

# CHEM MATTERS

## FEBRUARY 2007 TEACHER'S GUIDE

<b>ABOUT THE GUIDE</b> .....	<b>3</b>
<b>STUDENT QUESTIONS</b> .....	<b>4</b>
<b>ANSWERS TO STUDENT QUESTIONS</b> .....	<b>5</b>
<b>PUZZLE: CHEMICAL NUMEROLOGY</b> .....	<b>7</b>
<b>PUZZLE ANSWERS</b> .....	<b>8</b>
<b>CONTENT READING GUIDE</b> .....	<b>9</b>
NATIONAL SCIENCE EDUCATION CONTENT STANDARD ADDRESSED .....	9
<b>ANTICIPATION GUIDES</b> .....	<b>11</b>
MENTOS AND DIET COKE .....	11
THE SCIENCE OF NASCAR .....	12
THE SUN: FUSION AT WORK.....	13
YOUR COLORFUL FOOD.....	14
ALICE BALL: YOUNG CHEMIST GAVE HOPE TO MILLIONS .....	15
<b>READING STRATEGIES</b> .....	<b>16</b>
NASCAR: CHEMISTRY ON THE FAST TRACK.....	17
NASCAR CAR - ORDINARY CAR - SIMILARITIES .....	18
THE SUN: FUSION AT WORK.....	19
YOUR COLORFUL FOOD.....	21
ALICE BALL: YOUNG CHEMIST GAVE HOPE TO MILLIONS .....	22
<b>NASCAR: CHEMISTRY ON THE FAST TRACK</b> .....	<b>23</b>
BACKGROUND INFORMATION .....	23
CONNECTIONS TO CHEMISTRY CONCEPTS .....	28
POSSIBLE STUDENT MISCONCEPTIONS .....	29
DEMONSTRATIONS AND LESSONS.....	29
SUGGESTIONS FOR STUDENT PROJECTS .....	30
ANTICIPATING STUDENT QUESTIONS .....	30
WEBSITES FOR ADDITIONAL INFORMATION .....	32
<b>THE SUN: FUSION AT WORK</b> .....	<b>34</b>
BACKGROUND INFORMATION .....	34
CONNECTIONS TO CHEMISTRY CONCEPTS .....	37
POSSIBLE STUDENT MISCONCEPTIONS .....	38
DEMONSTRATIONS AND LESSONS.....	38
STUDENT PROJECTS.....	39
ANTICIPATING STUDENT QUESTIONS .....	40
WEBSITES FOR ADDITIONAL INFORMATION .....	41
<b>“YOUR COLORFUL FOOD”</b> .....	<b>44</b>
BACKGROUND INFORMATION .....	44
CONNECTIONS TO CHEMISTRY CONCEPTS .....	47
POSSIBLE STUDENT MISCONCEPTIONS .....	48

DEMONSTRATIONS AND LESSONS.....	48
SUGGESTIONS FOR STUDENT PROJECTS.....	49
ANTICIPATING STUDENT QUESTIONS .....	50
WEBSITES FOR ADDITIONAL INFORMATION .....	51
<b>ALICE BALL .....</b>	<b>52</b>
BACKGROUND INFORMATION.....	52
CONNECTIONS TO CHEMISTRY CONCEPTS.....	61
POSSIBLE STUDENT MISCONCEPTIONS .....	61
DEMONSTRATIONS AND LESSONS.....	62
SUGGESTIONS FOR STUDENT PROJECTS.....	62
ANTICIPATING STUDENT QUESTIONS .....	62
WEBSITES FOR ADDITIONAL INFORMATION .....	63

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## Student Questions

### NASCAR: Chemistry on the Fast Track

1. What are the products of the reaction of gasoline with oxygen?
2. What is the windshield of a NASCAR racer made from?
3. What gas is used to fill the tires used in NASCAR racers?
4. What happens to the temperature of the gas inside a NASCAR racing tire when the car is moving at high speeds? What happens to the pressure of the gas inside the tire when the car is moving at high speeds?
5. What material is used to make the flame-resistant suits NASCAR drivers wear?
6. What chemical compound makes up dry ice?

### The Sun: Fusion at Work

1. The Greek Sun god, Helios is most like which other civilization's Sun god?
2. What was wrong with the contraction theory as the source of the Sun's energy?
3. Where was helium first discovered?
4. What portion of the energy emitted by the Sun reaches the Earth?
5. What is the scientific name for the large bodies of ionized gases, described as gigantic magnetic bubbles, that break away from the Sun?
6. How will an increase in solar storm activity affect us?
7. What are the two types of solar power now being developed?

### Your Colorful Food

1. What are the advantages of using synthetic food dyes rather than natural ones?
2. What is the difference between a natural food coloring and natural-identical colors?
3. What is a "lake" as used with food dyes?
4. Why is it necessary to use "lakes" when including certain dyes in food?
5. What is meant by a synergistic or synergetic effect in a chemical reaction?

### Alice Ball

1. In what year did the Hawaiian government begin moving people with Hansen's disease to Kalaupapa?
2. When was Chaulmoogra oil was first introduced to Hawaii?
3. Where was Alice Ball born?
4. What was he subject of Alice Ball's master's thesis?
5. What chemicals are used to synthesize an ester?
6. Name the bacterium that causes Hansen's disease.

## Answers to Student Questions

### NASCAR: Chemistry on the Fast Track

1. What are the products of the reaction of gasoline with oxygen?  
*Carbon dioxide and water are the products.*
2. What is the windshield of a NASCAR racer made from?  
*NASCAR windshields are made from Lexan® or polycarbonate.*
3. What gas is used to fill the tires used in NASCAR racers?  
*NASCAR tires are filled with nitrogen.*
4. What happens to the temperature of the gas inside a NASCAR racing tire when the car is moving at high speeds? What happens to the pressure of the gas inside the tire when the car is moving at high speeds?  
*Both the temperature and the pressure increase.*
5. What material is used to make the flame-resistant suits NASCAR drivers wear?  
*The suits are made of Nomex.*
6. What chemical compound makes up dry ice?  
*Dry ice is made of carbon dioxide.*

### The Sun: Fusion at Work

1. The Greek Sun god, Helios is most like which other civilization's Sun god?  
*The Greek Sun god, Helios was most like the Roman Sun god, Sol.*
2. What was wrong with the contraction theory as the source of the Sun's energy?  
*The contraction theory was found to be problematic because scientific evidence showed that the Earth was older than the Sun would be if it were powered by gravitational contraction alone, and that made no sense to scientists..*
3. Where was helium first discovered?  
*Helium was first discovered in the spectrum of the Sun.*
4. What portion of the energy emitted by the Sun reaches the Earth?  
*Only 1 two-billionth of the total energy emitted by the Sun reaches Earth.*
5. What is the scientific name for the large bodies of ionized gases, described as gigantic magnetic bubbles, that break away from the Sun?  
*These gigantic magnetic bubbles are called Coronal Mass Ejections, CMEs.*
6. How will an increase in solar storm activity affect us?  
*These solar storms will cause possible disruptions in cell phone service, TV signals, and global positioning systems, all caused by possible satellite damage. Power surges could also cause electrical power grids to crash, resulting in major blackouts.*
7. What are the two types of solar power now being developed?  
*The two types of solar power being developed presently are photovoltaics, producing electricity directly from solar energy, and solar thermal systems, converting solar light energy directly into heat.*

## Your Colorful Food

1. What are the advantages of using synthetic food dyes rather than natural ones?  
*Compared with natural food dyes, synthetic food dyes are less expensive, vibrant, consistent in color, and longer lasting.*
2. What is the difference between a natural food coloring and natural-identical colors?  
*A naturally occurring dye is that which is found and removed from some plant or animal source. A natural-identical dye is one that is synthesized with the exact same chemical structure as the naturally occurring dye.*
3. What is a "lake" as used with food dyes?  
*A "lake" is a pigment of various colors, made by combining an organic dye with a metallic hydroxide or other inorganic substance.*
4. Why is it necessary to use "lakes" when including certain dyes in food?  
*The dye that is to be used in food may not be soluble in fats or oils which means the food is water soluble (polar) rather than fat (non polar) soluble. To make it fat soluble, a "lake" is formed by adding some metallic hydroxide which can attach both to the dye and fat/oil molecules.*
5. What is meant by a synergistic or synergetic effect in a chemical reaction?  
*A synergetic effect in a chemical reaction is one in which several reactants together produce a larger effect than when the chemicals react independently of each other.*

## Alice Ball

1. In what year did the Hawaiian government begin moving people with Hansen's disease to Kalaupapa?  
*1866*
2. When was Chaulmoogra oil was first introduced to Hawaii?  
*1879*
3. Where was Alice Ball born?  
*Seattle, Washington*
4. What was he subject of Alice Ball's masters thesis?  
*The identification of the active constituents of kava root*
5. What chemicals are used to synthesize an ester?  
*An alcohol and a carboxylic acid*
6. Name the bacterium that causes Hansen's disease.  
*Mycobacterium leprae*

## Puzzle: Chemical Numerology

Chemists are into numbers in a big way. And about the most basic numbers are the integers zero through twelve. But they can provide a nice test of your knowledge of some chemical facts. Below are thirteen clues, each of which has an answer of either 0,1,2,3,4,5,6,7,8,9,10,11, or 12. Your task is to match the numerical answer to each clue. Every number gets used exactly once, so you may wish to cross them off as you proceed. It's OK to consult reference tables for some of the items. There are a few trick clues in there, so be warned!

**0    1    2    3    4    5    6    7    8    9    10   11   12**

Number of orbitals in any d subshell.

1 kJ / 1 nJ equals 10 to what power ?

The equivalent of 273K on the Celsius scale.

Atomic number of the element in period 2 with biggest electronegativity.

The approximate vapor density of carbon monoxide gas at STP.  
(Vapor Density is the density of a gas compared to that of air.)

The size of the positive charge on the stannic ion.

Total number of electrons in the ammonium ion.

The mass in grams of 0.20 moles of propyne.

Coordination number of the central atom in an octahedral complex ion.

The pH of a  $1 \times 10^{-9}$  M solution of hydrochloric acid (in really pure water).

The  $E_{\text{net}}^0$  of aluminum chloride forming in solution from its elements.

Number of isomers of chlorobromiodomethane,  $\text{CHClBrI}$ .

Number of neutrons in the  ${}^{23}_{12}\text{Mg}^{2+}$  ion.

## Puzzle Answers

### CHEMICAL NUMEROLOGY

0. The equivalent of 273K on the Celsius scale. (freezing point of water)
1. The approximate vapor density of carbon monoxide gas at STP. (both are  $\approx .29\text{g/L}$ , with  
(Vapor density is the density of a gas compared to that of air.) same molmass of  $\approx 28$ )
2. Number of isomers of chloro bromo iodo methane,  $\text{CHClBrI}$ . (stereoisomerism!)
3. The  $E_{\text{net}}^0$  of aluminum chloride forming from its elements. ( $E_{\text{net}}^0 = 1.66 + 1.36$ )
4. The size of the positive charge on the stannic ion. ( $\text{Sn}^{4+}$ )
5. Number of orbitals in any d subshell. (5 orbitals, capacity 10 e-)
6. Coordination number of the central atom in an octahedral complex ion. (8 faces, but 6 corners)
7. The pH of a  $1 \times 10^{-9}$  M solution of hydrochloric acid. (pH = 7 from the water itself !)
8. The mass in grams of 0.20 moles of propyne. ( $\text{C}_3\text{H}_4$ , = 40 g/mol x 0.20mol)
9. Atomic number of the element in period 2 with the biggest e.n. (Fluorine, Z= 9)
10. Total number of electrons in the ammonium ion. (= 7 + 4 -1)
11. Number of neutrons in the  ${}^{23}_{12}\text{Mg}^{2+}$  ion.. (= 23 - 12)
12. 1 kJ/ 1 nJ equals 10 to what power? ( $10^3 / 10^{-9} = 10^{12}$ )

# Content Reading Guide

## *National Science Education Content Standard Addressed*

<b>National Science Education Content Standard Addressed</b> As a result of activities in grades 9-12, all students should develop understanding	<b>Your Colorful Food</b>	<b>Alice Ball</b>	<b>The Sun: Fusion at Work</b>	<b>The Science of NASCAR</b>	<b>Mentos &amp; Diet Coke</b>
<b>Science as Inquiry Standard A:</b> about scientific inquiry.	✓	✓	✓	✓	✓
<b>Physical Science Standard B:</b> of the structure of atoms.			✓		
<b>Physical Science Standard B:</b> of the structure and properties of matter.	✓	✓	✓	✓	✓
<b>Physical Science Standard B:</b> of chemical reactions.	✓	✓		✓	
<b>Physical Science Standard B:</b> of motions and forces.			✓	✓	
<b>Physical Science Standard B:</b> of conservation of energy & increase in disorder.				✓	
<b>Physical Science Standard B:</b> of interaction of energy & matter.			✓		
<b>Science and Technology Standard E:</b> about science and technology.	✓	✓	✓	✓	✓
<b>Science in Personal and Social Perspectives Standard F:</b> of personal and community health.	✓	✓		✓	
<b>Science in Personal and Social Perspectives Standard F:</b> of science and technology in local, national, and global challenges.	✓	✓	✓	✓	
<b>Science in Personal and Social Perspectives Standard F:</b> of environmental quality.				✓	

<b>Science in Personal and Social Perspectives Standard F:</b> of natural and human-induced hazards.	✓	✓		✓	
<b>History and Nature of Science Standard G:</b> of science as a human endeavor.	✓	✓	✓	✓	✓
<b>History and Nature of Science Standard G:</b> of the nature of scientific knowledge.	✓	✓	✓		✓
<b>History and Nature of Science Standard G:</b> of historical perspectives.	✓	✓	✓		

## Anticipation Guides

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

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

### *Mentos and Diet Coke*

Me	Text	Statement
		1. Carbon dioxide is a polar molecule that dissolves fairly well in water.
		2. Ice cubes help carbon dioxide stay dissolved in water.
		3. Nucleation sites cause carbon dioxide molecules to come together and effervesce out of a bottle of soda.
		4. Mentos candies are full of pits, providing many nucleation sites.
		5. The chemicals in Mentos have little to do with the rapid effervescing we see in classic Mentos and Diet Coke demonstrations.
		6. Fruit-flavored Mentos and sugar-free Mentos work just as well as regular Mentos in producing the geyser effect that everyone enjoys watching.

**The Science of NASCAR**

<b>Me</b>	<b>Text</b>	<b>Statement</b>
		1. The frame of all NASCAR cars is thicker around the driver and thinner in the front and rear.
		2. NASCAR cars have air bags.
		3. The windshield of NASCAR cars is made of Lexan, which is also used to make CDs and water bottles for hikers.
		4. The gas tanks of NASCAR cars hold less than 10 gallons of gasoline.
		5. NASCAR cars have 8 cylinders arranged in a V-shape in their engines, reducing vibration.
		6. Gasoline must be vaporized in order to burn in a car engine.
		7. As gas volume increases, the gas pressure decreases inside the cylinders.
		8. NASCAR cars use unleaded 100-octane gasoline.
		9. The tires on NASCAR cars are more than 1 cm thick.
		10. NASCAR tires are filled with ordinary air.

***The Sun: Fusion at Work***

<b>Me</b>	<b>Text</b>	<b>Statement</b>
		1. If the Sun were made of coal, it would burn out in a few thousand years.
		2. By the end of the 19 <sup>th</sup> century, scientists realized that the Sun must produce energy through fusion.
		3. The Sun's temperature and pressure, not its mass, caused nuclear fusion to begin in its core.
		4. When a proton is converted into a neutron, a neutrino and a positron are released.
		5. Using spectroscopy, helium was discovered on the Sun before it was discovered on Earth.
		6. The Sun is about halfway through its life cycle, and it will eventually become a white dwarf.
		7. The Sun's core is where fusion takes place.
		8. Some scientists have predicted that solar storm activity will be intense from 2007-2012, and we will have occasional disruptions in services using satellites such as cell phones and GPS.
		9. About 1% of the solar radiant energy reaching Earth goes into photosynthesis.
		10. Thomas Edison did not believe that solar power would ever be useful.

