



April 2004 Teacher's Guide

| | |
|---|-----------|
| Puzzle: Missing Numbers | 3 |
| Puzzle Answers | 4 |
| Student Questions | 5 |
| Answers to Student Questions | 6 |
| Content Reading Materials | 9 |
| National Science Education Content Standard Addressed | 9 |
| Reading Strategies..... | 10 |
| Slide Rules Rule!..... | 10 |
| Building a Better Bleach: A Green Chemistry Challenge..... | 11 |
| Can Chemistry Stop What's Bugging You? | 12 |
| Lightning: Nature's Deadly Fireworks | 13 |
| Bacteria Power..... | 14 |
| Anticipation Guides | 15 |
| Slide Rules Rule!..... | 15 |
| Can Chemistry Stop What's Bugging You? | 16 |
| Lightning: Nature's Deadly Fireworks | 16 |
| Bacteria Power..... | 17 |
| Building a Better Bleach: A Green Chemistry Challenge..... | 17 |
| Slide Rules Rule! | 18 |
| Background Information..... | 18 |
| Connections to Chemistry Concepts..... | 21 |
| Possible Student Misconceptions | 21 |
| Demonstrations and Lessons | 21 |
| Connections to the Chemistry Curriculum | 21 |
| Suggestions for Student Projects..... | 21 |
| Anticipating Student Questions..... | 22 |
| Websites for Additional Information and Ideas | 22 |
| Can Chemistry Stop What's Bugging You? | 24 |
| Background Information..... | 24 |
| Connections to Chemistry Concepts..... | 27 |
| Possible Student Misconceptions | 27 |
| Demonstrations and Lessons | 27 |
| Connections to the Chemistry Curriculum | 28 |
| Suggestions for Student Projects..... | 28 |
| Anticipating Student Questions..... | 29 |
| Websites for Additional Information and Ideas | 30 |
| Bacteria Power | 31 |
| Background Information..... | 31 |
| Connections to Chemistry Concepts..... | 33 |
| Possible Student Misconceptions | 35 |
| Demonstrations and Lessons | 35 |
| Connections to the Chemistry Curriculum | 36 |
| Suggestions for Student Projects..... | 36 |
| Anticipating Student Questions..... | 36 |
| Websites for Additional Information and Ideas | 37 |
| Lightning: Nature's Deadly Fireworks | 38 |
| Background Information..... | 38 |
| Connections to Chemistry Concepts..... | 41 |
| Possible Student Misconceptions | 42 |
| Demonstrations and Lessons | 42 |

| | |
|---|-----------|
| Connections to the Chemistry Curriculum | 43 |
| Suggestions for Student Projects..... | 43 |
| Anticipating Student Questions | 43 |
| Websites for Additional Information and Ideas | 44 |
| Bleaching With Green Oxidation Chemistry | 45 |
| Background Information..... | 45 |
| Connections to Chemistry Concepts..... | 46 |
| Possible Student Misconceptions | 47 |
| Demonstrations and Lessons | 47 |
| Connections to the Chemistry Curriculum | 47 |
| Suggestions for Student Projects..... | 47 |
| Anticipating Student Questions..... | 48 |
| Websites for Additional Information and Ideas | 48 |

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Puzzle: Missing Numbers

Instructions:

In a quote box, the letters are dropped vertically from each column (but not necessarily in the order in which they appear) into the empty squares in the grid. For example, in the warm-up grid below, the very first letter will be either a T or an A, and the last letter a Y.

They will spell out a quotation of some interest to those concerned about our environment. It reads from left to right, line by line. Words may continue from one line to the next; black squares indicate ends of words; three black squares in a row indicates end of a sentence.

First an easy warm-up.

It's a famous slogan from the Earth Day movements of the 80's ..and still valid !

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | N | D | N | A | C | G | L | L | B | C | A | L | Y | Y |
| A | H | I | | K | | T | | O | O | A | L | L | L | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |

Each of the two longer quotes below also has an ENVIRONMENTAL theme.

The first is from John Muir, the great naturalist who "discovered" Yosemite Valley. The other is by Marshall McLuhan.

| | | | | | | | | | | | | | | | | | |
|---|---|---|--|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | N | E | | I | N | I | V | A | T | I | E | E | L | A | V | T | S |
| T | H | G | | O | N | | A | E | S | U | R | G | M | E | N | E | H |
| I | U | G | | U | N | | N | | R | S | N | | O | | D | | |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

(Hint: the first word in the above quote is NOT "the" !)

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | H | A | R | T | W | A | M | E | S | B | A | C | E | S | S | A | P |
| T | E | C | R | E | H | O | R | E | W | E | E | A | R | E | H | I | E |
| N | G | E | R | E | | | N | | M | N | O | R | P | A | | S | L |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

Puzzle Answers

WARM-UP: Think globally and act locally.

#1. Tug on a single thing in nature and the universe moves.

#2. There are no passengers on spaceship Earth. We are all crew members.

Student Questions

Slide Rules Rule!

1. What is the definition of a common logarithm? What is the logarithm of 1000? What is the logarithm of 0.01?
2. What is the product of $(10^{a+b})(10^{a-b})$?
3. What is the log (a/b) ?
4. Suppose you wanted to multiply $1,288 \times 3,572$ on a slide rule. How would you decide where the decimal point went?
5. Multiplying $1,288 \times 3,572$ on a calculator gives the answer as 4,600,736. Could you get this same answer using a normal slide rule? Why or why not?
6. In the calculation of $1,288 \times 3,572$, what different problems involving significant figures occur with a slide rule versus a modern electronic calculator?

Can Chemistry Stop What's Bugging You?

1. Describe the general chemical structures of "organic" insecticides.
2. Give some examples of "organochlorine" pesticides. Why have these been banned in the United States since the 1970s and 1980s?
3. Name two general categories of pesticides that function as acetylcholinesterase inhibitors. What are some specific examples of each?
4. Describe how acetylcholine functions in the transmission of nerve impulses.
5. What role does acetylcholinesterase play in the transmission of nerve impulses?
6. Describe how acetylcholinesterase inhibitors function.
7. What is the basic difference between the way carbamate insecticides and organophosphate insecticides react with acetylcholinesterase?

Bacteria Power

1. What unusual ability do the bacteria *Geobacter sulfurreducens* display?
2. Describe the basic structure of a battery and the general method by which it produces electricity.

3. Describe how Derek Lovley sets up an apparatus to use naturally occurring *Geobacter sulfurreducens* bacteria to produce electricity from a body of water.
4. Describe how the *Geobacter sulfurreducens* battery produces electricity, including the chemical reactions that occur.
5. Why are these kinds of electricity generating systems considered to be "environmentally benign?"

Lightning: Nature's Deadly Fireworks

1. If you rub the soles of your shoes on a carpet and then go to touch a metal object, you may experience a slight electric shock and observe a small spark as you go to touch the object. Explain what actually occurs to produce this shock.
2. Explain how the spark is produced.
3. Explain how a buildup of charges at the base of a cloud can result in a cloud-to-ground lightning strike.
4. What is a "stepped leader?"
5. How does the actual lightning strike occur?
6. How is the thunder that accompanies a lightning stroke produced?
7. What is the most common type of lightning, and why is this the case? How common is cloud-to-ground lightning?

Building a Better Bleach: A Green Chemistry Challenge

1. What is the "active ingredient" in ordinary household bleach, and what basic chemical process does it use to remove stains?
2. Give two common definitions of oxidation and reduction.
3. What environmental problem is associated with the use of chlorine bleaches?
4. What is the common bleaching agent in many "non-chlorine" bleaches? Do most non-chlorine bleaches actually contain this substance?
5. Describe the basic mechanism by which non-chlorine bleaches work.
6. What are two disadvantages connected to the use of hydrogen peroxide bleaches compared to bleaches that contain chlorine?
7. What are the advantages of using TAML molecules in a bleaching process?

Answers to Student Questions

Slide Rules Rule!

1. The common logarithm of a number is defined as the power to which 10 must be raised to produce the number. The logarithm of 1000 is 3, because $1000 = 10^3$. The logarithm of 0.01 is -2 because $0.01 = 10^{-2}$.
2. The product is 10^{2a} because $(10^{a+b})(10^{a-b}) = 10^{a+b+a-b} = 10^{2a}$.
3. $\text{Log}(a/b) = \log a - \log b$
4. You could either estimate the answer as approximately $(1000)(3600)$, or about 3,600,000, or you could transform the numbers into scientific notation before you did the calculation, i.e., $(1.288 \times 10^3)(3.572 \times 10^3)$. Therefore your answer would be something times 10^6 .
5. No. There wouldn't be any way to be able to read "between the divisions" to obtain what amounts to seven significant figures. Depending on what part of the scale you were using, the highest number of digits you could obtain on an ordinary slide rule was about four.
6. They produce opposite problems. Since both numbers used in the calculation have four significant figures, the answer is allowed four significant figures. But an ordinary slide rule would only allow you to read the answer to three significant figures, so if you wanted to know the fourth, you had to do the calculation by hand. The calculator produces the opposite problem. It gives the answer to seven significant figures, so you have to remember to round it to only the four that are allowed.

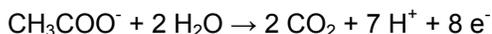
Can Chemistry Stop What's Bugging You?

1. Saying that an insecticide is "organic" means that the basic framework of the molecule is made of carbon. Attached to this framework are other atoms, most typically hydrogen, nitrogen, oxygen, phosphorus and/or chlorine atoms.
2. Some examples include DDT, aldrin, and chlordane. They have been banned because they persist in the environment and get concentrated as they move up the food chain. For example, birds and small animals may eat insects and in turn be eaten by larger birds. The concentration of the pesticide becomes greater in the larger birds, and when they lay their eggs, they may have extremely fragile shells that can crack when the birds nest.
3. Two general categories of pesticides that function as acetylcholinesterase inhibitors are carbamates and organophosphates. Examples of carbamates include propoxur, Sevin®, and bendiocarb. Examples of organophosphates include malathion and parathion.
4. When a nerve is stimulated, the impulse gets transmitted from one end of the nerve cell to the other. When the impulse reaches the end of the nerve cell, it has to cross the gap to the next nerve cell. Acetylcholine allows this to happen. Acetylcholine is stored at the end of nerve cells. When an impulse reaches the end of the cell, acetylcholine is released into the space between the nerves, called the synapse. It moves across the synapse where it attaches to a receptor on the next nerve cell. This triggers another impulse to move along that nerve cell until it reaches the end, where more acetylcholine is released to transmit the impulse to yet another cell, etc.
5. When nerve impulses are transmitted, acetylcholine is released into the space between nerve cells. In order for another impulse to be transmitted, this acetylcholine must be quickly removed. Acetylcholinesterase is a huge protein molecule that acts as an enzyme. It rapidly reacts with the acetylcholine, removing it from the synapse between the nerve cells.

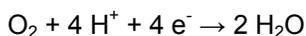
- Acetylcholinesterase inhibitors compete with acetylcholine for the acetylcholinesterase enzyme. If the acetylcholinesterase is tied up by the inhibitor, it is not available to react with the acetylcholine, so acetylcholine builds up in the synapses between nerve cells. This results in all kinds of physiological reactions, and in the case of insects, is designed to kill them.
- Carbamates are competitive inhibitors. This means that they compete with acetylcholine for acetylcholinesterase but eventually the acetylcholinesterase can be regenerated. Organophosphate pesticides, on the other hand, are irreversible inhibitors. When they react with acetylcholinesterase they bond so strongly that they basically never let go.

Bacteria Power

- They are capable of producing electricity.
- Batteries use chemical reactions to produce electricity. They have two poles—also called terminals or electrodes. One is positive and one is negative. Chemical reactions occur at the two electrodes and electrons flow from one terminal to the other. As the electrons flow between the two electrodes we can use some of their energy to do something that we find useful.
- The terminals of the *Geobacter sulfurreducens* battery are slabs of granite about one-fourth of an inch thick. One terminal is placed in the mud at the bottom of a body of water. *Geobacter* bacteria are naturally present there. The other terminal is placed in the clear water above. The two terminals are connected by a waterproof wire.
- The bacteria on the terminal that is in the mud feed off of decaying animal material. They oxidize acetate from the organic matter to carbon dioxide, also producing hydrogen ions and electrons:



The electrons released flow through the wire to the other terminal, where they combine with hydrogen ions and oxygen to produce water.



- Although they produce carbon dioxide as they generate power, the carbon dioxide that they produce comes from plant material. This plant material would decay to produce carbon dioxide anyway, so using the plant material to produce electricity really doesn't add any additional carbon dioxide to the environment. Carbon dioxide gas has been associated with global warming.

