

## April 2005 Teacher's Guide

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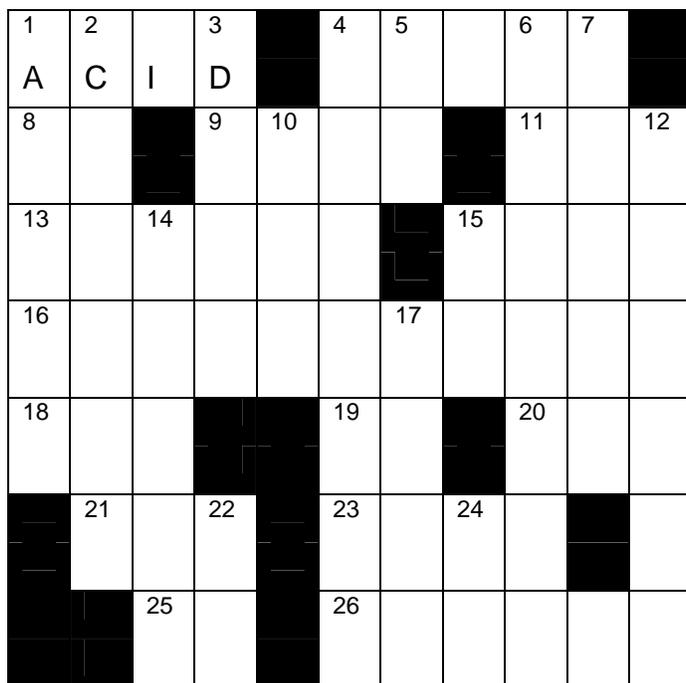
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## Puzzle: Double Cross

We double your trouble by offering below two identical crossword grids. For each number, there are two clues in random order; it's up to you to decide which answer goes in which grid. Roughly half the clues are "scientific". To get you started we have filled in 1 across in both grids. Two-letter answers clued by atomic information will be the symbol of an element. Don't get "double-crossed" as you tackle this puzzle !!

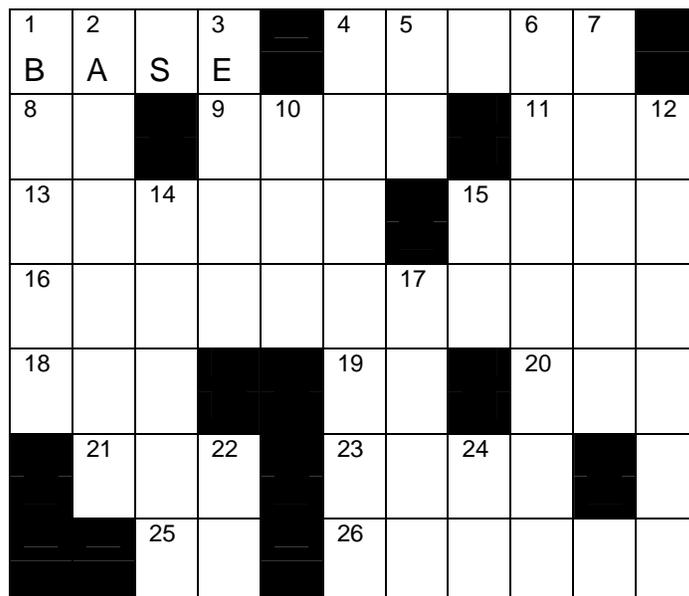


### ACROSS

- 1 Proton donor  
Proton acceptor
- 4 Dialect, regional usage  
Narcotic from poppies
- 8 Chemistry Nobel winner  
in 1939 (initials)  
Has 68 protons
- 9 SI prefix for  $10^{-9}$   
Mythical monster, ex. Shrek
- 11 Nickname for the sun  
Spoil, especially if organic
- 13 System where  $\text{pH} < 7$   
Indian tribe in SW USA
- 15 SI prefix for  $10^3$   
\_\_\_ drama, eventful play
- 16 Forms at cathode in  
electrolysis of brine  
Forms at anode in  
electrolysis of brine  
(both are two words)
- 18 Largest internet  
provider  
\_\_\_-Haw, country music  
show
- 19 Group 16, period 5  
The radioactive halogen
- 20 Cheer at a bull fight  
Tax-collecting federal  
agency
- 21 In basketball,  
wish, nothing but \_\_\_  
Carpet
- 23 As opposed to odd  
Unthreaded fastener  
for wood joints
- 25 Element name that  
honors great  
Russian chemist  
Metalloid abundant in  
sand
- 26 Felt, experienced  
PbO, CO, and NO<sub>2</sub>, for  
ex

### DOWN

- 1 Particle, symbol He<sup>2+</sup>  
Shorefront swimming place
- 2 William Tell, for example  
Child's coloring marker
- 3 Stern, sullen  
Prefix for energy into  
a system
- 4 Moves to action, rouses  
A spice used in cooking
- 5 Gym class (initials)  
First (and last) note on scale
- 6 Roots, sources  
Apply Au foil when gilding  
(two words)
- 7 1 mole solute / kg of solvent  
1 mole solute / L of solution
- 10 78 % N<sub>2</sub>, 21 % O<sub>2</sub>.  
Sedan model type
- 12 Thrown, pitched  
As opposed to winners
- 14 Car engine is on, but in neutral  
Part of the intestines
- 15 Energy due to motion (initials)  
In +7 or +4 state, a good oxidizer
- 17 Movie actress \_\_\_ Campbell  
Form 1040 done via the internet  
(hyphenated)
- 22 Seventh note on the scale  
Lanthanide with half-filled  
4f subshell
- 24 XVI ÷ VIII  
Measure of attraction for an  
electron pair (initials)



## Puzzle Answers: Double Cross

1	2		3		4	5		6	7	
A	C	I	D		O	P	I	U	M	
8			9	10				11		12
L	R		O	G	R	E		S	O	L
13		14					15			
P	A	I	U	T	E		M	E	L	O
16						17				
H	Y	D	R	O	G	E	N	G	A	S
18					19			20		
A	O	L			A	T		O	L	E
	21		22		23		24			
	N	E	T		N	A	I	L		R
		25			26					
		S	I		O	X	I	D	E	S

1	2		3		4	5		6	7	
B	A	S	E		I	D	I	O	M	
8			9	10				11		12
E	R		N	A	N	O		R	O	T
13		14					15			
A	C	I	D	I	C		K	I	L	O
16						17				
C	H	L	O	R	I	N	E	G	A	S
18					19			20		
H	E	E			T	E		I	R	S
	21		22		23		24			
	R	U	G		E	V	E	N		E
		25			26					
		M	D		S	E	N	S	E	D

# Student Questions

## Mustard Gas

1. What is the chemical formula and chemical structure of mustard gas?
2. Why is this material called mustard gas, and what is misleading about its name? What must be done in order to use mustard gas as a weapon?
3. Describe some of the effects of exposure to mustard gas.
4. What happens if you try to wash mustard gas off your body with water?
5. What is the mechanism by which mustard gas produces its damaging effects?
6. What gas was the first to be used as a weapon during WWI? Where was it used, and what effects did it have on the soldiers who were exposed to it?
7. Describe the most common procedure used to dispose of mustard gas.
8. What is the Chemical Weapons Convention? When did it go into force, and what is unique about its provisions?

## Antimatter

1. How do matter and antimatter compare?
2. When and where was the first antiparticle created? What kind of particle was it? Did its creation come as a complete surprise, or was it suspected?
3. What was the first antiatom that was created? Describe it. When and where was it created? Have other kinds of antiatoms been created since then?
4. Describe what happens if a particle meets its antiparticle.
5. Describe the theoretical reason why the creators of Star Trek have the *USS Enterprise* spaceship being powered by antimatter.
6. What happens inside a particle accelerator? How large is the Fermilab particle accelerator? Why can't particle accelerators accelerate neutrons?
7. Describe how particles and antiparticles can be created inside a particle accelerator.
8. Describe one medical use of antiparticles.
9. Describe some evidence that suggests that regions of antimatter may exist somewhere in our universe.

## Going for Platinum

1. What two kinds of chemical processes does platinum enable a catalytic converter to perform? Give an example of each.
2. About how many grams of carbon monoxide, nitrous oxides and hydrocarbons were released into the atmosphere in 1960 for each mile that a car was driven? By how

much has this been reduced since automobiles were equipped with catalytic converters?

3. What happens inside a fuel cell, and what role does platinum play?
4. How does platinum increase the memory of computer hard disks?
5. What metals comprise what are called the platinum group metals? What are some of the properties of this group?
6. Which country supplies most of the world's platinum? What are some other places where platinum is being mined?
7. What is "ring quality" platinum? What is "white gold?"

## Do You Want Biodiesel With That?

1. What do the chemical formulas for regular gasoline and diesel fuel have in common? In what way do they differ?
2. Describe how the operation of a diesel engine compares to that of a gasoline engine.
3. What are the two main sources of biodiesel in the United States?
4. What is one of the environmental benefits attached to the use of biodiesel in place of regular diesel fuel or gasoline? Explain how this benefit arises.
5. Describe two other advantages attached to the use of biodiesel.
6. What is meant by the term "B20" when it is attached to a fuel containing biodiesel?
7. List four disadvantages of using biodiesel fuel.
8. What is the major goal of the "Green Chemistry" movement?

## Battling Zits!

1. Describe the basic structure and function of human skin.
2. Describe how a zit is formed. Why are outbreaks of acne more likely to occur during the teenage years?
3. What are four approaches used by various acne products to treat acne?
4. Name some acne products that contain salicylic acid. How does salicylic acid work to try and reduce acne outbreaks?
5. Describe how products containing benzoyl peroxide work.
6. List some antibiotics that can be used to treat acne and briefly describe some of their advantages and disadvantages.
7. What are retinoids, and how do they work to control acne?
8. What is Accutane? What are some of the undesirable and/or dangerous side effects connected to the use of this drug?

# Answers to Student Questions

## Mustard Gas

1. What is the chemical formula and chemical structure of mustard gas?

The chemical formula for mustard gas is  $C_4H_8Cl_2S$ . The chemical structure is  $Cl-CH_2-CH_2-S-CH_2CH_2-Cl$ .

2. Why is this material called mustard gas, and what is misleading about its name? What must be done in order to use mustard gas as a weapon?

It is called mustard gas because impure forms of the gas have an odor that resembles that of mustard. The name is somewhat misleading because at room temperature the substance is actually a liquid, not a gas. In order to be used as a weapon, it must be finely dispersed. This is typically done by using some sort of mortar or gun shell.

3. Describe some of the effects of exposure to mustard gas. Which parts of the body are most susceptible to attack?

The first symptom is itching. Over the course of a day, deep blisters form on the skin. Eyes can become sore and eyelids swollen. If a person is exposed to sufficiently high concentrations, the corneas can be damaged to the extent that blindness results. Moist parts of the body like the eyes, nose and lungs are especially susceptible to attack. If inhaled, it causes blistering in the lungs. If the damage is minor, chronic health problems may result, but if the damage is more extensive, it can even result in death.

4. What happens if you try to wash mustard gas off your body with water?

First, it is difficult to wash off, since mustard gas is nonpolar and therefore only slightly soluble in water. More significantly, it reacts with water to form a breakdown product called hemi-mustard, which is equally toxic, and in addition forms hydrochloric acid, HCl, another toxic material.

5. What is the mechanism by which mustard gas produces its damaging effects?

We are not sure. One hypothesis is that mustard gas reacts with DNA and causes breaks in the DNA strands. This causes a series of events in the cell that lead to the release of enzymes that dissolve cell membranes and cause cell death. A second hypothesis states that mustard gas inactivates a compound that is the major defense against attack by oxidation. In this scenario the cell itself is not actually attacked, but the cell is now vulnerable to the usual oxidative stress from reactive oxygen species. It also leads to inflammation.

6. What gas was the first to be used as a weapon during WWI? Where was it used, and what effects did it have on the soldiers who were exposed to it?

The first gas to be used in combat was chlorine. It was used on a battlefield near Ypres, Belgium. It attacked the respiratory system of soldiers who were exposed, causing a slow painful death by asphyxiation.

7. Describe the most common procedure used to dispose of mustard gas.

The favored method is hydrolysis and neutralization. Mustard gas is reacted with water. The water adds –OH groups, eventually forming thiodiglycol and hydrochloric acid. The hydrochloric acid is neutralized by sodium hydroxide, reacting to form sodium chloride and water.

8. What is the Chemical Weapons Convention? When did it go into force, and what is unique about its provisions?

The Chemical Weapons Convention is a treaty designed to prevent the use of chemical weapons. It went into force on April 29, 1997. It is unique in that it specifies stringent protocols for inspection and verification of the ban.

## Antimatter

1. How do matter and antimatter compare?

They are identical to each other in almost every way except for one. They have the same mass. If they have a spin, like an electron, the spin is the same. They carry the same amount of electrical charge, but the essential difference between a particle and its antiparticle is that the sign of the charge is opposite. If a particle carries a negative charge, its antiparticle will carry a positive charge and vice-versa.

2. When and where was the first antiparticle created? What kind of particle was it? Did its creation come as a complete surprise, or was it suspected?

The first antiparticle, the antielectron, was created in 1932 at Caltech. The existence of antiparticles had actually been predicted four years earlier by Paul A. M. Dirac, a British physicist.

3. What was the first antiatom that was created? Describe it. When and where was it created? Have other kinds of antiatoms been created since then?

The first antiatom created was antihydrogen. It consists of an antielectron outside of a nucleus consisting of an antiproton. It was created at the European Center for Nuclear Research (CERN) in 1995. Although it is now possible to make many thousands of atoms of antihydrogen, no other kinds of antiatoms have been created to date.

4. Describe what happens if a particle meets its antiparticle.

If a particle and its antiparticle meet, they are both instantly annihilated and converted into energy in the form of gamma rays.

5. Describe the theoretical reason why the creators of Star Trek have the *USS Enterprise* spaceship being powered by antimatter.

When matter and antimatter annihilate each other, the amount of energy released per gram of material is tremendous. A milligram of antimatter could produce more energy than two tons of rocket fuel.

6. What happens inside a particle accelerator? How large is the Fermilab particle accelerator? Why can't particle accelerators accelerate neutrons?

Particle accelerators can accelerate particles to nearly the speed of light using powerful electric fields. The Fermilab accelerator is composed of a ring that is 6.3 km (3.8 miles) in circumference. Since neutrons do not have an electric charge, they can't be accelerated by the electric field used by a particle accelerator.

7. Describe how particles and antiparticles can be created inside a particle accelerator.

The process is just the opposite of having a particle and an antiparticle annihilate each other and be transformed into gamma rays. Inside the particle accelerator gamma rays are generated when particles are broken apart at high velocities. If these gamma rays are of sufficiently high energy, they can spontaneously transform into a particle-antiparticle pair.

8. Describe one medical use of antiparticles.

One medical use of antiparticles is found in positron emission tomography, or PET scans. A patient is injected with a compound containing a particular isotope such as C-11, F-18, O-15, or N-13 dissolved in a liquid such as glucose solution or water. These isotopes are positron emitters. When these positrons encounter electrons in the patient's tissue, they annihilate, producing gamma rays. Donut-shaped gamma ray detectors placed around the patient's body pick up these gamma rays. This information can be fed into a computer to produce a three-dimensional image of the patient's body.

