



December 2004 Teacher's Guide

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Puzzle: Compound It

In the box below are 36 common words, arranged alphabetically. They can be combined (usually by twos) to form 17 new words widely used in chemistry; however, none are names of chemists or specific chemicals. The seventeen clues to the terms are given below the box. For example, if the words pound and com were in the box, we can form the single word compound from them, fitting a clue like “two or more elements per molecule”.

Sometimes the individual words (and their meaning) come through intact, but occasionally pronunciation or syllabication are changed, so be warned! One of our terms is a two word phrase, and there are two places where THREE simple words get compounded. Each word in the box is used just once, so you can cross them off as you work your way back and forth. #1 is done as an example.

aces	as	--cur->	leg	on	ropes
act	at	for	length	ox	surf
active	aver	free	lime	pro	ton
age	car	i	mate	radio	water
allot	char	ides	mine	--rent->	wave
am	coal	in	nob	red	zing

- current 1. A flow of electrons, perhaps along a wire.
_____ 2. The giving and gaining of electrons in some chemical reactions.
_____ 3. Elements 90 through 103. (compounded of three short words)
_____ 4. What a Bronsted acid donates.
_____ 5. Atomic Mass is the ____ of the masses of an element's isotopes.
_____ 6. 660 nm for red light, for example.
_____ 7. A salt of the acid HCOOH.
_____ 8. A unit of mass = 200 mg, used in work with precious metals.
_____ 9. Liquid to solid phase change.
_____ 10. Common name for Ca(OH)₂ aq.
_____ 11. A charged atom.
_____ 12. He or Kr or Rn, for example.
_____ (two words, compounded of three short words).
_____ 13. C-14 is, but C-12 and C-13 are not..
_____ 14. Where colloidal catalysts often do their work.
_____ 15. Diamond and graphite, or O₂ and O₃, as examples.
_____ 16. Produced by the incomplete combustion of coke or wood.
_____ 17. Name of the NH₃ group as a ligand in coordination compounds.

Puzzle Answers: Compound It

(first of words underlined)

1. current
2. redox
3. actinides
4. proton
5. average
6. wavelength
7. formate
8. carat
9. freezing
10. limewater
11. ion
12. noble gas
13. radioactive
14. surfaces
15. allotropes
16. charcoal
17. ammine

Student Questions

Ocean Bioluminescence

1. What is *bioluminescence*?
2. Explain how light is produced in a bioluminescent reaction.
3. How can having a red stomach help a transparent predator catch its meal?
4. Why do we think many bioluminescent organisms that live in the deep ocean emit blue light as opposed to other possible colors?
5. Why do animals that live in the very deep ocean tend to be dark-colored but never blue in color?
6. How do bioluminescent reactions provide an example of parallel evolution?

Cinnamon: The Bark Heard 'Round the World

1. What is the source of "true cinnamon," and how does it differ from sources of "fake" cinnamon?
2. How do the taste and properties of "true" cinnamon bark purchased from a store that sells it differ from the properties of "fake" cinnamon bark purchased from a local grocery store?
3. What chemical is responsible for most of the "heat" sensation of cinnamon? How do "true" and "fake" cinnamon compare in the amount of this chemical they contain? What additional chemical is found in "true" cinnamon?
4. How do "hot" spices like cinnamon and the capsaicin in chilli peppers produce "mouth burn" when eaten?
5. How might cinnamon be useful in the treatment of Type 2 diabetes?
6. What are two other documented benefits attached to the consumption of cinnamon?

The Transdermal Patch—Driving Drugs Skin Deep

1. What are some of the functions of human skin, and which of these functions tends to make it difficult for a transdermal patch to function effectively?
2. What three common features do drugs suitable for application by a transdermal patch need to have?
3. Explain how these three features operate to make a drug suitable for application via a transdermal patch.

4. What are the two basic designs of transdermal patches? Describe their basic features.
5. What are some advantages attached to the use of transdermal patches as opposed to taking medications either orally or by injection?
6. What are some disadvantages attached to transdermal patches?
7. What are some drugs that are currently deliverable via transdermal patches, and what conditions are they designed to alleviate?

The Science of Slime

1. What is meant by the *viscosity* of a fluid?
2. What does the phrase "slower than molasses in January" tell us about the viscosity of most fluids? Explain.
3. What is meant by the term "non-Newtonian" fluid?
4. What are some examples of "shear stresses," and how do Newtonian and non-Newtonian fluids differ when shear stresses are applied to them?
5. How do "shear-thinning" and "shear-thickening" fluids differ?
6. Explain how the behavior of Silly Putty demonstrates that it is a shear thickening fluid.

Two Faces of Carbon

1. How do the physical properties of graphite compare to the physical properties of diamond?
2. What is meant by the term "allotropes?"
3. How did Lavoisier demonstrate that diamond was made of pure carbon?
4. Describe the bonding in diamond and explain how this accounts for its physical properties.
5. Describe the bonding in graphite and explain how this accounts for its physical properties.
6. Since it takes very little energy, only 2.9 kJ/mol, to convert graphite to diamond, why can't pencil lead be easily made into a diamond?
7. What do the terms "brilliance" and "fire," mean when applied to a diamond?
8. What do the terms "carat" and "point" mean when applied to a diamond?

Answers to Student Questions

Ocean Bioluminescence

1. What is *bioluminescence*?

Bioluminescence is the production of visible light inside a living organism.

2. Explain how light is produced in a bioluminescent reaction.

Two key molecules are involved. An enzyme called *luciferase* catalyzes the reaction of a molecule called *luciferin* with oxygen. This produces an oxidized form of luciferin called *oxyluciferin*. This molecule is produced in a high-energy, or “excited” state. This is an unstable state and the molecule will quickly return to a lower energy or “ground” state. When this happens energy is released in the form of light.

3. How can having a red stomach help a transparent predator catch its meal?

A lot of their prey is bioluminescent. When the bioluminescent prey shines its light on the predator, the light would be reflected, making the predator visible and helping the prey to escape. But a red-colored stomach can absorb the blue light emitted by the prey. This helps camouflage the predator.

4. Why do we think many bioluminescent organisms that live in the deep ocean emit blue light as opposed to other possible colors?

As light penetrates deep into the ocean it is absorbed and scattered. Different colors are affected differently. Blue light is scattered the most and penetrates the water the best, which is why the ocean is blue. Deep in the ocean there is very little light, but any blue light that is produced by a bioluminescent organism will travel farther than any other color light, so producing this color light will maximize the distance that their signals travel.

5. Why do animals that live in the very deep ocean tend to be dark-colored but never blue in color?

At great depths the ocean is black, since no light can penetrate. If an organism was blue, it would reflect any blue light emitted by a bioluminescent predator, which would betray its presence.

6. How do bioluminescent reactions provide an example of parallel evolution?

Parallel evolution refers to animals utilizing various strategies to accomplish the same goal. When parallel evolution occurs, it underscores the importance of the strategy. Different organisms use slightly different kinds of bioluminescent reactions to achieve the same kinds of goals.

Cinnamon: The Bark Heard ‘Round the World

1. What is the source of “true cinnamon,” and how does it differ from sources of “fake” cinnamon?

“True” cinnamon comes from the inner bark of a specific tree, *Cinnamomum zeylanicum* (or *Cinnamomum verum*), which is native to Sri Lanka (formerly Ceylon). “Fake” cinnamon (but not really fake, and just as popular) can come from several other types of trees such as *Cinnamomum cassia*, *Cinnamomum burmanii* and *Cinnamomum loureirii*.

2. How do the taste and properties of “true” cinnamon bark purchased from a store that sells it differ from the properties of “fake” cinnamon bark purchased from a local grocery store?

“True” cinnamon is thin. The quills can be chewed straight and have a sweet-hot taste. “Fake” cinnamon, from the cassia bush, will have quills that are thick and woody and will roll in from both sides like a scroll. The bark is quite hard rather than chewy.

3. What chemical is responsible for most of the “heat” sensation of cinnamon? How do “true” and “fake” cinnamon compare in the amount of this chemical they contain? What additional chemical is found in “true” cinnamon?

Cinnamaldehyde, C_9H_8O , is responsible for the “hot” taste of cinnamon. “Fake” cinnamon has more cinnamaldehyde than “true” cinnamon. “True” cinnamon has some extra flavors, mainly eugenol, $C_{10}H_{12}O_2$, which is missing from “fake” cinnamon.

4. How do “hot” spices like cinnamon and the capsaicin in chilli peppers produce “mouth burn” when eaten?

They activate the same nerve cells (receptors) that register pain from heat. Activating these same nerve cells produces much the same sensation.

5. How might cinnamon be useful in the treatment of Type 2 diabetes?

A chemical known as MHCP, found in powdered cinnamon, is capable of both mimicking and enhancing the effects of insulin. Type 2 diabetes results when the body either doesn’t produce enough insulin or the cells do not utilize it properly.

6. What are two other documented benefits attached to the consumption of cinnamon?

Cinnamon can kill bacteria and can aid in digestion.

The Transdermal Patch—Driving Drugs Skin Deep

1. What are some of the functions of human skin, and which of these functions tends to make it difficult for a transdermal patch to function effectively?

Human skin serves several different functions. It acts as a barrier against any invasion by something from the outside. This is good, but unfortunately it also tends to prevent any medication on a transdermal patch from penetrating through the outer layers of skin and reaching the capillaries below, which it must do in order to be effective. Skin also metabolizes nutrients, excretes waste, and helps regulate body temperature.

2. What three common features do drugs suitable for application by a transdermal patch need to have?

They must be composed of small molecules, the molecules should generally be nonpolar, and the drugs must be potent.

3. Explain how these three features operate to make a drug suitable for application via a transdermal patch.

Small molecules can rapidly diffuse through very small pores. In order to diffuse, the molecules must be in solution, which means that they must be able to dissolve in the lipids that exist in human skin. Lipids are nonpolar molecules, so for the drug to dissolve, it should be nonpolar also, as indicated by the general rule “like dissolves like.” And since a loaded patch must deliver its dosage over a time period that may range from several hours to several days, the drug must be potent, since the amount of the drug present in the bloodstream at any time is limited by the size of the patch and the rate at which the molecules can diffuse through the skin.

4. What are the two basic designs of transdermal patches? Describe their basic features.

The matrix system—This design embeds the drug within a polymer. The polymer both serves as an adhesive so the patch will stick to the skin and delivers the drug to the skin.

The reservoir system—This design encloses a small pillow of the drug inside a permeable rate-controlling membrane. The adhesive layer is topped with an inert, flesh-tinted backing that protects the skin and prevents the drug from evaporating or leaking out of the area.

5. What are some advantages attached to the use of transdermal patches as opposed to taking medications either orally or by injection?

Many people do not like to receive injections, for obvious reasons. The use of “sharps” in medicine carries with it a small risk, especially to healthcare workers. Oral medications need to be able to resist the highly acidic environment inside the human stomach as well as the digestive secretions in the small intestine and liver. Transdermal patches can also deliver medications evenly rather than in large onetime doses and then stay in place for an extended period of time, which helps ensure that forgetful or neglectful patients receive the recommended drug dosage. If there is a sudden change in a patient’s condition, the administration of the drug can be stopped immediately by removing the patch.

6. What are some disadvantages attached to transdermal patches?

The adhesives used to attach the patches can irritate the skin of some patients. The patches must be carefully disposed of, since they still contain significant amounts of medications when removed. They only are suitable for the delivery of a limited number of drugs, since the drug must be made of relatively small, fat-soluble molecules.

7. What are some drugs that are currently deliverable via transdermal patches, and what conditions are they designed to alleviate?

scopolamine, for motion sickness
nicotine, for stopping smoking
estrogen, for menopause and osteoporosis
nitroglycerin, for angina
lidocaine, for pain relief
progesterin and estrogen, for birth control

The Science of Slime

1. What is meant by the *viscosity* of a fluid?

Viscosity refers to a fluid’s resistance to flow.

2. What does the phrase “slower than molasses in January” tell us about the viscosity of most fluids? Explain.

It tells us that for most common fluids, viscosity increases with increasing temperature and vice-versa. In the Northern hemisphere it is usually very cold in January. Therefore molasses, a relatively viscous fluid to begin with, will flow even slower during that month.

3. What is meant by the term “non-Newtonian” fluid?

A non-Newtonian fluid is a fluid whose viscosity is affected by factors other than temperature.

4. What are some examples of “shear stresses,” and how do Newtonian and non-Newtonian fluids differ when shear stresses are applied to them?

Examples of shear stresses include things like squeezing, stirring, agitating, or applying mechanical pressure to the surface of a fluid. The viscosity of a non-Newtonian fluid may change dramatically in response to a shear stress. It may become more or less viscous. But the viscosity of a Newtonian fluid remains constant when a shear stress is applied.

5. How do “shear-thinning” and “shear-thickening” fluids differ?

When a stress is applied to a shear-thinning fluid, its viscosity will decrease. When a stress is applied to a shear-thickening fluid its viscosity will increase.

