Images of Anthrax

A Team Approach

PHOTOS BY PAUL ROBERTS, MSOE

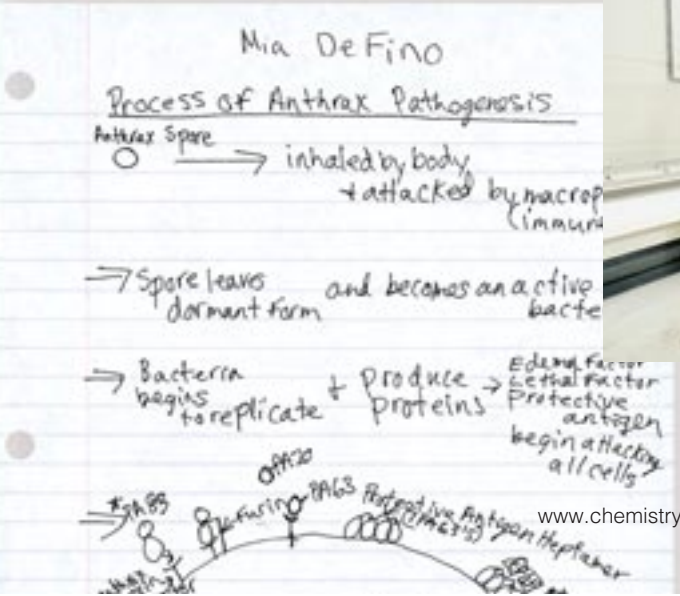
By Jonathan Knopp

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.

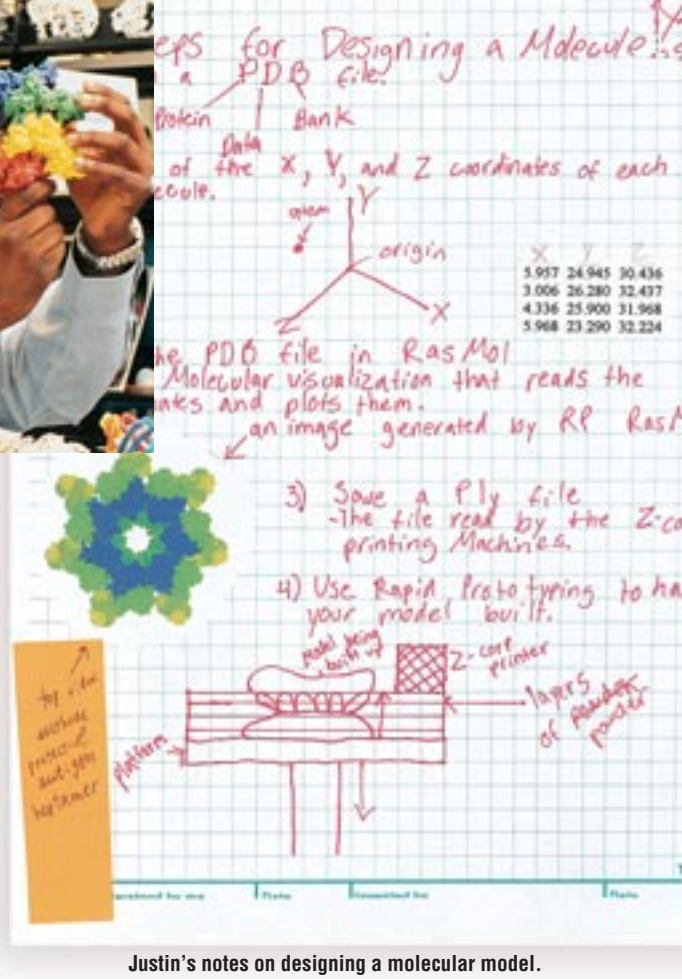
To build a model, the spatial coordinates guide the way. Additional software at MSOE relays the computer image data to a rapid prototyping machine—the machine that builds the three-dimensional model, one layer at a time (see sidebar below).

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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Shears, T. Models of Excitement. *Howard Hughes Medical Institute Bulletin, June 2002*, pp 46–47.

Young, J. A.T. and Collier, R. J. Attacking Anthrax. *Scientific American*, March 2002, pp 48–59.

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.

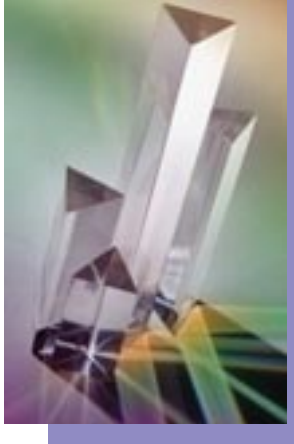


PHOTO FROM PHOTODISC

Teacher's guide: DECEMBER 2002

A supplement to *ChemMatters* magazine

ABOUT THE ARTICLES

Images of Anthrax—A Team Approach

Background Information

More about the student's activities and accomplishments:
Although the article describes in fairly specific terms what these students and their teacher accomplished, a conversation with their teacher, Jeff Anderson filled in some additional details about steps along the way:

1. They began by learning as much as they could about anthrax, especially the mechanism of anthrax within the host body.
2. They searched for key proteins involved in this process—the edema factor, the protective antigen (forming the heptamer), and the lethal factor.
3. They searched the protein data bank using these proteins as their search prompts.