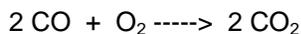
9. Describe some evidence that suggests that regions of antimatter may exist somewhere in our universe.

In 1996 a huge fountain of positrons was annihilating furiously with electrons in the center of our Milky Way galaxy, spewing out large quantities of gamma rays.

## Going for Platinum

1. What two kinds of chemical processes does platinum enable a catalytic converter to perform? Give an example of each.

oxidation (loss of electrons)



reduction (gain of electrons)



2. About how many grams of carbon monoxide, nitrous oxides and hydrocarbons were released into the atmosphere in 1960 for each mile that a car was driven? By how much has this been reduced since automobiles were equipped with catalytic converters?

In 1960 the average car released about 100 grams of carbon monoxide, nitrous oxides and hydrocarbons for every mile it was driven. The use of catalytic converters has reduced that to only about 2% of what it was.

3. What happens inside a fuel cell, and what role does platinum play?

Inside a fuel cell hydrogen (the fuel) and oxygen from the air are combined. The energy released in the reaction generates electricity. Platinum acts as a catalyst for the reaction.

4. How does platinum increase the memory of computer hard disks?

Hard disks are made of aluminum or glass and coated with a cobalt alloy to increase their magnetic properties. The magnetic layer stores data in a series of circular disks. The amount of data that can be stored in a given area depends on the strength of the magnetic field. Adding platinum to the cobalt increases the magnetic qualities, which in turn allows for higher-density data storage and improved access times.

5. What metals comprise what are called the platinum group metals? What are some of the properties of this group?

The platinum group metals consist of platinum, ruthenium, rhodium, palladium, osmium and iridium. They are rare and chemically similar. They have the ability to loosely bind organic molecules, which has made them valuable catalysts for systems like a car's catalytic converter. Platinum, iridium and osmium are also the densest known metals.

6. Which country supplies most of the world's platinum? What are some other places where platinum is being mined?

Most of the world's platinum is in Africa. Other places where platinum is mined include Russia, Canada, and Montana.

7. What is "ring quality" platinum? What is "white gold?"

Ring quality platinum is 95% platinum alloyed with other metals such as Cu, Ti, Pd, Rh, Ir, and Os.

White gold is actually an alloy made of yellow gold mixed with other metals such as nickel, palladium and/or silver. It is sometimes plated with rhodium, which gives it a brighter, whiter appearance, but this plating can wear away with time.

## Do You Want Biodiesel With That?

1. What do the chemical formulas for regular gasoline and diesel fuel have in common? In what way do they differ?

Both gasoline and diesel fuel consist of a mixture of hydrocarbons, but the hydrocarbon chains in diesel fuel are about 10-20 carbon atoms long, while the hydrocarbon chains in gasoline are only about 5-10 carbon atoms long.

2. Describe how the operation of a diesel engine compares to that of a gasoline engine.

Diesel engines use what is called compression ignition. In a diesel engine the air in the combustion chamber is quickly and dramatically compressed. This causes the air to become so hot that it can ignite the fuel that is then injected into the chamber. No external spark is required. In a gasoline engine the air is mixed with the fuel inside the combustion chamber and then ignited with a spark.

3. What are the two main sources of biodiesel in the United States?

Soybean oil and cooking grease.

4. What is one of the environmental benefits attached to the use of biodiesel in place of regular diesel fuel or gasoline? Explain how this benefit arises.

Burning biodiesel significantly reduces the amount of carbon dioxide that is added to the atmosphere when the fuel is burned, and carbon dioxide has been linked to global warming. Although burning biodiesel does release CO<sub>2</sub> into the atmosphere, CO<sub>2</sub> was absorbed from the atmosphere when the plants used to make the biodiesel were grown. These two effects basically cancel out, and although biodiesel is often blended with regular diesel fuel, there is still a significant reduction in the net release of carbon dioxide.

5. Describe two other advantages attached to the use of biodiesel.

Biodiesel is safer to use, because it has a higher flash point (300 °F), compared to that of regular petroleum diesel (125 °F). This means that it won't ignite as easily. In addition, it is as biodegradable and nontoxic as vegetable oil, so if it is spilled, it won't persist in the environment.

6. What is meant by the term "B20" when it is attached to a fuel containing biodiesel?

B20 means that the fuel consists of a blend of 20% biodiesel with 80% petroleum diesel.

7. List four disadvantages of using biodiesel fuel.

(1) It is more expensive.

(2) It is more viscous (thicker), which can be a problem in cold climates—the fuel can turn into a gel in the winter.

(3) It has about a 10% lower energy content than petroleum diesel.

(4) It may result in higher emissions of nitrous oxides (NO<sub>x</sub>).

8. What is the major goal of the "Green Chemistry" movement?

Green chemistry focuses on designing chemical products and processes that are more environmentally friendly.

### **Battling Zits!**

1. Describe the basic structure and function of human skin.

Skin is a flexible barrier designed to protect organs and provide a sense of feel. The top layer of human skin is called the stratum corneum. It is composed of dead cells that have migrated to the surface. Underneath the stratum corneum are the layers of the epidermis and dermis. Inside these layers are the sweat glands, sebaceous glands, and hair follicles.

2. Describe how a zit is formed. Why are outbreaks of acne more likely to occur during the teenage years?

The sebaceous glands in human skin produce an oily liquid called sebum. More sebum is produced during puberty. Dead skin cells in the follicle are also shed more rapidly. These skin cells mix with sebum and block the duct of the follicle. These blockages are called comedones. Since sebum is still being produced, it balloons up under the blocked duct. Irritation causes soreness and inflammation. Bacteria called *Propionibacterium acnes*, found on human skin and hair, multiply rapidly. These produce an enzyme called lipase, which breaks the oily sebum down into fatty acids. These fatty acids irritate the skin cells, causing more inflammation. This infection spreads to nearby pores, resulting in a breakout.

3. What are four approaches used by various acne products to treat acne?

1. Unblock ducts (remove excess dead skin).
2. Reduce sebum or sebum production.
3. Kill (control) bacteria.
4. Stop the inflammation.

4. Name some acne products that contain salicylic acid. How does salicylic acid work to try and reduce acne outbreaks?

Three acne products that contain salicylic acid are Stridex, Noxema and Oxy Deep. Salicylic acid is an oil soluble exfoliant that helps remove dead skin cells from clogged oily pores.

5. Describe how products containing benzoyl peroxide work.

Benzoyl peroxide is a molecule that contains an oxygen-oxygen bond that breaks easily and forms a free radical—a molecule that contains a very reactive unpaired electron. These free radicals react quickly with molecules around them. The “benzoyl” part of the molecule gives this peroxide a more lipophilic (fat loving) or nonpolar character, which is good, since it helps the medication target oily pores. The reaction weakens the cell walls of *P. acnes* bacteria, killing it. It also acts as an exfoliant.

6. List some antibiotics that can be used to treat acne and briefly describe some of their advantages and disadvantages.

Some antibiotics used to treat acne include:

azelaic acid—this works as an antimicrobial agent, controlling the number of *P. acnes* bacteria.

erythromycin and clindamycin—these are also bacteria-killing medications with the added effect of reducing inflammation

tetracycline—unfortunately, this has a strong odor and can stain both skin and clothes. Taking it internally avoids these problems.

minocycline and doxycycline are also used

7. What are retinoids, and how do they work to control acne?

Retinoids are molecules related to vitamin A. They can prevent the blockage of hair follicles that leads to comedones, and can also help to prevent inflammation in preexisting comedones.

8. What is Accutane? What are some of the undesirable and/or dangerous side effects connected to the use of this drug?

Accutane is the brand name for isotretinoin, a potent synthetic drug. It is very effective for treating acne, but can cause severe birth defects if a woman uses it during pregnancy. It also has been linked to depression and suicidal thoughts.

## Content Reading Guide

<b>National Science Education Content Standard Addressed</b> As a result of activities in grades 9-12, all students should develop understanding	<b>Going for Platinum</b>	<b>Biodiesel</b>	<b>Battling Zits!</b>	<b>Mustard Gas</b>	<b>Antimatter</b>
<b>Science as Inquiry Standard A:</b> about scientific inquiry.	✓	✓	✓	✓	✓
<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 conservation of energy and increase in disorder					✓
<b>Physical Science Standard B:</b> of the interaction of energy and matter.		✓	✓		✓
<b>Life Science Standard C:</b> of matter, energy, and organization in living systems.		✓			
<b>Earth &amp; Space Science Standard D:</b> of geochemical cycles.		✓			
<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 natural resources.		✓			
<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>Science in Personal and Social Perspectives Standard F:</b> of science and technology in local, national, and global challenges.	✓	✓	✓	✓	✓
<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 and complete the second column. In the space under each statement, cite information from the article that supports or refutes your original ideas.

### Going for Platinum

Me	Text	Statement
		1. Platinum costs more per ounce gold.
		2. Platinum is a catalyst used in the catalytic converters of automobiles.
		3. Platinum enhances the magnetic qualities of computer hard disks.
		4. Platinum is inert.
		5. Platinum is more dense than gold.
		6. Most platinum comes from Canada.
		7. One ton of ore yields between 100-1000 grams of platinum group metals.
		8. It is easier to make gold jewelry than platinum jewelry.

**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 and complete the second column. In the space under each statement, cite information from the article that supports or refutes your original ideas.

### Do You Want Biodiesel With That?

Me	Text	Statement
		1. If you want to use biodiesel in your diesel engine, you must get a converter kit.
		2. Biodiesel is now available commercially in the United States.
		3. Burning biodiesel fuel can help reduce the amount of CO <sub>2</sub> in the atmosphere.
		4. Biodiesel is safer to use than regular diesel.
		5. The largest consumer of biodiesel in the United States is the National Parks System.
		6. Biodiesel can be produced from fish oil.

**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 and complete the second column. In the space under each statement, cite information from the article that supports or refutes your original ideas.

### Battling Zits!

Me	Text	Statement
		1. Only about 50% of all teenagers suffer from acne breakouts.
		2. Acne formation is caused by a combination of blocked ducts filled with sebum and bacterial infection.
		3. Acne can be controlled by keeping your skin very clean.
		4. Many acne medications are antibiotics.
		5. Some acne medications block hair follicles and pore ducts.
		6. In the future, laser treatments may be used to control acne.

**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 and complete the second column. In the space under each statement, cite information from the article that supports or refutes your original ideas.

## Mustard Gas

Me	Text	Statement
		1. Mustard gas is a naturally occurring compound made of only four elements.
		2. Mustard gas is a liquid at room temperature.
		3. Mustard gas is easily washed off with water.
		4. Mustard gas first used as a chemical weapon in World War I.
		5. Mustard gas kills most people who are exposed to it.
		6. The United States has biological and chemical weapons in storage, waiting for disposal.
		7. Most of the mustard gas found in Germany after World War II was disposed of by hydrolysis, followed by neutralization.
		8. In the 1500s, Leonardo da Vinci was opposed to the use of chemical weapons.
		9. Chemical weapons may disrupt the nervous system, cause severe blisters, or attack lung tissue.

**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 and complete the second column. In the space under each statement, cite information from the article that supports or refutes your original ideas.

## Antimatter

Me	Text	Statement
		1. Antimatter exists only in science fiction stories.
		2. A positron is an antiparticle to an electron, identical to an electron in every way except its charge.
		3. Antiatoms have been produced.
		4. A matter-antimatter collision releases enormous energy in the form of gamma radiation.
		5. Particle accelerators can accelerate any small particles.
		6. According to Einstein's famous equation, $E = mc^2$ , energy can be converted into mass.
		7. There is evidence for the existence of antimatter in our own Milky Way galaxy.
		8. Antimatter has no practical uses in today's world.

## Reading Strategies

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

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

## Going for Platinum

Uses for platinum	What properties of platinum make this use possible?

### Steps in mining platinum to 99.95% purity:

Process description	Resulting material
1.	
2.	
3.	
4.	

## Do You Want Biodiesel With That?

To complete the chart, contrast diesel and biodiesel fuels, then list the similarities in the bottom frame.

Diesel	Biodiesel
<b>Similarities</b>	

## Battling Zits!

Causes of acne	Description
<b>Controlling acne chemically</b>	<b>Description</b>
<b>Future treatments</b>	

## Mustard Gas

Chemical description	
Symptoms of exposure to mustard gas	
How it works	
Use of mustard gas in weapons	
Disposal of mustard gas	
Future of chemical weapons	

## Antimatter

	Details
What is it?	
Who first predicted it? When?	
Who discovered it? When?	
Where is it produced?	
Why is it important?	
How does it relate to $E = mc^2$ ?	
How is it used?	

# Going for Platinum

## Background Information

### The historical price of platinum

Of course the price of platinum will vary, sometimes substantially, during the course of a given year. But looking at the price of a troy ounce of Pt at the beginning of each year from 1993 until 2005, one can see that while the general trend has been upwards, especially for the last few years, there have also been periods when the price has remained flat or even decreased.

1993 \$355	2000 \$445
1994 \$394	2001 \$615
1995 \$418	2002 \$486
1996 \$400	2003 \$602
1997 \$371	2004 \$815
1998 \$366	2005 \$864
1999 \$362	

### Platinum supply and demand

The article states that the demand for Pt has outstripped the supply for each of the past five years.

Figures purporting to state the supply and demand are somewhat uncertain, and one can find varying numbers from different sources. This said, one of the better Websites from which to obtain these figures for the years 1975-2003 is listed below.

[http://www.platinum.matthey.com/uploaded\\_files/Market%20Data%20Charts%202003/Pt\\_1975%20to%201993.pdf](http://www.platinum.matthey.com/uploaded_files/Market%20Data%20Charts%202003/Pt_1975%20to%201993.pdf)

[http://www.platinum.matthey.com/uploaded\\_files/market\\_data\\_charts/Pt%2094%2003.pdf](http://www.platinum.matthey.com/uploaded_files/market_data_charts/Pt%2094%2003.pdf)

Summarizing the basic overall figures, the trend in supply and demand is (years where the demand exceed the supply are boldfaced and italicized):

<u>Year</u>	<u>Supply (millions of troy ounces)</u>		<u>Demand (millions of troy ounces)</u>		
<b>1975</b>	2.53	2.60	1990	3.73	3.70
1976	2.60	2.43	1991	4.16	4.05
<b>1977</b>	2.61	2.70	1992	3.82	3.82
<b>1978</b>	2.65	2.82	1993	4.39	4.06
<b>1979</b>	2.80	2.88	<b>1994</b>	4.53	4.58
1980	2.82	2.36	1995	4.99	4.84
<b>1981</b>	2.33	2.46	1996	4.98	4.96
1982	2.49	2.35	<b>1997</b>	4.96	5.13
1983	2.48	2.20	1998	5.40	5.37
1984	2.72	2.66	<b>1999</b>	4.87	5.59
<b>1985</b>	2.76	2.86	<b>2000</b>	5.29	5.68
<b>1986</b>	2.83	2.88	<b>2001</b>	5.86	6.23
<b>1987</b>	3.10	3.32	<b>2002</b>	5.97	6.56
<b>1988</b>	3.28	3.65	<b>2003</b>	6.11	6.59
<b>1989</b>	3.43	3.47			

This data indicates that while in the majority of years the demand does exceed the supply, and has been the case for the past five years (as stated in the article), this is not always the case. There have been several years in the past twenty or so in which the supply of Pt has actually exceeded the demand.

