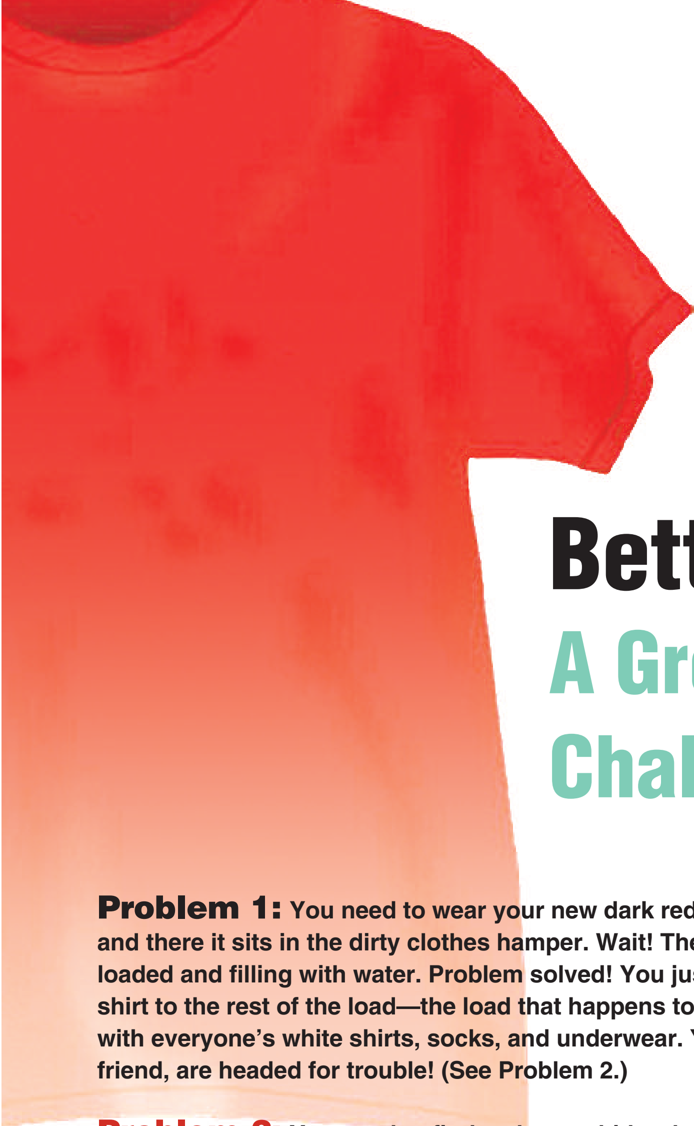


Building a Better Bleach: A Green Chemistry Challenge

Problem 1: **You need to wear your new dark red T-shirt, and there it sits in the dirty clothes hamper. Wait! The washer is loaded and filling with water. Problem solved! You just add the shirt to the rest of the load—the load that happens to be filled with everyone's white shirts, socks, and underwear. You, my friend, are headed for trouble! (See Problem 2.)**

Problem 2: **You need to find a place to hide when everyone starts screaming about pink underwear and socks!**

Problem 3: **You need to turn pink back into white.**

MIKE CIESIELSKI

By Kathryn Parent

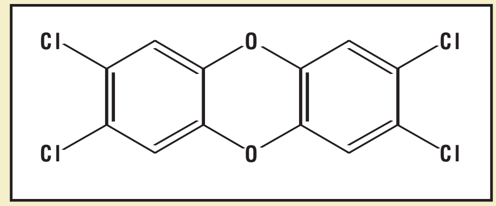
A stain is a color where you don't want it. It might surprise you that stain removal is actually not *removal* at all. The secret behind getting rid of the unwanted color is not a matter of removing the offending molecules, like detergents acting to remove soil. Instead, the stain molecules are altered chemically so that they no longer reflect light in just the same way as before. We'll call it *decolorizing*, or *bleaching*—words that imply the chemistry going on in the process.

Fine then! Let's get back to the problem at hand. What chemical is going to solve the problem? Let's start with ordinary household bleach. The active ingredient in bleach, sodium hypochlorite (NaOCl), keeps white clothing white and your bathtub sparkling. But handle with care. If you've ever spilled bleach, you know it can also add white blotches to a favorite pair of blue jeans.

