Question From the Classroom

By Bob Becker

Q. How do CD players work?

A. Good question! But first, how about a little game of "Name That Tune?" Here we go:

"1000010110101000110100001011000111100100010000110010 ..." So what was it? Impossible, you say? Perhaps for you, but for your computer or CD player, it's music to its electronic "ears". This string of ones and zeroes is referred to as *digital* information, and it's based on the idea that any information that exists—a song, a photograph, a computer game, words on this page—can all be converted into *digits*, series of numbers.

When we think of numbers, we think of "12" eggs in a dozen and Heinz "57" steak sauce and Levi's "501" jeans. But our computers think of "1100" eggs in a dozen, Heinz "111001" steak sauce and Levi's "111110101" jeans. Who's right? The answer is both. We like our *base ten* number system, probably because we have 10 fingers to count on. But computers have only two "fingers"—on and off. That limits them to a *base two* numbering system. And if you want to know how "501" in base ten comes out as "111110101" in base two, go ask your math teacher. It really is pretty cool.

CDs look similar to those ancient LP records your parents listened to (and—oh gross!—danced to). But there are some significant differences. LPs were played by dragging needles through bumpy grooves on the top surface, trailing them from the outside rim to the inside. Music resulted from sound vibrations set up when the needle hit bumps along the grooves. Instead of needles, CDs use laser light that reflects off the bottom surface, gradually reading from the interior to the outer rim. As I'll explain later, the tiny bumps along the way correspond to strings of ones and zeroes—digital information.

PHOTOS FROM PHOTODISC

Most impressive of all, CDs, smaller in overall size than LPs, contain a lot more information. The CD groove is only about 0.5 micrometer (μm) across and 0.1 μm deep—one-five hundredth the thickness of this page! With one-fifth the surface area of an LP, the CD groove is about 10 times longer—5 km long, compared to only about 500 m for the vintage vinyl LP. Thus, every CD has plenty of room for the 780 megabytes or 780 *million* bumps and valleys needed to code the information on a typical music CD!

So how do all these tiny bumps translate into the sweet sounds of that Atlantic Marmoset CD you listened to on the way to school this morning?

When you play your CD, it spins around (about 10 times faster than a record player), and the laser light hits it from beneath. The beam passes through the clear polycarbonate bottom layer and reflects off of a very thin mirror coating made of an aluminum alloy. If the beam hits *between* the bumps, it is reflected directly down into an optical sensor. The sensor reads the pulse of light as "1." But when the beam hits a bump, the reflected light misses the target sensor. This absence of light is read as "0."

The sensor takes this string of ones and zeroes and transforms it into an electrical signal that vibrates the audio speakers. Air vibrations set into motion by the speakers reach your eardrums. Their vibrations result in a series of nerve impulses to your brain. And that's how we get from bumps on a CD to the tune playing in your head!

Today, we can write and even rewrite our own CDs using the new recordable CD-Rs. Instead of having bumps stamped at the factory, CD-Rs come with a smooth reflective layer. Below this is a translucent layer of photosensitive dye. The CD "burner" is simply a high-powered writing laser. Wherever a laser pulse contacts the disk surface, it chemically changes the dye to an opaque spot. The resulting little dark spots act like the bumps described above. When the lower powered "reading" laser shines on them from beneath, they prevent the light from reflecting back to the sensor. Each little dot thus marks a "0" in the digital sequence.

For more information about how CDs and a lot of other stuff work, I recommend this popular Web site: **www.howstuffworks.com/cd-burner1.htm.**

TEACHERS!

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

ChemMatters®

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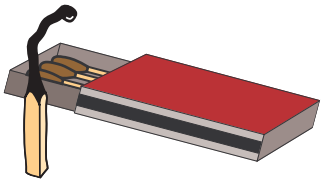
DEPARTMENTS

CM Puzzler

Why will a safety match light on the side of the box but not on the sidewalk? Find the answer in this issue of *ChemMatters*!



FEATURES

COVER PHOTO BY TONY FERNANDEZ AND MIKE CIESIELSKI

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Images of Anthrax

A Team Approach

PHOTOS BY PAUL ROBERTS, MSOE

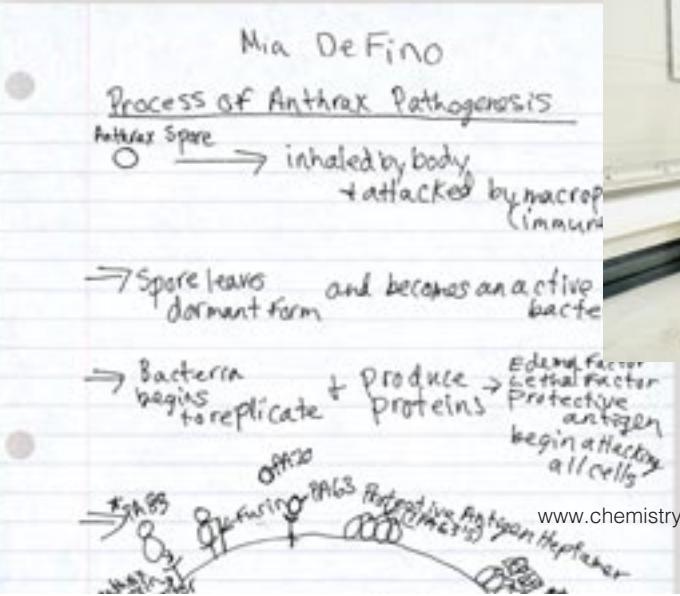
By Jonathan Knopp

The nation watched in horror as the catastrophic events of September 11, 2001, caused loss of life and massive destruction in a mere instant. Then, within only a few weeks, came the first of five reports of seemingly random deaths traced to anthrax—an infection thought to have long disappeared from the population. Gradually, news of anthrax contamination and exposures spread over ever-widening geographic areas.

These unforeseen acts of bioterrorism forever changed the lives of three Milwaukee teenagers as they began their senior year at Riverside University High School. In late summer 2001, Mia Defino, Mike Poliak, and Justin Snowden only knew that, thanks to their science teacher Jeff Anderson, they were looking forward to an interesting science internship at the Milwaukee School of Engineering (MSOE). Working as a team, their challenge was to select a protein from a database and make a molecular model. Why not choose some of the key proteins associated with this mysterious anthrax bacteria that was all over the news? At this point, no one dreamed that by mid-school-year, they would be conversing with some of the world's leading anthrax researchers and producing an important research tool in the nation's war against bioterrorism. Amid schoolwork and extracurricular activities like football and jobs, the students began reading research articles and any information they could obtain about anthrax. Their thoughts and their conversations centered on topics like the interaction of anthrax with cell surface receptors, the mechanism of attack, and details of cell destruction by anthrax. As former students in Anderson's Advanced Placement biology class, they relied on concepts previously learned. Mia recalls that AP biology helped a lot in the project. "It made us familiar with the vocabulary and some important microbiology topics such as the lytic cycle, endocytosis, protein synthesis, and just proteins in general."

Before long, they identified three key anthrax-related proteins that they wanted to model. Before 6:00 a.m. on school days, after school, and sometimes on weekends, the three traveled to MSOE to learn the process of biomolecular modeling. Students and teacher soon became known around the lab as "Team Anthrax".

At MSOE, rapid prototyping technology is coupled with computer-aided design to turn out three-dimensional models of molecules. In the automotive industry, engineers have regularly produced precise models of engine parts they design on their computer screens. Recently, this combined technology has been expanded and applied to the biomolecular world by Dr. Tim Herman, director of the Center for Biomolecular Modeling (www.rpc.msoe.edu/cbm) at the Milwaukee School of Engineering. The Protein Data



Top photo: Team Anthrax examines protein models. Left to right: Mia Defino, Justin Snowden, and Mike Poliak. Bottom photo: Mia examines a finished model.

NOTEBOOK PAGES COURTESY OF TEAM ANTHRAX

Bank (PDB) Web site at **www.rcsb.org/pdb**, contains the spatial x,y,z coordinates that give relative position information for the atoms in any listed protein. These data are contributed by X-ray crystallographers after determining the molecular structures. Today, anyone can freely access the information in the PDB. Atomic coordinate data from the PDB can then be translated through Rasmol, a freely available software program, into a computer image of the molecule.

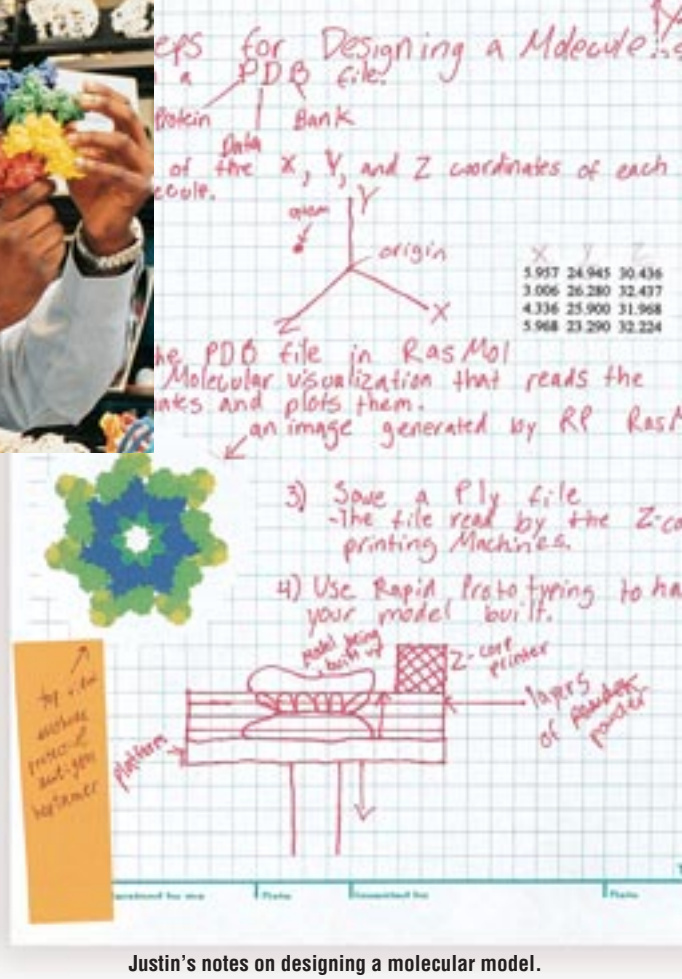
To build a model, the spatial coordinates guide the way. Additional software at MSOE relays the computer image data to a rapid prototyping machine—the machine that builds the three-dimensional model, one layer at a time (see sidebar below).

After learning to use these available tools, the students went to work on their selected molecules. They started by carefully examining the molecular structures in the PDB. With Herman's help, the students added monitor lines, additional components to be added as structural supports in the physical model. They removed glitches in the program where the computer perceived hydrogen bonding where none really existed.