Platinum is a relatively rare substance. It is far less abundant than gold, and there are only a limited number of commercially viable deposits on earth. The three main regions from which platinum can be mined are South Africa, Russia and North America. South Africa is by far the greatest producer, accounting for over two-thirds of

total world production. Russia is second, accounting for perhaps 15-20% of world production. The remainder comes primarily from the United States, most of it mined in Montana.

The article describes the general process by which platinum is obtained from its ores. Additional information along with a diagram that illustrates all the steps in the mining and purification process can be found at: <http://r0.unctad.org/infocomm/anglais/platinum/chain.htm>

### Where is platinum used?

The amount and percentage of platinum that is used for different purposes also varies from year-to-year and somewhat different figures are presented by different sources of information, but there are some fairly safe generalizations.

The most common use of platinum is in jewelry. This typically accounts for perhaps 40-45% of platinum usage, perhaps even a bit more in some years.

Automotive catalysts are the second most common application. About 20-25% of platinum is utilized for this purpose.

Other industrial applications use perhaps another 20-25%. These kinds of applications include things such as use as a general catalyst in the chemical processing industry, use for high-temperature and non-corrosive wires in contacts, use in the glass industry, use as a catalyst for crude oil cracking, and use in the dental/medical field.

About 3-6% of platinum is used strictly for investment purposes.

### More about catalytic converters

In an ideal world, the only substances that would be present in automobile exhaust would be carbon dioxide gas, water vapor and unburned nitrogen gas. In fact, these indeed are the primary emission products, but unfortunately, additional undesirable combustion products are inevitably created during the combustion process.

There are several things that are done to try to keep undesirable combustion products to a minimum. First, the air-to-fuel ratio is kept as close to the stoichiometric point as possible. The stoichiometric point is that ratio of air-to-fuel that theoretically would result in the complete conversion of the hydrocarbon fuel to carbon dioxide and water vapor with neither the fuel nor the oxygen being present in excess. For gasoline, this ratio is approximately 14.7:1 by mass, i.e., the mass of air present in the combustion chamber should be about 14.7 times as great as the amount of fuel (see *Demonstrations and Lessons*).

But it is not possible (nor necessarily desirable) to continually burn the fuel inside the combustion chamber at this "ideal" ratio. Sometime the air-to-fuel ratio has to be somewhat below 14.7. This is what is called a *rich* mixture. At other times the ratio is higher, a *lean* mixture.

Some of the undesirable polluting by-products of combustion include:

carbon monoxide, CO—this is a poisonous as well as colorless and odorless gas (see *ChemMatters*, Feb. 2005)

hydrocarbons or volatile organic compounds (VOCs)—these are primarily produced from unburned fuel. Sunlight can break down these substances to create oxidants that then react with oxides of nitrogen to cause ground-level ozone, O<sub>3</sub>, one of the major constituents of smog (see *ChemMatters*, Apr. 2003).

nitrogen oxides (NO and NO<sub>2</sub>, represented by the general formula NO<sub>x</sub>)—these contribute to both smog and acid rain and are irritating to breathe.

Modern catalytic converters are called *three-way* converters because they help reduce all three of the pollutants listed above. These converters contain both an *oxidation* catalyst and a *reduction* catalyst.

Most catalytic converters utilize what is called a honeycomb structure to house the catalysts, although ceramic beads can also be used.

The first stage of the catalytic converter is the reduction stage. It uses platinum and rhodium to help reduce the NO<sub>x</sub> emissions. What basically happens here is that when any nitrogen compound (NO<sub>x</sub>) makes contact with the catalyst, the nitrogen atom is ripped out of the molecule and held on the

catalyst's surface. The oxygen atoms are released in the form of O<sub>2</sub>. The nitrogen atoms on the catalyst combine to form N<sub>2</sub>, and are then released, transforming harmful NO and NO<sub>2</sub> into harmless nitrogen and oxygen gas.

The oxidation catalyst uses a platinum and palladium catalyst that oxidizes unburned VOCs and CO gas into carbon dioxide, CO<sub>2</sub> and water.

There also is a control system present before the exhaust gases enter the catalytic converter. This system monitors the exhaust and utilizes an oxygen sensor to determine how much oxygen gas remains in the exhaust. A computer then adjusts the air-to-fuel ratio to ensure that the engine is operating reasonably close to the stoichiometric point for combustion and that there is enough oxygen remaining in the exhaust to oxidize the unburned VOCs when they are in the catalytic converter.

### More about fuel cells

A fuel cell is basically a device that takes hydrogen and oxygen and combines them to form water. Normally this reaction takes place when the two gases make direct contact. This is an oxidation-reduction reaction. Hydrogen is oxidized and oxygen is reduced. The only product of the reaction is water, and virtually all of the energy released is released in the form of heat.

A fuel cell is a technological device in many respects like a battery. It "tricks" the reactants into transferring their electrons indirectly, and as these electrons flow from one electrode to the other we can utilize some of their energy. The basic difference between a battery and a fuel cell is that in a battery all the reactants are initially placed inside the battery. When they are gone, the battery is "dead." We either have to buy a new battery or recharge the old battery by using an outside source of electrical energy.

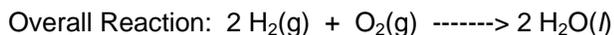
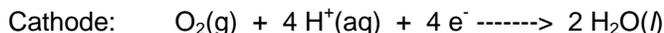
But in a fuel cell new reactants are continually fed into the system.

The basic operation is as follows.

Pressurized hydrogen gas flows over one electrode called the anode. This is where oxidation will take place. The anode contains the platinum catalyst. When the hydrogen gas makes contact with the catalyst, it is broken down into two hydrogen ions, H<sup>+</sup>, and two electrons are released. These electrons flow through an external circuit to the cathode. As they make their trip from one electrode to the other we can use some of their energy for whatever we want to use it for.

At the other electrode, called the cathode, reduction of oxygen gas takes place. The oxygen gas, O<sub>2</sub>, flows over the catalyst which separates it into two oxygen atoms. These then combine with the H<sup>+</sup> ions and two electrons to form water molecules.

The two half reactions that occur are;



The use of the catalysts allows the reaction to take place at a relatively low temperature, around 80 °C or so.

## Connections to Chemistry Concepts

### The troy weight system

The troy weight system is an old system of weights and measures that was superseded in Britain and other English-speaking countries by the Avoirdupois Weight System, which was actually an even older system. The troy weight system is no longer used with the exception of expressing the weights of precious stones and metals.

The “pounds” and “ounces” that we use in the United States come from the Avoirdupois Weight System. This system came from France, and was introduced to England around 1340 AD. The word “avoirdupois” meant “having weight” in medieval French.

The origin of the word “troy” is thought to have come from the city of Troyes, in France, located approximately 140 km (about 90 miles) southeast of Paris. In medieval times the city hosted large trade fairs for dealers in precious stones and metals. The city provided scales and weights whose accuracy was guaranteed by the local guilds.

Some of the most relevant (?) relationships are:

1 troy lb. = 12 troy ounces

1 troy ounce = 31.103475 grams

### Additional information about platinum

Although platinum was probably known to ancient cultures, its “discovery” is often attributed to the Spanish Conquistadors about 400 years ago. It was a byproduct that was collected when panning for gold, and was considered to be both a nuisance and worthless. It wasn't until 1751, when a Swedish Assayer by the name of Scheffer successfully melted and worked the substance that its high value was recognized. The Conquistadors had not been able to melt the material, as Pt has a very high melting point (1,772 °C), compared to 1,064 °C for Au. The word platinum is derived from the Spanish *platina*, or “little silver.”

Pure Pt is a silver-white metal that is malleable, ductile and lustrous. It is chemically inactive and is not affected by common acids, although it will dissolve in aqua regia (a highly corrosive fuming yellow liquid prepared by mixing one volume of concentrated nitric acid with three or four volumes of concentrated hydrochloric acid) to form chloroplatinic acid,  $\text{H}_2\text{PtCl}_6$ . It will react with halogens, sulfur or caustic alkalies, but will not directly react with oxygen gas, even at relatively high temperatures.

In nature it is usually found alloyed with other metals of the platinum-group elements (iridium, osmium, palladium, rhodium and ruthenium).

Atomic Number: 78

Atomic weight: 195.08

Boiling Point: 3,827 °C

Density: 21.45 g/cm<sup>3</sup>

### Possible Student Misconceptions

Because the article states that the demand for Pt has exceeded the supply for the past five years, students may assume that this is true in any year, which is not the case. See (*Background Information*). They may also come away with the impression that investing in platinum is a “sure thing,” since the article discusses how the price has risen over the past several years. While platinum may be an excellent long-term investment, its value can fluctuate significantly, and can decrease as well as increase (see *Background Information*).

### Demonstrations and Lessons

1. The article states that a troy ounce is “about 10%” heavier than a standard ounce.” Students could be challenged to do calculations, using common conversion factors such as 1 lb = 453.6 g and 1 lb = 16 ounces, to test whether this statement is reasonably accurate. There are a number of different ways to test this. One is shown below.

$$1 \text{ lb} = 453.6 \text{ g} = 16 \text{ ounces (avoirdupois)}$$

$$453.6 \text{ g}/16 \text{ ounces (avoirdupois)} = 28.35 \text{ g/ounce (avoirdupois)}$$

$$31.103475 \text{ g (troy ounce)}/28.35 \text{ g ounce (avoirdupois)} = 1.097$$

The troy ounce is about 9.7% heavier than the avoirdupois ounce, so the statement made in the article is “close enough.”

2. Is platinum a good investment? And if so, what is the best way to invest in the belief that the price of the metal will increase substantially in the not-too-distant future?

Students could be assigned to both sides of this issue and debate their positions. Arguments could be evaluated on the basis of the amount and relevancy of the factual information presented and the quality of the logic used in preparing their arguments. Some relevant informational areas that might be addressed could include:

The physical and chemical qualities of Pt that indicate that demand for the metal will increase.

The physical and chemical qualities of competing metals that indicate that the demand for Pt may not increase and may, in fact, decrease.

Worldwide reserves, coupled with economic and political considerations that argue that supply/demand considerations indicate that the price of Pt will increase (decrease) in the future.

Historical price data that argue for an increase or decrease in price.

The possible emergence of new technologies and the influence they may have on the price of Pt.

3. Websites dealing with the operation of catalytic converters sometimes state that the correct *stoichiometric* ratio of air-to-fuel in a gasoline burning engine is about 14.7:1 (see *Background Information*). Is this a reasonable figure?

Gasoline, of course, is not a pure substance, so it is virtually impossible to perform highly accurate calculations to test the validity of this specific figure. But is it in the correct ballpark?

Let's assume that gasoline can be represented by the formula for octane,  $C_8H_{18}$ , and that it undergoes complete combustion to carbon dioxide and water vapor.

Two possible versions of the problem for a class might be:

Easier version: Given that air is approximately 23.2% oxygen by mass, calculate the stoichiometric mass ratio of air-to-fuel for the combustion of gasoline.

More difficult: Given that air consists of approximately 78.09% nitrogen, 20.95% oxygen, 0.03% carbon dioxide and 0.93% argon by *volume*, calculate the stoichiometric mass ratio of air-to-fuel for the combustion of gasoline.

If you desire a worked out solution to these problems, just send an email to [chemtchur@aol.com](mailto:chemtchur@aol.com) with the title *Gasoline combustion problem solutions*. For obvious reasons replies can only be made to your school email address.

## Connections to the Chemistry Curriculum

This article connects very strongly to many general and specific topics. Discussing the properties of platinum will connect to melting points, boiling points, density, atomic number, atomic weight, the Periodic Table, and the general properties that cause a particular element to be classified as a metal or nonmetal. A discussion of the unit called a troy ounce can lead to a general discussion of several different systems of measurement that have been used in the past and are still being used today. Discussing the operation of a catalytic converter or a fuel cell will quickly lead to a discussion of oxidation-reduction reactions, electrochemical cells, catalysts, stoichiometry, combustion and pollution products and how they affect our atmosphere.

## Suggestions for Student Projects

1. One of the most controversial phenomena to hit popular science in recent years is the notion of "cold fusion." In 1989, two scientists, Stanley Pons and Martin Fleischmann, reported in a press conference that they had been able to obtain energy from a nuclear fusion reaction at room temperature. If their claim was true, and the process could be harnessed on a large-scale basis, it would arguably have constituted one of the most significant technological breakthroughs of the 20<sup>th</sup> century. Pons and Fleischmann were both electrochemists working at the University of Utah in Salt Lake City. Their experiment involved electrodes made of of palladium, one of the platinum group metals.

Most scientists have discredited their work, and "cold fusion" has been relegated to the trash heap of what is often referred to as "junk science."

But there remain to this day researchers who continue to investigate the process.

Students could prepare a report on this phenomenon, how it was supposedly achieved, the theory behind it, the failure of efforts to duplicate the process, and the status of the issue today. Such a report could go far toward illustrating how science operates, both in the laboratory and in both the professional and popular media.

2. Students (autoshow?) could prepare a report on how modern catalytic converters operate and the significant impact they have had on reducing air pollution from automobile exhausts.
3. Another possibility would be for students to prepare a report on fuel cells, covering the basic chemistry that underlies their operation and explaining the kinds of oxidation-reduction reactions that take place, the role of the anode and cathode and the catalysts they contain, and how useful energy is obtained from the device.
4. Platinum is one of the “platinum group” metals that include palladium, osmium, iridium, rhodium and ruthenium. Students could prepare a report comparing and contrasting the properties, value and uses of the various members of this important group of elements.

## Anticipating Student Questions

### If the demand for platinum exceeds the supply, shouldn't we all be investing in this metal?

The demand does not always exceed the supply, and while the general trend has been for the price of platinum to increase over time, the price can and has fallen. See *Background Information*.

### How, exactly, does a fuel cell work, and how does it generate electric power?

See *Background Information*.

### Is platinum the most expensive of all the platinum-group elements?

Since prices fluctuate, the most expensive of the platinum-group metals can change from year-to-year. At one time palladium metal was very expensive, but the price dropped precipitously. On the day this was being written (Jan. 24, 2005), the most expensive of the platinum-group metals was rhodium, Rh, with a price of \$1,490/oz, while platinum's price was at \$874/oz.