### *Your Colorful Food*

<b>Me</b>	<b>Text</b>	<b>Statement</b>
		1. Artificial colorants have been used only since the 19 <sup>th</sup> century.
		2. William Perkins, the chemist who synthesized the first synthetic dye, was attempting to synthesize quinine.
		3. Most dyes today are synthesized from petroleum.
		4. The FDA has approved more than 10 synthetic dyes to be used in foods.
		5. Allergic reactions to food colorings were first noticed in the 1980s.
		6. Some synthetic dyes have a greater toxic effect when they are combined with other chemicals such as MSG and aspartame.
		7. Natural dyes are safer than synthetic dyes.
		8. The active ingredient in turmeric, curcumin, is being studied as a possible treatment for Alzheimer's.
		9. Water-soluble food colorants are more desirable than fat-soluble colorants.
		10. Lycopene is a natural dye and antioxidant extracted from tomatoes.

**Alice Ball: Young Chemist Gave Hope to Millions**

<b>Me</b>	<b>Text</b>	<b>Statement</b>
		1. AIDS and Hansen's disease (leprosy) are both caused by viruses.
		2. Long, nonpolar hydrocarbons with high molecular weights are water soluble.
		3. A carboxylic acid and an alcohol can react to form an ester.
		4. Many of today's drugs are salts prepared from reacting the salt of a carboxylic acid with sodium hydroxide.
		5. The ethyl esters of chaulmoogric acid prepared by Alice Ball were water soluble and less viscous than previous treatments for leprosy.
		6. High viscosity is a desirable characteristic for an injectable drug.
		7. Alice Ball died before she could publish the results of her discovery and witness how she helped people with Hansen's disease.
		8. The injectable form of chaulmoogra oil is still used today to treat Hansen's disease.

## Reading Strategies

These matrices 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. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. 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

### Teaching Suggestions:

- Many of the articles include **structural formulas**. If you have not yet taught these shortcuts to your students, you may want to introduce them before your students read the articles.
- **Vocabulary not defined in the reading:**  
“Your Colorful Food”
  - coal tar
  - adsorbed
  - vegans
  - azo dyes

**NASCAR: Chemistry on the Fast Track**

*Examine the safety features found in NASCAR cars by completing the chart below.*

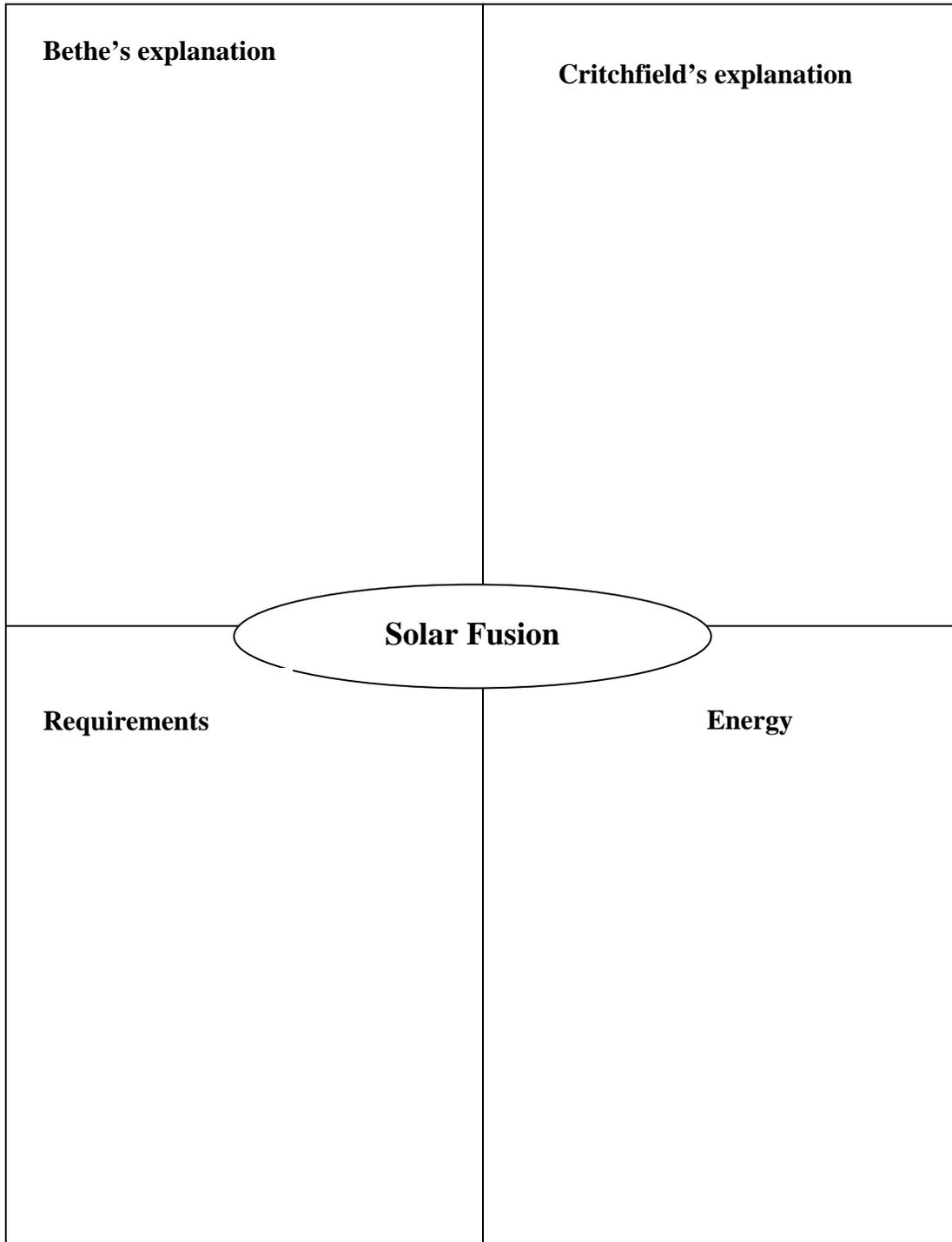
**Safety Features**

<b>Where found</b>	<b>Description</b>	<b>Chemistry involved</b>
<b>Windshield</b>		
<b>Helmet</b>		
<b>Gas Tank</b>		
<b>Cooling System</b>		
<b>Tires</b>		

Compare and contrast the engines and fuels used by NASCAR cars and ordinary cars in the chart below.

	<b>NASCAR Car</b> ↓	<b>Ordinary Car</b>	<b>Similarities</b> ↓
<b>Engine</b>			
<b>FUEL</b>			

*The Sun: Fusion at Work*



Many terms describing Sun-Earth interactions are easily confused. In the chart below, describe each phenomenon.

Term	Description and interesting facts
<b>Solar wind</b>	
<b>Solar flare</b>	
<b>CMEs</b>	
<b>Sunspots</b>	

In the chart below, compare and contrast photovoltaic cells and SEGS.

<b>Photovoltaic cells</b>	<b>SEGS</b>
<b>Similarities</b>	

***Your Colorful Food***

As you read the article, complete the chart below comparing synthetic dyes and natural dyes.

<b>Synthetic Dyes</b>		
<b>Examples</b>	<b>Advantages</b>	<b>Disadvantages</b>

---

<b>Natural Dyes</b>		
<b>Examples</b>	<b>Advantages</b>	<b>Disadvantages</b>

*Alice Ball: Young Chemist Gave Hope to Millions*

<b>Hansen's disease</b> <ul style="list-style-type: none"><li>• Formerly known as _____.</li><li>• Caused by _____.</li><li>• Symptoms include:</li></ul>	
<b>Chaulmoogra oil</b>	
<b>Source</b>	
<b>Reason for disappointing results prior to 1900</b>	
<b>Problems with using the oil to treat Hansen's disease</b>	
<b>Alice Ball's role in solving the problems related to using chaulmoogra oil to treat Hansen's disease</b>	
<b>Other achievements of Alice Ball</b>	
<b>Treatment for Hansen's disease today</b>	

# NASCAR: Chemistry on the Fast Track

## *Background Information*

### **More on Polymers**

Many of the materials discussed in this article are polymers, from the Kevlar in the helmets to the rubber in the tires. Polymers are materials that are made of giant molecules containing thousands of atoms, often arranged in long chains. In addition to Kevlar and rubber, there is Nomex in the drivers' fire-retardant clothing, polyurethane foam in the fuel tank, nylon in the safety harnesses, Lexan<sup>®</sup> (a type of polycarbonate) in the windshield, polypropylene or polystyrene in the helmet liner, and of course that Styrofoam cup underneath the driver's foot is made of polystyrene, too.

Polymers are useful as materials because they generally have robust physical and mechanical properties, such as good strength. This arises from the chain-like structure of polymer molecules. Some chains, like the molecules that make up Kevlar, are very rigid. Meanwhile, other polymer molecules are flexible. This leads to the tangling of polymer chains, which in turn increases the mechanical robustness of the material at the macroscopic level.

There are many different kinds of polymers, with a wide variety of properties, from flexible elastomers (rubber) to stiff and rigid materials like Lexan<sup>®</sup> polycarbonate. The reason for this variety is that many variations in chemical structures are possible within the common chain-like structure.

A polymer molecule is synthesized by chemically joining together many small molecules, called *monomers*. Because long chain-like molecules of a polymer are often made from thousands of identical monomer molecules, they usually contain a simple arrangement of atoms that repeats over and over again, called a repeat unit. Simple changes to the repeat unit structure can cause big changes in the polymer's macroscopic properties.

Many of the polymers used in race cars are crosslinked, that is, chemical reactions are carried out that covalently join all the polymer chain molecules in a material sample together into a giant random three-dimensional network. Tires are made of crosslinked rubber. The Fiberglas body parts of a NASCAR racer are made of a crosslinked polyester that is reinforced with glass fibers. Materials like Fiberglas are called *composites*, because they are fabricated from more than one material. A driver's helmet also contains composites made of crosslinked polymers reinforced with carbon fibers.

Carbon fibers are an unusual kind of material, very closely related to graphite. Graphite is made of carbon atoms, covalently bonded to form extended sheets of aromatic rings joined in a hexagonal "chicken wire" arrangement. If you can imagine graphite sheets which are shaped in the form of long molecular ribbons, and a number of these ribbons bundled together, joined by the attraction of the interacting pi-clouds of all those aromatic rings, you'll get an idea of what carbon fiber is like at the molecular level.

Carbon fiber and Kevlar both can be spun into very strong fibers, and both are used to reinforce composite materials. While the cars raced in NASCAR have frames made of steel, some racing cars like those used in Indy Car and Formula 1 racing have carbon fiber chassis.

More in-depth information about polymers can be found at *The Macrogalleria*, a website created by the University of Southern Mississippi, at <http://www.pslc.ws/mactest/maindir.htm>.

From the main Macrogalleria homepage you can navigate to pages on these particular topics of polymer chemistry relevant to the article:

- Nylon
- Polycarbonates (Lexan<sup>®</sup>)
- Polyurethanes
- Polystyrene
- Polyesters
- Polyisoprene
- Polybutadiene
- Composite materials
- Thermoplastics
- Elastomers
- Thermoplastic elastomers

### **More on Alloys**

Polymers aren't the only materials found in racing cars. Steel makes up the frame and the engine. Steel is an alloy of iron and carbon, and often other metals. Adding carbon to iron makes it stronger and tougher, that is, less brittle. Chromium is sometimes added to steel to protect it from rust, while tungsten makes steel harder. In automobile engines, the steel in the engine block often contains a small amount of nickel that helps it stand up to high temperatures better. While NASCAR engine blocks are made from steel, some racing engines are made from aluminum to save weight. Because aluminum has a much lower melting point than steel, special cylinder liners are needed in aluminum engines. In the 1980s, Porsche developed an alloy of nickel and silicon that resists heat very well, and this was used to make cylinder liners for Formula One racing engines.

### **More on Hydrocarbons and Motor Fuels**

Gasoline is a mixture of hydrocarbons, with larger molecular masses than the hydrocarbons that make up gaseous fuels like propane, butane, and liquefied petroleum gas, but smaller molecular masses than the hydrocarbons in kerosene, diesel fuel, and lubricating oils. Gasoline contains various linear and cyclic isomers of hexanes, heptanes, and octanes, among others. In addition to these aliphatic compounds, gasoline also contains aromatic hydrocarbons like benzene. (In fact, the German word for "gasoline" is *Benzin*.)

Gasoline is made from petroleum in several steps. Gasoline as such does not exist in crude oil. Rather, crude oil is mostly made up of larger hydrocarbons, like pentadecane (C<sub>15</sub>H<sub>32</sub>) for example. "Cracking" is a method by which these large hydrocarbon molecules are broken down into the lighter hydrocarbons of gasoline. There are two kinds of cracking, catalytic and thermal. Catalytic cracking is the preferred method of making gasoline because it requires lower temperatures (making the method cheaper) and because it produces better gasoline. Catalytic cracking makes use of zeolite catalysts, which are aluminosilicate materials, to break down large hydrocarbons at temperatures of around 500°C and at pressures of around 13 atmospheres. Not only are large hydrocarbon molecules broken down into smaller ones in this process, but linear

alkanes are rearranged into highly branched ones, or into aromatic molecules like benzene and toluene. By contrast, thermal cracking requires much higher temperatures (around 700°C) and produces mostly linear alkanes, which make poorer fuels than branched alkanes and aromatic hydrocarbons.

Linear alkanes make poor fuels because they tend to ignite before they're supposed to inside the engine. Ideally, the fuel should ignite when the piston is at the highest point in its path up-and-down inside the cylinder. It is at this top-most point that the air inside the cylinder is most compressed and under the highest pressure. Knowledge of chemical kinetics tells us that a chemical reaction takes place faster when the concentrations of the reactants are higher or, in the case of gas phase reactions, when the pressure is higher. The combustion of the fuel will take place most rapidly, and we'll get the most power from that combustion, when pressure inside the cylinder is the highest. Premature combustion, known as "knock," reduces the amount of power an engine produces. Using gasoline made from branched alkanes reduces knock and improves engine performance.

The octane rating is a measure of how well a gasoline performs. High-octane gasolines result in less knock, while low-octane gasolines produce more knock when they are burned. The standard for measuring octane rating is a compound called iso-octane or, in IUPAC nomenclature, 2,2,4-trimethylpentane. Pure iso-octane is a branched hydrocarbon and makes a very good fuel. This compound is arbitrarily given an octane rating of 100. At the other end of the scale, pure heptane makes a very poor motor fuel, being a linear alkane. Heptane is arbitrarily given an octane rating of 0. Gasolines are rated by the amount of power they can produce, compared to iso-octane and to heptane.

Octane ratings greater than 100 are possible if a fuel performs better than iso-octane. Gasolines with octane ratings higher than the 90s are rarely used for passenger cars, but octane ratings over 100 are common in fuels used in racing and in aviation fuels used by piston-powered aircraft.

Branched alkanes reduce knock and increase the octane rating of a fuel, but additives can achieve the same effect. For many years tetraethyl lead was added to gasoline to increase performance. While tetraethyl lead has been banned in consumer fuels in the United States since the 1970s, it continues to be used in NASCAR racers, though there have been calls to eliminate its use in racing.

