

#### Production Team

Carl Heltzel, *Editor*  
Cornithia Harris, *Art Director*  
Leona Kanaskie, *Copy Editor*  
Michael Tinniesand, *Contributing Editor*

#### Administrative Team

Terri Taylor, *Administrative Editor*  
Sandra Barlow, *Senior Program Associate*  
Peter Isikoff, *Administrative Associate*

#### Technical Review

Seth Brown, *University of Notre Dame*  
David Voss, *Medina High School, NY*

#### Teacher's Guide

William Bleam, *Editor*  
Donald McKinney, *Editor*  
Mark Michalovic, *Editor*  
Ronald Tempest, *Editor*  
Susan Cooper, *Content Reading Consultant*  
David Olney, *Puzzle Contributor*

#### Division of Education

Mary Kirchhoff, *Acting Director*  
Michael Tinniesand, *Associate Director for Academic Programs*

#### Policy Board

Doris Kimbrough, *Chair, University of Colorado—Denver*  
Ron Perkins, *Educational Innovations, Inc., Norwalk, CT*  
Barbara Sitzman, *Tarzana, CA*  
Ingrid Montes, *University of Puerto Rico*  
Susan Gleason, *Middletown, DE*

*ChemMatters* (ISSN 0736-4687) is published five times a year (Sept., Oct., Dec., Feb., and Apr.) by the American Chemical Society at 1155 16th St., NW, Washington, DC 20036-4800. Periodicals postage paid at Washington, DC, and additional mailing offices. POSTMASTER: Send address changes to *ChemMatters Magazine*, ACS Office of Society Services, 1155 16th Street, NW, Washington, DC 20036.

#### Subscriber Information

Prices to the U.S., Canada, and Mexico: \$14.00 per subscription. Inquire about bulk, other foreign rates, and back issues at: ACS Office of Society Services, 1155 16th Street, NW, Washington, DC 20036; 800-227-5558 or 202-872-6067 fax. Information is also available online at <http://chemistry.org/education/chemmatters.html>.

The American Chemical Society assumes no responsibility for the statements and opinions advanced by contributors. Views expressed are those of the authors and do not necessarily represent the official position of the American Chemical Society. The activities in *ChemMatters* are intended for high school students under the direct supervision of teachers. The American Chemical Society cannot be responsible for any accidents or injuries that may result from conducting the activities without proper supervision, from not specifically following directions, from ignoring the cautions contained in the text, or from not following standard safe laboratory practices.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form by any means, now known or later developed, including but not limited to electronic, mechanical, photocopying, recording, or otherwise, without prior permission from the copyright owner. Requests for permission should be directed in writing to *ChemMatters*, American Chemical Society, 1155 16th St., NW, Washington, DC 20036-4800; 202-833-7732 fax.



© Copyright 2006, American Chemical Society  
Canadian GST Reg. No. 127571347  
Printed in the USA

COVER ILLUSTRATION BY JIM NUTTLE



# Question From the Classroom

By Bob Becker

**Q:** My parents are looking into buying a heat pump. A brochure they got said that in the winter, a heat pump takes heat from the cold outside air and pumps it into the house. In the summer, it pumps the heat from the inside air out. How can it do that?

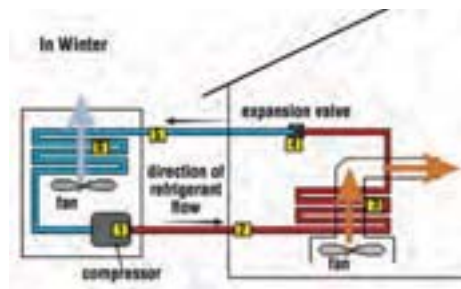
**A:** As strange as this seems, that is fundamentally how a heat pump works, but the truth is, your family already owns a heat pump — in fact they probably own three or four. Your refrigerator and air conditioners — both for your house and for your cars — are heat pumps. They only work one way of course, but the principle is still the same.

So let's take a look at how a refrigerator works first. The explanation begins (as all good explanations do) at the molecular level, and what we will need is a substance with a boiling point about 50°C below room temperature. As you may have already learned, or will soon, molecules are attracted to one another. In some substances the attractions are very weak, like between two H<sub>2</sub> molecules. Because the attractions between H<sub>2</sub> molecules are so weak, the substance is a gas at room conditions and must be taken to extremely low temperatures before those attractions take over and allow it to condense into a liquid. Its boiling point is -253°C — way too low for our purposes. In other substances, like H<sub>2</sub>O, the intermolecular forces of attraction are so strong that the substance is a liquid at room temperature, and must be heated up quite a bit to convert it into a gas. The boiling point of H<sub>2</sub>O is 100°C—way too high. Some compounds though, known as refrigerants, have just the right amount of intermolecular attractions to give them the optimum boiling points. Dichlorodifluoromethane (CCl<sub>2</sub>F<sub>2</sub>) — also known as Freon-12 — is one such refrigerant, and it has a boiling point of -30°C (room temperature is about 20°C).

Now, when a substance boils, it changes from a liquid to a gas; its molecules are pulled away from one another, and the attractions between them are broken. This takes heat energy in — we say the process is “endothermic” — and that's half of the story of how a refrigerator or heat pump works. If those

gaseous molecules are then pushed closer together by a compressor, the intermolecular forces can take over and cause the substance to condense back into a liquid. This process gives off heat; we say it is “exothermic” — and that is the other half of the story!

So, imagine some CCl<sub>2</sub>F<sub>2</sub> under enough pressure that it is in the liquid state, and then have it injected into a compartment that is not at high pressure. The liquid would immediately boil, taking in heat from the surroundings, making the compartment and the air around it get quite cold. Now move that gas through a pipe and into a separate compartment where a compressor increases the pressure and condenses it back into a liquid. This condensation would release heat to the surroundings, making this compartment and the air around it get quite warm. Transferring this pressurized liquid back into the low pressure compartment allows this whole cycle to start again.



This cycle takes place inside — and behind — your refrigerator, and although it is called a “refrigerator,” it actually does as much heating up as it does cooling down. Go touch the metal grate on the back side of your fridge. The warmth you feel there is the heat released by the condensing refrigerant, and indirectly it is the heat that has been “pumped” out of your food and beverages! The grate has a lot of surface area to allow the heat to dissipate quickly. An air conditioner works the same way: that big unit outside your house is where the exothermic condensation process occurs. And when you're trying to cool down an entire house full of air, heat dissipation becomes an even bigger task. That is why there is a fan blowing air across the coils. Hold your hand over the unit and feel the heat being pumped out of

your house. Even when the outside temperature is at its highest, the air blowing out of that unit is hotter still. The boiling (endothermic) side of the cycle is not quite so accessible, but it is there — inside your house, in the duct work with the air being cooled as it blows across the coils.

So what exactly is special about a heat pump? A heat pump is simply an air conditioner that can be run in reverse. In the winter, with the refrigerant flowing the opposite direction, the condensing now takes place inside your house and provides the warmth. Meanwhile, the boiling is going on outside your house and making the cold air out there even colder. Cool gas enters the compressor which increases the pressure (1). The gas, now under high pressure, condenses into a liquid making it very hot (2). Inside air is warmed as it blows across the warm liquid (3). As the warm liquid passes through an expansion valve (4), the pressure is allowed to drop. Under reduced pressure, the liquid begins to boil and gets very cold (5). The gas is now heated by the outside air that is blown across the coils (6), and the process is repeated. As strange as this might seem, this method of heating can be three to four times more efficient than a conventional furnace, and thus with reduced energy bills, a heat pump can essentially pay for itself over the years.

Furnaces generally produce heat the same way ovens do—either by burning fuel (natural gas, propane, or oil) or by passing high-voltage electricity through a resistor. Neither of these is as efficient as a heat pump. The one drawback, however, to heat pumps is that they do not work as well below 0°C. At such low temperatures, ice begins to form on the outside coils and this insulates them and prevents the heat from getting in. Many home-owners are now installing dual systems: a heat pump for the summer and for the mild winter days, and a conventional electric furnace that automatically switches on for the occasional deep freeze. ❄️

### Check out these great Web sites:

<http://www.smeco.com/energy/heatpump/learn.html>

<http://home.howstuffworks.com/question49.htm>

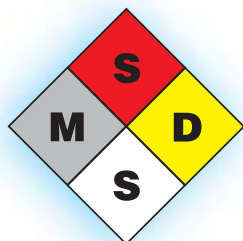
<http://www.honeywell.com/sites/sm/410a/Air-Conditioners.htm>



MINE CHELSESKI



MINE CHELSESKI



# CHEM MATTERS®

Vol. 24, No. 3

OCTOBER 2006

## Question From the Classroom 2

How does a heat pump work?

## Glass: More Than Meets the Eye 4

The sound of glass shattering. A scream in the night... Acts of violence often involve broken glass and it's a common type of evidence found at crime scenes. How do forensic police match samples of glass?

## ChemSumer

### Chemistry Builds a Green Home 9

It seems that everything is turning "green" these days. When the concept is brought home, the results are impressive. Today's homes can be both environmentally friendly and esthetically pleasing.

### Sick Buildings—Air Pollution Comes Home 12

When your parents tell you to go outside and get some fresh air, are they really doing you a favor? Take a look at the toxins lurking around your home before you answer.

## ChemHistory

### The New Alchemy 15

The elements from hydrogen to uranium were created in the Big Bang or afterward during the life cycles of stars, but what about the transuranium elements, those that lie beyond uranium on the periodic table? How were these artificial elements created and who were the men and women responsible for their discovery?

### Material Safety Data Sheets: Passports to Safety? 18

Next time you blow out a candle, will you be properly armed with a self-contained breathing apparatus and dry chemical fire extinguisher? An MSDS is an important safety tool — but how do you gauge the accuracy of the information it contains?

**TEACHERS!**  
 FIND YOUR COMPLETE  
 TEACHER'S GUIDE FOR THIS ISSUE AT  
[www.chemistry.org/education/chemmatters.html](http://www.chemistry.org/education/chemmatters.html)



# More Than Meets the Eye

By Brian Rohrig

**A** 23-year-old single female is awakened in the middle of the night by an intruder standing over her bed. She screams. The intruder flees in a panic, diving through a closed window. The police are notified immediately. They apprehend a suspect several blocks from the scene. He claims to be innocent, yet the police discover several shards of glass in the suspect's hair and clothing. When these samples are compared to the glass of the broken window, they are discovered to be the exact same type of glass. On the basis of this evidence, the intruder is eventually convicted and sent to jail.

