications containing antihistamines (against histamine) are generally prescribed for controlling allergy symptoms. Including familiar brand names like Zyrtec, Claritin, Benadryl, and Allegra, these medications block receptor sites in cells where histamine would normally bind to generate itching and sneezing. Antihistamines are most effective if taken before exposure to the allergen. Taken regularly, they also reduce the amount of histamine released by mast cells.

The newer antihistamine products have fewer side effects than before. Older antihistamines made many people feel sleepy and too groggy to perform normal tasks. Newer products are less sedating, but still cause dry mouth and restlessness in many.

In other products, antihistamine is combined with a decongestant, usually pseudoephedrine. The decongestant works to dry out and reduce the swelling in the nasal passage. Common decongestants are Sudafed, Coricidan and Neo-Synephrine. Besides commonly resulting in restlessness, jitters, and rapid heartbeat, nasal decongestants used longer than five days can cause a rebound effect. The result is the risk of becoming even more congested than earlier.

Steroid-containing nasal sprays have become frontrunner medicines for chronic allergies. These steroids are not the same as the illegal steroids used to enhance sports performance; however, their use may still

register on some drug tests that precede athletic contests. Steroid nasal sprays, with names like Flonase, Vancenase, and Nasalide, work to reduce inflammation in the nose by making the tissues less reactive. These medicines require a couple of weeks of use to reach their full effectiveness. Negative effects like sneezing, dryness, a burning sensation in the nose, or a bad taste in the mouth usually decrease over time.



Histamine is released by mast cells during an allergic response by the body. Histamine triggers a cascade of events that leads to inflammation of blood vessels, itching, and sneezing.

Allergy shots are sometimes used as a desensitization therapy. By injecting tiny amounts of allergen on a daily or weekly basis, the shots work to decrease the number of IgE antibodies. Doctors are not completely sure why the therapy works. Each sequential injection has a slightly higher dose of the allergen. After a time, the shots are given only once or twice a month. Many people can drop the therapy after about five years with no recurrence.

Asthma attack!

An asthma attack usually involves the same stages as an allergic reaction, except

that the airway tissue affected is the lining of the bronchioles. As the cells release histamine and leukotrienes, swelling occurs and excess mucus forms. To make matters worse, the muscles around the bronchioles tighten. Imagine a balloon with a string wrapped around it. When the string is tightened, it mimics the muscles constricting the bronchial tubes. Because the diameter of the bronchial tubes decreases dramatically, the person cannot breathe in or expel the air accumulated in the alveoli. The effort to inhale causes a wheezing sound.

Asthma attacks can be triggered by allergies or by irritants like tobacco smoke, cold air, aerosol particles, and vigorous exercise. Even strong emotions can trigger an attack in some people.

Asthma meds

When a person is having an asthma attack, there is only one priority helping them to get air into their lungs. Once an attack is under control, the focus shifts to preventing attacks. Some medications for asthma are prescribed for daily use to prevent the underlying inflammation; others are effective during an attack.

Corticosteroids are prescribed to be inhaled or taken as pills. Inhaled medicines generally have fewer side effects, because the drug is delivered directly to the site of inflammation, the lungs. As a result, smaller doses are effective. Medicines containing cortico-





PHOTO DISC

steroids such as Beclovent, Vanceril, Aerobid, and Azmacort work to reduce the inflammation of the airways and to reduce the amount of mucus in the lungs.

Oral steroids, like Prednisone, risk more serious side effects than the inhaled versions, but are still useful for people suffering from severe attacks. A person on oral steroids should watch for symptoms such as blurred vision, increased urination, or skin rash.



MIKE CHIESLAK

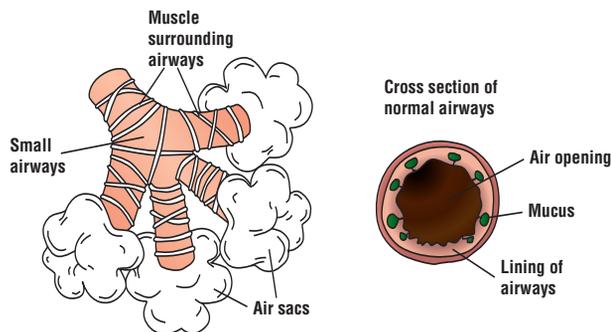
The drug theophylline has a chemical structure much like caffeine. It may be taken orally in a slow-release form. Many doctors prescribe a dose of this medicine for the evening to help prevent nighttime attacks. It works to relax the sensitive “twitchy” muscles of the airway.

The medicines that most people associate with asthma are the inhaled beta-adrenergic drugs. When a person with asthma speaks of “my inhaler”, it usually means a device that delivers a metered dose of albuterol (Proventil or Ventolin) or a related pharmaceutical. These drugs work to relax the muscles con-

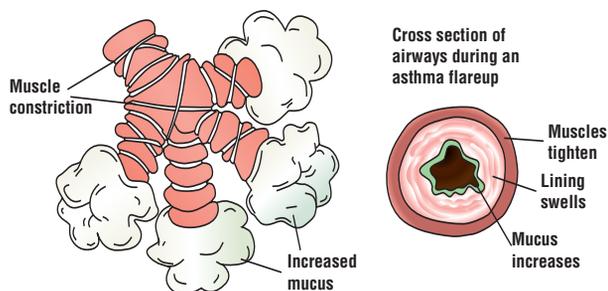
Inflammation is the culprit

Asthma and several types of allergies have been described, and you probably noticed that one symptom that shows up in nearly all of these conditions: *inflammation*. Respiratory allergies and asthma consistently involve an inflammation of the airway. In fact, inflammation is the first event of an allergy breakout or an asthma attack. Many doctors favor long-term medications to reduce inflammation over those that merely

Normal airways



Airways during an asthma flareup



Release of histamines and other chemicals from immune cells leads to inflammation of the airways. This causes bronchial tightening and constriction during an asthma attack.

stricting the bronchioles. The inhalers can be used during attacks or before exercise if exercise is an attack trigger.

Newer medicines such as Singulair, an anti-inflammatory, and Advair, a combination bronchodilator and corticosteroid, have been added to the growing list of medications that allergists prescribe.

treat the breakout or attack. With a lower tendency for inflammation, there is a lower tendency for an attack.

