

# CHEM **1** MATTERS®

DECEMBER 2006

DEMYSTIFYING  
EVERYDAY CHEMISTRY

## CORN

### The A"maiz"ing Grain

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**Unusual Sunken  
Treasures**



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# Question From the Classroom

By Bob Becker

**Q:** We learned in class that all objects have mass—even a helium balloon. So why then does a helium balloon rise?

**A:** The answer most often given to your question has to do with density. Just as a piece of wood will float upward in a lake because it is less dense than the water, so too will a helium balloon rise in the room because it is less dense than the surrounding air. Although there is certainly truth in that explanation, it really isn't the whole answer. A helium balloon does indeed have mass, and the force of gravity would therefore make it accelerate downward—toward the center of the earth. There must be some greater force acting on it in the opposite direction to make it accelerate upward. And there is; it is known as a buoyant force, and it acts on every object in the room, not just those that are less dense than air.

That buoyant force is rather small, only enough to lift about 0.0028 pounds (1.3 g) for every liter of air the object displaces. For most things around us that we might try to lift—a desk, a glass of water, a chemistry textbook, a friend—the buoyant effect is so slight that you would certainly never notice, but it is still there. What this means is that you actually weigh more than you think you do! Let's say you weigh 154 pounds—at least that's what you think you weigh. You would displace about 70 L of air. This translates into a buoyant force upward of about 0.200 pounds\* coming from the surrounding air.

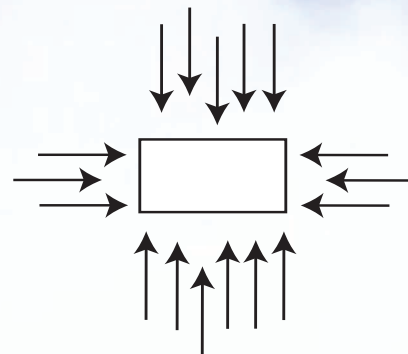
$$70 \text{ L} \times 0.0028 \text{ lb/L} = 0.196 \text{ lb, or } 0.200 \text{ lb}$$

Take that air away, and you take away the buoyant force. So if you lived in a vacuum (a place with no air or gas of any kind to buoy you up) and you stepped onto a sensitive enough scale, it would show your "true" weight: 154.2 pounds. Hopefully, that would not be cause for alarm—certainly, if you lived in a vacuum, you'd have more to worry about than a little weight gain—but it is something to think about.

But, what if instead of being a 70-L person, you were a 70-L helium balloon!? The helium inside you would weigh about 0.027

pounds and the balloon itself would probably weigh another 0.040 pounds, for a total "true" weight of 0.067 pounds, as measured in a vacuum. Now, factor in the air, and that 0.200-pound buoyant force acting upward on you makes a huge difference. In fact, it would give you a negative apparent weight:  $-0.133$  pounds, which is why you would find yourself accelerating upward toward the ceiling.

But where exactly is this buoyant force coming from? Well, if you have learned about gases, then you are probably familiar with the fact that gas molecules exert pressure in all directions as a result of their continuous bombardment with surrounding surfaces. You are also probably familiar with the fact that the pressure exerted by the atmosphere decreases at higher elevations. The higher up one goes, the thinner (less concentrated) the air is. With fewer molecules colliding, the collective force is weaker. This is certainly true for the air at the top of the mountain—the atmospheric pressure at the top of Mount Everest is about 70% lower than it is at sea level. But it is also true, to a much lesser extent, for the air at the top of a room. This means that there are slightly more air molecules per second hitting the bottom of an object and pushing it upward than there are hitting the top of the object and pushing it downward. There are also molecules hitting the sides of the object, but their forces effectively cancel each other out. This is most easily understood if we simplify the object by making it rectangular as shown in the figure below. The forces acting on the right would be evened out by the forces acting on the left. But this would not be true for the forces acting on the top and bottom; they would add up to a total force upward, and this is what we call the buoyant force.



So how exactly does density enter into the picture? It turns out that the buoyant force acting upward on an object is exactly equal to the weight of the fluid (air, water, whatever!) that is being displaced. This is sometimes referred to as Archimedes' principle. Because a liter of air weighs 0.0028 pounds, a one-liter object displaces that much air and has a buoyant force acting upward on it of 0.0028 pounds. If the object has the same density as air, it would have a true weight of 0.0028 pounds. With the buoyant force factored in, it will have an apparent weight of precisely 0 pounds. That is, it will be neutrally buoyant, neither floating nor sinking. If the object is denser than air, its weight will be greater than the buoyant force; it will, therefore, have a positive apparent weight, and accelerate downward. And if the object is less dense than air, its weight will be lower than the buoyant force; it will therefore have a negative apparent weight and accelerate upward.

Now, here's one more thing to think about: when you make a sharp turn in a car, you and everything else in the car tend to go flying outward. Right? Not necessarily. If one of the objects in the car is a helium balloon, you might be in for a surprise. Check out what it does. But please, make these observations from the passenger seat, not while you're driving! See if you can explain why it behaves that way.

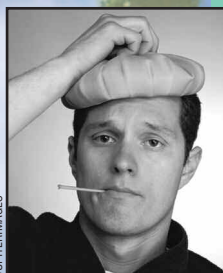
\*The metrically minded students out there may be wondering why pounds are being used instead of grams or kilograms. Because this article pertains to forces, the author decided to stick with pounds, which truly are units of force. Grams and kilograms are not units of force. And although 0.200 pounds translates into 90.8 grams, it would be inappropriate to talk about a 90.8-gram force. The correct translation would be into newtons (a 0.89 N force)—the metric unit of force, but for those students who have not yet had a course in physics, a newton would only conjure up images of fig-filled wafers! ▲



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# Corn

## The A"maiz"ing Grain

By Gail Haines

There is a legend that old-timers tell of one particular summer when it got so hot that the corn in the fields started popping right off the stalks. The cows and pigs thought it was a snow blizzard, and they lay down and froze to death.

The popularity of corn cannot be denied. As Dr. Paul Mangelsdorf says in his book *Corn: Its Origin, Evolution, and Improvement*: "It is the most efficient plant that we have for capturing the energy of the sun and converting it into food. True, we consume directly only small amounts of corn: roasting ears, breakfast cereals, Indian pudding, and, for a somewhat different purpose, a beverage invented by a Kentucky minister of the Gospel, bourbon whiskey. But transformed, as three-fourths of it is, into meat,

milk, eggs, and other animal products, it is our basic food plant, as it was of the people who preceded us into this hemisphere. Corn is as important today as it was for our native peoples." Native American legend has it that corn is of divine origin—the food of the gods that created the earth.

But as in many other instances, modern humanity has managed to stir up controversy with this "perfect" gift. Today, genetically modified corn, gasohol from corn, and even high fructose corn syrup have become sensitive issues with people taking sides. Meanwhile, industry leaders call corn a future "manufacturing plant"—pun intended; the list of corn-based products is constantly increasing.

The Spanish called it "maíz," and the botanical term became *Zea mays*. The English word was a bad choice, because "corn" refers to different grains in different places. The name gaining popularity among scientists today is "maize."

In less than a thousand years—cyber-speed by evolutionary standards—tiny "ears" of corn were growing all over Central America. Long before Columbus or Cortez arrived, corn had become a major food crop across both American continents. The explorers carried ears back home, and within another 100



years, corn spread as far as China. Now, corn is cultivated on six continents and is harvested in more countries than any other single crop.

### We need corn and corn needs us

Corn has partnered with humans for more than 8000 years. Early Mesoamerican wall paintings tell of the food's "discovery," in the flatulence of a fox. In a common Mesoamerican myth, a fox follows an ant inside a large mountain or boulder where the fox discovers a cache of maize. After eating the grain a vision of a wondrous new food was made evident in the haze of the fox's flatulence!



Possibly, a more likely scenario is that in ancient Mexico, people practiced selective breeding on a grass called teosinte the old-fashioned way. By only using the best/biggest/sweetest seeds, the ancestors of modern corn evolved over time. People have been modifying the genetics of crop plants since time immemorial by this type of selective breeding.

People needed maize to survive. Vegetarians, take note! Combined with beans and squash—the way native tribes prepared it—corn supplies all the amino acids needed for a healthy diet. And corn needs people, because the ears can't reseed themselves. Farmers must remove the kernels from the cob before they can be planted in the ground, and the seedlings must be nurtured for them to grow.

Consider a typical fast food meal: hamburger, fries, and a soft drink. The single food that links all these is ... you guessed it, *corn* to feed the beef, *corn* syrup in the soft drink, the bun, and the ketchup, and *corn* oil to fry the potatoes. Every day, the average American eats around two pounds of corn in the form of dairy products and meat produced from corn-fed cows, not counting roasted ears, muffins, cereal, chips, and the 56 quarts of popcorn each of us consume every year. Much of it is grown in 12 contiguous Corn Belt states around Illinois.

## Now for the biology

Maize is a cross-pollinating annual grass, with a tall stalk, male tassels, and female ears. Seeds consist of an oily germ and an endosperm composed of starch and protein. The outer shell or hull of the seed is the pericarp. Hundreds of different varieties still grow in rural Central America, with kernel colors ranging from white to purple. But most cultivated strains fall into five types (with the percent of commercial crops devoted):

1. **Popcorn**—the original cultivated corn. Moisture in the starchy core explodes with heat into, arguably, the world's oldest snack food (<1%)

2. **Sweet corn**—more sugar than starch. Add salt and butter (<1%)
3. **Flour corn**—soft. Makes great tortillas (12%)
4. **Flint corn**—hard. Grows in colder weather, used industrially and for livestock feed (14%)
5. **Dent corn**, a flint/flour cross, accounts for a whopping 73% of commercial crops. The starchy interior feeds livestock and provides raw materials for the chemical industry. In the United States, much of it is genetically engineered.

A sixth type of corn called pod corn is only used for research. Each kernel has its own husk, so it is too labor intensive to use commercially.

## Genetically modified corn—isn't that Frankenfood?

Who eats genetically modified or transgenic (GM) corn? If you live in the United States, you do. Cows, pigs, chickens, and dogs do too. Some 70% of the processed food on grocery store shelves contains genetically modified corn and other plants in use since the early 1990s. In the United States, GM foods are considered "nutritionally identical" to the ordinary kind, so they are not normally labeled.