4. After they found these structures they talked with researchers to determine whether making 3 dimensional models of these structures would be beneficial.
5. In some cases the files were not in the Protein Data Bank because the files were still in prepublication or there were copyrights issues, etc.
6. After communicating with researchers and explaining what they were trying to accomplish the researchers agreed to release the prepublication files. The students were sworn to secrecy.
7. The students used Rasmol to visualize the files, both those obtained from the Protein Data Bank and those that came directly from researchers.
8. Once these files were viewed, the students added something called monitor lines. These would serve as structural support for the model they planned on making. They also removed glitches in the program caused by perceived hydrogen bonding where none really existed.
9. These files were then sent to a *magix* program, the interface program between the PDB file and the rapid prototyping machine.
10. Directed by magix, the model was made. The students were there for the building process. They were anxious, sometimes too anxious, to pull the first few models out of the machines so that they might use air guns to blow the remnant dust off the completed models. They initially suffered some minor burns to their fingers on the hot objects.
11. They submitted their models for approval. In some cases they resubmitted revised builds. In other cases the models were approved and they painted them using IUPAC standard colors.
12. All of this culminated with their proud presentation of the models to the researchers and to the public at large.

More about molecular models:

The molecular models created at the Center for Biomolecular Modeling are physical representations of proteins and other biomolecules. Their features are based on the atomic coordinates that are deposited in the Protein Data Bank (PDB). There are two stages to the creation of a model. First the model is designed utilizing a program called RP-RasMol. Then one of five different possible rapid prototyping machines is used to actually construct the model. The materials from which the models are made range from plastic resins and fused nylon polymers to paste and starch. The materials selected depend on which rapid prototyping technology is used.

The models created have two general purposes. They are used by researchers as “thinking tools” during small group discussions, providing assistance in visualization. In science classrooms they serve as valuable teaching aids to help students and teachers “see” what are very complex structures.

Photos of several different molecular models can be viewed at:
http://www.rpc.msoe.edu/cbm/modelgallery.php

It is even possible to borrow a molecular model from the Center for Biomolecular Modeling. If you are interested, go to:
http://www.rpc.msoe.edu/cbm/sepa/educationmodels.php

Rapid Prototyping Technology

The Center for Biomolecular Modeling uses five different kinds of rapid prototyping technologies. This allows them to create molecular models in several different formats.

Stereolithography (SLA)
This technique utilizes a laser to “cure” a liquid photopolymer. This was the first technology employed by the Center Biomolecular Modeling. One advantage of this technology is that it produces some of the most spectacular looking models. But unfortunately, a considerable amount of work remains after the model is produced by the machine because supports are required to build the model in a liquid environment, and these supports have to be removed. More information about this technique can be found at http://www.rpc.msoe.edu/machines_sla.php

Laminated Object Manufacturing (LOM)
This technique uses a laser that cuts successive layers of paper as they are glued together to form the object. This technology is primarily used to make large format surface representations of proteins. More information can be found at http://www.rpc.msoe.edu/machines_lom.php

Selective Laser Sintering (SLS)
This technology utilizes a laser to melt (sinter) layers of powdered nylon. One advantage of this approach is that it does not require any supports like the SLA technique requires. The unsintered powder is adequate to support the model as it is being created. Models made using this technique are very durable and also somewhat flexible. More information is available at http://www.rpc.msoe.edu/machines_sla.php

Fused Deposition Modeling (FDM)
This uses a heated print-head to melt plastic wire and extrude the material layer-by-layer to form the model. It is used to create surface models of proteins, but has essentially been replaced by the Z Corporation Color Printer. For more information, go to http://www.rpc.msoe.edu/machines_sla.php

The Z Corporation Color Printer (ZCM)
This actually uses a regular HP color printer cartridge to deposit a mixture of pigment and binder on successive layers of either plaster or starch. It represents the first rapid prototyping technology that prints in color, so there is no need to paint the models that it produces. Most current research centering around the improvement of rapid prototyping technology is centered on this approach. For more information go to http://www.rpc.msoe.edu/machines_zcorp.php

The Science Education Partnership Award:
The Center for Biomolecular Modeling offers a Science Education Partnership Award (SEPA) program. This program is supported by a grant from the National Institutes of Health. It is a three-year professional development program designed for high school science teachers.

The goals of the program are to:
1. update teacher's knowledge in the area of molecular structure and function.
2. facilitate the creation of a community of scholars among participating teachers.
3. empower teachers by providing them with unique human and physical resources that enable them to realize their potential as professional educators.
4. model an inquiry-based approach to teaching the "Flow of Genetic Information" that integrates the physical and chemical sciences with biology.

Information about the program and the application procedure is available at http://www.rpc.msoe.edu/sepa/Program_Description.htm

Possible Student Misconceptions

When high school students think of "molecular models," they probably envision the "ball-and-stick" models that we normally use to represent fairly simple organic or inorganic molecules. Proteins are obviously much larger and more complex, so this article, especially the graphics, should prove valuable in getting students to realize that the term "molecular model" can refer to objects that differ significantly in both their overall appearance and what they actually reveal about the molecule that they represent.