The future

Given the vast population of sufferers, scientists are always searching for new allergy and asthma treatments. Nasal immunotherapy, undergoing tests in Italy, holds promise as a desensitization therapy. Instead of injections, an allergy patient sprays their nose with increasing amounts of allergen. Other researchers are going beyond pharmaceutical research to look for genes that predispose a person to have allergies. It is hoped that someday a kind of gene therapy may reverse susceptibility to allergies and asthma, thereby stopping sneezes and wheezes in their tracks. ▲

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CESAR CAMMERO

Bling ZINGER

The Lead Content of Jewelry



By Christen Brownlee

Could your jewelry make you sick? You have probably never given much thought to how much a 25 cent purchase could change your life. But last summer, a 25 cent purchase may have forever changed the life of 4-year-old Colton Burkhart and his family. While on a routine trip to the local store, Kara Burkhart gave her son a quarter to use in the gumball machine. For his quarter, Colton's prize was a small gold-colored necklace with a medallion ... just a small trinket, but highly valued by any 4-year-old.

Unfortunately, Colton, like many young children, could not resist the urge to put his new prize in his mouth and swallowed the small medallion. Soon after the accidental ingestion, Colton experienced severe stomach pains and flu-like symptoms. After being taken to the hospital, X-rays revealed that the toy was lodged in his digestive tract. Other tests indicated that Colton's blood levels for the element lead were 12–13 times normal levels ... potentially lethal limits for a young child. The pendant was removed, and subsequent analysis revealed that the toy contained upward of 40% lead! The high levels in Colton's blood were due to lead that was leaching out of the 25 cent toy! If doctors had not identified the source of Colton's illness, he could have died.



PHOTO DISC

The news of this event sparked a national outcry. Independent testing revealed that many of this nation's leading retail stores were selling jewelry with dangerous levels of lead. The federal Consumer Product Safety Commission also got involved in testing and over 150 million pieces of jewelry have since been recalled. You might be surprised to learn that the jewelry you are wearing even as you read this article may pose a health risk. If lead poi-

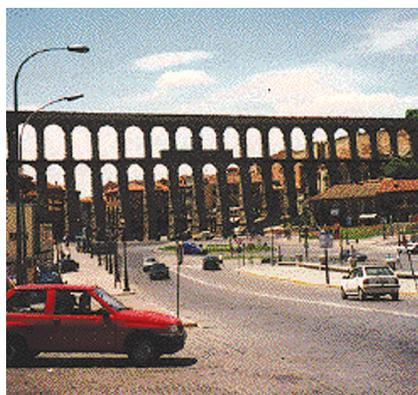
soning is such a serious concern, why would manufacturers use lead in their jewelry and why would retailers carry it? Great question ... glad you asked.

Lead in history

Lead is used in making jewelry because it is malleable, gives the jewelry some heft, and is inexpensive. The element lead (Pb) derives its name from the Latin *plumbum*, from which

we get our English word plumber, or one who works with lead pipes. It is uncommon to find native lead (elemental form) on the earth but its ores (compounds) are abundant. Lead's primary ore, galena (PbS) can be found in many regions around the world.

Lead is believed to have been the first metal extracted from its ore, most likely the result of heating rock containing galena in a campfire. Lead is a soft metal, easy to work with and able to resist most corrosive environments. These characteristics gave lead great appeal to early humans. As a result, it was widely used in a variety of applications. Artifacts in museums around the world show that lead had appeal to early humans.

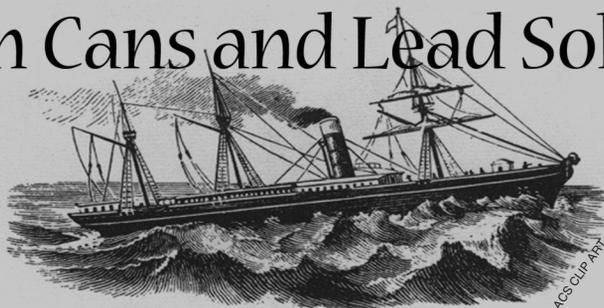


Roman aquaduct in Segovia, Spain (built ~100 A.D.).

Lead use became very common during the Roman era. It is a universally agreed upon belief that the Romans were responsible for promoting the use of lead throughout the known world at the time of the Roman Empire. The Romans, in their attempt to "civilize" their empire, used lead in their plumbing. Lead-lined aqueducts (many of which still stand throughout Europe) brought fresh water to cities; and lead pipes were used to take water to and from Roman homes, public baths, and fountains. Lead was also used throughout the empire as roofing material, wall linings, and other building applications.

Early artisans also found lead to be useful. Lead was used to some extent by jewelry makers, although its dullness made it much less attractive and less widely used than metals such as silver and gold. Early potters enhanced the aesthetic appeal of their creations by adding lead compounds to their glazes. These compounds gave the pottery brilliant color and served a utilitarian purpose as well. These compounds seemed to prevent the pottery from cracking as it cooled after firing. Lead was also added to glass, which sig-

Tin Cans and Lead Solder



The tin can, invented in England in 1811, could arguably be considered one of the greatest innovations of all time. The ability to can food allowed early explorers to take enough food supplies to last for long periods of time. The practice of stocking ships with canned foods was widely used in the 1800s, an era of exploration. The cans were formed by placing a tin-coated iron sheet around a cylindrical form, overlapping the ends, and then soldering to create a seal. Solder is an alloy of metals that when heated, melts (alloying metals can lower melting points) and flows into the joints where two edges of metal come together. Upon cooling, the solder hardens to produce the seal for the joint. **The solder used at the time was about 90% lead and would not flow easily, making it difficult to obtain a perfect seal.** Poor quality assurance in the can-making process could certainly provide an opportunity for lead contamination.

One such example can be found on Sir John Franklin's tragic expedition to map the Northwest Passage in 1845. The Franklin party embarked on their expedition, never to be seen again. Five years into a search for the crew, three graves were discovered on Beechley Island and on a later search an expedition log was found on King William Island 350 miles to the south. The log reported that the two ships, the *Erebus* and *Terror*, were trapped in ice off King William Island in 1846. The crew had remained with the ships for two years, but Franklin had died in 1847, along with many of the crew. In April 1848, 105 survivors started on a journey across the ice for Hudson Bay to the south. Debris was discovered along what was thought to be the crew's path but that was the only evidence recovered ... the remaining crew disappeared.