How does genetically modified compare with selective breeding? Well, selective breeding is really just a primitive form of genetic tinkering. A farmer must choose a male and a female plant, hoping that the gene responsible for a desired trait is transferred to their offspring. The breeder can only guess, however, that the desired gene is present in the parent plants based on visual inspection; there is no guarantee that the offspring will indeed have the desired traits. Success in selective breeding only comes after a long trial-and-error process.



**A qualitative test for GM corn. Hybrid corn samples turn test solution dark blue, while normal kernels do not.**

Genetic engineering is a more targeted approach, allowing the breeder to take selected genes from one organism and place them into another. The offspring in this case is called a genetically modified organism (GMO), or a transgenic organism. This is pretty straightforward and direct—plus, it allows something the selective breeder can never accomplish—genes from one species can be transferred to another, different species. Want grape-flavored corn? Not a problem, but impossible with selective breeding. But seriously, although the process is not quite that simple, enhancing flavor, crop yields, and resistance to herbicides are desirable traits that have already been engineered into GM corn. Genetic engineering has also allowed the incorporation of a gene that codes for the *Bacillus thuringiensis* toxin, protecting corn plants from insects.

Genetic modification may sound like biology, but chemistry makes it fly. DNA molecules get cut and pasted by chemicals called restriction enzymes, and "gene guns" shoot gene-coated, microscopic particles of gold or tungsten directly into plant cells. Again, it is not as simple as injecting a single gene into the plant's cells. A combination of genes from bacteria, viruses, and the gene from the donating organism is assembled. The bacterial and viral genes are used to break down barriers between the two species being crossed, and they allow a mechanism for making sure the desired gene is incorporated. As the genes are injected into the plant's cells, it is suspected that the injection triggers a wound response which helps its DNA integrate the new gene. With the new genes on board, one may engineer increases in the corn's productivity, or protein concentration or whatever is desired.



COURTESY OF JOHN DORRLEY, PHOTO BY TUGH ILTIS



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## Sounds great ... why isn't everyone on board?

Europeans are not fond of GM crops; only within the last two years have GM crops been allowed in Europe, where each product must display a special GM label. And in spite of the United Nations official support, many developing nations still are hesitant to consume GM crops, including corn. GM agriculture has had bad press around the world; some activists call it Frankenfood. Many people are not interested in eating unnatural food; corn is not supposed to taste like grapes!

Also, there are fears that unpredictable results may occur when multiple copies of a foreign genetic code are injected into the plant. Critics of genetic engineering fear that new pathogens may be created within the plant, including bacteria that will be resistant to available antibacterial drugs.

Experimental attempts to coax corn into producing protein-based drugs and vaccines inside the kernel are called "pharming." This process is thought by some to be safer and cheaper than growing drugs in animal cell cultures. But in 2002, "pharm" corn that was engineered to produce a pig vaccine slipped into food fields by accident. In another case, some untested GM corn was processed into taco shells before the mistake was caught; no one ate any of the shells and the foods were destroyed. Still ... corn pollen spreads far and wide, riding on the wind and farm machinery. Transgenic strains have been found fertilizing other varieties. Scientists are supposed to test every new strain for possible allergens. Some people are worried that new "superweeds" or resistant insects will develop in response to genetic tinkering with nature.

You don't want pig vaccine in your taco, and preserving genetic diversity is very important, but transgenic plants are already controlled far more rigorously than other foods. Fear of GM corn is costing lives in a few African countries that have refused American food donations because they contain GM products, which Americans eat every day. Scientists try to stay ahead of the game, developing corn strains that are sterile and even strains that grow underground, where no pollen can escape.

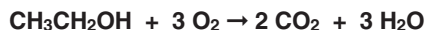
## Ethanol

Ethanol, the chemical name for ethyl alcohol,  $\text{CH}_3\text{CH}_2\text{OH}$ , is in beer, whiskey, and wine and is one of the first chemicals people learned to make. Corn whiskey was the original "White Lightning" of Prohibition days. The largest volume corn-based product on the market today is fuel-grade ethanol—4 billion gallons of it is made each year. You already burn some "gasohol" in your tank. All cars now sold in the U.S. can handle a 15% ethanol, 85% gasoline fuel mix. "Flex-Cars" can burn at least 85% ethanol—E-85. The 2007 Indianapolis 500 will run on 100% ethanol fuel made from corn—bringing new meaning to "lightning fast!"

Ethanol burns cleaner than gasoline, producing little to none of the black, sooty smoke you see pouring out of an old car's exhaust pipe.



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Both ethanol and gasoline produce carbon dioxide when burned, which becomes atmospheric "greenhouse gas" pollution. But there is a difference—corn captures  $\text{CO}_2$  from the air as it grows. Petroleum-based fuels, on the other hand, release tons of  $\text{CO}_2$ , which have been trapped underground for millions of years.

You may have heard gasohol production uses more energy than it provides. Critics

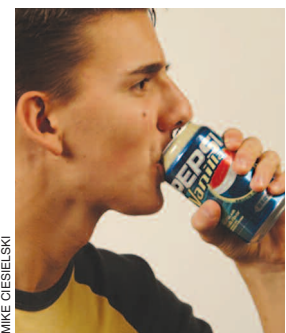
count every BTU of energy used to produce the gasohol, grow the corn, make the fertilizer, irrigate, and even build the farm machinery. Proponents use the newest technological data for growth and production, and then they subtract coproducts made from corn protein and corn oil and the energy value of sunshine. A cradle-to-grave analysis of the costs of producing ethanol would be a useful exercise, perhaps one that might be suggested by your teacher. What we do know is that, thermodynamically, every energy conversion uses more raw energy than it produces in fuel. The gain is convenience: coal to electricity, crude oil to gasoline, corn to ethanol. Better technology favors the proponents, and ethanol already is replacing gasoline-from-petroleum at an ever-increasing rate.

## Oh, the sweet taste of—corn?

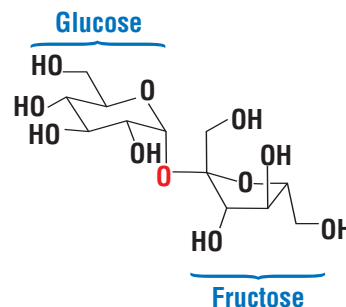
Along with  $\text{CO}_2$  in your can of soda, the sweetener is almost certain to be pure corn. High fructose corn syrup (HFCS) is corn's major refined food product.

Corn syrup, mostly glucose, is not very sweet. Table sugar (sucrose  $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ )—with each molecule composed of one glucose and one super-sweet fructose—has the taste we love. Food chemists found ways to get that taste from corn. They increased the fructose level in corn syrup to 42% (HFCS-42), 55% (HFCS-55) or 90% (HFCS-90), to make it as sweet as—or sweeter than—table sugar.

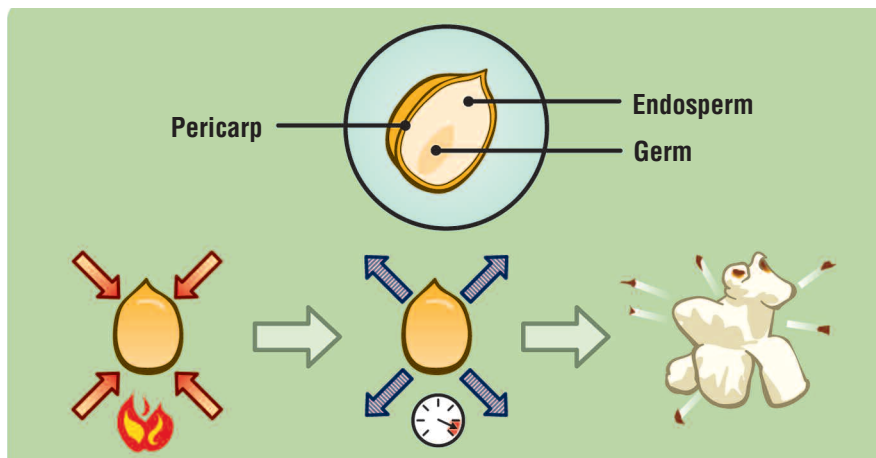
The 42% fructose syrup is produced by adding an enzyme that interconverts glucose



MIKE CHESIELSKI



Sucrose is made of one glucose and one fructose unit.



The ins and outs of popcorn.

and fructose; the 42% fructose/58% glucose represents the equilibrium ratio. The 90% fructose syrup is produced by a partial separation of the two sugars using a column that has a high affinity for fructose. The 55% fructose syrup is made from blending the 90% and the 42% and seems to be the standard sweetener for products such as soft drinks.

HFCS is cheaper than sucrose. It also promotes browning in bread, makes cookies chewy, prevents freezer burn, preserves canned fruit texture, enhances flavors, and more. HFCS is in ketchup, hamburger buns, bacon, lunch meat, whole wheat bread, and products you would never suspect had sugar at all.

## Popcorn

Long, long before there were movies there was popcorn. Popcorn thought to be 5,600 years old was found in a cave in central New Mexico. Today's typical American eats over 50 liters of popcorn each year. And Americans don't just eat the stuff — they are the world's largest producers. Most of the world gets its popcorn from the U.S. Midwest: Indiana, Iowa, and Nebraska.

A popcorn kernel is simply a seed with three parts: the germ is the part that sprouts out of the seed during growth; the endosperm is the starch that expands during the popping process; and the pericarp, or outer hull, which is made partly of cellulose. Now, not all corn has the potential to pop. The maize must have the right type of pericarp to produce the fluffy food. The pericarp needs to keep moisture trapped inside the corn kernel while it's being cooked. As the temperature of the kernel increases, the pressure exerted by the gaseous H<sub>2</sub>O inside the kernel also increases. Once the internal pressure exceeds that outside and the pericarp can no longer withstand

the force, the kernel splits open, turning the kernel inside out.

No one likes chomping down on unpopped kernels. The highest quality popcorn has a pericarp with a highly ordered crystalline arrangement of its cellulose molecules. The two main reasons why kernels don't pop is they have insufficient moisture, or that the hull leaks. The ideal popcorn has about 14% moisture and must be stored in a tightly sealed container so it won't dry out.