6. Explain how the behavior of Silly Putty demonstrates that it is a shear thickening fluid.

If you pull Silly Putty apart slowly, it can be stretched a great distance. Pulling it apart slowly means that you are applying only a small shear stress. But if you try to pull it apart quickly by applying a large shear stress, it will break. Its viscosity increases dramatically with the application of a shear stress, which is what is meant by the term “shear thickening.”

Two Faces of Carbon

1. How do the physical properties of graphite compare to the physical properties of diamond?

They are almost completely opposite. Graphite is a silvery black, soft solid. It is an electrical conductor and leaves a streak when drawn across a sheet of paper. It is an excellent lubricant.

Diamond is transparent, the hardest natural substance known, and an electrical insulator. It is used in cutting and grinding tools.

2. What is meant by the term “allotropes?”

Allotropes are different forms of the same element, like graphite and diamond.

3. How did Lavoisier demonstrate that diamond was made of pure carbon?

He burned a diamond in an atmosphere of pure oxygen and found that the only product of the reaction was carbon dioxide gas.

4. Describe the bonding in diamond and explain how this accounts for its physical properties.

In diamond, every carbon atom forms a strong covalent bond to four other carbon atoms, which in turn are bonded to four atoms of carbon. This structure can continue indefinitely. Since all of carbon's four bonding electrons are “tied up” in strong covalent bonds, there are no electrons that are free to move through the crystal, which explains why diamond is an electrical insulator. And since every atom is strongly bonded to four others, it is very difficult to tear atoms out of the crystal, which explains why diamond is such a hard substance.

5. Describe the bonding in graphite and explain how this accounts for its physical properties.

In graphite each carbon atom is strongly bonded to only three other carbon atoms, which in turn are strongly bonded to a total of three carbon atoms, etc. This forms what basically are flat two-dimensional planes of carbon atoms. These planes are arranged parallel to each other, like a stack of papers. The fourth electron is highly delocalized across many atoms, which makes it easier to conduct electricity. Since there is no significant bonding between the planes of carbon atoms, they can easily slide over each other and be removed, which explains why graphite is soft and can be used in pencils.

6. Since it takes very little energy, only 2.9 kJ/mol, to convert graphite to diamond, why can't pencil lead be easily made into a diamond?

Although the process requires very little net change in energy, the conversion requires very high pressures and the activation energy is very high, making the change difficult to achieve.

7. What do the terms “brilliance” and “fire,” mean when applied to a diamond?

Brilliance refers to a diamond's ability to reflect back any light that enters it. Fire refers to the ability of a diamond to separate white light into the many colors of a rainbow.

8. What do the terms “carat” and “point” mean when applied to a diamond?

A carat is a unit of mass. One carat is equal to 0.200 g, or 200 mg. A point is a hundredth of a carat.

Content Reading Materials

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	Two Faces of Carbon	The Transdermal Patch	Ocean Biolights	Cinnamon	The Science of Slime
Science as Inquiry Standard A: of abilities necessary to do scientific inquiry.					✓
Science as Inquiry Standard A: about scientific inquiry.	✓	✓	✓		✓
Physical Science Standard B: of the structure of atoms.	✓				
Physical Science Standard B: of the structure and properties of matter.	✓	✓		✓	✓
Physical Science Standard B: of chemical reactions.	✓		✓	✓	✓
Physical Science Standard B: of the interaction of energy and matter.			✓		
Life Science Standard C: of the cell.		✓			
Life Science Standard C: of the interdependence of organisms.			✓		
Life Science Standard C: of matter, energy, and organization in living systems.		✓	✓		
Science and Technology Standard E: about science and technology.	✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of personal and community health.		✓		✓	
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✓	✓			✓
History and Nature of Science Standard G: of science as a human endeavor.	✓	✓	✓	✓	✓
History and Nature of Science Standard G: of the nature of scientific knowledge.	✓	✓	✓	✓	✓
History and Nature of Science Standard G: of historical perspectives.	✓	✓		✓	✓

Anticipation Guides

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

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

Two Faces of Carbon

Me	Text	Statement
		1. It is possible to make a diamond from the cremated remains of a person or a favorite pet.
		2. Graphite and diamond are made of different elements.
		3. When diamond burns, the only product is carbon dioxide.
		4. In graphite, each carbon atom forms four covalent bonds.
		5. Graphite and diamond have similar physical properties.
		6. It is possible to distinguish synthetic diamonds from natural diamonds.
		7. A diamond has been found by astronomers in a crystallized white dwarf.

The Transdermal Patch—Driving Drugs Skin Deep

Me	Text	Statement
		1. Applying medications to the skin is a new idea.
		2. Drugs that can penetrate the skin are made of large polar molecules.
		3. One advantage of a transdermal patch is that it delivers medication directly into the bloodstream.
		4. An advantage of transdermal patches is that they deliver medications in large one-time doses.
		5. Ultrasound treatment can make the skin more porous.
		6. The 3M Company, manufacturer of Scotch Tape and Post-It Notes, have several patents for transdermal drug delivery.
		7. Fewer than 10 drugs are currently available by transdermal patches.

Ocean Biolights

Me	Text	Statement
		1. In the upper two kilometers of the ocean, 90% of the animals can produce light.
		2. Bioluminescence is an exothermic chemical reaction.
		3. Bioluminescence reactions involve only a single molecule.
		4. Almost all of the light that strikes the ocean's surface makes it to a depth of one meter.
		5. In the deep ocean, most bioluminescence is red.
		6. Bioluminescence may be used for camouflage or even as bait, and is critical to the survival of deep ocean animals.
		7. The majority of bioluminescent marine organisms have their own biochemical apparatus to enable them to be self-luminous.

Cinnamon: The Bark Heard 'Round the World

Me	Text	Statement
		1. Cinnamon has been used in cooking for 5000 years.
		2. Cinnamon flavor comes from the roots of the cinnamon bush.
		3. All cinnamon, regardless of origin, is the same color.
		4. "True" cinnamon from Sri Lanka has eugenol, a compound not found in other cinnamons.
		5. Cinnamon candies such as Red Hots and Atomic Fireballs have extra synthetic cinnamaldehyde added to them.
		6. Powdered cinnamon may help treat Type II diabetes.
		7. Powdered cinnamon is an effective bactericide and fungicide.

The Science of Slime!

Me	Text	Statement
		1. Isaac Newton observed that the viscosity of fluids is affected only by temperature.
		2. Oil is more viscous than water.
		3. Whacking a bottle of ketchup makes the ketchup more viscous.
		4. Struggling in quicksand makes the quicksand more viscous.
		5. All non-Newtonian fluids are synthetic.
		6. Slime is a non-Newtonian fluid.
		7. Silly Putty becomes more viscous if left to set on the table for a few minutes.

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

Two Faces of Carbon

Complete the chart below to compare and contrast diamond and graphite.

	Diamond	Graphite
Physical Properties		
Structure		
Uses		
Synthetic production		

The Science of Slime!

Complete the chart below describing slime and its properties. If possible, make slime using the directions in the article to experience the properties of slime for yourself!

Term	Definition	Examples
Slime (as used in the article)		
Viscosity		
Non-Newtonian fluid		
Shear thinning		
Shear thickening		
Cross-linking		

The Transdermal Patch—Driving Drugs Skin Deep

Complete the chart below explaining the advantages of the transdermal patch (TDP) and problems associated with developing the patches.

Advantages of TDP	Explanation of how this advantage is achieved
1.	
2.	
3.	
<hr/> <hr/>	
Problems with medication penetrating the skin	Solutions to the problems
1.	
2.	
3.	

Cinnamon: The Bark Heard 'Round the World

In the table below, compare and contrast true cinnamon with other cinnamons.

	True Cinnamon	Other Cinnamon
Source		
Description		
Older uses		
Chemical structure		
New uses		

Ocean Biolights

Complete the box below to describe bioluminescence as completely as you can.

Describe chemical reaction	Examples in organisms
Vampy's special talents	Parallel evolution meaning and examples

Bioluminescence

Two Faces of Carbon

Background Information

More about LifeGem Diamonds

At the moment, the largest diamond one can obtain from LifeGem is 1 carat, but the company's Website states that "flawless diamonds of up to 3 carats"... "will be available in the very near future."

It is possible to make well over 100 diamonds from one person's remains if someone desired and could pay for it.

Their Website also states that carbon is extracted from the remains and "coalesces with the natural carbon used in the diamond growth process."

Your Teacher's Guide Editor was curious as to what percent of the carbon in the final product might come from the remains themselves and what percent might come from outside sources, so an email asking about this was sent to LifeGem.

A response quickly arrived, saying, "The percentage of carbon varies from one set of remains to another. In some cases we can purify and extract 100% of the carbon from only the remains, but in other cases the combination of carbon from the remains and from natural carbon is 50%."

A curious turn of phrase—is the carbon in me somehow unnatural?

More properties, characteristics and interesting facts about diamond

Diamond is the hardest naturally occurring substance. The second is boron nitride, BN, when in a structural form identical to diamond.

Diamond derives its name from the Greek *adamas*, which means "untamable," or "unconquerable." This was meant to refer to its hardness.

Although diamond is a very poor electrical conductor, it is a tremendous thermal conductor. It has the highest thermal conductivity of any known solid at room temperature. The thermal conductivity is about five times that of copper, for example. The thermal conductivity is so unusually high that this property can actually be used to determine if something is a true diamond.

Any color that a diamond has is due to the presence of impurities. An absolutely pure diamond would be transparent and colorless.

Diamonds are valued according to what are often called the "four C's," namely *cut*, *clarity*, *color*, and *carat*.

Cut

Diamonds were first crudely cut during the late Middle Ages. Before that they were simply left in their natural state. Early cutting did little to improve the beauty and radiance. One cut, called a *table cut*, basically involved cutting away about half of the natural crystal. A table cut diamond would appear black to the eye. Many paintings made during that time show diamonds that way.

In 1676 the *rose cut* was created by Belgian cutters. This was the first genuine multifaceted cut.

Around 1900 good diamond saws and jewelry lathes were developed. This created modern cuts, such as the *round* and the *brilliant*.

Cutting a diamond always results in a great loss of weight. Even with modern knowledge and cutting tools, a cut diamond is rarely more than half as big as the uncut stone from which it was made.

The article carries an illustration of how all the light entering a diamond is refracted out of the face of the diamond. It should be noted that this only happens if the diamond is an ideal cut, i.e., the ratios of the depth to the width, to some of the other dimensions of the diamond have the ideal values. If a diamond is cut "too deep" or "too shallow," some of the entering light will not be refracted out the front.

Why wouldn't a diamond be cut to ideal dimensions? The answer is simple. As mentioned previously, much of the weight of a diamond is lost in cutting. Cutters would like to retain as many carats of the original diamond as possible, so sometimes a compromise is made between cutting for weight vs. cutting for a given set of dimensions.

Clarity

“Clarity” measures the amount of internal imperfections that exist within a diamond. These imperfections are referred to as *inclusions*.

There is more than one agency that grades diamond clarity. The one that is most common in the United States is done by the Gemological Institute of America. You may have heard the term “GIA” attached to a clarity rating.

The GIA grades diamond clarity according to the following scale:

FL—“flawless”—this means that there are no inclusions visible at 10X magnification.

IF—“internally flawless”—this means that while no inclusions are visible at 10X magnification, some small blemishes may be visible.

VVS1 and VVS2—the “VVS” stands for “very very small.” This means that the diamond may contain very very small inclusions that are visible, but very difficult to see at anything under 10X magnification. VVS1 is better than VVS2.

VS1 and VS2—this means that very small inclusions are visible under magnification, but are not visible to the naked eye.

SI1 and SI2—“SI” stand for “small inclusions.” This means that small inclusions may be visible to the naked eye if you know where to look.

I1, I2 and I3—“imperfect.” These grades have inclusions that are visible to the naked eye. For I3, the inclusions impact the brilliance of the diamond and are large and obvious.

Color

The GIA specifies the color of a diamond by using the letters “D” to “Z.”

colorless: D, E, F

near colorless: G, H, I, J

faint yellow or brown: K, L, M

very light yellow or brown: N, O, P, Q, R

light yellow or brown: S, T, U, V, W, X, Y, Z

Colorless diamonds carry a higher price tag than yellow diamonds, but interestingly, when a diamond’s color gets beyond the “Z” grading it now is classified as a “fancy color,” and may actually demand a premium price. This is especially true if the color is intense and rare. Fancy color diamonds come in virtually all colors of the rainbow. One famous example is the Hope Diamond, which is a deep blue color.

Color differences are very subtle. When a gemologist is attempting to specify the color of a diamond, it is often placed against a white background and next to a diamond whose color has previously been established.

There is another color factor called *fluorescence*, which more accurately should be called *photoluminescence*. When a diamond contains trace amounts of the element boron it will fluoresce when exposed to ultraviolet light. This fluorescence should be described on the diamond’s certificate as none, faint, medium, medium blue, strong, strong blue, and intense blue. This can be considered a “plus” or a “minus,” depending upon the specific characteristics of a particular diamond and the purchaser’s personal preference.