In August 1984, Owen Beattie and a team of scientists from the University of Alberta dug up the three graves on Beechley Island ... those of John Torrington, John Hartnell, and William Braine, the first crew members to die on Franklin's expedition. Routine studies carried out on bone fragments of Franklin sailors, as well as those of Inuit Eskimos found in the same area, revealed one striking difference. The lead content of the Eskimo bones was within normal limits, while that of the English sailors examined was 20 times higher. Further analysis on tissue and hair samples confirmed the original findings ... dramatically high levels of lead. On the basis of the evidence, the University of Alberta scientists concluded that the increase in lead content had occurred during the expedition. The crew could have been exposed to a number of sources of the lead, but attention was soon focused on the thousands of tin cans ... enough canned food to last for three years! As strange as it might seem, many of Franklin's crew may have died from complications associated from lead poisoning ... the result of eating food from tin cans soldered with lead solder (3)!



nificantly improved its clarity. This mixture, known for the "ringing" sound created when lightly struck, is known as leaded crystal.

Lead compounds even found their way into prepared foods. Lead acetate ($\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$), known as *sugar of lead*, is water soluble and has a sweet taste. This

compound was sometimes used to sweeten wine and other foods. As we will come to discover, this may not have been one of the Roman's better decisions.

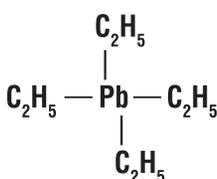
Lead was truly an important metal to early humans. But its value didn't come without a cost. From the earliest times, humankind

has been aware of lead's toxic nature. By the 1st century, the Greek physician Dioscorides noted the relationship between exposure to lead and its toxic manifestations. Noting intestinal problems and swelling as well as paralysis and delirium, he is quoted as saying, "lead makes the mind give way."

Lead in the modern world

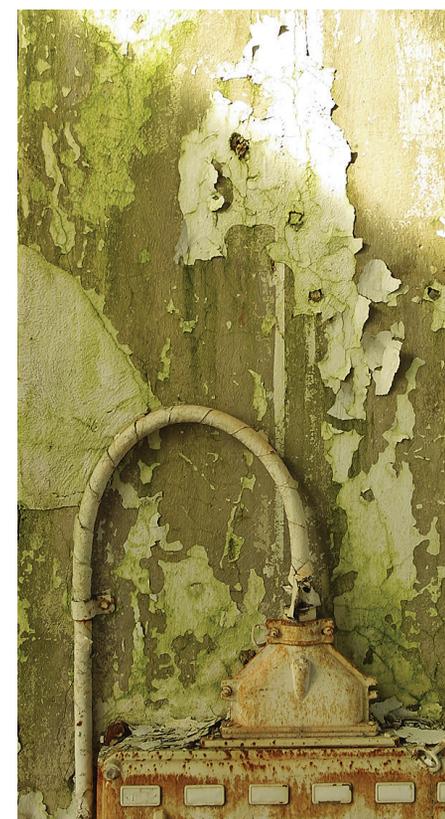
Tetraethyl lead

Before the 1970s, most gasoline contained an additive known as tetraethyl lead, which decreased the amount of engine "knocking".



As the U.S. population grew during the 1970s and 1980s, so too did gasoline consumption. To keep pace, the manufacture of tetraethyl lead also rose. At one point, approximately 20% of all lead produced in the United States was used as a gasoline additive (1). However, car exhausts released lead directly into the atmosphere making leaded gasoline a major contributor to the amount of lead in the environment. An entire population was being exposed to dangerous levels of lead.

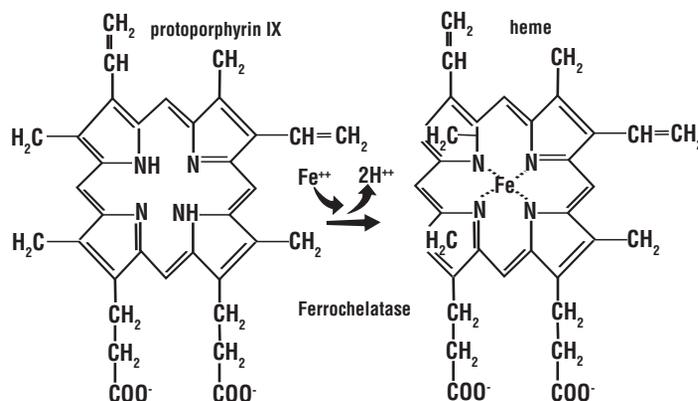
Tetraethyl lead is considered to be a neurotoxin ... a chemical that directly affects the nervous system. When lead enters the body, whether through ingestion, inhalation, or absorption (the three most common routes of entry into the body), it is rapidly absorbed into the bloodstream. From there, it's a quick and costly trip to the brain and central nervous system. Symptoms of exposure are lethargy, tremors, and muscle fatigue. Chronic exposure can even result in brain damage and/or death.



The good news is that times have changed. Data collected over the past 20 years shows a positive trend. Atmospheric lead levels have declined by 90% and not surprisingly, so have the instances of lead exposure. The prohibition of tetraethyl lead as a fuel additive has greatly benefited both the environment and the public's health.

Lead paint

Lead compounds were also commonly used in the manufacture of house paints. If you were to take a trip to your local hardware store today, you would find it next to impossible to find lead-based paints. But before 1978, lead-based paints lined the shelves! Basic lead carbonate, $\text{PbCO}_3 \cdot \text{Pb(OH)}_2$, when pure, is a brilliant white substance that makes an excellent paint pigment, called *white lead*. While the use of white lead has been banned, many buildings still have significant levels of lead-based paints. This has precipitated the U.S. Centers for Disease Control and Prevention to set a "level of concern" for children at $10 \mu\text{g}$ per deciliter of blood (2). The vast majority of lead absorption in children is through the gastrointestinal tract ... small children tend to put things into their mouths — the gateway to this system! And once an object, such as chip of lead paint, is placed in the mouth, there is a great chance that the object will be swallowed. Let's not forget that lead paint chips do have a sweet taste, which might addition-

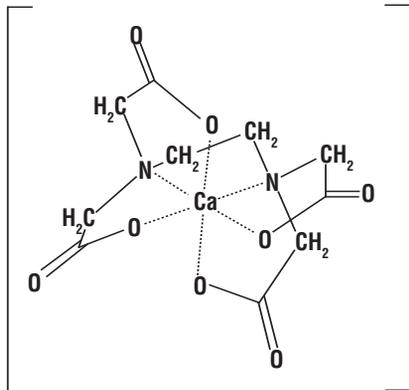


Ferrochelatase, an enzyme, is responsible for inserting an iron (II) ion into the heme molecule.

ally encourage a small child to put them into their mouths. This places small children in the high-risk group for lead poisoning. But they are not alone. Anyone who ingests objects with high lead content can absorb significant levels of this toxic heavy metal. Now let us direct our attention to the most recent concern for new cases of lead poisoning ... jewelry.