Tetraethyl lead works by interfering with the combustion of gasoline. This may sound counter-intuitive, but by inhibiting combustion, tetraethyl lead prevents the premature combustion of fuel that causes engine knock. Combustion is a complex chemical process that involves many reactions in which fuel molecules are broken down, and in which atoms and groups of atoms combine with oxygen. Many of these reactions are radical reactions, that is, they take place between molecular fragments containing unpaired electrons. Tetraethyl lead easily breaks down to produce ethyl radicals as its ethyl groups dissociate from the central lead atom. Radicals are very reactive, reacting with just about anything, but they are most reactive with other radicals, as the unpaired electrons in two different radicals join to form an electron pair (and a covalent bond). These ethyl radicals react with the radicals that are intermediates in combustion processes, halting premature combustion in its tracks, reducing knock.

Tetraethyl lead was removed from street-legal gasoline for two reasons. First, when leaded gasoline is burned, it adds toxic lead compounds to

automobile exhaust. Such compounds have been connected to impaired brain development in children. (This is also why lead compounds have been banned for use in paints in the U.S.) Second, in the 1970s federal law began to require that all new cars come equipped with catalytic converters, devices which clean automobile exhaust before it is released into the atmosphere. Most catalytic converters rely on platinum-based catalysts, but lead compounds in the exhaust produced by leaded gasoline poisons the catalysts, rendering them inactive. For catalytic converters to work properly, unleaded gasoline was necessary.

Catalytic converters are necessary because the combustion of gasoline in an auto engine is not always complete. Ideally, hydrocarbons burn to produce carbon dioxide and water. However, the reaction is not always complete, and some carbon monoxide is produced. The use of computers to ensure a stoichiometric balance of fuel and oxygen in the engine greatly reduces the amount of CO produced, but carbon monoxide isn't eliminated entirely. In the catalytic converter, the platinum catalyst catalyzes the conversion of CO to CO<sub>2</sub>, greatly reducing the toxicity of automobile exhaust. Catalytic converters also eliminate compounds like ammonia, produced by reactions of atmospheric nitrogen with gasoline, by converting them back into N<sub>2</sub> and water. Despite the work of catalytic converters, auto exhaust is still rich in carbon dioxide. While this gas doesn't present a real risk to human health the way carbon monoxide and ammonia do, CO<sub>2</sub> is a greenhouse gas, and CO<sub>2</sub> produced by automobile exhaust is generally accepted to be a major contributor to global warming. NASCAR racers do not use catalytic converters because they can reduce engine horsepower.

There has been discussion in NASCAR of switching from gasoline to ethanol as a racing fuel. Alcohols are often used as motor fuels. Many gasoline blends sold in the United States currently contain a small percentage of ethanol, while one blend, E-85, is actually 85% ethanol mixed with only 15% gasoline. Indy cars have long burned methanol instead of gasoline.

## Historical Perspectives

Gasoline:

When Edward Drake built the world's first oil well in western Pennsylvania in 1859, he wasn't interested in fuel. Petroleum was mostly used for lubricating machines. Coal powered industry and the railroads, and light came from whale oil. Only when whale populations dropped from over-hunting was kerosene, made from petroleum, marketed as lamp fuel. Even then, gasoline was a waste product of kerosene refining with no commercial markets. Gasoline would find its niche with the invention of the internal combustion engine in the 1880s.

At first, gasoline was produced from those 6-8 carbon alkanes naturally found in petroleum. Since petroleum is mostly heavier hydrocarbons, not much gasoline could be extracted from a barrel of oil. Originally thermal cracking used high temperatures to break heavy alkanes down into smaller ones. But this process produced mostly linear alkanes, which make poor fuels. A French oil chemist named Eugene Houdry was working in the United States for Sun Oil Company (now Sunoco) when he developed catalytic cracking, which was first used commercially in 1936. Houdry's process soon saw wartime use as it was used to produce the 100-plus octane fuels used by Allied military aircraft in World War II, in addition to high-octane gasoline for automobiles. It was a few years

earlier, in the early 1920s, that Thomas Midgely, Jr. first developed tetraethyl lead as a gasoline additive to reduce knock and improve engine performance. Interestingly enough, it was Houdry who invented the catalytic converter in the 1950s, which would eventually lead to the elimination of tetraethyl lead from gasoline in the 1970s.

Fuel additives are still a matter of concern for many reasons. In the 1990s, a fuel additive called methyl *tert*-butyl ether (MBTE) became widely used because it made automobile exhaust cleaner. However, it was found that MBTE was leaking from underground storage tanks at gas stations and seeping into ground water. Since MBTE is a suspected carcinogen, it was banned from use in gasoline to prevent contamination of drinking water supplies.

### *Materials*

When NASCAR began in the late 1940s, most parts of a racing car were made from steel, from the engine to the chassis to the body. This was actually high-tech for the time, as the first all-steel framed automobile, the Chrysler Airflow, had only debuted in the 1930s, and it was a flop in the market place. Up until then, wood frames were the norm, and a skeptical public didn't think a steel frame would keep passengers as safe as a wooden one, oddly enough.

Plastic body panels for cars were only an experimental idea in the 1940s. Synthetic polymers had been around awhile. Leo Baekeland invented Bakelite resins in 1907, Wallace Carothers at DuPont invented nylon in 1935, and acrylic plastics came on the scene in the 1940s. Polycarbonate or bisphenol A was invented independently by two scientists. Hermann Schnell working for Bayer invented the material, though production didn't start until several years later. Bayer sells the polymer under the name Makrolon<sup>®</sup>. In the United States, D. W. Fox invented the same material, also in 1953, while working for General Electric. GE sells the material under the name Lexan<sup>®</sup>.

It was in the early 1940s that Henry Ford showed off a car whose body panels were made from a soy-based plastic. In public demonstrations, he would take a sledge hammer to the body, only to have his hammer bounce off the panels as they sprung back into shape after absorbing the blows. While this soy plastic was never used in production, polymer body panels made their production debut in 1953, when Chevrolet introduced the Corvette. Its body was made from Fiberglas, a composite material made from a crosslinked polyester reinforced with glass fibers. This is the same basic material that now makes up the bodies of NASCAR racing vehicles.

Tires inspired big advances in polymer chemistry in the decades before the green flag dropped for the first time on the first NASCAR race on the sand at Daytona. Charles Goodyear made rubber much more useful by learning how to crosslink it in 1839. The pneumatic (inflatable) tire was invented in Ireland by J. B. Dunlop in 1888, not for a race car but for his son's tricycle. The invention of the automobile a few decades later created a whole new market for Dunlop's tires. Natural rubber remained the material of choice for tires for many years. Over the decades there were many attempts to make synthetic rubber, but they only bore fruit during World War II. When Japan occupied Malaysia and Indonesia, where most of the world's natural rubber is grown, the Allies needed to develop a replacement. Natural rubber is a polymer called polyisoprene, but since it was very difficult to produce synthetically, scientists instead developed a different polymer called styrene-butadiene rubber, or SBR. SBR is a copolymer – that is, a polymer made from two different monomers – made from the

monomers styrene and butadiene. This new synthetic rubber performed about equally as well as natural rubber, and it saw wide military use during the war. Afterward, it became equally widely used in tires for civilian use. Both natural and synthetic rubbers are currently used for tire treads. Today, formulating special elastomers just for racing tires is still a challenge for rubber chemists.

For more on the history of rubber and its use in tires, visit The Story of Rubber, from the University of Southern Mississippi Polymer Science Learning Center and the Chemical Heritage Foundation:

<http://www.pslc.ws/macrog/exp/rubber/menu.htm>

### *Connections to Chemistry Concepts*

1. **Types of chemical reactions** — The process of combustion is one of the five basic types of chemical reactions.
2. **Balancing chemical reactions/equations** — Combustion reactions provide extensive examples to use as students learn the process of balancing equations.
3. **Stoichiometry and chemical reactions** — The combustion of fuel in an engine is a chemical reaction, and stoichiometric balance is very important for achieving maximum power and the cleanest possible exhaust.
4. **Isomers and chemical structure** — Understanding the chemistry of gasoline requires understanding the chemical structures of simple organic compounds like alkanes and aromatic hydrocarbons. Also central to gasoline is a grasp of the concept of isomers, compounds with the same molecular formula but different molecular structures.
5. **Gas laws** — The heating of nitrogen gas in a NASCAR racer's tires causes an increase in pressure of the gas according to Gay-Lussac's law. A kinetic molecular model of gas behavior is also necessary to understand how expanding gases move pistons in an internal combustion engine.
6. **Chemical kinetics** — Compression effectively increases the "concentration" of the reactants in the combustion of fuel inside the cylinder. Higher compression means more rapid, and more powerful combustion.
7. **Polymers** — Many of the materials in NASCAR racers are polymeric, which also relates to chemical bonding.
8. **Latent heat of phase changes** — NASCAR drivers must use cooling systems to keep their bodies cool because sweating isn't an effective way to lower body temperature when a driver is wearing all the protective clothing safety requires, because the sweat cannot evaporate. Since evaporation requires that water (or any other liquid) absorb heat from its surroundings, the process normally can cool the body by absorbing heat from the body as the water evaporates.

### **Possible Student Misconceptions**

1. **“Gasoline is a pure substance – octane.”** — Gasoline is a complex mixture of hydrocarbons. Even the performance standard, iso-octane, is only one of many compounds found in normal gasoline.
2. **“Octane is a good motor fuel.”** — Iso-octane is a different compound from *n*-octane, the straight-chain eight-carbon alkane. While iso-octane is a powerful motor fuel, *n*-octane is a poor fuel. Straight-chain alkanes usually are poor fuels compared to branched alkanes like iso-octane.
3. **“Lexan<sup>®</sup> is soft, so it must be flexible, too.”** — Softness, technically speaking, is the ease with which the surface of a material is scratched. It is a property of the surface of a material, and not a property of the bulk material. Lexan<sup>®</sup> is soft, that is, easily scratched, but the bulk material is very rigid. (Lexan<sup>®</sup> is the same polymer that is used to make compact discs, if you'd like the students to see this firsthand.)
4. **“The glass in NASCAR racing helmets is a large single piece of glass like a window or a bottle.”** — Very thin glass fibers are used to reinforce polymers in composite materials. Oddly, when glass is spun into very thin fibers it loses its brittleness, and becomes tough and flexible, and a very good reinforcing material.
5. **“Air is ‘sucked’ into the partial vacuum behind a speeding race car.”** — The surrounding air pushes itself into the region of reduced pressure because its moving molecules are met with little resistance from the air of lower pressure in the partial vacuum. The vacuum does not “suck” or exert force on the surrounding air in any way. Likewise, a car “drafting” behind the speeding race car isn't “sucked” into the partial vacuum. Rather, it just meets little air resistance as it moves by the power of its engine into the region of reduced pressure, allowing the second car to move at the same speed as the first car, but while using less fuel than the first.
6. **“NASCAR racers are powered by fuel cells.”** — The use of the phrase “fuel cell” to refer to the gas tank of a racing car can be misleading here, since the phrase is also used to describe devices for generating electrical energy by breaking down chemical compounds. However, this is a different kind of fuel cell, and NASCAR racers are powered by old-fashioned internal combustion engines, not high-tech fuel cells.

### **Demonstrations and Lessons**

1. **Micro Mole Rockets** — In this experiment, students fill beral pipettes with mixtures of hydrogen and oxygen, and igniting the mixture turns the pipette into a tiny rocket. Students adjust the ratio of oxygen and hydrogen to find out what ratio gives the biggest bang. This models the importance of stoichiometric balance of fuel and oxygen in automobile engines.

<http://marian.creighton.edu/~ksmith/Rockets.htm>

A kit for carrying out this experiment is available from Flinn Scientific:

**Micro Mole Rockets—Hydrogen and Oxygen Mole Ratio**

<http://www.flinnsci.com/Sections/spotlightDisplay.asp?ID=217&cat=2>

2. **Fiberglass repair** — You can prepare fiberglass composite similar to the kinds used in NASCAR bodies using a simple fiberglass repair kit, available at most auto parts stores. The kits consist of an epoxy resin and a fabric of woven glass fibers, and instructions on how to fabricate a composite from them. The chemistry involved is that of forming a crosslinked polymer, as the liquid epoxy molecules join to become a solid network upon curing. (Note the repair kits use an epoxy polymer as the matrix, while most fiberglasses themselves use polyesters as matrices.) Such products should be demonstrated outdoors or under a fume hood.
3. **Fractional distillation** — along with cracking, distillation of petroleum is an important step in making gasoline. It is also one of our oldest chemical techniques, first being used by Arab alchemists many centuries ago. This procedure describes a lab activity for separating a solution of water and isopropanol; part of Antibiotics in Action, a Pharmaceutical Achievers module from the Chemical Heritage Foundation.

<http://www.chemheritage.org/educationalservices/pharm/tg/antibiot/activity/distil.htm>

### ***Suggestions for Student Projects***

1. Students can research different alternative fuels and give reports or presentations on the chemistry involved.
2. Students can research different polymers involved in NASCAR racing, each student preparing a report or presentation on his or her assigned or chosen polymer.
3. Students could investigate the issue of whether NASCAR should eliminate tetraethyl lead from its fuels, and write an opinion report on their position on the issue.

### ***Anticipating Student Questions***

1. **“Why can't you use 110-octane fuel in a regular street automobile?”** — NASCAR gasoline contains tetraethyl lead, which can damage the catalytic converters of street automobiles. Even unleaded gasoline with too high an octane rating can damage the catalytic converter and other emissions-control equipment of a street-legal car. Most cars are designed to use 87-octane gasoline. Most cars have computers that control the fuel-to-air mixture precisely to achieve the best performance. A higher-octane gasoline, more resistant to premature combustion (knock) might not burn completely in an engine designed, tuned, and programmed for 87-octane gasoline. Then unburned gasoline and incompletely burned gasoline are sent through the exhaust system. Catalytic converters are designed to be able to convert a small amount of unburned or partly burned gasoline into carbon dioxide and water, but too much unburned fuel can damage the catalytic converter.

2. **“Why do octane and iso-octane have similar names if they are so different?”** — The trivial names for aliphatic hydrocarbons (but not necessarily their IUPAC names) are based on the number of carbon atoms in the molecule. Molecules of both octane and iso-octane contain eight carbon atoms, even though those eight carbon atoms are arranged differently.
3. **“Why can't liquid gasoline burn?”** — Combustion is reaction with oxygen. Fuels burn when their molecules break down, and the atoms in those molecules combine chemically with oxygen atoms. For this to happen, the molecules in gasoline must come into contact with oxygen molecules from the air. This only happens when gasoline molecules evaporate and enter the air.
4. **“If liquid gasoline can't burn, why is it a fire hazard?”** — A liquid always exists in equilibrium with its vapor. Wherever there is liquid gasoline, there are gasoline vapors, which can ignite very easily. When the vapors burn, they give off lots of heat, which causes more liquid gasoline to evaporate, then burn, giving off more heat, making more gasoline evaporate and burn in a vicious cycle. Gasoline has a much higher vapor pressure than water, due to its molecules being non-polar, exacerbating the situation. Thus gasoline has a very low flashpoint of around 40°C, depending on the blend.
5. **“Why do mufflers reduce the power of an automobile engine?”** — Mufflers restrict the flow of exhaust gases in an automobile. Exhaust gases are forced out of the cylinders and through the exhaust pipes by the upward motion of the pistons after the combustion stroke. The more restrictive the exhaust system, the more energy of the motion of the pistons is used up in pushing out the exhaust gases, and the less is available to turn the crankshaft and drive the wheels.

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"Cracking Alkanes."

<<http://www.chemguide.co.uk/organicprops/alkanes/cracking.html>>

"How Oil Refining Works."

<<http://science.howstuffworks.com/oil-refining4.htm>>

### *Websites for additional Information*

**As Far as Fuel, NASCAR Still a Bit Too Old School** — news story about the call for NASCAR to switch to ethanol fuel, from the *Tapei Times*, Monday, Jul 11, 2005.