Team Anthrax turned out two models representing protective antigen and lethal factor, two of the three known anthrax proteins. About the size of one's fist, the models have been scaled up 17 million times larger than life. And with the production of these models, a whole new phase of engagement began.

Justin: "Someday, I can tell my kids that I was on a high school team that made the world's first models of anthrax protein."

In December 2001, Herman and a colleague at MSOE, Dr. Mike Patrick, were attending a meeting at the Howard Hughes Medical Institute (HHMI) in Washington, DC. At lunch, they were discussing the anthrax models with an HHMI investigator from the University of Chicago who mentioned that his colleague, Dr. Wei Jen Tang, had just solved the structure of another anthrax toxic agent. Herman suggested that Team Anthrax contact Dr. Tang for his assistance. To their delight, Tang agreed to share three years of his research data on the anthrax protein, edema factor—data that were about to be published in *Nature*, one of the world's premier scientific journals.



Justin's notes on designing a molecular model.

Now, Team Anthrax had all the data needed to make the world's only models of all three known anthrax proteins. Tang was invited to travel to Milwaukee, where the students proudly presented him with a set of models. It was during the visit the team realized they had advanced their own knowledge to the point that they could converse with a leading researcher, sharing insights and asking important questions. The hard work had paid off!

The Team Anthrax story began to get attention in the local and regional press. Mike recently reflected on the impact of the public attention. "The project took a lot of time from chemistry class, and it caused stress because of the public speaking engagements. But now, because of the project, I can talk in front of people."

Making Models by Rapid Prototyping –One Layer at a Time

Rapid prototyping (RP) is an additive manufacturing process by which accurate three-dimensional models are constructed, layer by layer. Since each layer is only three thousandths of an inch thick, RP is actually a slow process, often taking 15–20 hours to complete a model. A Z Corp 3D printer, the rapid prototyping machine used by Team Anthrax, looks like a large automatic washing machine. Layering begins when a scanning arm equipped with an ink jet cartridge sweeps back and forth over a layer of powder leaving a trail of droplets. Each droplet includes glue so that when the droplet contacts the powder, a minuscule solid particle results. After the scanning arm has completed its passage over the layer of powder, the entire powder layer, which is supported on a tray, is lowered by three-thousandths of an inch into a bin. A second arm spreads out another layer of powder to prepare for the next passage of the scanning arm. This layering and gluing sequence repeats over and over for thousands of times. The process resembles the formation of a cave stalagmite on the floor of a slowly descending elevator. After the last passage of the scanning arm, the model is complete. Remove the bin, blow away the free powder with an air gun, and Voila! A model appears! The technician examines the product, completing the model by infiltrating it with resins to harden it.

A completed physical model represents a molecule, enlarged about 17 million times, yet true to the relative positions of the constituent atoms and functional groups.

Mike compares a finished model to its screen image using Rasmol software.

PHOTO BY PAUL ROBERTS, MSOE

The real value of the anthrax models became even clearer to the team when researcher John Young at the University of Wisconsin–Madison invited the students to his laboratory in February 2002. Young, a recognized authority on the anthrax bacterium, coauthored the March 2002 cover story in *Scientific American* entitled "New Antidotes to ANTHRAX" that was just about to appear on newsstands. When given an anthrax protective antigen heptamer model, Dr. Young stopped all conversation and began to inspect the model. Soon, he and his colleagues began to discuss their own work in terms of binding sites readily identifiable on this unique model. Continuing to examine it, Dr. Young held onto the model for the rest of the visit.

Then, Young had an idea. He told the team that he had been invited to speak before a special Congressional hearing on bioterrorism on Capitol Hill in Washington, DC. Could the students make enough copies of the models for him to distribute to members attending the Congressional hearing to facilitate their understanding of anthrax? The team was thrilled. They readily agreed to make 25 protective antigen heptamer models.

And what do their friends think of all this? Their reactions have been "interesting", and, for the most part, positive. According to Mike, "A lot of people came up in the hallway at school saying 'We saw you on TV.' or 'We heard about you on the news.' They weren't sure what it was about except they thought it was cool."

Mia, Mike, and Justin give a lot of credit for the success of the project to their mentors. Anderson, their teacher "was always willing to help us with anything and everything at any time for this project. Dr. Herman and Jennifer Morris at MSOE went above and beyond in offering their help."

Where will Team Anthrax members go from here? For the immediate future, they will be in college. Forty years into the future, Mike hopes to look back and view his Team Anthrax experience as the first step toward his science career. Justin thinks about the emotional impact of the experience, "People will always talk about September 11, and I can tell my kids that I was on a high school team that made the world's first models of anthrax protein."

Jonathan Knopp, a former science teacher in the Milwaukee Public Schools, now works as a consultant in the Center for Biomolecular Modeling at MSOE.
The author gratefully acknowledges Jeff Anderson and the students of Team Anthrax for their generous assistance with this article.

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X-ray Patterns in the Crystals

In the health sciences, radiologists use X-rays for diagnosis and cure. In the world of protein research, crystallographers direct X-rays at protein crystals to understand their structure.

The first task of a crystallographer is to prepare crystals of a given protein to be analyzed. Often, during this difficult task, two versions of the protein crystal are prepared. One version is the natural protein, whereas another is of the same protein infused with atoms such as mercury or selenium to act as markers for comparison. Often less than 0.5 mm on a side, the crystals are suspended in a glass capillary tube and then bombarded by an X-ray beam. Atoms of the crystal, especially the marker atoms, scatter the incoming beam to produce diffraction patterns that are recorded on a photographic plate. The complex patterns are analyzed mathematically, resulting in assigned coordinates for every atom in the protein. Crystallographers are proud to deposit their data on the Protein Data Bank (PDB) maintained by the Brookhaven National Laboratory.

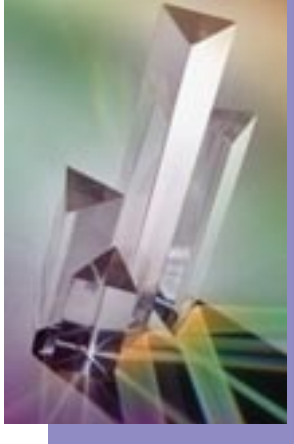


PHOTO FROM PHOTODISC

Biosensors
Early Warnings of Unseen Enemies

By Sonya Senkowsky

We have smoke alarms in homes and schools that sense the presence of smoke to warn us if there's a fire. Some of us have carbon monoxide detectors to sense the presence of that invisible, odorless, and deadly gas. So why don't we have a bioterrorism detector—something that could warn you if your mail has been contaminated or the air tainted with just as deadly, and maybe even highly contagious, microorganisms?

Maybe you thought about this when anthrax made the news last year. After all, how can we defend ourselves against these smallest of enemy agents—microorganisms like the deadly *Bacillus anthracis*—if we can't even see them?

Bioterrorism defense experts are constantly concerned about these threats, and their concerns are not limited to anthrax. They worry about diseases like smallpox, once thought to be eradicated from the population. Children who were born after 1972 no longer received smallpox vaccinations, and even those who were vaccinated before 1972 probably have lost their protective immunity without regular booster shots. Face it. If someone released the variola virus responsible for causing the deadly and contagious smallpox disease, there could be a couple of weeks during which thousands would be exposed before people started exhibiting symptoms.

Some threats are obvious. "No one needs an explosion detector," points out bioterrorism expert Rocco Casagrande. But we could use a pathogen detector, a sort of bioattack smoke alarm for warning us of the release of deadly microorganisms before they start causing harm.

What is a biodetector?

A smoke alarm is a kind of detector. The simplest versions sense the presence of smoke by passing an electrical current through an ion-filled chamber inside the device. When that area is filled with smoke particles, the current is interrupted, setting off an alarm.

Imagine trying to alter the device to detect pathogens.

How would you tell it to set off the alarm only when it sees harmful microorganisms, but to remain silent for those that are harmless? How could you make sure that the pathogens in the air would make it into the device? And, finally, how would you be able to tell the device to distinguish between one kind of deadly microorganism and another?

Biosensor developers are working to develop creative solutions for meeting these challenges. Biosensors rely on biochemical materials commonly found in living cells and tissues to trigger a reaction, just as smoke detectors use mechanical parts to trigger an alarm. The biochemical components of the sensor work at the molecular level to identify specific chemical signals. Biosensors are often used in medical care. One well-known example, used in managing diabetes, is the biosensor that relies on the interaction between an enzyme and a drop of blood to signal whether a person's blood sugar is too high.

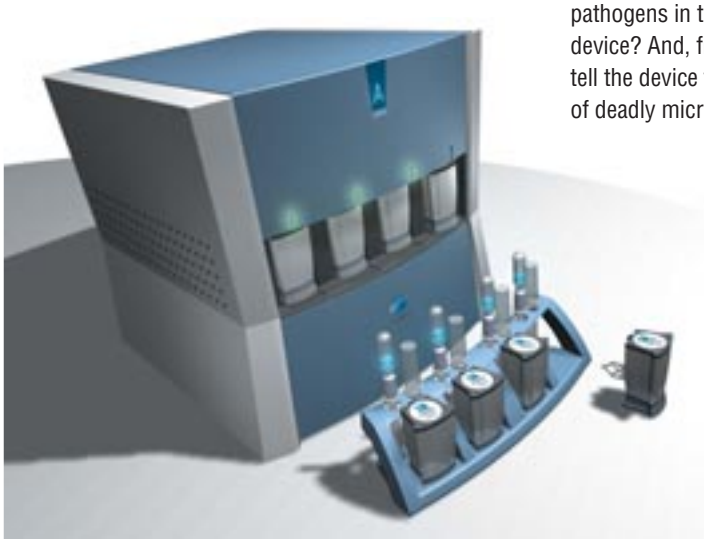
Such devices are now being developed to detect pathogens. Typically, these pathogen detectors rely on strategies borrowed from the body's immune response.

Within the body's circulatory system, specialized proteins called antibodies identify and bind with antigens, characteristic proteins on the surfaces of intruding pathogens. This interaction is the normal immune response that both enables the body to fight disease and makes vaccines so effective.

Simple biosensor tests based on this immune response involve the use of testing strips. These strips contain antibodies specific for the antigens on the surface of a pathogen, like the pathogen that causes anthrax. When the antibodies bind with the target antigens, they are designed to give off a signal—typically, a change of color.

Within minutes, the simplest of these antigen-based detectors provide a simple yes or no answer, indicating whether the pathogen of interest is present or not.

But such simple antigen-based tests are not foolproof, and their answers are not final. Unfortunately, these simple tests can still be fooled by reactions from other microorgan-



COURTESY OF VERSAGGI BIOCOMMUNICATIONS AND CEPHEID

Figure 1. Cepheid's GeneXpert-a automatically extracts and purifies DNA from a test sample and detects up to four gene targets in less than 30 minutes.

isms containing similar antigens. Or a test might miss genetically altered bacteria. It might also miss organisms that aren't present in high enough numbers to trigger a reaction.