Eating popcorn is typically considered to be a healthy act. It is fat-free, low in calories, and provides fiber. And it's natural — according to the Popcorn Board (a nonprofit group of popcorn processors), there is no genetically modified popcorn currently available for sale in domestic or international markets.

## Increased use of HFCS = increased size of American?

Now HFCS is getting blamed for making Americans fat. Is this true? Or is it "Frankenfat"? Evidence shows today's average American is heavier than previous generations, and the time frame of the weight increase—since the mid-1970s—matches the huge spike in HFCS use. But over the same 30 years, among other things, Americans have super-sized their diets, averaging 300 extra calories a day.

Chemically, HFCS-42 and HFCS-55 are similar to sucrose at 50–50%, but the body handles extra glucose or fructose differently. Glucose is used directly by the body's cells; fructose goes first to the liver. Glucose spikes a surge of insulin and also leptin, a hormone that signals you have eaten enough. Fructose doesn't, so you may just keep eating! Fruc-



**In American Indian folklore, some tribes were said to believe that quiet, contented spirits lived inside of each popcorn kernel. When their houses were heated, the spirits would become angrier and angrier, shaking the kernels, and when the heat became unbearable, they would burst out of their homes and into the air in a disgruntled puff of steam.**

tose you don't burn for energy and converts easily into body fat.

Research is under way. Meanwhile, if weight is a problem, avoiding those 32-ounce "super" drinks—sweetened with HFCS or sucrose—would be a no-brainer.

Solving controversy can supercharge science. Maize is already a great human achievement—8000 years and still growing. Watch for further developments. ▲

### REFERENCES

- Mangelsdorf, P. *Corn: Its Origin, Evolution, and Improvement*, Belknap Press, Cambridge, MA, 1974.
- Tandjung, A., et al. Role of the pericarp cellulose matrix as a moisture barrier in microwavable popcorn. *Biomacromolecules*, **2005**, 6, 1654–60.
- Other information courtesy of Linda Stradley and her web site, What's Cooking America, at <http://whatscookingamerica.net>.
- Other references may be found in the Teacher's Guide.

**Gail Haines** is a science writer and book author from Olympia, WA. Her most recent article, "Honey: Bee Food Extraordinaire," appeared in the December 2005 issue of *ChemMatters*.



# Sticky Situations: The Wonders of Glue

By Linda Shiber

For many of us, the allure of glue peaks during early elementary school. We eat it as a forbidden delicacy, we use it to create seasonal construction paper crafts, and some of us may even use the colored varieties to spice things up. After, say, second grade, most individuals forget about glue. The initial fascination evaporates, and, instead, we begin taking the sticky stuff for granted. In actuality, however, glue deserves far more attention. It comes in many forms, is derived from surprising sources, and fulfills a plethora of functions.

## Creatures that stick and sticky stuff from creatures

What do mussels, fish, and geckos have in common? They all have the ability to stick, or become sticky. The most impressive member of this group is the mussel. Mussels spend their lives permanently attached to rocks in the ocean. It's a stressful life—they're constantly bombarded by harsh waves, yet they don't get washed away. Their secret? Well, the key to the mussel's tenacity is a gluey secretion called byssus, which originates from glands in its "foot". University of California at Santa Barbara researcher Herbert Waite discovered that these glands secrete two materials: resinlike pro-

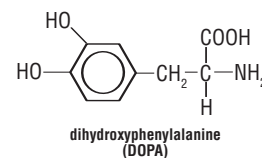


Mussel adhering to a sheet of polytetrafluoroethylene (Teflon).

WILKES GROUP AT PURDUE UNIVERSITY

teins and hardening substances. When the two mix and contact water, they harden, forming a bond that is able to oppose thousand-pound forces. The hardening process is where all of the interesting chemistry comes in.

Before the glue hardens, the molecules in the byssus are in the form of polymer chains that have side groups made of DOPA, or dihydroxyphenylalanine.



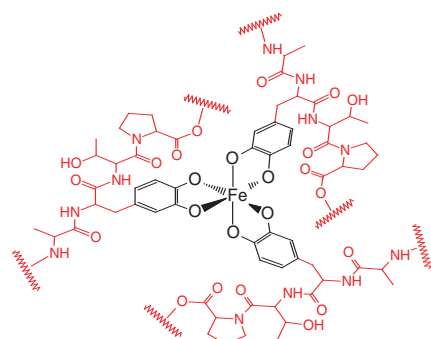
Polymer chains are simply long chains of molecules that are covalently linked together. Why is DOPA important? Well, in its oxidized form, it is involved in the cross-linking between the protein chains of the





mussel glue, creating a meshwork that binds the mussel to its rock. Cross-linking is important for making the glue stick to itself and to the surfaces to which it is adhering. However, the DOPA cross-link story doesn't end here. Mussel glue contains a remarkably high concentration of iron, and Jonathon Wilker at Purdue University wanted to find out why. Research done by Wilker in 2004 revealed that mussels use iron that is in the surrounding water to join the byssus molecules together via their DOPA side chains, forming this cross-linked framework. It turns out that each iron atom can bind three DOPA side chains.

When the iron-DOPA linked molecules are exposed to oxygen, the complex forms radicals. Radicals are extremely reactive substances, and in this case, their reactivity is responsible for internal cross-linking of the glue and for connecting the glue to surfaces. The end result of the process is a strong, waterproof adhesive that keeps mussels on the rock of their choice for life.



Each iron atom binds to three DOPA side chains.

## Fish glue

Although mussel glue is impressive for its sheer strength, it only serves the purposes of the mussel. Other animal-derived glues have been used by humans for serving their own needs. Fish glue, as an example, is prepared by heating the skin or bones of certain types of fish in water. Extra-pure fish glue may be manufactured from swim bladders. The protein-based substance was patented in the 1750s, and it is still used today for various tasks. Fish glue is special because it bonds well to leather and can be easily removed with hot water or steam (without damaging the bonded surfaces). These qualities make it a good candidate for, interestingly, pipe organ restoration and repair. Pipe organs rely on leather for the pneumatics, which control how much air is expelled from the pipes when a key is depressed. More specifically, when an

organist presses a key, an electric current travels through a cord to valves that open to specific increments, controlling the air that leaves the pipes and, in turn, the sound that's produced. Leather is used on the valve disks, the gaskets, and the pneumatics. These leather components inevitably wear out and require replacement. Fish glue is the choice when one must reattach new leathers, because when they deteriorate (after 50 years or so), the glue can be removed without causing damage to the instrument.

## Off to the glue factory ...

Marine animals aren't the only sticky organisms, though. Glues are also made by boiling the hooves, hides, and bones of animals such as horses. You may have heard the saying that elderly horses are led off to the glue factory. There is some truth in it. For instance, hide glue was used in the past to make bows, glue together ceramics, and is still used today in woodworking. The glue is made by heating hides and skins in an alkaline solution containing lime ( $\text{Ca}(\text{OH})_2$ ), which softens and breaks down the tissue, releasing collagen. Next, the hides are run through a water rinse to remove excess lime, and hydrochloric acid is added to aid in the lime removal by neutralizing it. The resulting material, called "stock", gets heated for a specific amount of time, which allows further breakdown of the collagen into a gluey material. As this hide glue cools, it attains a gelatinous quality. When all water has been evaporated, the hide glue becomes concentrated in sheets or blocks. To use the hide glue, an appropriate amount is added to hot water, melted, and then spread onto whatever needs gluing.

## We've got geckos climbing the waals

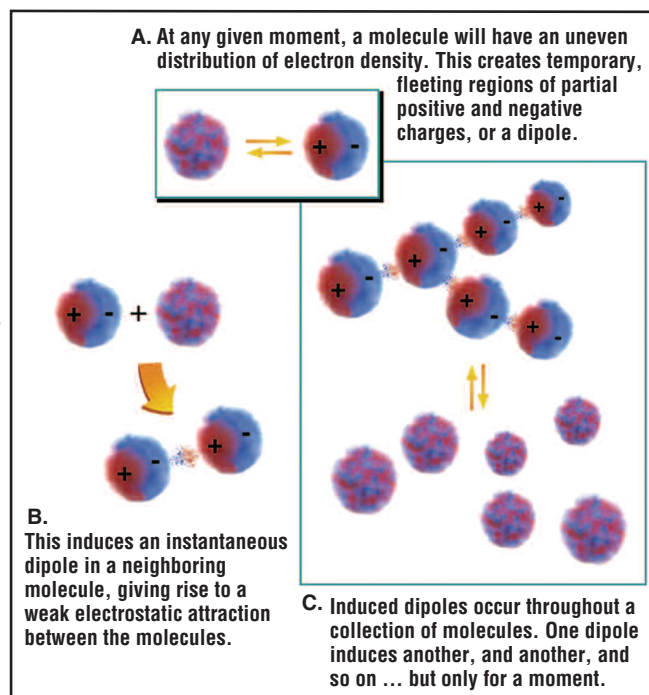
Geckos climb on all kinds of surfaces, including ones that are completely vertical. Professor Autumn Keller and undergraduate



AUTUMN KELLER, LEWIS AND CLARK COLLEGE

students at Lewis and Clark College have discovered how the critters can defy gravity. The key to the gecko's nimble footwork are millions of tiny hairs, called setae, which are arranged on the pads of its feet. The setae each split into more tips called spatulae (amounting to figures in the billions), which are microscopic. These miniscule hairs work to hold the gecko on a surface through a mechanical approach, rather than by, say, secreting a gluey substance. The key to the gecko's "stickiness", then, is something called van der Waals forces.

Van der Waals forces refer to three types of attractive forces that can exist between neutral molecules: dipole-dipole forces, hydrogen bonding, and London dispersion forces. The type of van der Waals force employed by the agile gecko is London dispersion. These are weak electrodynamic forces between molecules caused by an instantaneous, temporary dipole of one atom inducing a similar temporary dipole on an adjacent atom, causing the atoms to be attracted to one another.



Van der Waals forces.

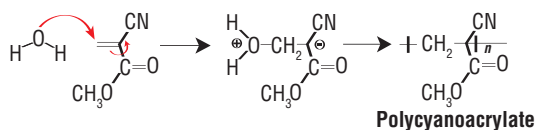
All molecules experience van der Waals forces, but the gecko's secret is its surface area. Because there are so many setae and spatulae, the total area of the gecko's foot in contact with the surface that it's scaling can be immense, so all the tiny attractions can add up to serious stickiness.