Carat

This, of course, refers to the size (or more correctly, the mass) of a diamond. One carat is equal to 0.200 g, or 200 mg. A “point” is one-hundredth of a carat. A “10 point” diamond is 0.10 carat. Doesn’t “10 point” sound more impressive than “two-hundredths of a gram?”

Diamond Certifying Laboratories

A diamond certification is a detailed quality report issued by an accredited independent gemological laboratory. The four most recognized gemological laboratories that provide certified diamond quality reports to the diamond and jewelry industry are:

G.I.A.—the Gemological Institute of America

A.G.S.—American Gem Society

E.G.L.—European Gemological Laboratory

I.G.I.—International Gemological Institute

The first two are generally considered to be the strictest in assigning grades.

It might be noted that to some small degree, certifying a diamond is somewhat subjective. The amount of color in a diamond might be judged somewhat differently by two different gemologists, so it is not unusual for a diamond certification report from two different certifying laboratories to differ slightly depending on which gemological laboratory prepared the report. A given diamond may possess some qualities that are “on the line” between two different grades. But if both gemologists are skilled, there really shouldn’t be a difference of more than one grade on any given aspect.

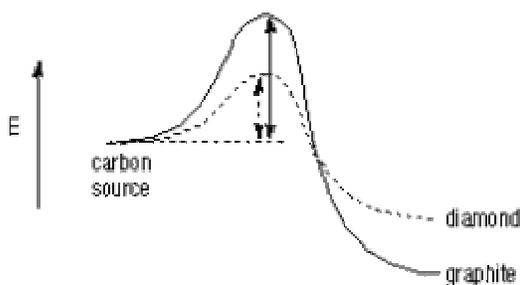
A diamond certification should not be confused with a diamond appraisal. A Diamond Certificate is a document that is issued by a Gemological Laboratory and is always performed on loose diamonds. Gemological laboratories will not grade a mounted diamond. Once a diamond is issued a Diamond Certificate this certificate remains with the diamond and never changes as long as the diamond is not chipped or otherwise changed.

An appraisal can be performed on either loose or mounted diamonds. If mounted, estimates are made on some values. Then a dollar value is placed on the diamond, which obviously can change with time. Appraisals are often done for insurance purposes. While diamond certifications are always performed by disinterested certifiers at gemological laboratories, appraisals can be done by individuals that either have no vested interest in the value of the diamond or who may, in fact, have a vested interest. There are no licensing requirements to become a diamond appraiser.

More about the Chemical Vapor Deposition process for creating artificial diamonds

This process is briefly described in the article and much research is still being devoted to its improvement.

In one simple sense, methane, CH_4 , is a “logical” starting material because it has tetrahedral bonds, much like those found in diamond. In the CVD approach, methane is converted into diamond, which is somewhat surprising, since graphite is the more stable allotrope of carbon at the conditions at which the process is run (see *Connections to Chemistry Concepts*). The reason this can occur is due to the fact that while graphite may be more thermodynamically stable, it isn’t formed as rapidly as diamond, i.e., the kinetics of the process favor the formation of diamond rather than graphite. The activation energy for forming diamond films is lower than that for forming graphite. This is illustrated in the diagram below:



So the trick is to set up the conditions so you form diamond, but not graphite, i.e., you arrange things so the kinetics of the process dominates over the thermodynamics.

Although the reasons are not yet fully understood, it has been discovered that you can keep graphite from being created by forming the diamond under a constant stream of hydrogen. The role of the hydrogen is thought to be to etch away any graphite that might be formed.

There are variations on this process. Sometimes oxyacetylene torches or simple heated tungsten filaments are used instead of a microwave. Recently the methane has been replaced by buckyballs (another allotrope of carbon with a formula C_{60} and the subject of a future *ChemMatters* article).

Connections to Chemistry Concepts

There is a lot of both simple and very complex thermodynamics and kinetics connected to the transformation of graphite to diamond and vice versa.

Thermodynamically, graphite is more stable than diamond at room conditions. This means that a diamond will “spontaneously” transform itself into graphite if given enough time. But this obviously doesn’t occur, and the reason is fairly simple and common.

One could just as easily ask why a diamond doesn’t spontaneously burst into flame, since it is thermodynamically favorable for a diamond and oxygen to transform into carbon dioxide and water.

The reason is a very common one for many “spontaneous” chemical reactions. The transformation has a high activation energy barrier. Somewhat simplified, in order for the transformation to take place, the colliding molecules (or atoms) must overcome an energy barrier. If the colliding molecules do not possess enough initial kinetic energy when they collide, they will simply bounce off each other and will not transform into the product molecules.

A similar question might ask why your morning newspaper doesn’t spontaneously burst into flame before you can read it. Again, the answer is that the reaction of paper with oxygen, although highly exothermic, requires that the colliding molecules possess enough initial energy to surmount the activation energy barrier. If you provide this energy via a match, some molecules can then react, and the energy released when they react can be used by other molecules to get over the barrier, and the energy they release, etc., etc. Once we get the reaction going, it becomes self-sustaining.

A match will work to ignite a newspaper, but will not ignite a diamond. The activation energy for converting a diamond and oxygen gas to carbon dioxide and water is so high that a burning match isn’t at a sufficiently high temperature to accomplish this. In fact, if your house burns down, don’t rush in to save your diamonds, as they will not burn at the temperature of an ordinary house fire.

Diamonds don’t spontaneously convert into graphite at room temperature simply because the activation energy barrier for this conversion is very high.

Although graphite is thermodynamically more stable than diamond, the energy difference is quite small, only about 2.9 kJ per mole of carbon. Then why can’t we just take some graphite, put it in an environment without air, get it very hot (so we can surmount the activation energy barrier) and convert it into diamond?

We might just as well ask why we wouldn’t be converting a diamond into graphite via this procedure? In fact, this is what would probably happen if we tried it this way. Graphite is thermodynamically favored, so it is more likely that a diamond would convert into graphite, but not the reverse. This was done in a great scene in Philip Morrison’s *The Ring of Truth* series.

But at very high pressures diamond becomes more stable than graphite. A diamond is a more compact structure—the atoms are closer together. High pressure favors this structure, so if we apply enough pressure and also get the system to a high enough temperature to surmount the activation energy barrier, the transformation of graphite to diamond can take place.

This is what happens deep in the earth and this is how early artificial diamonds were made.

Possible Student Misconceptions

Most students probably don’t know much about diamonds, and may assume that it is the size, or number of carats that is the sole determiner of a diamond’s value. This, of course, is only one aspect that determines the cost of a diamond. See *Background Information*.

Students may assume that all other factors being equal, a diamond’s cost will be directly proportional to its weight, i.e., a two carat diamond will cost twice as much as a one carat diamond. This is definitely not the case. Diamond prices increase exponentially with weight. A two carat diamond will cost much more than twice what a one carat diamond of the same quality costs.

Students may think that a diamond certification is the same as a diamond appraisal. This is definitely not the case. See *Background Information*.

Demonstrations and Lessons

1. On their FAQ page, LifeGem answers the question, "What is the quality of a LifeGem diamond?" by stating, "The LifeGem techniques create some of the most valuable diamonds in the world, both because of the diamond quality and the memorial it creates. A LifeGem is also rare because they come in colors uncommonly found in nature. Our overall quality target is at the VS level."

An interesting class discussion might center around the specific phrases used and exactly what they might or might not actually be saying.

2. The conversion, or lack thereof, of graphite to diamond and vice versa can be used as a very nice example of how thermodynamic and kinetic factors determine whether a given transformation can (thermodynamics) and will (kinetics) take place under a given set of conditions. While such a discussion might be somewhat beyond the level of a typical "regular level" chemistry course, it could certainly be appropriate for an honors or Advanced Placement class. See *Connections to Chemistry Concepts*.

Connections to the Chemistry Curriculum

This article connects nicely to several topics. Included are allotropes, bonding, molecular structures, and how the properties of a solid are related to the bonding that exists within the solid.

The conversion of graphite into diamond can provide a strong connection to the topics of thermodynamics and kinetics and can be discussed at a fairly simple or very sophisticated level.

The optical properties of diamond connect to a discussion of refraction in general and what is meant by the index of refraction of a material.

Suggestions for Student Projects

1. Most people probably have an interest in learning more about diamonds, given their value and the fact that many people will purchase them at one or more points in their lives. Purchasing a diamond can be an intimidating process, given the different qualities, sizes, cuts, and the number of different types of vendors from which they can be purchased.

A good project would be for students to research how diamonds are graded and how prices are established. They could do a lot of basic research on the internet, but could also visit and interview local jewelers. They might focus on some of the common misconceptions and errors that people make when purchasing diamonds.

2. There are a fairly large number of different kinds of diamond cuts. Some examples are round, radiant, pear, marquise, emerald, oval, heart, and princess. Students could research and present a project that would illustrate the differences in some of these cuts and what might cause some to be popular at one time and others at a different time.
3. Students could research and interview a local jeweler and prepare a report regarding the factors that determine a diamond's value (see *Background Information*). How is the value determined? What should one look for when purchasing a diamond? What kinds of tricks and/or deceptions are used by unscrupulous dealers?
4. The fact that diamond carries such a high value is certainly related to its unusual properties. Nevertheless, as one might surmise, diamond merchants like De Beers have conducted a strong marketing campaign for many years to promote diamonds as a symbol of love and devotion. For example, the modern engagement ring dates back to a campaign that began in 1938.

Students could research the kinds of marketing techniques that have been used to promote diamonds. Some of them include:

- showing diamonds as wedding gifts in popular romantic movies;

- publishing stories in magazines and newspapers that would connect diamonds with celebrities;
 - using fashion designers and similar individuals to promote diamonds on radio and television;
 - actually enlisting the Royal Family of the United Kingdom to directly promote diamonds.
5. It is possible to “improve” flawed diamonds with the use of lasers and fillers. Vendors of these kinds of diamonds may call them “clarity enhanced.” One vendor states: “The result is a more visually stunning diamond that you can purchase for significantly less than a similar-looking, nonenhanced diamond, where only you and your jeweler will ever know that you own a Clarity Enhanced Diamond.”

So do these kinds of diamonds represent exceptional value or are they a trap for the unknowledgeable? Students could prepare a report detailing exactly what kinds of procedures are used on clarity enhanced diamonds and how the properties of the final product compare to the natural, unenhanced diamonds that they are attempting to replace.

Anticipating Student Questions

1. Can LifeGem make more than one diamond from a person’s remains?

Definitely. In fact their Website states that they are able to create over 100 certified, high-quality LifeGem diamonds from one individual.

2. What is the quality of a LifeGem diamond?

To quote from their Website, “The LifeGem techniques create some of the most valuable diamonds in the world, both because of the diamond quality and the memorial it creates. A LifeGem is also rare because they come in colors uncommonly found in nature. Our overall quality target is at the VS level.” See *Demonstrations and Lessons*.

3. If natural diamonds were formed deep in the earth’s interior, how did they get to the surface?

This question puzzled scientists for many years. We are still not completely certain, but it is generally thought that volcanic pipes running down into the earth allowed diamonds to be transported via violent eruptions. See *Background Information*.

4. Can we create an artificial substance that is harder than a diamond?

We think so. Computer calculations have suggested that a compound composed of carbon and nitrogen with the formula C_3N_4 arranged in a diamond-like structure would be harder than an actual diamond. The material has been made, but not in sufficient quantities to prove that it actually is harder than diamond.

Websites for Additional Information and Ideas

A very good source for information on diamonds that contains a large number of links to related information: <http://diamond.wikiverse.org>

For a very thorough and highly technical discussion of the factors that influence the creation of synthetic diamond: <http://www.htracyhall.org/pdf/19610151.pdf>

For a discussion of how De Beers has dealt with the threat posed by synthetic diamonds: http://edwardjayepstein.com/diamond/chap15_print.htm

The Transdermal Patch—Driving Drugs Skin Deep

Background Information

More about transdermal patches

The article discusses the two main designs of transdermal patches, the matrix system and the reservoir system. There are a few specific elements used in the design of any transdermal patch. Designs differ in how many of these elements they utilize and exactly how they are arranged.

Design elements include:

Backing—this is the top layer that protects the pharmaceutical formulation from the environment, prevents evaporation or loss of the drug or other volatile components, anchors the formulation, and provides flexibility, comfort, and printability.

adhesive—serves to adhere the various components together and also adhere the system to the skin.

membrane—used in the reservoir system—the membrane forms the wall of the reservoir. It compartmentalizes and controls the rate of release of the drug.

liner—protects the formulation during the storage period before use. The liner is removed before the patch is applied.

All transdermal patches contain a liner and a backing. They differ in the number and type of layers in between the liner and backing.

A typical matrix system patch will have layers in this order, from top to bottom.

backing, adhesive, drug, liner
here the adhesive forms a concentric and protective configuration around the semi-solid third layer, which contains the drug

A typical reservoir system has layers in this order.

backing, drug, membrane, adhesive, liner
here the membrane controls the rate of flow of the drug to the skin

Some patches are single layer drug-in-adhesive systems. The order of layers is backing, drug-in-adhesive, liner. This probably represents the simplest type of transdermal patch.