Because acts of violence often involve broken glass, glass is one of the most commonly encountered forms of evidence found at crime scenes. However, many pieces of glass appear identical to the naked eye even though they can differ markedly in their chemical composition.

## How do forensic scientists match samples of glass?

Careful observation can reveal subtle but important differences between various types of glass. The forensic chemist may use several methods for determining whether two samples of glass originated from the same source. The first step is to visually examine the glass. Physical properties of the glass are then measured. Subsequent steps involve analysis of the chemical composition and differences in the way it was manufactured.

### Physical examination

Some important features to note are edge thickness, color, and the presence of any labels or imprints on the glass. A blacklight lamp may be used to check for repairs as hairline cracks will glow under ultraviolet light. Modern paints will also glow under a blacklight.

### Thickness

Glass thickness is generally a function of its application. Glass from a light bulb is going to be thinner than a pane of window

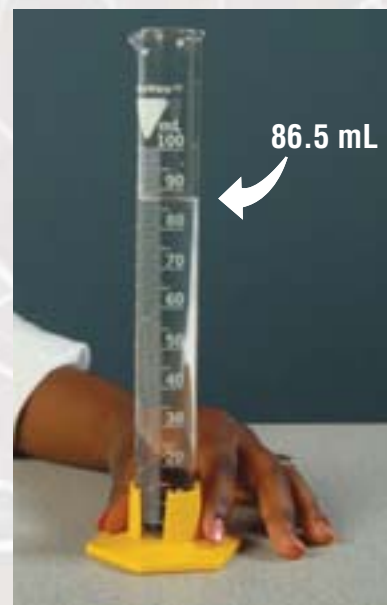
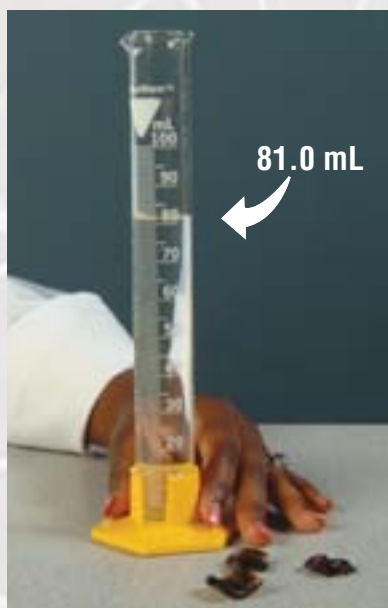
glass. The glass used in a picture frame is generally not subject to gusts of wind, so it will be thinner than glass used in a window. Glass used in a door is generally even thicker, to withstand the forces applied as a result of frequent opening and closing (and sometimes slamming!).

### Density

One of the most common methods for matching glass samples is the determination of density. The formula for density is mass/volume, and the density of two pieces of glass will always be the same if they come from the same source, regardless of the size of the two pieces. The formula method for determining density involves measuring the volume of a glass sample of known mass. The volume can be determined by displacing water in a volumetric flask.

Another more accurate method of comparing densities is the flotation method. A sample of glass is dropped into and sinks to the bottom of a liquid containing an exact volume of a dense liquid, such as bromobenzene ( $d = 1.52 \text{ g/mL}$ ). Then, a denser liquid, such as bromoform ( $d = 2.89 \text{ g/mL}$ ) is added dropwise until the piece of glass rises up from the bottom and attains neutral buoyancy. Neutral buoyancy occurs when an object has the exact





The formula method for determining density: After finding the mass of an object, measure its volume by water displacement.

MIKE CIESIELSKI

same density as the surrounding fluid, and neither sinks nor floats but is suspended in one place beneath the surface of the fluid.

The same procedure is then performed with another piece of glass, and if the volume needed to attain neutral buoyancy is the same as for the first sample, then the densities of the two samples are equal. The exact density of each sample can be calculated by using the following formula:

$$d = \frac{X(2.89) + Y(1.52)}{X + Y}$$

X and Y refer to the volumes of the respective liquids, with the numbers in parentheses referring to the densities of each liquid. Any two liquids can be used, as long as they are miscible in one another and have appropriate densities. But when determining the density of glass, liquids with a relatively high density must be used, since glass is always denser than water. The density of a typical piece of single-pane window glass ranges from 2.47 to 2.56 g/mL. If the density of a 1.5-g sample of glass were 2.48 g/mL, what would you predict the density to be for a 3.0-g sample of the same glass? (*Find the answer at the conclusion of this article.*)

## Refractive index

Another very accurate method used to compare samples is to determine their index of refraction, or refractive index. Any object that transmits light has its own refractive index, which is a measure of how much the object slows the speed of light. When light passes through any medium, it is slowed down. The denser the medium, the slower the light travels. The refractive index of any substance is a ratio of the velocity of light in a vacuum to the velocity of light in that particular medium. For example, the refractive index for water is 1.33. This means that light travels 1.33 times faster in a vacuum than it does in water. And when light passes from one medium to another one with a different refractive index, refraction (or bending) of the light occurs. This is why objects appear bent or distorted under water.

Every liquid has its own refractive index. If a piece of glass is placed in a liquid with a different refractive index, an outline of the glass is clearly visible—known as the Becke line. However, if a piece of glass is placed in a liquid with the same refractive index, the Becke line will disappear and the glass will seem to disappear. This is because the glass bends light at the same angle as the liquid.

Glycerin has a refractive index of 1.473. If a piece of glass seems to disappear in glycerin, then it too has a refractive index of 1.473. If two samples of glass have the same refractive index, this does not necessarily prove they are from the same source. But if two samples have different refractive indexes, they are definitely not from the same source. The FBI has a database of refractive index values for approximately 2000 different types of glass, allowing forensic scientists the ability to identify samples. The most common value for the refractive index of glass is 1.5180.



The beaker on the left contains water and the one on the right, glycerin. Both beakers also contain a glass stirring rod. Because the glass rod and glycerin have the same refractive index, the glass rod in the beaker on the right seems to “disappear.”

MIKE CIESIELSKI

## Chemical composition

If both the density and refractive index of two samples of glass are the same, then the final test will involve sophisticated methods to determine their chemical composition. The difference between types of glass can be due to the chemical composition of the glass itself or differences in how the glass was manufactured. Most glass is made from silicon dioxide ( $\text{SiO}_2$ ), the primary ingredient in sand, which has been heated above its melting point of  $1600^\circ\text{C}$ . Various substances are then added, depending on what type of glass is desired.

Different additives can impart different properties to the glass. Sodium carbonate or soda ( $\text{Na}_2\text{CO}_3$ ) is added to the silicon dioxide during glassmaking, lowering both its viscosity and melting point. The soda increases the water solubility of  $\text{SiO}_2$ , making it much easier to fashion into glass. Calcium oxide or lime ( $\text{CaO}$ ) is added next, restoring water insolubility to the mixture. As a result of these two additives, most glass used to make windows or bottles is known as soda-lime glass.

Boron oxide ( $\text{B}_2\text{O}_3$ ) is used to make Pyrex glassware. The beakers and test tubes you use in chemistry lab are most likely made from Pyrex, as is the glass used to make auto headlights. Glass made with boron oxide expands and contracts very little when heated and cooled, which is why Pyrex glassware can be heated and then cooled without breaking.

To make eyeglasses, a very sturdy glass is desired, so the additive potassium oxide ( $\text{K}_2\text{O}$ ) may be used. This imparts hardness to the glass. Other metallic oxides can give glass a specific color. Copper and cobalt oxides are used to make glass blue, manganese oxides give glass a purple color, and lead-antimony oxide imparts an opaque yellow.

## Who fired first?

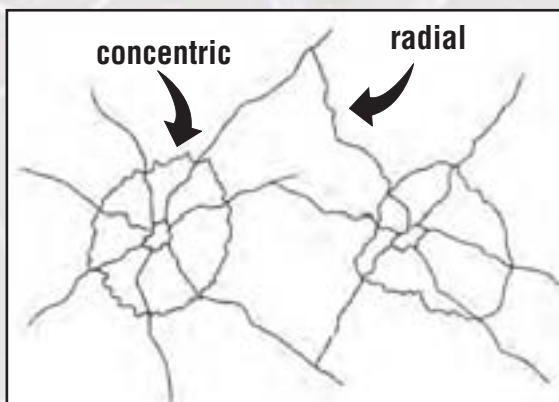
When a bullet strikes a pane of ordinary window glass, careful observation can reveal several crucial details. First of all, glass has a certain degree of elasticity and will break when this elastic limit is exceeded. This elasticity produces the familiar pattern of concentric and radial fractures that accompany penetration of glass by a projectile. The radial fractures are produced first and always form on the side of the glass opposite to where the



A bullet hole in window glass.

impact originated. Radial fractures look like spider webs that spread outward from the impact hole. Concentric fractures form next, and these lines encircle the bullet hole. Concentric fractures always start on the same side as that of the destructive force.

A radial fracture will always terminate into an existing fracture (see illustration). If there is a second bullet hole in a piece of glass, its radial fractures will always terminate into the cracks from the first bullet hole. The radial cracks from a third bullet will terminate into the radial fractures from the second bullet, and so forth. The sequence of numerous bullet holes can be determined by this method. If the glass is shattered, it may be



The sequence of shots can be determined: the radial fractures of the second hole terminate in those from the first hole.

necessary to reconstruct the broken pieces first. There has been more than one case of a shootout ensuing through the windshield of a car between a police officer and a suspect. By examining the termination lines of the radial fractures from each bullet hole and by com-

paring the size of the exit and entrance holes of each bullet, it can be determined who fired first.

The direction from which a bullet was fired can be determined by comparing the size of the entrance hole to that of the exit hole. Exit holes are always larger, regardless of the type of material through which a bullet penetrated.

Because glass is elastic and bows

outward when struck by a bullet, a larger piece of glass will be knocked out on the surface where the bullet is leaving as opposed to the very small hole the bullet makes when it enters.

Because of its elasticity, glass always blows back in the direction the impact originated. Because of the violent tendency of glass to snap back after being stressed, it can blow back glass several meters in the direction from which the shot originated. If a bullet strikes a window from the outside and shatters it, most of the glass will be on the outside. This piece of information can be extremely valuable in determining from which direction a shot was fired.