<http://www.taipeitimes.com/News/sport/archives/2005/07/11/2003263141>

**Fuels and Society** — a series of three case study lessons based on the story of tetraethyl lead in gasoline, from Kennesaw State University's Chemcases.com.

<http://chemcases.com/fuels/index.htm>

**History of Catalysis** — an online exhibit from the University of Kentucky featuring information on catalytic cracking.

<http://crtc.caer.uky.edu/history.htm>

**The Houdry Process** — the story Eugene Houdry and his catalytic cracking process, from the American Chemical Society's National Chemical Historic Landmarks.

[http://acswebcontent.acs.org/landmarks/landmarks/hdr/hdr\\_houdry.html](http://acswebcontent.acs.org/landmarks/landmarks/hdr/hdr_houdry.html)

**Kathleen Taylor** — short bio of a chemist who made important improvements to catalytic converter technology, part of *Her Lab in Your Life*, from the Chemical Heritage Foundation.

[http://www.chemheritage.org/women\\_chemistry/enviro/taylor.html](http://www.chemheritage.org/women_chemistry/enviro/taylor.html)

**The Macrogalleria** — A broad tutorial on polymer chemistry, including information on specific polymers used in NASCAR racers, from the University of Southern Mississippi.

<http://www.pslc.ws/mactest/maindir.htm>

**Motor Oil** — Feature story on the lubricants that keep engines running, from *Chemical and Engineering News*, March 13, 2006.

<http://pubs.acs.org/subscribe/journals/cen/84/i11/html/8411oil.html>

**The Story of Rubber** — The history and science of elastomers, natural and synthetic, from University of Southern Mississippi Polymer Science Learning Center and the Chemical Heritage Foundation.

<http://www.pslc.ws/macrog/exp/rubber/menu.htm>

# The Sun: Fusion at Work

## *Background Information*

### **More on Stellar Element Synthesis**

[Editor's Note: The following is a very simplified version of some of the theories of stellar nucleosynthesis.]

The **proton-proton fusion cycle** (at temperatures of 5-10 million K) described in the article explains the production of helium nuclei in the cores of stars similar to that of the Sun, which is about as far as the Sun goes in its nucleosynthesis process.

Another process that produces helium in nucleosynthesis is called the **CNO cycle**. This process uses an already-present carbon-12 nucleus as a catalyst to produce helium through a series of 6 steps, producing isotopes of nitrogen and oxygen in the process of finally reproducing the carbon-12 nucleus and forming a new helium nucleus.

To build nuclei heavier than helium, higher temperatures are required. These higher temperatures are typically reached only in stars that are more massive than our Sun, because more mass results in greater density, and greater density means more fusion, and more fusion means more energy produced. Several major processes are believed to occur at these higher temperatures. **Helium burning** (at temperatures of 100 million K) forces three helium nuclei to fuse together, producing carbon and other nuclei close to carbon in atomic mass. Then **carbon burning** (temperatures of 500 million K) fuses two carbon nuclei together to produce magnesium and other elements close to magnesium in atomic mass. To produce heavier nuclei, **oxygen burning** (1 billion K) produces silicon nuclei, and **silicon burning** (2 billion K) can produce iron. Typically, iron is as far as nucleosynthesis goes in average stars. In order to produce elements beyond iron, extremely hot stars, such as supernovae, are the only stars that have high enough energies to overcome the extreme repulsive forces required to make larger nuclei.

At these higher temperatures, more complex nucleosyntheses occur. Two of these processes are referred to as **slow-neutron capture (s-process)** and **rapid-neutron capture (r-process)**. Slow-neutron capture produces a stable nuclide before it captures any successive new neutrons, whereas rapid-neutron capture results in a nuclide capturing many neutrons before it has a chance to decay. The neutron density (flux) determines which process occurs; a high neutron flux results in rapid neutron capture (many are added before it can decay), while low neutron flux gives the nuclide a chance to decay before capturing another neutron. Both these processes produce heavier elements. The s-process is responsible for the production of elements up to the atomic number of iron, and the r-process produces elements heavier than iron.

The information above was taken from two sources: 1) <http://zebu.uoregon.edu/textbook/energygen.html>. (This website also includes animations and narrations on many of the processes discussed above.) 2) <http://astro.berkeley.edu/~niccolo/astro10/Lectures/Presentation15.ppt>.

### **More on Sun's Structure and Fusion in the Sun**

The core of the Sun is estimated to be about 0.2 of the Sun's radius. The density of the core is estimated to be  $150,000 \text{ kg/m}^3$  (150 times the density of water here on Earth). All the energy produced by the Sun originates in the core. All the other parts of the Sun merely transfer energy from the core. Approximately  $3.6 \times 10^{38}$  hydrogen nuclei are fused together in the core every second. This results in the loss of about 4.3 million tons of matter being lost every second. The energy equivalent of this loss is  $9.1 \times 10^{10}$  megatons (that's 91 billion megatons) of TNT! The first step in the proton-proton chain process, that of fusing two protons together, is calculated to require about 1 billion years to happen. There are so many protons in the core of the Sun, however, that the reaction can still occur at a rate rapid enough to sustain fusion.

The hydrostatic equilibrium discussed in the article refers to the fact that the fusion process in the core is density-dependent, so the rate of fusion is self-correcting. If fusion occurs too rapidly, the kinetic energy of the core increases, the core expands, and its density decreases, thus lowering the rate of fusion. If the rate of fusion decreases, the core cools slightly, lowering the kinetic energy and the core would contract, thus increasing its density and increasing the rate of fusion.

The photons of energy emitted in the core from the fusion process are primarily gamma rays and x-rays. These photons absorb and re-emit energies over and over again from all their interactions with other photons, gradually losing energy as they move through the outer zones of the Sun until they reach the photosphere, where they are finally able to escape into space. It is estimated that each gamma ray emits several million visible light photons before it escapes into space.

(Information for the above discussion came from

[http://en.wikipedia.org/wiki/Solar\\_core](http://en.wikipedia.org/wiki/Solar_core), but has been verified from other sources)

### **More on Photovoltaics (solar cells) Research and Development**

Recent History:

In the 1970's, the United States took an early lead in research and development of solar cells that generate electricity, although other countries have also been involved in that research. Although it took approximately 30 years for the world to produce its first billion watts (a Gigawatt) of electricity generated by photovoltaics (PV), it only took 3 years to exceed the second GW, and the rate of PV-electricity-generating has been increasing steadily ever since.

Unfortunately, the lead the US enjoyed dwindled as other countries, particularly Japan and Europe, have invested more government funds in research than has the US. In Japan, the cost of solar-generated electricity is nearly on par with that of conventional generating plants (using non-renewable sources), due in large part to government subsidies for low-cost loans and residential rebates for the installation of rooftop PV units on new home construction. The actual cost of producing energy in Japan by photovoltaic units is about 11 cents per kWh, while that of conventional generating plants is about 21 cents per kWh, so once the unit is built and installed, PV generated electricity is actually cheaper than conventionally generated electricity. This cost does not include the cost of constructing or installing the units, however.

More information on this topic can be obtained from "Power from the Sun", an article in the *Chemical and Engineering News* June, 2004 issue, and online at <http://pubs.acs.org/cen/coverstory/8225/8225solarenergy.html>  
The source of the PV electricity production data, 1971-2003, is [http://www.earth-policy.org/Indicators/2004/indicator12\\_data.htm](http://www.earth-policy.org/Indicators/2004/indicator12_data.htm).

#### Chemistry:

The June 21, 2004 issue of *Chemical and Engineering News* cover story, "Photovoltaic Cells: Power at a Price", provides an insight into how photovoltaic cells work.

At the heart of a solar cell is a light-sensitive, semiconducting material--most commonly silicon. Photons impinging on the semiconductor can excite electrons from the material's valence band to its conduction band. The process generates electron-hole pairs--meaning pairs of negative and positive charge carriers.

If the semiconductor has been doped with impurity atoms so that it contains positively charged (p-type) regions and negatively charged (n-type) regions, then electron-hole pairs created near the interface between the two types of regions (known as a p-n junction) will be affected by a potential difference across the interface. Electrons will migrate toward the positive side of the junction and holes toward the negative side, leading to a flow of electric current.

Solar cells made from wafers of crystalline silicon are common. Large, high-purity single crystals are used to make high-performance cells capable of converting some 25% of incident sunlight into electricity. Even higher efficiencies--roughly 30%--have been demonstrated. But these types of high-end cells, which have proven to be durable in space applications, are very costly because of demanding and energy-intensive crystal-growth and manufacturing processes.

Less expensive forms of silicon, including material with smaller crystal domain sizes and noncrystalline forms, have been studied for years and continue to be investigated. "But you pay a price for using low-cost materials in terms of impurities and defects, which reduce quality and performance," says Ajeet Rohatgi, director of the University Center of Excellence for Photovoltaics at Georgia Institute of Technology. Low-cost amorphous silicon, for example, has been used to make inexpensive solar cell watches and calculators. But such cells degrade with use; their already low efficiencies (around 7%) often fall to half of their initial value.

Research is being done on combinations of semiconductor elements to create solar cells that generate larger amounts of electricity. Sunlight consists principally of infrared, visible, and ultraviolet light. This light corresponds to roughly 1-4 eV of energy. The wavelengths of light absorbed by semiconductors in solar cells depend on the band-gap of the cell material. The band-gap is the energy needed to promote an electron from the valence band to the conduction band in a material. If photons don't have the required energy to match the band-gap, they will not be absorbed, while photons with too much energy will be absorbed, but their excess energy will be re-emitted as heat.

If materials with different band-gaps can be stacked, it is theorized that the range of wavelengths a semiconductor can be widened, thus increasing the efficiency of a PV cell beyond 35%. This has not been as easy as it sounds, however, because their lattice structures frequently do not allow them to be stacked. One candidate for this process is InN, indium nitride, with a band-gap

around 0.7 eV. This compound can be alloyed with GaN (3.4 eV band-gap). By varying the proportions of these two, it is suggested that scientists can produce alloys that will cover the entire solar spectrum, from 1-4 eV. This would allow photovoltaic cells to absorb sunlight at all frequencies. More information can be found in a report in the June 21, 2004 issue of *Chemical and Engineering News*, "Photovoltaic Cells: Power at a Price", or online at <http://pubs.acs.org/cen/coverstory/8225/8225solarenergy1.html>

### **More on Incoming Solar Radiation (Insolation)**

[Editors note: This section is not covered in the article, but this new discovery can have a dramatic impact on our lives in the near future, and this may be something students would want to discuss/research.]

A recent NOVA television show, entitled, "Dimming the Sun", reported that incoming solar radiation is decreasing. After revealing much research that led to the discovery, as well as careful examination, and finally, explanation of the phenomenon, the commentators concluded that the Sun itself has not reduced its radiative output over the decades, and hence is not the cause. Rather pollution in the atmosphere is responsible for "global dimming", specifically, soot and other tiny airborne particles. These particles act as nucleation sites on which water droplets can condense, causing clouds to form. The more particles, the more water droplets form, the more clouds can form. And these clouds contain more smaller water droplets and fewer big ones, allowing larger clouds to form than would normally. Each water droplet in the clouds reflects sunlight. Thus these extra clouds act as giant mirrors and reflect ever-larger amounts of solar radiation back out to space, thus reducing the amount of sunlight that hits the Earth.

This can have a significant effect on the efficiency and efficacy of PV-generated electricity (not to mention the climatological effects, which was the actual focus of this video). A not-to-be-denied side effect of global dimming is the true impact of global warming. Global dimming offsets a significant portion of the actual effect of global warming (caused by the greenhouse effect), so global warming would be increased if we reduce global pollution. Global warming produces 2.6-3.0 watts per meter of land surface area, while the global dimming subtracts about 1.0-1.5 watts per meter. This seems to be a "catch-22" situation. We know we must reduce global pollution, but this will have both good and bad results.

More information, including how to purchase the NOVA DVD and extensive teacher materials to accompany the video, can be found on the PBS website at [http://www.pbs.org/wgbh/nova/teachers/programs/3310\\_sun.html](http://www.pbs.org/wgbh/nova/teachers/programs/3310_sun.html).

### **Connections to Chemistry Concepts**

1. **Nuclear chemistry** – Fusion and stellar synthesis of elements
2. **Reaction kinetics and rates** – If you pursue the proton-proton chain process, you can discuss the mechanism of the fusion reaction, and the initial 2-proton collision reaction as the rate-determining step.
3. **Thermodynamics** – Fusion is an exothermic reaction
4. **Solar spectrum and light emission** – In the section on photovoltaics, the absorption spectra of various semiconductors can be discussed, as

well as the solar emission spectrum. Class discussion can focus on wavelength, frequency and energy calculations.

5. **Activation energy** – The semiconductors in the photovoltaics section need photons that have minimum energies in order to force electron-ejection.
6. **Stellar chemistry** – Students can discuss distribution of elements related to stellar mass.
7. **Bonding** – You can discuss band-theory in metals and metalloids: valence bands, conduction bands, n-layers, p-layers, p-n junctions in solar cells.
8. **Phosphorescence** – Materials absorb sunlight (visible and UV) and then re-emit it as visible light.

### ***Possible Student Misconceptions***

1. **“The Sun is fueled by burning hydrogen.”** Although astrophysicists refer to the process as “burning” hydrogen to produce helium, to a chemist, burning means combining with oxygen to produce heat and light and, since there is virtually no oxygen in the atmosphere or interior of the Sun, there can be no (chemical) burning.
2. **“The Sun’s temperature is the same throughout.”** The article dispels this misconception. The Sun is hottest in the core, where the fusion process is taking place, and is much cooler at its surface.
3. **“Fusion is a one-step process.”** The proton-proton chain shows at least 3 steps in the process – and this process is the simplest of all the nuclear synthesis processes!
4. **“The protons just collide with each other to make a helium nucleus.”** Protons can’t “just collide” due to their strong nuclear repulsions. They must be forced together at high pressures and speeds, as exist in the core of the Sun.
5. **“The Sun is a huge ball of hot gases.”** Actually, the Sun is a huge ball of hot plasma. Gases can’t exist at temperatures as high as those in the Sun. Temperatures this high strip all the electrons off gaseous atoms, resulting in ions only; hence, plasma.
6. **“Photovoltaics could one day solve all our energy problems.”** Photovoltaics will probably never be able to produce all our energy needs. Best estimates say that PV could produce at most about 10-15% of our energy requirements.

### ***Demonstrations and Lessons***

1. To demonstrate the heat that can be generated by the compression of gas, you can use the fire syringe demonstration. It was described fully in the October, 2006 issue of the Teachers Guide to *ChemMatters*, [http://acswebcontent.acs.org/education/chemmatters/Oct\\_06\\_TG.doc](http://acswebcontent.acs.org/education/chemmatters/Oct_06_TG.doc). Scroll down to “Chemistry Builds a Green Home,” Demonstrations and Lessons, number 4. The emphasis in that lesson was on the kinetic energy changes that molecules undergo as they are accelerated by forcing down on the syringe. In the context of this article, the focus

should be on the effect on temperature when a gas is compressed, similar to, but much less intense than what goes on in the core of a star. Students would have to imagine increasing the pressure on this gas by at least 10 billion times that which you the teacher can create in the classroom.