Lightning: Nature's Deadly Fireworks

- When you rub the soles of your shoes on the carpet, electrons are transferred from the carpet to your feet. Your body becomes negatively charged. As you go to touch a piece of metal, the negative charge on your body repels the electrons on the surface of the metal. The piece of metal becomes positively charged, and as you get close to the metal, electrons jump from your body to the metal, which you experience as a shock.
- When electrons jump from your body to the piece of metal they collide with the electrons that are contained in molecules of nitrogen and oxygen in the air. The electrons in these molecules pick up some of the energy from the "jumping" electrons, which raises them to higher energy levels. These electrons then return to their normal lower energy states, releasing this previously absorbed energy in the form of visible light.
- When enough negative charges build up in the base of the cloud, the relatively neutral surface of the earth begins to feel their effect. Since like charges repel, the negative

charges in the base of the cloud will repel negative charges on the ground, resulting in the ground becoming positively charged. Lightning occurs if the gap between these negative and positive charges is bridged.

4. A stepped leader is a channel of electrons that flows downward from a cloud. This channel of electrons ionizes the air molecules by knocking away electrons, which creates an excellent conductive path.
5. As the stepped leader approaches the ground, it attracts positive charges from the ground below. A stream of positive charges will then flow from the ground. When the negatively charged stepped leader meets the stream of positive charges from the ground the electrical circuit is complete. In less than a thousandth of a second 10^{18} to 10^{19} electrons will be deposited into the ground. This movement of electrons is accompanied by the simultaneous movement of positive charges, known as the return stroke. The return stroke is responsible for the flash we see.
6. The return stroke heats the air to a very high temperature, perhaps around 30,000 °C. This causes the air to expand rapidly, and this expansion is responsible for the sonic booms we hear as thunder.
7. The most common type of lightning is actually within a cloud itself, because this is the easiest way to complete an electrical circuit. Only about 20% of lightning strikes are cloud-to-ground.

Building a Better Bleach: A Green Chemistry Challenge

1. The active ingredient in ordinary household bleach is sodium hypochlorite, NaOCl. It removes stains by using a chemical process called oxidation.
2. Oxidation is often defined as the loss of electrons and reduction the gain of electrons. Another definition of oxidation is the gain of oxygen atoms or the loss of hydrogen atoms, while reduction can be defined as the loss of oxygen atoms or the gain of hydrogen atoms.
3. When chlorine from bleach is released into the environment it can react with organic-rich waste streams to form hazardous substances such as dioxins.
4. The common agent in non-chlorine bleaches is hydrogen peroxide, H_2O_2 , but this substance is not actually present in the product you buy. Since H_2O_2 is a liquid, solid laundry non-chlorine bleaching products typically contain ingredients like perborate or percarbonate. These compounds react with water to produce hydrogen peroxide.
5. The H_2O_2 that is produced decomposes into water and oxygen gas, and in the process it releases free radicals. Free radicals are highly reactive molecules that oxidize other molecules and thus alter their molecular structure so they no longer have color.
6. The peroxide oxidation process can be unselective. Molecules can be oxidized that we don't want to be oxidized. Second, the use of peroxide requires higher temperatures and pressures and a longer reaction time than is required for chlorine bleaches.
7. The use of TAML molecules allows the hydrogen peroxide oxidation process to proceed at lower temperatures and pressures. In addition, TAML molecules are catalysts, so they are not actually consumed in the process.

Content Reading Materials

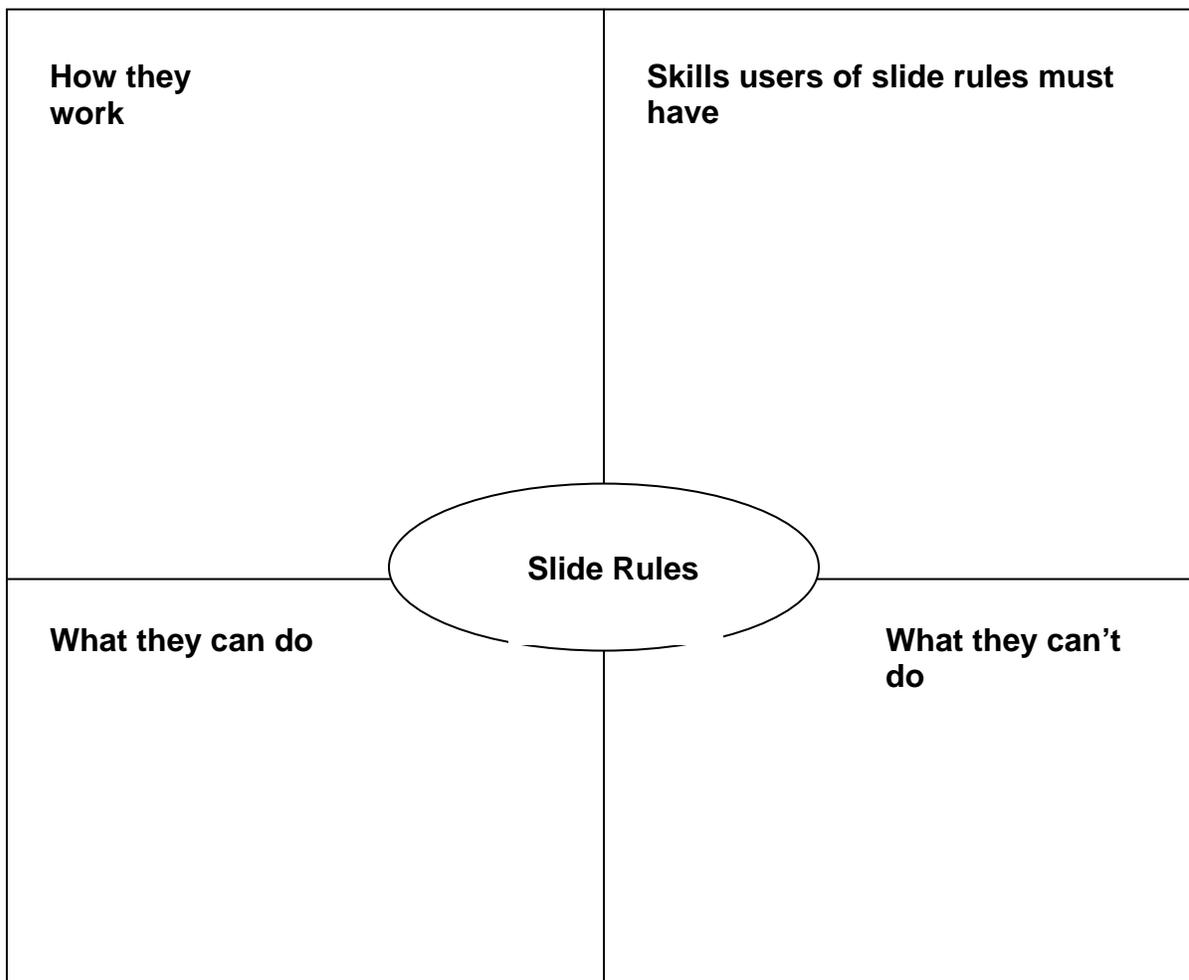
| National Science Education Content Standard Addressed | Building a Better Bleach | Slide Rules Rule! | What's Bugging You | Lightning | Bacteria Power |
|---|---------------------------------|--------------------------|---------------------------|------------------|-----------------------|
| As a result of activities in grades 9-12, all students should develop understanding. | | | | | |
| Science as Inquiry Standard A: and abilities necessary to do scientific inquiry. | | | | | ✓ |
| Science as Inquiry Standard A: about scientific inquiry. | ✓ | ✓ | ✓ | | ✓ |
| Physical Science Standard B: of the structure of atoms. | | | | ✓ | ✓ |
| Physical Science Standard B: of the structure and properties of matter. | ✓ | | ✓ | ✓ | ✓ |
| Physical Science Standard B: of chemical reactions. | ✓ | | ✓ | | ✓ |
| Physical Science Standard B: of interactions of energy and matter. | | | | ✓ | ✓ |
| Life Science Standard C: of the cell. | | | ✓ | | |
| Life Science Standard C: of the interdependence of organisms. | | | ✓ | | |
| Life Science Standard C: of matter, energy, and organization in living systems. | ✓ | | ✓ | | ✓ |
| Life Science Standard C: of the behavior of organisms. | | | ✓ | | ✓ |
| Earth and Space Standard D: of geochemical cycles. | | | | ✓ | |
| Science and Technology Standard E: and abilities of technological design. | | ✓ | | | ✓ |
| 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 natural resources. | | | | | ✓ |
| 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. | ✓ | ✓ | ✓ | | |

Reading Strategies

These content frames and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. If you use these reading strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

| Score | Description | Evidence |
|-------|----------------|---|
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding. |

Slide Rules Rule!



Building a Better Bleach: A Green Chemistry Challenge

Compare chlorine and non-chlorine bleaches using the chart below. In the top part, list their differences. In the bottom box, list their similarities.

| Chlorine Bleach | Non-chlorine Bleach |
|------------------------|----------------------------|
| Similarities | |

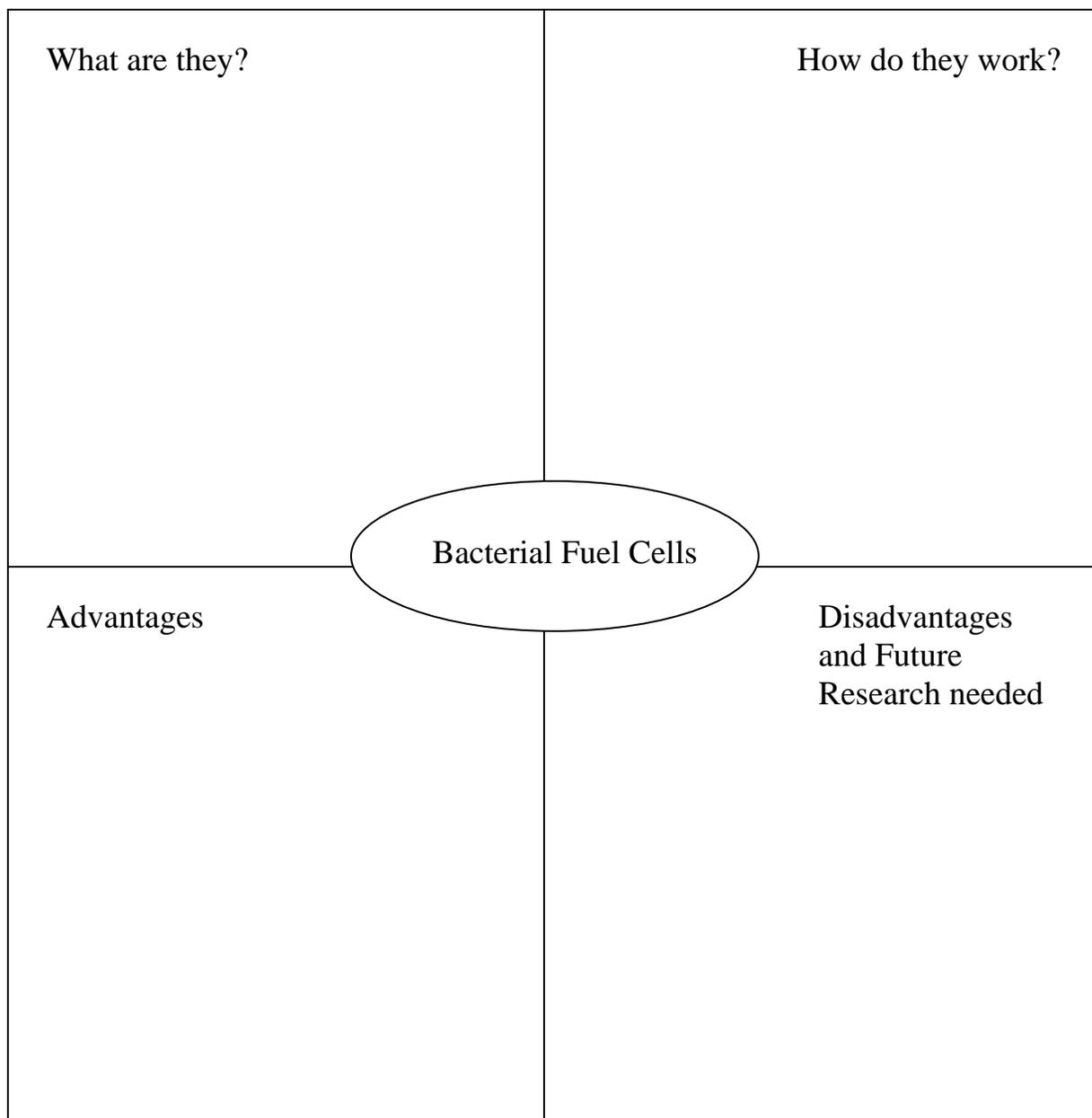
Can Chemistry Stop What's Bugging You?

| Type of Pesticide | Organochlorines | Carbamates | Organophosphates |
|---------------------------------|-----------------|------------|------------------|
| Elements found in the pesticide | | | |
| Where the pesticide is used | | | |
| How the pesticide works | | | |
| Advantages of the pesticide | | | |
| Disadvantages of the pesticide | | | |

Lightning: Nature's Deadly Fireworks

| Lightning | |
|-----------------------------------|--------------------------------|
| Facts I already knew | Facts I was surprised to learn |
| 1. | 1. |
| 2. | 2. |
| 3. | 3. |
| 4. | 4. |
| 5. | 5. |
| Lightning Safety Reminders | |

Bacteria Power



Anticipation Guides

help engage students by activating prior knowledge and stimulating student interest. If you have time, discuss their responses to each statement before reading each article. Students should read each selection and look for evidence supporting or refuting their responses. Evaluate student learning by reviewing the anticipation guides after student reading.