## Was the light on or off?

Here's a bit of information that can be valuable in crime scenes involving a broken incandescent bulb, especially among vehicle collisions. It is easy for someone to drive at night with their lights off while driving down a well-lit street. But suppose you're cruising down the road one night, and bam! You get into an accident with a motorist who did not have his lights on. If it could be proven that the other motorist failed to turn on his headlights, this would be a big boost to your case. But suppose it is his word against yours. By examining the broken filament of a light bulb, it can easily be determined whether the bulb was on or off when it was broken.

Light bulbs do not actually burn, but rather, glow as the tungsten filament becomes very hot due to the resistance that the elec-



trons encounter as they pass through the very narrow wire filament. The definition of incandescence is the property of emitting light as a result of being heated, but not actually burning. The electrons in the filament material absorb energy and jump to higher atomic orbitals (excited state). They then release a photon as they fall back to their original ground state orbital. In a properly functioning light bulb, the glowing filament is inside of the bulb filled with a noble gas such as argon.

But if the filament is glowing when the bulb is broken, it will immediately react with oxygen in the air and break in half. This will form a thick layer of yellowish-white tungsten oxide on the filament due to the reaction of the tungsten with oxygen. If the presence of tungsten oxide on the filament is found, then it can be proven that the bulb was on when the accident occurred. The absence of tungsten oxide on the filament reveals that the bulb was probably off when it was broken.

## Solving the crime

Sometimes, a bit of deductive reasoning is all it takes to solve a crime. In 1988, there were dozens of claims by consumers that they had found shards of glass in jars of Gerber baby food. After forensic investigators examined these contaminated jars, they discovered many different types of glass—glass from mirrors, bulbs, and car headlights were all found. If the glass came from the manufacturing plant due to an accident such as a light bulb breaking over the production line, then you would expect to find only one type of glass in the jars, not several. It was therefore concluded that the glass found in the jars of baby food was a result of deliberate tampering.

The field of forensic science provides a fascinating glimpse into how science can be used to solve crimes. A well-trained forensic scientist uses aspects of biology, chemistry, physics, and mathematics to reconstruct what may have happened at a crime scene. Criminals may break society's laws, but they cannot break the laws of nature.

## Answer to question:

The 3.0-g sample of glass has the same density as the 1.5-g sample. It might be twice as massive, but then it has twice the volume. Since density is  $M/V$ , the density of both pieces would be identical. Remember, density does not depend on the size of the sample! 🦋

# Disappearing Glass

**Here is another cool activity involving glass.**

## Materials

approved protective eyewear  
paper towels  
(2) 10-mL graduated cylinders  
1 glass stirring rod  
glycerol (about 10 mL)  
water (about 10 mL)



MIKE CIESIELSKI

**Wear your safety goggles during this activity, and do not taste any of the liquids used.**

1. Obtain a glass stirring rod from your teacher.
2. Place about 8 mL of glycerol in a 10-mL graduated cylinder and 8 mL of water in another 10-mL graduated cylinder.
3. Put the stirring rod into the graduated cylinder with the water in it.
4. Record your observations.
5. Remove the stirring rod and dry it off with a paper towel.
6. Now place the rod in the graduated cylinder containing the glycerol. What happens?
7. Record your observations.

After discussing this activity with your small group, devise an explanation for what you observed. Be prepared to share this with the class.

## REFERENCES

Ellis, W. S., *Glass*. Avon Books: New York, 1998.  
Fisher, D. *Hard Evidence*. Dell: New York, 1995.  
Saferstein, R. *Criminalistics: An Introduction to Forensic Science*. Pearson Prentice Hall: Upper Saddle River, NJ, 2004.

## INTERNET RESOURCES

Automobile Window Glass—A Design Defect That Should Not Be Overlooked, <http://www.auto-law.com/CM/PracticeAreaDescriptions/PracticeAreaDescriptions58.asp>.  
Bullets Out, None In, <http://www.discover.com/issues/nov-03/rd/bullets-out-none-in/>.  
Different Types of Glass, <http://www.diydata.com/materials/glass/glass.htm>.  
Glass, <http://en.wikipedia.org/wiki/Glass>.  
How does safety glass work?, <http://computer.howstuffworks.com/questions508.htm>.  
Tempered Glass Breakage, <http://alumaxbath.com/tech/tgb.htm>  
What makes glass transparent?, <http://science.howstuffworks.com/question404.htm>.  
What's That Stuff? Glass, <http://pubs.acs.org/cen/whatstuff/stuff/8147glass.html>.

**Brian Rohrig** teaches at Jonathan Alder High School in Plain City, OH. His most recent *ChemMatters* article, "The Chemistry of Digital Photography and Printing", appeared in the February 2006 issue.

## TRY THIS

# Forensic Identification of Glass Activity

As the article on glass points out, it is relatively common to find pieces of broken glass associated with crime scenes. Forensic scientists are often asked to determine the origin or prove the identity of various samples of glass shards.

## Finding the Density of Glass:

Because the liquids mentioned in the article are not considered safe for routine high school use, here's an alternative method that will demonstrate the same concept.

### **Before you begin, answer these questions:**

1. If you place small bits of plastic in water, will they float or sink? Will they float or sink in rubbing alcohol? What information would you need to know in order to make a prediction?
2. If you used a much larger piece of the same type of plastic, would it affect whether or not it floats in the liquids?
3. If a piece of plastic sinks in a liquid, what does that mean about the density of the plastic relative to the density of the liquid? In terms of the density of plastic relative to the density of the liquid, what does it mean if the plastic floats?

## Materials

approved protective eyewear  
100-mL graduated cylinder  
small pieces of plastic from a pen top  
100-mL beaker  
10-mL graduated cylinder  
isopropanol (rubbing alcohol, 70%)  
water  
balance  
dropper pipet

Be sure to wear safety goggles while completing this activity.  
Do not taste any of the liquids used in this activity.

Your teacher will provide you with pieces of plastic that have come from ordinary ballpoint pens. Use a balance to determine their mass; record the mass as accurately as possible. Place 50.0 mL of isopropanol in a 100-mL beaker. Add water slowly until the plastic pieces begin to rise. Record the exact amount of water needed to get the plastic pieces to attain neutral buoyancy; that is, they stay suspended about half way to the top of the liquid mixture.

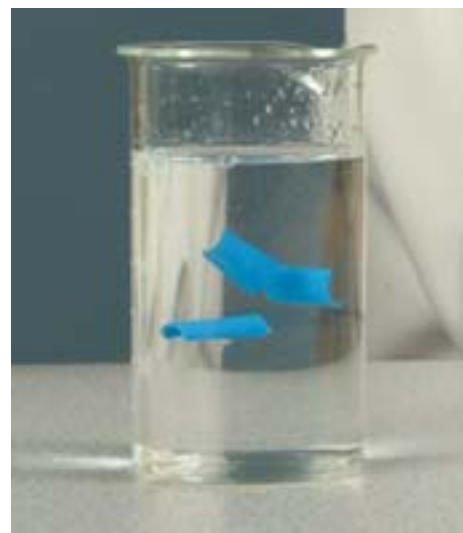
Using the equation from the article, calculate the density of the plastic.



Placing pieces of plastic in isopropanol.



Carefully adding water until the pieces of plastic begin to rise.



At this point, the densities of the plastic and the solution are the same.

MIKE GIESIELSKI



# Chemistry Builds a GREEN HOME

## Reduce, Reuse, Recycle!

By Roberta Baxter

You probably learned that slogan in first grade when you celebrated Earth Day. But beyond recycling aluminum cans and newspaper lies the building of an environment-friendly home. Builders across the country are competing to design and build green homes. Not greenhouses, for growing plants—green homes, meaning environmentally responsible homes and construction practices. The idea is to reduce waste in the building process, create energy-efficient, water-saving homes, and promote the use of sustainable materials.

Sustainability is a hot buzzword in the “green” arena, but what does it mean? The U.S. Environmental Protection Agency (EPA) defines sustainability as “the ability to achieve continuing economic prosperity while protecting natural systems of the planet, providing a high quality of life for its people.” This calls for everyone taking responsibility for solving the problems of today and caring for the planet for the generations of tomorrow.

The U.S. Green Building Council (USGBC) has created a pilot program called LEED, or Leadership in Energy and Environmental Design. The program is an effort to move the home-

building industry toward high-performance, sustainable practices. Certain criteria are used in giving a home-building project the “green building” label, using a common standard of measurement. For example, homebuilders can earn points by these actions, along with others:

- reducing construction waste to less than 2.5 pounds per square foot of home;
- reducing energy costs by using efficient appliances;
- building a well-insulated structure;
- installing energy-efficient lighting, heating, and cooling systems; and
- reducing water usage with high-efficiency toilets and natural landscaping.

Homes receiving the highest number of points receive a platinum rating, followed by gold, silver, and certified ratings. The USGBC hopes to increase consumer awareness of the benefits of green building, stimulate green competition, and transform the practices of the building industry.



## Reduce

The residential construction industry generates 58 million tons of waste per year, according to a study conducted for the EPA. Home renovation projects account for 55% of the waste, demolition accounts for 34%, and new construction accounts for 11%. Any reduction in the amount of this waste is a step in the right direction.





One of the biggest costs of homeownership is energy. The chemical company BASF sponsored the construction of a Near-Zero-Energy home in Paterson, NJ. The home was built with concepts developed by the Oak Ridge National Laboratory in Oak Ridge, TN, and PATH/Build America, the Partnership for Advancing Technology in Housing. The demonstration home is claimed to be 80% more energy efficient than a typical home. On sunny days, the home could easily produce more energy than it uses. It is also more durable, has a lower environmental impact, and is faster to construct than conventionally built homes.

Rather than using wood studs and siding for the walls, the Near-Zero-Energy home was constructed with foam-insulated concrete forms. These are rigid plastic foam forms that hold concrete in place while it hardens, and they remain in place afterward to offer extra thermal insulation. The foam insulation keeps heat and cold out of the house by trapping air in the holes of the foam. Air is a very poor conductor of heat, which makes it a good resistor, impeding the flow of heat. Note that it's not the plastic foam (or in other cases, fiberglass, stone, wool, or feathers) that slows the heat loss, but the air that's trapped in between the layers of an insulating material.

