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.

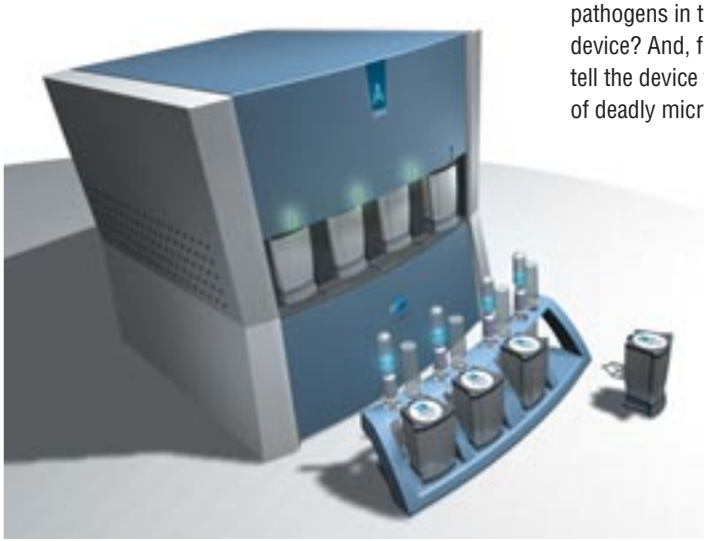
Such devices are now being developed to detect pathogens. Typically, these pathogen detectors rely on strategies borrowed from the body's immune response.

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).

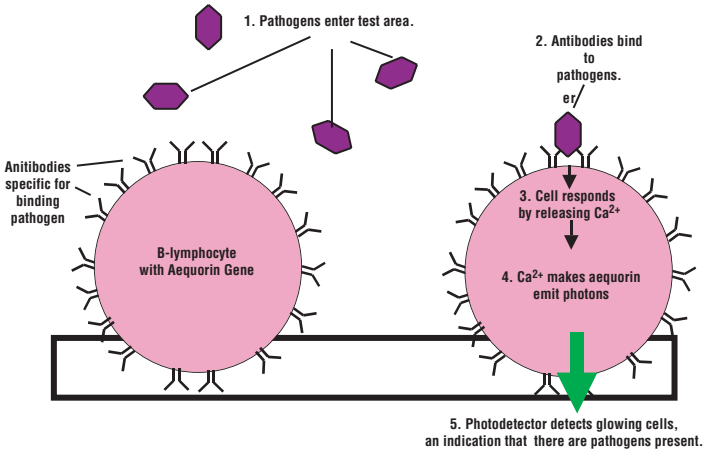


Figure 1. CANARY. With a jellyfish gene on board, human white blood cells are engineered to register the presence of certain pathogens by glowing.

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."

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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.

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

“A” into “B.” They can often recognize a difference as small as a single atom in chemical “A,” (called the substrate). Once they have transformed “A” into “B,” the device must then be able to convert the presence of “B” into some sort of detectable signal. For a more general discussion of enzymes go to *Connections to Chemistry Concepts.*

Some biosensors employ *antibodies*. Antibodies are also proteins. Our immune systems produce antibodies that are constantly fighting off attacking viruses and bacteria. When we are vaccinated against a disease such as smallpox, the vaccination stimulates our immune system to produce antibodies against the antigens peculiar to the pathogen without our actually having to exhibit symptoms of the disease. Any future invading pathogen of the same species will encounter a rapid deployment of these defending antibodies.

Antibodies operate by bonding to antigens—prominent features on the surfaces of foreign cells and tissues. Once coated with antibodies, the antigens are marked for attack from other parts of our immune system. Antibodies are very specific. They have to be. If they weren’t, they would signal our immune system to target cells and tissues in our own bodies for attack—an unfortunate phenomenon associated with autoimmune diseases such as rheumatoid arthritis.

A typical biosensor design that utilizes antibodies involves placing the antibody on the transducer part of the biosensor. When the sensor is exposed to the pathogen, these antibodies bind the pathogens to produce an antibody-antigen combination. This, in turn, alters some physical property of the system. Often this is an optical parameter, like the one described in the article, but it can also be a change in an electrical property or even something as simple as the change in mass. For example, an antibody can be mounted on an extremely sensitive piezo-electro quartz microbalance. When it comes in contact with a pathogen, the attachment of the antibody to the pathogen will increase the weight on the crystal, and this change can be detected by the microbalance.

Associated with DNA, a constituent of all living things, biosensors that utilize the Polymerase Chain Reaction (see *Connections to Chemistry Concepts*) are highly reliable at detecting a specific pathogen or perhaps a range of pathogens. The problem, however, as pointed out in the article, is that currently available PCR sensors must constantly be replenished with fresh reagents. This is not a practical requirement for a sensor designed to continuously monitor the environment and sound a quick alert if a dangerous pathogen is present.

The article only touches briefly on different types of transduction schemes—the means by which the presence of a pathogen is transformed into a signal. Some common transduction schemes are:

Amperometric devices detect a change in the amount of current flowing through the device when it is kept at a constant voltage.

Conductimetric devices detect a change in conductivity between two electrodes.

Potentiometric devices detect voltage changes for a given amount of current, which is normally zero.

Optical transducers detect optical changes that occur when a pathogen is encountered. (Often involving fluorescent dyes)

Calorimetric devices detect small changes in temperature.

Although the article focuses on the application of biosensors to combat bioterrorism, the use of biosensors is much more established in the healthcare, food processing, environmental monitoring (especially wastewater analysis), and in agriculture and related industries.