Another kind of biosensor probes inside the cells to analyze genetic sequences.

These genetic-based biosensors break apart the cells of sampled microorganisms to extract their DNA, molecules containing genetic information unique to every cell. Using probes that look for certain genetic sequences, a detector can identify a gene found only in one kind of pathogen. Or it can raise an alert for a whole set of organisms. One set might be gram-positive bacteria, the group that includes pathogens for anthrax, botulism, and tuberculosis. Because these devices are analyzing information inside the cell and not just on the surface, they are not as easily fooled as antigen-based sensors.

BIOCAPTURE COURTESY OF MESOSYSTEMS

The handheld BioCapture air sampler is a boon to emergency responders—like firefighters and medics—who can't afford a long wait to find out if biohazards are present.

Sensitive genetic-based sensors can even "amplify" a sample, making it possible to get results even if testing a minute sample of pathogens.

To do this, these devices make use of a naturally occurring enzyme called a polymerase, which is sort of a DNA copy-and-repair device for the cell. Scientists put polymerases to work for them by using small pieces of synthetic DNA—"primers"—to trigger their copying activity. By the time this Polymerase Chain Reaction (PCR) is done, a single strand of DNA may be copied more than a 100 times, ensuring it is not overlooked (see Figure 1 on page 7).

Anthrax spores in the mail added to the nation's anxiety in late 2001.

PHOTO FROM PHOTODISC

Some sensors use surprising combinations. One bioelectric sensor now being developed by the Massachusetts Institute of Technology for the Air Force even uses a gene from a jellyfish! The sensor is called CANARY, short for Cellular Analysis and Notification of Antigen Risks and Yields—a reference to the days when miners used the small birds to detect poison gas in mines.

CANARY developers genetically altered white blood cells with a bioluminescent protein from a jellyfish. When antibodies in the blood cells bind with their target antigens (using the immune response described earlier), the connection triggers an enzyme to release calcium within the cell. This in turn causes the calcium-sensitive jellyfish protein to glow. A photodetector measures the luminescence and interprets the results (see Figure 1).

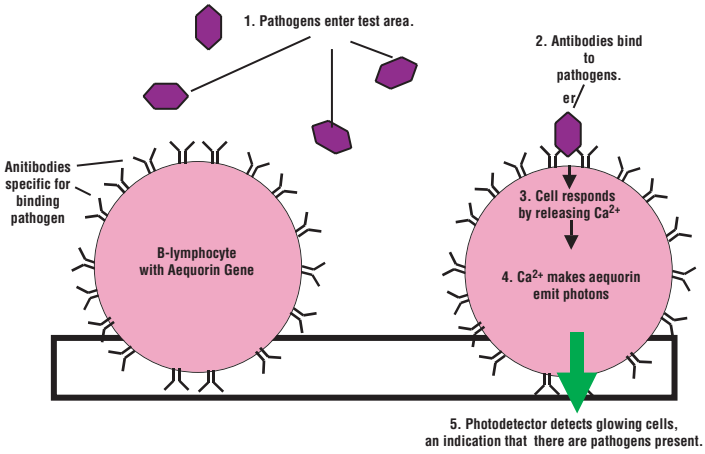


Figure 1. CANARY. With a jellyfish gene on board, human white blood cells are engineered to register the presence of certain pathogens by glowing.

So, where's my alarm?

The technologies so far described have proven useful for testing after you know there's been an attack. But what about that bioterrorism alarm we were talking about?

Such an alarm would have to constantly monitor the environment, performing test after test after test. But so far, the best devices using these technologies—now in use by the military—need to be maintained regularly, as often as every 8 hours, some with the addition of chemicals and water to make the constant testing possible.

Having such a high-maintenance monitor would be like having a smoke detector requiring new batteries and maintenance every day—expensive to maintain and easy to neglect! Don't expect to see a home version for sale anytime soon.

In addition to always-on monitors, experts are exploring other kinds of devices for possible use in sensitive areas—like special walk-through sensors Casagrande is developing for detecting pathogens on persons and animals. "Someday," he says, "these may be used on farms, in airports, or even in schools."

Developers are considering other technologies, including mass spectrometry for separating microrganisms by mass, light probes for distinguishing between pathogens, and even an electrochemical nose for distinguishing bacteria by odor. But most of these strategies are far down the road.

According to Casagrande, the first place you might encounter these modern types of biosensors could be in your doctor's office, perhaps even the nurse's office at your school. Although originally designed to foil bioterrorism, they might someday be useful for diagnosing your flu symptoms.

"We can imagine a device that checks the air you're breathing out and says you need exactly this type of antibiotic," he says. In part because of bioterrorism defense research, "those things aren't too far away."

Sonya Senkowsky is a freelance science writer based in Anchorage, AK.

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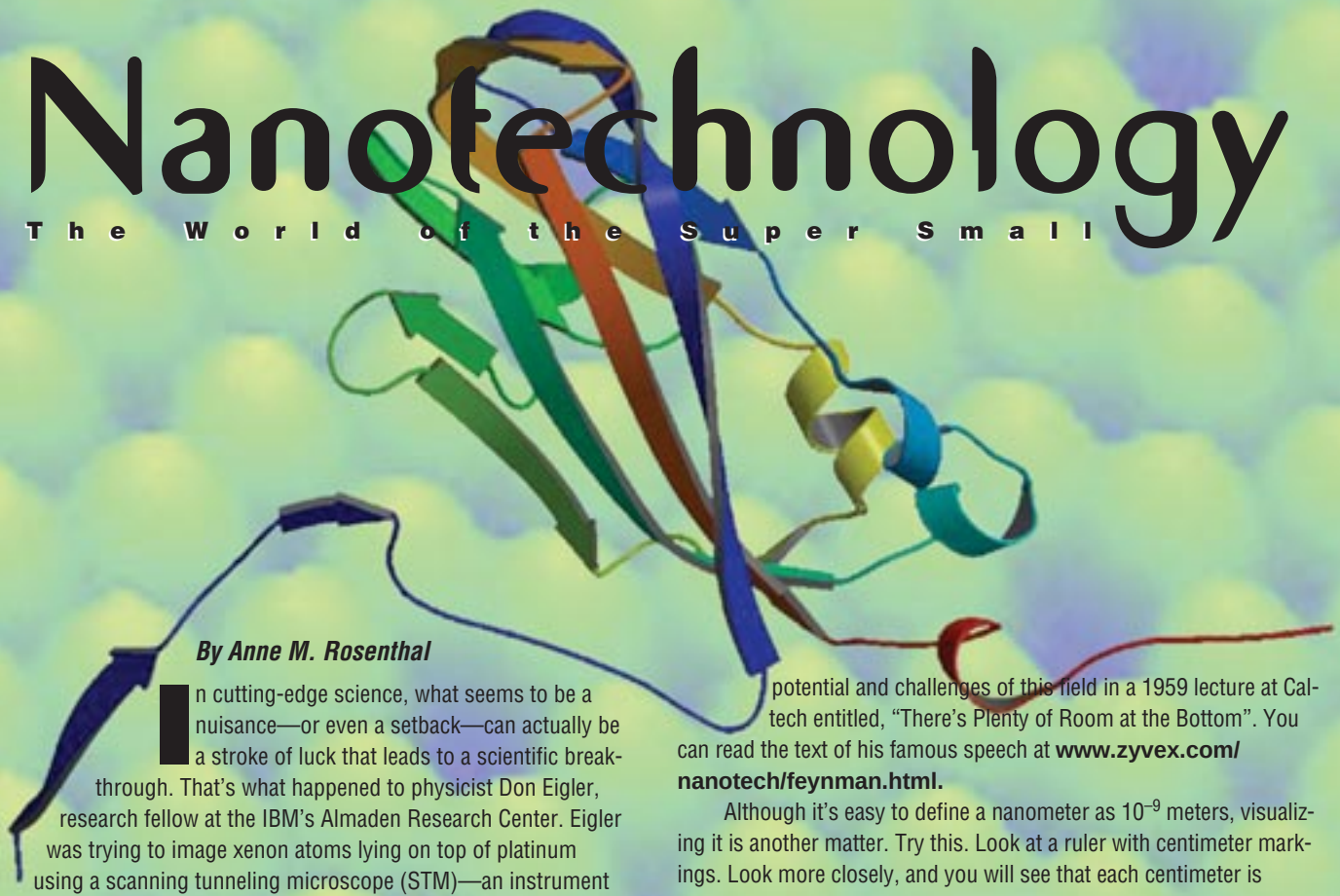
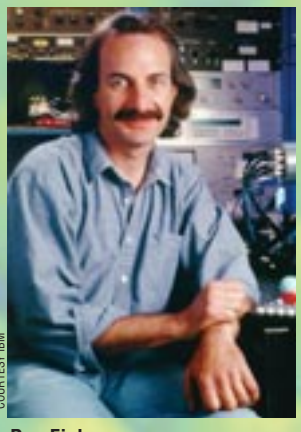
Nanotechnology

The World of the Super Small



By Anne M. Rosenthal

In cutting-edge science, what seems to be a nuisance—or even a setback—can actually be a stroke of luck that leads to a scientific breakthrough. That's what happened to physicist Don Eigler, research fellow at the IBM's Almaden Research Center. Eigler was trying to image xenon atoms lying on top of platinum using a scanning tunneling microscope (STM)—an instrument invented at the IBM Zurich Research Laboratory in 1981 by Heinrich Rohrer and Gerd K. Binnig. The STM is no ordinary microscope. It can produce images showing not only the positions of individual atoms, but even their distributions of electrons. But when Eigler attempted to image the xenon, the microscope tip kept dragging the atoms around, ruining the images (Figure 1).



COURTESY IBM

Don Eigler

Then Eigler began thinking about how that could be useful. He spent a few days fine-tuning the software associated with the microscope and became the first scientist to move individual atoms at will, a capability he demonstrated by arranging atoms to spell out his company's name: IBM (Figure 2, page 10). His discovery led to new types of studies at the atomic level. Today, both the STM and another microscope developed at IBM, the atomic force microscope, are used both to visualize and move atoms.

Eigler was working at the smallest end of the rapidly advancing field called nanotechnology. The term includes the prefix *nano*, which stands for one billionth or 10^{-9}. Nanotechnology encompasses both the study and engineering of structures with at least one dimension between one and several hundred nanometers. This is the realm of atoms and molecules! Engineers in this field are working with the tiniest possible components and mechanisms. Physicist Richard Feynman, famous for his teaching and writing, was the first to predict the potential and challenges of this field in a 1959 lecture at Caltech entitled, "There's Plenty of Room at the Bottom". You can read the text of his famous speech at **www.zyvex.com/nanotech/feynman.html.**

Although it's easy to define a nanometer as 10^{-9} meters, visualizing it is another matter. Try this. Look at a ruler with centimeter markings. Look more closely, and you will see that each centimeter is divided into ten parts called millimeters (mm). There isn't much point in placing smaller lines between the millimeter marks. They would be so close together that we'd fail to see any separation between them. But imagine taking a strong magnifying glass and a very fine pencil and drawing 10 individual lines between any two adjacent millimeter marks. But now imagine trying to draw another hundred lines between each of *those* lines. You still aren't anywhere near the nano level! You have reached the micrometer level, the "micro" world of cells and bacteria. But to make the nano level, you need to draw another 1000 lines between each of those lines (Figure 3, page 11). Welcome to the world of the super small—the realm of atoms and molecules!