In addition to van der Waals forces, the gecko's ability to stick is attributable to geometry. When a gecko runs, its foot moves in such a way that optimizes the contact between its setae and the surface. The gecko actually pushes its foot pads down and slides them forward slightly, thereby initiating the sticking. To lift their feet back up, the angle at which the setae touch the surface is increased, and the gecko "peels" each foot off the ground.

## A glue by any other name

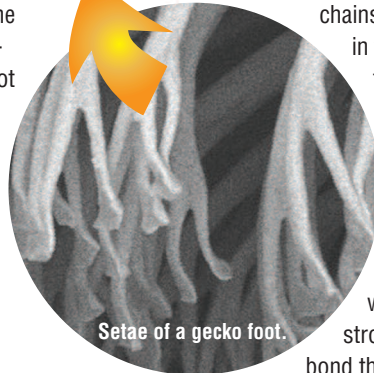
Although hide glue might be news to you, products like superglue and gorilla glue are probably much easier to recognize. Superglue comes in small containers and packs a whole lot of stickiness. The molecule responsible for its adhesive qualities is cyanoacrylate, an acrylic resin. Cyanoacrylate was discovered in the 1940s by a man named Harry Coover who was working at the Eastman Kodak company. Following his discovery of this sticky substance, Eastman Kodak began looking into alternative uses for the material. The key to cyanoacrylate glue was that it stuck to skin. Hence, research was done to see if it could be used medically to hold the tissue surrounding surgical incisions together. It could and it did. In fact, during the Vietnam War, a cyanoacrylate glue spray was used on battle wounds as a fast way to stop bleeding until the injured person was transported to a medical facility.

So how does cyanoacrylate work its adhesive magic in products like Superglue? Well, in its liquid state, Superglue's main ingredient is the monomer methyl-2-cyanoacrylate. Exposure to water (or, the trace amount of hydroxide ion present in water) causes the monomers to undergo a polymer-



ization reaction in which they form long chains that can connect two surfaces together.

Because trace amounts of moisture exist on most surfaces, Superglue cures quickly and without much coaxing. The reason that Superglue doesn't stick to the walls of its



Setae of a gecko foot.

package is because an acidic stabilizer has been added. This stabilizer prevents the formation of polymer chains but is overridden in the presence of the thin layer of water molecules that coats most surfaces wherever there is moderate humidity. Is there any way to reverse the strong, waterproof bond that Superglue

makes? There are some factors that may weaken its adhesiveness. For instance, heating glued objects to a temperature greater than 180 °F, or exposing it to temperatures less than 30 °F will soften the glue or cause it to become brittle. Acetone, a substance found in nail polish removers, can also soften the bond by partially dissolving the polymer chains, making it easier for them to slip past each other.

## Primates and polyurethane

Another type of human-made glue that may be familiar to you is Gorilla Glue. Gorilla Glue is used in home repairs and woodworking and is lauded for its waterproof bond. In contrast to Superglue, Gorilla Glue doesn't dry within seconds. Rather, it allows the person using it a 20-minute window in which surfaces may be shifted and adjusted to glueable perfection. What's the key to this bond? The answer is polyurethane polymers. A polyurethane polymer is a chain of molecules attached to one another via urethane links. The central reaction responsible for chain formation is between two types of monomers: a polyol (polyethylene glycol or polyester polyol) and a diisocyanate (either aromatic or aliphatic).

Depending on the type of monomers and/or catalysts used, polyurethanes have widely different properties. Although the substance is used as a glue, through variation of the polymerizing reagents and through various additives, it may acquire properties that allow it to act as a varnish or a foam. For example, using an aromatic diisocyanate monomer would create a substance with differing mechanical properties as opposed to using a linear monomer. The same variation is

seen with the polyol used; a polyethylene glycol monomer produces a softer, more flexible polyurethane than a polyester polyol might.

## The sticky-icky lowdown

Now that we've profiled how different kinds of glue form bonds, the next logical question is how do glues interact with the surfaces they're gluing? How does a glob of glue convince two objects to stick to it and to each other? There are several ways this can occur. The first way is pretty much common sense. Glues work mechanically by invading the pores and cracks in the two surfaces, increasing the area that becomes sticky. Sometimes, the effectiveness of glue can be increased by making the surfaces rougher. This provides the glue with plenty of crannies it can diffuse into and occupy.

Another major way that glues work is by taking advantage of electrostatic forces present on the surfaces of the objects being glued. Different objects contain molecules with varying dipole moments, which may attract them to one another. An adhesive force is created when electrons are transferred from one surface to another, creating positive and negative charges, which are attracted to one another.

It's clear that there's a lot more to glue than its sentimental role as a childhood snack. Animals make it, people make it, and it holds together so many of the items we rely upon every day. Look around. Glues are everywhere, from the natural world to the chemistry lab. It would be virtually impossible to separate our lives from them. Not that we'd want to, of course. The bottom line, then, (and pardon the pun) is that we're stuck on glue.

Period. ▲

## REFERENCES

- Burdick, A. Biochemists Turn to Mussels for a Real Bonding Experience. *Discover*, **2005**, 24.
- Cobb, C. and M. Fetterolf. *The Amazing Science of Familiar Things*. New York: Prometheus Books, 2005.
- Goho, A. Marine Superglue: Mussels Get Stickiness From Iron in Seawater, *Science News Online*, **2004**, 165.
- Additional references can be found in the Teacher's Guide.

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# Unusual Sunken Treasure

By Tim Graham

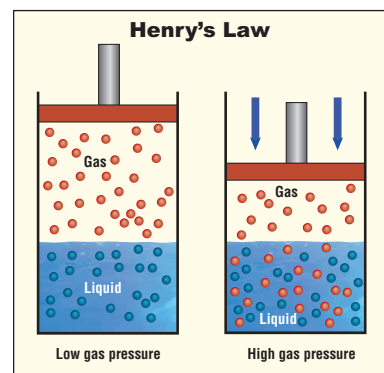
**D**uring World War I, German submarines were feared in the waters of the North Atlantic and in the Baltic Sea between the coasts of Sweden and Finland. Many commercial freighters were sunk in the frigid waters because they were suspected of carrying war supplies or troops. The German attack sub, U22, located the two-masted Swedish schooner *Jonkoping* 28 miles from the Finnish coast. There was little doubt as to the outcome. The fateful morning for the *Jonkoping* was November 3, 1916. Her resting place for the next 82 years would be 197 feet below the surface in the icy cold waters of the Baltic Sea.

Swedish divers Claes Bergvall and Peter Lindberg located the almost perfectly preserved wreck in 1997. The divers found the rigging destroyed, but there was only a small hole in the hull. The wreck was of great interest because of its cargo ... she was loaded with 10,000 gallons of cognac, 17 barrels of Burgundy wine, and 3000 bottles of Heidsieck & Co. Monopole 1907 "Gout Americain" champagne, intended for officers in the Russian army. (\*Note of interest ... the 1907 Hei-

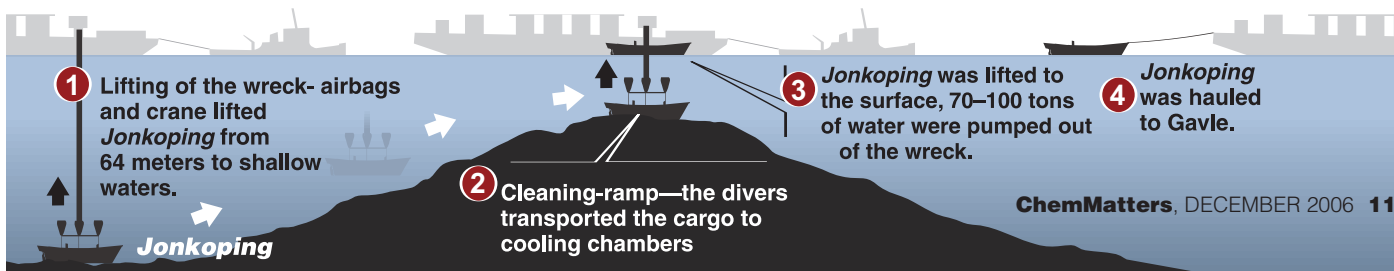
dsieck was also the wine on the H.M.S. *Titanic's* maiden voyage.)

In July, 1998, salvage operations began to remove the precious cargo from the ocean floor. Because of the exceptional condition of the wreck, salvagers expected the best ... recovery of what would now be considered some of the rarest alcoholic beverages on earth! From the cargo, 21 barrels of cognac were salvaged, as well as 2500 bottles of the 1907 champagne. The cognac was discovered to contain salty seawater and was not suitable for drinking, but the champagne proved to be a real "treasure." The champagne was so well preserved because it was shipped in strong wooden cases, which prevented most of the bottles from breaking while the *Jonkoping* sank. And for 82 years, the bottles were stored in the complete darkness, 197 feet below sea level at a constant temperature of 3 °C (about 37 °F). At this depth, water pressure (every 33 feet in depth provides one additional atmosphere of pressure) helped to keep the corks in place and the effervescence inside the bottles. The Baltic is a young sea in evolutionary terms and the absence of wood-destroying worms or parasites further helped to preserve the champagne.

But the pressure at these depths also provided salvagers with a challenge—how to get the bottles to the surface without "blowing their corks." Two gas laws come into play when bringing "carbonated" beverages from an area of high pressure to an area of low pressure. The first, Henry's law, states that the solubility of a dissolved gas decreases when the partial pressure above the solution is decreased. In a mixture of gases, the partial pressure of a gas is the pressure it would exert if it alone occupied the same volume at the same temperature. The second law to con-



In accordance with Henry's law, as the pressure on the corks decreases, more CO<sub>2</sub> will come out of solution.