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.

Slide Rules Rule!

| Me | Text | Statement |
|----|------|---|
| | | 1. Handheld calculators have been common in high school classrooms for forty years. |
| | | 2. Slide rules are calculating devices based on logarithms. |
| | | 3. The logarithm of 1000 is 3. |
| | | 4. When multiplying numbers using logarithms, the problem is changed to an addition problem. |
| | | 5. Slide rules were used for about 100 years before being replaced by handheld calculators. |
| | | 6. Slide rules usually give 3 significant figures. |
| | | 7. Slide rules calculate the location of the decimal point. |
| | | 8. Students today frequently make lab calculation errors by reporting too many significant figures. |

Can Chemistry Stop What's Bugging You?

| Me | Text | Statement |
|----|------|--|
| | | 1. Organic molecules come from farms that don't use pesticides. |
| | | 2. Organochlorine pesticides have been banned for more than 20 years in the United States because they cause environmental problems. |
| | | 3. Some pesticides were developed as a result of research to develop nerve gases that are found in some chemical weapons. |
| | | 4. Acetylcholinesterase is an enzyme that destroys acetylcholine. |
| | | 5. Carbamate pesticides can cause death because the nerve becomes so excited, nerve transmission finally stops. |
| | | 6. Organophosphate pesticides work chemically the same way as carbamate pesticides, and they have the same toxicity. |
| | | 7. Pesticides today are harmless to people. |

Lightning: Nature's Deadly Fireworks

| Me | Text | Statement |
|----|------|---|
| | | 1. Lightning strikes the Earth thousands of times every second. |
| | | 2. Lightning can never strike the same place twice. |
| | | 3. People have been killed while talking on the phone during a thunderstorm. |
| | | 4. A typical bolt of lightning is about 5 km long. |
| | | 5. When the base of clouds accumulate an abundance of negative charges, a positive charge is induced on the ground, and lightning may strike. |
| | | 6. A typical flash of lightning carries about 10 amps of current. |
| | | 7. Most lightning flashes are from cloud to ground. |
| | | 8. A car is a safe place to be during a thunderstorm because of the rubber tires. |

Bacteria Power

| Me | Text | Statement |
|----|------|--|
| | | 1. Bacteria may be used to provide electricity for large cities. |
| | | 2. Bacterial fuel cells work by producing sulfuric acid, the same acid found in car batteries. |
| | | 3. Graphite electrodes are used in bacterial fuel cells. |
| | | 4. Researchers have determined the genome of several species of Geobacter so that they can develop a more efficient bacterial fuel cell. |
| | | 5. Bacterial fuel cells are harmful to the environment. |
| | | 6. Bacteria can be used to clean up sites contaminated by uranium mining. |
| | | 7. The materials needed for bacterial fuel cells are dangerous and not suitable for student experiments. |

Building a Better Bleach: A Green Chemistry Challenge

| Me | Text | Statement |
|----|------|---|
| | | 1. Bleaching removes colored molecules from clothing. |
| | | 2. Oxidation may be defined as the loss of electrons, or the gain of oxygen atoms. |
| | | 3. Chlorine from bleach may form dioxins and other hazardous compounds when added to wastewater. |
| | | 4. Hydrogen peroxide is found in most non-chlorine bleaches. |
| | | 5. Hydrogen peroxide is more hazardous to the environment than bleach. |
| | | 6. "Green" chemists are working to develop environmentally benign products for home and commercial laundry use. |

Slide Rules Rule!

Background Information

More about the principles underlying slide rules

Logarithms were discovered by John Napier in 1614, and as the article points out, this allowed one to perform multiplication and division by adding or subtracting the logarithms of the numbers that were to be multiplied or divided.

For example, suppose you wanted to multiply 2 x 3.

Let $x = \log 2$

By definition, x is the power to which 10 must be raised to be equal to 2, i.e., $10^x = 2$.

Let $y = \log 3$, i.e., $10^y = 3$

So 2×3 is the same as $10^x \times 10^y$

and from the principles underlying multiplication of exponential numbers,

$$10^x \times 10^y = 10^{(x+y)}$$

So if I actually knew what the logs of 2 and 3 were, then I could add them and they would be equal to the logarithm of the product of 2 and 3.

The point, of course, is that these logarithm values were determined and put into a table so you could look them up.

The log of 2 is 0.3010.

The log of 3 is 0.4771.

So the $\log(2 \times 3) = \log 2 + \log 3 = 0.3010 + 0.4771 = 0.7781$.

And $2 \times 3 = 10^{0.7781} = 6$.

Now this is obviously a pretty silly way to find the product of 2 x 3, and it's probably easier to just do the multiplication longhand even for something like 5,739 x 7,229. Looking up logs and doing all these conversions may not be worth the time.

But what if we didn't have to actually use a log table? What if we could do this same thing just by sliding a piece of wood back and forth?

That, of course, is the slide rule.

Take another look at the first diagram shown in the article. Even though it doesn't actually represent a slide rule, it could be used to multiply two numbers, like 2 x 3, but it would be tedious. You'd have to use a ruler to measure the distance from the beginning of the bottom line to "3." Then you'd have to measure off this same distance starting on the number "2." Where you ended up would be the product of 2 x 3 (try it and see). This is basically what Edmund Gunter developed in 1620. It allowed numbers to be multiplied and divided by utilizing these "calculating lines" along with a compass to measure distances.

The reason this works is because the logarithmic distance from 1 to 3 is the same as the logarithmic distance from 2 to 6, i.e.,

$$\log 3 - \log 1 = \log 6 - \log 2$$

This is easily seen. Since

$$3/1 = 6/2$$

from the properties of logs,

$$\log 3 - \log 1 = \log 6 - \log 2$$

$$\log 3 - 0 = \log 6 - \log 2$$

$$\log 3 = \log 6 - \log 2$$

We can verify this by plugging in the actual values:

$$0.47712 = 0.77815 - 0.30103$$

$$0.47712 = 0.47712$$

The “double” logarithmic scale developed by William Oughtred saves us from having to do this. The distance from the beginning of the scale to “3” is the same as the distance from “2” to “6,” so if we place the “1” on the upper scale over the “2” on the lower scale and then locate “3” on the upper scale, we have effectively found the product of 2 x 3 on the lower scale.

Even though the principles laid out above are relatively simple, they probably don't appear that way to many students. For we more “mature” teachers who grew up during the “slide rule era,” I think it is safe to say that most of us simply learned how to use a slide rule without too much thought directed at the mathematical principles upon which it was based.

A manual for a 1948 Stanley slide rule stated:

The principles of logarithmic calculators are too well known to those likely to be interested for it to be necessary to enlarge upon the subject here, especially as it is absolutely unnecessary to have any knowledge of the subject to use the calculator.

and from a manual of a different manufacturer:

Anyone can calculate with the Fuller after a brief study of the following instructions without any mathematical knowledge whatsoever.

So you want to see or buy some slide rules?

There is a surprisingly vast interest and market for slide rules. They have basically become collector's items. They can be purchased on the most popular auction websites as well as from sites specifically devoted to their purchase and sale. Many individuals have websites where they proudly display their collections.

The number and variety of slide rules is amazing. One needs to remember that prior to the development of the electronic calculator, slide rules were probably the single most commonly used device to do *all kinds* of calculations. Consequently, very specialized slide rules were created for very specialized applications. This is what makes collecting them so interesting to those that do.

If you are interested in getting involved, either as a spectator or active participant, you will have no difficulty whatsoever in locating websites devoted to individuals who share your interest. An advanced google search using the phrase “slide rules” produced 29,100 “hits.”

Here are just a few:

<http://groups.yahoo.com/group/sliderule/>

Dave's House of Slide Rules

<http://foraker.research.att.com/~davek/slide>

Ron Manley's Slide Rule site—contains an amazing collection of slide rules from around the world, many very specialized and unusual. It also contains complete instruction manuals on how to use a slide rule.

In addition, there is an incredibly comprehensive list of prices at which slide rules are sold on Ebay. Prices range from just a few dollars to several hundred.

<http://www.sliderules.clara.net>

The following website contains some very nice advertisements for slide rules. One ad, from 1954, says, "Shall a price tag burden a man's career?"—an interesting comment on how females pursuing science as a career were viewed at that time. There also are ads from 1942 along with photographs of some of the manuals that accompanied slide rules and some of the slide rules themselves.

<http://www.amug.org/~puppy>

If you really want to know more about how slide rules operate

One very good website that contains a fairly comprehensive discussion of both the theory behind the operation of the slide rule as well as specific illustrations on how to use one is:

<http://dSPACE.dial.pipex.com/town/square/gd86/slides.htm>

This website includes a discussion of multiplication, division, chained calculations (doing several multiplications and divisions in sequence), square scales, cube scales, reciprocal scales, pi-shifted scales, logarithm scales, trigonometrical scales, log-log scales, and square and cube root scales.

A little bit about how far we've come

We all know that computing power has increased tremendously over the past thirty years or so, while costs have plummeted. The following statistics certainly dramatize this change.

In 1977 one of the most revered and popular personal computers debuted. It was the original TRS-80 Model 1. Its 53 key keyboard contained all the computer circuits. It had a black and white monitor. It had 4K of RAM and a ROM with the boot-up software. It could not be connected to a printer. The base price was \$599.95. That's equivalent to about \$1800 in today's money. It was considered by many to be an incredible value for its day. It was sold out for months. It took almost two years to catch up with the demand for TRS-80 computers. This was especially true for later versions of this evolving design.

One of the first mass-market calculators for the general public was called the "Bomar Brain." It cost about \$135 in 1975, equivalent to about \$470 today. All it did was add, subtract, multiply and divide numbers. My wife bought me my first calculator around that same time. It wasn't a Bomar Brain, but it did exactly the same thing and cost \$99. Interestingly enough, I wanted it for addition and subtraction as much as for multiplication and division. You can't add or subtract on a slide rule and our department only had one adding machine that had to weigh at least fifteen lbs.

One of the first and almost certainly the most popular "scientific" calculators was the HP-35, introduced on Feb. 1, 1972. Its introductory price was \$395, equivalent to about \$1700 today.

Connections to Chemistry Concepts

The mathematical principles that lie behind the operation of a slide rule are discussed in the article and elaborated upon in the *Background Information* section.

Possible Student Misconceptions

Students may very well assume that no one is interested in slide rules anymore. In fact, there is a rather extensive market for both purchasing and selling them, with many collectors around the world seeking unusual and rare examples. See *Background Information*.

Demonstrations and Lessons

It has been many years since slide rules were in common use. As a consequence the number of chemistry teachers who used and still remember how to use them grows smaller every year, and I personally do not know of even one “old timer” who continues to use a slide rule.

But one can argue that in some ways using a slide rule to do calculations was educationally superior to blindly punching numbers into a calculator. The most noteworthy difference was that students had to be able to put numbers into scientific notation, had to know how to multiply and divide exponentials, and perhaps most importantly, often had to think about what was a reasonable magnitude for the answer and perhaps estimate it in their head, as discussed in the article.

If a slide rule (or slide rules) can be obtained, and time permits, it might be interesting to teach students how to do simple multiplication and division and then compare what they do, how they think, and the efficiency of solving a problem like $(45,873.6)(0.0000234)/78.82$ using both a slide rule and a calculator while *both observing and not observing significant figures*.

It isn't very likely that such an activity will result in anyone preferring the slide rule over a modern electronic calculator, but it certainly might engender a deeper appreciation for the convenience they offer along with some understanding of how calculations were done in the recent past and perhaps even some of the intellectual advantages of doing them that way.

This might make a good activity to “fill in” the time between when students take the AP exam and when the school year ends.

Connections to the Chemistry Curriculum

While there obviously are no direct connections to chemistry concepts, this article certainly connects strongly to the kinds of mathematical principles and operations that our students need to perform and understand if our course includes any significant amount of computational problem solving.

Suggestions for Student Projects

1. It would be fun to have some enterprising students actually construct a slide rule from scratch. It could be made out of good heavy poster board or perhaps wood. It could be small or large enough to show to an entire class. If any students are enrolled in woodworking or have access to the necessary equipment, they might even make a rule where the sliding and stationary scales fit together in the sort of “tongue in groove” manner used in commercial slide rules. This keeps everything in place while still allowing the movable scale to slide between the stationary scales.
2. Our students have all grown up in the age of computers and electronic calculators, as have many younger teachers. We all know that computing power has increased exponentially for many years as costs have dropped in a like manner. But our students have not been alive

for much of that increase. They might research some of the early computers and calculators, such as the TRS-80 from Radio Shack, or the “Bomar Brain”—one of the first popular calculators, or the HP-35 scientific calculator, and then compare computing power vs. price, adjusted for inflation. It is an eye-opening activity and helps one appreciate the computational and research tools that are now available or at least potentially available to most people. See *Background Information*.