COURTESY STRUAN GRAY, LUND UNIVERSITY, SWEDEN WWW.SLJUS.LU.SE

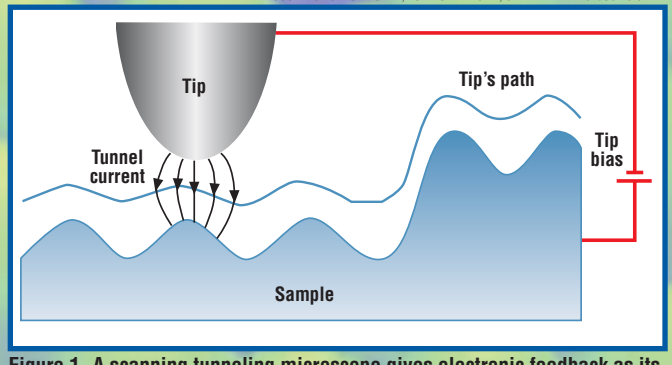


Figure 1. A scanning tunneling microscope gives electronic feedback as its tip rides over the atoms on a surface. Eigler found that sometimes the tip dragged atoms to new positions.

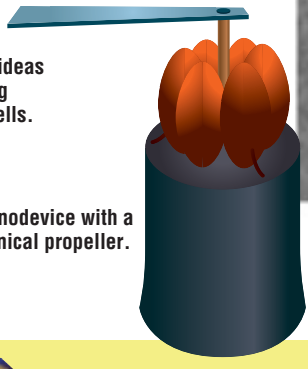
Designing in miniature

Nanoengineers can't merely miniaturize larger-scale inventions because objects in the nano size range tend to behave according to their

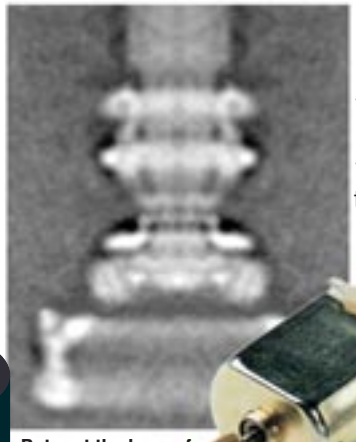
own set of rules. Nanometer-sized particles tend to break the laws of Newtonian mechanics. Named after Sir Isaac Newton, the 17th century physicist who first formulated them, these laws predict the behavior of falling objects, thrown baseballs, and even objects as small as a few micrometers in diameter. But the behavior of nanoscale objects isn't comfortably described in terms of quantum mechanics, either—an area of physics that describes the behavior of atoms and subatomic particles.

Anyone designing a nanomachine must also face the fact that, as an object gets smaller, it has a greater surface area-to-volume ratio, giving frictional forces a bigger role. Other characteristics of substances can change with size, too. For example a metal oxide that's permanently magnetic at one size may hold magnetism only temporarily at another size. All this can make working in the unfolding field of nanotechnology unpredictable and challenging.

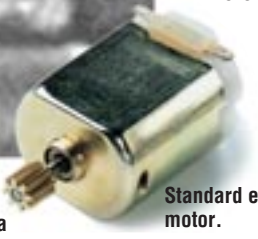
PHOTOMICROGRAPH COURTESY DR. DAVID DEROSEIER, BRANDEIS UNIVERSITY



Design for a nanodevice with a rotating mechanical propeller.



Rotor at the base of a bacteria cell's flagellum is part of a natural nanomotor.

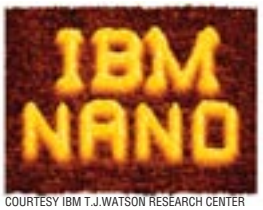


Standard electrical motor.

Figure 4. Researchers get ideas for nanodevices by studying examples found in living cells.

Nanotechnology spans the sciences

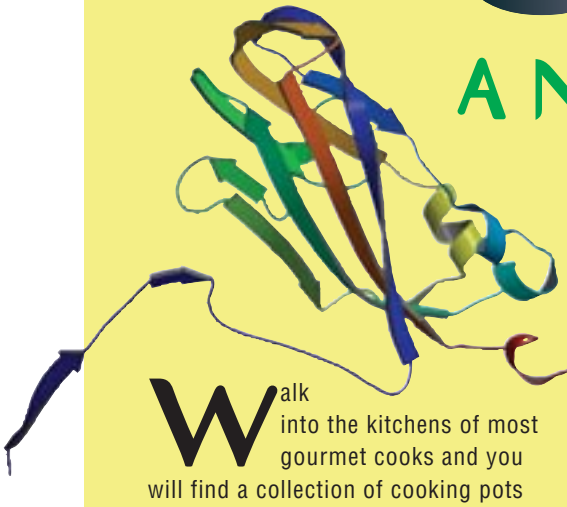
Scientists are discovering some naturally occurring nanomachines in living things. There's the enzyme "helicase," a molecular motor that unwinds helical DNA molecules as it moves along the long spiraled DNA like an inchworm. Researchers are also intrigued with the rotors at the base of flagellae, long rotating whiplike projections that propel bacteria through their liquid medium. These molecular machines, composed of proteins, look a lot like standard electric motors (Figure 4).



COURTESY IBM T.J.WATSON RESEARCH CENTER

Figure 2. Eigler demonstrated the power of the STM by arranging atoms to spell the company name.

Studies of these natural mechanisms give scientists ideas for how to design and build their own nanostructures and mechanisms. Human-engineered nano creations run the gamut, with potential applications as diverse as monitoring and labeling devices, medicine, and computer



CCMV GRAPHIC COURTESY SCRIPPS RESEARCH INSTITUTE, VIPER WEBSITE

A Nanotechnology Kitchen

Walk into the kitchens of most gourmet cooks and you will find a collection of cooking pots and utensils all nicely specialized for particular jobs. Mark Young and Trevor Douglas of Montana State University, Bozeman, are designing their own set of cookware at the nanometer scale, starting with the protein shells of viruses known as "viral capsids."

As the infectious agents for the common cold, smallpox, polio, and a host of other human, animal, and plant afflictions, viruses are generally considered fearsome disease organisms. Yet, they are some of nature's simplest, and most ingenious, inventions.

Viruses travel light, packing only a few genes inside their shell-like *capsids*. These genes are coded in the four-base language of nucleic acid, either DNA or RNA. To reproduce, a virus makes contact with a host cell. By one of several possible mechanisms, the contents of the capsid enter the host cell, thereby introducing genes that rapidly take over the host's cellular machinery to manufacture more viruses.

Nanoengineers Young and Douglas manufacture viral capsids that don't contain any nucleic acid, rendering them noninfectious. Then they use the empty protein shells of these tiny parasites as reaction vessels. "It's like having little cooking pots in a range of sizes for a nano kitchen," Young says (Sidebar Figure 1).

Most of the work by Young and Douglas, with Jack Johnson's group at The Scripps Research Institute has centered on the cowpea chlorotic mottle virus (CCMV). Like the bacterium *E. coli* and the fruitfly *Drosophila*, the readily available CCMV has been studied in depth by many scientists. The extensive sci-

Figure 1. Empty CCMV capsids serve as little "cooking pots" in a nano kitchen.

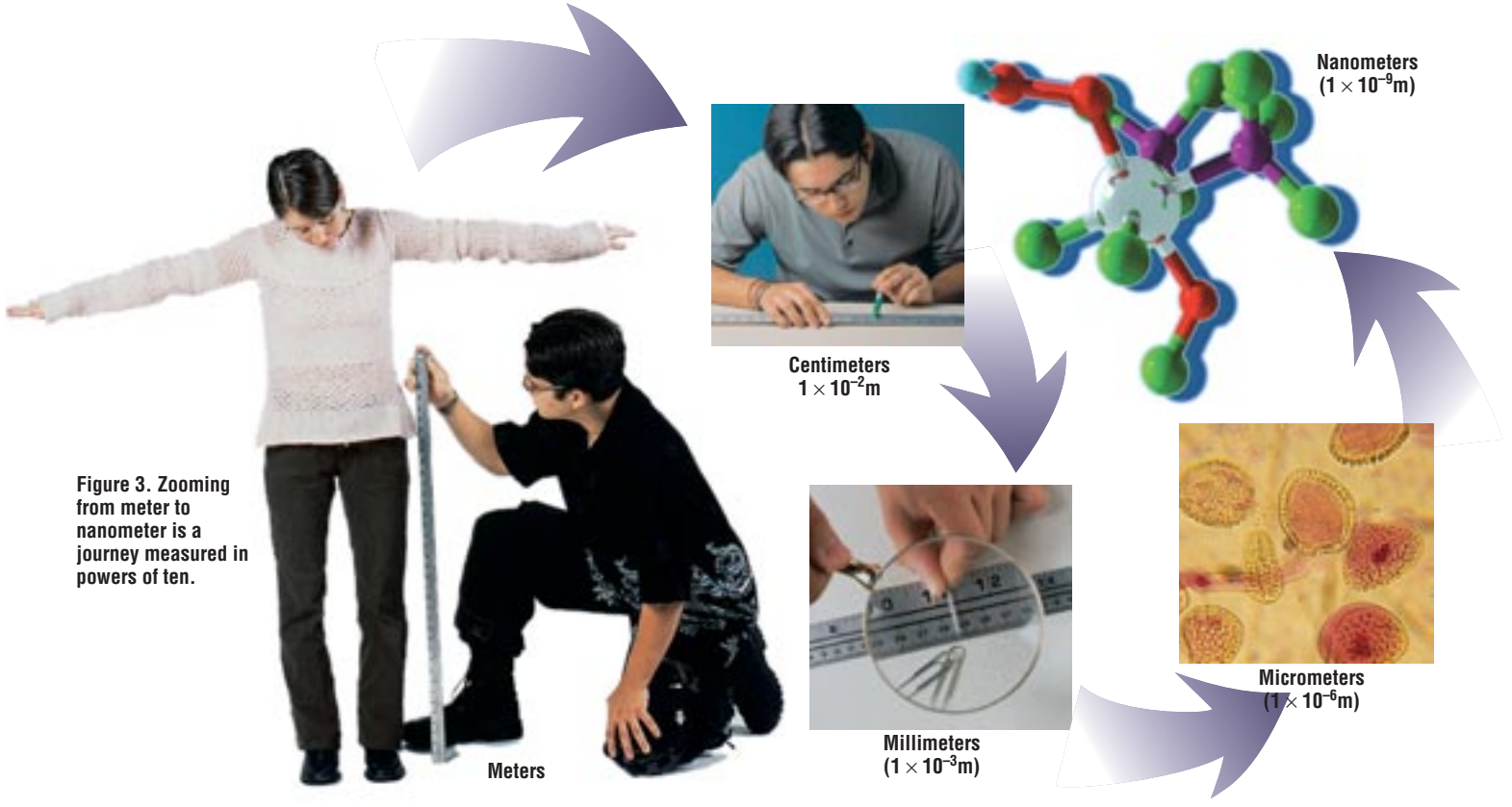


Figure 3. Zooming from meter to nanometer is a journey measured in powers of ten.

entific knowledge about CCMV helps researchers use the virus as a tool.