The concrete form technique is quicker than building a traditional block foundation, and the concrete can be poured and allowed to harden in more extreme climates than normal poured concrete. Concrete is an artificial stonelike material that is made by mixing wet cement, sand, and gravel together. The cement gradually sets, binding the other components together to give the rock-like material you are familiar with. Using concrete for the structure eliminates the need to cut down trees—a green advantage.

A home in New Mexico was chosen as the VISION House 2006 for *Green Builder Magazine*. This is one of over 1 million homes using a geothermal system to reduce the cost of conditioning indoor air. The concept behind a geothermal heating system is to use the heat energy of the earth to moderate the air temperature in our homes: geo (earth) + thermal (heat). Over most of our planet, the top 10 feet of the surface stays consistently in the 50–60 °F range (10–16 °C). That means there is a giant, mostly untapped heat and power source right below our feet.

A geothermal system runs a refrigerant or a water and antifreeze mixture through pipes buried in the ground below frost depth.



A pump and compressor circulate the mixture through a heat exchanger. In the winter, when the temperature underground is warmer than the surface, the thermal energy of the earth is drawn up through the pipes, moved into the home, and is allowed to disperse into the rooms. Usually, duct fans distribute the heat throughout the house. The process is reversed in the summer when the ground temperature is cooler than the surface, helping to cool the house. Unwanted heat is concentrated, sent on down the line and absorbed by the earth, while cool air is returned.

Geothermal systems are quiet and, compact, and they emit no gases so they can be placed indoors. A side benefit is that they provide inexpensive hot water throughout the summer. Best of all, the heat source is renewable—a sustainable system that uses no fossil fuels and emits no greenhouse gases.

In the early 1990s, the U.S. Department of Energy contributed significantly to the development of low-E window coatings. Also referred to as low-emissivity, these windows use tin or silver metallic oxides that greatly reduce the amount of energy needed to heat or cool a home. The coatings can be applied into the molten glass, sprayed on, or added as a thin film pressed between layers. The windows are designed to be solar selective, admitting as much daylight as possible while



**Low-E windows are spectra-selective; they allow selected portions of the solar spectrum to pass through while restricting others.**

blocking transmission of the infrared, or “heat” radiation. Low-E windows are more insulating than normal windows because they reduce radiative heat transfer. They cut down on solar heat gains in the summer and prevent loss of interior heat in the winter.

## Reuse

The “reuse” part of the slogan also comes into play in green homes. Contractors are working hard to reuse pieces of wood and drywall to cut their costs during new home construction. Several companies reclaim old wood from demolished houses, buildings, and barns. Some lumber is even dredged up from river bottoms where logs have sunk during logging operations. The wood is cut and sanded and fashioned into wood flooring. Using the hardwood from these reclamations saves trees and reuses wood that would otherwise be headed for landfills.



An unusual application is kitchen and bath cabinets made from wheat straw. The straw is a waste product from agriculture. Wheat heads are cut off the plant, leaving the stems behind. The chopped straw is glued together with nonformaldehyde containing adhesives and pressed into shape. The cabinets look and feel just like wood, and they are produced from 85% renewable materials.



Vision House 2006 in Albuquerque, New Mexico.

## Recycle

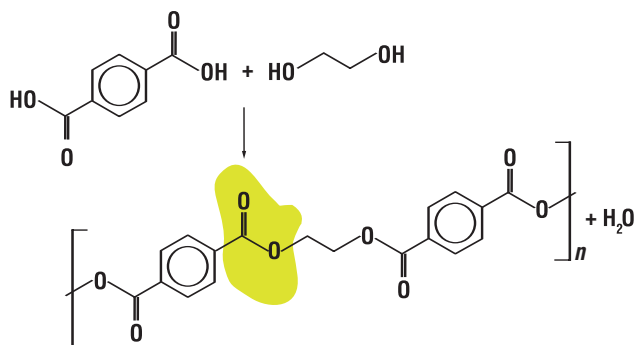
Recycling is a vital part of any green home. Environment-friendly contractors search for materials that have been recycled and those that can be easily recycled at the end of their use.

One popular product made from recycled materials is carpet. About half of the polyester carpet in the United States is made from recycled plastics. It takes five two-liter bottles to make one square foot of carpet, so there might be 500 recycled bottles on your living room floor.

Plastics are synthetic polymers, and polymers are long chains of repeating molecules linked together ("poly" means many, and "mer" means unit, or part). The typical two-liter bottle is made of a polymer called polyethylene terephthalate, or PET for short. You might have seen this familiar logo on the bottom of some plastic product. PET is a thermoplastic, meaning it can be repeatedly reheated and reshaped. Once a bottle is used, it can be recycled by cutting it into pieces, then cleaning and remelting the pieces. Once it has been warmed, the plastic can be either molded to make new bottles or spun into fibers to make items such as carpet and even clothing.

PET is made via a condensation reaction, in which molecules are joined together while a molecule of water is split out.

Another important aspect of the carpet story is keeping old carpet out of landfills.



The condensation reaction that forms polyethylene terephthalate (PET). PET is a polyester polymer; one of the ester groups is highlighted.



Recycling: part of Green Living includes sustainability, taking responsibility for the protection of our natural resources.

MIKE DIESELSKI



Representatives of the carpet industry estimate that 3.5 billion pounds of carpet waste goes to landfills each year. Mostly, it is old carpet that cannot be reused, but industry giants DuPont and Antron are implementing carpet-recycling programs. If carpet can be cleaned and reused, it is donated to charity or sold. If reuse is not possible, the carpet is recycled into new

plastic products, such as filtration devices, furniture, and automotive parts.

Another homebuilding material that is often made of recycled plastic is composite lumber. Used for decks and window and door frames, this material is a 50/50 mixture of wood fibers from sawdust and recycled plastic. The wood fibers reinforce the plastic lumber, so that it is stronger than 100% recycled plastic. Furthermore, the plastic protects the wood from rotting. So the

combination of natural and synthetic materials brings out the positive characteristics of both wood and plastic.

A huge advantage for the homeowner is that plastic lumber does not have to be painted. Color can be added during the manufacturing process. As a further blessing to the environment, composite lumber is made of plastic and sawdust that would otherwise end up in a landfill.

Glass winds up in landfills about as often as plastic, and concrete waste places a huge burden on landfills. Kitchen countertops for the VISION 2006 house were made from 75% recycled concrete and glass. The material looks like natural stone.

As homebuilders and the public become more aware of the possibilities of building green homes, more innovative products will come along. Your next home may be green enough to save thousands of dollars in construction and maintenance costs. Just think what you could do with that green! 🌱

## Ways To Be Green

Many techniques for being green were presented to you way back in first grade or were offered by your parents. Here are a few ideas:

1. Turn off lights and electronics when not in use.
2. Recycle anything possible: paper, aluminum, glass, and plastic.
3. Close curtains on sunny summer days and open them on sunny winter days.
4. Buy energy-efficient appliances and electronics when possible.
5. Use appliances wisely; for example, it's usually more efficient to heat with a microwave than an oven, and run clothes and dishwashers only when full.
6. Set thermostats at 68° in winter and 72° in summer.
7. Caulk around doors and windows.
8. Use fluorescent light bulbs.
9. Drink tap water rather than bottled water.
10. Use indoor plants like Golden pothos or English ivy to remove indoor air pollutants.
11. If you are an outdoor gardener, use ladybugs rather than chemical insecticide to get rid of plant-eating insects.



**Roberta Baxter** is a science writer who lives in Colorado Springs, CO. Her most recent *ChemMatters* article, "Battling Zits", appeared in the April 2005 issue.





# Air Pollution Comes Home

# Sick Buildings—

By Michelle Laliberte

**“Why don’t you go play outside and get some fresh air?”**

**H**ow many times have you been told this? You might have thought this was just a way to get you out of your parents’ hair for a while. But there might be some sound chemical reasons to spend some time outside of the house. That’s because air pollution can sometimes be a real problem—*inside* the home!

All kinds of activities that take place inside the home can release chemicals or particles into the air. Some are obvious, such as using an aerosol deodorant or painting a room. Some are less obvious, like taking a shower, frying food, or rolling on the new plush carpet with your pet dog. In drafty old buildings, this was not a big problem, because there was enough ventilation to prevent these substances from building up. But to bring fresh air into a building and heat it in the winter or cool it in summer costs money. In response to the energy crisis in the 1970s, builders started sealing up homes and office buildings and air circulation decreased drasti-

cally. With poorer circulation, chemicals released inside the home could build up to potentially dangerous levels. Now, growing public awareness of indoor air pollution has given birth to new terms such as “indoor environmental health” (IEH), and “sick building syndrome” (SBS). But news reports may sometimes go too far, sensationalizing the subject to the point of scaring the daylights out of us. Should we be worried? What should you do?

## Sources of indoor air pollution

Stanley Watras lived in Boyertown, PA and worked at the Limerick Nuclear Power Plant. During December of 1984, Stanley set off alarms at the plant as he attempted to *enter* through portal radiation monitors. Every day for two weeks Stanley went through decontamination while the authorities at the nuclear power plant tried to find the source of his radiation contamination. It was confusing because the power plant was not yet producing fission products, but the contamination source was eventually found.

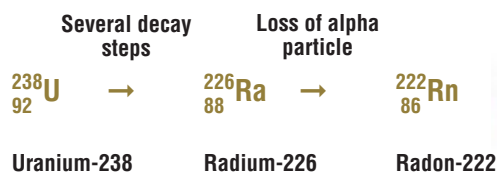
It was coming from Stanley’s house. At Stanley’s urging, his home was tested for

radiation contamination, and it showed radon levels 650 times the average level. Radon is a naturally occurring radioactive gas that is a byproduct of decaying uranium and a known cause of lung cancer. His family, including small children, was immediately evacuated. High radon levels were also found in nearby houses. Stanley’s home is on the Reading Prong, a region that stretches from Reading, Pennsylvania through New Jersey and into New York. This granite formation has very high deposits of low-grade uranium.

## Radon

Radon-222 is produced by the natural disintegration of the radioactive element radium-226. Radium itself is produced by the decay of uranium-238, which is found in rock layers and bedrock. It is present in most of the soil and rock around the world, especially areas with lots of granite, shale, and phosphate rock.