Connections to Chemistry Concepts

The article mentions and describes one simple type of household smoke detector to provide an example of how many of us use a "detector" in our homes. The most common type of smoke detector is what is called an *ionization* detector. It utilizes a small amount of a radioactive element, typically americium. For more specific information about how such a detector works, see:
http://www.howstuffworks.com/smoke2.htm

One type of device used to detect specific biological organisms is the mass spectrometer. There is a general description of how this detects organisms in the *Background Information* section. For a more thorough description of a mass spectrometer, see:
http://www.chem.vt.edu/chem-ed/ms/ms-intro.html

Enzymes are biological *catalysts*. There is no all-encompassing definition of a catalyst, but an adequate definition is the following: A catalyst is a substance that speeds up the rate of a chemical reaction without being permanently consumed in the reaction.

Catalysts work by lowering the energy needed to get the two reacting molecules to react with each other. This energy is often referred to as the *activation energy* for the reaction, and the lower the activation energy, the greater the percentage of colliding molecules that are capable or reacting upon collision.

Some catalysts are never actually consumed. For example, a "surface" catalyst can function by simply holding a reacting molecule on its surface in a position where it is more likely to react with another molecule in its environment. Other catalysts are temporarily "consumed," in an early step in the reaction mechanism, but then regenerated in a later step.

Most biological catalysts are enzymes. A few are *ribozymes* with the catalytic activity occurring in the RNA part of the molecule rather than in the protein part.

For a more thorough discussion of catalysts in general and enzymes in particular, go to:
http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Enzymes.html

The article discusses PCR, or the *polymerase chain reaction*—the means by which scientists can take a segment of DNA and rapidly duplicate it multiple times to increase the amount of material. A *polymerase* is a biological macromolecule. It is an enzyme that catalyzes both the formation and the repair of DNA, thereby insuring the faithful replication of all living matter.

Scientists have learned how to manipulate the PCR. They can start or stop polymerization at specific points along a single strand of DNA. Simply described, the PCR "unzips" a DNA molecule into two complementary strings. These are then immersed in a "soup of DNA nucleotides. Under the right conditions, two complete copies of the original DNA result from the two separate strands. Repeating the procedure, you generate four copies, then eight. Given the nature of "doubling," it is relatively easy to produce millions or even billions of copies of the original DNA. In a typical biosensor the DNA is only amplified by a factor of about a hundred.

One obvious advantage of PCR is that its ability to duplicate the pathogen's DNA allows for successful detection even when only a small population of the pathogen is present. One disadvantage is that the sample must be repeatedly heated and cooled, thus placing demands on energy requirements.

For more about the history of PCR and details about the experimental procedures involved, see:
http://sunsite.berkeley.edu/pcr/whatisPCR.html

Possible Student Misconceptions

By detailing recent advances in the development of biosensors and their critical importance in protecting the American public from biological attack, students may wrongly assume that (1) these devices are close to being perfected and are widely available, and/or (2) the government is devoting a large percentage of its homeland defense funds to the design and manufacture of biosensors. Neither appears to be the case. The technology is far from being perfected, and the current cost-benefit analysis of making them universally available hasn't resulted in budgeting for their development on a large scale.

For example, in Bush's proposed 2003 budget, the Department of Defense's Chemical and Biological Defense Program will receive $933 million, an increase of almost 85%. But only $34.3 million of that is targeted for biosensor funding, an increase of only 7%. Another DoD group funding military biosensor research will receive spending increases from $433 million to $2.68 billion, but the number of dollars targeted for biosensor research is actually slated to decrease by $5 million to only $25 million.

Demonstrations and Lessons

1. This article could initiate a discussion of several different detection techniques that can be used in biosensors. See *Background Information* and *Websites for Additional Information and Ideas.*
2. There are kits available for demonstrating the antibody-antigen reaction. One such kit from Carolina Biological utilizes blood sera from horses, swine, and cattle. When a sample of horse serum containing the right antibodies is exposed to swine serum, a clumping reaction results. If the samples are allowed to converge on plain agar medium, their point of contact appears as a cloudy band. Students can experiment with the conditions surrounding the reaction. Find the kit by searching on "antigen-antibody sets" among the physiology supplies at www.carolina.com.
3. Health-care professionals use a variety of biosensors as diagnostic testing tools. A resource person might be invited to demonstrate and describe these to the class.

Connections to the Chemistry Curriculum

This article relates strongly with many curricular topics covered both in biology and chemistry courses, especially at the advanced level. Included are the general topics of catalysts, enzymes, the polymerase chain reaction, DNA and RNA, antibodies and antigens, analytical detection methods such as the mass spectrometer and other spectral methods of detection. It also ties to the general nature of the immune system and ways in which our body battles pathogens.

Suggestions for Student Projects

1. One pathogen that produces great concern for the threat of biological attack is *Variola,* the virus responsible for smallpox disease. Once effectively eradicated, vaccination of the general public ceased in 1972, meaning that individuals born after that date carry no immunity to the disease. In addition, there is some concern that the vaccinated population has lost all or most of their immunity in the intervening years. Students might research the history of this terrible disease, its eventual eradication, and the state of current concerns about its use as a bioterrorism agent.

2. A related project could be a debate on the topic of whether the United States should revaccinate the general population against smallpox.

Anticipating Student Questions

Are there any common biosensors that are being used in domestic households today?

Not in the sense that they are described in the article. But there is one biosensor used routinely by many individuals—personal blood glucose monitoring for diabetes.