Like many viruses, CCMV resembles a miniature soccer ball. Its 20-sided geometry is called an *icosahedron* (Sidebar Figure 2). These viruses are composed of identical protein subunits, which the invaded cell faithfully manufactures following a viral RNA blueprint. Once created, the subunits self-assemble—not only inside the host cell, but also under the right conditions, in a test tube. And that's a feature a nanotechnologist appreciates. Using techniques from microbiology, researchers can even introduce the CCMV genetic blueprint into yeast cells, turning them into factories for subunit manufacturing and assembly.

Figure 2. The CCMV resembles a miniature soccer ball.

Researchers can open the capsids to add reactants.

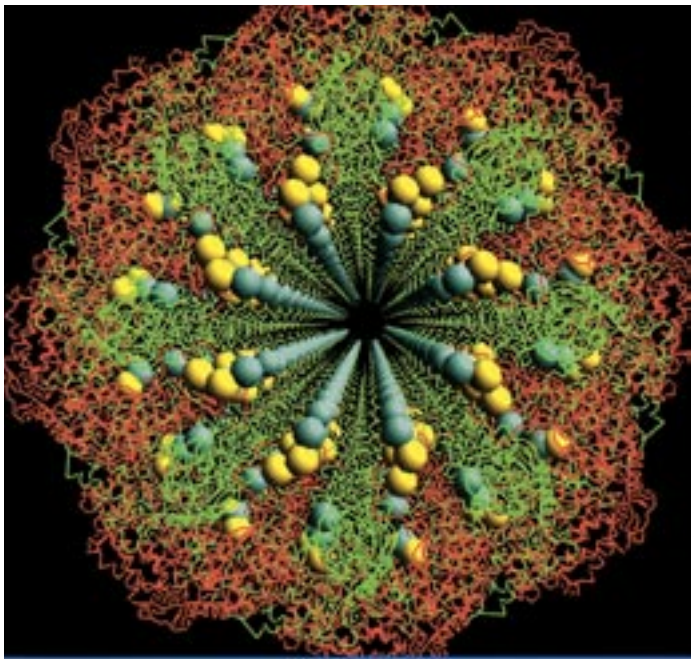
Some viral capsids, like the CCMV protein shell, have a special characteristic, notes Young. They contain gate-like pores that open and close, according to chemical cues. By adjusting the pH of the surrounding solution, the researchers can open the capsid "windows" to let in reactants for manufacturing specific compounds. Then they can batten down the hatches while the reaction proceeds.

The inside of a naturally occurring CCMV capsid is positively charged, explains Young. Each of its protein subunits is composed of a single folded polypeptide chain of linked amino acids. In a CCMV, the subunits project into the capsid interior, terminating in a string of basic, positively charged amino acids—arginine and lysine. This arrangement sets up a strong positive charge inside the capsid that effectively captures and sequesters the negatively charged viral genetic material within.

Working with empty capsids, the scientists found that they could select and introduce certain negatively charged ions into the capsid interiors—ions capable of reacting where they nucleate at the positively charged sites. Nucleation means that the molecules involved are brought close together—close enough for a reaction to occur.

A Nanotechnology Kitchen, continued on next page

PHOTOS BY MIKE CIESIELSKI



COMPUTER IMAGE BY CHRIS HENZE AND BRYAN GREEN, NASA AMES RESEARCH CENTER WWW.NAS.NASA.GOV

The computer image of a protein nanotube reveals the intricate symmetry of a complex molecule.

technology. Nanometer-sized zinc oxide particles, used in sunscreen, promise to provide protection without the telltale white mask because the particles are too small to scatter light. A variety of nanoscale "vehicles" might deliver intravenously administered drugs precisely where they are needed, minimizing side effects (see sidebar, "A Nanotechnology Kitchen").

Engineers are constantly striving to reduce the size, weight, and cost of our vast array of electronic devices. Transistors play a key role in this miniaturization trend. Used in devices as diverse as computers and radios, transistors control the flow of current in an electrical circuit. The thousands of transistors etched on every computer chip are each capable of being "on" or "off". This capability explains how computers are able to perform thousands of logical operations every second.

Today, nanoengineers are designing molecular switches to downsize these devices to the extreme. Researchers have created nanotransistors based on the behavior of individual molecules and the movements of single electrons. A molecule might have two different configurations that can be controlled chemically. For the molecule, one configuration represents "on", and the other "off". Thus, acting as a molecular switch, the molecule controls the flow of electrons on the smallest imaginable scale.

But once something is designed at the nanoscale, how do you manufacture it? There are two main approaches, top-down and bottom-up.

In the top-down approach, nanoengineers remove tiny parts, sometimes simply atoms, from a surface. Or they may add on small amounts

A Nanotechnology Kitchen, continued

But Young, Douglas, and their colleagues were also interested in chemical reactions that require a negatively charged capsid interior. They decided to use genetic engineering techniques to alter the viral gene's coding for the amino acids on the polypeptide subunit chains. This time, the identical chains terminated with the more negatively charged glutamic acid. To their delight, the scientists found that the capsids still self-assembled into cooking pots.

Young and his colleagues wanted to show that their newly engineered capsids could also nucleate reactions; that, in fact, scientists could change the nanoreaction vessels by design for different types of chemistry. For proof of principle, Young and his colleagues decided to mimic a natural protein cage called ferritin present in living organisms. "Evolved over millennia, the iron storage molecule ferritin is what prevents you from rusting," Young points out. Within the newly designed viral capsids, Young and his colleagues were able to complete the oxidization of Fe^{2+} to Fe^{3+}.

Along practical lines, Young, Douglas, and MSU physicist Yves Idzerda are using the nano kitchen to prepare magnetic materials such as those used in electronic devices. For use in memory devices, the researchers synthesize metal oxides within the viral cages and then pack the metal-filled capsids into two- and three-dimensional arrays. These can be used to create what is known as magnetic memory, memory that remains on when your computer is turned off. The viral capsid approach results in memory much smaller, denser, and faster than magnetic memory currently available, says Idzerda.

MSU scientists are also experimenting with an entirely different application for the viral capsids—as portable scaffolding, on a nanoscale, for paramagnetic materials—materials with unpaired electrons. One such material, the element gadolinium, is introduced into the body as part of a medical imaging technique called magnetic resonance imaging (MRI).

Young and his colleagues have found a way to incorporate gadolinium into the capsid framework, which "gives orders of magnitude brighter signal," Young says. This potentially allows the physician to image whatever the gadolinium-bound capsid is targeted to—like cancer cells—even if only a few are present. One way that targeting is achieved is by attaching to the capsid exterior molecules capable of binding with proteins found on the surface of cancer cells. By means of these gadolinium-carrying capsids, clinicians could detect tumors while they are still tiny. Then by means of some radiation-sensitive trigger, they might open the capsid gates releasing a potent drug stored inside. In the future, chemotherapy might thus be focused exactly where needed, dramatically reducing the toxicity many cancer patients now encounter with broadly targeted treatments.

of materials, for example, by using a block of soft polymer to stamp them on a surface. In contrast, the bottom-up approach begins with atoms or molecules and takes advantage of nature's tendency to self-assemble if conditions are favorable (see sidebar, "A Nanotechnology Kitchen").

Meanwhile, back in the corral

Don Eigler's luck didn't stop with the xenon atoms. A decade later, in 2000, he was using the scanning tunneling microscope to corral electrons within an ellipse of cobalt atoms on a copper surface.

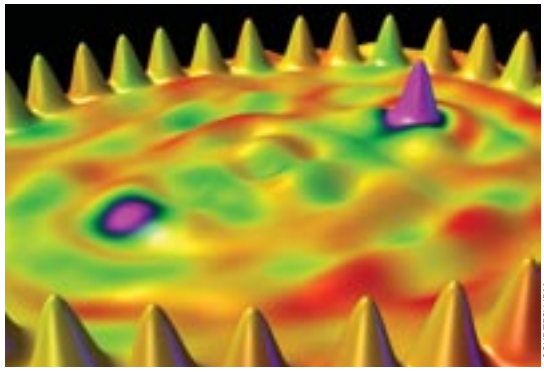
"When electrons are placed within a small structure," explains Eigler, "they have distinct spatial and temporal patterns called quantum states." This is analogous to the classical physics of a plucked guitar string. Each string oscillates at distinct, characteristic frequencies, the so-called resonant frequencies of the string. "It is important to recognize that a wave is not something that exists in just one place. A wave, fundamentally, is distributed in space," says Eigler.

The two foci of the elliptical quantum corral, Eigler's name for the ellipse of cobalt atoms, are locations of high electron density. Eigler tried an experiment. He placed an additional cobalt atom at one of the foci. That was similar, Eigler says, to placing your finger on a guitar string, at the point where oscillation of the guitar string is greatest, the antinode. Just like your finger affects how the string resonates, the cobalt atom affected how electrons resonated within the corral. And just like you can hear the change your finger—a local modulator—makes to the way the guitar string resonates, the scientists could use the STM to detect the effect of the interior cobalt atom on electron resonance within the ellipse (Figure 5).

But to their surprise, the scientists not only detected the effect of the actual cobalt atom, they detected a mirage effect. There were changes in electron resonance as if there was also a cobalt atom at the second focus!

The quantum mirage discovery opened the door to the possibility of using the wave nature of electrons to transmit information. Placing an atom at one focus of an elliptical quantum corral informs the focus at the other end. Transfer of information is one of the basic functions inside a computer, says Eigler. And unlike transistors on a computer chip that must be insulated from each other for their information to remain intact, waves can pass through each other without being changed.

Small world! The familiar expression takes on whole new meanings as advancing nanotechnology refines the devices on which we rely, one nanometer at a time.



COURTESY IBM

Figure 5. Cobalt atoms form a corral for holding electrons.

Is a science research career in your future?