Other patches can be multi-layer drug-in-adhesive systems. A typical system of this type might have the following layers—backing, drug-in-adhesive, membrane, drug-in-adhesive, liner. Here the bottom drug-in-adhesive provides an initial burst of the drug while the second drug-in-adhesive layer provides a later and more gradual release that is controlled by the membrane.

Needle sticks and disease transmission

Transdermal patches offer obvious advantages to people who require medical injections, and this advantage extends to health care workers who must administer the injections. Despite extensive precautions and procedures, health care workers still carry some risk of accidental infection caused by needle sticks. Although AIDS is the most feared, transmission of hepatitis-B is far more common. Accurate statistics on the number of accidental needle sticks that occur to health care workers and the number of AIDS and hepatitis cases that result from them appear to be difficult to come by. The Centers for Disease Control had reported 28 proven cases of HIV transmission from patients to health-care workers since 1981 and another 18 cases where such transmission may have occurred, but could not be proven. Another source reports that 52 health care workers in the United States are known to have contracted HIV from patients, 46 of these occurring because of needle sticks. It is suspected that the actual number may be higher due to some cases not being reported.

Estimates are that about 10,000 health care workers contract hepatitis-B on the job, resulting in about 200 deaths. Since there is a vaccine that can build immunity to hepatitis-B, it would appear prudent for all

health care workers to get vaccinated, and OSHA regulations require that employers provide the vaccine free of charge.

Hepatitis-C is also a growing threat, although the number of infected workers is not known.

All forms of hepatitis are liver diseases caused by viruses. Several distinct types have been identified. If you desire more information about these diseases, one good source is:

http://www.medicinenet.com/viral_hepatitis/article.htm

The actual number of needle sticks that occur is unknown, but is estimated to be in the range of 800,000/year. Fortunately, most needle sticks do not result in the transmission of disease. Factors that determine whether a disease will be transmitted include the depth of the stick, the amount of virus that is transferred, the specific medical state of the patient, and the resistance of the person who gets stuck. It is estimated that only about 3 out of every 1000 individuals who are exposed to the HIV virus because of an accidental needle stick will actually become infected with the virus.

Risks associated with the use of transdermal patches

Any procedure that delivers medication is prone to error. Just as this is true of injections and oral medications, it is true of transdermal patches as well. For transdermal patches, the fact that there are patches of different designs contributes to the possibility of error. Some factors that vary from patch to patch include:

- dosage-strength expression
- frequency of administration
- shape
- size
- color
- site of administration

Transdermal patches are often applied by the patients themselves, which can increase the possibility of human error. There have been reports of patients not realizing that the medication was absorbed directly into the skin and proceeding to apply subsequent patches on top of the original patch. Some patients do not realize that they need to entirely remove the protective liner before applying the patch. Some patches need to be applied to a particular area of the body to be effective. There are also reports of patients applying more than one patch at a time. While these and other potential problems exist, there can be similar problems involved with the administration of any kind of medication, whether it is intravenously or orally administered.

Another potential difficulty is that the patch must remain in good contact with the body to be effective. Excessive sweating or vigorous physical activity can sometimes cause patches to loosen or fall off, meaning that the patient will not receive an adequate amount of the drug that is being delivered. On the other hand, immediately replacing the patch may result in the patient receiving too much of the prescribed medication.

Transdermal patches can be damaged, and if this happens it is possible that either too little or too much drug will be administered.

Most transdermal patches only deliver a small fraction of the total amount of drug they contain. Most patches will still retain about 95% of the total drug amount when they are to be discarded. This not only is wasteful, but places an added demand for proper disposal. It is recommended that each patch should be folded in half and the adhesive sides should be stuck together. Perhaps surprisingly, the recommended disposal technique is to flush the patch down the toilet.

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.

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"

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 aren't. 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.

Possible Student Misconceptions

Because the article emphasizes the advantages attached to the use of transdermal patches, students may come away thinking that no potential problems are associated with their use. This is not always the case. See *Background Information*.

The article cites the often quoted "like dissolves like" idea. While this is a useful generalization, it is not always followed. See *Connections to Chemistry Concepts*.

Students may think that transdermal patches are a relatively new drug delivery system, but the first was actually approved to treat motion sickness in 1981.

Students may think that a large number of drugs can be delivered via a transdermal patch, but as the article points out (and see *Background Information*) only a handful of drugs are currently suited to this type of delivery system.

Demonstrations and Lessons

1. The article mentions the oft-quoted idea that "like dissolves like," to explain why nonpolar medications are more suitable for administration via a transdermal patch. If you utilize this general notion in your course, this could be a good time to either introduce the idea or demonstrate it. Some possible sources for demonstrations include:
<http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA2/MAIN/LIKEDIS1/CD2R1.HTM>
<http://chemed.chem.purdue.edu/genchem/demosheets/24.16.html>

Also, see *Connections to Chemistry Concepts*.

2. As is almost always the case, there are a large number of Websites attempting to sell transdermal patches to cure or alleviate a large number of conditions. Are they all to be believed? This might be an opportune time to look at one or more Websites that probably "set off our skepticism alarm" by making what appear to be exaggerated "too good to be true" type claims and that contain, at best, what are confusing scientific claims and/or terms that are virtually meaningless. If you do a google search using "transdermal patches," a number of these sites should emerge. A couple that might provide the basis for a class lesson on "don't believe everything you read" can be found at:
<http://1800patches.com/lepatch/index.html>
<http://www.ebotek.com/patch.htm> (note: some conditions discussed here involve sexual attributes and performance)

Connections to the Chemistry Curriculum

This article probably doesn't provide as many strong connections to the typical high school chemistry curriculum as most articles, but it does tie nicely to one often quoted generalization that "like dissolves like," which is used to account for the idea that nonpolar drugs are more likely to be applied via a transdermal patch since they must dissolve in nonpolar lipids in order to enter the human body. Transdermal patches provide a practical application of this generalization.

Suggestions for Student Projects

1. The article mentions several specific examples of drugs that are commonly delivered via transdermal patches. Included are scopolamine for motion sickness, nicotine to help people quit smoking, pain medication after surgery, and others. Students could select one specific application to research. Questions that might be answered could include:

How long have transdermal patches been used for that particular application?
What advantages do transdermal patches offer over other means of drug delivery for that application?
What disadvantages might be attached to their use?
How effective are they? Have controlled studies been performed to compare their effectiveness to other approaches?
How does the cost compare?

2. Are there creative thinkers in your class? Challenge students to think of unique futuristic types of transdermal patches. For example, one might envision a transdermal patch that can detect blood sugar levels and then transmit a signal to another transdermal patch that would administer a proper dose of insulin. Or perhaps a transdermal patch that could measure sun exposure and then inject appropriate amounts of a new sunburn reducing drug into one's bloodstream.
3. How effective are nicotine patches in a stop smoking effort? While *Anticipating Student Questions* gives a general answer, students could delve much more deeply into the procedural details and statistical results of one or more studies and/or compare the results of a few different studies. How does the use of a transdermal patch compare to other procedures, such as counseling or group support?

Anticipating Student Questions

1. How long have transdermal patches designed to deliver drugs been in existence?

They've been in existence since 1981. The first transdermal patch was designed to combat motion sickness.

2. How many drugs are currently being commonly delivered via transdermal patches?

Since 1981, there have been about 35 transdermal patch products approved by the FDA (Food and Drug Administration) that involved 13 different molecules. While this may not seem like much, by 2001 this amounted to a \$1.2 billion market. Eleven molecules were involved at that time. They were fentanyl, nitroglycerin, estradiol, ethinyl estradiol, norethindrone acetate, testosterone, clonidine, nicotine, lidocaine, prilocaine, and scopolamine.

3. Can a nicotine-containing transdermal patch really help someone quit smoking?

Smoking is an extremely addictive habit that is very difficult to stop no matter what kind of treatment one undergoes. Controlled double-blind studies have been done with populations of smokers who wanted to quit. Some received a transdermal patch that released nicotine, some received a transdermal patch that only contained a placebo. In some studies patients also received concomitant behavioral therapy while in other studies patients were basically left on their own.

Of course, different studies will produce somewhat different results, but a general pattern appears to have emerged. Using a nicotine-releasing transdermal patch does appear to increase the probability of a smoker being able to quit, perhaps twice as likely, as a generalization. That's the good news. The bad news is that the success rate is still very low and decreases with the passage of time. For example, in one study 12% of the nicotine-receiving group had not resumed smoking after six weeks compared to only 5.5% of the placebo group. By twenty-four weeks the percentages had dropped to 8.2% for the nicotine-receiving group vs. 4.0% for the placebo group.

4. How should you dispose of a transdermal patch?

Because so much drug remains when a patch is due to be changed (see *Background Information*), it is recommended that each patch should be folded in half and the adhesive sides should be stuck together. The recommended disposal technique is to flush the patch down the toilet.

Websites for Additional Information and Ideas

A very nice Website that provides excellent illustrations of different patch designs can be found at:

http://www.3m.com/us/healthcare/manufacturers/dds/jhtml/patch_anatomy.jhtml

Two rather comprehensive sources for information on several aspects of transdermal drug delivery:

http://www.uspharmacist.com/index.asp?show=article&page=8_1061.htm

<http://www.drugdeliverytech.com/cgi-bin/articles.cgi?idArticle=143>

Ocean Biolights

Background Information

More about “Red Tides”

The term “Red Tide” is really somewhat of a misnomer. First, it has absolutely nothing to do with tides. Secondly, red tides are not always red. While red may be the most common color, other colors include variations of red, orange, yellow, pink, and brown, even though the term “red tide” is typically used for all of them.

The preferred scientific term is *Harmful Algal Blooms*, or *HAB*'s. While this term more correctly describes the characteristics of the phenomenon, the term “red tide” persists in common usage.

One commonly accepted definition of a red tide, or *HAB*, is water that is discolored by the “presence of a sudden overpopulation of phytoplankton or [micro]algae.”

The article focuses on one type of phytoplankton, dinoflagellates, which is the most common cause of *HAB*s. Diatoms, another type of phytoplankton, can also be responsible for *HAB*s, although this is less common.

Phytoplankton are single-celled plants that form the basis for most sea life. They engage in photosynthesis and thus establish the beginning of the complex food chain that exists in the oceans. With the exception of hydrothermal vent organisms (see *ChemMatters*, Dec. 2003), every animal that lives in the ocean environment is ultimately dependent on phytoplankton for their survival. Phytoplankton are also known as microalgae. This name is given to all algae that are too small to be seen with the naked eye. Phytoplankton are a subset of all microalgae.

One can make a good argument that phytoplankton represent one of the most unusual organisms in existence. These single-celled organisms are capable of:

engaging in photosynthesis

eating other organisms

exhibiting bioluminescence

assimilating dissolved organic substances

producing toxic substances that prevent them from being eaten by other organisms

It should be noted that different species possess different sets of the above properties. For example, some are heterotrophic (they eat other organisms), while others are autotrophic (they engage in photosynthesis), and others are both.

They exhibit biorhythms and can change their depth in the ocean water column. Indeed, “phyto” means plant, and “planktos” means to wander. Dinoflagellates accomplish this by means of a flagella, or whip-like tail, as contrasted to diatoms, that need to rely on ocean currents for transport.

Scientists do not really know what causes phytoplankton to suddenly overpopulate. The phenomenon does not appear to be related to human activities, although there is some slight speculation that it might possibly be related to global warming or increased levels of phosphates produced from the discharge of chemical cleaning agents. It appears to be related in a very complex way to various oceanographic features such as currents, winds, and other factors.

A “bloom” occurs when the concentration of cells reaches about one million cells per liter of seawater. When the bloom produces harmful biotoxins, it is termed a Harmful Algal Bloom.

More about dinoflagellates

There are about 2,000 species of dinoflagellates. Approximately 10% are found in freshwater and 90% in salt water.

One interesting feature of bioluminescent dinoflagellates is that they exhibit a circadian rhythm that determines when they will exhibit bioluminescence if disturbed. They will undergo photosynthesis only when they “think” it is day and bioluminescence only when they “think” it is night. In a natural environment this will correspond to the natural daylight and nighttime hours. But this can be reversed. If dinoflagellates

are grown in a laboratory or home environment their circadian rhythm can be reversed by exposing them to light during normal nighttime hours and keeping them in the dark during the daytime. It takes about a week to accomplish this reversal.

More about bioluminescence

A single dinoflagellate can produce enough light to be detected by the human eye if it has been dark adapted. A single flash releases about 6×10^9 photons of light and lasts for about a tenth of a second. The intensity of the flashes emitted appear to be related to the intensity of the sunlight on the previous day. The brighter the sun, the more intense the flashes.

Larger bioluminescent organisms emit brighter light. A jellyfish, for example, may emit about 2×10^{11} photons in a flash the may last for tens of seconds.