If it is so easy to monitor the amount of glucose in your blood using a "biosensor," then why haven't we developed sensors that can do the same for things like anthrax, or *Salmonella*?

One reason glucose is relatively easy to monitor is that the concentration of glucose in human blood is typically measured in "millimolar" amounts. That translates into about 10^{20} molecules of glucose in a pint of blood. Other infectious agents are typically found in much smaller concentrations.

What are some of the most significant general barriers to the development of practical, low-cost biosensors?

1. Speed. Biosensors often require the amplification of a pathogen, such as using PCR to produce additional amounts. This takes time.
2. Shelf life. Many antibodies and other proteins are very unstable.
3. Cost. Many proteins are expensive to produce, purify, and store.

Websites for Additional Information and Ideas

Some good general Websites devoted to biosensors and their applications are:

http://www.fraserclan.com/biosens1.htm

http://www.ibeweb.org/IBE2/news/news1.1/biotech.htm

http://www.janes.com/security/international_security/news/nbcd/nbcd011016_1_n.shtml

http://128.84.243.18/~saltzman/Classes/ENGRI_120/Research_Papers/paper20.PDF

http://www.biovista.com/pan-trnd-TEMPLATE.asp?ID=4

http://info.med.yale.edu/external/pubs/ym_sp02/biosensor.htm

http://www.cranfield.ac.uk/biotech/chinap.htm

http://www.aatl.net/publications/Bio-sensor.htm

Nanotechnology—The World of the Super Small

Background Information

Growth and funding of nanotechnology

The rise of nanotechnology and its potential practical applications has shifted significant sums of federal dollars from life science research into physical science and engineering. For example, from 1970 to 2000, federal spending for life science research approximately tripled in constant dollars while spending on the physical sciences and engineering remained relatively constant. But with the National Nanotechnology Initiative (NNI) came a big boost in research and engineering funding related to the very small. For the fiscal year that ended on September 30, 2001 about $464 million was spent on nanotechnology research. This represented a near 70% increase over the previous year. This trend is continuing during the Bush administration. The FY2002 funding level increased by about 30% from FY2001, and the proposed FY2003 budget provides for another increase of approximately 18%. Although the major spending focus remains cancer and defense, nanotechnology has made significant strides in competition for federal dollars.

There has been a corresponding growth in nanotechnology research centers. As of September 2001, there were about 30 such centers associated with universities, more than triple the number that existed only two years earlier.

The "top-down" and "bottom-up" approaches

The article mentions that after something is designed at the nano level, there are two general techniques for manufacturing it, the "top-down" and "bottom-up" approaches.

The top-down approach basically mimics the work of a sculptor. Just as a sculptor creates a sculpture of an elephant by starting with a block of material and "removing everything that doesn't look like an elephant," top-down practitioners can remove material to create the structure they desire. Alternately, they may add bulk material to a surface. One top-down example is the method by which microchips with circuit lines of only about 100 nanometers are manufactured. Other common top-down manufacturing techniques include conventional photolithography, soft photolithography, and dip-pen lithography. The September 2001 issue of *Scientific American* clearly explains of the basics behind each of these manufacturing techniques.

Top-down manufacturing processes begin with a pattern designed on a larger scale to be reduced prior to actually manufacturing the nanoscale structure. The approach has some inherent weaknesses. Currently, top-down techniques fail to create nanostructures cheaply and quickly. Thus the interest in bottom-up approaches.

Bottom-up techniques involve atoms or molecules self-assembling spontaneously when placed in an appropriate environment. One well-described use of this technique is in the manufacture of carbon nanotubes—nano-scale graphite cylinders with unusual electrical properties. Scientists create long, cylindrical tubes of carbon by utilizing a catalyst that consists of a nanoscale-sized drop of a molten metal such as iron. The versatile viral capsid "reaction vessel" described in the article's Nano Kitchen sidebar provides another example of bottom-up manufacture.

Another example of bottom-up technology occurs in the the manufacture of *quantum dots*. Quantum dots are crystals of only a few hundred atoms. In a crystal that small the electrons are confined to widely separated energy levels. This means that when such a crystal is electrically excited, it will emit only one wavelength of light. This property leads to some very practical applications. The crystal can be used as a biological marker, for example. It is possible to "tag" proteins and nucleic acids with quantum dots. When illuminated with ultraviolet light, the quantum dot emits its characteristic wavelength, thus signalling the location of the protein.

Some promises of nanotechnology

It is very difficult to predict, at this early point in time, what kinds of nanoscale devices and materials will become available in the reasonably near future, and what benefits and advantages they may possess. Some fear that the practical realities of nanotechnology may be no match for the great media-generated expectations for their potential. A Congressional Research Service Report written in 2000 states: "While nanotechnology may hold great promise, some scientists contend that the field's definition is too vague and that much of its 'hype' may not match the reality or present scientific speculation."

The most realistic expectations for nanotechnology are in the realms of computer technology and data storage. Others include the manufacture of light-weight materials of special interest to the aerospace industries.

Much research centers on designing nanodevices to be incorporated into electronic circuits. Understandably, these attempts have involved modifying the fabrication methods currently used to manufacture microchips. Researchers at the IBM Thomas J. Watson Research Center have developed colloidal nanoparticles containing about 1,000 iron and platinum atoms. When these particles are spread on a surface and the solvent allowed to evaporate, these nanoparticles form

an array which preliminary studies indicate can store perhaps 10 to 100 times as much information as the best memory devices now available.