## Websites for Additional Information and Ideas

A good site for general information: [http://www.gold-eagle.com/editorials\\_02/paulos031902.html](http://www.gold-eagle.com/editorials_02/paulos031902.html)

For additional information on specific mines from which platinum is being obtained and how it is processed, go to: <http://www.platinum.matthey.com/production/africa.html>

For more information on catalytic converters: <http://autorepair.about.com/cs/generalinfo/a/aa080401a.htm>

For more information on fuel cells:

<http://science.howstuffworks.com/fuel-cell.htm>

[http://www.dft.gov.uk/stellent/groups/dft\\_roads/documents/page/dft\\_roads\\_024056-03.hcsp](http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_024056-03.hcsp)

For more information on “white gold:” <http://www.artisanplating.com/faqs/whitegoldfaqs.html>

# Do You Want Biodiesel with That?

## Background Information

### More about Rudolph Diesel and his engine

Born in Paris, France, on March 18, 1858, Diesel was trained as an industrial engineer. By 1880 he was building steam engines. Steam engines were notoriously inefficient, converting only about 10% of the energy from the fuel they burned into useful work. Diesel was convinced that a more efficient engine could be built. He theorized that if air were sufficiently compressed, its temperature would rise to the point where any fuel injected into an ignition chamber containing this hot air would spontaneously ignite. The resulting explosion would be capable of driving the piston downwards and the motion of this piston could then be harnessed to propel a vehicle or perform other useful work.

By 1893 he had built his first working model. It ran with an efficiency of 26%, a remarkable improvement from that provided by steam engines. By 1897 he had improved the design to where efficiencies of up to 75% were achievable.

By 1900 Diesel was ready to exhibit his new engine at the 1900 Paris Exposition. It was fueled by 100% peanut oil and received the Grand Prix.

Diesel intended and assumed that his engine would operate on biomass. He envisioned that farmers, small industries and those in isolated communities would be capable of producing their own fuel, and this would provide competition to the large monopolies that controlled all energy production at that time. He stated, "The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it."

As it turned out, vegetable oils were indeed used as the fuel for diesel engines until about the 1920s. Around that time diesel engine manufacturers modified the injection system of the engine so it could run on lower viscosity fossil fuels. This was advantageous because fossil fuels were plentiful and relatively low in cost. An argument can also be made that the oil tycoons of that time utilized their significant influence to push events in that direction.

Diesel suffered an untimely and controversial death in 1913. He was traveling across the English Channel when he disappeared over the side of the ship. His body was recovered ten days later from the water, but the cause of his demise was never firmly established. There are some who argue that he was murdered for political reasons. The French navy was already using diesel engines, and, as the argument goes, may not have wanted the English navy to acquire them. Diesel was also opposed to the politics of Germany at that time, and did not want the German navy to be able to utilize his engine. After his death the entire German submarine fleet was powered by diesel engines.

But a case can be made that Diesel actually committed suicide. He evidently was troubled for much of his life. One historian describes him as being vain, oversensitive and a bit paranoid. There is that old joke that just because you're paranoid doesn't mean that people aren't out to get you, and in Diesel's case, that may have been true.

There is little doubt that Diesel deserves credit for being the first person to elucidate the basic principles that underlie the operation of the engine, which Diesel worked out from his knowledge of thermodynamics. He also built the first working models, although some have been described as being "catastrophic failures". By around 1897 Diesel thought, probably mistakenly, that he was done with "inventing" the engine, and all that remained was some additional development. In fact, the engine required significant additional improvement before it would actually be ready to be marketed. It took about eleven additional years of improvements and innovations before a practical diesel engine was truly available. During this time Diesel basically had a nervous breakdown from the stress connected with trying to promote an engine that wasn't really ready for widespread and practical use.

Diesel felt that he had done all the real work and invention, and denigrated the work of many other talented engineers who tried to improve the design and make it commercially feasible. He evidently was terribly troubled by the criticism and controversy when he vanished.

## How a diesel engine works

If any students are interested in learning more about how a diesel engine works and how its operation compares to that of a normal gasoline-powered internal combustion engine, there is an animated Website that does an excellent job of explaining and demonstrating all of this. It can be found (with additional links) at:

<http://www.howstuffworks.com/diesel.htm>

### The main differences between a gasoline engine and a diesel engine are probably:

In a gasoline powered engine a mixture of vaporized gasoline and air is first compressed and then ignited with a spark. A diesel engine does not require a spark. It simply compresses the air to such an extent that its temperature rises to the point where the fuel spontaneously ignites when it is injected into the chamber containing the compressed air. To achieve this higher temperature upon compression, the compression ratio (ratio of the volume of the cylinder before compression to the volume after compression) in a diesel engine ranges between about 14:1 to 25:1, whereas in a gasoline engine it only ranges from about 6:1 to 12:1.

Gasoline engines mix the air and fuel either by utilizing a carburetor, which mixes the air and fuel before they enter the cylinder, or fuel injection, in which case the fuel is injected outside the cylinder just before the intake stroke. In a diesel engine the fuel is injected directly into the combustion cylinder.

### Comparing regular (not biodiesel) diesel fuel and gasoline

Compared to gasoline, diesel fuel is thicker (higher viscosity) and oilier. It evaporates much more slowly than gasoline and has a higher boiling point. When burned, diesel fuel releases more energy than a comparable volume of gasoline. Burning one gallon of diesel fuel will release about 155 million Joules of energy, compared to 132 million Joules for a gallon of gasoline.

### Composition of biodiesel

First, it should probably be pointed out that blends of biodiesel and regular petroleum-based diesel fuel (such as B20) are technically not classified as biodiesel. They should be called biodiesel blends. That said, in practice it is probably somewhat common to refer to these blends as being “biodiesel” fuel, even though the majority of the fuel is actually composed of normal petroleum-based diesel and technically the name is being used inappropriately.

As the article points out, the term *biodiesel* does not refer to a specific material—similar to what is true for the term *gasoline*. Gasoline is not a pure substance. It is a mixture of various hydrocarbons and comes in various grades. Biodiesel, and biodiesel blends are general terms that refer to any fuels designed to be used by a diesel engine and comprised, at least in part, of oils derived from plant or animal sources other than petroleum.

Like gasoline, regular diesel fuel derived from petroleum is a mixture of several different hydrocarbons. The specific composition will vary. There are different kinds of diesel fuel, so it is not really possible to state with specificity and confidence what the composition of any particular fuel might be. The number of carbon atoms in the various hydrocarbons contained in diesel fuel may vary within the range of 9-23, i.e.,  $C_9H_{20}$  to  $C_{23}H_{48}$ , but the amounts at the extreme ends is, at best, very low, so the range of 10-20 carbon atoms stated in the article is a reasonable representation.

The percentage of non-petroleum oil in biodiesel blends can range from very little to, in principle, 100%. One of the most commonly used formulations, B20, consists of a blend of 20% non-petroleum oil and 80% normal diesel fuel.

### Advantages and disadvantages of biodiesel

There are obvious advantages to the use of biodiesel, many of which are pointed out in the article. Included among these are:

It is made from renewable resources such as soybeans or recycled cooking oils from restaurants.

There is an overproduction of soybeans in the United States. Using more biodiesel could

provide a good use for some of this excess production.

It is less polluting than petroleum diesel. It emits less soot, carbon monoxide, unburned hydrocarbons and sulfur dioxide.

The absence of sulfur in 100% biodiesel is expected to result in an extension of the life of catalytic converters.

It can be used in combination with heating oil in residential and industrial buildings.

Blends of 20% biodiesel with 80% petroleum diesel can be used in unmodified diesel engines. The use of pure biodiesel fuel usually

requires that modifications be made in the engine to avoid both performance and maintenance problems.

It has lubricating effects that may extend the lifetime of engines.

It is nontoxic and biodegradable.

It has a higher cetane (above 100) number than petroleum-based diesel fuel (about 40). The cetane number measures a fuel's ignition quality. The higher cetane numbers for biodiesel fuel are beneficial for cold starting and low idle noise.

It reduces our dependence on foreign oil.

Of course there must also be some disadvantages. Otherwise there wouldn't be any reason to use petroleum diesel at all. Some of the disadvantages are:

It is more expensive than petroleum diesel—about 50% more expensive. Part of the difference arises from the fact that soybeans are only about 20% oil. This cost can be reduced if it is made from recycled cooking oil or a plant that contains a higher percentage of oil.

It takes energy to grow and harvest the soybeans that are used to produce the diesel fuel.

It can cause damage to the rubber hoses in some engines, especially those built before 1994.

It cleans dirt from the engine. This sounds like a good thing, but the dirt then tends to clog fuel filters, especially when biodiesel is used in an engine for the first time.

It is not as widely distributed, so it can be somewhat difficult to obtain. This problem should lessen as the fuel becomes more widely utilized.

It is a good solvent. It will dissolve paint, so it shouldn't make contact with the body of a vehicle for any length of time.

It gels faster than petroleum in cold weather when used in its pure form.

Because it is partially oxygenated, biodiesel contains approximately 10% less energy content than a hydrocarbon/petroleum diesel.

### More about the Energy Policy Act (EPAAct)

The EPAAct of 1993 required companies with fleets of at least 50 vehicles weighing 8,500 pounds or more to acquire alternative fuel vehicles. This evidently represented a burden in many cases, as compliance would require the purchase of new vehicles when the companies already possessed vehicles that ran well on normal diesel fuel. Consequently the act was amended in 1998 to allow the use of B20 fuel, which can be burned in a normal diesel engine without modifications.

This modification had immediate effects. Between 1999 and 2000 the use of blended biodiesel fuel increased dramatically. Biodiesel is also the only alternative fuel that has passed the EPA's Tier I and Tier II Health Effects Testing under the Clean Air Act. Other bio-fuels such as ethanol have only passed Tier I.

### Connections to Chemistry Concepts

An understanding of the details of how biodiesel is made from vegetable oil requires some knowledge of organic chemistry functional groups, nomenclature and reactions. A good Website covering organic nomenclature can be found at: <http://people.ouc.bc.ca/woodcock/nomenclature/>

The URL for the IUPAC is: <http://www.acdlabs.com/iupac/nomenclature/>

## Possible Student Misconceptions

Students may not understand the difference between a regular gasoline-powered internal combustion engine and a typical diesel engine. They probably do not understand the differences in how the fuel is ignited and how the differing compression ratios allow for this difference. See *Background Information*.

Because the article is basically devoted to the benefits and possibilities connected to the use of biodiesel, students may erroneously assume that the fuel offers nothing but benefits and that it is simply inertia that keeps it from being more widely used. Of course there are disadvantages as well. See *Background Information*.

Students may think that any blend of biodiesel with regular diesel is classified as being "biodiesel." Technically this is not the case. Although the term "biodiesel" is often casually assigned to blended fuels, only fuels made from 100% biodiesel should actually be called biodiesel.

## Demonstrations and Lessons

1. If your course includes a discussion of bond energies and estimating enthalpies of reaction from bond energies, you could assign the following problem:

The density of gasoline is 0.78 g/mL. The density of regular diesel fuel is 0.85 g/mL. A gallon is equal to about 3.8 L. Given the following average bond dissociation energies:

C-C (347 kJ/mol)  
C-H (413 kJ/mol)  
O=O (495 kJ/mol)  
C=O (799 kJ/mol)  
H-O (467 kJ/mol)

and assuming that gasoline can be represented by the formula  $C_8H_{18}$  and diesel fuel by the formula  $C_{14}H_{30}$ , estimate the number of Joules of energy that would be released when one gallon of gasoline and one gallon of diesel fuel are burned. Assume the only products of the reactions are gaseous carbon dioxide and water vapor.

Alternately, even less information could be given and students could be expected to look up or calculate some of the required information. Stating the problem with minimal information one might ask:

Using average bond dissociation energies, estimate and compare the amount of energy released when one gallon of gasoline and one gallon of diesel fuel are burned. Assume their respective formulas are  $C_8H_{18}$  and  $C_{14}H_{30}$  and the only products of the reactions are carbon dioxide and water vapor.

If you would like the solution to either or both of these problems, please send an email to [chemtchur@aol.com](mailto:chemtchur@aol.com), using the title, "Solutions to Biodiesel Problems." Replies can only be made to your school email address for obvious reasons.

2. Since the manufacture of biodiesel from vegetable oil is a transesterification process, this would be an excellent time to run an activity designed to have students prepare various esters in the laboratory. The ChemCom curriculum has a lab connected to this in the petroleum unit.

## Connections to the Chemistry Curriculum

This article can connect with several commonly taught topics. Organic chemistry clearly heads the list, as the composition and synthesis of biodiesel immediately gets one into organic structures and reactions, especially esterification.

The properties of biodiesel can connect to concepts such as viscosity, flash point and the energy released in combustion reactions. See *Demonstrations and Lessons*.

## Suggestions for Student Projects

1. Almost every class contains one or more students who have a strong interest in and perhaps knowledge of automobiles. These students might want to prepare an illustrated report on how the operation of

gasoline-powered internal combustion engines compares and contrasts to the operation of a diesel engine. See *Background Information*.

2. The continuing and even increasing dependence of the United States on foreign oil has serious economic and political consequences. Students could prepare a report tracking our increasing use of oil over the past century or so, and how changes in the availability and price of oil have affected the United States. This could be followed by a discussion of the extent, both ideally and practically, to which the use of biodiesel fuel might alleviate some of the problems tied to our significant dependence on foreign sources of petroleum.

## Anticipating Student Questions

### Is biodiesel being widely used in the United States at the present time?

It is difficult to obtain accurate data, since it is changing rapidly, but it is probably reasonable to say that its use is increasing rather significantly. Some sources estimate that its use will double in a relatively short period of time. Use of biodiesel rose from 500,000 gallons in 1999 to 20 million gallons in 2001. The United States Senate passed a bill in early 2002 that lifted a restriction that limited government vehicles to using biodiesel for no more than half of their alternative fuel requirements. This was considered significant because government vehicles represent a very significant consumer of biodiesel fuel.

Some of the major fleets currently making some use of biodiesel include:

The U.S. Department of Agriculture	State fleets in Iowa, Ohio, Delaware, New Jersey and Virginia
The U.S. Postal Service	
The U.S. military	Public utility fleets like Duke Energy, Alabama Power and Commonwealth Edison
The U.S. Department of Energy	National Park Service

More than 100 cities have test projects or have run demonstrations involving more than 1,000 buses and over a million miles using biodiesel.

### Do most engines using biodiesel fuel use it in its pure form?

No. It is mixed with normal petroleum diesel. A typical mixture will contain between 2-20% biodiesel, with the upper limit being most typical. Biodiesel fuels are labeled with a number that designates the percent of biodiesel in the mixture. For example, a fuel labeled B20 would contain 20% biodiesel and 80% petroleum diesel.

### If biodiesel is so great, why are we still mostly burning petroleum diesel in diesel engines?

There are a number of reasons. Cost is perhaps the major one, but biodiesel does have some disadvantages. See *Background Information*.

### Are there filling stations that sell biodiesel?

Yes. There are dozens of public pumps in many states, and more are coming online almost every week. You can see a map of pump locations at:

<http://www.biodiesel.org/buyingbiodiesel/retailfuelingsites/default.shtm>

### Can I use biodiesel fuel in a regular car in place of gasoline?

No.