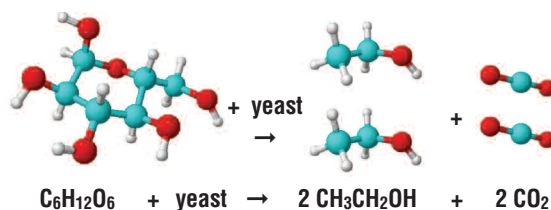
sider is Boyle's law, which states that at a constant temperature, as pressure decreases, the volume of the gas bubbles will increase. (See sidebar "Scuba and the gas laws", in "SCUBA: The Chemistry of an Adventure", pp. 8-9, *ChemMatters*, Feb. 2001) Together, these two gas laws could result in the bottles "blowing their corks" with the ultimate loss of their precious contents.

Eighty-two years in the Baltic Sea had corroded away the wires that the bottlers had used to secure the corks in the bottles. Divers had to first engineer a way to keep the corks in place prior to bringing them to the surface where the pressure is drastically reduced. A wire screen was eventually secured over the cork of each bottle to keep the precious "bubbly" in the bottles. Once this obstacle was overcome, the salvage operation could begin.

## Chemistry of champagne

Champagne is named after the region in northern France where the "bubbly" wine first gained its reputation. Champagne from this region is made from three varieties of grapes: Pinot Noir, Pinot Meunier, and Chardonnay. To start, the grapes are pressed, and the juice is separated from seeds and skins before they have had time to impart any color. This juice then undergoes its first fermentation, usually in large containers. During this primary fermentation, the simple sugars (glucose and fructose) present in the grapes are converted to ethanol ( $\text{CH}_3\text{CH}_2\text{OH}$ , also called ethyl alcohol) and  $\text{CO}_2$ . A wine master will then decide how the three varieties of grapes will be blended to achieve the desired still wine. Still wine is wine with no fizz.

Now the process of making the "fizz" begins. After the still wine has been blended, it is bottled in a thick glass bottle to withstand the pressure created by carbon dioxide bubbles that form during the second fermentation process. A dose of sugar solution and *Saccharomyces cerevisiae*, or yeast (the mixture is called



The formation of  $\text{CO}_2$  and ethanol via the fermentation of sugar using yeast. The reaction is depicted using ball-and-stick models (top) and molecular formulas (bottom).

## Wreck with champagne being lifted

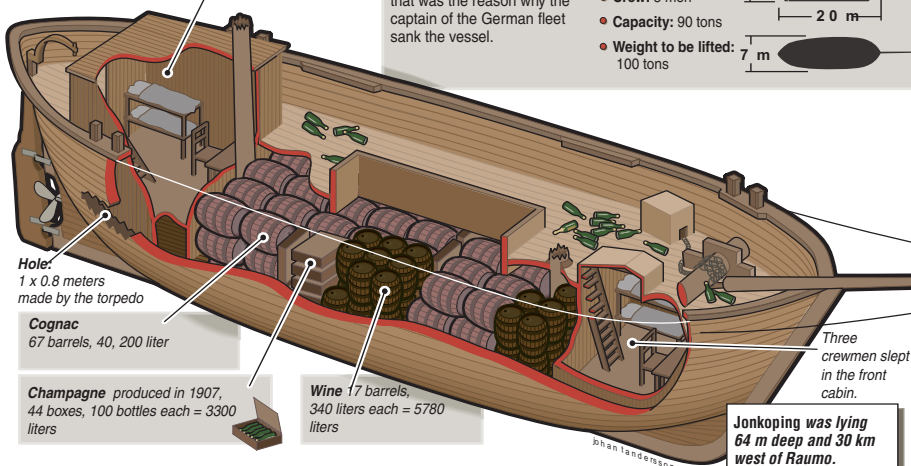
www.sgb.se

Beginning in November 1997 the work began to lift schooner *Jonköping*.

### Jönköping cargo

The value of the cargo was estimated to be 100–500 million kronor which is about \$16–\$84 million.

Two crew members lived in the back cabin.



**Hole:**  
1 x 0.8 meters  
made by the torpedo

**Cognac**  
67 barrels, 40, 200 liter

**Champagne** produced in 1907,  
44 boxes, 100 bottles each = 3300  
liters

**Wine** 17 barrels,  
340 liters each = 5780  
liters

**Jonköping was lying  
64 m deep and 30 km  
west of Raumo.**



*liqueur de triage*) is added to the still wine, and the bottle is capped. As the sugar in the wine ferments, more ethanol and carbon dioxide are produced. The carbon dioxide gas dissolves in the wine under the increased pressure (~5–6 atmospheres) and the "fizz" is created.

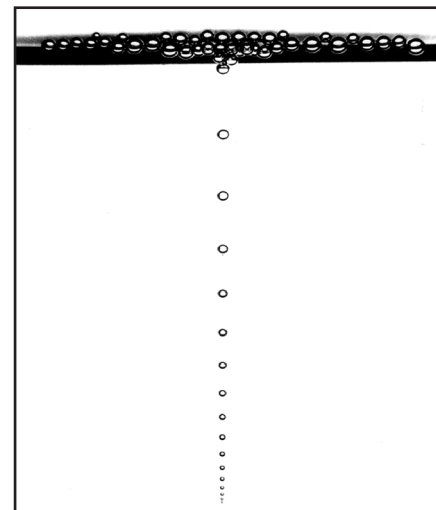
This process must be kept under anaerobic conditions to prevent oxygen from reacting with the ethanol, turning it to acetic acid. Oxygen could also react with the sugar directly, producing only  $\text{CO}_2$  and water.

## Effervescence: understanding bubbles

When one thinks about champagne, a glass of bubbling beverage usually comes to mind. But why do bubbles form in champagne? The bubbles form as a result of previously dissolved carbon dioxide gas escaping from solution. Carbon dioxide is a gas at room conditions with only minimal solubility in water. Reduction in pressure or addition of heat reduces its solubility further. After the cork comes out, the pressure above the liquid is reduced, and the carbon dioxide starts its journey to the surface! But in order for the  $\text{CO}_2$  to come out of solution, it first needs a place where microscopic vapor bubbles can congregate until they form a buoy-

ant bubble. Called a nucleation site, it may be an imperfection in the glass, some dust or any other deposit that prompt the  $\text{CO}_2$  to make a phase transfer or to come out of solution.

Once the bubble develops enough buoyancy, it detaches from the nucleation site and continues to grow as it rises. Bubbles grow as they ascend in the glass or bottle because carbon dioxide diffuses from the liquid into the gas bubble. The higher pressure of the gas dissolved in the liquid compared with that



Typical photograph of a regular bubble train. The nucleation site is at the very bottom, possibly a tiny imperfection in the glass.

## Other Treasures From the Deep

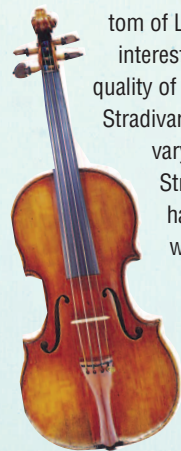
Sunken treasure can also be found in the Great Lakes of North America. No gold doubloons or precious jewels from sunken pirate ships, but treasure nonetheless. The Great Lakes are currently being mined for valuable submerged lumber! Sonar equipment is being used to locate and salvage logs that were lost between the mid-1800s and early 1900s while the wood was en route to lumber mills.

The dense virgin forests in which this wood grew no longer exist. This lumber, preserved in the cold waters of the Great Lakes, is unlike anything that can be found today. The density and grain quality of the wood are extremely high, with the added benefit that it comes from tree types such as red birch, red oak, hard maple, beech, and white pine that may no longer be available to woodworkers. Its long stay under water has done much to change the wood's chemistry, which, in turn, has added to its value as "recovered treasure".

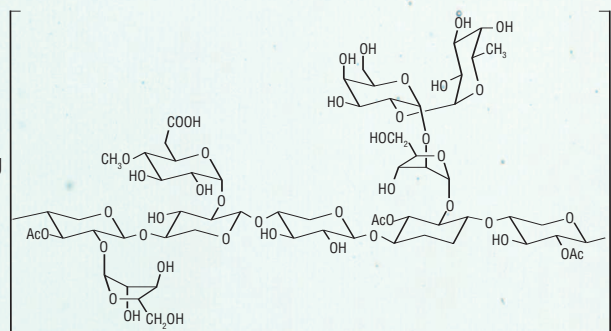
When wood is submerged in water, anaerobic bacteria eat a cell wall material called hemicellulose. Hemicellulose is a natural polymer with a random, amorphous structure. The monomers that are joined to make this polymer include glucose, mannose, arabinose, xylose, and glucuronic acid.

Once the hemicellulose has been digested, it is theorized that minerals seep into the cells, crystallize, and ultimately enrich the quality of the wood. Salvaged lumber is finding new life in the making of fine furniture and, even more interesting, musical instruments.

Joseph Nagyvary (retired professor of biochemistry, Texas A&M, College Station, TX) has been building violins recently from wood found at the bottom of Lake Superior. Long interested in the superior quality of the legendary Stradivarius violin, Nagyvary theorized that Stradivarius may have soaked the wood he used for



making violins, sometimes for months or even years, in mineral-rich water. Once dried, this wood took on outstanding qualities found only in the now-famous violins. Salvaged lumber is becoming a prize for woodworkers around the world. And those who are selling salvaged lumber are certainly finding it to be like "treasure", every bit as valuable as gold. Boards cut from this rare lumber are selling for hundreds and even thousands of U.S. dollars! Not bad for an old piece of wet wood.



The structure of hemicellulose.

inside the bubble determines how big the bubble will ultimately become. This bubbling phenomenon is known as effervescence.

Champagne makers would like to better understand their bubbles and learn to control them because people (especially in France) make a connection between the quality of the champagne and the smallness of the bubbles. Recent scientific studies of champagne have revealed some interesting information. The data have shown that different concentrations of protein molecules in the champagne affect the bubble chemistry (and physics). Rising bubbles often pick up suspended or dissolved materials that stick to bubble surfaces.

Adsorbed molecules stiffen a bubble by forming a molecular layer on its surface. According to fluid mechanics, a stiffer sphere moving through a liquid runs into more resistance, or drag, than one with a more flexible skin. These adsorbed molecules tend to slow bubbles down. In the absence of other influences, such as a nearby glass wall, the most rigid bubbles show the greatest drag. Champagne has little protein to form the more rigid bubbles found in other beverages (like soda, for example) and therefore grow too quickly to produce much drag. As a result, small bubbles in champagne rise to the surface rapidly ... a trait that characterizes "bubbly."