Demonstrations and Lessons

It might be useful to have students consider the nature of the molecular models discussed in the article. Why are rapid prototyping machines needed? Why don't they just make a model of a protein by using the "ball-and-stick" kinds of models that we use to represent molecules like methane, ethane or carbon dioxide? What are some of the advantages of the kinds of molecular models featured in the article? What are some limitations inherent in these kinds of models?

Connections to the Chemistry Curriculum

Beyond the topic of molecular models, the article has fewer high school chemistry connections and more biology connections. The mechanisms involved in the anthrax *lytic* cycle are especially relevant to microbiology topics and concepts.

The most significant point of this article is the laudable accomplishments of "Team Anthrax"—three motivated high school seniors and their outstanding teacher. They accepted a challenge and persevered until they were successful. Along the way they learned a lot, did a lot of interesting things, met a lot of interesting people, and pushed themselves to succeed in areas where they perhaps had never seriously ventured, such as public speaking. These ambitious and talented young people from an average urban high school managed to achieve goals as exciting as any in the more visible fields of sports and entertainment. As a result, they garnered the respect and admiration from teachers and fellow students as well as the research community.

This pursuit of excellence connects to any phase of the high school curriculum.

Suggestions for Student Projects

The specific action by which the anthrax bacterium first invades and then destroys cells is fairly complex. If you have students with a good biology background they might want to learn more about the particulars of anthrax and prepare a report, either written or verbal.

Anticipating Student Questions

How does anthrax kill a person?
Anthrax is caused by a bacterium, *Bacillus anthracis*. The bacterium produces a toxin composed of three distinct proteins. For historical reasons these proteins are called the *protective antigen*, the *edema factor* and the *lethal factor*. Individually, the three proteins are non-toxic, but in combination they can prove deadly. Protective antigen is secreted in a preliminary form which then forms a heptamer. This acts on cells and allows the other two factors to enter the target cell. The edema factor leads to an impairment of the host defenses. The lethal factor finally results in cell destruction.

Websites for Additional Information and Ideas

The Website of the Center for Biomolecular Modeling is http://www.rpc.msoe.edu/cbm
The site offers a number of links (and links to other links) dealing with many facets of biomolecular modeling.

There are some Web pages offering photos of Team Anthrax and their teacher, some of the researchers they worked with, and some of the models they created. These include:
http://www.rpc.msoe.edu/sepa/teamanthrax.htm
http://www.ruhs.uwm.edu/users/staff/jeffan/TeamAnthrax.html

For photos of several different anthrax models, such as the protective antigen heptamer, the lethal factor and the edema factor, see:
http://www.rpc.msoe.edu/cbm/PA_Heptamer.php
http://www.rpc.msoe.edu/cbm/LF.php
http://www.rpc.msoe.edu/cbm/EF+CaM.php

http://www.rpc.msoe.edu/cbm/EF-CaM.php
http://www.rpc.msoe.edu/cbm/OtherPhotos.php

Biosensors—Early Warnings of Unseen Enemies

Background Information

The article does not lay out a clear definition of "biosensor", as the word apparantly does not have a universally accepted definition. But within the context of the article, biosensors are protrayed as fairly sophisticated devices that can recognize specific organisms or at the very least, a small range of organisms. Although there are many different types of biosensors, depending upon what they are designed to detect and the type of technology involved in achieving this goal, all biosensors have some common features.

(1) They contain some sort of a biological sensing element that is capable of recognizing the molecule, pathogen, or other organism it is designed to recognize.
(2) They contain a physical element that can transform the information sensed into some sort of detectable physical signal. This is often referred to as a *signal transducer.*

An effective biosensor:
(1) identifies specific substances unambiguously.
(2) identifies a substance even at low concentrations.
(3) takes samples over a large or small area.
(4) is accurate according to its published standards.

A more complete definition of a modern biosensor is found at http://www.cranfield.ac.uk/biotech/chinap.htm.

The number of different types of biosensors is quite large and the jargon used to describe them can be both confusing. Terms include: immunosensors, optrodes, CANARIES (described in the article), SQUIDS, evanescent waves, resonant mirrors, enzyme electrodes, biochips, and biocomputers, and many others. One writer describes this entire range of devices as a "biosensor jungle."

"Biosensors" have been important tools medicine for some time—typically involved in blood work and culturing. While accurate, these sensors have often proved to be frustratingly and even dangerously slow in yielding results. Thus, the push to develop biosensors that can perform their desired function quickly without sacrificing accuracy.