## Websites for Additional Information and Ideas

A good general Website for information on biodiesel that contains a large number of useful links is the official site of the National Biodiesel Board. It can be found at:

[http://www.biodiesel.org/resources/biodiesel\\_basics/default.shtm](http://www.biodiesel.org/resources/biodiesel_basics/default.shtm)

A nice Website listing the properties of various hydrocarbons and their most common uses is at:

<http://www.obio.com/hydrocarbon%20chains.htm>

Another good general Website that also shows the general kind of reaction that produces biodiesel and also discusses the actual production process is at:

[http://www.esru.strath.ac.uk/EandE/Web\\_sites/02-03/biofuels/what\\_biodiesel.htm](http://www.esru.strath.ac.uk/EandE/Web_sites/02-03/biofuels/what_biodiesel.htm)

Some other good general sites:

<http://en.wikipedia.org/wiki/Biodiesel>

<http://www.monsanto.co.uk/biofuels/071202.html>

# Battling Zits!

## Background Information

### More about how a “zit” is formed

As pointed out in the article, the formation of a zit occurs when a sebaceous gland produces sebum that then mixes with dead skin cells in a hair follicle and forms blockages called comedones (plural of comedo).

The oil always found on human skin is a complex mixture. It consists of sebum, lipids from the surface of the skin, sweat, and materials that enter from the environment.

Sebum is produced by the sebaceous glands (now who would have thought that?). Sebaceous glands are found over virtually the entire human body, but are larger and more numerous on certain areas, specifically the mid-back, forehead and chin, where their concentration may reach 400-900 per cm<sup>2</sup>. The hands and feet contain relatively small numbers and there are none on the palms or soles of the feet.

Most sebaceous glands open out into a hair follicle, although there are a few exceptions that open directly to the surface of the skin.

Sebum is not one chemical or even a consistent mixture of chemicals. Its composition can vary, but typically consists of glycerides, free fatty acids, wax esters, squalene (an intermediate in the biosynthesis of cholesterol with the formula C<sub>30</sub>H<sub>50</sub>), cholesterol esters and cholesterol.

Since it is the blockage of the duct of the hair follicle that leads to the formation of a zit and it is the mixing of sebum with dead skin cells that leads to this blockage, the presence of acne is connected to the overproduction of sebum that often occurs around the age of puberty.

Sebum is always being produced, even in newborns, where its composition closely resembles that produced by an adult. After about age 6 months and until about age 8, a child's sebum contains less wax and squalene and more cholesterol.

At puberty, sebum production increases dramatically, up to fivefold in males, somewhat less in females, which obviously accounts for acne being primarily a problem associated with the teenage years. After that sebum production declines with age.

Photographs of various types of acne can be found at:

<http://www.nlm.nih.gov/medlineplus/ency/article/003236.htm>

### Some different types of “zits”

As any person suffering from the condition is aware, acne can manifest itself in more than one type of lesion. Four common ones are:

Papules—these are inflamed lesions that typically appear in the form of small, pink bumps that can be tender to the touch.

Pustules (pimples)—this may represent the “classic” symptom of acne—papules that are topped by pus-filled lesions.

Nodules—these are large, painful, solid lesions that actually reside deep within the skin.

Cysts—these are also deep, painful, pus-filled lesions that can result in scarring.

### More about *Propionibacterium acnes*

*P. acnes* is a ubiquitous skin-dwelling bacterium. Because it is so widespread and has an excellent ability to survive in a wide range of environments it is also one of the most common contaminants of blood in blood banks. Besides being involved in causing acne, it has also been connected to corneal ulcers, gallstones and several other diseases as well as inflammations involving heart valves and prosthetic devices. Its complete genome was sequenced and analyzed in 2004.

For many years it was easily treated with antibiotics, but like many other bacteria, it began to exhibit resistance to common antibiotics in the late 1970s and this resistance has continued to increase.

### Alpha hydroxy acid compounds

The article mentions that alpha hydroxy acids (see *Connections to Chemistry Concepts* for an explanation of the meaning of this term) are often used in the treatment of acne. Alpha hydroxy acids are commonly found in and isolated from several different kinds of fruits. Some common examples include *malic acid*, found in apples, *citric acid*, found in all citrus fruits, and *glycolic acid*, found in honey or sugar cane.

When natural products undergo fermentation, one of the fermentation products can be an alpha hydroxy acid such as *lactic acid*, found in sour milk, and *tartaric acid* that can be isolated from fermented grapes.

The United States Food and Drug Administration (FDA) has reported that studies conducted by the cosmetics industry have given indications that the use of acne products containing alpha hydroxy acids may make users more sensitive to sunlight, particularly the ultraviolet wavelengths that are associated with sunburn and skin cancer. They recommend that any person using these products should take precautions when exposing themselves to sunlight, including wearing a hat with a brim of at least four inches, wearing lightweight sun protective clothing, including long sleeves, and applying a sunscreen with an SPF (Sun Protective Factor) of at least 15. These precautions should be taken even if the product is not being used on the day sun exposure occurs.

By law, any cosmetic product that contains an AHA must list it on their outer packaging. There are a large number of cosmetic products that contain AHAs, and different AHAs that one might encounter (many are synonyms of each other). Included are:

glycolic acid	alpha-hydroxyethanoic acid + ammonium alpha-hydroxyethanoate	sugar cane extract
lactic acid		alpha hydroxy and botanical complex
malic acid	alpha-hydroxyoctanoic acid	L-alpha hydroxy acid
citric acid	alpha-hydroxycaprylic acid	glycomer in crosslinked fatty acids alpha nutrium (three AHAs)
glycolic acid + ammonium glycolate	hydroxycaprylic acid	
	mixed fruit acid	

In 1997 the FDA announced, in response to concerns surrounding the side effects that might be associated with the use of alpha hydroxy acids, that they were safe to use providing the following guidelines were observed.

- (1) The concentration of the AHA should be no higher than 10%.
- (2) The pH of the final product should be above 3.5.
- (3) The product should either contain an effective sunscreen or carry a warning that people using the product should apply a sunscreen if they were going to be exposed to the sun.

#### **More about Accutane**

The article mentions Accutane (Isotretinoin) as the “nuclear” option for treating acne, and this may be a fair representation. It is certainly one of most effective treatments available. Acne can be and often is a very stubborn and persistent condition that can significantly affect the lives and happiness of young people. While it is somewhat difficult to accurately estimate the percentage of severe and persistent cases that are “cured” by the use of Accutane, there is no doubt that a significant percentage of cases are reduced to a very tolerable level and many others experience significant improvement.

But as the article points out, Accutane can have several unfortunate and even catastrophic side effects, so it is never considered to be the first line of treatment.

On Oct. 26, 2004, Roche, the manufacturer of Accutane, issued revised and very strict guidelines for its use.

Potential side effects can take several different forms.

The most serious side effect occurs if Accutane is taken during pregnancy. Any woman who is or who becomes pregnant while taking Accutane must realize that there is a very high probability that her baby will be born with serious deformities and may not even survive. Any female being prescribed Accutane should undergo two pregnancy tests and should utilize two different methods of birth control, such as the use of both birth control pills and condoms.

One unfortunate and fairly common occurrence when a patient begins treatment with Accutane is actually a short-term increase in the severity of the condition before improvement takes place. This can sometimes be lessened by initially taking a lower dose for the first month or two.

Other side effects may include:

dryness of the lips, nasal membranes, eyes or skin  
nosebleeds  
a minor rash on the back of the hands  
increased sensitivity to sunlight  
minor eye irritation  
contact lens intolerance  
thinning scalp hair

occasional pink eye infections  
muscle aching and/or joint pains  
headaches  
an adverse affect on blood cholesterol and blood triglyceride levels  
loss of appetite  
stomach pain  
an increased risk of depression and suicide

USA Today reported approximately 66 cases of suicide and over 1,300 cases of psychiatric problems "associated" with the use of Accutane that were reported to the FDA. In April, 2002, Roche Pharmaceuticals was served with a \$70 million lawsuit claiming that Accutane was the cause of severe psychosis.

## Connections to Chemistry (and Biology) Concepts

### More about human skin

The skin is the largest organ in the human body. It serves multiple functions. Besides the obvious one of providing protection, it also serves to regulate body temperature, stores water and fat, and is a sensory organ. It is divided into three main sections, the epidermis, the dermis and the subcutis. Two Websites that provide nice cross-sectional diagrams of human skin can be found at:

[http://www.nmsl.chem.ccu.edu.tw/tea/SKIN\\_910721.htm](http://www.nmsl.chem.ccu.edu.tw/tea/SKIN_910721.htm)

The above site is very extensive and consists of a total of thirty-two pages of material devoted to the structure and function of human skin.

[http://kidshealth.org/kid/body/skin\\_noSW.html](http://kidshealth.org/kid/body/skin_noSW.html)

The above is a much more limited site designed to inform children about the basic structure and properties of human skin.

The outmost layer, the epidermis, consists of three parts, the stratum corneum, or horny layer, the keratinocytes or squamous cells, and the basal layer. The stratum corneum is made of fully mature keratinocytes that contain fibrous proteins called keratins. It typically is between 15-20 cells thick. These layers of cells are held together by lipids which fill the spaces between the cells, like mortar between layers of brick. This outermost layer is continually being shed and replaced. Just beneath this layer is a layer of keratinocytes, or squamous cells. As these mature, they replace cells shed from the stratum corneum.

Underneath the keratinocytes is a layer of basal cells. This is the deepest layer of the epidermis. These cells constantly divide and form new keratinocytes that in turn replace the keratinocytes that replaced the cells shed from the stratum corneum.

Beneath the epidermis lies another layer called the dermis. This layer contains blood vessels, lymph vessels, hair follicles, sweat glands, collagen bundles, fibroblasts and nerves. It also contains receptors that signal pain and sense touch.

The deepest layer of skin is called the subcutis. It also consists of a network of collagen and fat cells. It conserves the body's heat and protects it from injury by acting as a shock absorber.

### A few words about "like dissolves like"

The article mentions that the "benzoyl" part of benzoyl peroxide gives the molecule a more lipophilic (fat-loving) or nonpolar character and that this is a good thing because it helps the medication target oily pores.

This ability to "target oily pores" is a consequence of the often cited chemical principle that "like dissolves like."

This phrase, common to many introductory chemistry courses, is meant to convey the general notion that polar solutes tend to be soluble in polar solvents and nonpolar solutes tend to be soluble in nonpolar solvents.

As a rough generalization, this notion is probably an acceptable one, but it should not be taken too literally. For example, ionic solids might be considered an extreme example of "polarity." Yet some ionic solids are very soluble in water, while others are almost completely insoluble. This generalization probably is more consistently true when it is applied to the mixing of two liquids. Nevertheless, many "demonstrations" designed to illustrate the principle will use solid materials.

What is it that makes many consider this rule to be a fairly reasonable generalization, at least at the introductory level?

Although somewhat oversimplified, the basic idea is that how soluble one substance is in another depends on two factors, (1) the energy change that occurs when the two substances mix, and (2) the entropy change that occurs.

If the dissolving process is exothermic, then two substances will tend to be rather soluble in each other. If the dissolving process is endothermic, they will tend to have low solubilities in each other.

If entropy increases as the substances dissolve, they will tend to be soluble in each other and vice-versa.

Unfortunately, it is not always easy to intuitively predict how these two factors will play out. "Mixing" two liquids is usually associated with an increase in entropy, although there are exceptions when the two different molecules strongly interact.

There are "exceptions" to the "like dissolves like" generalization because the specific kinds of interactions that can occur between the particles that make up two substances varies greatly.

But as a generalization, the reason the rule is often obeyed hinges around the idea that polar molecules tend to attract each other rather strongly, while nonpolar molecules tend to have somewhat weaker intermolecular attractions.

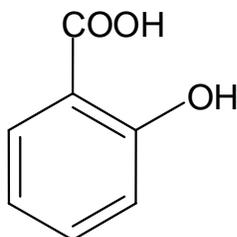
If you try to mix a polar and a nonpolar substance, in general it will take a lot of energy to separate the polar molecules from each other to make room for the nonpolar molecules to mix in (forming a solution). This is endothermic, which is "bad," and unless this energy can be overcome by interactions between the polar and nonpolar molecules and/or entropy effects, the molecules are not likely to mix (dissolve). More often than not, this is the case.

But if you mix two polar liquids, call them A and B, the energy released when molecules of A are attracted to molecules of B may be enough to compensate for the energy required to separate molecules of A from each other and molecules of B from each other. And even if it isn't quite enough, the dissolving process may be accompanied by a sufficient increase in entropy to make the overall dissolving process favorable.

When two nonpolar liquids are mixed, the energy required to separate molecules of A from each other and molecules of B from each other is (as a generalization) not as great as is true for polar liquids. Then molecules of A are attracted to molecules of B. The energy released when this occurs is probably somewhat comparable to the energy required to separate the original molecules. Toss in the effect of entropy, which probably increases upon mixing, and there is a good chance that the two nonpolar liquids will be soluble in each other.

### Alpha and beta hydroxy acids

The structure of salicylic acid is:

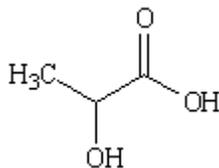


The reason it is referred to as a "beta" hydroxy acid relates to the fact that the hydroxy (OH) group is located two carbon atoms away from the carbon contained in the carboxylic acid (COOH) group.

A perhaps more systematic name for salicylic acid is 2-hydroxybenzoic acid.

Another class of hydroxy acids called “alpha” hydroxy acids (AHAs) is so named because the hydroxy (OH) group is located on a carbon atom that is immediately adjacent to the carbon atom containing the carboxylic acid (COOH) group. (See *Anticipating Student Questions*).

Lactic acid is a simple example of an alpha-hydroxy acid. Note that the –OH group is located on a carbon atom that is adjacent to the carbon atom of the –COOH group.



Another systematic name is 2-hydroxypropanoic acid.

### Possible Student Misconceptions

There are many generally accepted ideas surrounding acne that have not been supported by either research or clinical experience. The article deals with a few of these. Some others are that frequent washing of one's face can help prevent acne flare-ups and that stress or sexual activity will result in an outbreak of acne. Some students may think that acne is solely a problem of teenagers. While acne does become less prevalent after the teenage years, it can still be a problem for many people in their 20's, 30's and even older.

### Demonstrations and Lessons

1. The article ends by listing some of the fallacies that are commonly associated with acne. The first is that eating chocolate will cause acne to flare up. It is probably safe to say that there are still many individuals who are certain that at least in *their* case, eating chocolate (or perhaps some other particular food or type of food) will trigger a breakout. However, several studies done over the past thirty years or so have failed to detect any link between chocolate consumption and the incidence of acne.

How could one test the hypothesis that chocolate causes acne outbreaks? How might a scientifically valid experiment be performed? How many individuals would need to participate in the study in order for the results to be deemed statistically reliable? What kinds of controls would have to be in place? What kind of “double blind” procedures would have to be set up to avoid bias?

Discussing exactly how such a study would have to be set up could be an excellent exercise in getting students to understand something about how valid scientific studies need to be conducted and what kinds of pitfalls must be avoided. It might also go far in teaching them how many studies that claim to support wild-sounding claims (such as ESP) are often lacking in such basic controls that their purported results should be treated, at best, with high skepticism and probably completely rejected.