2. A lab which asks students to construct the elemental particles that existed at the time of the Big Bang and soon thereafter can be found at this website: <http://www.csuchico.edu/~cp55/labs.htm/labs.htm/lab2.htm>. Although this sounds trivial, it asks students to actually use their models to produce He from H, and on to larger elements, and then asks pointed questions about the products. You might want to revise several of the questions, based on what you cover in your course (and to correct misspellings), but it is a good way to match physical models to symbols on paper. It also relates fusion in the Sun to fusion in the hydrogen bomb.
3. A lesson on light and electromagnetic emissions can be found at [http://www2.fsec.ucf.edu/en/education/k-12/curricula/use/documents/USE\\_1\\_ElectromagneticSpectrum.pdf](http://www2.fsec.ucf.edu/en/education/k-12/curricula/use/documents/USE_1_ElectromagneticSpectrum.pdf). This lesson focuses on group work researching and reporting on the eight fundamental types of electromagnetic waves. An evaluation rubric is provided.
4. This activity lets students model the Earth:Sun ratio by using a penny to represent the Earth. Students then measure how large the Sun would be, draw a circle with chalk to represent the Sun, and then they place pennies on the diameter to show how many pennies would fit in the diameter of the circle and compare that to their calculated result. The activity can be found at: <http://vathena.arc.nasa.gov/curric/space/sun/sunearth.html>
5. A group project to research and report on specific topics involving solar energy and the history of solar energy can be found at [http://www2.fsec.ucf.edu/en/education/k-12/curricula/use/documents/USE\\_16\\_solar\\_history.pdf](http://www2.fsec.ucf.edu/en/education/k-12/curricula/use/documents/USE_16_solar_history.pdf).

### ***Student Projects***

2. Students can be asked to research the ways in which photovoltaics are being used in the space program and to compare the actual cells used for space to those used for terrestrial purposes.
3. Students can research the way(s) PV cells are manufactured.
4. Students can research the advantages/disadvantages of passive vs. active solar energy production.
5. Students might want to research the scientific methods used to observe the Sun and discover its secrets. NASA might be a good place to start this project. NCAR, alluded to in the article, is another good source. See the active list of solar observing tools used by NCAR at the right side of the screen at this website: <http://www.ucar.edu/research/sun/>. Although this list is extensive (13 different instruments are cited), the background information found at each link may be well beyond the student's ability to understand. (The title of this list, after all, is "For Researchers". Nevertheless, students could use the names of these instruments to begin their search.

6. Glow-in-the-dark (GITD) objects use light (solar or man-made) to cause a chemical reaction, elevating electrons to higher energy levels. Students can experiment with GITD material to learn more about it. The Energy Information Association web site at <http://www.eia.doe.gov/kids/classactivities/GlowInTheDarkSecondaryDec2002.pdf> is a site that gives background information about light-emission by objects that have been exposed to light, and then poses a series of questions to get students started in the experimentation phase of GITD materials. A reference cited by the site in the April 2002 issue of *The Science Teacher* deals with the wave-particle nature of light and phosphorescence.
7. Students could research the energies associated with light-initiated chemical reactions, and then experiment with various colors/wavelengths of light to see if they can replicate the established activation energies. This project would require in-the-lab experimentation and possibly extensive supervision by the teacher.

### ***Anticipating Student Questions***

1. **“Why did ancient civilizations care so much about the Sun?”** Ancient civilizations depended upon the Sun for warmth, light, and to help them grow crops. Being able to track the sun’s movement meant they would know when the seasons would change, when to plant their crops, etc. Basically, their very existence was dependent on their knowledge of the Sun. And since their lives depended on the Sun, it probably seemed natural to them to deify it.
2. **“When will the Sun burn out? (Do I have to worry about the Sun running out of fuel?)”** Scientists believe the Sun has been producing light and heat for about 5 billion years, and has at least as long to go before it becomes a red giant. So, no, you (the student) do not have to worry – at least about the Sun running out of fuel.
3. **“Do sunspots and other solar phenomena affect me?”** Possibly, especially if satellite communications are knocked out for any length of time.
4. **“Does the proton-proton fusion cycle explain the synthesis of all the elements?”** No, the proton-proton cycle only explains the synthesis of helium. Neutron capture is the theory scientists use to explain producing nuclei larger than helium.
5. **“If the Sun only produces helium, where do the heavier elements come from?”** Heavier nuclei come from more massive stars that generate much higher temperatures in their cores. These higher temperatures cause much higher-energy collisions, allowing larger nuclei to overcome their nuclear repulsions and join together into heavier elements.
6. **“Have scientists duplicated the conditions of the Sun’s core in their labs?”** No. Although fusion researchers have achieved temperatures in the millions of degrees range, they have not been able to combine that with the tremendous pressures that exist in the core.

## **Websites for Additional Information**

### **More websites on Solar Energy History**

John Perlin has authored a book, detailing the history of solar energy, that can be found at the California Solar Center website, <http://www.californiasolarcenter.org/history.html>. If you click on each of the three terms in the introduction, photovoltaics, solar thermal, and passive solar architecture, you will be taken to another page of the website that highlights portions of his book dealing with that topic.

This site is a course on the history of solar energy, offered by the University of Rochester: <http://www.history.rochester.edu/class/solar/solar.htm>. The site is used heavily, and you may get a notice that “the page cannot be displayed. There are too many people accessing the web site at this time.”

Another brief history of solar energy research and development in the last 150 years can be found at [http://www.solarenergy.com/info\\_history.html](http://www.solarenergy.com/info_history.html).

A timeline of the history of photovoltaics can be found at <http://inventors.about.com/od/timelines/a/Photovoltaics.htm>.

Another timeline on the history of solar energy, this one including passive solar energy and dating back to the time of the Greeks, can be found at the end of this activity: [http://www2.fsec.ucf.edu/en/education/k-12/curricula/use/documents/USE\\_16\\_solar\\_history.pdf](http://www2.fsec.ucf.edu/en/education/k-12/curricula/use/documents/USE_16_solar_history.pdf).

A brief coverage of ancient history of passive solar energy can be found at <http://www.uccs.edu/~energy/courses/160lectures/solhist.htm>. Socrates appears to be the first person credited with designing architecture to capture the Sun’s heat in the cooler seasons and reflect it in the warm seasons.

An extensive timeline of solar energy use can be found at this government site: [http://www1.eere.energy.gov/solar/solar\\_timeline.html](http://www1.eere.energy.gov/solar/solar_timeline.html).

### **More websites on Using Solar Energy**

This site first gives a brief history of solar energy use, then describes each of the important mechanisms: [http://www.need.org/needpdf/infobook\\_activities/SecInfo/SolarS.pdf](http://www.need.org/needpdf/infobook_activities/SecInfo/SolarS.pdf). The last section of the site describes with diagrams how a photovoltaic cell works. This section alone is “worth the trip”.

Another site that describes the process of electricity production inside a photovoltaic cell, along with a diagram illustrating the process, can be found at: [http://www.nmsea.org/Curriculum/7\\_12/PV/explore\\_pv.htm](http://www.nmsea.org/Curriculum/7_12/PV/explore_pv.htm).

### More websites on the Sun's Structure

This site contains much information, not only about the Sun's structure (and the other planets), but also about the mythology that surrounded the Sun in man's early history. Visit it at [http://www.mikehagan.com/Helios\\_mod.htm](http://www.mikehagan.com/Helios_mod.htm)

A site that contains diagrams and photographs that accompany the discussion of the structure of the Sun can be found at <http://www.pas.rochester.edu/~afrank/A105/LectureVII/LectureVII.html>. The site also gives a little background information on the process by which scientists have discovered the Sun's structure.

NASA provides information about the Sun's structure at <http://son.nasa.gov/tass/content/structure.htm>.

### More websites on Fusion Reactions

For a slightly more detailed coverage of the proton-proton chain reaction, see <http://www.answers.com/topic/proton-proton-chain-reaction>, or <http://hyperphysics.phy-astr.gsu.edu/hbase/astro/procyc.html>.

For an animated version of the individual steps in the proton-proton chain, check out the "Astronomy Hyper Textbook" at <http://zebu.uoregon.edu/textbook/energygen.html>, or find the same information at <http://burro.cwru.edu/Academics/Astr221/StarPhys/ppchain.html>.

This site isn't quite as flashy as the previous two showing the proton-proton chain, but the animation is slower and easier to follow: <http://www.physics.mun.ca/~jjerrett/protonproton/pp.html>.

A downloadable slide show from a course on astrobiology is available here: <http://astrobiology.asu.edu/class/archive/dante/index.htm>. The PowerPoint show contains slides that may be irrelevant to this discussion, but it also contains slides showing the processes that produce heavier elements than helium, and cut-away illustrations of stars that produce these elements. It also provides a chart of relative abundances of the elements, and a nice slide showing how heavier elements can be built by the addition of helium nuclei. Several of the slides are supposed to include animation (the proton-proton cycle again), but I could not view the animations from within the slide show; however, they are accessible from the home page of the website.

For a description of nuclear synthesis that gives a good overview without too much depth on the specific synthesis reactions, see [http://www.astro.umd.edu/~immler/Lecture\\_20.pdf](http://www.astro.umd.edu/~immler/Lecture_20.pdf). This website begins a little further back in the history of nuclear synthesis – way back to the time of the Big Bang!

A tutorial section of the web support materials for the textbook, *Chemistry, The Science in Context*, by W. W. Norton Publishers, shows animated views of the 3 parts of the proton-proton cycle, as well as the slow (s) and rapid (r) neutron capture processes for synthesizing heavier elements in more massive stars. The

relevant specific section of the site is at  
<http://www2.wwnorton.com/college/chemistry/gilbert/tutorials/ch2.htm>.

### **More websites on the Neutron Capture Processes**

This site, from the “Windows to the Universe” project of the University Corporation for Atmospheric Research, shows an animated example for each of the two neutron capture processes:

[http://www.windows.ucar.edu/tour/link=/sun/Solar\\_interior/Nuclear\\_Reactions/Fusion/Fusion\\_in\\_stars/ncapture.html&edu=high](http://www.windows.ucar.edu/tour/link=/sun/Solar_interior/Nuclear_Reactions/Fusion/Fusion_in_stars/ncapture.html&edu=high). (The movies actually came from the University of Oregon.)

### **More websites on the Electromagnetic Spectrum**

NASA gives a brief history of the electromagnetic spectrum at  
<http://son.nasa.gov/tass/content/electrospectrum.htm>.

### **More websites on General Information about the Sun**

The aforementioned Wikipedia site,  
<http://en.wikipedia.org/w/index.php?title=Sun&oldid=50042408#Core>, also contains much more information, including an extensive list of references and web links. One link, “a collection of solar movies”, shows what the sun looks like through photos of its photosphere, chromosphere and corona.

# “Your Colorful Food”

## *Background Information*

The article, “Your Colorful Food,” has as its emphasis the use of dye materials, also known as color additives, in foods and the resultant safety and health issues that accompany ingestion of these dyes. Oversight concerning health issues resides with the Federal government agency, the Food and Drug Administration (FDA).

## **More on the Food and Drug Administration**

The FDA came into existence in 1906 through the Food and Drug Act. A voluntary certification program was established at the same time and was administered through the U.S. Department of Agriculture (USDA). At that time seven “man-made” color additives were listed for inclusion in food, down from 80 in use in 1900. An interesting history of food dyes with many examples of specific chemicals (many toxic) used to dye foods prior to 1906 is found in the ChemMatters article, “*The Unadulterated History of Food Dyes*” (ChemMatters, Dec. 1999, pp. 6-7). These seven color additives became known as “certifiable color additives”. But there was a need to separate various color additives into groups depending upon their use. The categories established were:

- Food, Drug and Cosmetic (FD & C)
- Drug and Cosmetic (D & C)
- External Drug and Cosmetic (External D & C)

“In 1960, the Color Additive Amendments to the FD&C Act placed color additives on a ‘provisional’ list and required further testing using up-to-date procedures. One section of the amendment, known as the Delaney Clause, prohibits adding to any food a substance that has been shown to cause cancer in animals or man regardless of the dose. Under the amendments, color additives exempt from certification also are required to meet rigorous safety standards prior to being permitted for use in foods.” (p. 3, <http://www.cfsan.fda.gov/~lrd/colorfac.html>)

There is also the issue of the efficacy of using synthetic dyes vs. dyes from natural sources. Under the jurisdiction of the FDA, there is a well-established protocol for testing and approving any substance that is to be used as a food color additive. (See the previous reference, [www.cfsan.fda.gov](http://www.cfsan.fda.gov)). In addition to the testing protocols, there is a separate Adverse Reaction Monitoring System (ARMS) that investigates all complaints by individuals or their physicians that are believed to be due to the consumption of a particular food, vitamin or mineral supplement. The computerized database serves as a reference point for officials to decide if a public health hazard exists and to take necessary action. Two issues surface in the article related to potential health hazards:

- Allergic reactions (all ages)
- Hyperactivity in children

## **More on Allergic Reactions**

The basic principles behind allergies/allergic reactions revolve around the biological concept that the human body, through its immune system, reacts to ingestion of a foreign substance, usually protein, bacterial or viral in nature as well as a variety of chemical substances found in pharmaceuticals. The potential is present in any one human being to react against any particular substance ingested through its immune

system. Repeated exposure to the same substance can set off a highly sensitized immune system in a fatal scenario known as anaphylaxis.

Even so, in the human population, an immune reaction that produces hives, for instance, produces such a reaction in less than one person per 10,000 when exposed to FD&C Yellow dye #5. For all immune reactions from various sources, the average rate of allergic reaction is between one and four per 10,000 according to various medical sources. In an abstract of an article, "**Adverse Reactions to Food Additives**", Ronald A. Simon, MD (in *Current Allergy and Asthma Reports* 2003, **3**:62-66, Current Science, Inc. ISSN 1529-7322) remarks that with "...individuals who have reactions to single additives, most of the medical literature involves patients with asthma or chronic idiopathic urticaria (hives or skin rash)/angiodema (swelling below skin surface) whose conditions are exacerbated after ingestion of food additives. Many of these reports are characterized by poorly controlled challenge procedures. Recent studies performed under properly controlled conditions imply that sensitivity to food additives in patients with chronic urticaria/angiodema is very UNCOMMON."

### **More on Hyperactivity**

Much the same story is associated with the implication that ingestion of food additives is a major inducer of hyperactivity in children. The FDA in its publication "Food Color Facts" (U.S Food and Drug Administration, FDA/IFIC Brochure, found at [www.cfsan.fda.gov/~lrd/colorfac.html](http://www.cfsan.fda.gov/~lrd/colorfac.html)) states that, "Although this theory (food additive-induced hyperactivity) was popularized in the 1970's, well-controlled studies conducted since then have produced no evidence that food color additives cause hyperactivity or learning disabilities in children.

A Consensus Development Panel of the National Institutes of Health concluded in 1982 that there was no scientific evidence to support the claim that colorings or other food additives cause hyperactivity. The panel said that elimination diets should not be used universally to treat childhood hyperactivity, since there is no scientific evidence to predict which children may benefit." There is an interesting find that is related to what appears to be an increase in the incidence of allergic reactions (all sources) in children. There appears to be an inverse correlation between allergic reactions and hygiene, i.e., with increased hygiene and the reduction of microbial exposure, there is an increase in allergic reactions!

The use of natural sources of food dyes is limited because of their lack of stability and the increased cost of isolation from their source compared with synthesized dyes, be they copies of natural types or simply a different molecule that is able to produce the needed color in food. The FDA lists a variety of natural food dyes from plant sources that are exempt from certification. They include such things as paprika, carotene, beet powder, caramel, turmeric fruit and vegetable juice, among others. Other plant extracts such as grape skin extract and grape color extract are exempt from certification but are restricted to specific uses.

### **More on Food Additives**

When it comes to the health benefits of various food additives, including some dyes, the scientific literature presents a complicated and unclear picture of the resultant effects of many specific chemicals thought to have some medicinal benefit for a particular health issue. Two examples come to mind. One is that of lycopene (the red coloration in tomatoes) and the other is curcumin, the active ingredient of the Indian curry spice, turmeric.