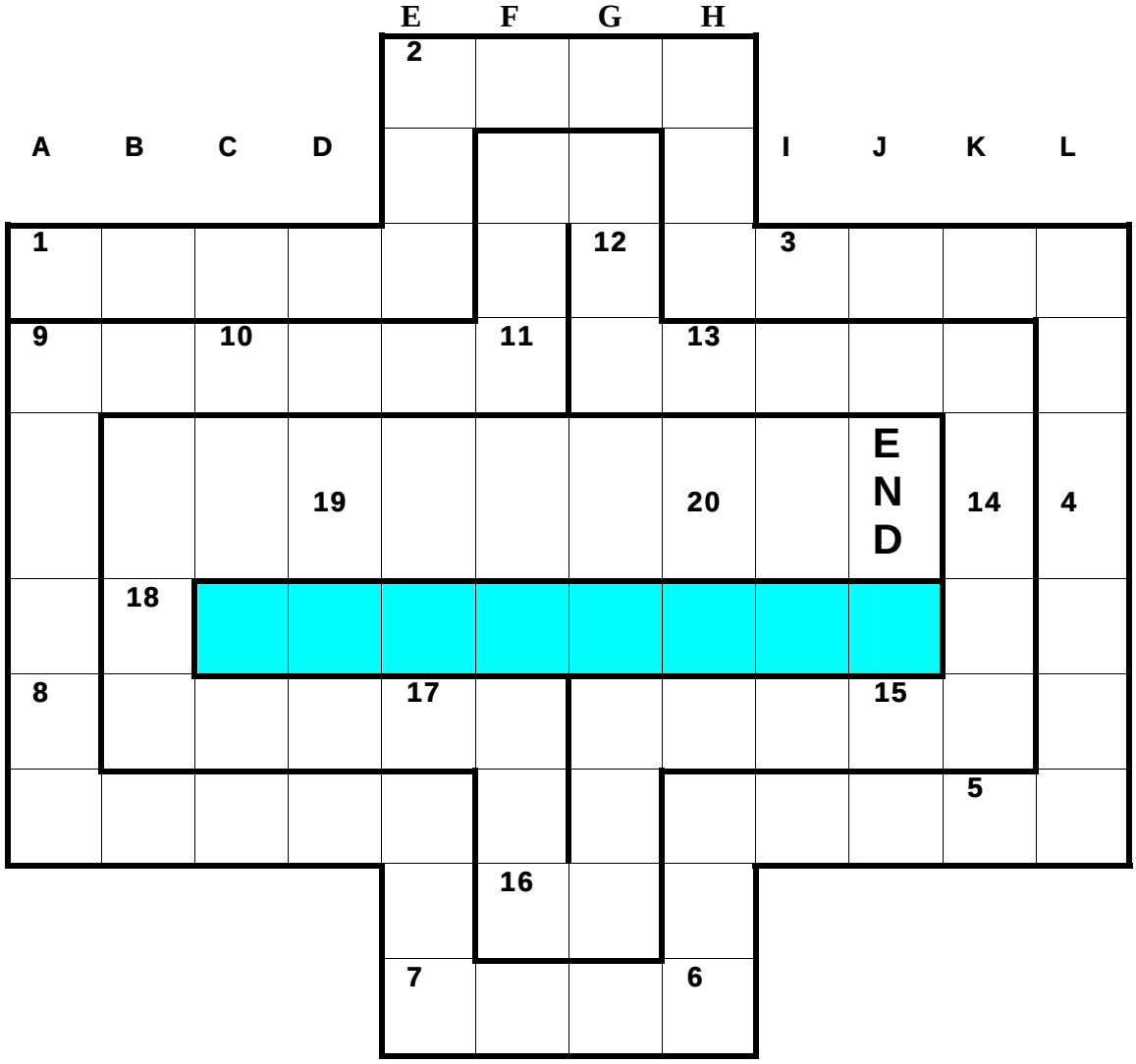
Most current research efforts are centered around three basic types of biosensor systems, (1) chemical mass spectrometry systems, (2) biochemical systems, and (3) biological tissue-based systems.

The article mentions the use of mass spectrometry (see *Connections to Chemistry Concepts*). One disadvantage of this approach is that it requires live tissue or other kinds of biological reagents that have to be preserved. The sample of material must be vaporized and then bombarded with electrons so the fragments become ionized. After being accelerated through an electric field, the charged fragments are then passed through a magnetic field. Charged particles move through a magnetic field traveling in a circular path. The radius of curvature of the circle depends upon the mass and charge on the fragment. Different biological species such as specific bacteria yield specific kinds of fragments that can be identified. This data helps to identify the specific biological species.

Another type of biosensor briefly mentioned in the article utilizes enzymes. In fact, biological recognition systems are often divided into two general types, catalytic, and non-catalytic. Enzymes are protein molecules that function as catalysts. Being catalysts, they are usually selective in regard to the specific chemical reaction that they affect. They will almost always turn

PUZZLE: WORD CROSS

This puzzle has answers going in two different directions. The DOWN answers are in 12 columns, and consist almost entirely of names from chemistry (people, elements, organic groups, etc). In columns E-H there are two names; you must determine where the break is. The PATH clues start at upper left corner in square 1, and follow the winding path twice around the cross to the word "end". The clues here are a mixed bag of chemical and non-chemical terms.