Anticipating Student Questions

1. Do any companies still make slide rules?

No, to the best of our knowledge.

2. Can you still buy slide rules?

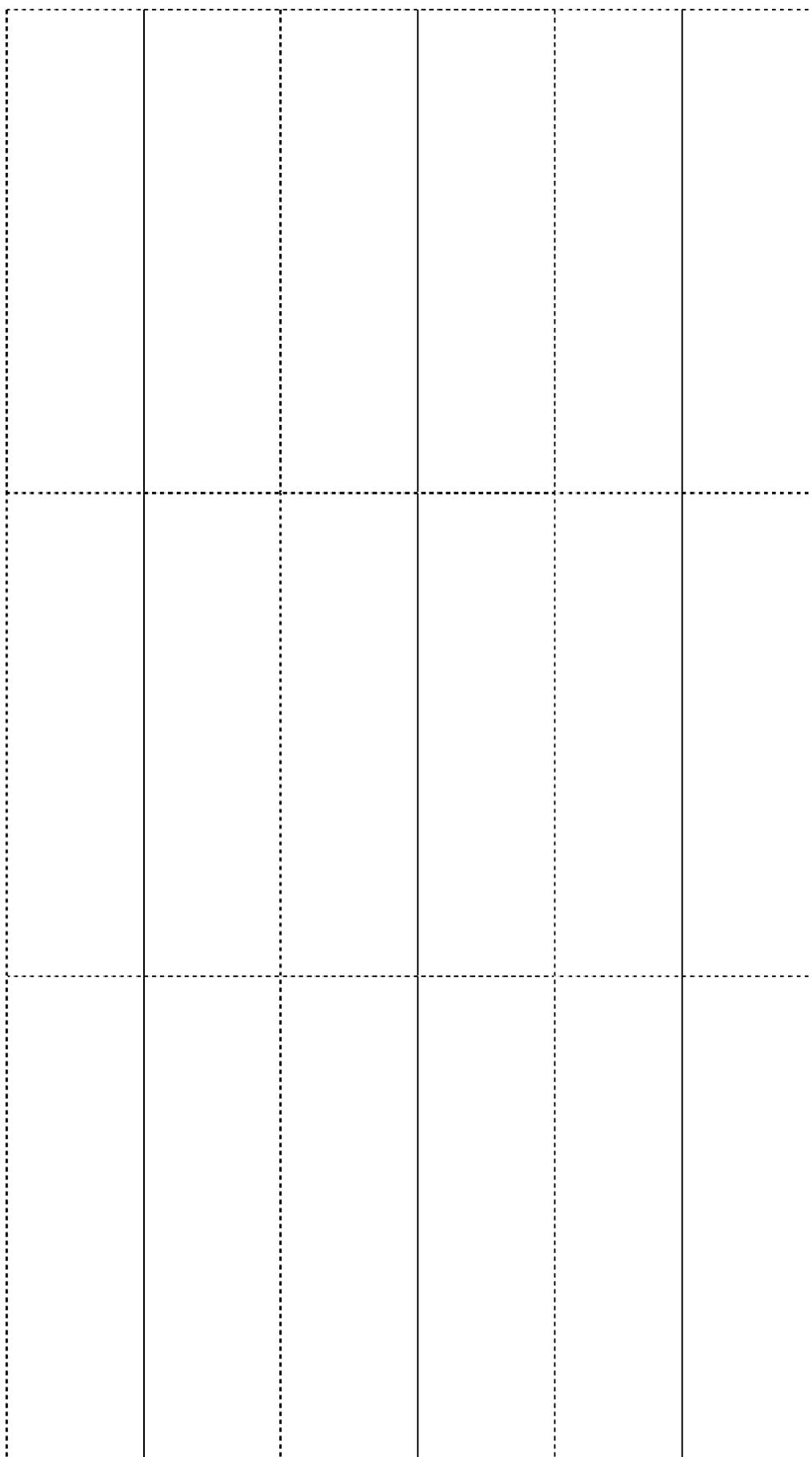
Absolutely. There is a booming market for buying and selling old slide rules of every kind. Many people collect them for a hobby. See *Background Information*.

Websites for Additional Information and Ideas

See *Background Information*.

**Slide Rule
Cursor
Template**

Print on
transparency
film for laser
printers or
copiers. Cut
into 9 equal
sized pieces
(with a line
down the
center).



Can Chemistry Stop What's Bugging You?

Correction: On page 9, for the nerve cell diagram, the balls (representing Na^+) entering the receiving nerve cell should be blue to distinguish them from the green balls (representing acetylcholine) that bind to the acetylcholine receptors.

Background Information

Acetylcholine is often abbreviated as ACh. Its systematic name is 2-(acetyloxy)-N,N,N-trimethylethanaminium.

Some history of pesticides

It is probably not at all surprising that human use of pesticides to try and eliminate destructive and unwanted insects, rodents, and other undesirable creatures dates back over a few thousand years. The historical record of pesticide use and development includes:

- 1200 B.C.—the Egyptians use both hemlock and aconite to try and control pests
- 1000 B.C.—the Chinese use sulfur as a fumigant and Homer describes how Odysseus “fumigated the hall, house and court with burning sulfur to control pests.”
- 23-79 A.D.—Pliny the Elder, a Roman historian and scholar records the use of “gall” from a green lizard to protect apples from worms.
- 100 A.D.—The Romans use Hellebore to kill insects and rodents
- 800 A.D.—the Chinese try to control insect pests with a mixture of arsenic and water
- 1669—arsenic is mixed with honey to attract and kill insect pests

It was during the early 1600s that it was discovered that many plants had insecticidal properties. Some of these included:

- Nicotine—from tobacco plants
- Caffeine—from tea and coffee
- Quinine—from cinchona bark
- Morphine—from the opium poppy
- Cocaine—from cocoa leaves
- Ricinine—from castor oil bean
- Strychnine—from strychnos plants
- Coniine—from hemlock

- 1690—“Black Leaf 40” was marketed. It is a poison containing nicotine used to control pear tree pests.
- 1874—DDT created, but not used as an insecticide
- 1920s—public concern is voiced because pesticides are found in some fruits and vegetables
- 1938—organophosphate chemistry developed by German scientists
- 1940—introduction of parathion
- 1945—introduction of chlordane
- 1947—introduction of toxaphene
- 1947—creation of Allethrin, the first pyrethroid
- 1950—introduction of malathion
- 1950s—development of carbamates
- 1962—publication of Rachael Carson’s book, *Silent Spring*
- 1970—creation of the EPA—Environmental Protection Agency
- 1973—complete ban on the use of DDT in the United States
- 1980s—second generation of pyrethroids developed—permethrin, cypermethrin
- 1988—chlordane banned after an episode on the TV program “60 Minutes”
- 1990s—third generation of pyrethroids developed—deltamethrin

Basic classes of pesticides

Although the major focus of the article centers around pesticides that function as acetylcholinesterase inhibitors, as might be expected, there are a fairly wide variety of pesticides in use today. The basic categories include:

Insecticides

- Organochlorines
- Organophosphates
- Carbamate esters
- Pyrethroids
- Botanical insecticides

Herbicides

- Chlorophenoxy compounds
- Bipyridyl derivatives

Rodenticides

- Zinc phosphide
- Fluoroacetic acid and derivatives
- Anticoagulants

Fungicides

- Hexachlorobenzene
- Organomercurials
- Pentachlorophenol
- Phthalimides
- Dithiocarbamates

Fumigants

- Phosphine
- Ethylene dibromide
- Dibromochloropropane

More about DDT—The first, and probably the most significant insecticide of modern times

DDT (dichlorodiphenyltrichloroethane), the first of the chlorinated organic insecticides was actually first prepared in 1874. But it wasn't until 1939 that Paul Muller, a Swiss chemist, independently produced it and more importantly, discovered its effectiveness as an insecticide. It was hailed as a "miracle" (Muller received the Nobel Prize in 1948) for several reasons, including:

It was a "broad spectrum" insecticide. It killed many crop-destroying and disease-producing insects but did not appear to exhibit much toxicity to mammals.

It was persistent. It didn't break down quickly in the environment. At first this was considered to be a real "plus," since this meant that it didn't need to be constantly reapplied.

It wasn't soluble in water. Again, this was considered a good thing, since that meant that it wouldn't be washed off by rain.

It was very inexpensive to produce.

Originally used in agriculture, its use quickly spread. It was used to delouse soldiers during WWII. Until the 1960s it was often indiscriminately sprayed in residential areas to control mosquitos (see <http://www.alternatives2toxics.org/ddt.htm>), but with the publication of *Silent Spring* in 1962, people and governmental officials began to assess the actual and potential dangers associated with its use. The creation of the EPA was essentially a result of the debate over the use of DDT and other pesticides.

More about organophosphates being irreversible inhibitors

The toxicity of a pesticide is proportional to the rate at which a pesticide molecule leaves the active enzyme site. Based on this criterion, organophosphates are about 30-40 times more toxic than carbamates. In addition, the enzyme/pesticide complex can result in the formation of a strong covalent bond. When this happens the inhibition of the enzyme activity is essentially permanent, as discussed in the article.

Some references to both sides of the environmental debate surrounding the use of pesticides

The *Demonstrations and Lessons* section suggests possibly holding a debate centering around the use, abuse, benefits, and dangers associated with pesticides. It is not at all difficult to find a large number of websites on both sides of the issue, and they often offer widely differing versions of the "truth." For example, the website of the EPA states the following about DDT:

Although banned since 1972, it can take more than fifteen years to break down in our environment.

Its breakdown products, DDE, and DDD, are persistent, bioaccumulative and toxic.

It is a probable human carcinogen.

It damages the liver.

It temporarily damages the nervous system.

It reduces reproductive success.

It can cause liver cancer.

Infants may be exposed through breast milk.

Other websites contain statements such as:

At least one out of seven people are significantly harmed by pesticides each year.

Children are at increased risk.

Pesticides are thought to be responsible for increased risk of a wide range of illnesses and diseases, including breast cancer, leukemia and brain cancer in children, birth defects, miscarriages, blindness, liver and kidney dysfunction, stroke, and immune system disorders.

95% of the pesticides used on residential lawns are possible or probable carcinogens.

Golf course superintendents have abnormally high rates of death attributed to cancers of the brain, large intestine, and prostate.

The EPA continues to allow more than 2000 secret "inert" ingredients in pesticides.

No one registers the safety of pesticides. Just because a product is registered with the EPA doesn't mean its safe.

Most pesticides in use today have not been tested for their health effects on children.

And the list could go on and on.

Then you have the other side. The website <http://junkscience.com/ddtfaq.htm> counters with statements such as the following:

"To only a few chemicals does man owe as great a debt as to DDT...In little more than two decades, DDT has prevented 500 million human deaths, due to malaria, that otherwise would have been inevitable."—quoting the National Academy of Sciences, Committee on Research in Life Sciences of the Committee on Science and Public Policy, 1970.

Rachael Carson ...represented the science of DDT erroneously in her 1962 book Silent Spring.

The environmental movement used DDT as a means to increase its power.

Science journals were biased against DDT.

DDT was banned by an EPA administrator who ignored the decision of his own administrative law judge.

Feeding primates more than 33,000 times the average daily human exposure to DDT was inconclusive with respect to a carcinogenic effect of DDT in nonhuman primates.

Actual human exposures have always been far lower than “acceptable” levels.

DDT was found to reduce tumors in animals.

DDT was alleged to have thinned bird egg shells, but many experiments on caged-birds demonstrate that DDT and its metabolites do not cause serious egg shell thinning, even at levels many hundreds of times greater than wild birds would ever accumulate.

To the extent egg shell thinning occurred, many other substances and conditions could have been responsible.

The point, of course, is that it is very difficult, for students, teachers, and the general public, to sort out the conflicting statements made by opposing sides. So how does one go about formulating a reasonable and reasonably informed opinion on this and other issues? That's an extremely difficult question to answer and is the motivation behind the suggested Demonstrations and Activities.

Connections to Chemistry Concepts

This article calls upon a knowledge of both organic structures and nomenclature. There is no way to “cover” organic nomenclature here, but if you would like to visit a couple of excellent websites that cover organic nomenclature in detail, you can go to:

<http://people.ouc.bc.ca/woodcock/nomenclature/index-2.htm>

<http://www.chem.ucalgary.ca/courses/351/Carey5th/nomenclature/>

Possible Student Misconceptions

The article discusses three general categories of pesticides, organochlorines, carbamates, and organophosphates, and from there discusses acetylcholine and how acetylcholinesterase inhibitors work. Although it specifically states that it is carbamates and organophosphates that function as acetylcholinesterase inhibitors, some students may incorrectly lump the organochlorines in with these other two groups. Organochlorines do not function as acetylcholinesterase inhibitors. They operate via different mechanisms by keeping sodium channels in nerve cells open longer than usual.

Demonstrations and Lessons

This article provides an opportunity to pursue what might turn out to be one of the most significant and far-reaching lessons in a student's high school career, if time permits.