Lead is a cumulative poison, building up in the body until it reaches toxic levels. Once the body is exposed, lead is quickly distributed to blood, soft tissue (kidney, bone marrow, liver, and brain), and mineralized tissue (bones and teeth). Part of lead's toxicity can be explained by how it interferes with the production of *heme*, needed for red blood cell hemoglobin. An enzyme called *ferrochelatase* is responsible for inserting the iron (II) ion into the heme molecule. Lead ions interfere with this process, and abnormal red blood cells are formed. These abnormal red blood cells are destroyed, but the body may not be able to produce replacement red blood cells quickly enough. Bone marrow attempts to do its part by ramping up production of red blood cells; however, these red blood cells are not sufficiently mature and are likely to be destroyed in the spleen (1). These processes cause the anemia that is associated with lead poisoning, as there is both decreased red cell production and increased red cell destruction. Lead also affects the intestines and vascular smooth muscles. Intestinal spasms due to the contraction of vascular smooth muscle are the cause of some very painful cramps that tend to characterize extreme lead exposures.

Most of lead's neurological effects are due to its ability to mimic and inhibit the actions of calcium ions. Calcium ions play an important role in the nervous system; they help convert the electrical pulse into a chemi-



Calcium EDTA is used as a chelator in some cases of lead poisoning.

cal signal. Cells absorb lead ions using the same channels through which they absorb calcium ions. High levels of lead ions are known to cause these channels to uptake more lead ions into the cell, as well as inhibit the transport of calcium ions. Lead ions, even at low concentrations, can both promote and limit the release of the specific neurotransmitters, which are chemicals that regulate the brain. This can have serious consequences on the developing nervous system of an infant or a child. It is believed that this is one of the causes of learning and behavioral problems that occur in children.

In the central nervous system, lead also increases the permeability of the blood-brain barrier, which produces brain edema, an accumulation of fluid in the brain that causes extreme swelling. Lead exposure causes a disruption in this barrier, and the resulting changes in osmotic pressure cause the concentration of water to be altered, and ultimately, edema of the brain and intracranial pressure. With the increased pressure, the neurological development of a maturing child can be altered. As you can see, lead exposure can have severe immediate and long-lasting effects. So what can be done to treat a 4-year-old whose blood contains 12–13 times the normal amount of lead?

Chelation therapy

A chelator (means “claw-like”) is a chemical substance that acts to bind metal ions and take them out of solution. Designing a chelating agent for treatment of lead exposure can be challenging, because it should not remove essential metal ions (in this instance calcium or iron ions) from the blood, but it should remove the lead ions. Thus, the chelator must have a higher affinity (likes it better)

2- for the lead ions than for the calcium ions. It must also have a higher affinity for the lead ions than the binding sites in the body. Think of this therapy as a microscale *tug-of-war* ... if the chelator can remove the lead ions, the chelator wins; if not, the lead ions remain bound to the cells and the chelator won't work. Also complicating matters is the variety of heavy metal binding sites—with both high and low affinities—within the body. The longer the lead ions are in the body, there is a greater chance that they will migrate from the lower-affinity binding sites to the higher-affinity binding sites. This makes it even more difficult for the chelator to pry it loose. As a result, early chelation therapy is best. Calcium EDTA (Calcium disodium edetate) is the nearly perfect chelator for lead ions. It is water soluble and can be administered intravenously or by injection. Calcium EDTA has a greater affinity for lead ions than for calcium ions; therefore, when lead ions are encountered by the calcium EDTA, the calcium ion “pops” off the chelator and is replaced by the lead ion. When this happens, the lead is not metabolized, is eliminated through the urine, and has few toxic effects.

Are U.S. teens at risk from toxic jewelry?

So you're a teen, you go to the mall, you see some costume jewelry that you like, and because it's inexpensive, you buy it without giving it much thought. It looks good, you look good, life is good. But a careful inspection reveals that much of this jewelry is manufactured in China, India, Korea, and other countries where labor is cheap, making the jewelry affordable.



The hidden costs might have to be paid for with your health and not with your money! As of July 2004, more than 150 million pieces, found in vending machines and in low-end discount stores nationwide, were recalled. The problem also extends to fine jewelry available at many retail outlets, including malls and jewelry stores. Buyer beware ... your jewelry may be the source of potentially harmful levels of lead.

Currently, there are no federal or state laws that regulate lead content in jewelry. (California may be the exception by publication of this article). Although efforts over the past 20 years have done much to eliminate lead from U.S. food, water, air, etc., the lead content of jewelry seems to have snuck in under the radar! Costume jewelry is cheap enough to attract teen buyers and therefore potentially poses some risk of lead exposure. There is little risk in just wearing this jewelry. The real risk comes when the lead gets into your system. To be safe, be sure you keep your jewelry out of your mouth and out of reach of children, such as younger brothers and sisters.

A happy ending?

Colton Burkhart, now 5 years old, has undergone extensive chelation therapy to remove the lead from his system. So far, the results have been good, but even a year later, lead levels in his blood remain higher than normal. Only time will tell if his lead exposure will have any long-lasting effects on his development. ▲

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Tim Graham teaches chemistry at Roosevelt High School in Wyandotte, MI. His most recent article “Secrets of the Samurai Sword Revealed” appeared in the December 2005 issue of *ChemMatters*.