DOWN

A. Has 27 protons/atom
B. An allotrope of ozone
C. NH_3 as a ligand
D. A radioactive alkaline earth
E. Spanish money; A pair of genes
F. Indian chemist and type of spectra ; Cd,Hg, or U, for ex.
G. Jewish biblical heroine and a homophone of RCOOR/ family ;

PATH

1. Rough, unrefined
2. Like better
3. Fiber once used in ropes
4. Evil Hindu goddess
5. A Red Sea country
6. Snake-like fish
7. One of 100+ in periodic table
8. Place to do experiments
9. Neutered bull
11. amo,___, amat
12. Product of alpha decay of U
13. Underground part of a plant
14. First cardinal number
15. Native of N.W. Italy
16. One more O than "ite"
17. Debussy's Clair de __
18. Place to get indoor athletics
19. Niels Bohr, for example

Source of $C_{12}H_{22}O_{11}$

H. Fe^{2+} ion; Suffix for C_nH_{2n} family

I. Has a bright yellow flame test

J. IO_3^-

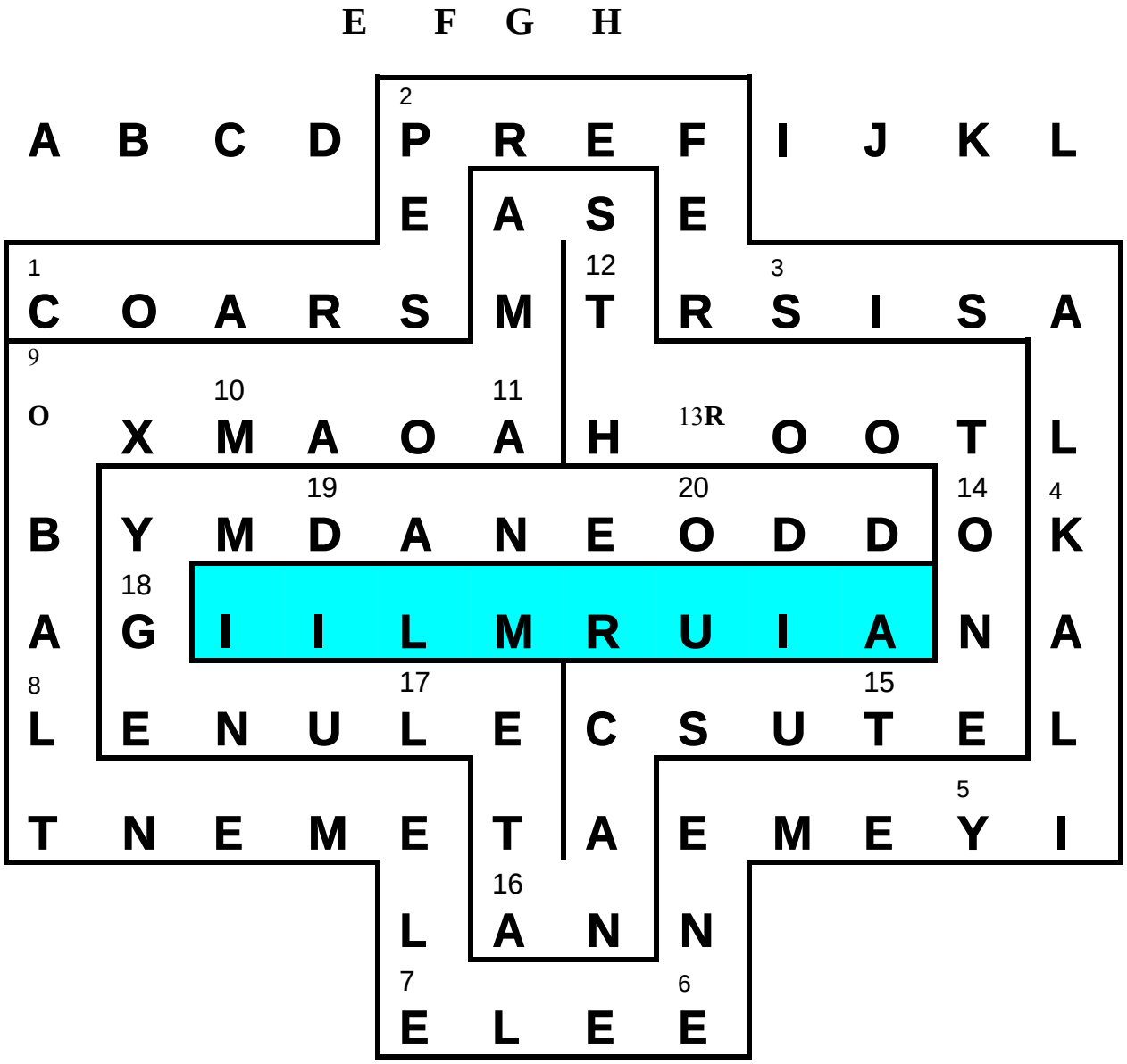
K. Coined the word “electron”

L. Any element of Group 1

10. 1st leader of Communist China

20. Unusual, strange

PUZZLE ANSWERS



DOWN ANSWERS

A.cobalt
B. oxygen
C. ammine
D. radium
E. peso; allele
F. Raman; metal
G. Esther; cane
H. ferrous; ene
I. sodium
J. iodine
K. Stoney
L. alkali

PATH ANSWERS

1. coarse
2. prefer
3. sisal
4. Kali
5. Yemen
6. eel
7. element
8. lab
9. ox
10. Mao
11. amas
12. Th
13. root
14.one
15.Tuscan
16. ate
17. lune
18. gym
19. Dane
20. odd

STUDENT QUESTIONS

Biosensors—Early Warnings of Unseen Enemies

1. List three problems that need to be overcome in order to develop a workable biosensor.
2. In general, how does a biosensor work?
3. Describe how antibodies are used in some biosensors.
4. How is DNA analysis used in some biosensors? What is a Polymerase Chain Reaction (PCR), and how is it important in some biosensors?
5. Tell what the acronym CANARY stands for and describe how this biosensor works.