The article mentions the rotors that exist at the base of flagellae and are used to propel bacteria through a liquid medium. In what almost seems like something out of science fiction, Carlo D. Mantemagno of Cornell University has been able to extract a rotary motor protein from a bacterial cell and connect it to a metallic nanorod with dimensions of about 750 x 150 nanometers. The rotary motor was only 11 nanometers tall. Powered by adenosine triphosphate (ATP), the motor was capable of rotating the nanorod at a speed of eight revolutions per minute. Although no practical applications for the device are under discussion, its demonstration shows the potential of these tiny devices.

But not all applications lie in the future. The article mentions the manufacture of everyday products like a zinc oxide sunscreen that doesn't require painting your nose white. IBM has utilized nanoscale layering in disk drives, allowing for more data storage density. Gilead Sciences has created lipid spheres called liposomes. Measuring about 100 nanometers in diameter, liposomes encase anticancer drugs used to treat the AIDS-related Kaposi's sarcoma. Carbon Nanotechnologies has improved manufacturing processes to make carbon nanotubes more affordable, and Nanophase Technologies offers nanocrystalline particles for improving the performance of a number of products, such as the sunscreen previously mentioned.

Basic principles governing the behavior of nanoscale structures

The name "nanotechnology" may actually be a misnomer for many things now falling under that umbrella. Many scientists are quick to point out that much of what is now described as "nanoscale" technology in fact is more appropriately labeled *mesoscale* technology. Many so-called nano devices have dimensions larger than the accepted nanoscale range of one to several nanometers. *Nanotechnology* has become the glamorous buzzword—a buzzword that can sometimes impact spending decisions.

The natural laws that govern the behavior of mesoscale structures are complex and not well understood. These kinds of structures may contain too many atoms to be understood by strictly applying the principles of quantum mechanics; however, quantum effects exert a significant effect on their observed behaviors. Meso- and nanostructures are too small and of too little mass to be understood by applying the laws of classical physics. Sometimes unforeseen properties emerge when these structures are tested. Scientists are discovering patterns in the behavior of mesoscale systems by creating these complex systems of atoms and then observing and measuring their interesting behaviors. Learning more about their behavior will assist engineers in their efforts to create novel and reliable nanodevices. Nobel Prize winning physicist Richard Feynman anticipated this in his 1959 speech, when he said, "At the atomic level, we have new kinds of forces and new kinds of possibilities, new kinds of effects. The problems of manufacture and reproduction of materials will be quite different."

Problems with nanoscale devices

Although each specific application of nanotechnology has unique problems to overcome, there are at least two features common to all nanoscale systems that are likely to present technical problems.

The first feature affects communication between the nanoworld and the macroworld. A nanoscale device needs a method of communicating to the outside macroworld. In turn, the outside world must be able to provide feedback and control back down to the nanoscale device. But one principle of quantum mechanics is that any measurement made alters that which is being measured (see *Connections to Chemistry Concepts*). In what one author describes as "collateral damage", linking a nanosystem to something that can report back to the macroworld will always change the properties of the nanosystem to some degree—a change likely to be significant even if the nanosystem is comprised of millions or even billions of atoms. We must also, of necessity,

extract some energy from the nanosystem as we perform our measurements. This, in turn, can degrade its performance.

Another feature is the fact that when an object becomes smaller, its ratio of surface area to volume increases. Depending on the environment, surface effects can be significant even in the macroscopic world, as any baseball player trying to hit a good curveball will attest. At nanoscale dimensions, surface effects can be profound. For example, nanotubes exhibit ideal characteristics when placed in a true vacuum. But exposed to ordinary conditions of air currents and humidity, the electronic properties of nanotubes change significantly. Mechanical properties can vary significantly as well.

The time involved in constructing nanodevices may present significant and practical problems. With any top-down assembly plan, one tedious manufacturing step must be completed before another begins.

Connections to Chemistry Concepts

The article and the *Background Information* section mention that quantum effects significantly affect the behavior of nanoscale systems. One effect relates to the Heisenberg Uncertainty Principle. Arguably one of the most significant discoveries in 20th century physics, this principle has profound implications. For a thorough discussion of this principle, the various ways it is stated, named, and for information about Heisenberg himself, see:
http://www.aip.org/history/heisenberg/p08a.htm

In very general terms, the concept behind the principle is that one can never measure anything *exactly,* because the very act of measuring something will alter the magnitude of what is being measured. In the macroscopic world this change in magnitude is completely insignificant, and the principle can be ignored. But in the world of the atom, it is very significant. Students often mistakenly think that this has something to do with the notion that no measuring instrument is perfect. In their experience, their lab balances are "off" by perhaps 0.001 grams, thermometers by perhaps 0.2 ^{o}C, etc. But this is not what is being referred to in the Uncertainty Principle. The idea is more subtle. It implies that the very *act* of measuring something will change its value.

Let's take a "silly" macroscopic example. Suppose you are asked to measure the temperature of a beaker of water *exactly*. You have a perfect thermometer. You place the thermometer in the water, and after a sufficient period of time (an infinite amount of time, in principle), you state that the temperature is 23.89365003747… ^{o}C (to an infinite number of decimal places, all of which will *not* be written here).

Fine. But unfortunately, placing the thermometer in the water *changed* the temperature of the water because the thermometer was either warmer or colder than the water itself. You know what the temperature of the water *is*, but you were asked to find out what it *was*.