2. Many teenagers are afflicted, to various extents, with acne, and those not afflicted may very well still be concerned that they may be “next.” It would be both educational and hopefully reassuring if a local dermatologist (perhaps a family member of a student) could speak to them. Although the article discusses various kinds of treatments, a physician could speak to the most typical course of treatment and why it is followed as well as how treatments can be designed to specifically address each different individual and each different case.
3. If you discuss the function and structure of salicylic acid and are due to run an organic synthesis lab, the synthesis of aspirin might make an appropriate laboratory activity. Some Websites with background information and directions include:  
<http://tooldoc.wncc.nevada.edu/aspirin.htm>  
<http://www.chemheritage.org/EducationalServices/pharm/tg/asp/asp31.htm>  
<http://www.pc.maricopa.edu/chemistry/151LLWeb/Synthesis%20of%20Aspirin%20Lab.htm>

## Connections to the Chemistry Curriculum

While this article may have stronger connections to the biology curriculum, it does have a strong tie-in to organic structures and nomenclature and could be used to introduce some basic information regarding some basic structures and functional groups and how they are named. There also are connections to the concepts of acidity and pH, and in addition any discussion of the lipophilic nature of a chemical like benzoyl peroxide can lead to a discussion of the often cited chemical generalization that “like dissolves like.”

## Suggestions for Student Projects

1. One Website selling salicylic acid states:

“Beta hydroxy acids have a larger molecule than their cousin, alpha hydroxy acids. The larger molecule size keeps the beta hydroxy acid on the surface of the skin allowing it to more effectively penetrate and exfoliate within the pore.”

And later, “The larger molecule size of salicylic acid produces less irritation than alpha hydroxy acids, making it a welcome alternative for those with sensitive skin.”

Students could prepare a commentary on the probable accuracy of the various statements made in the above sentences.

2. If you go to a local drugstore and peruse the various over-the-counter products designed to treat acne, the names under which the various products are sold can be, at best, somewhat confusing, and at worse, perhaps misleading. Words and phrases like “maximum,” “maximum strength,” “ultra,” often appear, but do not seem to have any specific meaning. For example, one product from the same company is labeled “ultra,” and contains 10% salicylic acid, while another product is labeled “maximum strength,” but still only contains the same 10% formulation.

An interesting and educational project might be to examine the labels on several over-the-counter medications and then compare the actual ingredients to the suggestive words that appear on the front of the package. Is there any consistency at all? Do some of the labels on the front of the packages appear to perhaps even be intentionally misleading?

The project could also involve comparing the cost per given amount of active ingredient for various brand name products and nonbrand name products.

## Anticipating Student Questions

### How can some acne products contain acids, when acids are so corrosive? Wouldn't they burn your skin?

While the acid products contained in acne formulations are indeed acids in the sense that they release  $H^+$  ions in solution, their properties are significantly different from the kinds of acids like HCl,  $HNO_3$  or  $H_2SO_4$  that you may have used in a chemistry experiment. These acids are called *mineral* acids, and they are indeed very corrosive and should never be applied to the skin in any significant concentration.

But chemicals like salicylic or benzoic acid are *organic* acids. While they can be dangerous and corrosive, especially at high concentrations, in general they are less corrosive than mineral acids and are commonly found in many everyday products. All organic acids contain one or more acid ( $-COOH$ ) groups attached to a molecule that contains several carbon atoms.

Some common examples include *acetic acid*,  $CH_3COOH$ , found in vinegar, and *lactic acid*,  $CH_3-CHOH-COOH$ , found in sour milk.

### What's the difference between acne, eczema and psoriasis?

They are completely unrelated conditions. Eczema actually is a group of skin conditions that affects people of all ages. Mild cases are characterized by skin that is dry, hot and itchy. More severe cases result in skin that can be broken, raw and bleeding.

Psoriasis is a disease that begins deep in the immune system. It reveals itself in the form of a dramatic increase in the number of skin cells in the top layers of the skin. Whereas normal skin cells take about a month to mature, skin cells in a person suffering from psoriasis may mature in perhaps three or four days. This accumulation of cells forms the characteristic scaly areas denoted by the disease.

### **Does washing your face several times a day help to prevent acne?**

Unfortunately, no, although this would seem logical, since acne breakouts are connected to both bacteria and oils. But the black area in a "blackhead" is not a piece of dirt that is trapped, but simply trapped oils and other materials. You do want to wash your face, perhaps with a product designed to remove dead skin, etc., but excessive washing will not help and may even aggravate the condition, especially if a rough cloth is repeatedly rubbed on the face.

### **If Accutane is such a powerful treatment for acne, why hasn't my dermatologist prescribed it for me?**

Accutane has some very serious side effects. See *Background Information*.

### **Websites for Additional Information and Ideas**

A discussion of different types of comedones, including photographs can be found at:

<http://dermnetnz.org/acne/comedones.html>

For additional information about Accutane:

<http://www.fda.gov/cder/drug/infopage/accutane/medicationguide.htm>

# Mustard Gas

## Background Information

### More on the effects of exposure to mustard gas

Oddly enough, when one is exposed to a typical dose of mustard gas, more often than not there is actually a delay of perhaps several hours before the effects become pronounced. If exposed to the liquid form this delay is shortened. Very often no significant effects are felt for the first hour or so after exposure, although this is not always the case.

Generally within about 2-6 hours symptoms begin. These include nausea, fatigue, headache, eye inflammation accompanied by intense pain, lachrymation (excessive secretion of tears) , blepharospasm (spasmodic winking caused by the involuntary contraction of an eyelid muscle), photophobia (an abnormal sensitivity to or avoidance of light), and rhinorrhoea (excessive nasal discharge). The face and neck typically become very red, the throat becomes very sore, and there is an increased pulse and respiratory rate.

These symptoms continue to increase in severity over the next twenty hours or so and are accompanied by skin inflammation, followed by blister formation in the warmest areas of the body such as the genitals, the buttocks, the armpits and the inner thighs.

These conditions generally continue to become more severe for the 2<sup>nd</sup> twenty-four hours. Blistering increases and worsens. Severe coughing begins, often producing mucus, pus and necrotic slough. There is intense itching of the skin with increased pigmentation.

If the degree of exposure is much higher than what is typical, convulsions followed by a coma and death can occur within an hour.

Mild exposure to small amounts (such as might be experienced by workers involved in the manufacture of the material) can produce delayed effects months and even years later. Respiratory problems are the most common delayed effect. In addition, workers involved in mustard gas production have a higher incidence of cancer, influenza, pneumonia and chronic respiratory disease.

One American study involving 7,000 cases of exposure to mustard gas showed the following areas to be those most typically affected.

Eyes-----	86.1%
Respiratory tract-----	75.3%
Genitals-----	42.1%
Face-----	26.6%
Armpits-----	12.5%
Arms-----	11.7%
Legs-----	11.4%
Abdominal regions-----	6.4%
Hands-----	4.3%
Feet-----	1.5%

### Chemical and Biological Weapons Timeline Events

The article sidebar lists some of the significant events in the development and use of chemical weapons. Some additional events, including what would be more correctly listed as the use of biological weapons are:

5<sup>th</sup> Century BC—During the war between Athens and Sparta, the Spartan forces besieging an Athenian city placed lighted mixtures of wood, pitch and sulfur under the walls of the city. They hoped that the noxious fumes would incapacitate the Athenians, but the attempt was not highly successful.

1346 AD—A battle had been raging around the town of Caffa (Crimea, Russia). The town was under the control of Genoans from northern Italy, but Tartars from the east had been attempting, unsuccessfully, to retake the city for three years. The city was walled, highly defended, and self-sufficient.

This was the time of the bubonic plague. The plague struck the Tatar's ranks, but rather than providing victory for the Genoans, it led to their defeat. The Tartars had the rather ingenious idea of destroying their enemy by decimating them with plague, and they achieved this by catapulting infected corpses over the walls of the city. The technique proved successful and the Genoans were forced to surrender. There is some speculation that survivors fleeing the city were responsible for the spread of the disease from Asia to Europe and the subsequent death, over the next four years, of approximately 20,000,000 people.

1422—A similar thing occurred during the battle of Carolstein. Lithuanian soldiers adopted the same technique of hurling plague-infected bodies, and in addition they hurled about 2,000 cartloads of excrement over the walls of the castle they were putting under siege.

1500—Leonardo da Vinci—the chemical weapon he envisioned involved a mixture of sulfide or arsenic and verdigris (see *ChemMatters*, Feb. 2003). He wrote:

*throw poison in the form of powder upon galleys. Chalk, fine sulfide of arsenic, and powdered verdigris may be thrown among enemy ships by means of small mangonels, (a military device used to hurl stones and other objects) and all those who, as they breathe, inhale the powder into their lungs will become asphyxiated.*

Evidently it is not known whether the device was actually ever utilized.

1500s-1800s—During this period there are several episodes involving the use of smallpox to defeat an enemy. Conquistador Hernando Cortez used contaminated clothing to infect natives in his conquest of Peru. During the Indian wars in the United States it was a fairly common practice to try and induce smallpox into the Native American population by the use of contaminated blankets and handkerchiefs taken from hospitals. These were sometimes presented as "gifts."

1672—During the siege of the city of Groningen several different explosive and incendiary devices, some filled with belladonna (a poisonous herb) were used with the intention of producing noxious fumes.

1854—Lyon Playfair, a British chemist, proposed using a cacodyl cyanide artillery shell against enemy ships during the siege of Sevastopol. Although backed by Admiral Thomas Cochrane of the Royal Navy, the proposal was rejected by the British Ordnance Department as "bad a mode of warfare as poisoning the wells of the enemy." Playfair's response to their objection was used as a justification for the use of chemical warfare well into the next century.

*There was no sense in this objection. It is considered a legitimate mode of warfare to fill shells with molten metal which scatters among the enemy, and produced the most frightful modes of death. Why a poisonous vapor which would kill men without suffering is to be considered illegitimate warfare is incomprehensible. War is destruction, and the more destructive it can be made with the least suffering the sooner will be ended that barbarous method of protecting national rights. No doubt in time chemistry will be used to lessen the suffering of combatants, and even of criminals condemned to death.*

WWII—It is often stated that there was no use of chemical weapons during the 2<sup>nd</sup> World War. This is basically a valid statement, although they did see some very limited use and both sides certainly had amassed significant quantities of these kinds of weapons. Nazi Germany discovered the nerve agents tabun, sarin and soman. They developed large stockpiles of these and other agents, but although used in some limited contexts, these were never utilized on a large-scale basis. Evidently they interpreted the lack of discussion of these types of agents in Allies' scientific journals as evidence that they had actually developed the ability for their large scale use and the lack of journal articles was evidence that information regarding these agents was being suppressed.

In 1945, the Allies seized vast quantities of chemical weapons that had belonged to Germany. These included approximately 300,000 tons of mines, grenades, aerial bombs and artillery shells that were filled with mustard gas or other poisonous compounds.

### **Other gases used during WWI**

Mustard gas and chlorine were hardly the only poisonous gases used during WWI. One comprehensive Website lists all of the following, along with the sides that used it, some of their effects, and the mode of delivery:

benzyl bromide

Germany, tearing, first used in 1915

bromoacetone

Both sides, tearing/fatal in concentration, first used in 1916

carbonyl chloride (phosgene)

Both sides, asphyxiant, fatal with delayed action, first used in 1915

chlorine

Both sides, asphyxiant, fatal in concentration, first used in 1915, cylinder release only

chloromethyl chloroformate

Both sides, tearing, first used in 1915, artillery shell

chloropicrin

Both sides, tearing, first used in 1916, artillery shell

cyanogen (cyanide) compounds

Allies, Austria, asphyxiant, fatal in concentration, first used in 1916, artillery shell

dichloromethyl ether

Germany, tearing, first used in 1918, artillery shell

dibromomethyl ethyl ketone

Germany, tearing, fatal in concentration, first used in 1916

diphenylchloroarsine

Germany, asphyxiant, fatal in concentration, (dust-could not be filtered), first used in 1917, artillery shell

diphenylcyanoarsine

Germany, more powerful replacement for diphenylchloroarsine, first used in 1918

ethyldichloroarsine

Germany, less powerful replacement for diphenylchloroarsine, first used in 1918, artillery shell

ethyl iodoacetate

British, tearing, first used in 1916

monobromomethyl ethyl ketone

Germany, more powerful replacement for bromoacetone, first used in 1916

trichloromethylchloroformate (diphosgene)

Both sides, asphyxiant, fatal with delayed action, first used in 1916

### The Geneva Protocol of 1925—What did it actually prohibit?

The article mentions the Geneva Protocol of 1925 and presents some of the opening words. The complete protocol is:

TIAS 8061

#### **PROTOCOL FOR THE PROHIBITION OF THE USE IN WAR OF ASPHYXIATING, POISONOUS OR OTHER GASES, AND OF BACTERIOLOGICAL METHODS OF WARFARE**

ENTRY INTO FORCE: 8 February 1928

The undersigned Plenipotentiaries, in the name of their respective governments:

Whereas the use in war of asphyxiating, poisonous or other gases, and of all analogous liquids, materials or devices, has been justly condemned by the general opinion of the civilised world; and Whereas the prohibition of such use has been declared in Treaties to which the majority of Powers of the world are Parties; and To the end that this prohibition shall be universally accepted as a part of International Law, binding alike the conscience and the practice of nations;

Declare:

That the High Contracting Parties, so far as they are not already Parties to Treaties prohibiting such use, accept this prohibition, agree to extend this prohibition to the use of bacteriological methods of warfare and agree to be bound as between themselves according to the terms of this declaration.

The High Contracting Parties will exert every effort to induce other States to accede to the present Protocol. Such accession will be notified to the Government of the French Republic, and by the latter to all signatories and acceding Powers, and will take effect on the date of the notification by the Government of the French Republic.

The present Protocol, of which the English and French texts are both authentic, shall be ratified as soon as possible. It shall bear today's date.

The ratifications of the present Protocol shall be addressed to the Government of the French Republic, which will at once notify the deposit of such ratification to each of the signatory and acceding Powers.

The instruments of ratification of and accession to the present Protocol will remain deposited in the archives of the Government of the French Republic.

The present Protocol will come into force for each signatory Power as from the date of deposit of its ratification, and, from that moment, each Power will be bound as regards other Powers which have already deposited their ratifications.

In witness whereof the Plenipotentiaries have signed the present Protocol.

Done at Geneva in a single copy, the seventeenth day of June, One Thousand Nine Hundred and Twenty-Five.

### **The Biological and Toxin Weapons Convention of 1975**

This is a much more comprehensive and involved document. If you would like to obtain more information regarding the history of this document or perhaps read the document itself, some good Websites include:

<http://www.state.gov/t/ac/trt/4718.htm>

<http://www.pbs.org/wgbh/nova/bioterror/bwc.html>

### **The Chemical Weapons Convention (CWC) and the Organization for the Prohibition of Chemical Weapons (OPCW)**

Once again, the following Websites may prove very useful.