For Further Research
Select a specific type of biosensor that is designed to detect the presence of a particular pathogen. Research the overall design of the detector. Describe the specific method by which the detector identifies the pathogen and then produces a detectable signal to indicate its presence.

Matches—Striking Chemistry at Your Fingertips

1. What is one unusual property of white phosphorus, P_4, that makes it necessary to store the substance under water? Write a balanced chemical equation for this unusual reaction.
2. Describe the early type of match invented by Robert Boyle.
3. Describe the type of "strike anywhere" match invented by John Walker in 1827 and write a balanced chemical equation for the chemical reaction it involved.
4. What discovery allowed the creation of the first true safety match, and how was this discovery used in its design?
5. There are two general types of matches in use today, "strike anywhere" matches and safety matches that must be struck on a specific surface. How do the reactions for igniting the two types of matches differ?

For Further Research

Research the differences between white phosphorus and red phosphorus. Find out the way their atoms are bonded together, and describe some of their thermodynamic properties such as their enthalpies of formation, free energies of formation, and entropies. Explain how differences in their molecular structure and formation account for some of the differences in their properties.

Nanotechnology—The World of the Super Small

1. Describe how physicist Don Eigler was able to spell out "IBM" with individual atoms.
2. Why can't nanoengineers simply miniaturize larger-scale inventions to produce identical nanoscale devices that would behave the same way—just on a smaller scale?
3. Why do frictional forces have an exaggerated effect on the behavior of nanoscale particles?
4. Describe two naturally occurring nanomachines in living things.
5. Name and describe the two basic approaches to manufacturing nanodevices.

For Further Research
Select one nanoscale device described in the article and report on it current design and manufacturing status as well as actual and potential uses.

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1. What is *rapid prototyping technology*? Give an example.

2. Describe the general procedure by which a 3-D model of a molecule such as a protein is produced at the Center for Biomolecular Modeling.
3. How many anthrax proteins are known? What were the first models produced by the students at Riverside University High School in Milwaukee?
4. How did the students obtain the information they needed to make a model of the third anthrax protein?
5. Describe the general procedure by which scientists can determine the structure of a molecule like a protein.

For Further Research
Research the specific mechanism by which the anthrax bacterium invades a person and eventually causes his/her death.

Murder She Floats

1. The calculations presented in the article were part of the "expert" testimony presented at the Capano trial. How did the calculations help to persuade the jury that Capano was guilty?
2. State Archimedes' Principle.
3. If the cooler would remain afloat when completely filled with water alone, how can we conclude that it would float with water *plus a body* filling the inside space?
4. What additional evidence pertaining to the cooler was obtained that also pointed to Capano's guilt?
5. If the human body is less dense than saltwater and therefore will float in saltwater, why do people sometimes drown in the ocean?

For Further Research
Locate or design an experiment that can demonstrate the correctness of Archimedes' Principle. Test this using at least one liquid other than water.

Answers to Student Questions

Biosensors—Early Warnings of Unseen Enemies

1. The device must be able to signal the presence of a harmful organism but not respond to harmless organisms. There must be some way to insure that the organism will make it into the detector. The device must be able to distinguish between one type of harmful organism and another.
2. It utilizes some sort of biological material, like pieces of living cells or tissue that can trigger a reaction which produces a signal that can be detected that indicates the presence of the pathogen the biosensor was designed to detect.
3. Antibodies are proteins. They identify and bind with antigens that are on the surface of the intruding pathogens. These antibodies are placed inside the biosensor, perhaps on a testing strip, for example. When they bind with the antigens they give off a signal, perhaps a change in color.
4. These biosensors begin by breaking apart the cells of sampled microorganisms to extract their DNA. Since the amount of DNA available may be very small, this amount is magnified by using the Polymerase Chain Reaction. PCR allows a single strand of DNA to be copied and recopied until an adequate amount for analysis is obtained. Since the DNA of every organism is unique to that organism, this allows the specific organism to be identified.
5. CANARY stands for Cellular Analysis and Notification of Antigen Risks and Yields. This type of biosensor utilizes a gene from a jellyfish. CANARY uses genetically altered white blood cells from a jellyfish that contain a bioluminescent protein. When antibodies in the blood cells bind with their target antigens, this causes an enzyme to release calcium within the cell. This in turn causes the calcium-sensitive jellyfish protein to glow. The light emitted is detected and measured by a photodetector, which also interprets the results.