## Back to making champagne

The wine is now stored in a cool (11 °C) dark cellar, sometimes for several years, during which time the dead yeast cells called lees give flavor to the wine. Occasionally, the bottles, now stored upside down, will be turned and tapped to release the dead yeast cells, which will fall into the neck of the bottle. This part of the process is called remuage. Next comes degorgement; the neck of the bottle is frozen, and the frozen sediment of dead yeast cells is removed. The remaining solution is topped off with wine and sealed with cork, wire, and foil and voila ... champagne! The entire process takes at least 1 year for nonvintage champagnes, while vintage champagnes require three years or more. Quality vintage champagnes can command a high price, sometimes even hundreds of dollars. And rare vintage wines have commanded thousands of dollars per bottle at auction. In 1985, Malcolm Forbes paid \$156,450 for a single bottle of Thomas Jefferson's Lafite Rothschild 1787!

## Back to our story

Over 2000 bottles of rare, vintage Heidsieck & Co. Monopole 1907 "Gout Americain" champagne were eventually salvaged from the *Jonkoping*. Chemical analysis and tasting revealed that the bottles contained exceptional champagne with no negative effects from the long stay on the floor of the Baltic Sea. In October 1998, the famous auction house, Christie's, sold 24 bottles at a staggering price of about \$3000 per bottle. (This was still far below what Christie's had estimated ... \$8000/bottle.) Much of the champagne is now in storage and will eventually be sold. Current estimates place the value of the cargo at between \$8 and 10 million. ▲

### REFERENCES

- Lemonick, M., Stradivari's Secret—Biochemist Joseph Nagyvary's Research on Violin-Making, *Discover*, July, 2000.  
Liger-Belair, G., Effervescence in a Glass of Champagne: A Bubble Story, *Europhysics News*, 2002, 33.  
Weiss, P., The Physics of Fizz, *Science News*, May 6, 2000.  
Additional references can be found in the Teacher's Guide for this issue.

**Tim Graham** teaches chemistry at Roosevelt High School in Wyandotte, MI. His most recent articles of *ChemMatters* include "Poisoned" and "The Secrets of the Samurai Sword Revealed" which both appeared in December 2005.

# THERMOMETERS



**You are feeling sick.  
You call the doctor and  
she wants to know the  
average kinetic energy  
of your body's molecules.  
What will you do?**



By Brian Rohrig

**W**e have all used a thermometer—to check for a fever, record data during a chemistry lab, or to help us decide how to dress before leaving for school in the morning. But have you ever thought about how a thermometer works? And when you measure temperature, just what exactly are you measuring?

The prefix thermo- refers to heat. Thermodynamics is the study of heat. A thermos either keeps heat in or out. You wear thermal underwear to prevent body heat from escaping. Despite its name, however, a thermometer does not actually record heat, but rather temperature. Temperature and heat are two radically different concepts.

Temperature is a measure of the average kinetic energy of the molecules within a substance. When you record the temperature of something, you are making a statement about how fast the molecules are moving. When you are waiting for a bus in the morning in the middle of January, instead of saying, “Boy, its cold out here this morning,” it would be more accurate to say, “Boy, the molecules in the air are moving quite slow this morning!”

## Heat vs. temperature

Heat is a little trickier to define. Heat refers to the movement of energy from a substance of high temperature to one of low temperature. Heat always refers to energy in transit. A substance can have a high temperature, but little heat available to transfer. A drop of boiling water contains less actual heat than a bathtub full of water at a lower temperature. Temperature is a measure of only the average kinetic energy of molecules, but because heat depends on the total energy, there is not a simple, universal relation between the two.

Here's an everyday example that helps to illustrate the difference between heat and temperature. Consider ice: when you cool a drink using ice, a lot of heat flows from the drink into the ice (so the drink's temperature falls). But the temperature of the ice does not rise, it stays at 0 °C—the heat goes into breaking the interactions between water molecules to melt the ice (at 0°) to form water (still at 0°). Ice and water at 0° have the same temperature but very different amounts of heat.

## Temperature scales

In the United States, most thermometers for everyday use are calibrated in degrees Fahrenheit. Most of the rest of the world measures temperature in degrees Celsius. At one point during the 18th century, there were nearly 35 different temperature scales in use! Many scientists felt the need to devise a uniform temperature scale that would meet widespread acceptance.

One temperature scale that met with some success was the Romer scale, which was first used in 1701. This temperature scale was invented by Ole Christensen Romer, a Danish astronomer whose biggest claim to fame was measuring the speed of light in 1676. His temperature scale set the boiling point of water at 60° and the freezing point at 7.5°. The lowest temperature you could achieve with a mixture of salt and ice was 0°. Because most people from that time period were not too concerned about the temperature of ice and salt, this scale was destined for the dustbin of history.

Daniel Gabriel Fahrenheit, a German physicist, published an alternate scale in 1724. Borrowing from the work of Romer,

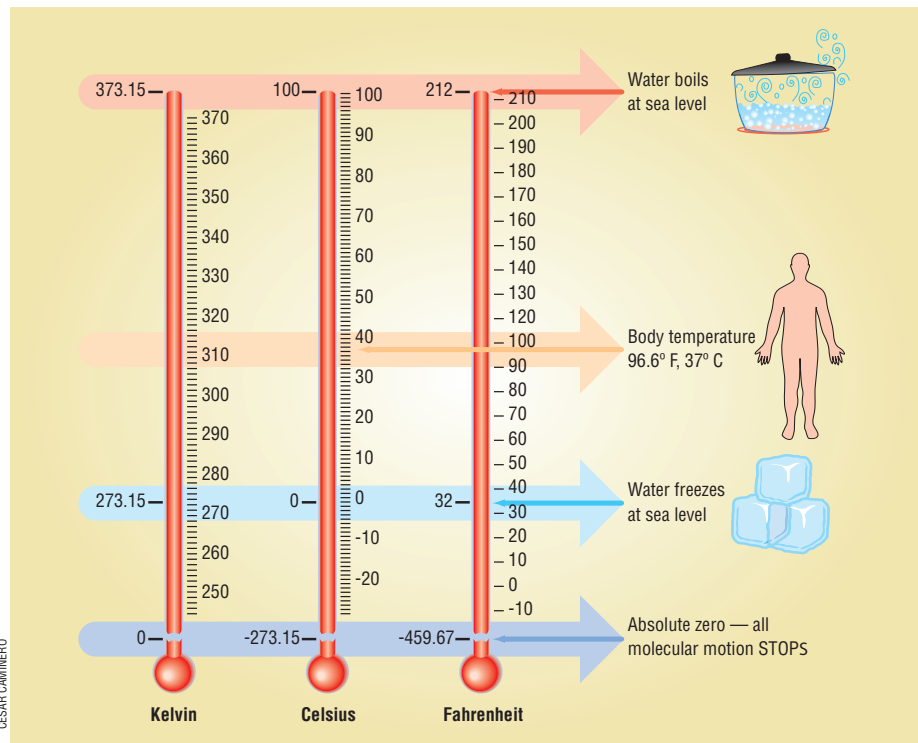
he set 0 °F as the lowest temperature that could be achieved with a mixture of salt, ice, and ammonium chloride. (It is unclear whether Romer also used ammonium chloride in his experiments, as many of his records were destroyed in a fire.) Fahrenheit set the freezing point of water at 32° and the body temperature of a person at 96°, which he determined by measuring the temperature under his wife's armpit. Each degree of his scale corresponded to one ten-thousandth the initial volume of mercury used in his thermometer. To this day, there is considerable controversy as to how Fahrenheit actually arrived at his temperature scale. He never did reveal exactly how he arrived at the reference points for his thermometer, as he did not want others to construct and sell the thermometers he had spent much of his life perfecting.

His scale met widespread acceptance because everyone could relate to it, since 0 °F and 100 °F were the lowest and highest temperatures typically experienced on any type of regular basis in Western Europe. If the temperature rose above 100°, you knew it was really hot. If the temperature dipped below 0°, you knew it was quite cold. Whether these points were intentionally chosen to represent these extremes or just happened to work out this way is still being debated today. The biggest problem with this scale was the freezing and boiling points of water were set at 32° and 212°, not exactly round numbers. This was an issue not so much with the general public, but rather with scientists, who tend to obsess over such things. However, others have postulated that placing 180 degrees between the freezing and boiling points of water was not arbitrary but quite rational, as this number represents the number of degrees in half a circle.

To counter this problem, Swedish astronomer Anders Celsius came up with another scale in 1742, setting the freezing and boiling points of water at 0° and 100°, with 100 divisions in between. Hence, it was termed the Centigrade scale, since the prefix centi- represents one-hundredth. Celsius had initially set the freezing point of water at 100° and the boiling point at 0°. This was later reversed after his death. Most countries that have adopted the metric system of mea-

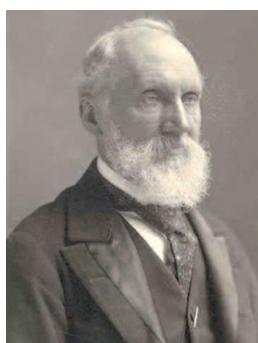


Anders Celsius



A comparison of three temperature scales.

surement use this temperature scale, as it is conveniently broken down into units of 10. In 1948, the Centigrade scale was officially designated the Celsius scale, although some people still use the outdated term.



Lord Kelvin

The most scientific scale in use today is the Kelvin, or absolute, temperature scale. It was devised by British scientist William Thomson (Lord Kelvin), in 1848. Because temperature is a measure of molecular

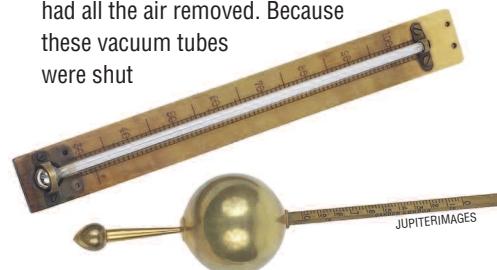
motion, it only makes sense that the zero point of your scale should be the point where molecular motion stops. That is exactly what the Kelvin scale accomplishes. 0 Kelvin (K) is the point at which all molecules stop moving. 0 K is known as absolute zero, which has never actually been reached. In 2003 at MIT, scientists came very close to reaching absolute zero, obtaining a frosty temperature of  $4.5 \times 10^{-9}$  K.