With the loss of an alpha particle, radium is converted to radon gas. Radon itself is not harmful. It is chemically inert (it’s a noble gas after all) and has a short half-life of only 3.8 days. However, Rn-222 undergoes radioactive decay to form polonium-218, which in turn undergoes decay in a continuing chain termi-



nating in stable Pb-206. These progeny nuclei are charged and chemically reactive, so they attach to airborne dust particles that can be inhaled into the lung. Several of the progeny are alpha-emitters; when they undergo decay, the energetic alpha particles blast into and damage the surrounding cells.

Because radon is a gas, it can permeate your house through the basement or crawl space or through exposed soil and rock beneath and around your home's foundation. Sometimes, it can seep in through well water, or migrate into your home through natural gas lines.

In order to measure and report an amount of radiation, we need a standard unit; the standard measure for the intensity of radioactivity of some radioactive substances is the curie (Ci). The curie is a measure of the number of atoms in a collection of atoms that are giving off radiation per an interval of time. Radium decay is used as the basis for the curie, and one gram of Ra-226 gives off 2.2 trillion decays per minute. A curie is a lot of radiation, so we routinely speak of radiation intensity in terms of a picocurie. Pico is a prefix meaning one trillionth, or  $10^{-12}$ , so a picocurie (pCi) is equal to 2.2 disintegrations per minute.

Back to radon—the EPA has set safe limits for indoor radon at 4 picocuries per liter of air (4 pCi/L). The average indoor level of Ra is 1.3 pCi/L, and about 0.4 pCi/L is normally found in air outdoors. The level of radon gas in Stanley's (remember Stanley?) home was an astonishing 415 pCi/L, a level that has been estimated to carry a risk equivalent to smoking 135 packs of cigarettes per day. In fact, this level of radon far exceeds that allowed in uranium mines!

Radon gas problems can be corrected (mitigated) by increasing ventilation throughout the house, especially in the basement. Sealing cracks and openings in the foundation can also help to keep some of the radon out. You can't smell it, so to be safe, all homes should be tested for radon gas levels; commercial test kits are available at many hardware stores. So, what happened to Stanley Watras? He and his family eventually moved back into the home after fixing the radon



Test kits for radon and CO are commercially available.

problem, and now Stanley is successfully working in the radon mitigation field!

## Formaldehyde

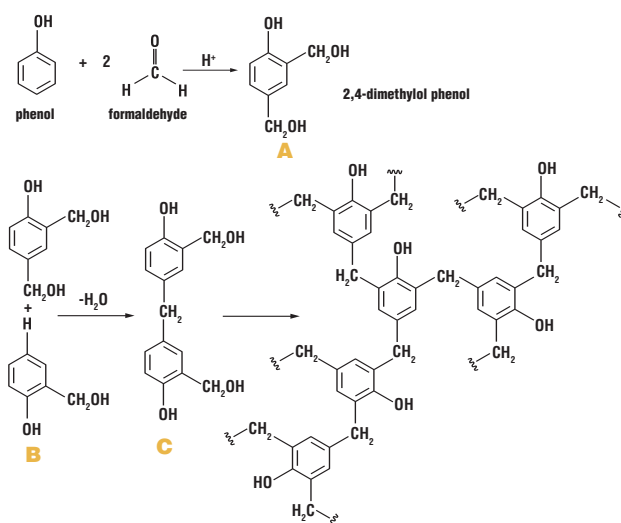
Formaldehyde ( $\text{CH}_2\text{O}$ ) is a volatile and flammable organic chemical that can be released into the air as a pungent, suffocating gas. It is naturally produced in our bodies in very minute quantities as part of normal metabolism. We are exposed to formaldehyde in the air, food, and in cosmetic products. Known by its other names methanal, methylene oxide, and formalin (a 37% mixture in water), formaldehyde is one of the top 25 most abundantly produced chemicals in the world. It is used as a disinfectant, preservative, fire retardant in foam insulation, clothing, paper products, carpeting, and—yuck—embalming fluid. Formaldehyde is added to cotton products to give them wrinkle-resistance, and is added to many more products, including (believe it or not) Italian cheeses, fish, dried foods, and toothpaste.

When combined with urea or phenol, formaldehyde makes an excellent adhesive resin, so it is widely used in the building and furnishings industry. The construction of pressed-wood products such as particleboard often involves the use of formaldehyde-based resins. You can

find particleboard all through a home as subflooring and shelving. The formaldehyde reacts chemically with urea or phenol to form a resin that binds the materials of particleboard together. Formaldehyde reacts with phenol to form 2,4-dimethylol phenol (A). This compound reacts with 2-methylol phenol (B) in a condensation reaction to form compound C. A condensation reaction is one where two reactants are joined together as a small molecule is split out; in this case, the small molecule is  $\text{H}_2\text{O}$ . Compound C polymerizes to form the resin known as Bakelite, which sets, or hardens, binding particles together.

When the polymer resin forms and the material sets, there is not supposed to be any formaldehyde left; it should have all reacted. The problem comes from small amounts of unreacted formaldehyde that gets entrapped in the resin and is released over time. The release, or outgassing, of the excess formaldehyde is gradual, occurring rapidly at first and then slowing over time. Thus, exposure is greater in a new home furnished with new products.

Formaldehyde is a potent eye, upper respiratory and skin irritant. Exposure causes central nervous system problems, including headaches, fatigue, and respiratory depression. It has the potential for inducing asthmatic attacks and recent epidemiological studies of work-exposed individuals suggest that formaldehyde causes nasal cancer. To minimize your exposure, buy solid wood furniture when possible, and keep your home properly ventilated.



The formation of a polymer resin used for particleboard. Formaldehyde is a key reagent.



## Molds and biological pollutants

Molds, mildew, fungi, bacteria and house dust are some of the main biological pollutants in the home. Spores generated from mold and mildew are released into the air and form new colonies wherever they land. Areas of the home with high humidity, such as bathrooms, kitchens, laundry rooms, and basements are sources for these living pollutants. Mold can be found growing on paper, textiles, grease, dirt, and even soap scum.

Rather than a single substance, house dust is a varied mixture of potentially allergenic materials. It may contain fibers from different types of fabrics; cotton lint, feathers, and other padding materials; dander from cats, dogs, and other animals; bacteria; food particles; bits of plants and insects; and other allergens peculiar to an individual home.

House dust also contains microscopic dust mites. Dust mites feed off of human dead skin cells. They live in bedding, upholstered



**Dude—do you have any idea what's crawling all over your pillow?**

furniture, and carpets; thriving in summer and then dying off in winter. The Mayo Clinic estimates the average bed contains between 100,000 and 10 million dust mites. You may be sharing your bed with millions of them! The particles seen floating about in a shaft of sunlight include dead dust mites and their waste products. Dust mites have been identified as the single most important trigger for asthma attacks. Asthma, a chronic ailment that afflicts millions around the world, causes inflammation of the airways and affects the way air enters and leaves the lungs, thereby disrupting breathing.

You can pinpoint these triggers of indoor allergens in your home by visual detection.



Keeping mold growth under control is accomplished by making sure basements, bathrooms, and other rooms are clean and dry. Chlorine bleach will remove any visual mold and can be used to clean out humidifiers and air-conditioning condensing units. Use vacuums with high-efficiency filters and consider replacing old carpet with hard surface flooring if anyone in your home is sensitive to these allergens. Wash sheets, pillowcases, and blankets weekly. This removes dust mites' primary source of food—your dead skin cells.

## Carbon monoxide

According to the *Journal of the American Medical Association*, 1,500 Americans die each year from accidental exposure to CO, and over 2,000 from intentional exposure (suicide). Carbon monoxide is an extremely hazardous gas that has no warning taste or odor. It is produced by incomplete combustion of organic fuels such as wood, gasoline, natural gas, coal, charcoal, and fuel oil. Like oxygen, carbon monoxide binds to the iron atoms of the hemoglobin (Hb) protein molecules found in our red blood cells, forming a complex called carboxyhemoglobin. Carbon monoxide binds to hemoglobin about 200 times more strongly than does oxygen. It was long believed that because carboxyhemoglobin is unable to transport oxygen, fatal carbon monoxide poisoning is due to asphyxiation. This sounds bad enough, but a detailed examination of carbon monoxide poisoning reveals a more complicated, more insidious situation.

Hemoglobin is a tetramer, that is, each hemoglobin protein has the ability to bind to four oxygen molecules. Its oxygen binding exhibits a phenomenon called cooperativity: once the first oxygen molecule binds, the protein changes its shape in such a way that the remaining three sites bind oxygen more tightly. This is physiologically important, making Hb better at binding O<sub>2</sub> in the oxygen-rich lungs and better at releasing O<sub>2</sub> in the oxygen-poor muscles. However, the CO-bonded iron looks (as far as the protein is concerned) a lot like the O<sub>2</sub>-bonded iron. So the Hb shifts into high-affinity mode when even one CO is bound per protein molecule. This means that it picks up the O<sub>2</sub> well in the lungs but cannot release it in the tissues! A person suffering from exposure to carbon monoxide actually has high oxygen blood content. It's just that the oxygen cannot



**A barbeque grill is an example of a CO-producing device. Never use a grill indoors.**

be released where it is needed: the brain, heart, and skeletal muscle. For more information on this topic, see Tim Graham's article "The Silent Killer" in the February 2005 issue of *ChemMatters*.

Carbon monoxide buildup occurs when flues or chimneys become blocked and exhaust cannot be vented outside. Faulty furnaces, fuel-burning space heaters, ovens, ranges, and even grills operated in the home without adequate ventilation will also cause carbon monoxide buildup. To prevent this exposure, carbon monoxide alarms and detectors are available in stores and should be installed to alert you of dangerous levels. Also make sure you have your combustion heating systems and chimneys checked by trained professionals every year.

## Safe haven

Even though we have only listed several of the many toxic indoor air contaminants, the subject can be frightening. Our homes should be a safe haven, not a hazardous waste dump. Every time you get dizzy, have a sore throat, or have itching, burning eyes will you wonder if it has to do with the air quality of the room? Education is the key to keeping your indoor air clean and healthy. Remember, it's not just the outside air we have to be concerned with anymore. A little forethought and action can go a long way in preventing major health problems arising from contamination occurring in your own home. ▲

*Michelle Laliberte* is a science writer living in Medina, OH. This is her first article for *ChemMatters*.