Most of us would probably like to think that what we teach will in some way be of value to our students long after they have left the confines of our classroom. One argument often made in support of high school science classes is that many modern issues, both personal and political, have a strong underlying science component. Is global warming both a real phenomenon and caused by human activities? If so, what, if anything, should be done about it? What about acid rain and air pollution? Should we allow drilling for oil in formerly prohibited areas? Should we increase our reliance on nuclear power or move away from it? What about alternative sources of

energy, or stem cell research, or genetic engineering? Should we irradiate food? Is “organic” food really better and worth the extra cost?

The list goes on and on.

Of course there continues to be an ongoing debate about the use of pesticides. Should they be used? Should any restrictions be placed on their use, and if so, what kinds of restrictions? What benefits are derived from their use? What costs in human health are attached to their use? Do the benefits outweigh the costs, and how does one evaluate and compare them? What role should government play in this issue?

The use of pesticides in the agricultural industry certainly touches everyone in very direct ways. On one side there are those who argue that the development and use of pesticides has contributed more to human welfare than possibly any other single scientific achievement. On the other side are those who argue that the use of pesticides has not resulted in any significant improvement at all, and in fact is responsible for many human deaths and illnesses.

It is easy to quickly align oneself with one side or the other and find support for whatever position one wishes to take. But what are the facts, and how does one weigh the value of one thing vs. another? This is not easy to do.

Done properly, with the emphasis on the presentation of factual information and the formulation of properly laid out arguments (as opposed to an “opinion before knowledge” debate), students can effectively debate questions like:

Should restrictions be placed on the agricultural use of pesticides? If so, what kinds of restrictions, and for what pesticides? What about the use of pesticides by homeowners?

Does the presence of pesticides in food constitute a significant or minuscule health hazard? Do the benefits connected with pesticide use outweigh the costs, or are the costs too great for the perceived benefits?

For some information and views from both sides of these kinds of issues see *Background Information*.

Connections to the Chemistry Curriculum

This article has strong ties to two possible curricular goals. If your course includes an organic component, there is a very strong tie-in to organic structures, nomenclature, and functional groups. If your course has a significant societal component, such as is found in *ChemCom*, then the issue of pesticide use, abuse, benefits, and possible environmental and health concerns can provide an outstanding opportunity to pursue the kinds of goals that are often connected to a discussion of these kinds of issues. See *Background Information* and *Demonstrations and Lessons*.

Suggestions for Student Projects

1. *Demonstrations and Lessons* contains a suggestion for a possible debate centered around the use of pesticides. While holding such a debate might be of great educational value, the realities of time pressures may preclude holding such a debate on a classroom-wide basis. An alternate approach would be to have students tackle this kind of project on an out-of-class basis. They might even hold their debate after school hours (after all, students do stay after school for any number of activities) and videotape the activity.
2. In 1962, the publication of Rachael Carson’s book, *Silent Spring*, alerted the world to potential dangers that might be connected with the use, both controlled and indiscriminate, of pesticides such as DDT. As might be expected, the book has been both revered and

attacked by individuals and groups on both sides of the ongoing debate over the “risks vs. benefits” connected to the use of pesticides. The book is now over forty years old, but is still in print, and in addition, a number of books have been published since that time that relate to both the book itself and the environmental view that it takes. A good student project might be to read this book along with at least one additional related book that has been published much more recently and then prepare a report on the two. Any search on a website such as amazon.com will quickly produce several suitable titles.

3. As mentioned in *Anticipating Student Questions*, organochlorines do not function as acetylcholinesterase inhibitors. Students with a strong interest and background in biology might want to prepare a report discussing the mechanism by which these kinds of pesticides kill.
4. The discovery of DDT (dichlorodiphenyltrichloroethane), its subsequent widespread use and eventual banning, represent an outstanding opportunity for students to investigate the evolution of a chemical's perception from being considered one of the most valuable chemicals ever discovered—see *Background Information*, to eventually being banned in the United States and several other countries. It is often said that the entire environmental movement owes its origin to DDT and the book *Silent Spring*. It is an outstanding example of the maxim that “The solution to one problem can often lead to another problem.”
5. If you are teaching an advanced course with a strong organic component, it would be a challenge for students to find the structures of many of the common pesticides mentioned in the article and the accompanying figures, present these structures along with the systematic names for these compounds, and possibly even explain how and why the systematic name fits the drawn structure.

Anticipating Student Questions

1. How can a person insure that the food he/she consumes is entirely free of harmful chemicals?

While one can take measures to reduce the amount and variety of undesirable or toxic chemicals that one ingests from food, it is impossible to eliminate them completely. According to the American Council on Science and Health, “No human diet can be free from all carcinogens or toxic substances. It is hard to find *any* food that does not contain *some* harmful chemical that occurs in it naturally or that is produced by cooking or microbial decomposition.”

2. Are organochlorine pesticides still being used?

They have been banned in North America and Europe, but are still being used in some developing countries.

3. Why would any country use a pesticide that has been banned in North America and Europe?

It's basically a risk/benefit decision. Organochlorine pesticides are inexpensive to manufacture. They are effective, and despite being banned are considered by many to be relatively safe to humans. In some developing countries it is thought that the benefits of better food production and disease control outweigh any potential or actual effect on the environment or human health that might be connected to their use.

4. Have the carbamates and organophosphates replaced the organochlorines because they are less toxic to humans?

No. Their human toxicity is actually higher, but their ecological toxicity is less. They degrade relatively rapidly in the environment.

5. How can a person find out how toxic a certain pesticide is?

The EPA rates pesticide toxicity to humans on a scale of 1 to 4. Pesticides in category 1 are considered to be highly toxic, and their labels must bear the word "DANGER." Pesticides displaying the word "DANGER" should be applied by certified applicators only. Pesticides in category 2 are less toxic, and will bear the key word "WARNING." Pesticides in categories 3 and 4 are the least hazardous, and bear the key word "CAUTION." Other hazards may also be listed on the label, such as toxicity to aquatic life and birds. To protect yourself and the environment, use any pesticide strictly according to its label instructions.

Websites for Additional Information and Ideas

If you would like to see the structural formulas of various pesticides and other relevant chemicals, several can be found on the following websites:

<http://aquaticpath.umd.edu/toxnurse/pesticides.pdf>

<http://www.chem.ox.ac.uk/mom/ddt/ddt.html>

<http://www.sciencedaily.com/encyclopedia/Acetylcholine>

Some good websites for additional information on pesticides in general include:

<http://aquaticpath.umd.edu/toxnurse/pesticides.pdf>

<http://www.epa.gov> and then search under "pesticides"—or, one good page to go to is:

<http://www.epa.gov/ebtpages/pesticides.html>

The EPA offers a 54 page document entitled *Citizen's Guide to Pest Control and Pesticide Safety*. It covers topics such as:

What steps to take to control pests in and around your home.

What alternatives to chemical pesticides are available, including pest prevention and non-chemical pest controls.

How to choose pesticides and how to use, store, and dispose of them safely.

How to reduce your exposure when others use pesticides.

How to choose a pest control company.

What to do if someone is poisoned by a pesticide.

It can be accessed directly by going to:

http://www.epa.gov/oppfead1/Publications/Cit_Guide/citguide.pdf

Bacteria Power

Background Information

More about Derek R. Lovley and his work

Although he is one of the most outstanding microbiologists in the country, Lovley never set out on that career path. When he was an undergraduate at the University of Connecticut in the 1970s, he was not a microbiology major. "I was mainly interested just in environmental science. I basically wanted to get a job working outdoors. That was the level of my sophistication at that age."

He tended to equate microbes with disease and microbiology with medical research.

"Most people think of microorganisms as pathogens, germs. Even a lot of microbiologists. I remember being in graduate school; there were still some professors who seemed to be amazed that microorganisms were important in the environment. But that's where 99.99 whatever percent of bacteria live, in natural environments. It's now being recognized that they live not only on the surface but also very deep in the earth."

Lovley points out that the weight of the planet's microorganisms far exceeds the total weight of all the plant life on earth!

Although the specific focus of the article centers around Lovley's work with *Geobacter sulfurreducens* bacteria and their ability to generate electricity, Lovley's research extends to several additional very significant areas. His general focus is on the physiology and ecology of novel anaerobic microorganisms. He approaches these at three levels--genetic, biochemical, and ecological. The range of his research projects is extremely impressive and includes:

- microbial metabolism and community structure in the deep subsurface and hydrothermal zones
- evolution of anaerobic respiration
- mechanisms of electron transport to Fe(III) and humic acids
- anaerobic bioremediation of petroleum-contaminated subsurface and aquatic habitats
- bioremediation of metal contamination

The Dec. 2003 issue of *ChemMatters* contained an article on hydrothermal vents and giant tubeworms. Lovley and a co-researcher, Kazem Kashefi, discovered an extremophile (see *ChemMatters*, Dec. 1999) captured from a vent at the bottom of the Pacific Ocean that can survive a temperature of 130 °C (266 °F) and that can actually grow and reproduce at a temperature of 121 °C (250 °F). This is well above the normal boiling point of water and represents a temperature at which it was previously thought that no organism could possibly survive, let alone thrive. But when this organism (as of yet unnamed but for obvious reasons dubbed "Strain 121") was placed in an autoclave at 121 °C for 24 hours, it not only survived, but had doubled in number.

The previous extremophile record holder had been *Pyrolobus fumarii*, which stops growing at 113 °C and is killed in a 121 °C autoclave after about an hour.

The discovery of Strain 121 represents more than just an interesting example of an unusual organism. The vent where Strain 121 was discovered sits about two miles under the ocean's surface. Since no oxygen is available at that depth, Strain 121 uses iron for its metabolism. The early Earth was iron-rich and oxygen poor, and it is speculated that perhaps early forms of life might have utilized metabolic mechanisms similar to that used by Strain 121. The fact that there is at least one organism capable of surviving such high temperatures in the absence of oxygen also increases the possibility that life might exist on other planets, either in our own solar system or elsewhere in the universe. As Lovley says, "No one had ever seen a bug like this before."

Strain 121 was obtained from a "black smoker" like the kind described in the *ChemMatters* article. John A. Baross of the University of Washington in Seattle and his crew sent an unmanned

submarine to the ocean floor and removed part of the chimney with a remotely controlled chainsaw. It was quickly transferred to an oxygen-free container. Lovley was able to culture Strain 121 from part of this chimney.

Some general information about the metabolism of *Geobacter sulfurreducens*

The *geobacter sulfurreducens* discussed in the article represent only one of an entire family of *geobacteraceae* (Latin for “earth” and “rod,” which relates to where they live and their shape) bacteria. At least fifty species have been isolated and it is thought that many more may exist. The family was discovered by Dr. Lovley.

We are so accustomed to biological systems that utilize oxygen gas for their metabolic activities that it may be somewhat difficult to “understand” biological systems that use other reducible substances. But the principle is relatively straightforward.

There is nothing “magical” about oxygen, but it is a very suitable substance upon which to base metabolic activities. First, it is plentiful. Second, it is a good oxidizing agent, meaning that it is readily reduced. Third, the products of reduction are typically carbon dioxide and water, easily released after metabolism.

What is important is that the metabolic oxidation process and the accompanying reduction release energy the organism needs in order to survive. In principle, any material that is capable of undergoing reduction might conceivably be used.

Geobacter sulfurreducens can use iron(III). Substances taken from their surroundings, such as decaying plant material, are oxidized. The electrons removed, instead of being picked up by oxygen, are picked up by Fe(III) that is contained in materials like Fe(III) oxide. The process releases the energy which the organism needs to survive. *Geobacter* can actually sense the presence of iron in their environment and will move towards it. Genetic and biochemical studies have shown that *Geobacter* specifically produce flagella and/or pili (relatively short, hollow protein rods that are important in binding the cell to solid surfaces) in response to growth on insoluble electron acceptors such as Fe(III) and Mn(III). *Geobacter* are naturally present in soil and mud, and their growth can be easily stimulated by simply adding an acetate-containing material such as vinegar.

In one experiment, Dr. Susan Childers set up a series of microscope slides. In order to survive, the *Geobacter* would have to move across the slide to reach the metal required for their survival, and that’s exactly what they did. They grew the required flagella and swam towards the metal source. Once they got there, they grew pili which allowed them to anchor themselves to the metal. To quote Dr. Childers, “The *Geobacter* doesn’t waste energy growing flagella or pili unless it genuinely needs them. But if it’s not located near metal, it somehow senses that it better get up and start moving, and the gene that governs the growth of flagella comes into play.”

The process described in the article is slightly different. Instead of iron(III) accepting the electrons, the electrons are picked up by the graphite electrode and then sent through wires to the water’s surface, where they are picked up by oxygen in the presence of hydrogen ions.

It turns out that hyperthermophiles can anaerobically oxidize not only acetate, but aromatic compounds and long-chain fatty acids as well. They can also reduce not only Fe(III) and U(VI), as described in the article, but also Mn(IV), Tc(VII), Au(III) and some other metals.

The potential uses to which microorganisms might be put is extremely broad. To help direct research efforts to areas with a higher probability of success, computer models of genomes have been created in order to see how an organism might function in a given environment. According to Lovley, this represents the strategy of the future. We can “tweak” the genome by moving genes around. There is the potential to design organisms to accomplish a certain task.