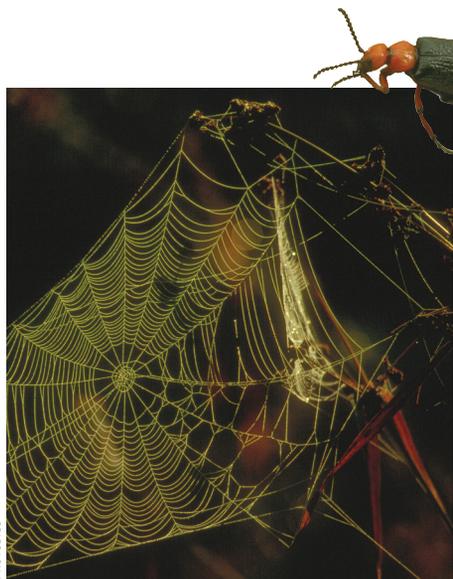


PHOTO:ISC

BIOMIMICRY— Where Chemistry Lessons Come Naturally

By Kathryn E. Parent and Jennifer L. Young

Look around and you'll see many little chemical factories in nature that are nonpolluting and environmentally friendly. Inside a leaf or a bug, there lies some sophisticated chemistry, often turning out incredible materials that are the envy of today's chemists and engineers.

In fact, you might say that today's industrial chemists are developing a green thumb. Green chemistry is the design of chemical products and processes that reduce or eliminate the use and production of hazardous substances. Green chemists look for new ways to do chemistry that is benign by design, thus preventing pollution before it starts.

Why are chemists turning to nature for ideas? Think about it. Nature uses renewable sunlight for energy and recycled starting materials to make a lot of things. Organisms synthesize medicines, plastics, and all kinds of other useful materials without releasing toxic chemicals into the environment or using large amounts of heat or pressure. Nature's chemistry embodies many of the principles of green chemistry, using processes that have met the tests of time.

Scientists call the study of these natural chemical processes biomimicry, a term that means imitating life and involves applying nature's lessons to new human inventions. Janine Benyus, the author of *Biomimicry: Innovation Inspired by Nature*, calls it "the conscious emulation of life's genius". But that's not to say that every process in nature is nonpolluting. For example, it is well known that animals release carbon dioxide and methane, greenhouse gases, into the environment.

Although biomimicry is getting increased attention today, several famous inventions of the past were inspired

How do they do that? How do spiders spin a web that's stronger than steel? How do bombardier beetles launch chemical bombs at their enemies without hurting themselves? How do tiny mussels stick to rocks in the pounding surf? How do green plants generate a steady supply of safe and renewable energy?

by nature. Take the telephone, for instance. Alexander Graham Bell studied the human tongue and eardrum to help him design the first telephone. The Wright Brothers watched birds gliding in the wind for shaping airplane wings before taking the first flight. And nearly everyone is familiar with synthetic Velcro, which was inspired by the way the tiny hooks on seed pod burrs attach to the loops of thread in cloth.

Whether forms, processes, or systems, biology includes a wealth of ideas for chemists and engineers. When scientists apply the methods and systems practiced in nature to cutting-edge research challenges, creative and amazing scientific breakthroughs often occur.

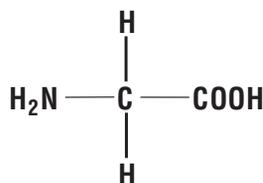
Spiders spin webs stronger than steel

Dragline silk from a golden orb weaver spider is five times stronger than steel (when compared gram for gram),

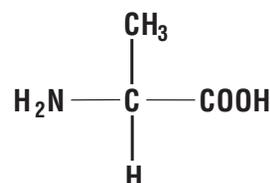
and can absorb five times the impact force of Kevlar—the synthetic fiber of bullet-proof vests—without breaking. What’s more, it can stretch 40% longer than its original length. For the spider, the durability and strength of silk means food. And for humans, it could mean an amazingly useful fiber that can be made from safer and less hazardous chemistry. Science writer Steve Miller describes the properties of good web fiber in a February 2001 *ChemMatters* article: “It must be strong enough to bear the weight of a bungee-jumping spider, flexible enough to withstand the impact of a flying insect, and stable enough to last for days. ... And it cannot require more raw material than the spider can replenish from ordinary food resources.” Even the U.S. military has taken notice. The U.S. Army has interest in a manufactured version of dragline silk for applications such as catching fighter jets as they land on aircraft carriers.

How does a spider make such an incredible fiber that humans have not yet fully reproduced? Scientists are still studying the chemical composition of the spider’s silk. Scientists know that spider silk is a protein and have identified the amino acids that are its building blocks. Glycine and alanine are the most abundant amino acids in the silk (see Figure 1). The three-dimensional structure of the fiber, which gives it the strength and flexibility, results from how the amino acid building blocks interact with each other. As a result of the diversity of amino acid interactions, some parts of the silk fiber are highly oriented, like uncooked spaghetti, and other parts are very nonoriented like cooked spaghetti.

To make the silk fiber, the spider synthesizes liquid protein by putting together the amino acid molecules and squeezes the protein through a spinneret (i.e., to spin the fiber). When it exits the spider, the soluble liquid protein becomes an insoluble, highly ordered, and extremely strong fiber. With this knowledge, scientists are trying to make a fiber that is similar to spider silk. This much is certain: spiders don’t use the high pressures, high temperatures, or corrosive acids often used in chemical syntheses. In manufacturing Kevlar, for example, industrial chemists rely on hot concentrated sulfuric acid. Nylon fiber, used in ropes and cords for rock climbing and parachuting, is manufactured under conditions of high pressure and temperature. The golden orb weaver spider manages to produce a high-performance fiber using chemistry mild enough to occur inside their bodies.



glycine



alanine

Figure 1. Chemical structures of glycine and alanine.

The bombardier beetle bomb



Bombardier beetles can fire, literally, a mixture of chemicals at predators. To prepare for attack, the beetles produce and store two chemicals, hydroquinone (C₆H₆O₂) and hydrogen peroxide (H₂O₂).

When the mixture of chemicals is pushed from the storage reservoir into the firing chamber, enzymes in the chamber wall react to release free oxygen (O₂) and steam (H₂O). They also oxidize the hydroquinone to benzoquinone, which is an irritant (see Figure 2). The resulting reaction is extremely exothermic. Heat and pressure force the chemical spray out an opening in the beetles abdomen with a loud bang. “The chemistry is simple, but the biology is beautiful” said Jerrold Meinwald, a researcher at Cornell University. Despite the heat, pressure, and irritating chemicals emanating from its body, the beetle remains largely unaffected. Unfortunately, the news isn’t as good for its enemies.