Zachary Pincus, now a Stanford graduate student in biological sciences, began working in Mark Young's laboratory as a volunteer the summer after his junior year in high school. He continued to work there the next two summers on an American Cancer Society fellowship, and as a paid laboratory employee. He started by assisting a graduate student, and learning basic techniques. The next two summers he worked on his own research project—investigating whether additional bits of protein could be added to the CCMV virus coat at specific points in the repeating units of the coat and whether the virus could still assemble.

PHOTO COURTESY ZACHARY PINCUS

Zach describes his experience working in Young's lab.

"I learned basic techniques in Mark's lab that have been invaluable in later lab work. And more importantly, I also learned a lot about thinking scientifically, setting up good experiments, and planning a research project. Going off to college already knowing a lot about this field really gave me a leg up, a confidence boost. I felt I knew what I was doing. All in all, my experience was overwhelmingly positive. Mark's excitement, interest, and trust in his students to carry out serious, independent investigations, made his lab an exciting and fun place to work and learn."

A number of programs make it possible for high school and college students to intern in research laboratories. The Physics Department at the University of Pennsylvania offers an extensive list of these opportunities on their Web page: **http://dept.physics.upenn.edu/undergraduate/natlab.html.**

Anne M. Rosenthal is a freelance science writer based in the San Francisco Bay Area. Her article, "Art Conservation—Chemistry to the Rescue" appeared in the October 2001 issue of *ChemMatters*.

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Matches—
Striking Chemistry at Your Fingertips

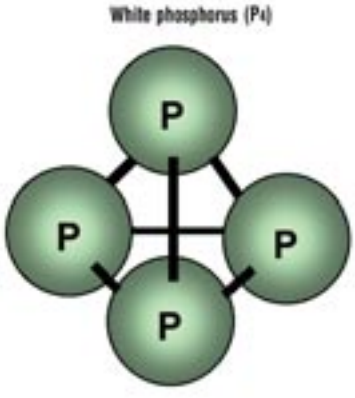
By Brian Rohrig

The simple match—so common, and yet so taken for granted. Billions are given away, simply to broadcast the advertising on their covers. But as Tom Hanks showed us in the movie "Cast Away", trying to start a fire without them can be a frustrating and exhausting experience.

At the tip of every match, you'll find the element phosphorus. So the fact that the story of matches bears a striking resemblance to the story of the element should come as no surprise. In 1669, a German alchemist named Hennig Brandt was pursuing the glorious and futile alchemist dream of converting common materials into gold. Regarding human urine to be a mysterious, magical, and not to mention yellow fluid, Brandt collected, and then evaporated a large quantity of it in a retort. Eventually, the mixture formed a solid lump. In what was probably an attempt to "fire" the lump into gold, he placed the retort in a furnace. Upon extensive heating, the solid began to glow. A shining liquid dripped out, igniting spontaneously when it contacted air. It wasn't gold, but he had to admit it was interesting!

PHOTOS BY MIKE DIESIELSKI

Today, we know that Brandt had succeeded in making highly reactive *white* phosphorus with the formula P_4—its four atoms arranged in a pyramid. In fact, white phosphorus is so reactive that it must be stored underwater. Its dramatic and spontaneous reaction with air remained a mystery well into the 18th century. Now we know that phosphorus reacts with the oxygen in the air at room temperature, but since oxygen hadn't been discovered in 1669, Brandt had no way of knowing what was actually occurring:



$$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s) + \text{heat}$$

Because of its dramatic combustion in air, phosphorus derives its name from two Greek roots: *phos* meaning light, and *phorus* meaning bearing. Ironically, the word phospho-

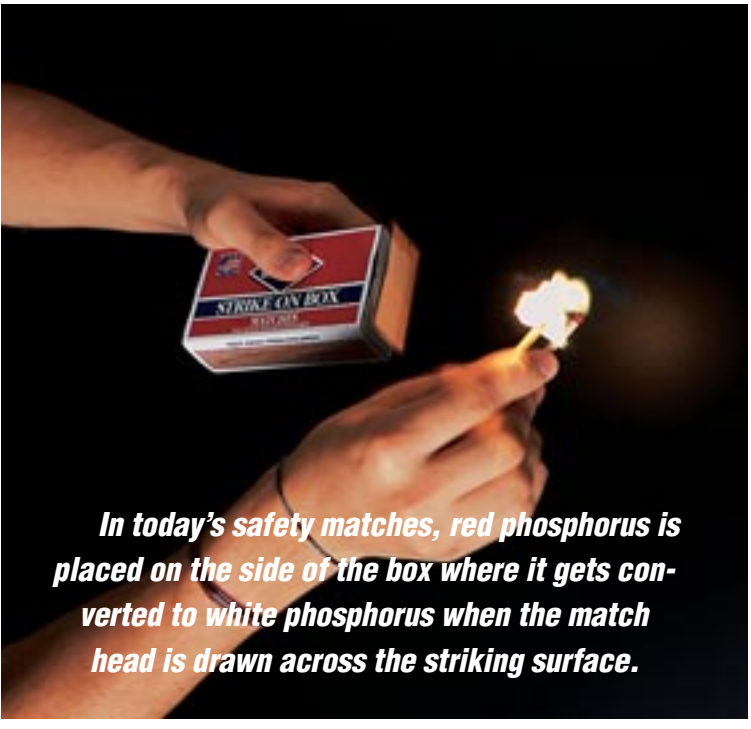
rescence has come to describe the way certain elements glow when excited electrons release energy as they return to their lower-energy ground states. These elements glow with a cool light emitting no heat energy in the process. Phosphorus, on the other hand, truly combusts on exposure to air, giving off not only light but also significant heat in the process.

Try lighting a safety match on a piece of sandpaper. No good! The chemistry just isn't there.

Go with the glow

After its discovery, there were reports of people painting their faces and hands with phosphorus in order to "glow" in the dark. But it's doubtful any person tried this more than once. Phosphorus produces painful burns on the skin. In the Sherlock Holmes mystery *The Hound of the Baskervilles,* a large dog is coated with phosphorus, making it appear as a ghostly apparition to frighten all who observed it.

Not long after phosphorus was discovered, the famous British chemist Robert Boyle began experimenting with it to create the earliest matches. Boyle coated a piece of paper with phosphorus and a small stick of wood with sulfur. When the stick was rubbed across the phosphorus its sulfur reacted, generating enough heat to produce fire. Impressive? Yes. But it proved impractical, because of the extreme instability of the white phosphorus. Nevertheless, Boyle's design represented the first example of a "safety" match—one that can only be lit if struck on a special type of surface.



In today's safety matches, red phosphorus is placed on the side of the box where it gets converted to white phosphorus when the match head is drawn across the striking surface.

Another early match invention involved coating the end of a stick with a paste of sugar and potassium chlorate ($KClO_3$). The end would then be dipped into a vial of concentrated sulfuric acid (H_2SO_4), causing the match to ignite. But the obvious hazards associated with handling concentrated acid soon halted the production of these matches.

The first strike-anywhere match was the invention of John Walker, an English pharmacist, in 1827. He mixed some potassium chlorate and antimony sulfide and applied it to a splint of wood. When the splint was drawn across a rough surface, enough heat was generated to start the following reaction:

$$Sb_2S_3(s) + 3KClO_3(s) \rightarrow Sb_2O_3(s) + 3KCl(s) + 3SO_2(g) + \text{heat}$$

The heat from this highly exothermic reaction in turn ignited the wood.

From the equation above, you see that sulfur dioxide (SO_2) is produced. SO_2 is a foul-smelling, poisonous gas. Warnings were included on the matchbox not to inhale the fumes after lighting. These bad-smelling matches, which made a loud bang when lit, became known as *lucifers*. This time, Latin was the source—*luc* meaning light and *fer* meaning to bear. The name was retained for nearly 100 years.

Eventually, a small amount of white phosphorus was added to each match tip during their manufacture. This addition made them easier to light and also eliminated the loud bang. The glue that held the match head together prevented the phosphorus from spontaneously combusting in air. However, due to the inherent instability of white phosphorus, these matches were somewhat dangerous. They often started accidental fires. In fact, they were so unstable they could ignite if a box of them were shaken. Or if exposed to direct sunlight, they would sometimes spontaneously combust.

A safer match

The world clearly needed a safer match, and such a match became a reality when another form of phosphorus was discovered in 1844. When white phosphorus is heated in a vessel devoid of oxygen, the unstable pyramidal P_4 molecules break apart and then relink to form a much more stable chain-like covalent structure called red phosphorus. Red phosphorus does not spontaneously combust when exposed to air. Now it was possible to remove phosphorus from the match head and put it on the side of the box, making accidental combustion less likely to occur.

People still demanded "strike anywhere" matches, so manufacturers still used white phosphorus despite all the health and safety problems associated with its use. Workers in match factories often contracted a disease known as necrosis or "phossy jaw". Inhaled vapors of white phosphorus corroded the teeth, finally working their way into the jaw, causing extreme pain. Workers mouths filled with open lesions that oozed pus.

Despite public demand, lucifers were outlawed in 1910. But soon the strike-anywhere match was reinvented in a new and safer form.

Match makers discovered that tetraphosphorus trisulfide (P_4S_3) could replace white phosphorus, with none of the health hazards associated with white phosphorus. This safer compound was made by heating phosphorus and sulfur in a 1:3 molar ratio:

$$P_4(s) + 3S(s) \rightarrow P_4S_3(g)$$

Next, the P_4S_3 was combined with potassium chlorate ($KClO_3$) and sulfur (S) to form a match head easily ignited by the heat of friction. Sometimes, powdered glass was added to the match head, producing more friction, and thus more heat when the match was struck. An added inert filler bound the ingredients together. The exothermic reaction went like this:

$$P_4S_3(s) + S(s) + 6KClO_3(s) \rightarrow P_4O_{10}(s) + 4SO2(g) + 6KCl(s) + heat$$

In today's safety matches, red phosphorus is placed on the side of the box, where it gets converted to white phosphorus when the match head is drawn across the striking surface. The white phosphorus then ignites spontaneously in the air. The generated heat initiates another chemical reaction with the sulfur and potassium chlorate to light the match. It works like this:

$$4P(red) + energy\ (friction) \rightarrow P_4(white)$$

$$P_4(s) + 5O_2(g) + 3S(s) + 2KClO_3(s) \rightarrow P_4O_{10}(s) + 3SO_2(g) + 2KCl(s) + heat$$

What happens when you blow out the match? Modern manufacturers have got that covered. Today, the wood of all matches is chemically treated to prevent accidental fire when a recently lit match is discarded. You've probably noticed that when an untreated wood splint is ignited and then blown out, a burning ember continues to glow. But when you blow out a wooden match, the match immediately ceases to glow. To accomplish this no-glow feature, wooden matches were once dipped in a solution of alum [$AlK(SO_4)_2$] or sodium silicate (Na_2SiO_3). Today, afterglow is prevented by dipping the wood for making matches in a solution of ammonium phosphate [$(NH_4)_2HPO_4$] and phosphoric acid (H_3PO_4).