Lycopene is known as a carotenoid (those pigments that produce yellow, orange or red color in plants) and is found in various organs of the body at higher levels than the

other carotenoids. Though known to be an antioxidant (a substance that prevents destruction or alteration of a chemical through the oxidation process), its activity in humans is unclear based on reliable scientific studies (a long list of references to these studies can be found at [www.mayoclinic.com/health/lycopene/NS\\_patient-lycopene](http://www.mayoclinic.com/health/lycopene/NS_patient-lycopene)). In studying the effects of lycopene, the estimates of consumption are based on reported tomato intake, not on lycopene supplements. Since tomatoes are sources of other nutrients including vitamin C, folate, and potassium, it is not clear that lycopene by itself is beneficial. In a listing of various disease conditions and the ameliorative effect of lycopene consumption, the Mayo Clinic article gave a grade of C (= unclear scientific evidence for the use of a certain substance in preventing a certain condition) to such things as age-related macular degeneration, asthma caused by exercise, prostate cancer, colorectal cancer prevention, and high cholesterol among others.

Another example of the complicated situation when doing research involving human physiology is the study of the natural food additive, curcumin, the active ingredient found in turmeric, one of the spices in curry. Anecdotal evidence suggests that curcumin improves mental functions, based on a survey of over a 1000 Asian people, ages 60-93, who ate yellow curry once every six months or more. The mental tests administered to these subjects produced higher results than in another group who did not eat the curry-based sauce. However, it is not possible to conclude that curry consumption was the agent of change; it is possible that the subjects with healthy habits also tended to eat the curry or some other cause and effect. On the other hand, studies done on mice suggest that curcumin might inhibit the accumulation of the plaque, beta-amyloid, in the brains of Alzheimer patients as well as break up the existing plaque. But, as usual, mice are not the same as humans. A known function of curcumin is the inhibition of two specific enzymes connected with inflammation that is associated with development of the plaque in Alzheimer's. (A regular regimen of non-steroidal anti-inflammatories, eg. daily use of 80mg aspirin, seems to correlate with a reduction in the incidence of Alzheimer's.

(ref. [www.newscientist.com/article.ne?id=mg10125635.500](http://www.newscientist.com/article.ne?id=mg10125635.500))

### **More on Non-Food Dyes**

In the general realm of non-food dyes, there is a lot of chemistry involved with the interaction of a variety of dyestuffs and the material (cloth, hair, leather) to which they are applied. The sources of these dyes and their chemical treatment to extract as well as to apply to different surfaces are extensive. These dyes have a history that stretches back to the times of the Greeks and Romans. Included in the collection is Tyrian purple extracted from a Mediterranean mollusk. Only royalty in the Roman Empire (think Julius Caesar) could wear cloth dyed with Tyrian purple. Insects provide dyes including the scarlet dye, Kermes, obtained from an insect that lives on oak trees as well as the famous red dye, cochineal, extracted from an insect that lives on cactus plants. Both dyes were known and used as early as 1400 BC (and documented in writings of that period).

Extracting the dye is one matter, applying the dye to cloth and having it stick to the cloth is another matter. That gets into the chemistry of mordants that help bind the dye to the cloth fibers (a coupling agent). Mordants are usually salts of metals- chromium, aluminum, copper, iron and tin. The dye molecule can change color when bound to the mordant. Indigo dye (originally from a plant, now synthesized) is an approved dye by the FDA for use in cosmetics. It is also the dye of choice for blue jeans using what is known as the "vat dyeing" process that does not require a mordant but rather the use of reduction, then oxidation of the dye molecule which becomes insoluble and therefore difficult to remove from the fibers. Two useful references on the chemistry of dyeing

materials are “**Natural Dyes**” in the December 1986 issue of ChemMatters, pp. 4-8, and a very extensive treatment in the chemistry teacher resource known as “**ChemSource**” (available through the American Chemical Society, <http://store.acs.org/cgi-bin/acsonline.storefront>), version 2.1. The module found in Volume 1, “Chemistry of Color”, includes some activities for the synthesis and application of several dyes along with background information that first year chemistry students can use.

The chemistry involved in trying to make a product such as lipstick clearly shows the complexity (and ingenuity, chemically speaking) of trying to mix a number of chemicals together that need to stay suspended in the mixture, not fade, and not turn rancid. If you consider a tube of lipstick, this product contains no less than seventeen chemicals in combination including 5 different FDA approved dyes for cosmetics (two of which are aluminum lakes), three different waxes, two oils (mineral and castor), one alcohol (propylene glycol), and several other chemicals including the plant extract aloe. The combination presents the problem of blending as well as preserving. A good reading on this particular product’s manufacture is found in ChemMatters, December 1985, pp.8-11.

### **Connections to Chemistry Concepts**

1. **Polar, non-polar molecules** — the mixing of dyes with foods and cloth fibers requires that the dyes match the polar or nonpolar characteristics of the substance to be dyed (“like dissolves like”)
2. **Mordant** — mordants act like soaps in chemically “connecting” (bonding) a dye to its substrate, particularly when the dye and the substrate are opposite in terms of polar/nonpolar. Usually when working with dyes for cloth, the mordant is applied first, adhering to the cloth fibers. Then the dye is added which attaches to the mordant, rather than the cloth.
3. **Oxidation, reduction** — dyes in food and cloth materials can undergo oxidation and reduction with a change in color. Bleaching (sodium hypochlorite, sunlight, oxygen) works through the oxidation of a dye, changing what is known as the azo group in an organic molecule from  $-N=N$  to  $-N=N-O$ . Other chemicals can also “bleach” a color but do so by reduction, in which the reducing agent breaks the azo group, thus destroying the dye molecule’s ability to produce color through selective absorption/reflection of light.
4. **Acid-Base Indicators** — many indicators are weak organic acids that change molecular structure and color when accepting or losing a proton.
5. **pH** — the dyeing process depends on pH of the reacting solutions (or dye baths).
6. **Chromatography** — a separation technique that depends upon the interaction of a mixture of molecules in a separating medium (paper, silica gel, starch, gases) with the different molecules separating because of different rates of interaction with the separating medium’s molecules. Chromatography illustrates some fundamental properties of molecular interaction based on molecular structure.
7. **Synergism** — this phenomenon is as important in the genesis of environmental problems as it is in the physiological outcome of pharmaceutical and food ingestion in humans.
8. **Solubility** — the mixing of dyes with binders that can be applied to food, plant and animal fibers, body parts (think lipstick, makeup, skin preparations), and pharmaceuticals require a “match” in terms of polar/nonpolar properties. Otherwise,

mixing requires additional chemicals that join “unlikes”, be it a soap, a “lake”, or a mordant, among other chemical groups.

9. **Anti-oxidants** — chemicals that counter or reduce the rate of the oxidation process by reducing the rate of uptake of molecular oxygen. Oxidation is associated with corrosion of metal as well as the change in unsaturated fats that produces rancidity. Vitamins such as A, C, and E are antioxidants in use in the biological realm (food preservation, nutrition, medicine). Their effectiveness in nutrition and preventive medicine is still being investigated. A good summary can be found at <http://en.wikipedia.org/wiki/Antioxidant>.

### ***Possible Student Misconceptions***

1. **“Materials have color.”** — Light as we see it results from various wavelengths of electromagnetic radiation reaching our “light” sensitive eyes. What wavelengths of this spectrum reach our eye from a material that is exposed to “white light” depends on the interaction (absorption, reflection) of the light with the molecules of the material. The particular wavelengths that reach the retina from the material are interpreted by our brain to be a particular color.
2. **“Color produced by a substance is due to the absorption of that color.”** (A red dye color is produced when the dye absorbs red from the light source, a green leaf absorbs green light which we see.) — What light reaches our retina determines the color we associate with the source. If a particular color is absorbed, it could not reach our retina. So we see based primarily on reflection of light from a surface.
3. **“White light exists.”** — Technically, white light is produced when different wavelengths of light interact with the color-detecting cones in our retina. These cones detect magenta, cyan and yellow. The overlapping of these three primary additive colors produce white light. This can be demonstrated with traditional color wheels purchased from science supply stores.
4. **“Black light is the result of mixing red, green and blue light.”** — Black light does not really exist. Black is simply the absence of color. One has to distinguish the effect of producing white light through the addition of the wavelengths of the three primary colors (magenta, cyan, and yellow). Removing these three primary colors through absorption (subtraction) by materials (paint pigments) results in black.

### ***Demonstrations and Lessons***

1. **Separation of Food Colors in Candy** — “Activity2: Chromatographic Comparison of M&M™ Candies with Reese’s Pieces™ “ (ChemSource, Version 1.0, Vol. 2, Food and Chemistry module, p10-14)  
[http://chemmovies.unl.edu/chem\\_source\\_pdf/ChemSource.html](http://chemmovies.unl.edu/chem_source_pdf/ChemSource.html)
2. **Separation of Food Colors in Candy** — (see “How Many Ways Can You See Red?”, ChemMatters, December 1999, p. 8)
3. **Isolation of Chlorophyll by Paper Chromatography** — (see ChemSource, Version 1.0, Vol.4, Separations module, pp 21-22)  
[http://chemmovies.unl.edu/chem\\_source\\_pdf/ChemSource.html](http://chemmovies.unl.edu/chem_source_pdf/ChemSource.html)

4. **Isolation of the pigment in red cabbage by heating in water** — The pigment is sensitive to pH and can be used as an indicator. Set up test tubes with different molarities of HCl or NaOH to cover the pH range from 1-14. Students can use the cabbage juice to test the pH of various solutions, using the reference pH colors prepared above.
5. **Demonstrations showing the interaction of various wavelengths of light on different colored materials to demonstrate selective absorption, reflection and transmission.** — (See ChemSource, Version 2.1, Vol.1, “Chemistry of Color” unit, pp8-11. Additional activities related to instruction in the principles of light, color production and vision are also found in this unit. Check with your friendly physics teacher for demonstrations concerning the principles of the behavior of light.

### *Suggestions for Student Projects*

1. Students can put their research skills to use in documenting how much and in what ways fruits and vegetables are preserved both for transport to markets as well as color enhanced for display in stores. The same is true in boxed, frozen, and canned food. What are the preservatives? What antioxidants are added? Are these substances from natural sources or synthesized? Simply take a container and list all the ingredients present. These substances can then be identified in terms of chemical composition and function. One source to start with is <http://sci-toys.com/ingredients/ingredients.html>.
2. Students can investigate both the prevalence of food allergies in children and young adults and the causes of these allergies. (See references listed at the end of this guide).
3. Students can learn to extract pigments from plants and use as paints. In the process, they could evaluate how long the paints endure before fading. Are there particular colors that last longer? Are their particular plant sources that produce more, longer lasting colors? Does the addition of antioxidants such as the various vitamins A, C and E make a difference?
4. Students can test the stability of dyes under different chemical conditions. One such lab activity is found in **“Consumer Chemistry”** (published by Holt, Rinehart and Winston, ISBN # 0-03-054374-6)- Lab #D6, Cloth of Many Colors, p.27. Another set of similar activities is found in ChemSource, (Version 2.1), Vol.1, **“The Chemistry of Color”**, Activity #2 “Synthesis and Application of Dyes” pp. 17-24.
5. Students can synthesize a dye, Prussian Blue, and test its properties. Consult ChemSource (Version 2.1), Vol.1, **“The Chemistry of Color”**, Activity #1, p 14-16
6. Directions for making a dye from natural sources and dyeing an article of clothing can be found in ChemMatters, Dec. 1985, p. 12.
7. Students can research the rather amazing phenomenon of vision, including the manner by which electromagnetic radiation (including UV, infrared and visible light) produces vision through the interaction (and chemical changes) of the pigment molecules, rhodopsin (in the retinal rods) and iodopsins (in the color sensitive cones). The rhodopsin is synthesized from carotene that gives carrots their orange color. The carotene is converted to Vitamin A, then one step removed, rhodopsin. The iodopsins, found in the cones, are three different molecules that absorb in the three primary “color” wavelengths of yellowish-green, green, and greenish-blue to produce color vision. Each iodopsin differs by several amino acids that determine at what frequency (-ies) the molecule will vibrate (absorb energy). There is a lot of

chemistry happening to produce vision. One useful starting reference (with additional resources listed) is found at

<http://www.chm.bris.ac.uk/webprojects2003/rogers/998/Rhoeye>

8. Students could research the chemistry behind the process of photosynthesis which includes the design of the chlorophyll molecules (there are several) for their ability to vibrate at certain wavelengths of light, transferring the energy absorbed to excited electrons of the magnesium atom in the chlorophyll, then allowing for a cascade effect of the electrons as they return to their resting state in the magnesium. This can be compared with the energy transfer in vision, where the specific pigment molecules of the cones absorb the light energy at specific frequencies which in turn sets off the nerve impulses to the brain.

### *Anticipating Student Questions*

1. **“Why does a red object under blue light appear black?”** — The “dye” molecules that give the red color do so by absorbing out other frequencies of light in the light source (assume white light) but reflect back the red. If the light source is blue, the red object absorbs the blue (and any other frequencies present). No blue (or any other color) is reflected back to your eye. Black is the absence of color (absorption of red or magenta, yellow, and blue or cyan produces black or no color!).
2. **“How does a TV produce colors on the screen?”** — A TV set produces colors through the use of three different phosphors that emit one of three wavelengths of the three primary colors- magenta, cyan or yellow. These wavelengths are produced when the phosphors are bombarded with high-speed electrons. Absorption of the electrons gives energy to electrons in the atoms of the phosphors, changing their resting state energies. When the atom’s energized electrons return to their resting state position (and potential energies), there is a loss of potential energy that is emitted as a particular wavelength of light that we see as a color, depending on what individual wavelengths of light reach the color-absorbing cones in the retina of our eye. In turn the energy of the light absorbed by special chemicals in our retina produce nerve impulses through excited electrons in the retina’s pigment molecules (rhodopsin) that are “interpreted” in the visual cortex of our brain.
3. **“Can birds see in color (since many birds have brilliant colors)?”** — Recent research suggests that birds not only see in color but see better than humans. Based on DNA evidence, it seems that humans lost one of four original cone types (that are involved in color detection in the retina) found in our mammalian ancestors, whereas birds have kept the four cone types. The presence of four cones gives more acute and discriminating color detection compared with humans. It even allows birds to see in the ultraviolet region of the electromagnetic spectrum. Other mammals, including cats, cows and dogs, have only two types of cones, further limiting the range and acuity of color vision for them. (see Scientific American, July 2006, “What Birds See”, pp.68-75; [www.sciam.com](http://www.sciam.com))
4. **“Why do some sea creatures have bright colors when viewed out of the water?”** — Aren’t those colors the opposite of camouflage, i.e., won’t they make the animal more “visible” to a predator? Because seawater absorbs out various wavelengths of light the deeper the light source penetrates, we are no longer talking about the original “white light” (many different wavelengths of light). At any particular depth, the “colors” that remain to be absorbed or reflected by sea animals and plants will determine the appearance of that object which will be different than in “white

light” at the surface of the ocean. In other words, the sea creature or plant will be appropriately colored (camouflaged) for its location and the available wavelengths of light.

### ***Websites for additional Information***

The basic information about food color – testing, regulating its use, safety issues, and legislation – can be found at the Food and Drug Administration (FDA) websites: <http://www.cfsan.fda.gov/~dms/col-toc.html>, <http://www.cfsan.fda.gov/~lrd/colorfac.html>

A list of approved dyes for food, cosmetics and pharmaceuticals can be found at the FDA website, <http://www.cfsan.fda.gov/~dms/opa-col2.html>. The specific regulatory procedures for approving color additives and cosmetics can be found at this additional FDA website, <http://www.cfsan.fda.gov/~dms/cos-col.html>

For reliable scientific information about the status of food additives and their health benefits and risks, consult the Linus Pauling website at Oregon State University, <http://lpi.oregonstate.edu/infocenter/foods.html>, and the Mayo Clinic at <http://www.mayoclinic.com/>

A discussion of food allergies versus food intolerance, an important distinction, can be found at <http://www.clevelandclinic.org/health/health-info/docs/2900/2988.asp?index=10009>

If you really want to know what chemical additives, preservatives and food colors are contained in food and personal care products check this website, <http://sci-toys.com/ingredients/ingredients.html>.