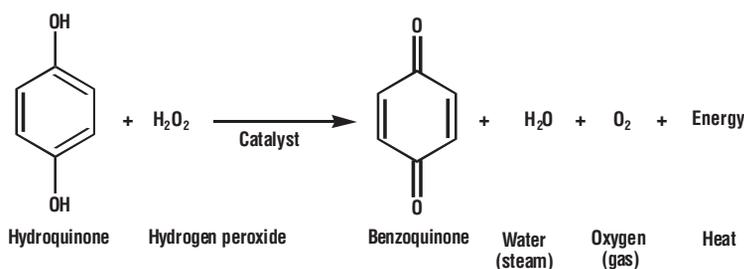


Figure 2. Oxidation of hydroquinone.

The March-April 2004 issue of *American Scientist* features the research of Andy McIntosh, a professor of thermodynamics and combustion theory at the University of Leeds in England. He is working to apply the bombardier beetle’s methods to find a better way to reignite aircraft gas turbine engines. Beyond engine reigniters, McIntosh envisions future applications of the bombardier beetle’s design, including rocket technology, automo-

bile airbags, and unmanned aerial vehicles, though all of these are beyond the scope of his current study. “I think the natural world is full of excellent designs that we can learn from,” McIntosh says.

Blue mussels make glue

Visit the seashore and you’ll find mussels clinging steadfastly to rocks, despite the crashing surf. How do they do it? Professor J. Herbert Waite from the University of Delaware has been researching this question for more than 30 years. The mussels are able to apply their protein-based glue underwater, where it cures and sticks to nearly anything amidst the harsh ocean. “They do it with chemistry” Waite realizes. But so far, no chemist has successfully synthesized this incredible marine superglue. Clearly, the product would be a boon to boaters of all descriptions. With a glue like that, they would no longer have to dry-dock boats for repairs.

Professor Kaichang Li, a wood chemistry expert at Oregon State University, used mussels as his model for developing a new soy-based wood adhesive. He explains, “Inspired by the strong and water-resistant binding of marine organisms such as mussels to rocks and other substances, we are investigating conversion of renewable natural resources such as soy protein, carbohydrates, and lignin to strong and water-resistant wood adhe-



PHOTO BY DAVE COWLES. HTTP://ROSARIO.WVC.EDU/INVERTS



COURTESY OF PROF. KAICHANG LI, OREGON STATE UNIVERSITY



PHOTO BY DAVE COWLES. HTTP://ROSARIO.WVC.EDU/INVERTS

sives.” He noticed that the chemical structure of the proteins in the mussels’ glue included a lot of ringed hydroxyl chemical structures. By modifying soy protein (e.g., tofu) to incorporate more of these types of structures, Li has developed a new glue that is stronger and more

water-resistant than the traditional formaldehyde-based adhesives used to make plywood. Even better, the glue doesn’t release hazardous air emissions during manufacturing processes or from the finished plywood boards. That’s good news for the environment, for plywood manufacturers, and for consumers of plywood.

New directions in biomimicry research

Writer Alexandra Goho, in a *Science News Online* February 12, 2005, article, highlighted several chemists who are using nature for inspiration in their laboratories. For example, Dr. David Liu at Harvard University has found ways to use one of nature’s premier templates, DNA, like a molecular laboratory for synthesizing chemicals in minuscule batches. DNA controls the order and amount of chemicals that react during a given process, limiting the number of undesired by-products.

At Cornell University, Dr. Tyler McQuade looks to cell biology for inspiration to develop an assembly-line system to make drugs like Prozac. His microcapsule enzyme-mimic approach, controls the order in which reactions take place, minimizing separation and purification steps that typically generate large amounts of waste.

Dr. John Warner at the University of Massachusetts-Lowell recognizes seashells as models for lowering the energy required to produce solar cells. To make their shells, mollusks rely on small organic molecules to choreograph the assembly of calcium carbonate (CaCO_3) into elaborate mineral structures. When Warner looked at films of titanium dioxide (TiO_2), used as an alternative to silicon (Si) metal for solar material, he saw a resemblance to the structure of seashells. So, Warner

tried using small organic molecules with multiple carboxylic acids (RCOOH) to assemble titanium dioxide particles into films of solar material. He was able to accomplish it at room temperature, a tremendous energy savings over traditional manufacturing methods that require heating titanium dioxide (TiO_2) films at $500\text{ }^\circ\text{C}$.

The examples above show the incredible variety in the research chemists’ and engineers’ approach using biomimicry. Imagine what we can create, using examples in nature to find new and better ways to design materials, processes, and systems. ▲

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Kathryn E. Parent and Jennifer L. Young are staff of the American Chemical Society’s Green Chemistry Institute (www.greenchemistryinstitute.org).

NANOMOTORS

By Anne M. Rosenthal

Olympic swimmers—think Ian Thorpe in the backstroke, Jenny Thompson in the butterfly. But *Escherichia coli* (*E. coli*) in the “100-nm rotor stroke” event? How fast can a bacterium go anyway?

It turns out that motile (self-propelled) bacteria move at about 10 body lengths a second, the bacterial equivalent of a human swimming a 5-s, 100-m freestyle (something that actually takes humans 10 times longer). It's all because of a biological nanomotor connected to a set of linear filaments called flagella. At first glance through a microscope, these superficially resemble long hairs on the bacterial surface. But each flagellum has a hollow core, surrounded by a helical structure composed of individual subunits of protein, which gives it a natural helical twist. And driving each flagellum at its base is an elegant rotary motor, only 50 nanometers (nm) in size.

Motors—The basics

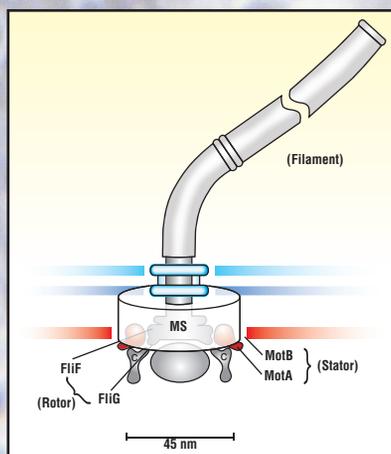
What exactly is a motor, and do the natural structures such as those that drive flagella in bacteria really qualify to be called motors? A motor is a machine or object that can convert various types of energy into mechanical energy, the energy of motion.