A partial list of bioluminescent organisms includes:

bacteria	clams (few)	sea cucumbers
fungi	squid (many)	hemicordate worms
dinoflagellates	octopods (few)	urochordates
radiolarians (single-celled marine organisms)	annelid worms (lots)	pyrosomes
cnidaria	earthworms	tunicate (one)
scyphozoa (jellyfish)	pyncogonids (sea spiders)	larvaceans
hydrozoa (hydroids and hydromedusae)	crustaceans	chordates
anthozoa (sea pens and sea pansies)	copepods	sharks (some)
ctenophores (comb jellies)	ostracods	fish (lots)
nemertean worms (1 type)	amphipods	centipedes
mollusca	decapod shrimp	millipedes
limpet (1 type)	euphausiids	insects
nudibranchs (a few)	chaetognaths	fireflies
	echinoderms	click beetles
	sea stars	fungus gnats
	brittle stars	railroad worms

Two things should be noted. Only some (in some cases very few) of each species exhibit bioluminescence, and there are no flowering plants, birds, reptiles, amphibians or mammals that do.

Although the general method by which a bioluminescent reaction occurs is similar, namely the reaction between a luciferin and a luciferase enzyme, there are more than a dozen slightly different specific mechanisms used by different organisms. For example, a specific type of luciferin called a coelenterazine is used by jellyfish, shrimp and fish. On the other hand, dinoflagellates use a different class of luciferins, etc. This leads scientists to speculate that bioluminescence may have evolved independently amongst different groups.

Bioluminescence, fluorescence, and phosphorescence

As the article points out, these three phenomena are different. Bioluminescence refers to the production of light by a chemical reaction that occurs inside a living organism. It is a kind of chemiluminescence, which is the production of light by use of a chemical reaction, such as occurs in light sticks. Fluorescence refers to the phenomenon where an object absorbs light of one frequency and immediately reemits light of a different frequency, i.e., it “glows.” “Glow in the dark” minerals you may have seen on exhibit are absorbing invisible ultraviolet light and then reemitting the energy as visible light. Phosphorescence is similar to fluorescence, except that the light is emitted over a longer period of time. This is the basis for glow-in-the-dark stickers, watch faces, or paint.

Terrestrial bioluminescence

With a few exceptions, bioluminescence is almost the exclusive property of marine creatures. Over 700 different marine species are known to be bioluminescent. Included are bacteria, fish, sponges, jellyfish, and some crustaceans. By contrast, there are only a handful of bioluminescent terrestrial creatures. The common firefly is best known, along with a few other insects, fungi, worms, and some microorganisms.

Connections to Chemistry Concepts

Enzymes are catalysts. Catalysts are substances that speed up a chemical reaction but are not permanently consumed in the reaction.

There is no such thing as “a” catalyst. Catalysts are very specific in their action, i.e., they may catalyze one or several different reactions, but they don’t affect other reactions. The mechanisms by which they operate are varied and specific to the reactions that they catalyze.

Catalysts work by lowering what is called the activation energy for a reaction. The basic idea, somewhat oversimplified, is that in order for a reaction to occur between two molecules (or ions or atoms, etc.) the molecules must be in contact with each other, i.e., they must collide. For most reactions, most of the collisions that occur produce nothing—the molecules simply bounce off each other and do not change their structure. But if the colliding molecules possess sufficient energy, called the activation energy, the collision can produce a high energy molecule called an activated complex. This activated complex may then split apart to form the product molecules.

This is much oversimplified. To get from the reactants to the products may take several steps, called elementary processes. The entire series of steps that take the reactants and eventually produce the products is called the reaction mechanism.

If you would like to know more about how catalysts work and reaction kinetics in general, some good Websites include:

<http://www.sparknotes.com/chemistry/kinetics/mechanisms/section1.html>

<http://atom.ecn.purdue.edu/~bt/Dealumination%20of%20Zeolites/Catalyst.htm>

[http://www.marling.gloucs.sch.uk/chemistryweb/Notes/physical/\\$Kinetics%20and%20catalysis%20.doc](http://www.marling.gloucs.sch.uk/chemistryweb/Notes/physical/$Kinetics%20and%20catalysis%20.doc)

Well, this one may be more about geology than chemistry.

The article discusses how the amount of light penetrating into an ocean environment decreases with depth. Like many other things, there are actually names attached to different ocean depths. They are:

- epipelagic zone—surface to about 200 m
- mesopelagic zone—200-1000 m
- bathypelagic zone—1000-4000 m
- abyssopelagic zone—4000-6000 m
- hadalpelagic zone—below 6000 m

Possible Student Misconceptions

Students may have heard that bacteria can be bioluminescent. One common myth is that bioluminescence is primarily a bacterial phenomenon. This is not true. While some bacteria do exhibit bioluminescence and while some organisms such as fish and squid do contain bacteria in their light organs, the vast majority of bioluminescent organisms produce their light without the benefit of bacteria. They have all the requisite chemicals within themselves.

Students may assume that fireflies are flies, and glowworms must be worms. But fireflies are actually beetles and glowworms are the larvae of flies.

Demonstrations and Lessons

1. Scientists do not completely understand why different organisms exhibit bioluminescence, i.e., what is the advantage they gain by utilizing this phenomenon?

There are several possible advantages, some pretty firmly established, others more in the realm of conjecture. But if one takes a Darwinian view, bioluminescence must convey some advantage in the battle for survival.

Humans do not exhibit bioluminescence. But what if we could? An interesting class discussion (or student project) could center around what advantages might accrue to human beings that had the

ability to exhibit bioluminescence. Under what circumstances would this ability be most useful? How might this ability be “fine tuned” to produce the greatest advantage?

2. While it may not be practical to try and work with bioluminescent organisms (although it is certainly possible—see *Suggestions for Student Projects*), it would be very easy to tie this article into a laboratory exercise involving chemiluminescence. Most educational scientific vendors sell kits for chemiluminescence experiments. Alternatively, there are many Websites that provide instructions for such an activity. A couple can be found at:
<http://www.kyantec.com/Tips/Chemiluminescence.htm>
<http://scifun.chem.wisc.edu/HOMEEXPTS/Chemilum.html>
4. There are no flowering plants, birds, reptiles, amphibians or mammals that exhibit bioluminescence. But what if we could use genetic engineering to produce some? What kinds of useful plants and/or animals might one envision? For example, one might genetically engineer a Christmas tree that produced its own light. A contest could be held (possibly with prizes) to see who could come up with the most creative and useful “new” kind of bioluminescent species.

Connections to the Chemistry Curriculum

While this article clearly has strong biological connections, the fact that bioluminescent reactions involve enzymes immediately leads to a discussion of catalysts, activation energy, reaction mechanisms, and the entire topic of reaction kinetics.

The fact that different wavelengths of light exhibit different absorbance as they pass through ocean water can lead to a discussion or review of the nature of light and the relationship between wavelength, frequency, and color.

Suggestions for Student Projects

1. It is fairly easy to grow dinoflagellates at home. A student or group of students could attempt to culture these organisms and then bring them to class to demonstrate their bioluminescence. Care would have to be taken to insure that the dinoflagellates think it is “night” (see *Background Information*). If any students are interested in pursuing this, some good Websites for information include:
<http://www.lifesci.ucsb.edu/~biolum/organism/dinohome.html>
http://meteor.pwnet.org/impact_event/dino.htm

A google search using search terms such as “dinoflagellates,” “grow,” and “home” will turn up many additional sources.
2. Phytoplankton represent a varied, complex, and interesting class of organisms. While the purpose of the article is hardly to delve deeply into the varied nature and characteristics of phytoplankton, students with a strong biological interest might enjoy learning more and preparing a paper or presentation on this fascinating and important class of organisms which exist in an amazing variety of what can be considered unusual and beautiful forms.
3. Red Tides or Harmful Algal Blooms (see *Background Information*) are a very interesting, complex, and not fully understood phenomenon which could also be the focus of a good student report or class presentation.

Anticipating Student Questions

1. Why would a single-celled organism like a phytoplankton want to bioluminesce when disturbed? What advantage does it gain from doing this?

Scientists are not sure. There are two popular ideas. One holds that by flashing, it startles a predator, and thus the phytoplankton is less likely to be eaten. Another thought is that by flashing, the phytoplankton attracts the attention of an even larger predator that in turn eats the organism that was planning on eating the phytoplankton.

2. Why do fireflies flash on and off instead of just leaving their light one way or the other?

First, fireflies, or “lightning bugs” are not flies. They are actually beetles, and their behavior of turning their light on and off is quite unusual. In fact, the mechanism by which they accomplish this has only been known for a few years. They produce light for three reasons. The primary reason is to find a mate. Males flash their light signals, and wait for females to respond. Females tend to stay on vegetation near the ground and will flash a response to attractive males.

Interestingly, different species of fireflies (and there are perhaps 1700-1900 different species) will flash at different rates and intervals. Females of one species are known to mimic the flash characteristics of a different species, and when the male approaches, he is eaten—a second use.

It is also thought that the flashing also signals to potential predators that they are not good to eat, since the light-producing chemicals do have a bitter taste. It is thought that this may be the primary reason that firefly larvae exhibit bioluminescence.

3. Are there any large animals that exhibit bioluminescence?

There are a few fish and sharks. But no bioluminescence is known in higher vertebrates above fish.

4. Why don't freshwater creatures exhibit bioluminescence?

We really don't know. There are freshwater environments that are essentially as dark as the deeper ocean depths, but no bioluminescence is observed there. We can only speculate why this is the case. There currently are no good theories or explanations.

5. What is a “glowworm?”

Just as “fireflies” are really beetles, glowworms aren't worms. They are actually fly larvae (maggots, if you will), and they live in caves.

Websites for Additional Information and Ideas

For additional information on Harmful Algal Blooms (HABs):

<http://www.who.edu/redtide/whathabs/whathabs.html>

For additional general information on bioluminescence:

<http://www.nswseakayaker.asn.au/mag/46/bioluminescence.html>

http://siobiolum.ucsd.edu/Biolum_q&a.html

More information on dinoflagellates can be found at:

<http://www.ucmp.berkeley.edu/protista/dinoflagellata.html>

<http://www.geo.ucalgary.ca/~macrae/palynology/dinoflagellates/dinoflagellates.html>

Cinnamon: The Bark Heard 'Round the World

Background Information

More about cinnamon

Cinnamon is the inner bark of a tropical evergreen tree. There are a large number of different species, perhaps between 50-250, depending as one source puts it, "on which botanist you want to listen to".

As the article points out, there are two main types of cinnamon. The first, often called "true cinnamon" grows in Sri Lanka, and is made from the *cinnamomum zeylanicum* tree, now usually referred to as *cinnamomum verum*, although both names are in common use. The very best is grown along a coastal strip. These trees prefer a hot, wet tropical climate at relatively low altitudes. The trees can grow quite tall, to a height of perhaps 56 ft or so if left in the wild state. The bark of the tree is relatively smooth and yellowish in color. The tree will flower with small yellowish-white flowers and dark purple berries, but the flowers actually have an unpleasant odor.

Commercial trees are not allowed to get very tall. The stems are constantly pruned so that the height never gets much above 10 ft. This pruning results in the growth of new stems with new bark that can be harvested.

Harvesting consists of scraping off the outer bark, cork, and the pithy inner lining. The bark that remains is then allowed to dry. As it does this, it curls and forms quills. The final product is made by rolling several of these quills together and cutting them into uniform lengths. These are then given various grades, depending on their thickness, aroma, and appearance.

As the article points out, most cinnamon purchased in the United States is probably not "true cinnamon" from the *cinnamomum verum* tree. It is most likely cassia, which can come from trees such as *cinnamomum cassia*, *cinnamomum burmannii*, or *cinnamomum loureirii*, all of which are native to Southeast Asia. If your experience with cinnamon suggests that it is a rather strong-tasting spice, that's very likely due to the fact that all the cinnamon you've tasted has come from the latter three sources. The article describes the differences in both appearance and taste.

Today "true" cinnamon comes not only from Sri Lanka (formerly Ceylon), but also from southern India, Brazil, and Indonesia as well as Seychelles and Madagascar. Cassia is grown in southern China as well as other Southeast Asia nations such as Vietnam, Indonesia, Sumatra, Malaysia, Laos, and Cambodia.

The Food, Drug and Cosmetic Act of 1938 allows all cinnamon and cassia spices to be labeled "cinnamon."

Cinnamon has probably been known since ancient times. Many sources state that early Egyptians utilized it as a flavoring and also for its medicinal properties, as well as in embalming, where body cavities would be filled with spiced preservatives. Some scholars, however, have doubts that the Egyptians were using true cinnamon from the island of Ceylon. Very early accounts are difficult to verify, and some are clearly incorrect. Whatever the specific details, it is probably safe to say that cinnamon or similar substances have been both known and valued for a significant period of time. By about 400 B.C., the use of cinnamon is clearly established. It was used to flavor wine, burned as incense, stuffed into pillows, and used in cooking food.