Now one might start to make a case that you could "correct" for this by knowing the specific heat of the thermometer, its initial temperature, its final temperature, etc. This would allow you to "calculate back" how much energy was absorbed by the thermometer, and thus determine the initial temperature of the water. But that only expands the problem. The fact is that you have to measure things to determine the specific heat of the thermometer, and so you get into an endless loop of "when I measure something I change it" problems.

Of course this example is far-fetched, but you get the idea.

The Uncertainty Principle can be stated in more than one way, but the most common understanding is that one can never simultaneously determine both the position and momentum of an electron with complete accuracy. To measure its position you have to shine "light" at an electron. But one principle of optics states that you cannot determine the position of an object to an accuracy greater than the wavelength of the light you use to determine its position. This

means that if we want to know the position of an electron with great accuracy, we need to use light of a very short wavelength. But light carries energy. Like a billiard ball bumping into another billiard ball, when a photon of light strikes an electron, the electron moves. Furthermore, the shorter the wavelength of the light, the higher its frequency ($v = \lambda\nu$), and the higher the frequency, the more energetic are the photons ($E = h\nu$). Consequently, as we shorten the wavelength of the light to more accurately determine the position of the electron, we in turn bombard it with a higher energy photon. The electron moves, and we no longer know where it is. We only know where it *was*. If we try to keep from moving it by using light containing low energy photons, we have to use light with a long wavelength, which means that we do not have a very accurate measurement of its position.

Mathematically the HUP is stated as follows:

One can never simultaneously determine both the position and momentum of an electron. The product of the error in position multiplied by the error in momentum must be greater than or equal to Planck's constant divided by 4π.

$$(\Delta\rho)(\Delta mv) > \text{or} = h/4\pi$$

Possible Student Misconceptions

Because of the tremendous amount of "hype" that surrounds the entire field of nanotechnology, students may think that great strides have been made and that incredible devices and applications are either already in use or just around the corner. This is probably not the case. See *Background Information*.

Because the name "nanotechnology" is almost exclusively used when discussing the kinds of applications discussed in the article, students may mistakenly assume that nanodevices must only have dimensions of a nanometer or at best a few nanometers. In fact, most devices are somewhat larger, and the term *mesoscale* is probably a more accurate description of the dimensional scales involved in this technology. But for practical and historical reasons (see *Background Information*), the term nanotechnology has come into accepted usage.

Demonstrations and Lessons

1. The article mentions Richard Feynman's famous and incredibly prophetic 1959 lecture at Cal Tech entitled "There's Plenty of Room at the Bottom." Richard Feynman was, at least in my opinion, the most brilliant and inspirational scientist of the 20th century—a true genius who never lost touch with ordinary humans. Feynman found words for conveying the most complex subjects in understandable and even entertaining terms. There is a wonderful book about his life entitled "Surely You're Joking, Mr. Feynman," that can easily stay in the minds of students long after their ability to solve mole problems has been forgotten. There is also a Nova program titled "The Best Mind Since Einstein," first broadcast on December 21, 1993. It can be purchased from the Nova Shop at
http://main.wgbh.org/cgi-bin/wgbh/shop/search.pl?q=Feynman&x=9&y=5

I've shown and discussed this video with my classes many times. Most students seem to both enjoy it and learn from it. It seems to be most inspiring for advanced students, even though the content is not at all technical. You might consider purchasing the video and thinking of ways to share it with your students.

2. Any discussion of nanotechnology will lead to considering the relative dimensions of various things such as atoms, molecules, microchips, etc. This discussion leads to a consideration of exponential notation, both its literal and practical meaning. There is an excellent book and movie

entitled *Powers of Ten*, as well as a Web site which provides an image starting with a dimension of about 10^{23} meters and then shrinking by factors of ten until a dimension of 10^{-16} m is reached (see *Web sites for Additional Information and Ideas*). The use of one or more of these resources might make for an excellent class session. The Web site is:
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/

Connections to the Chemistry Curriculum
One characteristic of nanotechnology that immediately becomes apparent is its relevance all areas of science. Nanotechnology is not the exclusive domain of either the biological or physical sciences. It is studied by theoretical and experimental researchers who have no practical applications in mind, and by others who are interested in building the proverbial better mousetrap. As a result, this nanotechnology is an excellent context for demonstrating the interconnectedness of all areas of science and mathematics. It is truly a scientific buffet, with something for everyone.

No topic is more effective at teaching the concept of scale than nanotechnology. It provides an outstanding opportunity to introduce or review powers of ten notation, the relative sizes of things, and their size relationships to each other.

The fact that quantum effects exert significant influence on the behavior of nanoscale devices leads to a consideration of the Heisenberg Uncertainty Priniciple. This principle is discussed in *Connections to Chemistry Concepts*.

Suggestions for Student Projects
1. Four techniques used to create nanostructures are conventional photolithography, soft lithography, dip-pen lithography, and quantum dot assembly. All four are described nicely in the September 2001 issue of *Scientific American.* A student or group of students could research these methods and prepare a class report on the basic features of one or more of these techniques, stating advantages, disadvantages, promises, and probable limitations.

2. One of the most anticipated applications of nanotechnology is in the use of nanodevices to replace silicon chips in computers. While researchers have succeeded in creating nanoscale components such as transistors, diodes, relays, logic gates, carbon nanotubes, and semiconductor nanowires, they still have not succeeded in wiring all these components together. The current state of this aspect of nanotechnology could provide the basis for a class report.