There is an official United States Chemical Weapons Convention Website at:

<http://www.cwc.gov/>

Other useful Websites include:

<http://www.cwc.gov/treaty/cwcIndex.html>

<http://www.un.org/Depts/dda/WMD/cwc/>

<http://www.fas.org/nuke/control/cwc/>

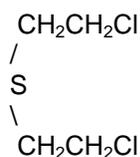
### **Mustard gas from WWII still poses a risk at sea**

After the Second World War, shells that were leaking mustard gas were dumped into the Baltic sea. While that probably seems like a completely irresponsible act of bad judgment, during that time ecological concerns were not that common, and in fact, it was generally believed that dumping materials such as this into the seabed was actually one of the safest methods of disposal. It turns out that contact with sea water alters mustard gas's normal liquid state. It becomes very viscous and can even transform into a solid material. It is thought that significant quantities of this form of mustard gas remain at the bottom of the Baltic sea even today and pose a risk. Eleven fishermen have suffered from exposure to this mustard gas. Their symptoms included highly inflamed skin, including blisters and painful inflammations of the eyes producing transient blindness. Two of the fisherman also suffered pulmonary edema.

## **Connections to Chemistry Concepts**

### **More about mustard gas**

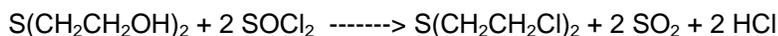
As stated in the article, the structure of mustard gas is



Mustard gas is classified as a *thioether*. Ethers are organic compounds with the general formula R-O-R', where R and R' represent hydrocarbon chains. "Thio" indicates that the oxygen atom in a regular ether molecule has been substituted by a sulfur atom. It goes under more than one chemical name. Included among them are 1,1-thio-*bis*-[2-chloroethane], 2,2'-dichlorodiethyl sulfide and *bis*-(2-chloroethyl)-sulfide.

It is also referred to as *sulfur mustard*, Yperite, *H*, *HT*, *HD*, and *Kampfstoff Lost*. The last name is derived from two men who developed a process for mass-producing the substance for war use at the German company Bayer AG. Their names were Lommel and Steinkopf.

Mustard gas can be synthesized in more than one way. One common method is to react thiodiglycol (see below) with thionyl chloride:



The Material Safety Data Sheet (MSDS) for mustard gas can be found at:

[http://www.castleviewuk.com/Frameless/Safe/msds/ex/MSDS\\_mustard.htm](http://www.castleviewuk.com/Frameless/Safe/msds/ex/MSDS_mustard.htm)

The article states that mustard gas, being nonpolar, is only slightly soluble in water, making it difficult to wash off. But more significantly, it reacts with water to form "hemi-mustard" and hydrochloric acid. The hemi-mustard is thiodiglycol, and is a widely used material (for example, in inks). The equation for this reaction is:



### How does mustard gas produce its terrible effects?

As the article states, we are not certain, but there are some ideas. Mustard gas is an alkylating agent. This means that it has a strong tendency to bind covalently to nucleophilic molecules (molecules that typically contain an atom(s) with unshared pairs of electrons) such as DNA, RNA, proteins and components of cell membranes. It is thought that mustard gas causes cross linking of DNA strands, which results in disruption of their function. It can upset normal protein synthesis, resulting in cell death.

### Possible Student Misconceptions

Students may assume that Germany was the only nation that utilized chemical weapons during WWI. This was not the case. Chemical weapons were used by both sides (see *Background Information*). They may also think that chemical weapons were never used during WWII because of the Geneva Protocol. While this is approximately true, it is not entirely the case (see *Background Information*).

Students may have only heard about the use of mustard gas and chlorine during WWI, and may therefore assume that these were the only two gases that were utilized. This is evidently not the case (see *Background Information*).

Because mustard gas reacts with water, students may reasonably conclude that mustard gas cannot persist in the environment because it would be destroyed as soon as it got wet. This is not the case. Mustard gas can persist in the soil because it becomes coated with a material that insulates it from surrounding moisture. If dumped in the ocean, it once again can be altered into a viscous liquid or even a solid and thus can persist for many decades.

### Demonstrations and Lessons

1. Although the use of chemical and biological weapons has been condemned, and both the Geneva Protocol and the Biological and Toxin Weapons Convention of 1975 ban their use, these weapons are still being developed and have been used by multiple nations during the last few decades.

What should be the position of the United States? Should we renounce the use of chemical or biological weapons under any circumstances? Is there really any practical difference between killing people with these kinds of weapons compared to bombing or shooting? Since some other nations may not follow suit, should we continue to develop these kinds of weapons despite our stated formal position?

This issue could make for a very heated, but hopefully educational classroom debate. Of course such a debate could easily just be an exchange of personal opinion, so if such a debate is held, some ground rules might be advisable. These might include having some facts and figures regarding the probable effects of the use of various types of weapons, the amount of “collateral damage” that might be expected from each, and the potentially uncontrollable aftermath connected to the use of various types of weapons, both on populations and the environment. In addition, historical events and their consequences might be cited to support one position or another.

2. The Geneva Protocol of 1925 is often cited as a document that prohibited the use of chemical and biological weapons. If you read the entire document (see *Background Information*), you may be struck by things such as the following:

how brief the document is—the lack of detail  
the fact that the document in no way prohibits the manufacture of chemical or biological weapons, but rather only talks about their use in “warfare”  
there is no stipulation in regard to what kind of penalties or punishments will be attached to nations who violate the protocol

Once again, a class discussion or informal debate might be held about the actual value of this document. Was it a “step in the right direction,” or basically just a symbolic gesture with no real teeth or meaning?

3. Along a similar vein, a discussion or debate could be centered on the provisions, etc. of either the Biological and Toxin Weapons Convention of 1975 or the Chemical Weapons Convention (CWC) and the Organization for the Prohibition of Chemical Weapons (OPCW)

## Connections to the Chemistry Curriculum

While this article obviously has connections to organic structures, etc., the pure chemistry connections are probably not as strong as in many other *ChemMatters* articles. But if your course includes a significant societal content, such as is sometimes the case in the *ChemCom* curriculum, then this article could be a focal point for some very relevant and thoughtful discussions.

## Suggestions for Student Projects

1. The article itself contains a brief timeline regarding the use of chemical warfare. In addition, the *Background Information* section of this Teacher’s Guide adds several more examples of the use of chemical and biological agents. These listings, however, represent only a small fraction of the number of examples of both the use of chemical and biological weapons as well as the many cases where their use during a particular conflict was debated, but not realized. Students could prepare a more thorough report on this very controversial topic. Alternately, they could take one or two particular incidents and expand on them. What agents were debated or actually utilized? What arguments were presented to justify or condemn their use? For example, there is evidence that although they were never actually used, Churchill argued for the use of mustard gas against the population of Mesopotamia in 1920, and while there was only limited use of chemical agents by the Axis during WWII (see *Background Information*), such agents existed. Why weren’t they used?

Other possible topics include:

Chemical warfare during the Cold War

The “V” series of nerve agents, VE, VG, VM, and VX

The development of binary weapons—weapons in which the weapon is only loaded with the precursors to the actual chemical agent and the chemical agent is only created just prior to the use of the weapon.

2. There have been several international efforts to draft documents dealing with chemical and biological warfare, such as the Geneva Protocol of 1925, the Biological and Toxin Weapons Convention of 1975 and the Chemical Weapons Convention. What do these documents really say? How strong are they in their prohibitions? What penalties are connected to noncompliance? How do these documents compare to each other? Investigating the actual content and real effect(s) that these documents have had and may

have on preventing the use of chemical and biological weapons could make for an excellent student report. See also *Demonstrations and Lessons*.

## Anticipating Student Questions

**Does mustard gas have anything to do with mustard?**

No.

**How deadly is mustard gas compared to more modern chemical weapons, such as nerve gases?**

Mustard gas is less deadly than nerve gases and it would take a much larger quantity of mustard gas to kill the same number of people. On the other hand, mustard gas is capable of producing more lasting injuries if the person survives.

**What is the antidote for mustard gas exposure?**

There is no antidote. Symptoms are typically treated with antibiotics, painkillers, skin dressings and other therapies. In some cases eye operations, skin grafts or treatments for chronic respiratory conditions such as emphysema may be required.

**Is there a preventive medicine that can be taken if there is a danger of exposure to mustard gas?**

No.

## Websites for Additional Information and Ideas

A very comprehensive site for all kinds of information about mustard gas, its properties, its effect, etc. is:

<http://www.inchem.org/documents/pims/chemical/mustardg.htm>

A good site for structural and other information on several kinds of chemical warfare agents:

<http://groups.msn.com/CellNEWS/chemweapons.msnw>

Some good Websites dealing with the historical use of chemical and biological weapons are:

[http://www.fortworthgov.org/health/threats/bio\\_history1.asp](http://www.fortworthgov.org/health/threats/bio_history1.asp)

<http://www.hq.usace.army.mil/history/NBC%20Warfare%20History.htm>

<http://dsc.discovery.com/anthology/spotlight/bioterror/history/history2.html>

<http://library.thinkquest.org/27393/dreamwvr/print/timeline.htm?tqskip1=1>

<http://www.lsic.ucla.edu/classes/mimg/robinson/micro12/m12webnotes/Biowarfare/warfare.html>

To view actual newspaper stories printed at the time that chlorine gas was used during WWI, go to:

<http://www.lsic.ucla.edu/classes/mimg/robinson/micro12/m12webnotes/Biowarfare/chlorgas.html>

# Antimatter

## Background Information

### A brief history of antimatter

All ideas have to start somewhere. The very first notion that antimatter might exist occurred around 1928. It was, in one sense, an artifact that arose from some brilliant theoretical work done by a young British-born physicist named Paul Dirac. Dirac was attempting to develop a more complete description of electrons and their motions in electric and magnetic fields that would include aspects of both quantum mechanics and Einstein's Special Theory of Relativity. Dirac's calculations worked very well (he was awarded the Nobel Prize in 1933).

But there was an unusual artifact that emerged from the calculations. While the solutions obtained provided a much-improved description of electrons, the equations had additional solutions that described particles identical to electrons in every way except one. These hypothetical particles had the same mass, spin, and quantity of electrical charge, but the charge was of opposite sign. In addition, if this "anti-electron" ever encountered a normal electron, the calculations indicated that both particles would be completely destroyed and converted entirely into energy.

In an effort to gain more specific information on exactly how these additional solutions arose, your Teacher's Guide Editor contacted Dr. Steve Olsen, a professor of physics and astronomy and a high-energy physics researcher at the University of Hawai'i at Manoa. Dr. Olsen generously and quickly sent the following response:

*I am glad to learn of your interest in antimatter, one of my favorite subjects.*

*It was discovered theoretically by Dirac, when he tried to combine the Quantum Theory and Relativity. In the latter, the correct expression for  $E$  is not  $E = mc^2$ , but rather  $E^2 = (mc^2)^2$ . And, so, to be precise  $E = \pm mc^2$ .*

*Outside of Quantum Theory, it is legitimate to ignore the minus solution, but a fundamental requirement of Quantum Theory is that you have to keep all solutions, otherwise the theory just doesn't work. So, to make Quantum Theory and Relativity compatible, Dirac had to figure out what these negative energy solutions meant. He finally discovered that these corresponded to antiparticles.*

Dr. Olsen has a very entertaining Website at <http://www.phys.hawaii.edu/~solsen/>.

Some scientists thought that these additional solutions should simply be ignored, but others thought that they might be accurately predicting the existence of particles that had yet to be observed.

Our students may often be told that science always begins with observations and experiments and then theories are developed to explain these observations and experiments. While that may be the most common scenario, the truth is probably more complex. Experimental and observational results may often guide the development of theories, but theoretical results can and sometimes do guide what we look for and where and how we go about looking for it. It is easier to "see" something whose existence and nature have been specified than it is to "see" something that has never even been imagined.

The article states that the first antiparticle, the positron, was observed four years later (1932) by Carl Anderson when he "noticed" that some particles were identical in every way to an electron except that they had opposite charge.

The more complete story is more interesting. Anderson was not looking for antiparticles. He was studying the tracks produced by cosmic rays in a cloud chamber. He applied a magnetic field to the cloud chamber, which caused any charged particle entering the chamber to be bent in a more-or-less circular path. He took photographs of the tracks left by the particles, and by analyzing the path of each bending particle he was able to calculate the momentum and charge of each particle.

He observed both positively and negatively charged particles. This was not surprising, but the details shocked him. He thought that the positively charged particles should turn out to be protons, but the tracks they left were not consistent with this idea. Protons would leave a denser track, but these particles left tracks similar to those left by electrons, but bending in the opposite direction. Anderson thought that perhaps the tracks might simply be indicative of electrons that somehow or other were simply moving in the opposite direction. To test this idea, he inserted a thin lead plate into the middle of the cloud chamber. The particles were capable of passing through the plate, but in doing so they would lose some of their kinetic energy. Their path would be different on each side of the plate, and this would allow Anderson to determine in which direction the particles had been moving when they struck the plate. It turned out that the particles could not be protons nor could they be electrons moving in the opposite direction. Everything about their behavior was consistent with their being the

antiparticle to the electron whose existence had been predicted by Paul Dirac four years earlier. The first antiparticle had been detected in the laboratory. It might be noted that this proverbial Rome wasn't built in a day. Anderson, a young professor at the California Institute of Technology at the time, devoted the better part of one year of effort to the project. In 1936 he was awarded the Nobel Prize. It might also be noted that his results were confirmed by two scientists, Patrick Blackett and Giuseppe "Beppo" Occhialini. They also demonstrated that energy, in the form of gamma rays, could be transformed into positrons and electrons, a phenomenon termed *pair production*. Blackett received the Nobel Prize in Physics in 1948.

There is a photograph of Carl Anderson's Cloud Chamber at:

<http://www.orau.org/ptp/collection/Miscellaneous/cloudchamber.htm>

One physicist was so enthralled by the results of these kinds of experiments that he wrote, somewhat poetically:

*Who has said that there is no poetry in modern, exact and complicated science? Consider only the twin-birth of two quick and lively electrons of both kinds when an over-energetic light quantum brushes too closely against an atom of matter! And think of their death together when, tired out and slow, they meet once again and fuse, sending out into space as their last breath, two identical grains of light, which fly off carrying their souls of energy!*

There is a Website where you can download and print (or order) six cartoon-style posters connected to Paul Dirac and antimatter.

[http://www.space.com/scienceastronomy/dirac\\_posters\\_020808.html](http://www.space.com/scienceastronomy/dirac_posters_020808.html)

If you are interested in seeing some of the actual equations involved in Dirac's work, go to:

[http://www.shef.ac.uk/physics/teaching/phy366/antiproton\\_files/antiproton.pdf](http://www.shef.ac.uk/physics/teaching/phy366/antiproton_files/antiproton.pdf)

It might seem intuitively reasonable to suppose that once the existence of the positron had been firmly established, discovery of many additional antiparticles would soon follow, but this was not the case. The problem was that very high energy particles are needed to create most antiparticles, and other than cosmic rays, no such sources existed.

Thus was ushered in the era of high energy particle accelerators. Ernest Lawrence had invented the cyclotron in 1930. Over the years particle accelerators of higher and higher energies were developed. By 1954, Lawrence had built the *Bevatron* at the University of California at Berkeley. It was capable of colliding two protons together at an energy of 6.2 Gev ( $6.2 \times 10^9$  ev). This was considered to be the ideal energy to try and create antiprotons. Around the same time a team of physicists headed by Emilio Segre had built an apparatus that was capable of detecting antiprotons should they be created.

The stage was set, the pieces in place, and in 1955 the discovery of the antiproton was announced. Segre and a collaborator named Chamberlain were awarded the Nobel Prize in Physics in 1959.