Matches—Striking Chemistry at Your Fingertips

1. White phosphorus ignites spontaneously when exposed to air at room temperature. The balanced equation for the reaction that occurs is:
$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(g)$
2. Boyle coated a rough piece of paper with white phosphorus and a piece of wood with sulfur. When the piece of wood was rubbed across the piece of paper, a reaction between the sulfur and phosphorus took place that generated enough heat to light the sulfur and the stick.
3. Walker mixed potassium chlorate, $KClO_3$, and antimony sulfide, Sb_3S_3. on a wood splint. When the coated wood was drawn across a rough surface, the two chemicals reacted and enough heat was produced to ignite the stick. The chemical reaction that occurred was:
$Sb_2S_3(s) + 3KClO_3(s) \rightarrow Sb_2O_3(s) + 3KCl(s) + 3SO_2(g)$
4. The first true safety match was made possible by the discovery of red phosphorus. Since red phosphorus doesn't ignite spontaneously when exposed to air, it could safely be put on the side of a box of matches and the match could then be ignited by rubbing it across the surface that contained the red phosphorus.

5. In a strike anywhere match, the head of the match contains phosphorus sulfide, (P_4S_3), sulfur (S), potassium chlorate ($KClO_3$), and a few other materials, such as powdered glass increase friction, and an inert filler to hold everything together. When drawn across a rough surface, the heat generated will ignite the match. The reaction that occurs is:
$P_4S_3(s) + S(s) + 6KClO_3(s) \rightarrow P_4O_{10}(s) + 4SO_2(g) + 6KCl(s)$
In a safety match red phosphorus is placed on a rough surface on the outside of the box or book or matches and sulfur and potassium chlorate on the match head. When the match head is drawn across the surface containing the phosphorus, the following reaction occurs:
$P_4(s) + 5O_2(g) + 3S(s) + 2KClO_3(s) \rightarrow P_4O_{10}(s) + 3SO_2(g) + 2KCl$

Nanotechnology—The World of the Super Small

1. He was using an instrument called a Scanning Tunneling Microscope (STM). This instrument is capable of forming images of individual atoms. Eigler was trying to image individual xenon atoms lying on top of a platinum surface. But as he tried to do so, the STM kept dragging the atoms around, ruining the images. After fine-tuning the software associated with the microscope he was able to control the manipulation of the individual xenon atoms so as to spell out IBM.
2. The laws of physics that are adequate to predict and control the behavior of large devices cannot be applied the same way to devices with nanoscale dimensions. Objects that small do not obey the classical laws of motion known as Newtonian mechanics. Their behavior must be described by using quantum mechanics--an area of physics that describes the behavior of small particles. But because they are often considerably larger than individual atoms or molecules, even quantum mechanics does not always comfortably describe their behavior. Determining the laws that govern the behavior of nanoscale particles is still an area of current research.
3. As a particle becomes smaller, the ratio of its surface area to volume increases--smaller particles have a greater surface area relative to their entire volume. Since frictional forces operate on the surface of an object, they exert a significant effect on the behavior of a nanoparticle.
4. (a) The enzyme “helicase” can act as a molecular motor that unwinds DNA molecules as it moves along the long spiraled DNA like an inchworm. (b) Some bacteria have long rotating whip-like projections at the base of flagellae. Consisting of proteins, they can propel the bacteria through their liquid medium.
5. The two general approaches to manufacturing nanodevices are the *top-down* and *bottom-up* approaches:
In the *top-down* approach, individual tiny parts, often individual atoms, are removed from a surface to produce the desired structure.
In the *bottom-up* approach, individual atoms or molecules are either moved into desired locations or placed in an environment where they self-assemble into the desired structure.

Images of Anthrax—A Team Approach

1. *Rapid prototyping technology* refers to the general procedure by which scientists or engineers use computer data to produce three-dimensional models. The automotive industry has used it for many years to produce precise models of automobile parts, and the article explains how this procedure is now used to rapidly produce models of large molecules such as proteins.
2. There is a Web site called the Protein Data Bank. It is possible to obtain the x, y, and z coordinates of every atom in any molecule that is contained in their bank. This atomic coordinate data is translated using a program called Rasmol to make a computer image of the molecule. Additional software then relays this information to a rapid prototyping machine which produces the three-dimensional model.
3. There are three known anthrax proteins: the protective antigen, the edema factor, and the lethal factor. The first models the students produced were of the protective antigen and the lethal factor.
4. Dr. Wei Jen Tang had recently solved the structure of the third anthrax protein, the edema factor. He shared his three years of research data with the students, giving them the information they needed to prepare a molecular model of the protein.
5. The technique is called X-ray crystallography. A pure crystals of the protein is prepared. The crystal is suspended in a glass capillary and bombarded by an X-ray beam. The crystal scatters the incoming beam to produce an electron density pattern on a photographic plate. The complex pattern is described mathematically to allow the determination of the positions of every atom in the molecule.

Murder She Floats

1. Tom Capano's brother Gerard gave detailed testimony about the behavior of a cooler floating in the ocean with a body inside. There was little chance that Gerard could have known ahead of time that a cooler and body would actually behave that way. Consequently, these independent calculations supporting his account of the events were very helpful in convincing the jury he was telling the truth.
2. The buoyant force exerted on an object immersed in a fluid is equal to the weight of the fluid displaced.
3. Salt water is denser than a human body. That's why people float when they are swimming in salt water. Therefore a cooler completely filled with water would weigh more than a cooler with a body inside and the remainder of the space inside filled with water. Consequently if the cooler filled with water floats, the lighter cooler that contains a body and water would also have to float.
4. The cooler was recovered by a fisherman, who turned it in to authorities. The bar codes on the cooler showed that it had been purchased at the same store as the one where Tom had made his purchase.
5. Many people who find themselves in deep water panic. They expend a lot of energy trying to keep their faces above the water level at all times. As they become tired, they gasp for breath and inhale water. The added weight of the water increases their density so they have to expend even more energy in an attempt to keep their faces out of the water. This vicious cycle eventually causes them to drown.