The Kelvin scale is primarily used in science, and temperature must be expressed in Kelvin when solving many equations involving temperature, such as the gas laws. But it tends to be too cumbersome for everyday use, since the freezing point of water is 273 K and the boiling point is 373 K.

## Types of thermometers

### Early thermometers

The first thermometer in modern times was a crude water thermometer believed to have been invented by Galileo Galilei in 1593. In 1611, Sanctorius Sanctorius, a colleague of Galileo's, numerically calibrated the thermometer. Many of these first thermometers used wine, as its alcohol content prevented it from freezing and its red color made it easy to read. However, these first thermometers were very sensitive to air pressure, and functioned as much as a barometer as they did as a thermometer. So eventually, all thermometers were constructed of a sealed glass tube that had all the air removed. Because these vacuum tubes were shut



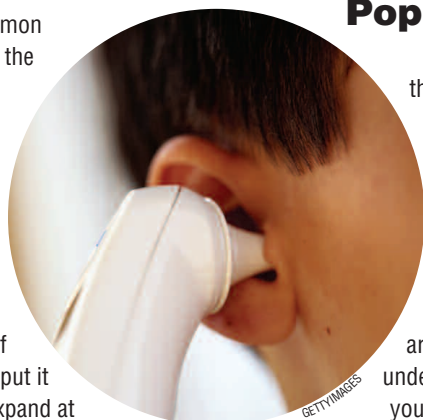
off from the outside atmosphere, changes in air pressure would not affect the temperature reading. In 1709, Fahrenheit invented the alcohol thermometer, and in 1714, he invented the first mercury thermometer. All thermometers work according to the same basic principle: objects expand when heated and contract when cooled.

## Bulb thermometers

The most common thermometer is the bulb thermometer, which comprises a large bulb filled with a liquid and a narrow glass tube through which the liquid rises. All liquids expand when heated and contract when cooled (with the exception of H<sub>2</sub>O near its freezing point; ice-cold H<sub>2</sub>O at 0 °C contracts until 4 °C where it expands like other materials), which explains why the liquid within a thermometer rises as the temperature increases and falls when it decreases. Mercury was the liquid of choice for many years, because it expands and contracts at a very constant rate, making mercury thermometers very accurate. However, because of concerns about mercury toxicity, mercury has often been replaced with alcohol that is colored red. Mercury has a silver color. It freezes at -39 °C, so it cannot be used if temperatures get colder than this.

## Bimetallic strip thermometers

Another very common type of thermometer is the bimetallic strip thermometer. This thermometer comprises two different metals, such as copper and iron, which are welded together. Each of the metals used has a different coefficient of linear expansion, or to put it simply, these metals expand at different rates. Connected to this bimetallic strip is a pointer, which points to the correct temperature on the face of the thermometer. Because these metals expand at different rates, when heated, the welded strip of metal will bend. When cooled, it will bend in the opposite direction. A variation of the bimetallic strip thermometer is the thermostat used in homes and automobile engines. These thermostats



Infrared thermometer

are made of a thin bimetallic strip, which is fashioned into a coil, making it more sensitive to minor temperature fluctuations.

## Infrared thermometers

A fascinating thermometer is the infrared thermometer. This handheld device is used by simply pushing a button as you point it toward an object. A digital readout tells you the temperature. All objects above absolute zero are emitting infrared radiation (IR)—an invisible (to human eyes) form of electromagnetic energy. The infrared radiation we emit is commonly known as body heat. The infrared thermometer has a lens that focuses the infrared energy into a detector, which measures the IR intensity and converts that reading to temperature. Infrared thermometers have a wide variety of applications. They are used by firefighters to detect hot spots in buildings and in restaurants to ensure that served food is still warm. Infrared thermometers are also used for determining the temperature of a human body, automobile engines, swimming pools, hot tubs, or whenever a quick surface temperature is needed.

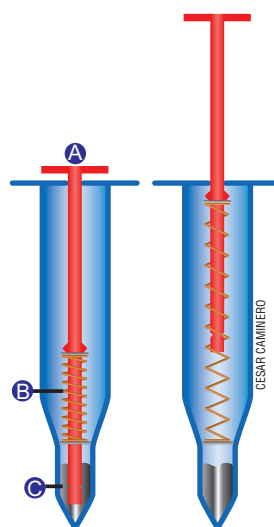


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## Pop ups

You are cooking that Thanksgiving turkey, and you want to make sure that the inside of the turkey is completely done. To ensure that you are not feasting on undercooked bird, you can use an ingenious device known as the pop-up turkey

timer. This instrument is simply stuck into the turkey, and when the turkey is done, a red indicator pops up (A). The little red indicator is spring loaded (B) and is held in place by a blob of solid metal (C). When this metal reaches a temperature of 85 °C, which is the temperature of a



Popup turkey timer

fully cooked turkey, it melts, causing the red indicator to pop up.

This technology is similar to that used in sprinklers found on the ceilings of many buildings, which actually served as the inspiration for the pop-up turkey timers. When a certain temperature is reached, a metal component within these sprinklers melts, activating the sprinkler. By mixing together different metals, a particular alloy can be created with a desirable melting point. Pop-up timers can be purchased for a wide variety of different types of meat, from ham to hens. You can even buy a pop-up timer for steak, which pops up in increments indicating rare to well done.

## And now for something completely different...

Perhaps the most unusual thermometer ever invented is the Galileo thermometer, based on a similar device invented by Galileo. This instrument does not look like a thermometer at all, as it is composed of several glass spheres containing different colored liquids that are suspended in a cylindrical



Galileo thermometer



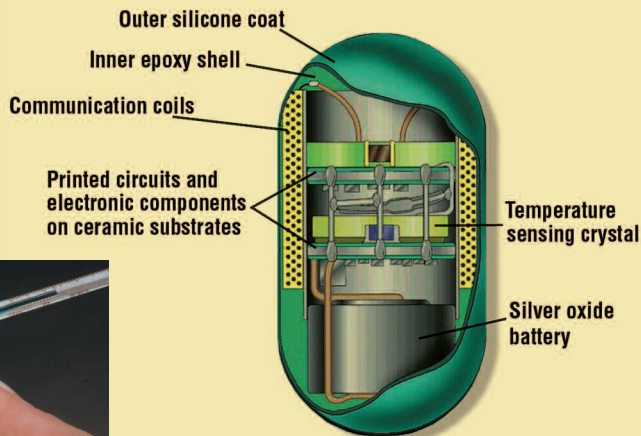
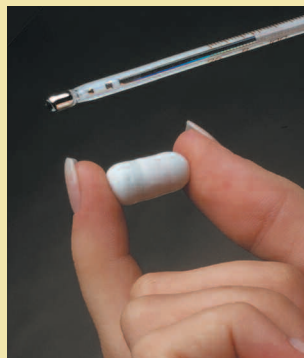
column of a clear liquid. Attached to each of the colored spheres is a little dangling metal tag with an engraved temperature. The temperature is determined by reading the tag on the lowest floating sphere. As the temperature rises, the spheres will begin to fall one by one. When the temperature falls, the spheres will then rise one by one.

The liquid within each glass sphere is composed of either colored water or alcohol. Each of the spheres is of a slightly different mass, and thus a slightly different density, since the volume of each sphere is the same. Each sphere differs in mass by about 0.006 grams. This difference is accomplished by making each tag a slightly different mass. The clear liquid surrounding the spheres is an inert hydrocarbon-based oil, similar to mineral oil. When this liquid is heated, it expands, becoming less dense. Less dense liquids exert a lesser buoyant force, so the most dense sphere will then sink. If the temperature continues to rise, the molecules of the surrounding liquid will continue to spread apart from one another, causing more spheres to fall. As the liquid cools, its molecules come closer together, exerting a greater buoyant force, causing the spheres to rise. The spheres themselves do not expand or contract nearly as much as the surrounding liquid when heated or cooled, since they are composed of glass, which hardly expands at all when heated.

Even though it looks nothing like a conventional thermometer, the Galileo thermometer still functions according to the same basic principle as most other thermometers: substances expand when heated and contract when cooled.

## What's the future for thermometers?

Technology has come a long way since Galileo's day, but his thermometer to this day has a futuristic look to it. Another futuristic thermometer that is available today is the CorTemp thermometer. Developed by Dr. Leonard Keilson of the Applied Physics Laboratory of the Johns Hopkins University in conjunction with NASA, the CorTemp thermometer is swallowed, allowing accurate temperature readings while it travels through, or is stationed at some particular spot in the body. The probe is enclosed in a small pill that is taken internally, while the temperature read-



The CorTemp system can measure and record the body temperature and/or heart rate of many athletes on the field during practices or competition. Once the probe is inside the gastrointestinal tract, a crystal sensor vibrates at a frequency relative to the temperature of the body tissues surrounding it. These data are then transmitted harmlessly through the body to the monitor.

COURTESY OF CORTEMP

ings are recorded on a device that is monitored externally.

No matter what device you use to take your temperature when you have a fever, none will make you feel better. But in this techno-

logically advanced world today, your choice of thermometer might bring you a bit of welcomed distraction while measuring the average kinetic energy of your body's molecules. ▲

### REFERENCES

- Maddox, B. Nightmare of divided loyalties. *Discover*. June 2006, pp 26–27.  
 Shactman, T. *Absolute Zero and the Conquest of Cold*. Houghton Mifflin Company: New York, 1999.

### INTERNET REFERENCES

- Fahrenheit  
<http://en.wikipedia.org/wiki/Fahrenheit>  
 How Pop-Up Turkey Timers Work  
<http://home.howstuffworks.com/pop-up-timer.htm/printable>  
 How Thermometers Work  
<http://home.howstuffworks.com/therm.htm/printable>  
 The History Behind the Thermometer  
<http://inventors.about.com/library/inventors/blthermometer.htm>

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## The Race for Iodine



By Mark Michalovic

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### The emperor

Napoleon Bonaparte was known for lots of things. He was a soldier, a general who conquered most of Europe. He was emperor of France. He had a dessert named after him. However, not everyone knows that the little emperor had a thing for science. It may seem odd that even though he was engaged in a war with England, Napoleon would allow the biggest star of British science to visit France to mix and mingle with the top French scientists of the day. Nevertheless, that's just what happened in October 1813. Napoleon granted Sir Humphry Davy permission to spend several weeks in France, even though their two countries were in the middle of a war. There wasn't much Napoleon loved more than war, but it seems even war could take a back seat to his love of science now and then. Little did the emperor realize how much trouble would be stirred up by his graciousness.