How does bleach act on stain molecules? Bleaching is an example of the basic chemical processes—oxidation and reduction—at work. Oxidation is generally defined as *losing* electrons, and reduction as *gaining* them. The two processes occur together, so one compound is reduced in the process of oxidizing another compound. Another common definition of oxidation is the gain of oxygen atoms or the loss of hydrogen atoms. Reduction is then the loss of oxygen atoms or the gain of hydrogen atoms. Here are two ordinary examples.

PHOTODISC

A DIOXIN



What are dioxins? They're a group of several hundred structurally similar compounds all sharing an uncanny ability to persist and accumulate in the food chain. People exposed to a large amount of dioxins can develop a condition called chloracne. Not your normal acne, chloracne is a severe skin disease causing lesions to appear on the face and upper body. High dioxin exposure has also been linked to an increased cancer risk in adults. The main sources of dioxins are waste incineration and forest fires. But dioxins can also be produced by industrial processes that use chlorine, like textile and paper manufacturing. Although the exact health risk posed by dioxins is controversial, the tendency for the compounds to linger in the environment prompts the U.S. Environmental Protection Agency to work with industry to find ways to limit their production.

Oxidation of carbon: $C + O_2 \rightarrow CO_2$

Reduction of nitrogen: $N_2 + 3H_2 \rightarrow 2\ NH_3$

Back to stains. The color of the stain is a physical property caused by the chemical structure of its molecules. When an oxidizing agent removes electrons from a molecule, the chemical structure of the molecule is changed, and the physical properties (like color) are altered. Chlorine bleaches are oxidizing agents that work efficiently and cheaply in the laundry. Any excess is washed away in the rinse water. Problem solved? *Yes*, if you're only worried about those pink socks. *No*, if you're worried about the environment. Sometimes, oxidation with chlorine bleach involves addition of *chlorine* atoms to the colored stain molecules rather than just removal of electrons. The fact is that the addition of chlorine to an organic-rich waste stream leads to the formation of hazardous byproducts, such as dioxins.

Nonchlorine bleaches to the rescue

If the release of chlorine—especially on a large scale— is bad for the environment, what else can we use to get rid of stains? Alternative "nonchlorine" bleaches are also available. They contain hydrogen peroxide or other peroxide compounds instead of sodium hypochlorite. Because H_2O_2 is a liquid, it is not actually present in solid nonchlorine laundry bleaching products. These solid bleaches contain ingredients like perborate or percarbonate—compounds that react in water to release hydrogen peroxide. Thus, H_2O_2 is the nonchlorine bleaching agent common to almost all of these products. Hydrogen peroxide is also the bleaching agent in many hair dyes. Alone, peroxide alters hair pigments to bestow the "peroxide blonde" effect, but most permanent dyes rely on peroxide as a key ingredient, either to alter natural pigment in the hair or to activate the new dye.

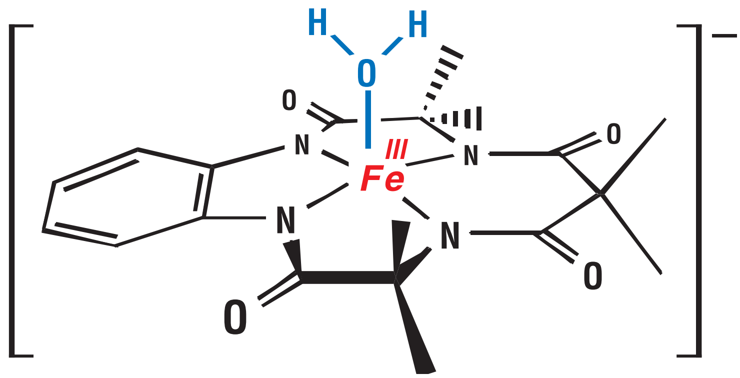
Dilute hydrogen peroxide (3%) is also commonly found in medicine cabinets. Used as an antiseptic for minor cuts and scrapes, it's also effective at removing bloodstains from clothing. The bubbling that occurs when the peroxide encounters blood is due to its decomposition into oxygen gas and water

$$H_2O_2 \rightarrow {}^1/_2\ O_2 + H_2O$$

In the process of decomposing, H_2O_2 releases free radicals—highly reactive intermediates that oxidize other molecules by removing electrons or hydrogen atoms from them. If these other molecules are colored stains or pigments, the chemical changes accompanying their oxidation may alter their physical properties, rendering them colorless—bleached.