About 100 years ago, 3 trillion matches were made each year. Today, with the availability of other fire-starting devices, half a trillion matches are manufactured annually. Modern box matches are still manufactured primarily from aspen and poplar woods, with few changes in the past century. Strike one, and you are looking at some fascinating chemistry—not to mention *chem-history*—right at your fingertips.

They're a Blast!

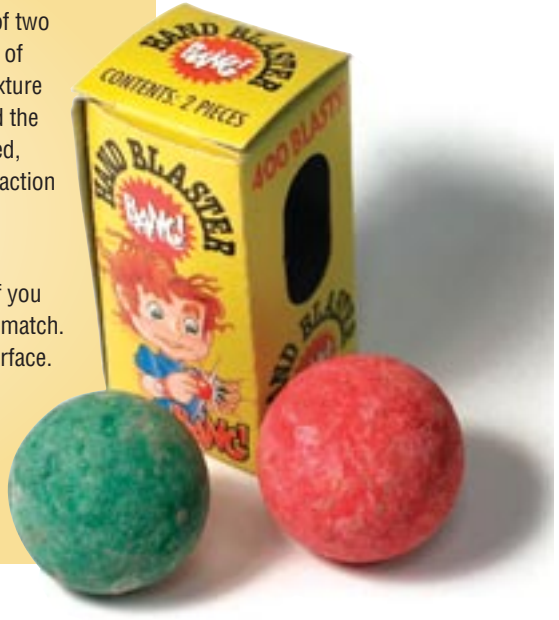
Called "Hand Blasters", "Blaster Balls", or "Cracking Balls", this novelty toy item is a set of two ceramic balls about the size of ping pong balls. On the basis of chemistry similar to that of matches, they make a loud popping noise when struck together. Each ball is coated with a mixture of potassium chlorate ($KClO_3$), sulfur (S), powdered glass, and glue. $KClO_3$ is the oxidizer, and the sulfur is the fuel. The powdered glass increases friction, and thus the amount of heat generated, when the balls are struck together. The heat of impact produces enough energy to initiate a reaction between the potassium chlorate and the sulfur.

$$3S(s) + 2KClO_3(s) \rightarrow 3SO_2(g) + 2KCl(s) + heat$$

Because both balls are coated with the same substance, you'll get the noisy effect even if you drop a single ball on a hard surface. In this way, Blaster Balls are similar to a strike-anywhere match.

All the ingredients necessary to carry out the chemical reaction are contained on each surface. The only thing necessary to start the reaction is heat.

Before you rush out to buy these, here's our advice. Plan to use them outside. That's for the sake of safety, as well as the sanity of everyone in the area.



Brian Rohrig teaches chemistry at the Eastmoor Academy in Columbus, OH. His most recent article for *ChemMatters*, "The Fizz-Keeper: Does It Really Keep the Fizz?", appeared in the February 2002 issue.

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Murder She Floats

By Robert Mentzner

On June 28, 1996, two New Jersey men set out to sea on a grizzly mission. Tom Capano and his brother Gerard, lifted the cooler containing the murdered body of Tom's former mistress, wrapped a chain around it, and dropped it overboard. But instead of sinking, the cooler merely bobbed up and down in the swells.

Now what do they do? They were some 70 miles off the New Jersey coast in Gerard's boat, and they had to get that cooler to sink. Taking a small shotgun used for killing sharks, Gerard fired a single shot that angled through the side and out the bottom of the cooler. "There, that ought to do it!" he said. It didn't. Amazingly, the cooler still floated. So Gerard maneuvered the boat next to the cooler, and Tom pulled it back aboard. Taking Ann Marie Feehey's body from the cooler, they wrapped the chain around her and tossed her body back into the ocean. This time the body sank. They tossed the empty cooler overboard and returned home.

When the Feehey family and the police began to look into her disappearance, they found in her diary that she and the wealthy and influential lawyer Tom Capano were having an affair—an affair she was trying to end. Tom immediately became a prime suspect. But there was no body and there were few clues to her whereabouts.

Investigators noted that Tom had purchased a large Igloo cooler and that he had made a phone call from Stone Harbor the day after her disappearance. Gerard kept his boat at Stone Harbor. Gerard was a drug offender on probation, so police raided his home and found violations of his probation. They threatened him with a long prison term unless he told them what he knew about Ann Marie's disappearance. Gerard cracked. He told them all about the cooler that wouldn't sink. Tom Capano was arrested for murder. Defense lawyers argued that Gerard's confession was a lie he made up to keep from going to prison.

If it were a lie it was an incredibly detailed lie. The defense knew that if they could refute any part, they could cast doubt on the whole confession. It was up to the prosecutors to argue that everything in the elaborate story was plausible, and that Gerard, very probably, was telling the truth.

PHOTO FROM PHOTODISC

True or false?

There were three key questions to be answered.

1. **Will the body actually fit inside the cooler?**
2. **Will the cooler float with the body inside?**
3. **Will the cooler still float with a hole in it that allows water to enter?**

The Igloo cooler that Tom Capano purchased had the labeled capacity of 162 quarts, or 153 liters. A 128-pound person has a mass of about 58.1 kg and a volume of about 59.5 liters. So there is ample room in the cooler for Ann Marie's body. And actual tests with similarly sized female volunteers showed that they could easily fit into the cooler. One question down, two to go.

Archimedes' principle states that an object immersed in a fluid will be buoyed up with a force equal to the weight of the displaced fluid. This means that an object placed in water will float if it displaces a mass of water equal to the weight of its own mass before it sinks below the surface. The cooler has outside dimensions of 104 cm long, 45.7 cm wide, and 53.3 cm high, and has a mass of about 13.6 kg.

If the cooler sinks one centimeter, it displaces

104 cm × 45.7 cm × 1.00 cm = 4750 cm^3 or 4.75 L of water

The mass of this much saltwater is

1.025 g/cm^3 × 4750 cm^3 = 4870 g

or 4.87 kg of saltwater displaced for every centimeter the cooler descends into the water.

The empty cooler has a mass of 13.6 kg.

If the 58.1-kg body is placed in the cooler along with a 13.6-kg chain around the cooler, the total mass is

13.6 kg (cooler) + 13.6 kg (chain) + 58.1 kg (body) = 85.3 kg

The cooler will now sink:

85.3 kg/4.87 kg/cm = 17.5 cm.

The cooler and body will sink 17.5 cm below the surface leaving 35.8 cm above water, or 33% under water, 67% above water (see Figure 1). That's not even close to sinking! Their boat is sinking farther into the water than the cooler.

So far everything Gerard has said checks out. But will the cooler still float if you shoot a hole in it and allow water to enter? Yes. It will float if the total mass of the cooler, the body, the chain, AND the water filling the cooler turns out to be less than the mass of the water the cooler would displace before it would sink below the surface. Got that?

Here's what the math looks like. Let's consider the extreme case in which water fills the entire cooler (Which it won't).

The inside dimensions of the cooler are

35.5 cm wide by 94.0 cm long by 43.2 cm high.

The Igloo cooler that Tom Capano purchased had the labeled capacity of 162 quarts, or 153 liters.

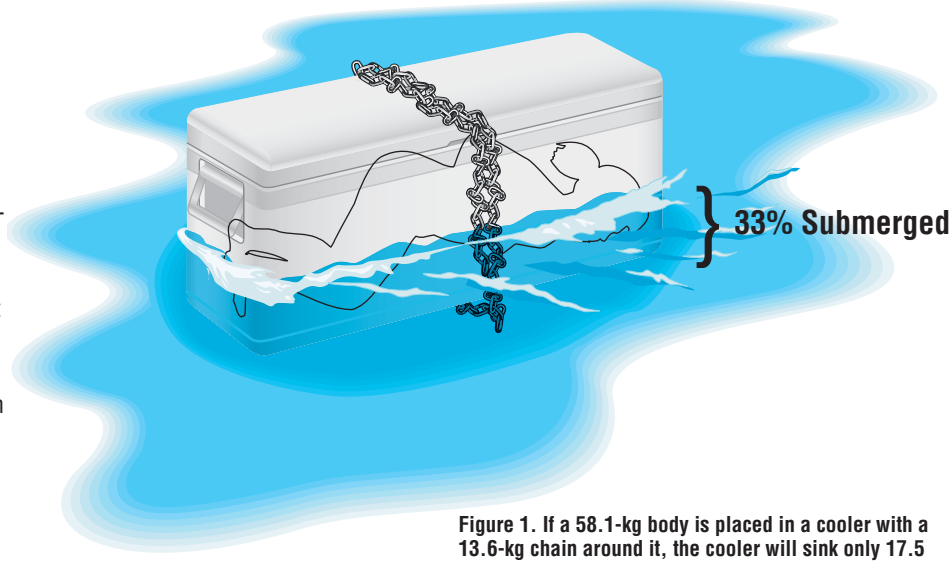


Figure 1. If a 58.1-kg body is placed in a cooler with a 13.6-kg chain around it, the cooler will sink only 17.5 cm into the water.

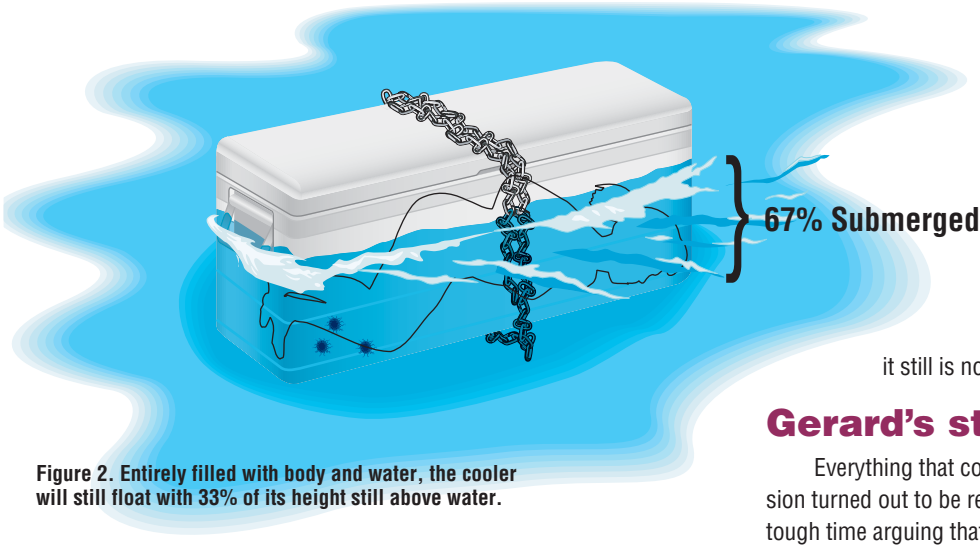


Figure 2. Entirely filled with body and water, the cooler will still float with 33% of its height still above water.