Other studied Fe(III)-reducing microorganisms exist, such as *Shewanella* and *Geothrix*, but microorganisms in the *Geobacteraceae* family represent the predominant metal-reducing

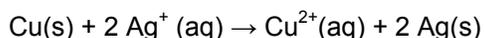
microorganisms in a wide diversity of subsurface sediments. The mechanism by which they access Fe(III) oxides and transfer electrons onto Fe(III) surfaces differs significantly from that of these other microorganisms. Furthermore, *Geobacteraceae* contains a high percentage of genes that are devoted to sensing its environment and then allowing it to regulate its metabolism in response to the environmental conditions.

Connections to Chemistry Concepts

No matter how technologically or chemically complex it might be, the basic concept behind the operation of any electrochemical cell, or battery, is quite simple. Oxidation-reduction reactions involve the transfer of electrons from one substance to another. When a redox reaction occurs in a beaker, for example, the reactants make contact with each other, and the electrons are transferred directly. Slightly oversimplified, the reason the transfer occurs is basically because the electrons are in a lower energy state when they are on one substance vs. being on the other substance. The substance that loses electrons is said to be oxidized while the substance gaining the electrons is said to be reduced. Oxidation and reduction always occur together.

An electrochemical cell is simply a technological “trick” that forces the electrons to travel through a wire (or other conductor) in order to get from the substance oxidized to the substance that is going to be reduced. As the electrons travel through the wire we can use some of their energy to light a light bulb, power a laptop computer, start a car, or whatever.

For example, let’s consider a very simple electrochemical cell, one that utilizes the reaction between copper metal and silver ions to produce copper ions and metallic silver:

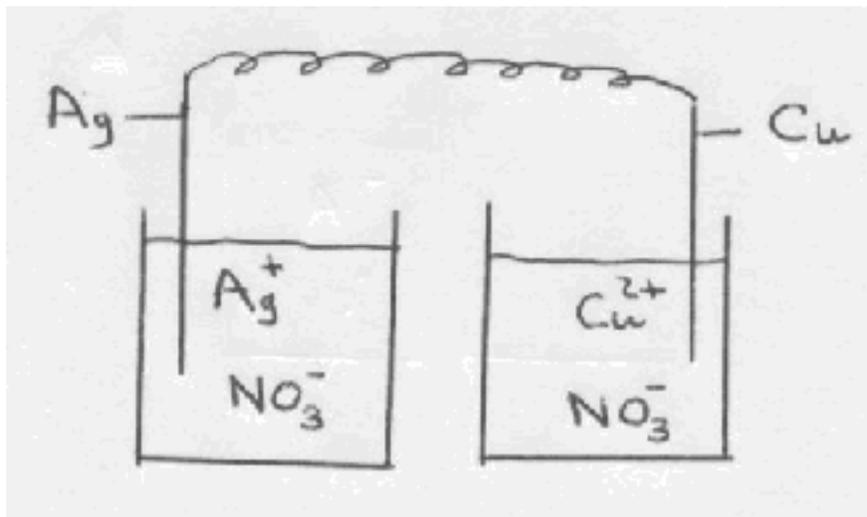


The copper metal is being oxidized and the silver ions are being reduced.

If we simply dip a piece of copper metal into a solution containing silver ion, the electron transfer will occur directly and we won’t be able to make much use of the energy of the electrons that are being transferred.

But suppose we place a copper electrode into a solution that contains some $\text{Cu}(\text{NO}_3)_2$, which in solution will exist as Cu^{2+} and NO_3^- . We actually don’t need the Cu^{2+} , since it isn’t one of the reactants, but we do need some ions that won’t react directly with the Cu electrode, so $\text{Cu}(\text{NO}_3)_2$ will do fine (we could have used NaNO_3 or any other salt that wouldn’t react with the Cu electrode). In another beaker we place a silver electrode in a solution of AgNO_3 , which will contain Ag^+ and NO_3^- ions. Here we actually don’t need an electrode made of Ag, since Ag isn’t a reactant. We could have used any nonreactive electrode, like graphite or platinum.

Now let’s place the two beakers next to each other and connect the two electrodes with a conducting wire:

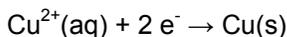


Since the two electrodes are now connected, one might assume that the electrons could travel from the Ag electrode to the Cu electrode. If this were to occur, then oxidation would be occurring at the Ag electrode, and reduction would be occurring at the Cu electrode. We have basically broken the entire reaction into what are called two “half-reactions.” If these two half-reactions were to occur we would have:

At the Ag electrode:



At the Cu electrode:



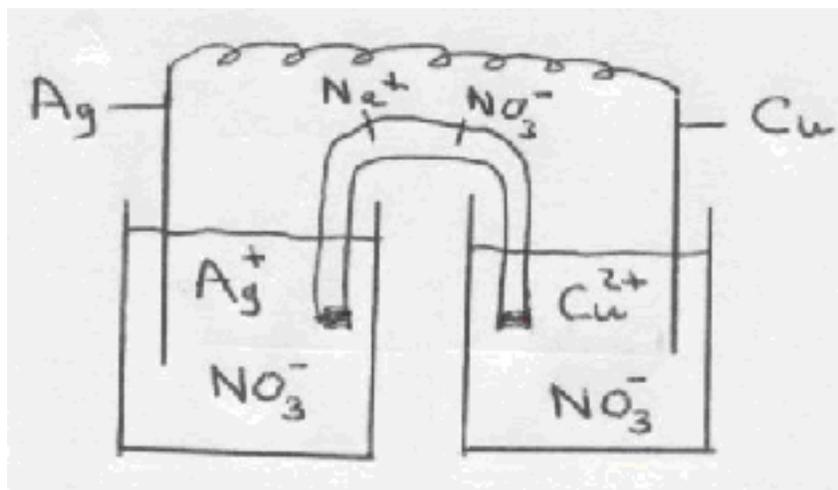
But there is one major problem. If these two half-reactions were to occur, the two solutions would no longer be electrically neutral. Positive ions (Ag^+) would be produced in the AgNO_3 solution while positive ions (Cu^{2+}) would be removed from the $\text{Cu}(\text{NO}_3)_2$ solution. This would leave the AgNO_3 solution with a net positive charge and the $\text{Cu}(\text{NO}_3)_2$ solution with a net negative charge.

This is not allowed. Solutions must be electrically neutral at all times.

To solve this problem we can use something called a *salt bridge*. There are other ways to solve this problem as well, but this is one good way.

A salt bridge is nothing more than a U-tube filled with a solution that contains unreactive ions. A solution of something like NaNO_3 will work well. The ends of the U-tube are plugged with cotton. This keeps the solution from falling out or mixing with the solutions in the beakers, but still allows ions to move in and out of the U-tube.

Once the salt bridge is in place the cell looks like this:



Now the cell will work. As Ag^+ ions are produced in the left-hand beaker they can migrate into the salt bridge, keeping the AgNO_3 solution electrically neutral. As Cu^{2+} ions are removed from the right-hand beaker, Na^+ ions can migrate into the solution to replace them and keep that solution electrically neutral also.

And most importantly, as the electrons flow from the Ag electrode to the Cu electrode, we can use some of their energy. That was the whole idea behind building this electrochemical cell in the first place.

And that's what the Geobacter are basically doing. They are oxidizing acetate from organic matter in the mud. The electrons released in the oxidation process travel from one graphite electrode at the bottom of the pond to another electrode placed in the clear water above, where they are picked up by oxygen molecules and hydrogen ions. As the electrons travel, we can use some of their energy.

Possible Student Misconceptions

The article briefly mentions that Geobacter can reduce U(VI), a "soluble form" to U(IV), an "insoluble" form. It is conceivable that some students may draw a couple of invalid conclusions from these statements. First, it isn't "uranium" that is soluble or insoluble. It is compounds of uranium. What the 'soluble form' and 'insoluble form' refer to in this instance is that the compounds typically formed by U(VI) in the environment are salts of the UO_2^{2+} ion, which are generally soluble, while U(IV) forms insoluble UO_2 . Some students may even incorrectly think that in some way this is eliminating or reducing the radioactivity. This, of course, is not the case at all. Radioactivity is a nuclear phenomenon, and no chemical process can remove or reduce it. But by changing the oxidation state of uranium from VI to IV, it transforms it into insoluble compounds that precipitate out rather than remain in solution. These compounds can then be collected and taken to a proper storage site instead of remaining in solution where they have the potential of migrating to other areas.

Because the article discusses the use of *Geobacter sulfurreducens* to produce electricity, students may assume that this is the only bacterium that is capable of engaging in this kind of activity. This is hardly the case. See *Background Information*.

Demonstrations and Lessons

National Public Radio conducted an interesting interview with Dr. Lovley and Barbara Methe, a coresearcher. It runs to just over 30 minutes and provides a nice "science for the general public" discussion of Dr. Lovley's work and its potential. Audience members call in with questions, which range from fairly knowledgeable and thoughtful to some that may be a bit off-base. It might be interesting to have students listen to this broadcast and then react to both its content and the

posed questions. Dr. Lovley and Dr. Methe handle all the questions nicely and never insult or talk down to the audience. The program can be accessed at:

<http://www.npr.org/rundowns/rundown.php?prgId=5&prgDate=12-Dec-2003>

Connections to the Chemistry Curriculum

This article connects particularly strongly with the topic of oxidation-reduction and electrochemical cells (see *Connections to Chemistry Concepts*). There are additional connections to the concept of oxidation states and how they affect the solubility of metallic compounds. The biological connections are obvious.

Suggestions for Student Projects

1. Although most organisms utilize oxygen for their metabolic processes, in principle any substance that readily undergoes reduction could conceivably be the basis for an organism's metabolic requirements. It might be both challenging and fun to have knowledgeable and creative students consider different possible reduction reactions (from a table of reduction potentials, for example) and then try and create a theoretically viable metabolic system that might be used by an organism. Some considerations would include the availability of the requisite materials, the energy release that might be anticipated, and the properties of the metabolic products.
2. Dr. Lovley's research includes studies of what are called extremophiles (see *Background Information*). *ChemMatters* published two articles that connect to Dr. Lovley's work. The Dec. 2003 issue contained an article on hydrothermal vents, and the Dec. 1999 issue contained an article on extremophiles. Students could learn more about Dr. Lovley's research in these areas, read both of the *ChemMatters* articles and the accompanying Teacher's Guide materials and then prepare a report that connects all of the information.
3. The use of microbes for bioremediation extends to many more areas than are mentioned in the article. For example, microbes can be used to clean up gasoline spills. Every day enormous quantities of gasoline are pumped into American motor vehicles. Inevitably some of this ends up in the environment. It has been demonstrated that microbes can be used to clean up much of this mess, and reporting on how this is done and the progress which has been made to date might provide a good topic for a student report.

Anticipating Student Questions

1. Since *Geobacter* react with iron and uranium in the soil could they also react with an undesirable metal like mercury, Hg, to remove it from the soil?

It hasn't been done yet, but it might be possible. *Geobacter* contain genes similar to other organisms that can remove mercury.

2. Could the kind of process described in the article be patented?

It already has been patented.

3. Is there a danger that by feeding these bacteria so they become prevalent enough to accomplish some useful activity we run the danger that they may grow out-of-control?

Not really. When you remove the acetate upon which they feed, their growth drops off.

4. Since these bacteria can feed on iron, is there a danger that they might feed off the iron in the hemoglobin in our blood and kill us?

No. *Geobacter* have no genes for pathogenicity. They cannot attack the blood.

5. Could *Geobacter* be used to clean toxic substances from humans?

No. They cannot grow in the human body. If we wanted to try and get them to accomplish something like this we'd have to alter their genome.

6. Is there a "microorganism for everything?"

No, but the potential that exists is awesome. For example, we have added chemicals to the environment, such as PCBs, that do not naturally exist. Nevertheless, organisms have emerged that are capable of biodegrading these kinds of materials.

Websites for Additional Information and Ideas

National Public Radio contains an interview with Derek Lovley and Barbara Methe from the Institute for Genomic Research. The interview and the accompanying call-in questions from listeners runs a bit over 30 minutes. It can be accessed at:

<http://www.npr.org/rundowns/rundown.php?prgId=5&prgDate=12-Dec-2003>

A much more thorough scientific paper published by Dr. Lovley and Daniel R. Bond on electricity production by *Geobacter sulfurreducens* can be found at:

<http://www.geobacter.org/publications/12620842.pdf>

Check out an article on "Plugging into the power of sewage" from The New Scientist magazine.

<http://www.newscientist.com/news/news.jsp?id=ns99994761>

Lightning: Nature's Deadly Fireworks

Background Information

More about how a cloud-to-ground lightning strike occurs

As stated in the article, a typical cloud-to-ground lightning strike begins with the faint discharge called a stepped leader. It's called a stepped leader for the simple reason that it progresses in discrete steps. There is considerable variation, but a typical stepped leader may consist of perhaps 100 segments, each perhaps 30-50 meters or so in length. Each step lasts for about 1 millionth of a second, or one microsecond, with a pause between steps of perhaps 20-50 microseconds. The approximately 100 segments have a length of perhaps 3000-5000m, or 3-5 km. Stepped leaders move towards the earth with a velocity that varies considerably, but is within a range of between 100-2600 km/s, with 200 km/s being perhaps a typical value.