The fundamentals of allergies, particularly in children, can be found at <http://kidshealth.org/parent/medical/allergies/allergy.html> as well as at the Mayo Clinic website mentioned previously (<http://www.mayoclinic.com/>)

A chemistry teacher resource that is worth having and has been referred to in this teacher guide is the ChemSource, a four volume publication covering every topic normally taught in a first year chemistry course. The organization of the volumes include teacher notes, demonstrations with background, laboratory activities, background information about various chemistry concepts, historical notes, AV resources and even humor. The most recent version, 2.1, can be purchased through the American Chemical Society (<http://store.acs.org/cgi-bin/acsonline.storefront>). That version includes the unit on the chemistry of color. The earlier version 1.0 can be accessed on the web and downloaded at [http://chemmovies.unl.edu/chem\\_source\\_pdf/ChemSource.html](http://chemmovies.unl.edu/chem_source_pdf/ChemSource.html).

# Alice Ball

## *Background Information*

### **More on Alice Ball**

Ball was born in 1892 and grew up in Seattle, Washington. She moved with her family from Seattle to Oahu, Hawaii, in 1903. Her father, James P. Ball Jr., was a lawyer and editor of an African-American newspaper. Her mother, Laura Ball, was a photographer. James Presley Ball Sr., her grandfather, was an abolitionist and renowned photographer who took portraits of influential African-American leaders and other prominent individuals.

Ball attended eighth grade at Central Grammar School in Honolulu before her family moved back to Seattle after the death of her grandfather. Upon their return to Seattle, Ball entered Seattle High School in 1906. She was admitted to the University of Washington in 1910, and graduated with two bachelor's degrees—one in pharmaceutical chemistry (1912) and the other in pharmacy (1914). She returned to Hawaii for graduate school at what is now known as the University of Hawaii. She received a Master of Science in chemistry in 1915.

As the article suggests, Ball's master's thesis was the chemical ingredients of the kava root (*Piper methysticum*). The plant extract had been used as a beverage in the islands of the Pacific for many years. It is known to be an effective anti-depressant and as a treatment for insomnia. The main active ingredients in kava root are called kava pyrones, or kava lactones. At least fifteen of these have been isolated including kawain, methysticin, demethoxy-yangonin, dihydrokawain, dihydromethysticin, and yongonin.

When she received her master's degree she was invited to remain at the university as an instructor, the first woman and the first African-American to do so at the University of Hawaii.

Because there was no effective treatment for Hansen's disease at the time, Dr. Harry H. Hollman, the U.S. public health officer in Hawaii, asked Ball to apply her knowledge of plant chemistry to chaulmoogra oil. Ball was able to isolate an ethyl ester of the oil, which became an injectable treatment for the disease.

J.P. Ball, Alice's grandfather, was a well-known photographer with studios in Europe as well as the United States. His work is included in a Smithsonian exhibition on black photographers that opened this month in Washington, D.C. Ball was a friend of Booker T. Washington and shot images of notable people such as Frederick Douglass. He moved to Hawaii for health reasons, and died in the islands on May 4, 1904, at age 79.

### **More on Harry Hollmann**

Dr. Harry Hollmann was head of the United States Leprosy Investigation Station in Hawaii when he recruited Alice Ball to work on chaulmoogra oil. According to the The Mamiya Medical Heritage Center, located in the Hawaii Medical Library:

“Harry Triebner Hollmann was born in Philadelphia, Pennsylvania, on December 13, 1878, the son of Harry and Mary (Thomas) Hollmann.

“His early education was received in the public schools of Philadelphia. He attended Temple University, Philadelphia, and the Medico-Chirurgical College (now part of the University of Pennsylvania) which granted him his medical degree in 1898.

“In 1900 he married Amelia Duncalfe at Richmond, Kentucky. He later married Benita Clarke in 1929, with whom he had three children, Bonita Leilani, Pamela Jane and Harry T. Jr.

“Dr. Hollmann was instructor in Pathology and Bacteriology at the Medico-Chirurgical College from 1898 to 1906. He was physician to the Bureau of Health in Philadelphia, 1903-06. From 1905-06 he was visiting ear, nose and throat surgeon at the Philadelphia General Hospital.

“Dr. Hollmann was internationally recognized as an authority on leprosy and was credited with having originated treatment with the ethyl esters extracts of chaulmoogra oil. Due to his interest in leprosy, Dr. Hollmann was appointed assistant superintendent of the leper settlement on the Island of Molokai in 1906. The following year he was transferred to the United States Leprosy Investigation Station, Honolulu. Dr. Hollmann was one of the first to cultivate the germ of "rat leprosy". He also wrote many articles on leprosy and skin diseases which were published by the U.S. Public Health Service. In 1917 and 1918 Dr. Hollmann was director of the Leprosy Investigation Station and medical superintendent of the Kalihi Hospital.

“Later he resigned to become superintendent of the Queen's Hospital for one year, following which he entered private practice in Honolulu, specializing in dermatology and urology.

“Dr. Hollmann died on December 13, 1942 at the age of 64.”

### **More on Arthur Dean**

Arthur Dean was the head of the chemistry department at the College of Hawaii when Alice Ball did her research on Chaulmoogra oil. He later became its president. Dean apparently continued her work and received credit for the discovery.

In an article published in Time magazine September 22, 1930, another name was added to the list of Chaulmoogra researchers—Richard Wrenshall. Wrenshall and Dean were colleagues. The article said:

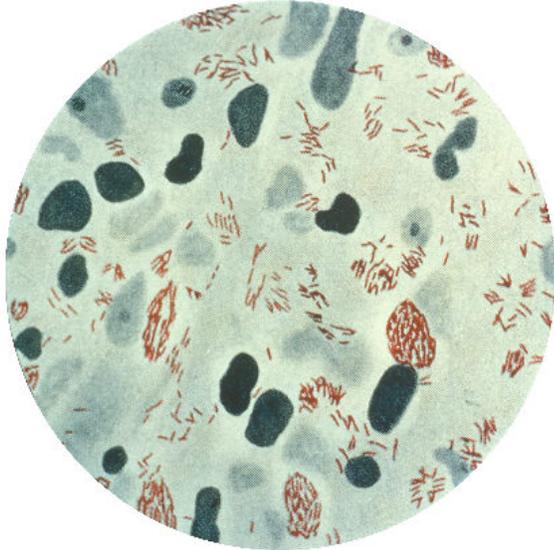
“Last week Medicine generally learned the name of Dr. Richard Wrenshall, professor of chemistry at the University of Hawaii. In a flat-topped, white building overlooking his university's experimental farms he has compounded a preparation of chaulmoogra oil which promises to be a better treatment for leprosy than standard chaulmoogra derivatives. Governor Lawrence M. Judd of the Territory of Hawaii heard of Dr. Wrenshall's work, asked for a report, published it last week.

“One of the standard treatments for leprosy has been to inject ethyl-esters of chaulmoogra oil into a muscle with a large bore syringe. This has been painful.

“Dr. Wrenshall developed a chaulmoogric acid in combination with an inorganic acid group. This is soluble in water, can be administered with an ordinary hypodermic syringe. More water-soluble than this double acid itself, and so more easily administered, is the sodium salt of this new acid. Tried out on dogs the Wrenshall acid, he reported, proved some six times more therapeutically active than the older ethyl-esters. The Territorial board of health decided to use at once the acid compound on human lepers.”

### More on Hansen's Disease

Hansen's Disease is a chronic bacterial infection caused by the bacterium, *Mycobacterium leprae*, which is related to the organism causing tuberculosis. *Mycobacterium leprae* is rod shaped and measures 1-8 microns. It is thought to be spread by droplets through the respiratory tract. The bacteria have a long incubation period, up to 20 years. (Image from U.S. Bureau of Public Health)



Photomicrograph of *M. leprae* from a leprosy skin lesion (CDC)

The early symptoms are white patches on the skin. Because they are painless and do not itch, they are often ignored. In many cases historically, nerve damage occurred as the disease progressed. This leads to numbness which, in turn, leads to the deformities on the extremities and face that are synonymous with Hansen's disease. Specifics on nerve damage to the body: There can be sensory nerve damage, especially in the hands and feet. As a result, the person does not feel pain and so is at risk for burns, etc., which may lead to loss of fingers or toes. Nerves in the eye can be damaged, leading to loss of vision. Motor nerves can be affected, and this may lead to forms of paralysis, including loss of the ability to blink the eyelids. Autonomic nerves can be damaged resulting in the loss of the ability to perspire.

Hansen's Disease is believed to have existed in Egypt as far back as 4000 BC. It became a common disease in Europe in medieval times. Its migration to Hawaii and other Pacific islands is likely part of the history of explorers bringing disease with them. For example, the crew of Captain James Cook, discoverer of the Hawaiian Islands, brought syphilis and gonorrhea to Hawaii in 1778. By 1836 Hawaiians screened all incoming vessels for small pox, which did not prevent the disease from killing 7000 Hawaiians in 1854. Influenza made its way to Hawaii via the gold miners returning from California.

The earliest cases of Hansen's Disease appeared in Hawaii in the early 1820's. The first documented case appeared in 1835. It was first confirmed in Honolulu in 1845, but it wasn't until 1863 that the disease was recognized as

serious by Hawaiian health officials. By 1865 the disease spread at a rapid rate among Hawaiians, and King Kamehameha V signed *An act to Prevent the Spread of Leprosy*, which authorized the isolation of victims of the disease. Kalaupapa settlement was established on January 6, 1866.

In addition to the treatments for Hansen's disease mentioned in the article, treatments that have been used for Hansen's Disease in the past include potassium iodide, arsenic, mercury, antimony, copper, sera, vaccines, thymol, strychnine, salicylic and pyrogalllic acids, hypophosphate of soda and aniline dyes. Brief information on some of these treatments:

**Arsenic and Mercury** Often administered as Donovan's solution, a mixture of arsenic iodide ( $AsI_3$ ) and mercury iodide ( $HgI_2$ ), it was frequently used for the treatment of skin diseases. Many of these types of treatments were also used to treat syphilis in the early 20th century.

**X-Rays** From the book *Roentgen Rays* by William Allen Pusey (1903, W.B. Saunders & Co.): "Sequiera has reported (*Brit. Med. Journal*, 1901, ii, p. 851) a case of tubercular leprosy of the skin which has shown marked improvement under x-rays, the hard nodules softening and flattening down. Allen (*New York State Journ. Med.* 1902, ii, p. 176) has been treating a case of leprosy with x-rays with perhaps some improvement." (p.399)

**Iodine** From a report in 1886, to the Hawaiian legislature from the president of the Board of Health: "Tonics, generally nervine, I have found to answer best . . . Potassium iodide does well in some cases , but in others it does not good." (p. 2)

<http://books.google.com/books?id=FhBZwxpq26sC&dq=leprosy+%22potassium+iodide%22>

**Pyrogalllic Acid** Oxidised pyrogalllic acid (1,2,3-benzenetriol) is prepared by the action of air and ammonia on pyrogallol. It occurs as a dark brown powder. It was used in the treatment of leprosy and of such chronic skin diseases as eczema and psoriasis, generally in the form of an ointment.

By 1946, the sulfone drugs, promin, diasone, and promizole were introduced as treatments. Although the sulfone drugs are useful against the Hansen bacillus, the incidence of sulfone-resistant disease requires a multidrug treatment. The three most used antibiotics are Dapsone, Rifampin and Clofazimine. Other antibiotics such as Clarithromycin, Ofloxacin, Levofloxacin and Minocycline also have excellent antibacterial activity against *M. leprae*.

Current treatment is a combination of rifampicin, clofazimine and dapsone. This is referred to as a multi-drug therapy (MDT). Rifampicin is the most important antileprosy drug and therefore is included in the treatment of both types of leprosy. Treatment of leprosy with only one antileprosy drug will always result in development of drug resistance to that drug.

### Multidrug Therapy

**Rifampicin (RFP):** An antimycobacterial The drug is administered in a single monthly dose. Exceptionally bactericidal against *M. leprae*, a single dose of 600 mg of RFP is capable of killing 99.9% or more of viable organisms.

**Diaminodiphenylsulfone (DDS, dapsone):** Once the main drug of treatment until resistance to it developed, its use in combination with other drugs has become essential to slow or prevent the development of resistance.

**Clofazimine (CLF):** CLF, which preferentially binds to mycobacterial DNA, both inhibits mycobacterial growth and exerts a slow bactericidal effect on *M.*

*leprae*. administered daily, the dosage used for MDT is well tolerated and has not shown significant toxicity.

Today, leprosy is found mainly in Angola, Brazil, India, Madagascar, Mozambique, Myanmar, and Nepal. These countries are taking steps to control leprosy through information campaigns and by providing diagnostic and treatment services to all communities, including the poor and underserved, and by incorporating leprosy diagnosis and treatment into the general health services.

### More on Leper Colonies in the United States

The **Carville** leper colony, or treatment center as it came to be known, was set up on Indian Camp Plantation at Point Clair, between New Orleans and Baton Rouge. The United States government took over the Plantation in 1917. By 1923, there were 425 patients at Carville.

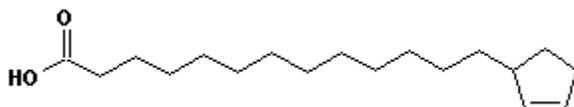
Carville (pop. 1108) is an unincorporated village in Iberville Parish, Louisiana that is 16 miles south of Baton Rouge on the Mississippi River. Carville is the hometown of political personality James Carville and was named after his father. The former leper colony is now the National Hansen's Disease Museum. The hospital has been closed, but several of the buildings remain.

New York City operated **Riverside Hospital on North Brother** beginning in 1885. In that era, the city placed typhus, TB, cholera, yellow fever and smallpox victims on North Brother. Riverside was later expanded to accept more and more patients including those who had leprosy. Mary Mallon (Typhoid Mary), was housed here.

**Penikese Island in Buzzard's Bay**, the site of the only leprosarium in Massachusetts. In all, 36 victims of leprosy, or Hansen's disease, lived on the isolated island, along with a handful of caregivers. The colony closed when the federal government opened a leprosy hospital in Louisiana. Today, the island is home to a private school for troubled youth.

### More on Chaulmoogra Oil

The oil from the plant *Taraktogenos Kurzii*. produces chaulmoogric acid, an unsaturated fatty acid containing a cyclopentenyl group, with a formula of  $C_{18}H_{32}O_2$ . Its systematic name is 2-cyclopentene-1-tridecanoic acid, which has the following structure:



Oil from two related species of trees, *Hydnocarpus Wightiana*, and *Hydnocarpus anthelmintica*, produced chaulmoogric acid but also produced a second acid with the formula  $C_{16}H_{28}O_2$ . This acid was named hydnocarpus acid, or 11-cyclopent-2-enyl-undecanoic acid..

Chaulmoogra oil was mentioned in Hindu writings 2000 years ago as a cure for leprosy. Joseph Rock identified the sources of the oil as the hydnocarpus tree. Plantations of the trees were begun in Hawaii. For a very complete paper on Chaulmoogra oil see

<http://lhncbc.nlm.nih.gov/lhc/docs/published/2003/pub2003048.pdf#search=%22%22alice%20ball%22%20leprosy%22>

## More on Esters

### Physical Properties:

1. Physical State: Lower molecular weight esters are colorless liquids. Higher weight esters are waxy solids.
2. Odor: All esters have a strong odor.
3. Solubility: Lower weight esters are soluble in water. The solubility decreases with increase in molecular weight. See examples below. Esters form hydrogen bonds with water. Esters are soluble in organic solvents. Esters themselves are good organic solvents.