# The New Alchemy

By Michael McClure

In 1927, Georges Lemaitre, a Belgian priest, proposed that the universe began with a cosmic explosion of gigantic proportion. He suggested that before the explosion, there was a time when all of the matter and energy of the universe were packed together into one fantastically dense and unstable mass that he called the *cosmic egg*. A few minutes after the violent blast, protons and neutrons joined to create simple atomic nuclei. Some time later, electrons began interacting with the nuclei and atoms of the simplest elements, hydrogen and helium, were formed. As the rapidly expanding universe cooled, great clumps of gas condensed, heated up, and exploded in a burst of light. The first stars were born.

The stars were the crucibles in which nuclei were fused to form heavier elements. A star's energy comes from the fusion of nuclei as mass is converted to energy, according to Einstein's famous equation  $E = mc^2$ . Carbon, oxygen, neon, and all of the elements up to and including iron are synthesized during the life cycle of a star. Elements beyond iron are made when massive stars end their lives as supernovae. The nuclear reactions that produce elements beyond iron require more energy than they pro-

duce, so these elements will not form under the conditions of a normal star. But the enormous energy available in an exploding supernova is sufficient to drive nuclei and other particles together. As nuclei are forced to absorb protons and neutrons, they can grow to form elements with masses greater than that of iron, and they can continue to grow, forming elements as heavy as uranium.

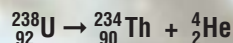
## The early years: Who were the players?

Billions of years later after that initial, tremendous blast, scientists in the 19th and 20th centuries would organize all of the known elements into neat rows and columns based on properties and atomic composition—the Periodic Table. In those early years, discoveries came fast and furious. It was predicted that new discoveries might one day reveal elements with masses and atomic numbers beyond uranium. What were these discoveries? Who were the men and women that unlocked the secrets of atoms and created the first transuranium (i.e., “beyond uranium”) elements? Who succeeded in doing what early alchemists failed at—transforming one element into another?

Before we dive into these discoveries, let's first take a look at the basics of radioactivity.

## Radioactivity

Radioactivity refers to spontaneous nuclear reactions that occur in various forms. Atoms that decay by alpha emission, for example, eject a particle consisting of 2 protons and 2 neutrons, in other words, a helium 2+ ion. The decay product, or daughter, is an element with two fewer atomic number units. For example, the isotope uranium-238 decays into thorium-234 by alpha emission.



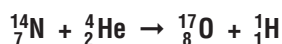
Other modes of radioactive decay include beta decay, positron emission, and electron capture.

Radioactivity can be used as a tool for exploring the atomic nucleus. In 1919, the New Zealand-born physicist Ernest Rutherford observed the reaction between alpha particles and gaseous nitrogen atoms in a cloud chamber. The cloud chamber is a flask filled with super-saturated vapor, in this case, nitrogen gas. Alpha particles streaking through the vapor knocked electrons from nitrogen molecules, creating electrically charged ions. Vapor mol-



ecules condensed around the ions, allowing Rutherford to see the alpha particle path as a trail of tiny droplets, like the contrails of a jet aircraft.

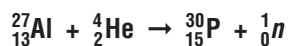
Rutherford recorded the short tracks of many alpha particles in his experiment. Occasionally, he observed condensation tracks that were longer than expected. Because longer tracks implied less massive particles, Rutherford suggested that perhaps alpha particles were knocking out protons from the nucleus of nitrogen atoms. Gaining two protons, then losing one proton would change the nitrogen nucleus into oxygen-17. Rutherford had just observed the first artificial transmutation of an element.



Transmutation is the transformation of one element into another through one or a series of nuclear reactions

## An artificial isotope

Later on in 1934, Irene Curie-Joliot, the daughter of Marie and Pierre Curie, and her husband Fredrick Joliot performed an experiment similar to Rutherford's. Instead of nitrogen, they used aluminum as the target. In addition to protons flying away from the collision event, they observed the emission of neutrons and some new form of radiation (called a positron emission). Surprisingly, when they stopped the experiment, neutron emission stopped, but the radiation continued. How could this be? Curie-Joliot and her husband discovered that the reaction created the artificial element phosphorus-30. This isotope does not occur in nature, and it decayed into silicon by this newly discovered form of radiation—positron emission. They had witnessed the first artificial transmutation of a stable element into a radioactive isotope, by emission of an artificial form of radiation. In 1935, the Curie-Joliot's shared a Nobel Prize for this work.



## Transmutation is the transformation of one element into another through one or a series of nuclear reactions

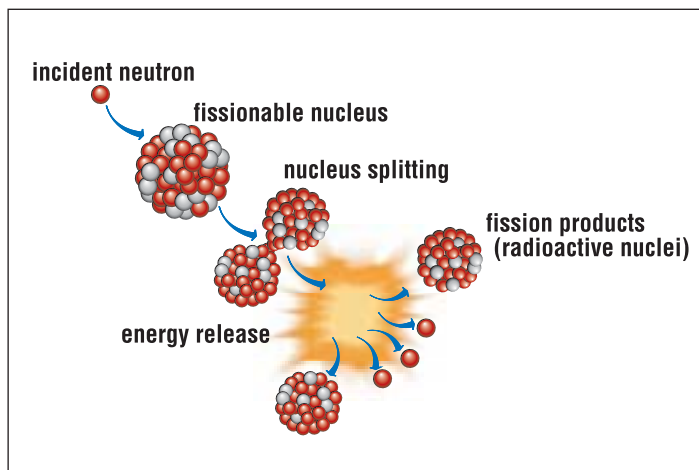
### Building new atoms and a stunning discovery

Early alchemists worked furiously trying to change one element into another, and they all came to the same conclusion: it's not easy. What they did not know is that positively charged protons inside the nucleus of every atom repel similarly charged particles. The characters of our story found that only positively charged particles with sufficient energy can overcome the strong repulsive forces and penetrate the nucleus. For this reason, Enrico Fermi, an Italian physicist, suggested that neutrons might make better nuclear missiles. Neutrons carry no electrical charge; they are neutral. Fermi and others believed that if a nucleus captured a neutron, it would try to correct for its neutron excess by beta decay, turning a neutron into a proton, thus creating an atom with an atomic number increased by one unit. Suppose uranium, the heaviest known naturally occurring element, could be forced to capture a neutron. This might make the uranium nucleus unstable and radioactive. If the unstable nucleus decayed by beta emission, a new element beyond uranium would be created.

Fermi and his collaborators bombarded uranium-238 (atomic number 92) atoms with

slow neutrons. Other research groups were performing similar experiments. Initially, everyone claimed success in creating a new element with atomic number 93. But the mass of the product did not agree with the expected mass of element 93. Furthermore, its chemical properties seemed surprisingly like barium, an element much lighter than uranium. Lise Meitner, an Austrian physicist, was troubled by these findings. Looking closely at the results and making detailed calculations she came to the astonishing conclusion that uranium nuclei were splitting into smaller fragments! In seeking new elements beyond uranium, Fermi and others had stumbled upon the process of atomic fission. This discovery and the subsequent development of nuclear weapons and nuclear reactors impacted all of humanity.

Today, we know that Fermi's uranium sample contained trace amounts of uranium-235, a rare isotope that undergoes atomic fission when bombarded with neutrons. What Fermi and others did not realize was that element 93 had actually formed in the experiment, but was undetectable in the complex mixture.



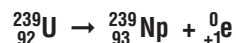
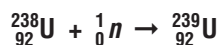
The process of nuclear fission.

## A planetary element

The emission of alpha particles creates a recoil effect. This causes the product isotopes to fly away from each other and deposit some distance from where the decay event occurred. American physicist Edwin McMillan in the Radiation Laboratory at the University of California, Berkeley, wanted to know exactly how far the fission products would travel through matter. His experiment was simple. First, he stacked thin sheets of paper together to form a small book. On the top sheet he placed a sample of uranium salt. Next, he

exposed the salt to a source of neutrons, which induced fission. As expected, the fission fragments traveled through the paper sheets stopping at various layers in the book. McMillan could determine the location of each fission product by separating the pages and measuring the radioactivity with a Geiger counter. But in addition to finding various fission products scattered among the pages, McMillan detected two separate beta activities in the topmost sheet. Two isotopes were not recoiling with the other fission fragments.

McMillan reasoned that perhaps not all isotopes of uranium undergo fission. Maybe uranium-238 was indeed capturing a neutron, as Fermi had suspected, and decaying into a new element. In 1940, Philip Abelson, another American physicist from the Carnegie Institution in Washington, went to Berkeley to help McMillan identify the mysterious beta activities. Soon they had successfully separated and identified the first transuranium element. They named the element neptunium (Np).



Why name #93 neptunium? First take a guess, and then look to the end of the article for the answer.

## The search went on ...

McMillan suggested that the second short-lived beta decay product in the mixture might be an element with atomic number 94. The American scientists Glenn Seaborg, Arthur Wahl, and Joseph Kennedy were working on the World War II Manhattan Project with McMillan and decided to test his idea. First, they had to overcome two difficult problems. In McMillan's experiment, only small amounts



Glenn Seaborg

of uranium-239 and neptunium were formed. And the long half-life of the unknown isotope made it difficult to measure its activity. Seaborg's group knew they would need to synthesize larger quantities of neptunium if they were to be successful in identifying the mysterious product. They solved these problems with the help of (American physicist) Ernest Lawrence's proton merry-go-round—the cyclotron. Lawrence's cyclotron could accelerate particles to enormous speeds, imparting enough energy to overcome the repulsive forces inside an atomic nucleus. Using the cyclotron, they produced large quantities of neptunium and then watched as the neptunium decayed into an element with atomic number 94. Seaborg's group was able to show that element 94 was radioactive, emitting alpha particles with a half-life of 90 years. After the tradition of naming elements for the planets, element 94 was named plutonium.

McMillan moved on to other projects, but

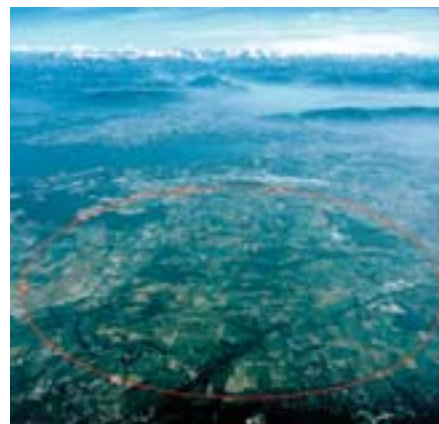


BETTY IMAGES

between 1944 and 1974, Seaborg's group discovered nine additional transuranium elements. A few were synthesized in ever larger and more powerful cyclotrons, and some in nuclear reactors. Two new elements, einsteinium and fermium, were discovered in the nuclear fallout during thermonuclear weapons testing in the 1950s.