The amount of charge carried by a stepped leader also varies, perhaps from 3-20 Coulombs, with 5 Coulombs often given as a representative value. The potential difference (voltage) with respect to the ground averages around several hundred million volts. As the leader approaches the earth, it induces a stream of positive charges to move upwards.

As stated in the article, once this leader reaches a point perhaps 50-100 meters above some point on the earth (a tall object like a tree is nice) the leader is connected to the stream of positive charges and the return stroke takes place, which is what we think of as being the bolt of lightning.

The return stroke is the nasty part. The first return stroke produces currents of perhaps 30,000 Amperes or so, with a range of perhaps 10-110 kA. It moves with a velocity of perhaps 80,000 km/s.

Occasionally, that's it, and we have what is called a single-stroke flash. But usually there is additional cloud charge available, and since the stroke channel has already been created, another leader can propagate down this channel. Since the channel is established and does not need to be recreated, the new leader is continuous, and is called a dart leader. Dart leaders can move faster than stepped leaders (after all, they don't have to create a path), perhaps at about 2000 km/s or so, but they carry less charge, perhaps around 1 Coulomb, with a range from 0.2-6C.

A single lightning bolt can consist of anywhere from just one to more than ten strokes.

Some lightning data and how it is reported

NOAA, the National Oceanic and Atmospheric Administration, is the governmental agency responsible for collecting and assembling reports of damaging weather phenomena. Reports are collected monthly by local NOAA-National Weather Service offices. These individual station reports are then sent to NOAA's National Climatic Data Center (NCDC) in Asheville, N.C. A publication called *Storm Data* is assembled for the entire country, as it has been for the past forty-five years.

You can access an extensive database of storm-related statistics at:

<http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms>

This Storm Events database contains data from the following sources:

All Weather Events from 1993-1995, as entered into *Storm Data*. (except 6/93-7/93, which is missing)

All Weather Events from 1996-Current, as entered into *Storm Data*.

Plus additional data from the Storm Prediction Center; Including
Tornadoes 1950-1992
Thunderstorm Winds 1955-1992
Hail 1955-1992

Searching along various parameters for different areas of the country can be fun. For example, there were three F5 tornadoes reported in Illinois from Jan. 1, 1950 through Sep. 30, 2003, resulting in a total of 30 deaths and 356 injuries. All but one death and six injuries were connected to a storm that occurred on Aug. 28, 1990.

For the same time period 122 lightning events were reported in Illinois, causing 15 deaths and 44 injuries.

In October, 1997, NOAA published a compendium of lightning statistics from 1959-1994. There were 3,239 nationwide deaths caused by lightning strikes, an average of between 92-93 per year.

There is a suspicion that these figures are probably underreported and do not represent the full extent of damage, injuries, and deaths due to lightning strikes. Possible reasons for this include:

Lightning casualties are often reported by the medical system as having lightning as the secondary rather than the primary cause of injury.

There has been a significant reliance on newspaper clipping services to obtain data on lightning events, and these probably do not capture all events.

The typical lightning casualty usually affects only one individual.

Florida leads the nation in deaths and injuries caused by lightning, while Pennsylvania has the largest number of damage reports. But if you weigh the data according to population, then New Mexico leads the nation in deaths and injuries over the past several decades.

The top ten states, along with Puerto Rico and the District of Columbia, and their number of casualties (deaths and injuries) from lightning strikes are:

| | |
|----------------|------|
| Florida | 1523 |
| Michigan | 732 |
| Pennsylvania | 644 |
| North Carolina | 629 |
| New York | 577 |
| Ohio | 545 |
| Texas | 498 |
| Tennessee | 473 |
| Georgia | 410 |
| Colorado | 394 |

The bottom ten were:

| | |
|-------------------|----|
| Delaware | 42 |
| Washington | 40 |
| Puerto Rico | 36 |
| North Dakota | 35 |
| Vermont | 30 |
| Oregon | 26 |
| Dist. Of Columbia | 23 |
| Nevada | 18 |
| Hawaii | 4 |
| Alaska | 0 |

There were 13,057 *Storm Data* casualties from 1959-1994, for an average of 363 per year. The National Lightning Detection Network reported an average of 21,746,000 cloud-to-ground flashes

per year in the United States from 1992-1995. This would indicate that on average, there is one casualty for every 60,000 flashes. The actual rate is probably closer to about one casualty for every 86,000 flashes, since it is estimated that perhaps only about 70% of flashes are actually detected.

July is the month where lightning reports reach their maximum, with 30% being reported in that month. This is followed by August, at 22% and June at 21%.

About two-thirds of all casualties occur between noon and 6 p.m.

Casualty reports were most common on Sunday, followed by Saturday.

So if you have a strong desire to be struck by lightning, go golfing in Florida in July, sometime in the mid-to-late afternoon.

Most incidents of lightning strike casualties involve only one person. For deaths, 91% involve only one person and 8% involve two, while 68% of injuries involve only one person.

Males are about 5.6 times more likely to be killed and 4.9 times more likely to be injured by lightning than females. One might conclude that lightning is attracted to testosterone, but current thinking is that this is due to the fact that men probably spend more time working and playing outdoors than women. It will be interesting to see if this statistic undergoes change in the future, as the trend toward women's increased participation in sports continues.

The most likely area in which lightning strike casualties occur are recreational areas. The next is people standing under trees and then people who are close to a body of water. Smaller numbers of casualties were reported by golfers, people engaged in agricultural activities, telephone users, and people in proximity to radios and antennas.

A very complete report of these kinds of statistics can be obtained at:

<http://www.nssl.noaa.gov/papers/techmemos/NWS-SR-193/techmemo-sr193-3.html#section3>

Common types of injuries caused by lightning strikes

Most people who are killed by a lightning strike die from cardiac and/or respiratory arrest. Many could be saved with the proper and quick administration of C.P.R. (Cardio-Pulmonary Resuscitation).

Other types of injury include:

Central nervous system damage

Burns

Deafness or hearing loss

Loss of eyesight

Muscle and/or ligament tearing

Bone Fractures—these are caused by violent muscle contractions due to the electric current from the lightning strike.

It is not unusual for lightning-strike victims to experience mysterious symptoms for which doctors have difficulty finding a specific physical cause. These may not be life-threatening, but they can be persistent and debilitating to various degrees. They include:

Muscle pains and cramping, often quite intense

Tingling sensations

Loss or alteration of senses

Dizziness

Disorientation

Nausea and/or vomiting

Headaches

Seizures

Mental depression

How the effects of being struck by lightning compare to suffering a normal serious electrical shock at work or at home

Most electrical shocks at work or at home rarely last longer than about a half-second. Either a circuit breaker shuts off the current or the person is thrown away from the conductor. Lightning strikes are even quicker—perhaps only a few milliseconds. In addition, most of the current from a lightning strike typically passes over the surface of the person's body, a process that is called "external flashover."

But the actual contact voltage of a lightning strike is much greater than that of even severe industrial shocks. A typical industrial shock may be 20-63 kV, while the contact voltage of a typical lightning strike may be more on the order of 300 kV.

Both kinds of shocks can result in burns at the point of contact. Contact points for industrial shocks tend to be centered on the hands, upper limbs and arms, while lightning strikes tend to occur more on the head, neck and shoulders.

Industrial shock victims often suffer deep tissue destruction along the entire electrical path that moved through the body. Lightning strike victims tend to experience burns more at the point of entry and exit. The main cause of death for both types of shock victims is cardiac or cardiopulmonary arrest.

Connections to Chemistry Concepts

Some "chemistry connected" mathematics surrounding lightning strikes

Any course that includes a unit on electrochemistry and electrolysis reactions probably includes problems relating to the mathematical relationships that exist between electric current, measured in amperes, the amount of electricity passed through a solution, measured in Coulombs and/or Faradays, and the amount of chemical change that occurs in terms of the number of moles of reactants consumed or products produced.

Some common mathematical relationships that relate to these kinds of problems include:

$$1 \text{ Ampere} = 1 \text{ Coulomb/s}$$

$$1 \text{ Faraday} = 1 \text{ mole of electrons} = 6.02 \times 10^{23} \text{ electrons} = 96,500 \text{ Coulombs}$$

$$1 \text{ Coulomb} = 6.24 \times 10^{18} \text{ electrons}$$

The article states that depending on the specific nature of the strike, something on the order of 10^{18} to 10^{19} electrons will strike the ground in about one-thousandth of a second.

Different lightning strikes can vary widely in both the amount of current they carry and the duration of the strike. The National Lightning Safety Institute mentions a range of 8 kA for 20 μ s and 200 kA for 300 μ s (see *Anticipating Student Questions*).

The figures cited in the above two paragraphs are consistent, as can be shown by the following calculations.

For an 8kA strike lasting for 20 μ s, the total number of electrons transferred to the ground would be:

$$(8,000 \text{ C/s}) (6.24 \times 10^{18} \text{ electrons/C}) (20 \times 10^{-6} \text{ s}) = 10^{18} \text{ electrons}$$

For a 200 kA strike lasting for 300 μs , the total number of electrons would be about 3.7×10^{20} electrons, which is not a contradiction, since this represents an “extreme” lightning strike.

Calculating how far away you were from a lightning strike

There is a rough “rule of thumb” that says you can estimate how far away from you a lightning strike occurred by simply noting the amount of time difference between when you observe the strike and first hear the thunder. The rule says that every five second delay represents about one mile in distance, so if you hear the thunder 1.5 seconds after you observed the flash, the strike occurred about 7-8 (7.5 calculated) miles from where you are. This is called the “Flash-to-Bang,” (F-B) calculation.

Of course, this is just an estimate. The speed of sound in dry air is 331.3 m/s at 0 °C, but will vary from this value depending on the temperature and humidity. At 28 °C, a warm day, it is more like 346 m/s, but this variation is not too significant if you just want to estimate how far away from you a lightning strike occurred.

A simple calculation will allow us to see how accurate the “5 seconds = 1 mile” rule of thumb is.

$$(331 \text{ m/s}) (5 \text{ s}) = 1655 \text{ m}$$

$$(1655 \text{ m}) (100 \text{ cm/m}) (1 \text{ in}/2.54 \text{ cm}) (1 \text{ ft}/12 \text{ in}) (1 \text{ mile}/5280 \text{ ft}) = 1.03 \text{ miles}$$

It's a pretty accurate “rule of thumb.”

A word about “voltage” and “amperage”

Students often and understandably confuse the terms *voltage* and *amperage*.

Amperage refers to the amount of electrical current that is flowing. One ampere is defined as a flow of 1 Coulomb of electrical charge per second, which amounts to 6.24×10^{18} electrons/sec.

Voltage refers to the difference in energy that an electrical charge has when it is located in one place compared to some other place. If 1 Coulomb of charge will have its potential energy change by 1 Joule as it moves from Point A to Point B, then the potential difference (voltage) between points A and B is defined as being 1 volt.

One analogy that is often used is water flowing over a waterfall. In this analogy, amperage is related to the amount of water that flows over the falls every second, while voltage is related to the height of the waterfall.

Possible Student Misconceptions

Several common misconceptions that students may have about lightning are addressed in the *Anticipating Student Questions* section. These include:

Airplanes can't be struck by lightning because they aren't connected to the ground.
You can't be killed by lightning if you are inside your home, no matter what you are doing.
As long as lightning isn't in your immediate area, you are safe.
Not many people who are struck by lightning survive.

Demonstrations and Lessons

1. There are a number of demonstrations relating to the buildup of static electricity and its effects that can be done. These can range from very simple activities involving balloons, combs, etc., to much more interesting and sophisticated demonstrations if you have access to a Van de Graaff Generator. One good source for detailed instructions for a demo that takes about 30 minutes to set up and 50 minutes to perform can be found at:

http://media.nasaexplores.com/lessons/02-069/9-12_2.pdf

2. If your course includes a unit on electrochemistry, the topic of lightning and some of the data surrounding typical values for the amperage, voltage, and velocities involved in a typical lightning strike can provide an opportunity to either teach or review several relevant quantities. See *Background Information* and *Connections to Chemistry Concepts*.

Connections to the Chemistry Curriculum

The strongest curricular connection with this article centers around the area of electrochemistry and electrical terms such as amperage and voltage. See *Connections to Chemistry Concepts*.