Hydrogen peroxide sounds like our ideal bleaching agent! In addition to its everyday use as a household cleaner or hair dye, oxidative bleaching is now used in the pulp and paper, textile, and laundry industries. Hydrogen peroxide (H_2O_2) is a greener, or more environmentally friendly, alternative to chlorine (Cl_2), chlorine dioxide (ClO_2), and sodium hypochlorite (NaOCl) that are traditionally used for bleaching color from substances. And, best of all, hydrogen peroxide does not contain any chlorine atoms. It oxidizes by

ACS STAFF PHOTO

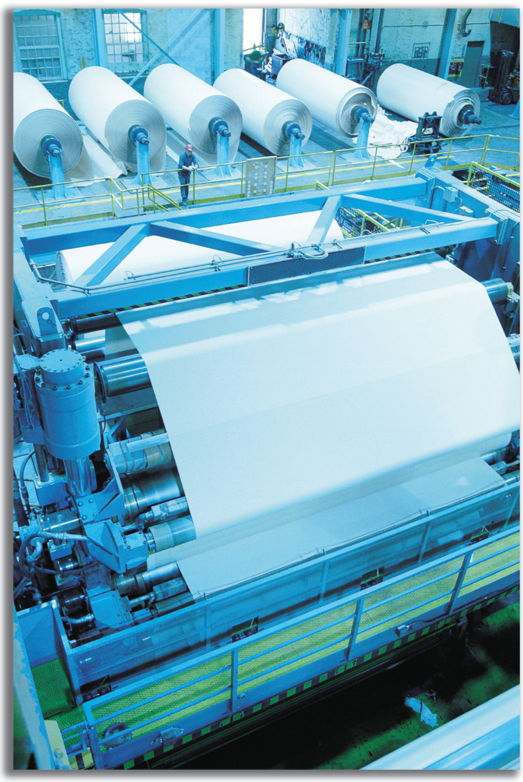


An example of a TAML oxidant activator

either adding oxygen or removing hydrogen atoms. As a result, the oxidized compounds do not include organochlorine-type pollutants, and the problem of hazardous pollution is prevented at the source.

So, what are we waiting for? Why not stop using chlorine bleach altogether and replace it with hydrogen peroxide alternatives? The challenge of replacing traditional chlorine bleaches with hydrogen peroxide is twofold. First, the peroxide oxidation process can be unselective. Because any molecules in the vicinity that are exposed to decomposing hydrogen peroxide get exposed to reactive free radicals, some unwanted chemistry might accompany the desired oxidation. Second, successful bleaching with H_2O_2 requires higher temperatures and pressures and longer reaction time than those required for chlorine bleach. On an industrial scale, this means higher costs for energy, equipment, and labor for the bleaching process.

A research group led by Professor Terry Collins at the Institute for Green Oxidation Chemistry (we'll get to the *Green* part in a minute) at Carnegie Mellon University may have solved our bleaching problems by developing some heroic molecules with names to match. Collectively, they are called *tetraamido macrocyclic ligands* or TAML for short. These versatile molecules (picture above) function as catalysts in the hydrogen peroxide bleaching process. Their presence allows hydrogen peroxide oxidation to proceed at much lower temperatures and pressures. And like all catalysts, they are not consumed in the process.



PHOTODISC

By using TAML activators, industrial processes like paper making and textile manufacturing that require bleaching, are becoming more energy efficient and less polluting.

That's the kind of good news the Environmental Protection Agency rewards with the annual Presidential Green Chemistry Challenge Awards, a program that recognized Prof. Collins's research team for their innovative research in 1999.

Green chemistry is the design of chemical products and processes that are environmentally benign by design. That means that the products can be made from renewable resources, that they consume minimal energy resources in their manufacture, and that they don't release polluting end-products into the environment that must be cleaned up later. It's easy to see how bleaching with TAML-activated H_2O_2 would be an ideal example of green chemistry in action. Made from naturally occurring biochemicals, TAML catalysts reduce energy costs and not only prevent pollution, but are also useful in cleaning up pollutants that other processes have left behind.