By the latter Middle Ages cinnamon was well known and highly valued. People wanted more of it, and were willing to pay—the kind of situation that often leads to both noble and brave quests and unfortunately brutal conquests. By the middle 1200s, reports from explorers reached the Western world indicating that cinnamon could be obtained from Ceylon. Christopher Columbus thought that he had found cinnamon along the north coast of Cuba. It most likely was the bark of a completely different plant, *Canella winterana*.

But by the 16th Century the origin of true cinnamon, Ceylon, was established. In 1505, the Portuguese discovered wild cinnamon growing on the island of Ceylon. They returned thirty-one years later to both occupy the country and gain control of cinnamon production. At first they simply demanded that the natives contribute a set amount of cinnamon each year. One record states that this amounted to about

250,000 lbs. annually. Later the Portuguese took over the management of cinnamon production, employing slave labor to grow and harvest the crop.

In the early 1600s, the Dutch took over Ceylon. Production was increased to about 400,000 lbs./year, but only at the expense of brutal treatment of the native population. The Dutch East India Company gained most of its money from the sale of cinnamon.

Around 1770, a man named Pierre Poivre (Peter Pepper?) smuggled some cinnamon plant cuttings out of Ceylon and planted them in the French island colonies off the east coast of Africa, the Seychelles. The plants grew, and in a few years another source of cinnamon became available. World prices plunged, despite Dutch attempts to prop up the price by burning large tracts of cinnamon plants. The attempt proved futile. In 1796, the British took over Ceylon and the Dutch East India Company went bankrupt.

But the battles over this valuable spice continued. One somewhat bizarre event occurred in 1780. At that time the British and French were involved in an intense rivalry centering around cinnamon production and sales. A ship flying the British flag approached the Seychelles. The French, believing that a British invasion was imminent immediately burned down their own cinnamon plantations so as to prevent a British takeover. It turned out that the ship was actually a French slave ship that was attempting to avoid a confrontation with any British ships by flying the British flag!

The British tried to carefully control the production of Ceylon cinnamon by keeping production under 500,000 lbs./year. But in 1833 the government monopoly was abolished, and the production of cinnamon was opened to private entrepreneurs.

Cinnamon prices quickly fell, because of this and other factors. The Dutch were still producing cinnamon from trees that had been cultivated in Java in 1825. Cinnamon produced from *Cinnamomum cassia* trees competed with the "true" cinnamon from the *Cinnamomum zeylanicum* tree.

It may be difficult for us today to understand why such a common material like cinnamon was so highly valued. After all, it's just a spice. But the world was much different then. There was no refrigeration. Meat easily spoiled, and cinnamon could mask the taste of spoiled meat, for instance. Its possession was also somewhat of a status symbol. One could flaunt their wealth or social rank by offering guests in their home a plate containing several exotic and expensive spices. One source states that the effect of the search for and commercial trade of cinnamon and other spices literally fueled the Age of Discovery and the Renaissance of Europe. It has even been suggested that much of the flourishing of art can be linked to the wealth that was available to commission and purchase great works. It clearly fueled conquests along with the terrible subjugation and treatment of native populations. One source, *The Complete Spice Book*, draws a parallel to the battles and economic disruptions that center around oil in today's world.

Cinnamon and Type 2 diabetes

Like cinnamon, diabetes has also been known since ancient times. The earliest record dates back to an Egyptian papyrus of 1552 B.C. Frequent urination is listed as a symptom. Early attempts at diagnosis utilized "water tasters," whose function was to taste the urine of individuals who were suspected of having the disease. The excess sugar in their urine gave it a sweet taste. By the early 1800s it was possible to perform chemical tests to detect the presence of sugar in urine.

It was noted early on that individuals who developed symptoms early in life, say before age 20, did not survive much past their youth, while individuals who developed symptoms later in life, say over age 40, often lived for many years, despite their condition.

By the 1870s observations had been made that patients who developed diabetes later in life fared better and lived longer if their diets were strictly controlled.

The great breakthrough occurred in 1921, when Dr. Frederick Banting and Charles Best discovered the link between pancreatic output of insulin and diabetes. After conducting research on dogs, they and two other colleagues, J. B. Collip and J. J. R. MacLeod ran the first human test in 1922 with great success. Mass production of insulin soon followed, and in 1923 Banting and MacLeod were awarded the Nobel Prize in Physiology or Medicine.

Although perhaps not as clear-cut as is sometimes suggested, diabetes is often classified into two main types, type 1 and type 2.

Somewhat oversimplified, type 1 diabetes, sometimes called *juvenile onset* or *insulin-dependent* diabetes, is an autoimmune disease. A person's immune system attacks the body's cells that produce insulin. Since the body cannot produce insulin, a person with type 1 diabetes must take insulin injections in order to survive.

Type 2 diabetes, sometimes called *adult onset* or *noninsulin dependent* diabetes is far more common, accounting for about 90% of diabetes cases. In this case a person's body either doesn't produce enough insulin and/or cells ignore the insulin. Depending on the severity and specific nature of the disease, type 2 diabetes can often be controlled with diet and exercise. Sometimes pills or insulin injections are recommended. But even if a person takes insulin for the condition, it is still considered to be a noninsulin dependent form of the disease, since a person with the disease can still be expected to survive for a significant length of time even if they don't receive insulin injections.

Unlike some claims made on behalf of "natural" or "herbal" products, the possible role that cinnamon may play in the treatment and prevention of type 2 diabetes has been the subject of serious scientific studies. Some of these studies have been performed at the University of California, Santa Barbara, Iowa State University, and the United States Department of Agriculture.

To quote Don Graves of the University of Santa Barbara, "Cinnamon itself has insulin-like activity and also can potentiate the activity of insulin. The latter could be quite important in treating those with type 2 diabetes. Cinnamon has a bioactive component that we believe has the potential to prevent or overcome diabetes."

A joint project between UCSB and the Sansum Diabetes Research Institute in Santa Barbara to study the effect of cinnamon on 60 diabetic mice was underway as this Teacher's Guide was being written. The results should be available when the Dec. issue of *ChemMatters* and the accompanying Teacher's Guide are available.

According to Don Graves, the mechanism of operation of cinnamon is as follows. Somehow, the active ingredient, called proanthocyanidin, worms its way inside cells. It then helps to activate that part of the insulin receptor that sticks into the cell.

The other end of the receptor sticks out of the cell membrane and into the bloodstream. Its role is to "catch" molecules of insulin. This insulin then escorts sugar molecules to cells.

According to Richard Anderson, a research scientist, "Cinnamon makes insulin more efficient. In diabetes, the problem is that insulin no longer does a good job of escorting sugar into cells. Cinnamon makes cells more sensitive to the insulin that is available. And if you improve insulin sensitivity, you improve blood lipids. Insulin is the driver."

A study was done using 60 volunteers in Pakistan who had Type 2 diabetes. Although the sample size is small and no broad conclusions should be drawn from the study, the results were strongly suggestive that small amounts of cinnamon, as little as one gram a day, can lower blood sugar by an average of 18-29 percent, triglycerides by 23-20 percent, LDL (low density lipoproteins), the "bad" cholesterol, by 7-27 percent, and total cholesterol by 12-26 percent.

Connections to Chemistry Concepts

More about the formula and properties of cinnamaldehyde

As the article points out, one difference between "true" cinnamon and the cassia-type cinnamons is the amount of cinnamaldehyde they contain. Cinnamaldehyde is what gives cinnamon its distinctive smell and what makes it "hot" to the taste.

Cinnamaldehyde has the molecular formula C_9H_8O , or $C_6H_5CH=CHCHO$. Its IUPAC or systematic name is (*E*)-3-phenyl-2-propenal. Other names are *trans*-cinnamaldehyde, cinnamic aldehyde, and *trans*-cinnamic aldehyde.

The LD50 (dosage that will kill 50% of a population of rats) is 2200 mg/kg of body weight. The dosage for mice is 3400 mg/kg.

It is considered a skin irritant, and is toxic in large doses. It is not believed to have any carcinogenic properties. It is excreted in the urine in the oxidized form of cinnamic acid.

The molecular basis for flavor

The molecular basis for flavor is the “lock and key” concept. The general idea is that when a molecule fits into an olfactory receptor, it causes nerve cells to fire, which ultimately results in what we perceive as a particular odor.

There are thought to be over a thousand olfactory receptors, so the perception of taste and odor is quite complex. In the 1970s, Amoore proposed a simple version of the “lock and key” concept, holding that there were only seven basic receptors, since shown to not be the case. Five basic odors were connected to different molecular shapes. A “camphoraceous” receptor accepted football-shaped molecules, which are sensed as a “mothball” smell. Necklace-shaped molecules are sensed as a musky smell. Wedged-shaped molecules trigger the sense of peppermint. Tadpole-shaped molecules smell like flowers, and long thin ether molecules are simply described as being “ethereal.”

Putrid and pungent smells were thought to be the result of partial charges being on the atoms within the molecule as opposed to being caused only by the molecule’s shape. Molecules with a putrid smell had a negative charge buildup. Molecules with a pungent smell, like vinegar, were thought to have a positive charge buildup. Molecules that could lock into more than one receptor had more complex odors.

So why do cinnamon and/or “hot” foods that contain capsaicin cause a burning sensation? It’s because the capsaicinoids (like cinnamaldehyde) bind to a receptor in the lining of the mouth. This is the same receptor that registers pain from heat, thus the effect is a burning feeling. This is a result of the flow of calcium ions from one cell to the next. The pungent molecule has an electron poor area, which is attracted to the electron rich area on the receptor protein.

Possible Student Misconceptions

There are many misconceptions that students might have about cinnamon (there are different types, not just one), where it comes from (both geographically and botanically), and the different properties of “true” cinnamon vs. cassia (and the fact that they may have never actually tasted “true” cinnamon). They may think (not unreasonably so), that claims that cinnamon helps in the treatment of diabetes and can kill bacteria are nothing more than hype spread by companies selling products that contain cinnamon. The article treats all of these misconceptions. Quizzing students about these could actually be an excellent way of measuring how well they have read, understood, and remembered the article’s contents.

One simple misconception that some students might have is that the “burning” produced by spicy foods results in an actual burn—which is clearly not the case (fortunately for us that enjoy spicy foods). The reason that the sensations are very similar is due to the nature of the effect that molecules like cinnamaldehyde and capsaicin have on taste receptors (see *Connections to Chemistry Concepts*).

Demonstrations and Lessons

1. Both the article and the *Background Information* section of the Teacher’s Guide discuss the tremendous impact that the spice trade had on the course of history. The connection between chemistry and/or technology and history is not always obvious. The spice trade could provide an outstanding opportunity to have an “exchange” between a history class and a chemistry class. The teacher, or students from each of the two classes, could go to the other. The chemistry students or teacher could explain the valuable chemical properties possessed by foods and spices such as cinnamon, cloves, pepper, vanilla, chocolate, etc. that make them so valued. The history counterpart could explain and dramatize the effects that the spice trade had on both the course of history and those individuals and nations that were affected by the trade.
2. If your course includes some of the classical kinds of problems centering around calculating the percent composition of compounds, finding empirical formulas and balancing equations, the formula for cinnamaldehyde, C_9H_8O turns out to be rather useful. Four possible problems that could be worked in class or as an assignment might be:
 - (a) Calculate the percent composition of cinnamaldehyde, C_9H_8O .

- (b) Find the empirical formula for cinnamaldehyde from its percent composition—of course the percent composition will either have been obtained from part a or will need to be provided. Since the formula for cinnamaldehyde is given, work will have to be shown to receive credit.
- (c) Balance the equation for the combustion of cinnamaldehyde in oxygen to form carbon dioxide and water.
- (d) When 1.0000 gram of cinnamaldehyde is burned in oxygen, 3.0000 grams of carbon dioxide and 0.5454 grams of water are produced. Form this information find the empirical formula for cinnamaldehyde—as in part b, work has to be shown.

If you would like a detailed solution to any of the above problems, just send an email to chemtchur@aol.com with the heading “Cinnamaldehyde solutions.” For security reasons replies can only be made to your school email address.

3. How real and distinctive are “true” cinnamon and the normal “cassia” type cinnamons that we normally purchase in grocery stores? An interesting activity would be to bring samples of both types to class as well as similar dishes prepared with the different types of cinnamon and then try to perform, to the extent possible, a “blind taste test.” What percentage of students can detect the differences? Which do they prefer?

Connections to the Chemistry Curriculum

While our job is to primarily teach chemistry, not history, there is such a strong and interesting connection between the properties of spices that gave them such a high value in the past and the consequent quests to obtain them that this may be one instance where a discussion of the connections and ramifications might be a useful educational activity. See *Demonstrations and Lessons* and *Suggestions for Student Projects*.

This article connects to some organic structures, functional groups, and nomenclature.

The formula for cinnamaldehyde can be used as a springboard to teach or review some of the “classical” problems that are often a part of an introductory chemistry course. See *Demonstrations and Lessons*.