## Revamping the periodic table

Where did the transuranium elements fit into the Periodic Table? Scientists soon learned that many transuranium elements had



CERN

Seven-kilometer-long accelerator in French and Swiss country side near Geneva.

properties similar to the transition metals. In 1944, Seaborg proposed his Actinide hypothesis. He predicted that thorium, protactinium, uranium, and the first 11 transuranium elements would form a series of chemically similar elements following actinium (atomic number 89), similar to how the lanthanides follow lanthanum. Much research into the chemical properties of the transuranium elements has confirmed Seaborg's hypothesis.

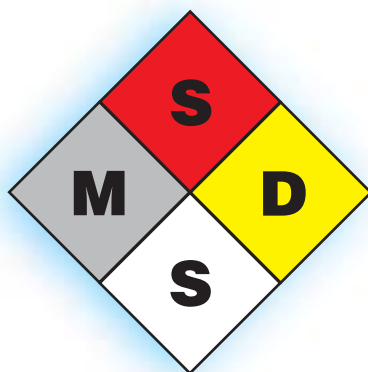
## The search continues ...

Today, 111 elements are listed in the Periodic Table. There are 19 transuranium elements named after planets, countries of discovery, and scientists. And elements beyond atomic number 111 have been reported but remain unconfirmed and unnamed. Will there be an end to the discovery of transuranium elements? Will scientists reach the hypothesized "Island of Stability" where theory predicts elements with atomic numbers as high as 126 may be stable? No one knows the answers. But we do know the search will continue, and perhaps you might be involved. Larger accelerators will be built to smash atoms. New detectors will allow researchers to track and interpret the zoo of particles that form when atoms collide. And each new discovery will increase our understanding of the world around us, including you and me! ▲

**Mike McClure** worked for several years as a chemist at a veterinary diagnostic laboratory, investigating unusual animal deaths. He now teaches chemistry at Hopkinsville Community College in Kentucky and is a regular contributor to *ChemMatters* magazine.

7	112-91	112-71	112-51	112-31	112-11	111-91	111-71	111-51	111-31	111-11	110-91	110-71	110-51	110-31	110-11	109-91	109-71	109-51	109-31	109-11	108-91	108-71	108-51	108-31	108-11	107-91	107-71	107-51	107-31	107-11	106-91	106-71	106-51	106-31	106-11	105-91	105-71	105-51	105-31	105-11	104-91	104-71	104-51	104-31	104-11	103-91	103-71	103-51	103-31	103-11	102-91	102-71	102-51	102-31	102-11	101-91	101-71	101-51	101-31	101-11	100-91	100-71	100-51	100-31	100-11	99-91	99-71	99-51	99-31	99-11	98-91	98-71	98-51	98-31	98-11	97-91	97-71	97-51	97-31	97-11	96-91	96-71	96-51	96-31	96-11	95-91	95-71	95-51	95-31	95-11	94-91	94-71	94-51	94-31	94-11	93-91	93-71	93-51	93-31	93-11	92-91	92-71	92-51	92-31	92-11	91-91	91-71	91-51	91-31	91-11	90-91	90-71	90-51	90-31	90-11	89-91	89-71	89-51	89-31	89-11	88-91	88-71	88-51	88-31	88-11	87-91	87-71	87-51	87-31	87-11	86-91	86-71	86-51	86-31	86-11	85-91	85-71	85-51	85-31	85-11	84-91	84-71	84-51	84-31	84-11	83-91	83-71	83-51	83-31	83-11	82-91	82-71	82-51	82-31	82-11	81-91	81-71	81-51	81-31	81-11	80-91	80-71	80-51	80-31	80-11	79-91	79-71	79-51	79-31	79-11	78-91	78-71	78-51	78-31	78-11	77-91	77-71	77-51	77-31	77-11	76-91	76-71	76-51	76-31	76-11	75-91	75-71	75-51	75-31	75-11	74-91	74-71	74-51	74-31	74-11	73-91	73-71	73-51	73-31	73-11	72-91	72-71	72-51	72-31	72-11	71-91	71-71	71-51	71-31	71-11	70-91	70-71	70-51	70-31	70-11	69-91	69-71	69-51	69-31	69-11	68-91	68-71	68-51	68-31	68-11	67-91	67-71	67-51	67-31	67-11	66-91	66-71	66-51	66-31	66-11	65-91	65-71	65-51	65-31	65-11	64-91	64-71	64-51	64-31	64-11	63-91	63-71	63-51	63-31	63-11	62-91	62-71	62-51	62-31	62-11	61-91	61-71	61-51	61-31	61-11	60-91	60-71	60-51	60-31	60-11	59-91	59-71	59-51	59-31	59-11	58-91	58-71	58-51	58-31	58-11	57-91	57-71	57-51	57-31	57-11	56-91	56-71	56-51	56-31	56-11	55-91	55-71	55-51	55-31	55-11	54-91	54-71	54-51	54-31	54-11	53-91	53-71	53-51	53-31	53-11	52-91	52-71	52-51	52-31	52-11	51-91	51-71	51-51	51-31	51-11	50-91	50-71	50-51	50-31	50-11	49-91	49-71	49-51	49-31	49-11	48-91	48-71	48-51	48-31	48-11	47-91	47-71	47-51	47-31	47-11	46-91	46-71	46-51	46-31	46-11	45-91	45-71	45-51	45-31	45-11	44-91	44-71	44-51	44-31	44-11	43-91	43-71	43-51	43-31	43-11	42-91	42-71	42-51	42-31	42-11	41-91	41-71	41-51	41-31	41-11	40-91	40-71	40-51	40-31	40-11	39-91	39-71	39-51	39-31	39-11	38-91	38-71	38-51	38-31	38-11	37-91	37-71	37-51	37-31	37-11	36-91	36-71	36-51	36-31	36-11	35-91	35-71	35-51	35-31	35-11	34-91	34-71	34-51	34-31	34-11	33-91	33-71	33-51	33-31	33-11	32-91	32-71	32-51	32-31	32-11	31-91	31-71	31-51	31-31	31-11	30-91	30-71	30-51	30-31	30-11	29-91	29-71	29-51	29-31	29-11	28-91	28-71	28-51	28-31	28-11	27-91	27-71	27-51	27-31	27-11	26-91	26-71	26-51	26-31	26-11	25-91	25-71	25-51	25-31	25-11	24-91	24-71	24-51	24-31	24-11	23-91	23-71	23-51	23-31	23-11	22-91	22-71	22-51	22-31	22-11	21-91	21-71	21-51	21-31	21-11	20-91	20-71	20-51	20-31	20-11	19-91	19-71	19-51	19-31	19-11	18-91	18-71	18-51	18-31	18-11	17-91	17-71	17-51	17-31	17-11	16-91	16-71	16-51	16-31	16-11	15-91	15-71	15-51	15-31	15-11	14-91	14-71	14-51	14-31	14-11	13-91	13-71	13-51	13-31	13-11	12-91	12-71	12-51	12-31	12-11	11-91	11-71	11-51	11-31	11-11	10-91	10-71	10-51	10-31	10-11	9-91	9-71	9-51	9-31	9-11	8-91	8-71	8-51	8-31	8-11	7-91	7-71	7-51	7-31	7-11	6-91	6-71	6-51	6-31	6-11	5-91	5-71	5-51	5-31	5-11	4-91	4-71	4-51	4-31	4-11	3-91	3-71	3-51	3-31	3-11	2-91	2-71	2-51	2-31	2-11	1-91	1-71	1-51	1-31	1-11	0-91	0-71	0-51	0-31	0-11
	Lanthanides																Actinides																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				





# Material Safety Data Sheets:

## PASSPORTS TO SAFETY?

By Michael Tinnesand

**So,** you've been out of high school for a few years and are enjoying your first job at a manufacturing plant. As manager in charge of production, you have many job functions, not the least of which is dealing with safety. Employees have ordered some new supplies, and one of your tasks is to review the Material Safety Data Sheets (MSDS) for each of the products. As you review the sheets looking for hazards, you notice some alarming information. For substance #1, the section on first-aid measures advises if it is taken internally, large quantities of water should be given and a physician or poison

control should be called at once. For substance #2, the fire-fighting instruction states, "Use triclass dry chemical fire extinguisher. Fire-fighters should "wear personal protective equipment (PPE) and self-contained breathing apparatus (SCBA) with full face piece, operated in positive pressure mode." The MSDS advises for substance #3, that one should avoid contact with eyes, skin, and clothing. Wear chemical splash goggles, chemical-resistant gloves, and chemical-resistant aprons.

Pretty scary. And what are these scary substances?

Substance #1 is baking soda.

Substance #2 is beeswax.

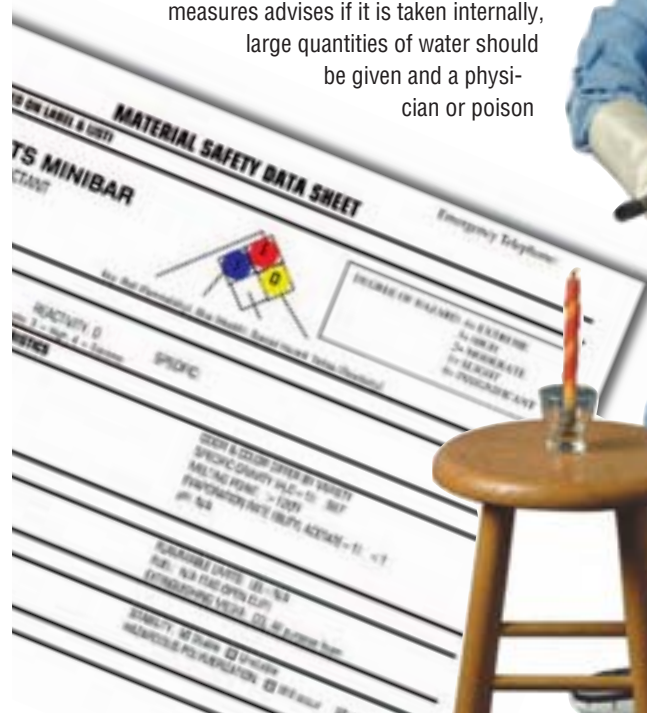
Substance #3 is cotton.