Let's get back to the pink underwear problem. You'll be happy to know that TAML technology has been applied to laundry. Commercial laundries, as well as homeowners in drought-stricken areas are looking for ways to reduce water usage. But using less water leads to problems with dye transfer. The highly selective TAML activators use the peroxide present in some detergents to hunt and destroy free dye molecules, while leaving fabric-bound dye molecules unchanged.

All of which might be too late for your current crisis. But TAML may protect you and your pink-outfitted family from suffering similar laundry mishaps in the future. Check the product labels.

Kathryn Parent is an outreach development consultant for the ACS Green Chemistry Institute.

PHOTODISC

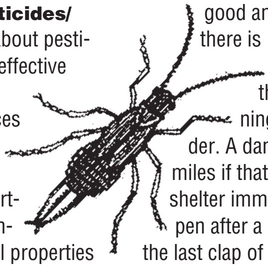
Chem.matters.links

More thoughts on bug control

Perhaps, while reading about bug spray and lightning, you happened to consider that not just humans can be electrocuted—bugs can be electrocuted too. In fact, bug zappers are designed to do just that. Are they effective at controlling bugs? Check out **http://home.howstuffworks.com/bug-zapper.htm** for more information on how bug zappers work.

The Environmental Protection Agency (EPA) has a site—**http://www.epa.gov/pesticides/index.htm**—chock full of information about pesticides and suggestions for their safe and effective use. The National Pesticide Information Center also has articles from many sources on pesticides and the implications of their use. http://npic.orst.edu/gen.htm.

Oxford University's chemistry department featured insect repellents in September 2002. They have models and physical properties of DEET and permethrin at **http://www.chem.ox.ac.uk/mom/insectrepellents/default.htm.**



Lightning safety

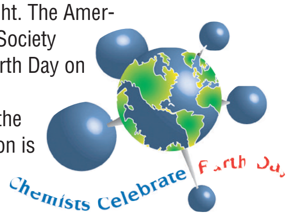

ACS

Do you know the 30–30 rule for lightning safety? According to the National Weather Service, you use the 30–30 rule where visibility is good and there is nothing obstructing your view of the thunderstorm. When you see lightning, count the time until you hear thunder. A dangerous thunderstorm is within 6 miles if that time is **30 seconds** or less. Seek shelter immediately. Lightning strikes can happen after a storm; wait at least **30 minutes** after the last clap of thunder before leaving shelter. A wealth of lightning and lightning safety information is located at **http://www.lightningsafety.noaa.gov/index.htm.**

More on bacteria power

Interested in learning more about Geobacter bacteria? The University of Massachusetts, Amherst maintains a Web site, **http://www.geobacter.org**, with pictures and information on the latest developments. If you decide you want to make your own battery, you might find it invaluable.

Chemists celebrate Earth Day



That's right. The American Chemical Society will observe Earth Day on April 22. The theme for the 2004 Celebration is "What do you know about H_2O?" To help celebrate the day, a series of hands-on activities are available for teachers and students at **http://chemistry.org/earthday.**

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Reach Us on the Web at
chemistry.org/education/chemmatters.html

ChemMatters

April 2004 Teacher's Guide

Building a Better Bleach: A Green Chemistry Challenge

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**
		E	**R**	**S**						**P**			**S**				
					■				■			■					
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	■					■								■	■	■	■

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 x 3,572 on a slide rule. How would you decide where the decimal point went?

5. Multiplying 1,288 x 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 x 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

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 As a result of activities in grades 9-12, all students should develop understanding.	**Building a Better Bleach**	**Slide Rules Rule!**	**What's Bugging You**	**Lightning**	**Bacteria Power**
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!

How they work	**Skills users of slide rules must have**
What they can do	**What they can't do**

Slide Rules

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	

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.

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.

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:

$$2\ NaCl + 2\ H_2O \rightarrow 2\ NaOH + H_2 + Cl_2$$

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

$$Cl_2 + 2\ NaOH \rightarrow NaOCl + NaCl + H_2O$$

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, ClO_2, 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 over, 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, NH_3, 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 NH_2Cl 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