### The showman

Humphry Davy was born in a far corner of England in a town called Pen-



Bonaparte

zance. His family wasn't wealthy, and Davy never had a lot of formal education. He educated himself through his own hard work and became the most important chemist in Britain. A man of many interests, Davy also wrote poetry. Samuel Taylor Coleridge, William Wordsworth, and Lord Byron were his good friends. He loved hunting and fishing as well.

Davy first made a big splash in science when he discovered the effects of nitrous oxide, or laughing gas, when he was only 21 years old. Later, he discovered two new elements, sodium and potassium, with the help of electricity from a new-fangled battery. He then went on and discovered four more elements: magnesium, calcium, strontium, and barium.

Davy wasn't just a researcher. He was also an entertainer. In those days, lots of people paid money to see science demonstrations. Davy wowed audiences with the wonders of chemistry and electricity. His charm and charisma made him the most famous

scientific showman in Britain, and there was nothing Davy loved more than fame.

He didn't mind money, either. In 1813, Davy had plenty of that too, as he married a wealthy widow named Jane Apreece, not long before he left for France. Humphry and Jane would make a sort of honeymoon out of the trip. Not many brides dream of spending their honeymoons in the middle of international scientific spats, but that's what awaited the new Mrs. Davy as the couple headed south across the English Channel.

### The protégé

Joseph-Louis Gay-Lussac hailed from a part of central France called Limousin. He was the exact opposite of Humphry Davy in many ways. While Davy had taught himself everything he knew about science, Gay-Lussac had attended the best schools for math and science in France. While Davy was flamboyant and charismatic, Gay-Lussac was calm and reserved. Davy loved leisure, spending lots of time on his many hobbies, while Gay-Lussac seemed to have been wholly devoted to his science. Spending time with his wife Josephine and their children was about his only escape from his work.

Gay-Lussac was patient and careful in the lab. A very by-the-book kind of guy, he was very cautious about drawing any conclusions from his experiments. When he did draw conclusions, he always had lots of experimental results to back them up. This approach paid off when Gay-Lussac discovered Charles' law ( $V_1 / T_1 = V_2 / T_2$ ) and when he discovered that gases always reacted in simple whole number ratios by volume.

Gay-Lussac and Davy were often rivals. After Davy discovered sodium and potassium, the two scientists competed to learn as much as possible about the two new metals. Each often thought the other was horning in on his scientific turf as they raced to make new discoveries. When Davy showed up in Paris in October 1813, perhaps it was only a matter of time before they'd end up competing against each other again.

Gay-Lussac was a friend of an older chemist by the name of Claude-Louis Berthollet. Berthollet had trained Gay-Lussac to work in the lab, and Gay-Lussac was like a son to Berthollet. Berthollet had also brought Gay-Lussac into a circle of scientists who often met at Berthollet's house in the village of Arcueil (pronounced "Ar-koy"), just outside Paris. This group was called the Society of Arcueil, and it included some of France's leading scientists. Members could use Berthollet's laboratory and were more likely to get their papers published in the scientific journals Berthollet published. It definitely paid to be a friend of Berthollet.

Berthollet had sent Gay-Lussac on one of his first adventures as a scientist. In 1804, Berthollet asked Gay-Lussac to carry out a very dangerous experiment. Wanting to measure the earth's magnetic field at high altitudes, he rode a hydrogen balloon to a height of over 23,000 feet above sea level. This set a world record that stood for almost 50 years.



Davy



Gay-Lussac

Nine years later, Humphry Davy was making a stir by visiting France during the middle of a war. In November 1813, while Davy was in Paris, Gay-Lussac was given an assignment by the National Institute, France's leading scientific organization. Two not-so-well-known chemists, Nicolas Clément and Charles Bernard Desormes had reported that a strange new substance had been discovered in seaweed. The substance formed small black crystals and could produce a purple vapor. Even though it was a solid, it seemed similar to chlorine in some ways. Clément and Desormes had carried out some experiments on the new substance and reported them to the Institute. They claimed, among other things, that the substance formed an acid when it came into contact with hydrogen. Gay-Lussac was assigned to review their experiments and repeat them to make sure the results were correct. He set to work, studying the substance carefully and thoroughly. While studying it, he gave the substance a new name. He called it iode, from an ancient Greek word for "purple." Little did he know that Davy had already been tipped off.

## The outsider

Perhaps more brilliant than any of the scientists in the Society of Arcueil was a physicist and mathematician by the name of André-Marie Ampère. He had been a child prodigy and made important discoveries about electricity. He was a scientific genius, but he could be awkward in social situations. He never cozied up with Berthollet and the Society of Arcueil the way Gay-Lussac had.

Maybe if Ampère had been tighter with the Society of Arcueil, they might have told him to be more careful about what he told Davy. At any rate, some time before Clément and Desormes announced their new substance to the National Institute, they gave a sample of the substance to Ampère. Six days before the announcement, Ampère, Clément, and Desormes paid a visit to Humphry Davy. Ampère brought with him a sample of the substance to show the famous visitor. It's at this point that a misunderstanding took place. Ampère probably thought he was showing Davy the new substance as a courtesy to a visitor. On the other hand, Davy claimed the French scientists were asking him to investigate the substance—as if French chemists weren't smart enough to do that themselves. (Davy was known for his big ego.) Davy had brought a trunk of scientific glassware and instruments with him from Britain. Now, he had a reason to use it and got to work. He began to study the new iode, and gave it its English name, iodine.

## The race

Once again, Davy and Gay-Lussac were in competition. Gay-Lussac thought Davy was being a bad guest by nosing in on a French discovery right on their home territory. Both probably couldn't forget that their two countries were at war, and the rivalry took on a nationalistic tone. Davy was researching for King and Country, while Gay-Lussac was researching for the glory of France. As they carried out extensive investigations of iode, neither Davy nor Gay-Lussac seemed to care much that they were both technically nosing in on Clément and Desormes, who had first brought iodine to everyone's attention in the first place.

Both had originally suspected that iodine was a compound of chlorine. But before long both Davy and Gay-Lussac were thinking that this might just be a new element. In those days, the word "element" didn't mean exactly

the same thing as it does now. Today, we learn in chemistry class that an element is a substance made of only one kind of atom. But in 1813, John Dalton's atomic theory was only a few years old, and not everyone accepted it yet. Davy especially didn't like it. Gay-Lussac thought Dalton was onto something but didn't say so publicly because Berthollet felt otherwise. Even so, chemists still talked about elements. To chemists of those days, an element was a substance that couldn't be broken down into simpler substances. In fact, this definition is just as valid today as it was then. Only now we have a microscopic view (where all atoms are the same) to complement the macroscopic view. Davy and Gay-Lussac both tried to break iodine down, hoping to free the chlorine they thought it contained. Neither succeeded, and both suspected that iodine wasn't a compound of chlorine, but an element in its own right.

Both Davy and Gay-Lussac published their ideas. Gay-Lussac beat Davy to press by one day, but each always insisted that he'd reached the conclusion first. Either way, Gay-Lussac probably discovered more new knowledge about iodine in the long run. While Davy soon left Paris, traveling with his new bride to Italy, where he studied the chemistry of diamonds, Gay-Lussac kept studying iodine. Gay-Lussac finally published a 155-page paper filled with his experiments and the results. It was considered the best source of information about iodine for many years.

It took several different scientists to get to the bottom of the puzzle of iodine. Courtois, Clément, Desormes, Gay-Lussac, and Davy all played roles. This is how science often works. Many people take part in a discovery, sometimes working together, sometimes competing against each other. Sometimes, the world outside the lab plays a big part in shaping what scientists do. While the path is seldom straight, the road to discovery is almost always an exciting one. ▲

### REFERENCES

- Crosland, M. *Gay-Lussac: Scientist and Bourgeois*. Cambridge: Cambridge University Press, 1978.
- Crosland, M. *The Society of Arcueil: A View of French Science at the Time of Napoleon I*. London: Heinemann, 1967.
- Knight, D. *Humphry Davy: Science and Power*. Cambridge, MA: Blackwell, 1992.

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## More on elements

In the *Race for Iodine* you looked back at an age where few elements were known. Today you have at your fingertips all sorts of information on over 100 elements. For an awesome Web site that provides loads of information on the elements, head to:

[http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=sitertools%5Cperiodic\\_table.html#](http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=sitertools%5Cperiodic_table.html#)

## Don't forget!

The deadline for the National Chemistry Week Poster Contest is January 31, 2007. The theme of your poster must relate to the chemistry of the home or home safety. There are prizes for all age groups. For more information, see the online guide at [www.chemistry.org/ncw](http://www.chemistry.org/ncw).

## Chemists, start your engines!

The February issue of *ChemMatters* will feature an article on a sport that arguably has the greatest amount of chemistry involved—stock car racing. Veteran writer Brian Rohrig will take us behind the scenes for the exciting chemistry behind NASCAR racing!



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## As for the He balloon in the car...

As the car turns sharply to the right (for example) and everything in the car leans to the left, the balloon actually accelerates to the right — into the turn! There really is no such thing as

centrifugal force. It's more the momentum of the objects in the car and their tendency to continue along a straight line path. As the car turns right, the objects inside tend to go straight, it seems that they are all being pushed outward. All except for the balloon—it seems to get "pushed" inward. But consider the air in the car: it also tends to continue in a straight line and therefore gets crowded to the outside. This creates a pressure gradient sideways inside the car, from a high pressure on the left side where the air is more concentrated to a lower pressure on the right. This is



just like the bottom to top pressure gradient caused by gravity in the room.

And whereas that gradient gives the balloon an upward acceleration, the sideways gradient in the car pushes the balloon inward (to the right).

## We'd like to hear from you!

The team at *ChemMatters* wants your input on how to make the magazine better. Send your comments and suggestions to: Editor, *ChemMatters* Magazine, ACS Room 823, 1155 16th St. NW, Washington, D.C., 20036.

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