Scary indeed.

Most students will recognize baking soda as a common kitchen ingredient, used for making cookies and cakes. Far from being considered a poison, it is often used as medicine for upset stomachs when taken as "bicarbonate of soda". Baking soda is the common name for sodium bicarbonate ( $\text{NaHCO}_3$ ), which is a weak base. Because it is a base, it can be used to neutralize excess acid in your stomach.



ACS/STAFF



Beeswax is a natural substance produced by honeybees. A mixture of long-chain hydrocarbons and esters, there is no simple chemical formula, but the molecules making up this type of wax will typically have between 20 and 40 carbon atoms. Beeswax is used in making wood polish and candles. The conventional method of extinguishing the flame of a beeswax candle is with a slight puff of air, usually from someone's mouth. Cotton is one of the oldest and most widely used textile fibers in human history. It is used for all kinds of clothing, notably for underwear, where it is worn next to the skin, generally without resorting to goggles or aprons.



JUPITERIMAGES

What exactly are these Material Safety Data Sheets and why do they seem intent on scaring us out of using substances we know to be safe?

MSDSs are a very important part of safety precautions mandated by the Federal government some 25 years ago. Before that time, workers were on their own to discover the potential hazards of chemicals used in the workplace. To make matters worse, many of the products they were using were listed only by their brand or trade names, often without a list of ingredients.

This made it nearly



impossible to find out what the hazards might be. In 1986, the Occupational Safety & Health Administration (OSHA) established the Hazard Communication Standard. The standard requires that

- Chemical manufacturers and importers must evaluate the hazards of the chemicals they produce or import, and prepare labels and MSDSs to convey the hazard information to their customers.
- All employers with hazardous chemicals in their workplaces must have labels and MSDSs for their exposed workers and train them to handle the chemicals safely.

Although the Hazard Communication Standard does not apply to state and local government, most states have enacted similar legislation or have endorsed the OSHA standards. Therefore, public and private schools must pay attention to MSDSs as well. As a result, many high school chemistry teachers receive instruction on how to read a MSDS as part of their general safety training for work in the laboratory.

But in order for an MSDS to be helpful, they must be accurate. That means being consistent and reasonable in stating the hazards associated with the materials in question.

A recent article by Stephen Ritter in *Chemical & Engineering News* highlighted some of the issues. The article cites an example of a MSDS for deionized water, hardly hazardous by most standards, but a common



MIKE CHESEBSKI

**When working with chemicals, be aware of the hazards involved. Know where the MSDSs are kept and how to interpret them.**

item for use in research and academic labs. Information on the MSDS included the solubility of water in water, a recommendation to wear gloves when dealing with it, and storing it in a cool, dry place! When getting deionized water in the eyes, one sheet recommended "irrigate with water".

To be fair, it is important to note that the vast majority of MSDSs are probably accurate and helpful, but users are well advised not to rely on them without cross-checking.

The American Chemical Society Committee on Chemical Safety publishes *Chemical Safety for Teachers and Their Supervisors, Grades 7–12*. It notes, "Usually, MSDSs are not written for the laypersons: they require interpretation by persons familiar with the technical terms used. Often, an overemphasis is placed on the toxic characteristics of the subject chemical. There may also be vague or insufficient information regarding other hazards that the subject chemical presents."

So, how is it that so many MSDSs are inaccurate or inappropriate? The primary reason is that there is no one to check the quality of MSDS content. After passing the legislation creating the MSDS, OSHA promptly excused itself from enforcing any level of quality in the sheets, instead leaving it to the manufacturers themselves to assess the hazards and write high-quality MSDSs. As *Chemical Safety for Teachers and Their Supervisors* puts it, "Generally speaking, MSDSs from well-known, established suppliers of laboratory chemicals are likely to be better and more reliable than MSDSs from other sources. Often, a comparison of MSDSs for the same chemical from a variety of suppliers will suggest a source of MSDSs that is likely to be the most authoritative."

OSHA recently responded to these concerns with a study of the Hazard Communication Standards. The report, *Hazard Communication in the 21st Century Workplace* was published in March 2004. It makes a number of recommendations, including a new short course to train those who write the MSDSs and a checklist to help review the content of the MSDS.

Perhaps, most importantly, OSHA staff will begin to critically review the MSDS for 10 chemicals, working with manufacturers to make certain they are accurate and reasonable.

So, perhaps things will get better. In the meantime, consult your teacher if you have

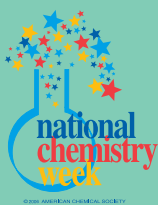


any concerns about chemicals in the lab. And you might want to be mindful of your outdoor activities, especially when it comes to dealing with sand. If you follow the

advice from one MSDS and avoid making contact with your skin or clothing, it is going to put a real damper on your time at the beach! 🏖️

**Michael Tinnesand** is the Associate Director of Academic Programs at ACS. His most recent article, "The Dog Ate My Homework and Other Gut-Wrenching Tales", appeared in the April 2006 issue of *ChemMatters*.





# National Chemistry Week 2006 Poster Contest

*“Your Home—It’s All Built on Chemistry”*



As part of the **National Chemistry Week 2006** celebration and in recognition of its theme, **"Your Home—It's All Built on Chemistry"**, the American Chemical Society (ACS) is sponsoring a poster contest for high school students.

Students are invited to create a poster that will serve as a public service announcement emphasizing the role of science/chemistry in the home.

### *Prizes!*

**1st Place:** \$200 Gift Certificate to amazon.com

**2nd Place:** \$100 Gift Certificate to amazon.com

There are also prizes for other categories (K-8),  
and for the teachers of winning students.

For important information about the contest, go to [chemistry.org/ncw](http://chemistry.org/ncw), or contact the American Chemical Society, Office of Community Activities at 800-227-5558, ext. 6097 or e-mail [ncw@acs.org](mailto:ncw@acs.org).



**National Chemistry Week October 22–28, 2006**

## CHEM1MATTERS

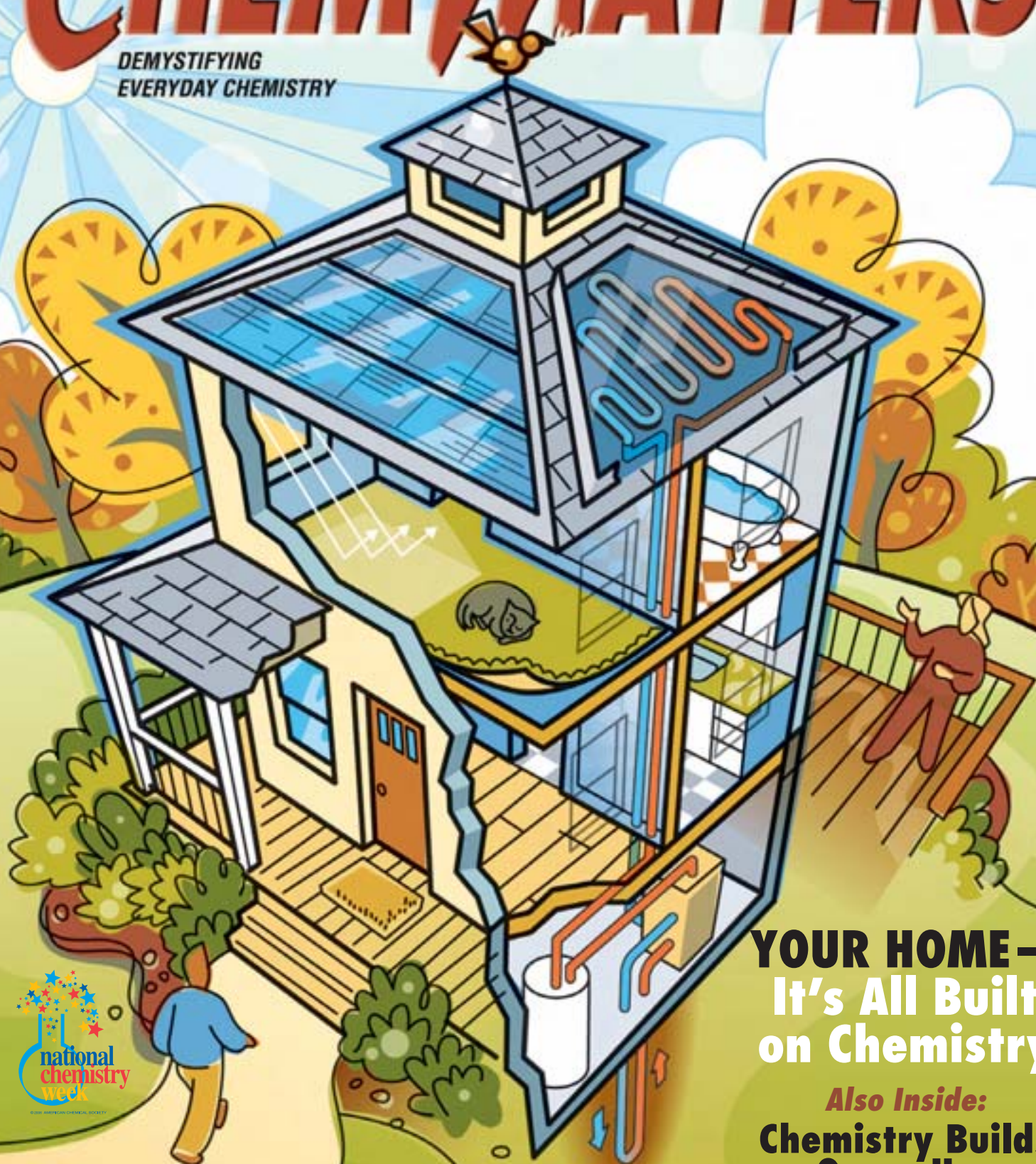
1155 Sixteenth Street, NW  
Washington, DC 20036-4800

Reach Us on the Web at  
[chemistry.org/education/chemmatters.html](http://chemistry.org/education/chemmatters.html)

OCTOBER 2006

# CHEM <sup>1</sup>MATTERS<sup>®</sup>

DEMYSTIFYING  
EVERYDAY CHEMISTRY



**YOUR HOME —  
It's All Built  
on Chemistry**

*Also Inside:*  
**Chemistry Builds  
a Green Home**



© 2006 American Chemical Society