Use the following table for finding connections between the December 2002 articles and the **National Science Education Content Standards** for grades 9–12.
✓ = Strong connection

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	Bio-sensors	Matches	Murder She Floats	Images of Anthrax	Nano-technology
Science as Inquiry Standard A: about scientific inquiry.	✓	✓	✓	✓	✓
Physical Science Standard B: of the structure and properties of matter.		✓	✓	✓	✓
Physical Science Standard B: of chemical reactions.		✓			
Physical Science Standard B: of conservation of energy and increase in disorder.		✓			
Physical Science Standard B: of interactions of energy and matter.					✓
Life Science Standard C: of the cell.	✓			✓	✓
Life Science Standard C: of the molecular basis of heredity	✓				✓
Life Science Standard C: of matter, energy, and organization in living systems.					✓
Science and Technology Standard E: about science and technology.	✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of personal and community health.	✓		✓		
Science in Personal and Social Perspectives Standard F: of environmental quality.	✓				
Science in Personal and Social Perspectives Standard F: of natural and human-induced hazards.	✓			✓	
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✓		✓	✓	✓

History and Nature of Science Standard G: of science as a human endeavor.	✔	✔	✔	✔	✔
History and Nature of Science Standard G: of the nature of scientific knowledge.	✔			✔	✔
History and Nature of Science Standard G: of historical perspectives.	✔	✔			✔

Anticipation Guides

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss their responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

Directions for all Anticipation Guides: In the first column, write "A" or "D" indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. Cite information from the article that supports or refutes your original ideas.

Murder She Floats

Me	Text	Statement based on information from Article
		1. Most people can easily float in water because their density is less than water's density.
		2. An object floating in water displaces the same weight of water as the object.
		3. 4.75 L of salt water has a mass of less than 4.75 kg.
		4. A foam cooler filled with salt water will sink in salt water.
		5. Knowledge of chemistry is important in solving many crimes, not just those involving guns and explosives.

Matches—Striking Chemistry at Your Fingertips

Me	Text	Statement based on information from Article
		1. Matches have been around for more than 400 years.

		2. All of today's common matches have phosphorous in them.
		3. The difference between the red and white forms of phosphorous is the molecular structure.
		4. Lucifers were bad-smelling matches named after the devil.
		5. More matches are manufactured today than were manufactured 100 years ago.
		6. Today's matches are chemically treated so that they won't glow after they are blown out.

Images of Anthrax—A Team Approach

Me	Text	Statement based on information from Article
		1. Teenagers would not have the expert knowledge needed to develop molecular models of complex proteins that would be respected by scientists.
		2. The scientists working on molecular modeling need a good understanding of biology, chemistry, physics, and mathematics.
		3. The three-dimensional models described in the article are 17 times larger than the proteins they represent.
		4. Understanding the structure of protein crystals is key to identifying bonding sites.
		5. Information in the Protein Data Bank (PDB) is freely accessible to anyone.

Nanotechnology—The World of the Super Small

Me	Text	Statement based on information from Article
		1. Objects a few nanometers wide obey Newton's laws of motion.
		2. Scientists have been able to move individual atoms around since the early 1980s.
		3. Scientists get ideas for how to make nano-sized machines from structures of enzymes and even bacteria.
		4. Nanoscale machines tend to be more affected by friction than regular scale machines.
		5. Nanoscale virus capsids can be used as reaction vessels.
		6. 1 nm > 1 μm > 1 mm

Biosensors—Early Warnings of Unseen Enemies

Note: Before reading this article, be sure your students know the meanings of the terms *pathogen* and *antigen*.

Me	Text	Statement based on information from Article
		1. Scientists have developed bioterrorism detectors for anthrax and smallpox.
		2. Biosensors are currently used in medical care, including managing diabetes.
		3. Bioterrorism defense research may contribute to medical diagnoses in the future.
		4. So far, knowledge of the body's immune response has not been helpful in developing pathogen detectors.

		5. Anthrax, botulism, and tuberculosis are in a genetically similar group, gram-positive bacteria.
		6. A Polymerase Chain Reaction (PCR) may be used to amplify a sample of a pathogen by copying a strand of DNA more than a hundred times.

* Another effective anticipation strategy for this article would be to have the class brainstorm problems that would be encountered in developing bioterrorism detectors.

STRUCTURED NOTE TAKING

Images of Anthrax—A Team Approach

Directions: As you read, describe how the student members of "Team Anthrax" solved the problem of building the three anthrax protein models.

Problem	Solution
Choosing a problem	
Background information needed	
Procedure	
Observations	
Communication	

Nanotechnology—The World of the Super Small

Directions: As you read, complete the concept map about nanotechnology.