The antineutron was discovered in 1960. With this discovery, all three of the basic antiparticles needed to make and antiatom were in place. Was it possible that these particles could assemble to actually make an antiatom? What would happen when an antiproton met an antineutron? Would they "stick together" to make an antinucleus?

This question was answered in 1965, when an antideuteron was observed. A deuteron is a hydrogen nucleus that contains one neutron. The antideuteron nucleus was made of one antiproton and one antineutron.

It took another thirty years before the first actual antiatom was created and observed. Paradoxically, this required that antiprotons be slowed down in order for a positron to join with the antiproton to create an antiatom. The apparatus built to do this was called the LEAR (Low Energy Antiproton Ring). It was built at CERN [the European Organization for Nuclear Research, (in English), the Conseil Européen pour la Recherche Nucleaire (in French)]. In 1995 nine anti-atoms of antihydrogen were made. They were later observed at Fermilab in 1997.

You can go to the CERN Website (where the Web was born!) by visiting:

<http://public.web.cern.ch/Public/Welcome.html>

### **Why is everything made of matter? What happened to (or where is) the antimatter?**

The honest answer is that we don't know. We are entering the realm of what might be termed speculation, although there are a few theories. The Big Bang theory holds that about 15 billion years ago, when the Big Bang presumably occurred, matter and antimatter would have been expected to have been created in equal amounts. Since there doesn't seem to be much antimatter around, two possibilities suggest themselves. Either antimatter

essentially disappeared during the history of our universe or the two forms of matter separated and formed different regions of the universe.

If the latter is true, it is thought that some antimatter originating from an “anti” region outside our galaxy might still possibly reach us. A major project is currently under development. It involves building an *Alpha Magnetic Spectrometer*, or AMS-02 and then installing it on the International Space Station. The two main goals of the project are (1) to provide a sensitive search for cosmic antimatter (antihelium) and dark matter and (2) to study the properties of cosmic rays. It appears to be currently scheduled for launch in Oct. 2005. An earlier, simpler version, AMS-01 traveled on the Space Shuttle Discovery for ten days in 1998. It analyzed about 3 million particles, but did not observe even a single antinucleus.

The CERN Website offers the suggestion that “nowadays it is strongly believed that there is merely one universe, composed primarily of matter.”

Of course there is always a small amount of antimatter around. Some antiparticles are produced when cosmic rays strike our atmosphere, and there are some radioactive substances that emit positrons, for example, during decay processes. At times relatively significant amounts can be produced. In July, 2002, during the eruption of a solar flare, about a pound of antimatter was created. It didn't threaten Earth as it was quickly annihilated when it collided with matter from the Sun. In addition, there is evidence that some highly energetic reactions that can occur at the cores of some galaxies and quasars can create antimatter. But this antimatter is rapidly annihilated and is not thought to be antimatter that was left over from the Big Bang. In April, 2002, it was announced, at a joint meeting of the American Physical Society and the American Astronomical Society, that comets are also natural sources of antimatter.

Another theory proposes that in the first billionth of a second during the Big Bang *almost* equal amounts of matter and antimatter were created. According to one theory (now backed by experimental evidence), a lack of symmetry allowed for the creation of more matter than antimatter. For every billion or so antiparticles that were created about a billion and *one* matter particles were created. Within a tiny fraction of a second they annihilated each other. All the antimatter was destroyed, but a “tiny” amount of matter remained. Within a second of the beginning of the expansion the temperature had cooled to the point where the energy that had been released could no longer be reconverted into matter and antimatter. The matter that was left created our known universe. The energy that was released is called the Cosmic Background Radiation.

What's the truth? Right now we really don't know.

### **More about how antimatter is stored**

The article states that antimatter can be stored in “an invisible container comprised of magnetic fields.” These storage containers are called Penning traps. They utilize a combination of very low temperatures and electromagnetic fields. By cooling antimatter to a very low temperature it can be “trapped” inside an electromagnetic field. But these traps can only hold very small amounts.

A diagram, photo and further explanation of how a Penning Trap works can be found at:

<http://www.daviddarling.info/encyclopedia/P/Penning.html>

## **Connections to Chemistry Concepts**

An apparently common erroneous concept believed by many people (and students) is that if you “split an atom” (like in an atomic bomb) a tremendous amount of energy is released—destroying a city, perhaps. This same erroneous notion can be attached to annihilation of matter with antimatter. While it is certainly true that on a relative basis an incredible amount of energy is released when, for example, an electron and a positron meet and are converted to energy, the amount of energy released by one atom-pair, or even a billion atom-pairs is very small (see *Possible Student Misconceptions*).

Let's do a simple calculation of the amount of energy released when one billion ( $10^9$ ) electrons and one billion positrons annihilate each other and are completely converted to energy.

The mass of an electron or positron is  $9.1 \times 10^{-31}$  kg. The velocity of light is  $3 \times 10^8$  m/s.

From the equation  $E = mc^2$ , the amount of energy released when these  $2 \times 10^9$  particles are converted to energy would be:

$$E = mc^2$$

$$E = (2 \times 10^9 \text{ particles})(9.1 \times 10^{-31} \text{ kg/particle})(3 \times 10^8 \text{ m/s})^2$$

$$E = 1.6 \times 10^{-4} \text{ kg m}^2/\text{s}^2 = 1.6 \times 10^{-4} \text{ J}$$

It takes 4.184 J to raise the temperature of one gram of water by one Celsius degree.

So if we were to take ALL of this “great amount” of energy being released when these electrons and positrons annihilated each other, it could raise the temperature of this one gram of water by about:

$$1.6 \times 10^{-4} \text{ J} = (4.184 \text{ J/g}^\circ\text{C})(1.00 \text{ g})(x \text{ }^\circ\text{C})$$

$$x = 0.000038 \text{ }^\circ\text{C}$$

Do you have a thermometer that can measure this?

It might be noted, that according to the CERN Website, if all the antiprotons produced at CERN during an entire year were converted into energy, you’d only have enough energy to light a 100 watt light bulb for three seconds!

But what if we converted a total of 2.00 GRAMS of electrons and positrons into energy, i.e. 1.00 g of each. Then:

$$E = (0.002 \text{ kg}) (3 \times 10^8 \text{ m/s})^2$$

$$E = 1.8 \times 10^{14} \text{ J}$$

Let’s see how many grams of water could be raised from 0 °C to 100 °C.

$$1.8 \times 10^{14} \text{ J} = (4.184 \text{ J/g}^\circ\text{C})(x \text{ g}) (100 \text{ }^\circ\text{C})$$

$$x = 4.3 \times 10^{11} \text{ g, which is about 475,000 tons!!}$$

Kind of gives one the impression that atoms must be pretty small.

## Possible Student Misconceptions

When discussing the collision of a particle with its antiparticle, terms such as “annihilation” are often used, along with phrases like “are completely converted into energy.” In addition, discussions of the energy released when matter and antimatter are converted into energy may state that the energy released is “greater than that released in nuclear explosions,” etc. It is very easy for students to come to the erroneous conclusion that if a particle and an antiparticle were to meet, a tremendous explosion would result. This is definitely not the case. Matter and antimatter meet often—in a PET scan, for example. Yet people undergo PET scans every day and feel nothing. While the energy released *per gram* is tremendous, the mass of one or even several billion particles of matter and antimatter is so small that the actual amount of energy released is insignificant.

However, one ought to be careful not to go too far in this. Even though the amount of energy released by a single nuclear event (say an electron-positron annihilation) is negligible on a macroscopic scale, it is, of course, quite significant on a *chemical* scale. Each such event is capable of breaking hundreds of chemical bonds. This is why radiation is potentially dangerous—the decay event can cause considerable chemical damage in, say, a cell. (Heating up the cell, in contrast, is of course negligible.) See *Connections to Chemistry Concepts*.

Because an electron and positron are completely destroyed and converted into energy when they annihilate each other, students may assume that this is true of all antiparticles, but that is not exactly the case. For example, when a proton and antiproton meet, other particles (mesons) are produced along with the energy that is released. But these particles quickly decay into other particles and gamma rays, and these particles in turn rapidly decay into things like positrons, neutrinos and antineutrinos, and these positrons will encounter electrons and be annihilated, etc., so it is often said that when a particle and its antiparticle meet they are destroyed and completely converted into energy.

## Demonstrations and Lessons

1. It is quite easy to build a cloud chamber and use it to observe the tracks of particles. The ChemCom curriculum includes such an activity. In addition, instructions can be found at several Websites, including the following:  
<http://amanda.wisc.edu/cooley/cloudchamber.html>  
[http://www.nuc.berkeley.edu/news/Sci\\_teachers\\_workshop/cloud.htm](http://www.nuc.berkeley.edu/news/Sci_teachers_workshop/cloud.htm)
2. It is not unusual to hear students (and adults) engaging in heated debate about who is or was the “greatest”—perhaps the greatest heavyweight, or the greatest home run hitter, or the greatest fullback, or the greatest baseball team. But who should be given credit as being the greatest scientist who ever lived? Einstein would certainly get a lot of votes, and deservedly so, but many votes are probably cast perhaps not out of knowledge but rather because of his notoriety, personality and appearance. Some argue that that honor should go to Max Planck, or Isaac Newton, or perhaps even Paul Dirac (who was a recluse and therefore shunned the spotlight). You may have other individuals to nominate.

A wonderful class debate could be held to try and “settle” this question. Preparing for such a debate and then participating could potentially be one of the most outstanding class activities of the year. Would that make a nice activity for the week after the AP exam?

3. If this article is discussed in class, it would provide an excellent opportunity to expand student’s knowledge about the fundamental particles that make up everything around us. While we all certainly discuss protons, neutrons and electrons, one can make a good argument that our students should know more about particles such as quarks, for instance (or do we leave this to the physics course?) Unfortunately, nature has not been kind to us. There are so many subatomic particles that learning their characteristics, classification and interactions, as well as the forces that act between them is a rather daunting task. If you are interested in tackling this task, there are some good Websites listed at the end of the Teacher’s Guide.

## Connections to the Chemistry Curriculum

This article obviously ties strongly to any discussion of the fundamental particles that make up our universe. All chemistry courses probably include a discussion of the three fundamental particles in an atom, the proton, neutron and electron. Their charges, masses and distribution within an atom are certainly central topics. The article delves a bit further, going into how neutrons are made of quarks. Protons are also (two “up” quarks with charges of  $+2/3$  and one “down” quark with a charge of  $-1/3$ ).

The article also connects to the relationship between mass and energy and Einstein’s famous equation  $E = mc^2$ . If your course includes a significant quantitative component, you can nicely tie some of the information in the article to quantitative calculations and unit analyses (see *Connections to Chemistry Concepts*).

There is, of course, a veritable cornucopia of subatomic particles (something like over 300 have been characterized). Trying to keep track of and “understand” the characteristics of all these particles and forces is a very daunting task. If you are interested in obtaining more information about subatomic particles and the Standard Model, some good Websites to visit might include:

<http://www2.slac.stanford.edu/vvc/theory/model.html>  
[http://particleadventure.org/particleadventure/frameless/standard\\_model.html](http://particleadventure.org/particleadventure/frameless/standard_model.html)  
<http://particleadventure.org/particleadventure/frameless/chart.html>  
<http://www.lns.cornell.edu/public/lab-info/quark.html>

## Suggestions for Student Projects

1. It is quite possible that there are a few “Trekkies” amongst your students. If this is the case, they might want to work up a “serious” presentation relating to how the starships utilize the annihilation of matter and antimatter in the core of the warp drive to generate the tremendous power needed to warp space and travel faster than the velocity of light. They could then also present a constructive criticism of the notion. A good source of information is *The Physics of Star Trek*, by Lawrence Krauss.
2. Mathematically inclined students might be interested in working out and presenting any number of calculations related to the conversion of mass into energy, the energy released in fission and fusion

reactions, the conversion of matter and antimatter into energy, etc. Students could design their own question to answer or might choose from questions such as the following.

How many gallons of octane,  $C_8H_{18}$ , would it take to release as much energy as would be released if  $10^{-6}$  grams of electrons and positrons annihilated each other?

How many grams of matter and antimatter would have to be annihilated in order to release as much energy as was released in the first atomic bomb exploded over Hiroshima (equivalent to about 13 kilotons of TNT)?

How many grams of matter and antimatter would have to be annihilated in order to raise the temperature of Lake Michigan by one Celsius degree?

## Anticipating Student Questions

1. What does antimatter look like?

It looks the same as matter. When you look at something, you are looking at the photons of light that are being emitted by the object. Both matter and antimatter emit the same kind of photons. Antimatter doesn't emit "antiphotons." So if there were a galaxy made of antimatter, you couldn't distinguish it from a galaxy made of matter just by looking at it.

2. Does antimatter have negative mass?

No. If it had negative mass, then when a particle and an antiparticle annihilated each other no energy would be released, since their total mass would add up to zero. The equation  $E = mc^2$  can be used to calculate the energy released, and if  $m = 0$ , then  $E = 0$ .

3. Are there antimatter galaxies?

We don't know. It's possible, but most scientists think it's not likely. Since matter and antimatter annihilate each other, an antimatter galaxy would have to be located far from matter galaxies. In addition, it would have to be comprised of antimatter that was left over from the Big Bang. It's difficult to envision how such antimatter could have survived and separated to form an antimatter galaxy. But you never know.

4. Do antiphotons exist?

No. Photons are quanta of light. They have zero charge, but unlike the neutron, which is made of quarks, photons do not contain things inside them that are charged. This means that a photon and an antiphoton are the same thing.

## Websites for Additional Information and Ideas

There are some terrific Websites relating to Matter and Antimatter that even offer free posters, etc. One such site is: <http://www.pparc.ac.uk/Ed/Notes/AMWebpage.asp>

If you enjoy science fiction (or do you read enough of it grading exams?), a listing of some books relating to antimatter can be found at:

<http://livefromcern.web.cern.ch/livefromcern/antimatter/everyday/AM-everyday03-a.html>

Here are some good Websites for additional information and relatively easy to understand explanations of many of the topics directly and indirectly related to the article:

<http://www.stanford.edu/dept/physics/people/faculty/docs/burchatAlumni2003.pdf>

The URL for Fermilab is: <http://www.fnal.gov/>

The URL for CERN is: <http://public.web.cern.ch/Public/Welcome.html>

### **A funny story.**

Several years ago I had an Advanced Placement chemistry class immediately followed by a lower level Chemistry for the Health Sciences class. The AP topic for the day included a discussion of Einstein's explanation of the photoelectric effect experiments (for which he received the Nobel Prize). During the lecture-discussion I wore a button with a photograph of Einstein. Not having time to go to my office between classes, I placed it on the front desk.

When the Health Science class ended, a student came up to turn in a late paper. Spying the button, she inquired, "Who's that?"

Somewhat shocked that a student might not recognize a photograph of Einstein, I responded, "You know who that is!"

She replied that no, she didn't.

Still having difficulty believing that, I said, "Look closely and think. You've certainly seen that face before. I'm sure you know who that is."

After looking at the photo for several more seconds, her face finally lit up with recognition and she proudly proclaimed: *Isn't that one of the Three Stooges?!!*