Name	Mol. Mass	Solubility (g/100 g water)
ethyl methanoate	64	10.5
ethyl ethanoate	76	8.7
ethyl propanoate	102	1.7

4. Acidic nature : Esters are neutral to litmus tests.

### Chemical Properties:

As the article describes, esters are one class of organic compounds. Ester molecules tend to be polar molecules and so have dipole interactions and dispersion forces. They do not form hydrogen bonds.

Hydrolysis of esters: Esters break down into their respective organic acid and alcohol from which they are formed in a process called hydrolysis. Hydrolysis of ester with an alkaline solution like sodium hydroxide is known as saponification (soap making).

### Uses of organic esters:

- in artificial perfumes or scents as they emit a sweet smell
- in making artificial food flavors that are added in foods like ice cream, soft drinks, sweets, etc. Some of the flavors and the esters responsible for them include:
  - ethyl acetate    peach, pineapple, raspberry
  - ethyl butyrate    banana, pineapple, strawberry
  - ethyl cinnamate    cinnamon
  - menthyl acetate    peppermint
  - methyl butyrate    pineapple
  - methyl salicylate    wintergreen
- as industrial solvents for making cellulose, fats, paints and varnishes
- as solvents in pharmaceutical industries
- as softeners in plastic industries and molding industries

Of some interest to students are more complex esters, specifically esters which are formed by the reaction of fatty acids with glycerol, which has three alcohol groups. Glycerol is also called 1,2,3-propantriol. These are called triesters or triglycerides. These are better known to students as fats or oils.

### **More on Women Chemists of the Time**

The article mentions the obstacles that Ball had to overcome in her life. There were few women who were chemists. But things were changing. As Ball was earning her first degree in pharmaceutical chemistry in 1912, the Progressive Party became the first national political party in the U.S. to support women's suffrage. As she was discovering the ethyl ester of chaulmoogra oil in 1916 the suffrage movement in the United States was moving the suffrage amendment to the Constitution toward the Congress. Among the pioneering women chemists at about the time of Alice Ball are the following:

**Rachel Lloyd (1839-1900)** Lloyd was the first American woman to earn a Ph.D in chemistry. She earned the degree at the University of Zurich, the only university at the time that would grant a doctorate to a woman. She taught chemistry at the University of Nebraska.

**Gerty Cori (1896-1957)** A contemporary of Alice Ball, Cori and her husband Carl developed an understanding of sugar metabolism, for which they won the Nobel Prize in Physiology and Medicine in 1947, making Gerty the first American woman to win a Nobel Prize.

**Alice Hamilton (1869-1970)** Also a contemporary of Ball, Hamilton was the first woman professor at Harvard Medical School. A crusader for occupational safety and public health, Hamilton served as an unpaid advisor to the Department of Labor from 1911-1921.

**Maude Menten (1897-1960)** In 1911, Menten earned one of the first M.D. degrees awarded to a woman in Canada. She also earned a Ph.D. in biochemistry from the University of Chicago in 1916. Among Menten's areas of study were enzymatic reactions, and the study of blood sugar, hemoglobin, and kidney functions.

**Marie Maynard Daly (1921-2003)** She was the first African-American female to earn a Ph.D. in chemistry. The degree was awarded in 1947 from Columbia University for her work on enzyme amylase. Daly also studied cell nuclei and the metabolism of the arterial wall and how this process is related to aging, hypertension, and atherosclerosis

You can learn more about these and other women in chemistry at [http://www.chemheritage.org/women\\_chemistry/index.html](http://www.chemheritage.org/women_chemistry/index.html)

### **More on African-American Chemists of the Time**

The span of Alice Ball's life was also a difficult time for African-Americans in the United States. In 1896, when Ball was just four, the U.S. Supreme Court validated the concept of "separate but equal" and gave rise to the Jim Crow Laws which permitted racial segregation. In the general time period covered in the article there were a number of trailblazing African-Americans making their mark in chemistry:

George Washington Carver (1861-1943):

George Washington Carver was born a slave in Missouri as the Civil War was breaking out, but he was freed by the Emancipation Proclamation in 1863, and grew up in Arkansas where he and his mother lived on the farm of their former master. He

studied agricultural science at Iowa State Agricultural College (Now Iowa State University). He earned his bachelor's degree in 1894 and a master's in 1896.

Around this time Booker T. Washington was founding a new school for African-Americans in Tuskegee, Alabama. Carver went to work at the new Tuskegee Institute. He was mainly interested in using chemistry to find ways to make life better for farmers in southeast Alabama where he lived. So he studied the soil there and found it was perfect for growing peanuts and sweet potatoes. Most farmers in Alabama and the rest of the South grew cotton, which is back-breaking work to pick, and makes soil infertile after a few years. Carver used chemistry to develop new products made from peanuts and sweet potatoes.

St. Elmo Brady (1884-1966):

St. Elmo Brady was born in 1884 in Louisville, Kentucky. At the age of 20 he left home to attend college at Fisk University in Nashville, Tennessee. At Fisk he was encouraged by his teacher Thomas Talley. When Brady graduated in 1908, he took a job teaching at Tuskegee Institute in Alabama. After two years he went back to school, this time at the University of Illinois, where he earned a master's degree in 1914 and his Ph.D. in 1916, the first African-American to earn a Ph. D. in chemistry. Brady headed the chemistry department at Fisk University for 25 years until he retired in 1952.

Edward Chandler (1887-??):

A native of Ocala, Florida, Edward Chandler went north to Washington, DC to attend college at Howard University. After graduation, he went to Clark University in Massachusetts where earned a master's degree. After that he went on to the University of Illinois, where he graduated with his Ph.D. in 1918. This made him the second African-American to earn a Ph.D. in chemistry, only two years after St. Elmo Brady had become the first, also at the University of Illinois. Chandler went on to spend his career working in the chemical industry, mostly inventing new synthetic dyes.

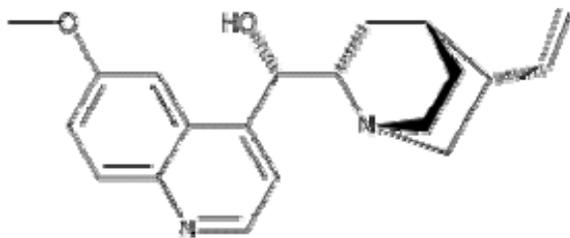
For more on African-American chemists and a complete biography of Percy Lavon Julian, who developed drugs from the Calabar bean and from wild yams, see <http://chemicalheritage.org/scialive/julian/activities/1c.html>

### **More on Isolating Chemicals from Plants**

The article describes the use of chaulmoogra oil, a plant extract, for treating Hansen's Disease. Students might be interested in examples of other medicines that are extracted or derived from plant sources.

Quinine:

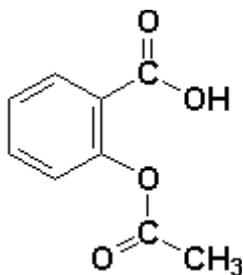
Natural quinine, once a major treatment for malaria, can be extracted from the bark of the Cinchona tree. The bark was ground into a fine powder and then mixed with water or alcohol. In the 1600's, South American Indians used Cinchona bark to treat fever without knowing, of course, that quinine was the active ingredient in the bark. By the mid-1600's the bark was being used to treat and prevent malaria. Quinine was not isolated from the bark until the early 1800's, however. In 1944, quinine was first synthesized by Robert Woodward and William Doering. Today it has been replaced by synthetic drugs such as chloroquine and mefloquine in the treatment of malaria.



Quinine structure

#### Aspirin:

Hippocrates (460-377 B.C.) noted that chewing the leaves of the weeping willow tree reduced pain, and this treatment was used extensively by the Greeks for pain and for reducing inflammation. Willow bark was also used by Africans and by Indians in North America for pain treatment. In the 1820's a compound named salicin was isolated from the willow bark, and later Karl Löwig in Germany treated salicin with acid to produce salicylic acid. Incidentally, an ester, methyl salicylate, was being used to treat muscle pain as oil of wintergreen. In the late 1800's researchers at Bayer added an acetyl group to the salicylic acid to make the familiar acetylsalicylic acid we know today as aspirin.



Aspirin structure

#### Digitalis:

This compound is found naturally in purple foxglove, *digitalis purpurea*, which had been known for its medicinal uses since at least the Middle Ages. Digitalis was identified as the active ingredient in about 1775 by the Scottish physician William Withering, and in 1785 he introduced it to medicine. The compound is dissolved and then recrystallized for use. Today, derivatives of digitalis are used to treat heart disease. For a more detailed history, see <http://www.csdl.tamu.edu/FLORA/Wilson/481/medbot/bot2.htm#A1>

#### Diosgenin:

This sapogenin steroidal compound is extracted from wild yams (*Dioscorea*) and is used to produce synthetic hormones used in birth control pills and fertility drugs. It is chemically very similar to cholesterol. Diosgenin provides about 50% of the raw material for the manufacture of cortisone, progesterone, and many other steroid hormones. It is a white crystalline powder, very soluble in gasoline and ethanol and insoluble in water.

#### Anticancer Drugs:

There are a number of drugs used to treat cancer which are derived from plants. Among them are:

- Rosy periwinkle (*Catharanthus roseus*) – used to treat leukemia and Hodgkin’s Disease
- Mayapple This plant contains podophyllotoxin, which is the starting material for producing the antitumor agent etoposide, used for the treatment of lung and testicular cancer.
- Pacific Yew (*taxus brevifolia*) contains the compound taxol, used in the treatment of ovarian and breast cancer.

### **Connections to Chemistry Concepts**

**Compounds** – The article is an opportunity to discuss the presence of chemical compounds as part of natural systems. This will allow you to highlight the nature of chemical compounds, bonding, definite proportions, etc. You can couple this with a discussion of the idea of “active ingredient” in many over-the-counter products.

**Separations** - A related class discussion would center on methods of separation. In most science classes, including chemistry, students use methods of separation, but in the context of the article you can show how important these methods are to chemists studying natural products. You can also engage students via discussion or lab work in the idea of “active ingredient” in many over-the-counter products. (see Demonstrations and Lessons, below)

**History** - This article might be thought of as part of the history of disease and the role that chemistry has played, and still does, in preventing and fighting disease. There are numerous web sites that provide information about the history of disease. One such site is <http://www.mla-hhss.org/histdis.htm>

**Women and Minorities** - Encouraging minority students and women to pursue chemistry careers should be part of every classroom. In the teachers guide are examples of both women and minority chemists who lived and worked in the general time of Alice Ball’s life. See “More on Women Chemists” and “More on African-American Chemists”, above.

### **Possible Student Misconceptions**

1. **“Plants are single substances.”** Despite what they may have learned in biology, many students may think of plants as single substances. You might emphasize that living systems as well as many familiar food products are actually mixtures of many chemical substances. And at the same time you can discuss the methods of separating compounds from natural mixtures.
2. **“Leprosy (Hansen’s disease) existed only in Biblical times.”** The article discusses the existence of Hansen’s disease in the early 1900’s and on through the present day. More effective treatments have greatly reduced the spread of the disease currently.
3. **“Leprosy is very contagious.”** It is not. It is a health issue in 24 countries in Asia, Africa and Latin America. It is a problem only in those countries where the disease is prevalent. It is contagious, but is only spread from person to person in respiratory droplets as a result of sneezing or coughing.

### ***Demonstrations and Lessons***

1. Preparing Esters – you can engage students in lab work that prepares esters chemically. Several different procedures are here: <http://www.steve.gb.com/science/esters.html> and <http://www.iit.edu/~smile/ch9205.html> and <http://dwb.unl.edu/Chemistry/MicroScale/MScale43.html>
2. Separations – There are standard procedures for separating mixtures in most lab manuals and texts. Some that apply directly to this article include distillation, solvent extraction, and chromatography. It is likely that the active ester was separated from Chaulmoogra oil by solvent extraction. A procedure you might use in the lab would be a simple extraction of tea from leaves, chlorophyll from plants (<http://www.vernier.com/caliper/fall06/innovativeuses.html>) or DNA from many systems (<http://learn.genetics.utah.edu/units/activities/extraction/>)
3. Active ingredients – Have students do labs like determining the vitamin C in oranges juice (<http://www.accessexcellence.org/AE/ATG/data/released/0490-MaryColvard/teacher.html>) , or antacid in Tums ([http://www.sciencebyjones.com/antacid\\_lab.htm](http://www.sciencebyjones.com/antacid_lab.htm))
4. Spread of Disease – Although usually thought of as a biology class activity, this version of an activity on how communicable diseases spread uses NaOH. <http://www.pbs.org/wgbh/aso/resources/guide/medact4index.html>

### ***Suggestions for Student Projects***

1. Assign students time periods in history and have them research major diseases of that period and the treatments for each. Possible beginning points might be <http://www.mic.ki.se/HistDis.html> <http://www.rhodes.edu/biology/glindquester/viruses/history.html> <http://www.amnh.org/exhibitions/epidemic/>
2. Divide students into teams in the class and assign each team one phase of the Hansen's disease story: history, cause, treatment, current statistics, colonies (like Kalaupapa), etc.

### ***Anticipating Student Questions***

1. **“Was it legal to quarantine people who had Hansen’s disease?”** It has been a well-established method of controlling widespread disease in the United States and other countries. Isolation procedures are used with patients with a confirmed illness. Quarantine rules and procedures apply to individuals who are not currently ill—but who are known to have been exposed to the illness (e.g., the person has been in the company of an infected person or has come in contact with infected materials). Title 42 United States Code, Section 264 (Section 361 of the Public Health Service [PHS] Act) gives the Secretary of Health and Human Services (HHS) responsibility for preventing the introduction, transmission, and spread of communicable diseases from foreign countries into the United States and within the United States and its territories/possessions.
2. **“If chaulmoogric oil is insoluble in water, why is an ester of the oil soluble?”** As the article describes, chaulmoogric oil, like most oils, has molecules that are nonpolar and, therefore, insoluble in water with polar molecules (“like dissolves like”). Esters, on the other hand, especially those with weights like those of esters of chaulmoogric oil, have more polar molecules and readily dissolve in water.

## References

*A Disease Apart: Leprosy in the Modern World*, Tony Gould, St. Martin's Press, 2005. A history of the disease, including profiles of many people who were instrumental in combating it.

*The Colony*, by John Tayman, Scribner, a division of Simon and Schuster, 2006. The well-researched story of the leprosarium at Kalaupapa on the island of Molokai.

*Molokai: The Story of Father Damien* (DVD) Inspiring true story follows the life of Father Damien, the Belgian priest who dedicated his life to caring for the colony at Kalaupapa. The movie has a PG rating.

### Websites for additional Information

The International Leprosy Association has a website that provides a great deal of information on the disease. See [http://www.leprosyhistory.org/english/bibsd\\_rs.htm](http://www.leprosyhistory.org/english/bibsd_rs.htm)

For a complete article on Chaulmoogra Oil and Leprosy, see <http://lhncbc.nlm.nih.gov/lhc/docs/published/2003/pub2003048.pdf#search=%22%22allice%20ball%22%20leprosy%22>

For a timeline and history of Carville, the leper colony in the United States, see [http://bphc.hrsa.gov/nhdh/HISTORY\\_MAIN\\_PAGE.htm](http://bphc.hrsa.gov/nhdh/HISTORY_MAIN_PAGE.htm)

For more background on Kalaupapa see <http://www.whirledwydeweb.com/kalaupapa/chronology.html>

To read Jack London's account of his 1908 visit to Kalaupapa see <http://carl-bell-2.baylor.edu/~bellc/JL/TheLepersOfMolokai.html>

To read an account of famed war correspondent Ernie Pyle's visit to Kalaupapa in 1937, see <http://www.whirledwydeweb.com/kalaupapa/colony.html>

Information about the sequencing of the genome of *Mycobacterium leprae* is available at <http://genolist.pasteur.fr/Leproma/help/project.html>