That makes the inside volume:

35.5 cm × 94.0 cm × 43.2 cm = 144,000 cm^3 or 144 L

If the cooler fills *completely* with saltwater, the added water would weigh:

1.025 g/ cm^3 × 144,000 cm^3 = 148,000 g or about 148 kg

The total mass of the cooler if it were filled with water would be

148 kg (water) + 13.6 kg (chain) + 13.6 kg (cooler) = 175 kg

175 kg/4.87 kg/cm = 35.9 cm

The cooler would float even when completey filled with water. In this worst-case scenario, about 33% of the cooler is still above water! (See Figure 2)

But the cooler cannot fill completely with water. Remember? There's a body inside. Here's another important fact: The density of a human is LESS than water—only about 0.95 as dense as saltwater (0.97 as dense as fresh water). That means that the actual mass of cooler's contents, body + water, would be LESS than the mass of a water-filled cooler.

So, if the cooler could float when completely filled with water, it would certainly float with both the water and the body inside. And Gerard is right again!

In summary, the cooler with only the body floats with about 18 cm of it under water. Even when a hole is shot in the side and water enters, it still is not even close to sinking.

Gerard's story floats

Everything that could be scientifically checked in Gerard's confession turned out to be reasonable. The defense was going to have a very tough time arguing that Gerard made all of this up.

Then the prosecution got another break. A fisherman who had read the story about the cooler in the paper called and said his friend had pulled a cooler with two holes in it from the ocean just a few days after Gerard claimed they had tossed it overboard. Evidently, that big white cooler could be seen from a long distance. The cooler was the same make and size as the one Tom had purchased earlier, and "bar codes" showed it had been sold by the same store. It had two patched holes that lined up perfectly and could have been made by a bullet.

Faced with such overwhelming evidence the defense now claimed that, yes, Tom had disposed of the body just as Gerard described. This time, they argued he was doing it to protect a woman who had accidentally shot Ann Marie. The woman denied any involvement. Tom Capano was convicted of first-degree murder, and he currently awaits execution in Delaware, as his attorneys continue to appeal the sentence.

Robert Mentzner is a former Dupont research chemist. Before retiring, he taught chemistry and physics at William Penn High School in New Castle, DE. His article "Fire in the Hold" appeared in the April 1997 issue of *ChemMatters*.

How dense are you?

The average adult has a density of 0.97 g/cm^3.

The 0.97 value means that in fresh water, most people float about 97% underwater and 3% above water. It's a little easier to float in saltwater with 95% under the surface and 5% above water. In either case, it doesn't leave much of us sticking out of the water! And for those with near-zero body fat—like young adult males in good shape—floating is an even greater challenge! Now if we had noses on top of our heads, like whales do, we could stop worrying about drowning.

Fact: Anyone who can float on his or her back can remain afloat indefinitely. Or one can float face down in the water, expend a little energy by taking a few strokes every 20 seconds or so while lifting the head to take a few breaths—a technique called treading water. Using this technique people have stayed afloat for long periods of time.

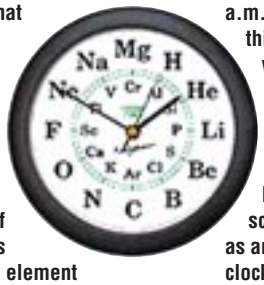
So why do so many people drown in deep water? Currents and water temperatures are certainly important factors, but many people who find themselves in deep water panic and expend energy trying to keep their faces continually above water. As they tire, they gasp for air and begin to swallow water. This extra water weight only adds to their total density, and soon they must exert even more effort to stay afloat. With more and more swallowed water, their density increases until they sink below the surface and drown.

Here's the best advice. Even if swimming lessons aren't for you, at least sign up for a water safety class at your nearest community pool. Do it before you find yourself in over your head!

Chem.matters.links

Wondering what to get that special someone this holiday season? Here are a couple of timely online links to gifts that are sure to please your most discriminating techie friends. One of these you may even choose to buy for yourself.

Time for Chemistry



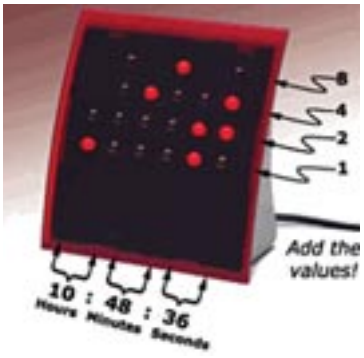
PHOTOS FROM WEBSITES LISTED

Here's a clock that measures time with help from your favorite subject—*chemistry*, of course. Study it carefully. What time is it if the short hand is approaching the element found in diamonds and the long hand is on an element found in ordinary table salt? If you said 5:55, this is the clock for you! The 24-hour Chem Time Clock, available from Educational Innovations, replaces the usual numbers found on the face of a clock with symbols of elements having corresponding atomic numbers. "H" replaces "1", "He" replaces "2", and so on. The idea for this clock came from Bassam Shakhashiri, a well-known chemistry educator and writer at the University of Wisconsin.

You'll find it at **www.teachersource.com.** Choose to browse the online catalog and then find your way to "timepieces and clocks". The Chem Time clock costs about $30.

This just in! News at 1111!

Whether you set your alarm for 110 a.m. or 111 a.m. is up to you, but this item is a must for those who want to bond with their computers. Those dots on the clock screen might not mean much to you now, but you'll soon be using them to tell time. With a little practice, you'll find the screen both easy to read and just as annoying as any other alarm clock. It's from the Mathematica exhibit of San Francisco's famous Exploratorium. As you found in the "Question From the Classroom" article on page 2, your computer uses *binary code*—a code consisting of two digits, 0 and 1—to store and process information. In a similar way, this clock uses an array of lights displaying only two states: on (1) or off (0).



You'll find the binary clock in the Exploratorium online catalog for about $20. Go to **http://www.exploratoriumstore.com/powoftwocloc.html.**

Tell us what you think

Let us know about the chemistry that counts in your life. Visit the *ChemMatters* Web page, and fill out a survey form. We'll use your thoughts and suggestions to make future issues even better. Find the forms at **www.chemistry.org/education/chemmatters.html.**

Statement of Ownership, Management, and Circulation for *ChemMatters* Magazine

ChemMatters is published quarterly by the American Chemical Society, 1155 16th St., NW, Washington, DC 20036. Both the office of publication and the general business office are at American Chemical Society, 1155 16th St., NW, Washington, DC 20036. Editor: Michael J. Tinnesand; Managing Editor: Helen G. Herlocker. Owner: American Chemical Society. There are no other known bondholders, mortages, and other security holders. The purpose, function, and nonprofit status of this organization and its exempt status for federal income tax purposes has not changed in the past 12 months. 45,000 copies of each magazine issue are printed. Average circulation during the past 12 months was 30,645. Circulation closest to the filing date was 21,938. There are no paid in-county subscriptions, no sales through dealers or vendors, and no other USPS mailings at other classes. There is no free distribution of *ChemMatters*. During the past 12 months, an average of 14,355 magazines per issue were not distributed. For the most recent issue (October 2002), 23,062 were not distributed. This statement was filed in accordance with Section E216.3.0 of the USPS Domestic Mail Manual on October 1, 2002, by Michael J. Tinnesand, Editor.

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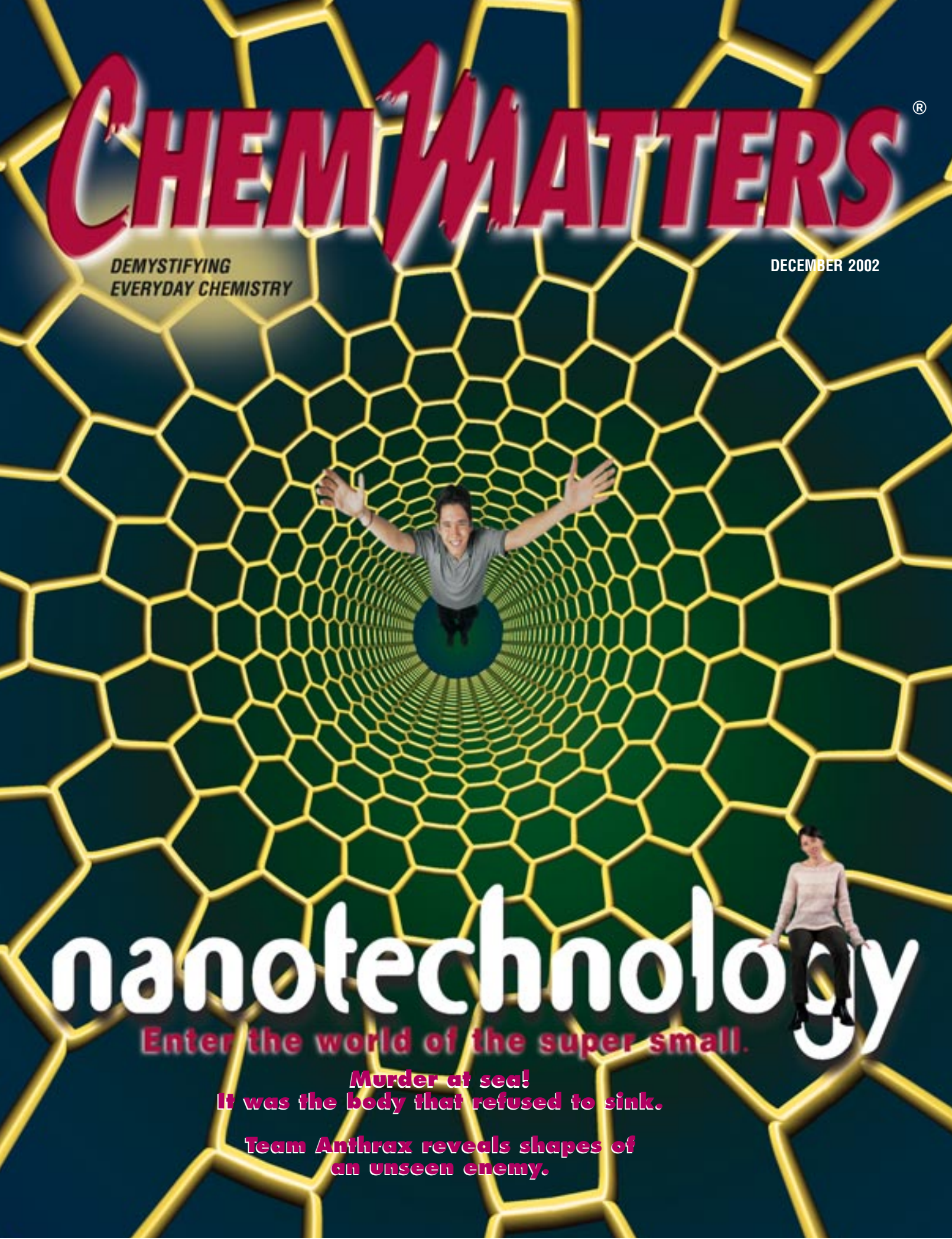

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Murder at sea!
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