Suggestions for Student Projects

- As noted in the article, cinnamon has shown some promise in the treatment of diabetes. A study utilizing 60 diabetic mice was underway as this Teacher’s Guide was being written. The study should be completed by the time the Dec. issue of *ChemMatters* is published. Finding out and reporting on the final results of this study could be the focus for a student project. They could also elaborate on the actual chemicals involved and the possible mechanism of their action. See *Background Information*.
- Both the article and the *Background Information* section of this Teacher’s Guide trace some of the history behind the production, trade, and use of cinnamon. It is probably safe to say that few students see much connection between what they may be studying in their history class and what they study in chemistry. But the battles, conquests and economic impact connected to the spice trade changed the course of history. Interested students might be able to prepare a fascinating presentation on the connection (1) between the kinds of societies that existed in perhaps the years 1400-1850 or so, (2) the tremendous differences in the standard of living and the lack of modern conveniences between those times and today and (3) how and why factors such as these made spices so valuable and led to conquests and changed the course of history. If refrigeration had existed in the 1500s and spices had been readily available from local sources, how might the course of history have been altered?

Anticipating Student Questions

- Why is it that some people with diabetes need to take insulin injections while others don’t?

First, it depends on what type of diabetes they have. There are two main types. Type 1 can only be controlled, especially in its later stages, with insulin injections. Type 2 can often be controlled through diet and exercise or other medications, although insulin injections may be part of the treatment. See *Background Information*.

2. Why do spicy foods taste “hot?” Does the heat you experience from spicy foods actually burn you the same way something that is too hot, in the temperature sense, will?

See *Possible Student Misconceptions and Connections to Chemistry Concepts*.

Websites for Additional Information and Ideas

Some good general Websites about cinnamon, its history, properties and uses are:

<http://www.recipes4us.co.uk/Specials%20and%20Holidays/Cinnamon%20Origin%20Uses%20Recipes.htm>

<http://www.theepicentre.com/Spices/cinnamon.html>

<http://www.bell.lib.umn.edu/Products/cinnamon.html>

A rather detailed and technical paper dealing with the molecular basis for odor and flavor can be found at:

<http://www.leffingwell.com/download/olfaction.pdf>

The Science of Slime

Background Information

More about viscosity

The general concept of viscosity is one that most students probably have a good intuitive grasp of, since it can be experienced both visually and tactically. Students can easily see that water and heavy motor oil flow quite differently. They can feel that it is much easier to stir a simple aqueous solution than it is to stir thick pancake batter or syrup. For most of our students, this intuitive grasp is probably educationally sufficient.

But like many other relatively simple and intuitive concepts, viscosity becomes much more complex when you attempt to define it rigorously and quantitatively and measure it accurately.

Viscosity basically measures a fluid's resistance to flow, a fluid considered to be a liquid or gas for this discussion. Since the article dealt only with liquids, the two terms "fluid" and "liquid" will be used interchangeably. Fluids resist the motion of any object through them. They also resist having one layer of the fluid move relative to the remainder of the fluid.

If you look at more technical information related to viscosity, one of the first terms you encounter is *shearing stress*. This stress is something that can be applied to a fluid. It is defined as the force that is applied per unit area, so basically it is a unit of pressure. Imagine applying a small force to a large flat piece of wood that is immersed in a liquid. This would create very little stress—we wouldn't expect the wood to move through the liquid very quickly. But if this same force were applied to a piece of wood with a very small surface area (like a small disk), we would expect the disk to move through the liquid with a significantly higher velocity.

Now imagine two identical flat pieces of wood placed into different liquids—one of high viscosity and one of low viscosity. Mathematically, viscosity can be defined as the ratio of the stress that is applied to what is called the *velocity gradient*. To understand what is meant by velocity gradient, you just have to realize that the liquid that is "in front" of the wood moves at the same velocity as the wood and tends to "drag" any liquid below or above it along with it. If the liquid has a high viscosity, the adjacent layers of liquid "stick" to the moving layer rather strongly, and therefore tend to move along at close to the same velocity. (In the most extreme case, a solid, all layers would move at the same rate—the entire solid would move as a unit). But of course as you move further and further away from the moving layer, subsequent layers are not dragged along as well, so they move at a lower velocity. In a liquid with low viscosity, this change in velocity occurs rapidly with distance—layers that are fairly close to the moving layer hardly move at all. The velocity gradient expresses how rapidly the velocity of different layers of liquid change with distance away from the layer that is experiencing the stress.

Viscosity is usually given the symbol η , (eta), and can be defined mathematically as:

$$\eta = (F/A)/(d_v/d_z)$$

where d_v/d_z expresses how rapidly the velocity of moving layers changes with distance.

The units are therefore:

$$\eta = (N/m^2)/(m/s)/m = (N/m^2)/s = N \cdot s/m^2$$

Since a N/m^2 is a Pascal, Pa, it has been proposed, but evidently not yet accepted, that the SI (International System) unit for viscosity will be the Pa·s, which has been given the name *poiseuille* (pronounced pwã zwěż)(PI).

However, an older unit from the cgs (centimeter-gram-second) system is still in common usage. This is called a *poise* (pwãz), and is a dyne s/cm².

The technical definition of a poise is—the viscosity of a fluid that requires a shearing force of one dyne to move a square centimeter area of either of two parallel layers of fluid 1 centimeter apart with a velocity of 1 centimeter per second relative to the other layer, the space between the layers being filled with the fluid.

The poise turns out to be a rather large unit for viscosity, so in practice viscosities are often expressed in centipoise or millipoise.

There are actually two different kinds of viscosity. The kind defined above is more technically called *dynamic viscosity*, *absolute viscosity*, or *simple viscosity*, although it is typically just called *viscosity*.

Another kind of viscosity is termed *kinematic viscosity*. It is given the symbol ν (nu), and is defined as the ratio of the viscosity of a fluid to its density. Kinematic viscosity has units of m^2/s . This unit does not actually have a name, probably because it is much too large a unit with which to conveniently express the kinematic viscosity of liquids. A more commonly used unit is cm^2/s , which is called a *stoke*. It was named after the British scientist George Stoke. Since this is even rather large, kinematic viscosities are often expressed in centistokes. A centistoke is equal to a mm^2/s .

Viscosities of some common liquids in mPa.s at 20 °C (unless otherwise noted)

water at 0 °C	1.79
water at 20 °C	1.00
water at 40 °C	0.65
water at 100 °C	0.28

The above values illustrate that for Newtonian liquids the viscosity decreases with increasing temperature.

motor oil, SAE 10	65
motor oil, SAE 20	125
motor oil, SAE 30	200
motor oil, SAE 40	310

milk at 25 °C 3

peanut butter 150-250

molasses 5

maple syrup 2-3

Newtonian and non-Newtonian fluids

The basic difference between a Newtonian and non-Newtonian fluid is that the viscosity of a Newtonian fluid (at a given temperature) is essentially constant. If you double the stress, you double the velocity gradient.

Non-Newtonian fluids do not have a constant viscosity at a given temperature. The more technical definition is that in a non-Newtonian fluid the relationship between the shearing stress and the velocity gradient is not linear—i.e., doubling the stress does not double the velocity gradient. Instead, it may more than double, or decrease or do any one of a number of things. As the article points out, there are a number of different types of non-Newtonian fluids.

How might you tell if a given liquid is Newtonian or non-Newtonian? Often simple stirring will allow a determination. Stir the liquid slowly and then rapidly. See if there seems to be any difference in behavior. Does the liquid appear to become “thicker” or “thinner” depending on whether you stir it slowly or rapidly? Stir the liquid for awhile and see if its viscosity seems to change with time. If you observe that the liquid’s resistance to flow seems to depend on what you do to it rather than being constant, you are dealing with a non-Newtonian liquid.

There are a number of terms that are often applied to non-Newtonian fluids, and these terms can easily be, and often are, confused with each other. These terms include:

shear thinning
shear thickening

pseudoplastic
dilatant
thixotropic
rheopectic

Shear-thinning fluids

Suppose a liquid's viscosity decreases the more rapidly you stir it. Technically this refers to a liquid whose shear stress decreases with shear rate. This means that if you try to stir the liquid slowly, it has a relatively high viscosity—adjacent layers of liquid to the liquid that is being moved tend to move with it. But if you stir it rapidly, the viscosity is less—adjacent layers of liquid do not tend to move with the layer that is being forced to move. The term “shear thinning” expresses this behavior rather well. As you increase the shear force (stir more rapidly), the liquid becomes “thinner” (lower viscosity). Another name for this type of behavior is *pseudoplastic*.

A common example is latex paint. If you've ever stirred a can of latex paint, you may have noted that it appears “thick” if you stir slowly, but seems to get “thinner” if you stir more rapidly. This property is also very useful when you try to paint a wall. When you apply the paint to the wall with a brush, the movement of the brush applies a stress, which causes the paint to be relatively “thin,” so it can be put on the wall. But if it remained this “thin” it would run down the wall rather than stay where you put it. Fortunately, as soon as the stress is removed, the paint becomes “thick,” and remains on the wall. Imagine if the paint behaved like water, a Newtonian fluid. While some would remain on the wall, much of it would run down and accumulate on the bottom of the wall—not exactly what we had in mind.

Toothpaste is another example of a pseudoplastic material. It is relatively “thick,” but becomes “thinner” if a stress is applied. This is exactly the property we want it to have in order to have toothpaste stay in the tube when it is opened, but come out of the tube when squeezed gently. Toothpaste actually has yet another interesting property. It is what is termed *viscoplastic*. This means that there is a minimum amount of stress that must be applied before the material will flow at all. It's very good that toothpaste has this property. If it didn't, then even the slightest pressure exerted on the tube would cause the toothpaste to begin to come out—probably before you could get your toothbrush in place. But if you gently hold a toothpaste tube in your hand, no toothpaste will come out of the tube. You have to exert a moderate force and then the pseudoplastic properties kick in. That's exactly what we want.

Thixotropic fluids and Pseudoplastic fluids—often and easily confused

There is a specific example of a kind of shear thinning liquid that is termed *thixotropic*. All thixotropic liquids are shear thinning, but not all shear thinning liquids are thixotropic. Some are pseudoplastic.

So what's the difference? The basic difference has to do with *time*. If you stir a thixotropic fluid, it becomes less viscous the longer you stir it (up to a point, of course). When you stop stirring, its viscosity remains lower for awhile. It does not immediately regain its original viscosity. It will regain its original higher viscosity after a period of time. How long it takes depends on the specific liquid involved. A pseudoplastic liquid has a lower viscosity if stirred more rapidly, but its viscosity returns to its original value as soon as you stop stirring. Latex paint is pseudoplastic. Ketchup is thixotropic. If you rapidly stir a can of latex paint, stop, wait two seconds, and then start to stir slowly again; its viscosity when stirred slowly remains relatively high. If you stir some ketchup rapidly, stop, wait two seconds; and then stir slowly; its viscosity will be much lower than it was the first time you stirred it.

Shear-thickening fluids

If a liquid's viscosity increases the more rapidly you stir it, it's appropriately called a shear-thickening liquid. Another term for this behavior is *dilatant*. Wet concrete is an example of a dilatant fluid.

Rheopectic fluids and dilatant fluids—often and easily confused

As was true for thixotropic and pseudoplastic fluids, rheopectic and dilatant fluids are often and easily confused. Once again, the difference is in their behavior over time. Dilatant fluids simply become more viscous with more rapid stirring, but their viscosity immediately returns to its original value when you stop.

Rheopectic fluids become more viscous as you stir them, and they retain their higher viscosity for awhile even after you stop stirring.

A few words about measuring viscosity

There are several different experimental methods that can be used to determine the viscosity of a given liquid. If the method does not involve using gravity to pull the fluid through some opening or measuring device then the viscosity that is determined is what is called the *dynamic viscosity* (see the earlier part of *Background Information*). If it does, then it is the *kinematic viscosity* that is being determined.

At the high school level, many viscosity experiments basically involve allowing a sphere (like a marble) to fall a given distance through a liquid and measuring the time it takes to reach the bottom. In these kinds of experiments the time required for the sphere to reach the bottom of a graduated cylinder or some other vessel filled with the liquid is often taken to be a way of comparing the relative viscosities of several liquids. It is assumed that the longer it takes the sphere to reach the bottom, the more viscous the liquid.

This kind of experimental procedure is probably acceptable if the purpose is to provide students with some sort of laboratory experience that provides both a visual and tactile connection to the concept of viscosity while taking some specific measurements. It obviously does not allow a calculation of the absolute viscosity of a given liquid nor does it actually allow a comparison of the viscosities of different liquids. Intuitively, it might appear that “the longer it takes the sphere to reach the bottom of the tube, the greater the viscosity of the liquid.” As it turns out, this isn’t quite the case. It is true that if a liquid has a higher viscosity, it will take the sphere longer to fall through the liquid. But there are other factors involved as well.