3. Nanotechnology plays a big role in many futuristic science fiction plots. Even as early as 1966, the movie *Fantastic Voyage* envisioned a team of doctors and their high-tech submarine being shrunk to a size so small that they could travel through the bloodstream of a patient to remove a blood clot. Creative students with a bent for writing could try creating an imaginary nanoscale device capable of performing great good or wrecking great havoc upon the world. They could prepare a dramatic scenario centered around the the impact of this fictional device on the general population.

Anticipating Student Questions

What is the meaning of the word "nanotechnology?"
Interestingly enough, there is no single accepted definition. One would assume that "nanotechnology" refers to manipulating individual atoms, or making devices with dimensions in nanometers, or working with structures with dimensions in the nanometer range. But in practice, this is not always the case. Some nanotechnology actually involves working with structures with micrometer (micron) dimensions—about 1000 times larger than an nanometers. And of course much nano-*technology* research would not be considered to be "technology" by most scientists since it involves very basic research devoted to discovering general principles and properties rather than making useful products.

A widely accepted definition of nanotechnology is that it involves structures with at least one dimension between 1-100 nanometers, it utilizes processes in which there is control over structures that have molecular dimensions, and it combines these small structures to form larger structures.

Can we expect that some new kind of nanotechnology product will replace the silicon chips that are in all of our computers now?
Nobody knows for sure. Some experts predict that the silicon-based technology used in current computers may become obsolete in 10-25 years and will be replaced by a nanotechnology product of some yet unknown material. But no one is certain. One large unknown is whether the use of carbon nanotubes or some other nanostructures will yield improvements in performance justifying increases in costs.

Websites for Additional Information and Ideas
The number of Websites devoted to nanotechnology is overwhelming. Some good sources include:

The National Nanotechnology Initiative (NNI)
http://www.nano.gov/
This Website contains links to many additional nanotechnology sites. Some major ones include: Participants, NNI Reports, Activities, Information on R&D, and Information on Education. The last one has links to Courses, "For Kids","Nano Pictures", and "Professional Societies".

Clicking on the "For Kids" link takes you to four additional links. One of the most useful is the *University of Wisconsin: Nanoworld for Kids.* Here you'll find additional links to useful information and activities for both students and teachers, such as:
Modules for high school teachers
Nanoworld cineplex of movies
LEGO nanobricks booklet (can be downloaded free of charge)
People and presentations
Internships in Public Science Education
Research Experiences for Teachers (RET)--this provides a professional development opportunity to K-12 science teachers by placing them in a research laboratory during the summer.
Take-Out Talk—This gives teachers materials for a presentation for either technical or non-technical audiences. Included are color transparencies that can be downloaded as .pdf files and props which can either be obtained from suppliers or borrowed for shipping and handling costs on a first-come first-served basis.

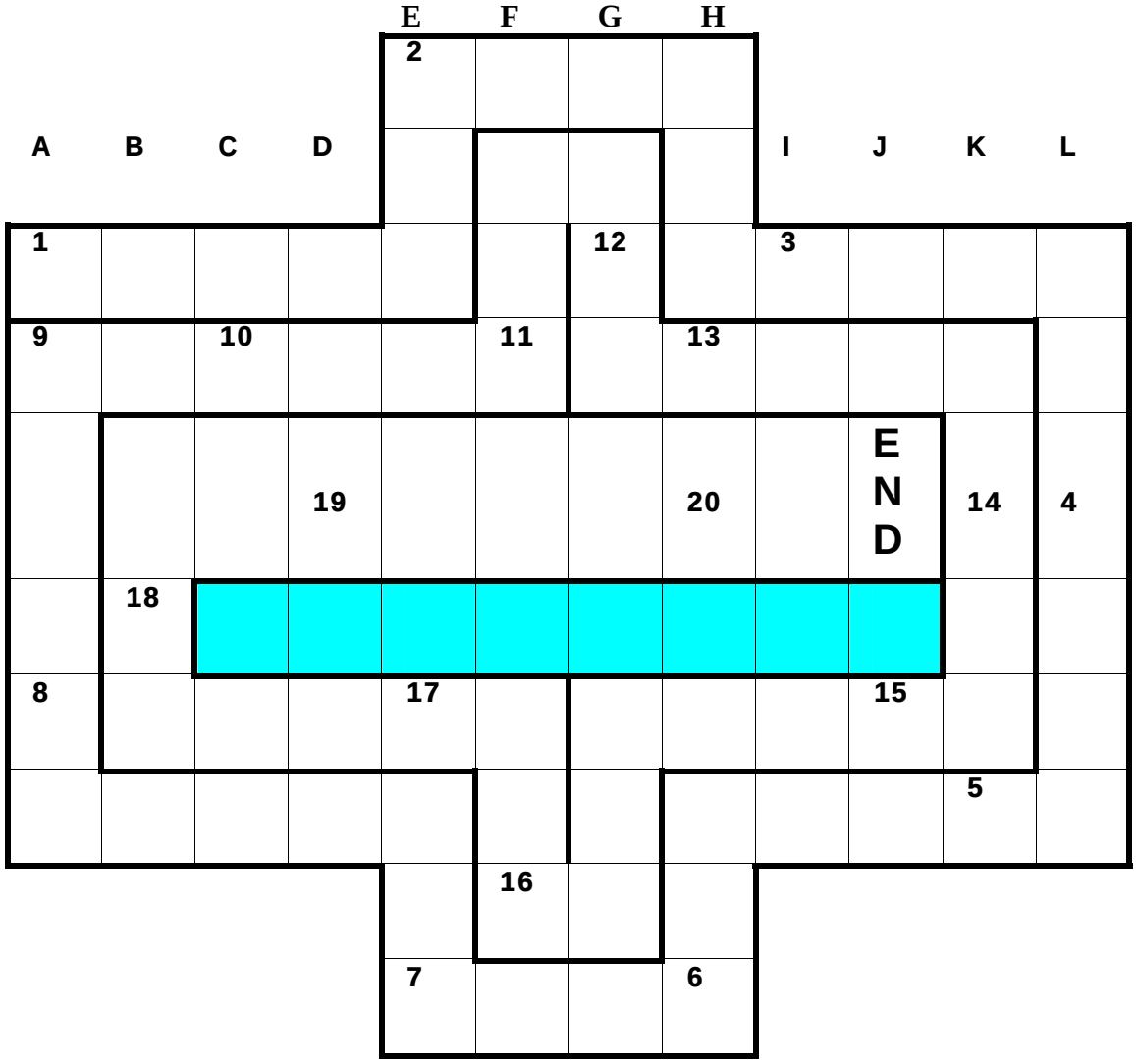
Additional links from the "For Kids" page include:

K-12 Education at the Nanobiotechnology Center, Cornell University
Rice University: NanoKids
Northwestern University: Materials World Modules

"Powers of Ten" Website
Most of us have probably either read the classic book, *Powers of Ten*, by Philip and Phylis Morrison or seen the corresponding movie. There is a Website that shows each of the images, starting at a dimension of 10^{23} meters, looking at the Milky Way, 10 million light years from Earth, and then successively moving through space with each successive image decreased in size by a factor of 10. The images continue until they reach a tall oak tree just outside the building of the National High Magnetic Field Laboratory in Tallahasee, FL. From there we move to a leaf, and then down to individual cells, the cell nucleus, DNA, and ultimately to the world of electron, protons, and quarks, reaching a final dimension of 10^{-16} m. This fascinating Website is at;
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/

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^-

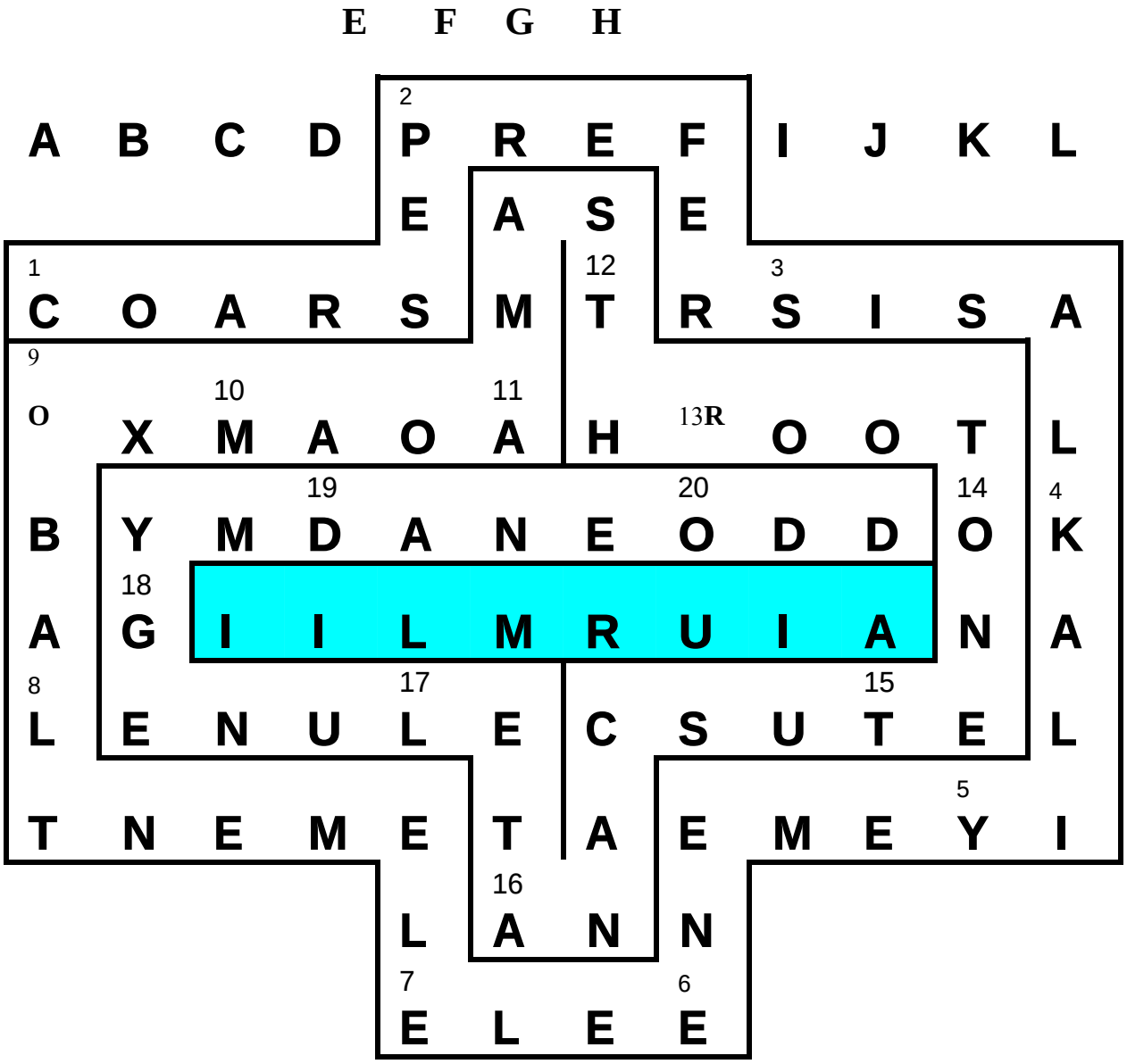
K. Coined the word “electron”

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.