Motors typically have two main components, a rotor and a stator. As the words suggest, the rotor moves and the stator remains fixed. Typically, the energy conversions happen between the rotor and stator, which ends up imparting motion to the rotor. It might be helpful to consider the electric motor, perhaps the type we are all most familiar with. In elec-

tric motors, electromagnetism is used to make the rotator move. Electric currents flowing through highly conductive metal wires wrapped in coils produce magnetic fields in the stator. By carefully controlling the movement of electric current, the resulting electromagnetic attraction causes movement in a rotor, which is also magnetic. Although the arrangement of the parts can vary dramatically, this is how all electric motors operate.

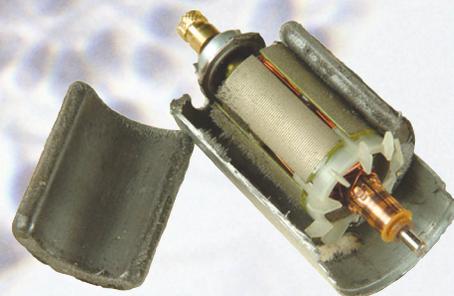
The flagellar motor

The same essential components are also present in the biological nanomotor. The bacterial motor is built primarily of proteins, the natural polymers that are the primary building material for much of the living world. A dozen or more unique protein subunits are produced. These proteins, with names such as MotA and FliG, self-assemble to form the basic structures of the flagellum.



The operation of the flagellar motor—much like the electric motor—is based on the interaction between the rotor and the stator.

In order to drive the *E. coli* forward, the motor must turn counterclockwise, which causes the flagella to bundle together, forming a propeller that is efficient in driving the cell ahead. When the environment turns nasty or



lacks nutrients, the bacteria briefly reverse their flagellar rotors. The helical filaments fall free from the bundle, and the bacteria begin a free-form tumble. This tumble points the bacterium in a new, random direction. The motors reverse again, pushing the cell off in search of more favorable conditions. But what drives the motor? The answer is protons, positively charged hydrogen ions. Protons move from outside the cell to inside the cell, passing through the nanomotor. The movement of the protons is thought to cause the MotA protein to move or change its shape, pushing against the FliG protein of the rotor. Each push moves the rotor a few degrees. It takes 50 or more pushes to make one rotation. The flagella turn at a rate of 10 cycles per second. But what causes the protons to move inside the cell? It is an electrical or pH gradient, that is, a lower concentration of protons

BACKGROUND PHOTO: PHOTODISC; MOTOR PHOTO: MIKE CHIESLESKI

CESAR CAMINERO

inside the cell as a result of cellular respiration. The protons diffuse from higher concentration outside the cell to lower concentration inside the cell, driving the motor in the process. It is sort of like the water wheel in an old stream-side mill being driven by the pressure of the water moving across it.

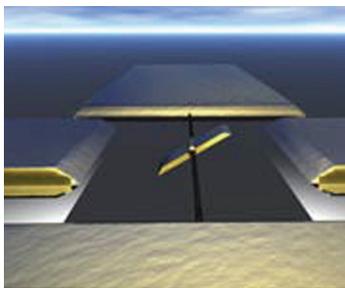
Synthetic nanomotors

And what about efforts by scientists to build nanomotors? One elegant example is a 500-nanometer motor fabricated by Alex Zettl, professor of physics at U.C. Berkeley and his graduate students.

Their motor is 300 times smaller than the diameter of a human hair. The rotor is between 100 and 300 nm long and is attached to a carbon nanotube shaft only a few atoms across, perhaps 5-10 nm in diameter.

The motor was constructed using a combination of chemistry and physics. First, a number of carbon nanotubes were created in an electric arc and deposited randomly on a flat silicon oxide surface, much like those used for creating computer chips. The nanotubes are located using an electron beam microscope because they are too small to see with a regular microscope—they are smaller than the wavelength of visible light. Anchors, stators and rotors are then attached to the nanotubes by evaporating a very thin layer of gold onto specific regions of the surface.

Then the area underneath is etched out using hydrofluoric acid, leaving the nanotubes and rotors suspended. The most clever innovation was making the rotor free to turn. The nanotube shaft of the rotor was actually a number of nanotubes within one another, sort of like the layers of a green onion. By



rocking the gold rotor back and forth between the stators with a strong electric force, they were able to break the bonds between the outermost layer of nanotube and the inner layers, creating a perfect way for the rotor to rotate freely, nearly frictionless. The rotor spins at a rate of 30 times per second.

One issue with many of the micromechanical devices fabricated to date has been the issue of how to harness the mechanical energy they produce.

In the February 21, 2005, issue of *Chemical & Engineering News*, Harvard Uni-

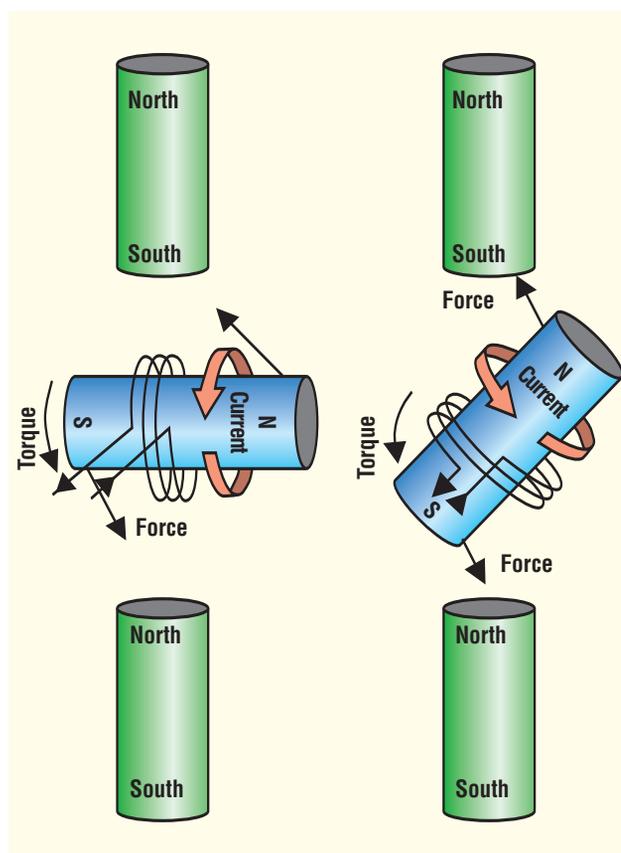
versity chemistry professor George M. Whitesides pointed out that "Much of the previous work on what have been called 'molecular motors' has not really described motors," he says. "Although there are molecules that change conformation when oxidized or reduced or when irradiated, they have generally been systems that were not able to do work in the thermodynamic sense and thus are not, in my opinion, really motors." In other words, if you can't use the device to move something else, you are not doing work and you have not made a true motor.