When a sphere falls through a fluid, it will at first accelerate. But the fluid exerts a “drag” force on the sphere, and this force increases as the velocity of the falling sphere increases. At some point the drag force and the gravitational force on the sphere become equal. At this point the sphere will fall with a constant velocity, which is called its *terminal velocity*. There is an equation called Stokes Law that relates the viscosity of the fluid to the terminal velocity of the falling sphere. This equation is:

$$\eta = 2(\Delta\rho)ga^2/9v$$

where

η = viscosity of the liquid

$\Delta\rho$ = difference in densities between the falling sphere and the liquid

g = acceleration of gravity

a = radius of the falling sphere

v = terminal velocity of the falling sphere

So in principle, students could drop a sphere through a liquid, allow it to reach terminal velocity, determine its terminal velocity, and by knowing or measuring all the other terms in the equation, determine the viscosity of the liquid.

In practice this can be difficult to do. If the liquid has a low viscosity, the sphere may fall too fast to measure the time accurately, and may take too long to reach (or may never reach) terminal velocity. Taking enough measurements to know when it has actually reached terminal velocity can be difficult.

So some high school lab experiments just have students run a “race” between the various liquids and use the compared times to “rank” the substance’s viscosities.

This would be fine if the falling times were directly proportional to the relative viscosities. Stokes Law (see above) shows that the viscosities are inversely proportional to the velocities, which in turn are inversely proportional to the falling times. This is fine, but unfortunately the time also depends on the relative densities of the falling sphere and the liquid. In the most extreme case, if the sphere were less dense than the liquid it would float. Of course you could turn the tube “upside down” and allow the sphere to rise, but the point is that falling times are not directly proportional to viscosities, the sphere may or may not have reached terminal velocity, etc., so this kind of class experiment should not be taken as being some sort of definitive determination of viscosities or even relative viscosities.

Nevertheless, “falling ball” viscometers do exist, and can be purchased commercially. A google search using the phrase “falling ball viscometer” produced 632 “hits.” Some sites that might be worth looking at include: http://phy.yonsei.ac.kr/~phylab/board/exp_ref/upfile/phywe/1_4_04.pdf

<http://home.ntelos.net/~duratech/fbv%20brochure.pdf>

Volume 3 of Bassam Shakhashiri's *Chemical Demonstrations* series contains an experiment that allows the determination of the relative viscosities of a series of liquids by measuring the time of flow through a matched set of capillary pipes.

If you are interested in learning more about the various methods that can be used to determine the viscosity of liquids, one good source is: <http://www.foodproductdesign.com/archive/1992/0992QA.html>

A bit on the history of Silly Putty

In the midst of WWII, the Japanese controlled many of the rubber-producing nations in the Far East. Since rubber was critical to the war effort, especially for the production of tires and boots, a major effort was undertaken to try and develop a synthetic material that could be used in place of natural rubber.

In 1943, a General Electric engineer named James Wright tried combining boric acid with silicone oil. He obtained an interesting gob of goo, and began to study its properties. It bounced if dropped; it would stretch farther than normal rubber, and it had a high melting point. Unfortunately, it didn't have many of the properties of natural rubber and he quickly realized that it would never make a suitable substitute. The product was deemed a “failure” and put on the shelf.

Wright even sent samples to several other scientists, hoping that they might find some useful purpose for the material. None of them did.

Although Wright saw no practical value for the material, he would still use it to entertain family and friends. Its unusual properties caused him to call it “Nutty Putty.”

In 1949 a toy store owner named Ruth Fallgatter was introduced to “bouncing putty”. An advertising consultant named Peter Hodgson convinced her to package the material in plastic cases and add it to her catalog. It sold for \$2—a significant sum in 1949—and outsold every other item in the catalog except for Crayola crayons. Despite this, she decided to drop the item the following year. Hodgson purchased a large quantity of the substance, packaged it into one-ounce balls and placed them in red plastic eggs. He renamed it “Silly Putty,” since silicone oil was one of the materials from which it was made.

In Feb. 1950, Hodgson took Silly Putty to a toy fair in New York, but its potential was still not realized. He managed to get the product into a couple of popular stores. By chance, a reporter for the *New Yorker* magazine purchased some and wrote an article that appeared on Aug. 26, 1950. The product was marketed as “The Real Solid Liquid,” and became a hit with, oddly, adults rather than children. But by 1955 children had discovered how much fun could be had with Silly Putty. By 1957, the product was being advertised on popular children's shows such as *Howdy Doody* and *Captain Kangaroo*. The rest, as they say, is history.

Connections to Chemistry Concepts

See *Background Information*

Possible Student Misconceptions

Although many courses, textbooks and teachers include “viscosity” at the high school level, they may not distinguish between two different types of viscosity, namely *dynamic* viscosity and *kinematic* viscosity. Students may consequently not be aware that the kind of viscosity that is being measured when, for example, a sphere falls through a liquid as opposed to when a liquid drains from a burette or similar device are not the same thing. See *Background Information*.

It is very easy to confuse pseudoplastic fluids with thixotropic fluids and dilatant fluids with rheopectic fluids. While both of the former are shear-thinning fluids and the latter shear-thickening fluids, the behavior

of thixotropic and rheopectic fluids are time-dependent, while the behavior of pseudoplastic and dilatant fluids is not time dependent. See *Background Information*.

Demonstrations and Lessons

1. There are a variety of things that can be done with slime.

Grasp the slime in two hands and do a quick-pull and a slow-pull test with your slime. Does it break apart easier when pulled quickly or slowly?

Place the slime in a ball on the table and do a quick-poke and a slow-poke with your finger. What happens?

See if your slime can bounce.

Place your slime in a ball on the table and observe it for a few minutes. Does it flow into a puddle or maintain its shape? Does this demonstrate that the slime is a liquid or a solid?

Press the slime down on a piece of newspaper. Is the image transferred to the slime? Try with other types of print, such as a photocopy, a page from an inkjet printer, and a page from a laser printer. Write on a piece of paper with a permanent marker and then with a water-based marker. Press the slime down on the writing. Is the image transferred to the slime?

Try to make slime bubbles by wrapping the slime around the end of a straw and blowing gently. An airtight seal must be made between the straw and the slime.

More great varieties of slime!

Try these variations on the slime recipe contained in the article.

To make a more viscous slime, use the same recipe, except do not add any water to the glue.

To make a less viscous slime, double the amount of water used in the recipe.

To make glow-in-the-dark slime, add some glow-in-the-dark pigment to the glue before adding borax.

To make fluorescent slime that will fluoresce brilliantly under a black light, prepare some fluorescent water to use in place of the ordinary water that is added to the glue. Prepare the fluorescent water by removing the tip from a fluorescent highlighter and placing it in a beaker containing up to 500 mL of water. After a few minutes, the water will be highly fluorescent. When this water is used to make slime, the slime will be highly fluorescent under a black light.

To make slime with a more slimy consistency, that is also translucent, use a 4% aqueous solution of polyvinyl alcohol in place of the glue and water. Add borax solution a few drops at a time to the polyvinyl alcohol solution until slime forms.

To make the slimiest of all slimes, use a solution of guar gum powder in place of the glue-water solution. Prepare the guar gum solution by adding 1 gram of guar gum powder to 100 mL of warm water and stir thoroughly until it has dissolved. Add borax solution a few drops at a time to the guar gum solution until slime forms.

2. A simple classroom experiment that investigates the thixotropic properties of ketchup can be found at: <http://www.seed.slb.com/en/scictr/lab/ketchup/ketchup.pdf>
3. Some teachers and courses put a great emphasis on analyzing the units that must be attached to any quantity and showing how various metric units can be derived from other metric units. Viscosity can be and is expressed in different units, such as the poiseuille and/or poise (see *Background Information*). This quantity can provide a springboard for a class lesson on unit analysis, especially if the students have some background in basic physics units and equations such as $F = ma$. There are

a number of Websites that contain information that could provide material for such a lesson or exercise. On excellent one is: <http://hypertextbook.com/physics/matter/viscosity>

This lesson or activity might involve showing that the units of kinematic viscosity work out to be m^2/s . It could involve showing that one centistoke is equal to $1 \text{ mm}^2/\text{s}$, or demonstrating that Stokes Law (see *Background Information*) does produce the correct units for viscosity.

For “security” reasons (if you decide to do this activity) derivations of these various units and relationships has not been given in this Teacher’s Guide. If you would like to see or check anything, just send an email to chemtchur@aol.com with the heading “Viscosity Unit Question.” The return address, for obvious reasons, will have to be to your school’s email box.

4. Non-Newtonian liquids are quite common. They include materials such as latex paint, ketchup, Silly Putty, whipped cream, Elmer’s Glue, peanut butter, and many others. These materials are easily obtained, and can be used to demonstrate not only non-Newtonian behavior in general but specific examples of several different types as well. These could include shear thinning, shear thickening, pseudoplastic, thixotropic, dilatant, and rheopectic examples (see *Background Information*). This could be done as a classroom demonstration or a student laboratory activity.
5. A fun exercise that examines the dilatant behavior of cornstarch can be found at: <http://www.stevespanglerscience.com/experiment/00000047>

Connections to the Chemistry Curriculum

This article provides a strong connection to several topics. If you delve into the topic of viscosity to any depth, you will quickly connect to a number of quantities such as force, velocity, density, and pressure. If you examine any of the equations that can be used to calculate the viscosity of a material from experimental data or even just look at the units in which dynamic and kinematic viscosity are expressed, this can provide numerous opportunities to have students examine the physical units for various quantities and how they are related to each other (see *Demonstrations and Lessons*).

This article also connects nicely with the topic of polymers. Discussing the properties of various types of non-Newtonian materials can lead to a discussion of colloids, hydration, cross-linking, and other concepts as well.

Suggestions for Student Projects

1. Although the specifics of the article may have little to do with Isaac Newton, he certainly ranks as one of the greatest scientists who ever lived and would make an excellent subject for a student paper or classroom report.
2. It is easy to obtain everyday materials that demonstrate several types of non-Newtonian behavior. These kinds of materials could be used for a teacher-directed classroom demonstration or laboratory activity (see *Demonstrations and Lessons*) or could be investigated and presented by a group of students.
3. Most high school viscosity experiments do not actually result in students measuring the actual viscosity of a material. The determination of actual absolute viscosity values can be both time-consuming, experimentally difficult, and involves the use of mathematical equations not typically covered in a high school course. However, motivated and advanced students might enjoy tackling this problem. See *Background Information*.

Anticipating Student Questions

1. Two different internet sources gave different dates for the birth of Isaac Newton. One said he was born on Dec. 25, 1642, while another said he was born on Jan. 4, 1643. How can there be confusion about the date when such a significant scientific figure was born?

There isn’t any confusion. The difference in dates arises because of calendar changes. The Roman calendar before Julius Caesar had all years consisting of 365 days with no leap years. Eventually

this started to get out of step with the seasons, so in 1582 Pope Gregory XII decreed that the day after Oct. 4th would be Oct. 15th.

In addition, there were variations as to when a “new year” began. January 1st was commonly used, but March 25th was also used.

So depending upon which calendar (Gregorian or Julian) is being used, Newton’s birthdate (as well as any other historical date) can be stated differently.

2. I’ve heard that glass is actually a liquid. Is this true?

Glasses are sometimes called *supercooled liquids*. This term reflects the concept that in a true solid the atomic or molecular particles that make up the solid are arranged in some regular pattern, while the particles in a liquid are not arranged in such an orderly manner, but are much more random in their arrangement. Since the particles in a glass are arranged in a pattern that much more closely resembles the arrangement in a liquid, the term supercooled liquid is sometimes used.

But this term is misleading because liquids “flow.” Even liquids with high viscosities will move and deform under a stress. Glasses really don’t do this. The bottom of a pane of glass in a window does not become thicker than the top, even after a period of many years. Consequently glasses should not really be called liquids. The term *amorphous solid* is probably better because glasses are really solid materials even though their particles are not arranged in a regular manner.

Websites for Additional Information and Ideas

For a relatively straightforward and understandable discussion of non-Newtonian fluids:

<http://www.clarkson.edu/subramanian/ch301/notes/nonnewtonian.pdf>

For a good discussion of shear thinning and shear thickening:

<http://www.newton.dep.anl.gov/askasci/gen99/gen99944.htm>

For a good discussion of some mathematical equations relating to viscosity:

<http://hypertextbook.com/physics/matter/viscosity/>

For a thorough list of definitions of important terms: <http://maji.utsi.edu/pdf/151/definitions1.pdf>

For a good general treatment of viscosity: http://www.sciencebyjones.com/viscosity_overview.htm

For a more advanced discussion: <http://www.ae.su.oz.au/aero/fprops>

Humorous Story

One very famous Newton quotation, taken from a letter he wrote to Robert Hooke is: *If I have seen further it is by standing on the shoulders of giants*. The sentiment expressed, as well as many of the actual words, was commonly used by earlier authors and thinkers, although the specific quotation does belong to Newton.

I always liked this quotation and would state it in class. One year a student raised his hand and said, “Well, considering how well I’ve been doing in this class, I must be standing on the shoulders of midgets!” He actually was doing quite well, but had an exceptional sense of humor. In fact, he not only eventually became a chemistry teacher, but ended up teaching in my actual classroom after I retired!