Images of Anthrax—A Team Approach

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

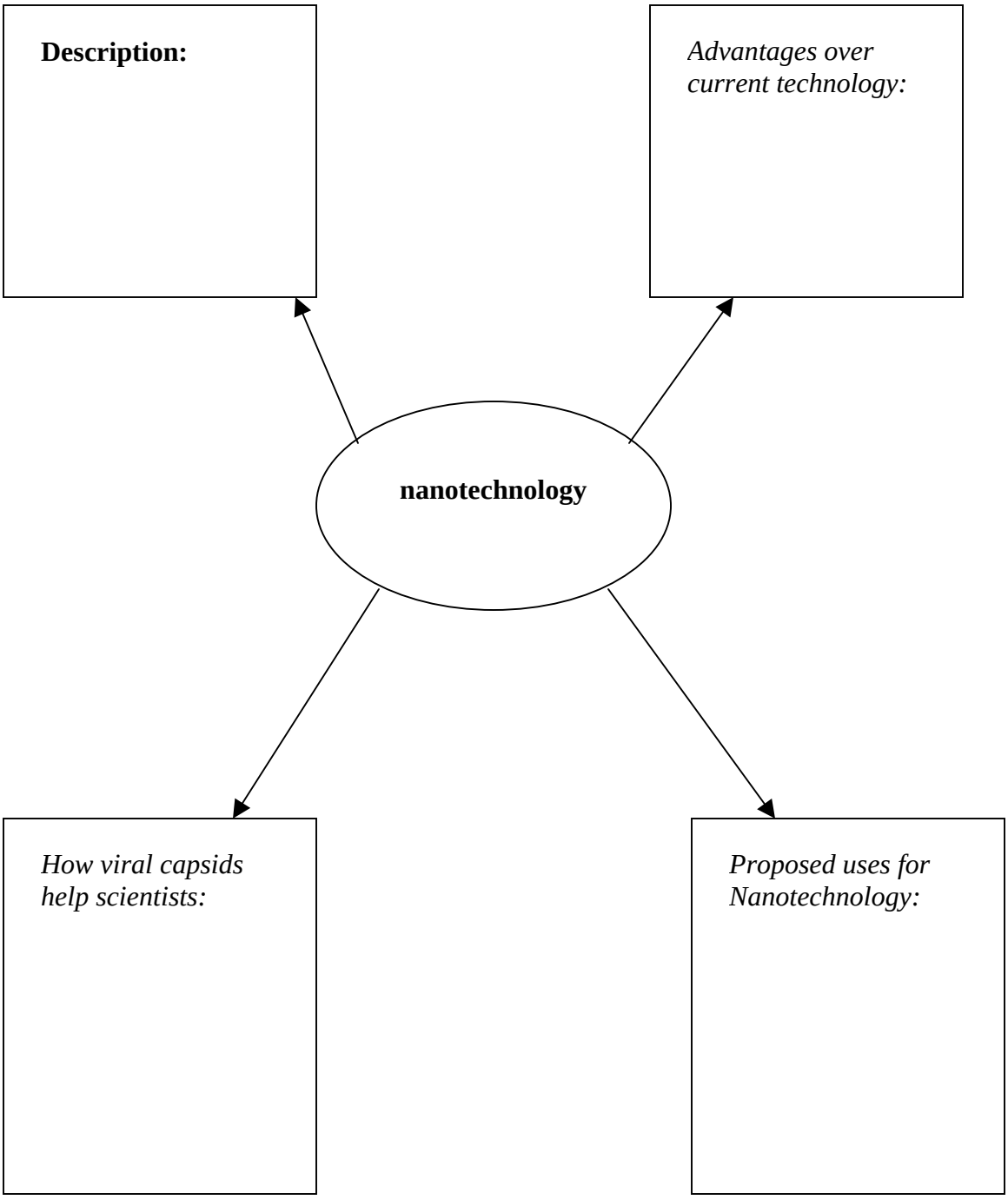
Images of Anthrax—A Team Approach

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.



Biosensors—Early Warnings of Unseen Enemies

Directions: As you read, look for information about the different kinds of biosensor tests being developed and complete the chart below.

Type of test	Description	Used before or after attack?	Amount of pathogen detectable
Antigen-based tests			
Genetic-based biosensors			
Environmental monitoring			

Matches—Striking Chemistry at Your Fingertips

Directions: As you read, look for information about different types of matches to help you complete the chart below.

Type of Match	Chemicals used	Advantages	Disadvantages
Robert Boyle's design			
Sugar & potassium chlorate			
John Walker's design			
White phosphorous			
Red phosphorous (1840s)			
Tetraphosphorous trisulfide			
Modern matches			

Murder She Floats

Directions: As you read, list scientific evidence that supported Gerard Campano's confession about the murder of Ann Marie.

Confession	Scientific Evidence
A woman's body can fit inside a large cooler.	
A large cooler with a body inside floats.	
A large cooler with a body inside floats even when a bullet hole allows water to enter.	
A large cooler filled with salt water floats even when no body is inside.	