Work (abbreviated **W**) is the energy transferred by a force to a moving object

An example of a very different kind of motor, with a big potential to move objects, is called a "catalytic nanomotor." This was described last year by Ph.D. student Walter F. Paxton, chemistry professors Ayusman Sen and Thomas E. Mallouk, physics professor Vincent H. Crespi, and co-workers at Pennsylvania State University. The nanomotors are rod-shaped particles, 370 nm in diameter, consisting of one 1,000-nm-long platinum segment and a similar-length gold segment. When the catalytic nanomotor is placed in a dilute solution of hydrogen peroxide (H_2O_2), the platinum catalyzes its decomposition into oxygen and water.



The gold section does not catalyze the reaction. The result causes the rods to move at speeds of up to 10 body lengths per second, the same rate as *Escherichia coli*! Catalytically driven nanomotors do not require external energy sources such as electricity or



This figure illustrates the basic operation of a simple motor. Current flows through wire wrapped around the blue cylinder creating a magnetic field. The blue cylinder rotates because of the attraction of its north and south poles for the opposite poles of the permanent magnet (green).

radiation. They derive their motion from the chemical reaction. One test the experimenters did to prove the motion was really due to the chemical reaction was to fabricate nanorods with three segments, gold on either end and platinum in the middle. The only movement in the rods was the random giggling caused by collisions with molecules, known as Brownian motion.

The creation of these nanomotors, along with dozens of others using other designs and technologies, show tremendous application of clever chemistry and technology. The only thing that is missing is an application. Or as Professor Whitesides puts it, "There is also a core question: What is the problem that requires having a nanomotor?" For *E. coli*, the answer is clear, getting from one place to another. For chemists working in nanotechnology, it is still an open question. ▲

Anne M. Rosenthal is a science writer based in the San Francisco area. Her most recent article "Ocean BioLights" appeared in the December 2004 issue of *ChemMatters*.

The Consumer Product Safety Commission

The Consumer Product Safety Commission (CPSC) is the government agency responsible for protecting the American public from potential injury by more than 15,000 consumer products excluding cars, foods, and drugs. The CPSC issues product recalls and safety warnings; it also provides consumers with a forum for reporting safety products. For example, the CPSC was intimately involved with the recall of the some of the jewelry described in "Bling Zinger". For more information on the CPSC, visit <http://www.cpsc.gov/index.html>.

Not even asthma can stop Olympians from going for gold!

Exercise-induced asthma is fairly common, impacting up to one in five athletes. These athletes can suffer from shortness of breath, chest tightness, and wheezing either during or after exercise. Even Olympians aren't immune to this respiratory disease. According to the American



Academy of Asthma, Allergy and Immunology (AAAAI), up to one in six of these world class athletes suffer from asthma. For more information on exercise-induced asthma, its triggers, and symptom management, visit <http://www.aaaai.org/patients/publicedmat/tips/exerciseinducedasthma.stm>.

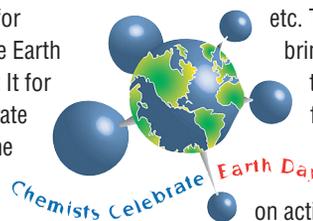
More on nanomotors

Synthetic nanomotors are an exciting and elegant creation at the interface of chemistry and physics. In "Nanomotors", the synthetic nanomotor created by Alex Zettl, professor of physics at UC Berkeley and his graduate students is described as a gold rotor attached to a carbon nanotube shaft. To view pictures and video of this 500-nm motor in action, visit http://www.berkeley.edu/news/media/releases/2003/07/23_motors.html.

Chemists celebrate Earth Day

That's right. The American Chemical Society will observe Earth Day on April 22. The theme for the 2006 celebration is "Dig It". The

community event for Chemists Celebrate Earth Day 2006 is "Plant It for the Planet." Celebrate the chemistry of the soil and plants by hosting activities that will benefit the community like planting flowers, trees, grass,



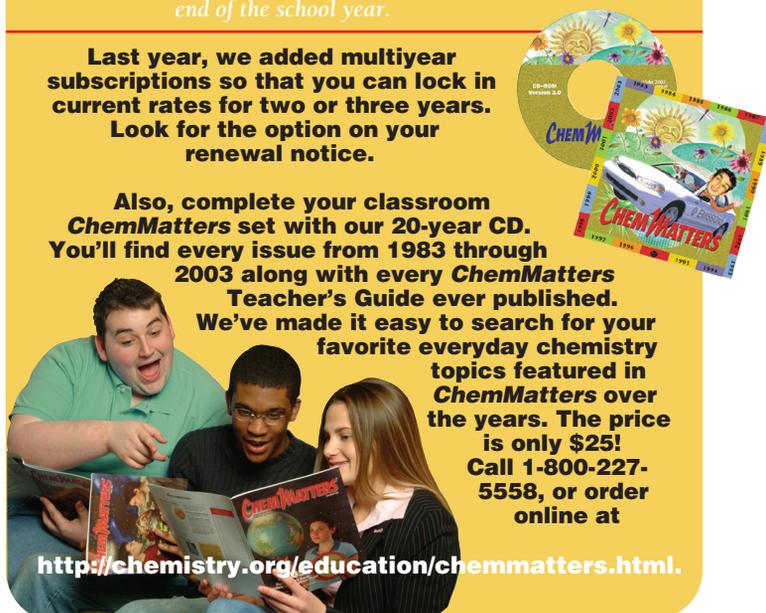
etc. This activity will bring the community together for a fun-filled day! To help celebrate the day, a series of hands-on activities are available for teachers and students at <http://chemistry.org/earthday>. ▲

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