Suggestions for Student Projects

1. One interesting electrical phenomenon that continues to engender debate is the phenomenon of “ball lightning.” Ball lightning is a slow-moving ball of light that is sometimes observed at ground level during thunderstorms. At first, even the actual existence of this phenomenon was hotly debated. Now it is generally accepted that the phenomenon exists, but debate still rages around how to explain exactly what it is and how it is formed. Students could research and report on this phenomenon. One warning should be noted. There are experiments that claim to have produced the same or at least a similar phenomenon inside microwave ovens, but these experiments can be hazardous both to the microwave and the person performing them, so under no circumstances should students attempt to duplicate them.
2. Another electrical phenomenon sometimes confused with ball lightning is St. Elmo’s Fire. This is a luminescent electrical discharge that is sometimes observed on tall poles or similar objects immediately preceding or following thunderstorms. This phenomenon is both accepted and scientifically explained and could also make for an interesting student report, as it connects to several scientific concepts.
3. The mechanism involved in lightning creation described in the article is referred to as the dipole model, which basically talks about the negative charge that builds up at the bottom of a cloud and the positive charge that builds up higher in the cloud. A more recent model is called the tripole model. Its name refers to the fact that this model includes a positive region as well as a negative region at the bottom of the cloud. Students could prepare a report on this model and the evidence upon which it is based.

Anticipating Student Questions

1. Are all lightning strikes about the same in terms of the amount of current they carry and how long they last?

No. They vary quite widely. According to the National Lightning Safety Institute, the electrical characteristics of an 8 kA (8,000 amps) strike with a duration of 20 μs (20×10^{-6} s) will differ significantly from a 200 kA strike with a 300 μs duration.

2. Is it possible for an airplane to be struck by lightning? If that happened, would the plane crash?

It is entirely possible that a plane could be struck by lightning. In fact, a photograph and video of such an event can be found at:

http://www.crh.noaa.gov/pub/ltg/plane_japan.html

However, it is very unlikely that this would cause the plane to crash or people to be injured because of the strike. For the strike shown in the photograph, it is thought that no one on the plane was injured and the plane may or may have not suffered any actual damage. Interestingly, it is thought that the plane itself actually triggered the lightning strike.

3. Where are the safest and least-safe places to be during a thunderstorm?

The safest places are large, permanent buildings or metal vehicles, such as an automobile. The least safe places are places near metal or water, under trees, on hills, or near electrical or electronic equipment.

4. Is it actually possible to be killed or injured by lightning when you are inside your home talking on a telephone during a thunderstorm? Would cell phones be as dangerous?

Yes. No.

5. How do you know when you should be worried about lightning when you are in the vicinity of a thunderstorm?

The standard recommendation is, "If you can see it, flee it; If you can hear it, clear it," but there are also more specific recommendations. It depends on how fast the storm is moving, the direction in which it is moving, and how long it would take you to reach safety. The National Lightning Safety Institute recommends a distance of six miles. This is equivalent to a 30 second "Flash-to-Bang" (see *Connections to Chemistry Concepts*). But some studies suggest that there really is no safe time interval and it is quite possible to get caught in a thunderstorm even if you try to move to safety at the very first sign of any danger.

Websites for Additional Information and Ideas

There are a large number of websites that can provide much more detailed and thorough information about lightning. Some good ones include:

http://www.boltlightningprotection.com/lightning_physics.htm

<http://www.ce-mag.com/archive/02/09/mrstatic.html>

<http://home.earthlink.net/~jimlux/lfacts.htm>

<http://hyperphysics.phy-astr.gsu.edu/hbase/electric/lightning.html>

Descriptions for specific lightning-strike events can be found at:

http://www.lightningsafety.com/nlsi_lls/incidents.html

And a "funny" quotation about golf and lightning

Professional golfer Lee Trevino has been struck by lightning while golfing. When asked if he was afraid of being struck again, he said no, he now knew how to avoid being struck.

"If you are caught on a golf course during a storm and are afraid of lightning, hold up a 1-iron. Not even God can hit a 1-iron."

Bleaching With Green Oxidation Chemistry

Background Information

More about Clorox® Bleach

According to the Clorox Company, about eight out of every ten American households use *Clorox*® bleach. The product was first introduced in 1916 and according to company sources, has remained the same since that time except for the introduction of quality control improvements.

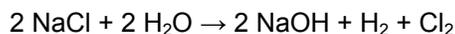
Even though some of Clorox's products have been around for many years—*Pine-Sol* cleaner, for example, has been on the market since 1929—company scientists still analyze them to insure that the actual ingredients match those specified on the label.

Two of the most utilized testing tools are “Otto the Robot” and the mass spectrometer.

Despite the catchy name, “Otto the Robot” is basically a computer controlled robot that measures and mixes formulas to the desired specifications. As might be expected, there are a number of these kinds of instruments used throughout both the science labs and the manufacturing plants.

The mass spectrometer is used to determine the identity of the molecular substances contained in raw materials, finished products, competitor's products and any new compounds that are synthesized. In one case it was used to identify a counterfeit product that was being marketed in a bottle and with a label that made it appear to the consumer to be *Pine-Sol*, when in fact, it wasn't. Subsequent legal action shut down the bogus operation.

Salt water, NaCl, is the beginning material from which sodium hypochlorite bleach is made. It is first electrolyzed to produce sodium hydroxide, hydrogen, and chlorine:



Then chlorine is added to the solution of sodium hydroxide to form sodium hypochlorite:



When the bleach is used, the cleaning process reconverts it almost completely back into salt water. The remaining hypochlorite is deactivated either at a municipal treatment facility or in a septic tank through biodegradation.

More about the Institute for Green Oxidation Chemistry

The article provides the website for the Institute for Green Oxidation Chemistry at Carnegie Mellon.

<http://www.chem.cmu.edu/groups/collins/about/index.html>

The Institute has been established as a research, education, and development center. There are three major areas where it is thought that green chemists can make major contributions. These are:

renewable energy technologies, especially solar technologies

the development of chemical feed stocks that come from renewable resources in order to both reduce our dependence on fossil fuels and reduce unfavorable atmospheric consequences

the replacement of polluting technologies by benign alternatives

You can listen to a lecture on green oxidation chemistry by Terry Collins by going to:

<http://www.chem.cmu.edu/groups/collins/research/green/index.html>

The lecture runs for slightly over one hour. See *Suggestions for Student Projects*.

More about the use of TAML® Catalysts in the Pulp and Paper Industry

There is a good chance that the use of TAML catalysts may prove of great benefit to the pulp and paper industry, both in terms of removing some environmental concerns as well as increasing profitability. TAML catalysts can provide improvements in peroxide pulp bleaching and in addition offer an alternative for the treatment of the effluent from any chlorine-based bleaching that is contaminated with what is referred to as “color,” and/or chlorinated lignin fragments. These lignin fragments are grouped together and given the name “AOX,” which stands for *absorbable organic halogen*. AOX represents chlorinated materials that can be adsorbed on activated carbon.

The basic problem is this. Wood pulp consists primarily of two different polymers. The major polymer is cellulose, but pulp also consists of between about 2-6% colored lignin. Lignin is undesirable because it produces a brown discoloration in the final paper. A diagram for the generalized structure of lignin can be found at:

<http://academic.scranton.edu/faculty/CANNM1/inorganic/inorganicmodule.html>

Bleaching attempts to remove the lignin from the cellulose. The conventional method of bleaching pulp is referred to as the Kraft process. It basically consists of a series of processes using alkali, acid, hydrogen and sodium peroxide, oxygen, dithionite salts, sodium bisulfite, and a wash water process. This is followed by chlorinating treatments to remove any residual lignin. Currently, the primary bleaching agent being utilized is chlorine dioxide, ClO₂, although chlorine or hypochlorite salts are also used in some cases. The chlorine dioxide breaks the lignin away from the cellulose, and the lignin appears in two forms, “little fragments,” and “big fragments,” with the former dominating.

These fragments are placed in artificial oxidation lakes, where they are digested by bacteria and other organisms before being returned to natural bodies of water. The problem is that the big fragments cannot be digested by the bacteria. When they are returned to rivers, lakes or other bodies of water, they retain their color and thus stain natural waterways. And the effect is not simply one of aesthetics. The addition of color can alter the flux of light that is absorbed by ecosystems.

TAML/peroxide is capable of removing about 56% of the color and 36% of the adsorbable organic halogen from the bleach plant effluent, and the process only requires small amounts of peroxide and miniscule quantities of TAML.

You can view a video showing a dye bleaching experiment by going to:

<http://www.chem.cmu.edu/groups/collins/research/dye/index.html>

Chlorine dioxide has largely replaced chlorine in the bleaching process because of environmental concerns. Chlorine reacts with lignin to produce chlorinated aromatic rings. One of the products produced is 2,3,6,7-tetrachlorodibenzo-4-dioxin, abbreviated as “TCDD,” and commonly referred to simply as “dioxin.” Dioxin has been connected to numerous health problems. The use of chlorine dioxide in place of chlorine lessens, but does not eliminate, the problem.

By using hydrogen peroxide in conjunction with TAML catalysts, the problem of the production of dioxin can be eliminated.

Connections to Chemistry Concepts

The article touches on the concepts of oxidation and reduction. It presents a couple, but not all of the common definitions.

If you would like to obtain more information about redox reactions, including redox equations and how to balance them, one good website you can go to is:

http://www.chemistry.co.nz/redox_begin.htm

From there you can link to a discussion of oxidation numbers and how to assign them and how to balance redox reactions. There also is an oxidation-reduction test sheet along with the test answers.

Possible Student Misconceptions

The article explains that the role of TAML catalysts is to increase the suitability and efficiency of hydrogen peroxide as an oxidant so that it can replace chlorine-containing materials that have been associated with environmental problems. Nevertheless, some students might incorrectly misread the article and conclude that it was the TAML catalysts themselves. The peroxide reacts with the TAML catalysts, producing an oxidized form of the catalyst which, in turn, reacts with the colored substances.

Demonstrations and Lessons

There are a number of common laboratory activities connected to the decomposition of hydrogen peroxide. The Feb. 2004 issue of *ChemMatters* contains an activity where students generate oxygen gas by reacting household bleach with a solution of H_2O_2 . It would fit nicely with this article as well.

The decomposition of H_2O_2 can also be catalyzed by a number of different substances, including potassium iodide, manganese dioxide, and liver. Some websites for suitable labs include:

<http://www.chemheritage.org/EducationalServices/pharm/tg/antibiot/activity/comcat.htm>
<http://www.phys.virginia.edu/Education/outreach/8thgradesol/DecompositionHydrogenPeroxide.htm>
<http://www.chemheritage.org/EducationalServices/FACES/teacher/env/activity/catalysi.htm>

This would also be a nice time to do the famous “Elephant Toothpaste” demonstration, which involves the catalytic decomposition of 30% H_2O_2 in such a way that foam shoots out of a tall graduated cylinder and resembles a massive amount of striped toothpaste. One good website for instructions can be found at:

<http://www.carolina.com/chemistry/experiments/elephant.asp>

Connections to the Chemistry Curriculum

This article ties nicely to several topics that are included in many high school courses. Several relatively simple chemical formulas and equations are presented which most students should be able to recognize as “old friends.” The concept of oxidation-reduction and its various definitions is touched on in the article and could be expanded upon if desired (for example, nothing is said about oxidation numbers and how oxidation and reduction are defined in these terms). Obviously, this article ties strongly to a discussion of catalysts—what they are and how they work. If your course includes an organic component, the article will connect to several different organic structures and groups as well as the nomenclature system used to name organic compounds.

Suggestions for Student Projects

1. Municipal treatment facilities often must choose among various chemicals when attempting to achieve a given objective. One interesting choice centers around the removal of hydrogen sulfide, H_2S , the gas with the “rotten egg” odor. This can be achieved by the use of chlorine, Cl_2 , sodium hypochlorite, NaOCl , or hydrogen peroxide, H_2O_2 . As the article points out, the use of hydrogen peroxide has some advantages. So why isn't it used exclusively? Students could research all the ramifications of choosing one chemical over the other, including efficiency, unwanted “side” reactions, residual pollution concerns, and of course, cost.
2. Terry Collins has recorded an excellent lecture on green oxidation chemistry which also addresses general environmental problems and the issue of sustainability-i.e. how much

longer can we continue to use up nonrenewable resources without creating serious and even perhaps catastrophic consequences? How should these kinds of problems be addressed, and what role will chemists play in addressing these problems? The lecture is accompanied by slides and runs just in excess of an hour. Ambitious students could watch and listen to this lecture and then report on its major theses.

3. Although the article touches on the problem involving the production of dioxin during the process of bleaching wood pulp, as might be expected, there is a lot more to the story, including much additional chemical content. Researching and reporting on the chemistry involved and how the use of hydrogen peroxide and TAML catalysts can alleviate the problem would make for an excellent student report, either written or as a class presentation.

Anticipating Student Questions

I've heard that one should never mix household bleach with an ammonia cleaner. Why?

Household bleaches such as Clorox® consist of a solution of sodium hypochlorite, NaOCl. If this is mixed with a solution of ammonia, NH₃, it can result in the production and release of powerful respiratory irritants. The exact products produced may vary depending on the ratio of the volumes of the mixed solutions, but can include chloramines such as NH₂Cl or even chlorine gas.

Websites for Additional Information and Ideas

A list of past Green Chemistry Award Recipients can be found at:

<http://www.epa.gov/greenchemistry/past.html>

If you'd like to see photographs of Terry Collins or some additional biographical information two good websites are:

http://www.cmu.edu/cmnews/020308/020308_greenchem.html

<http://www.chem.cmu.edu/fun/collins.html>