UNIT 8: SOLUTIONS

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#21: PREDICT THE PRODUCTS OF DOUBLE REPLACEMENT REACTIONS	UP IN SMOKE
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Tapping Saltwater for a Thirsty World

By Melissa Stewart

Water, water, everywhere,

And all the boards did shrink;

Water, water, everywhere,

Nor any drop to drink.

These famous words come from "The Rime of the Ancient Mariner," an epic poem written by Samuel Taylor Coleridge in the late 1700s. Nearly dying of thirst on a storm-damaged vessel, the sailor in the poem refused to drink the ocean water all around him. He knew the salty seawater would kill him more quickly than not drinking anything at all.

Our bodies are, by mass, between 55 and 65% water. If we lose just 2% of that fluid, we will feel extremely thirsty. And if we lose 20%, we will die. That's why it's so important to drink plenty of water every day. A person deprived of water can live for only 2–14 days, depending on the conditions.

Why is water so important? It helps our cells, tissues, and organs do their jobs. The fluid in our bodies helps digest food and circulate blood. Dissolved ions, or electrolytes, in the fluid regulate osmosis—the flow of materials in and out of our cells.

Most of the time, water flows across cell membranes from areas where electrolyte concentrations are low to areas where electrolyte concentrations are high. As a result, the concentrations of sodium (Na^+), chloride (Cl^-), potassium (K^+), and other ions determine the size and shape of cells. If too much fluid moves into a cell, it will expand and eventually burst. If too much liquid flows out of a cell, it will shrink and eventually shrivel up. Cells with too much or too little water cannot function properly.

Like our body fluids, ocean water contains dissolved ions. If you've ever swallowed a bit of seawater, you've tasted these salty particles. The salt in seawater is very similar to the salt you sprinkle on French fries. It consists mostly of sodium chloride, existing as positively charged sodium ions and negatively charged chloride ions. Depending on the location, seawater may also contain smaller amounts of 53 other ions.

When a person drinks too much seawater, the dissolved ions disrupt the normal balance of electrolytes in his or her body fluids. Because too many electrolytes suddenly flood the fluid outside cells, large amounts of water flow out of the cells. If a person's brain cells dehydrate too much, they will collapse, and the person will experience seizures, coma, and finally death.

See for Yourself

You will need:

A 1-L graduated beaker filled to the liter mark with water;
10, 25, and 50-mL graduated cylinders;
Three smaller beakers;
A dropper;
A piece of wax paper;
Measuring spoons;
Table salt (sodium chloride).

Imagine that the water in the 1-L beaker represents all the water on Earth.

1. Pour 28 mL of water from the 1-L beaker into a smaller beaker, labeled "A".

How many drops to drink?

In the modern world, very few people get lost at sea. But although three-quarters of Earth's surface is covered with water, 97 percent of it is too salty to drink. Another 2.5 percent is either frozen or too far below ground to reach, leaving just 0.5 percent of Earth's water for drinking, washing, flushing toilets, and watering crops.

In the past 50 years, the human population has skyrocketed to more than 6 billion. The United Nations estimates that by 2050, 9 billion people will have to share our planet's limited resources. The International Water Management Institute predicts that by 2025 only about one-quarter of the world's people will have enough clean, fresh water.

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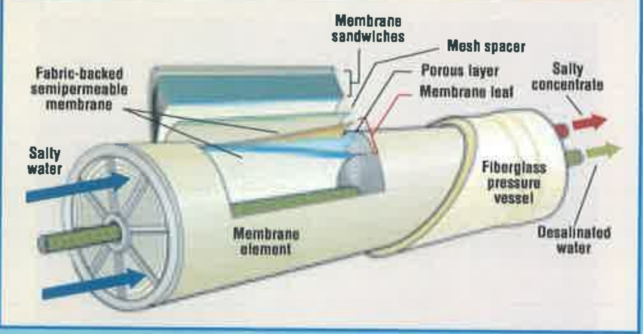

Reverse-osmosis systems are frequently spiral wound. Each membrane leaf contains a water-collecting porous layer sandwiched between two fabric-backed semipermeable membranes. Individual membrane leaves are separated from each other by a porous mesh spacer through which high-pressure saline water is passed. Purified water separates from the saline solution and passes through the membranes into the sandwich's central layer, which conducts the water spirally to the central perforated collection tube. Briny concentrate is collected in a separate tube.

What's the solution to the water dilemma? People all over the world must learn to use water more wisely and, at the same time, look for new sources of water. In the United States, many of the communities at greatest risk are located in coastal states. As a result, the ocean seems like an obvious potential source of water. But there's one major problem with this idea. Before seawater can pass human lips, the salt must be removed.

From deadly to drinkable

The process of removing salt from ocean water is called desalination. There are currently about 11,000 desalination plants in operation worldwide. But they provide less than 0.2% of the total global water supply.

About two-thirds of the world's desalination plants are located in the Middle East. Most of these facilities take advantage of distillation—a technique that imitates the natural water cycle to separate the salt from the water. During distillation, seawater is heated until the water molecules evaporate, leaving the dissolved salts behind. Next, the water vapor is trapped and cooled until the gas condenses, or returns to its liquid state. The pure water flows into a large collection tank. From there, it is piped to homes and businesses as needed.

Distillation is a good solution for water-poor, oil-rich Middle Eastern nations, but the high cost of heating the water makes the process less attractive in other parts of the world. On the island of Majorca, off the east coast of Spain, one of the largest desalination plants in Europe meets drinking water demands by using a process known as reverse osmosis.

After removing large solids from the seawater, the salty water is pressed against a series of thin membranes. The membranes have tiny holes that allow water molecules, but not salt particles, to flow through them. The final result is drinkable freshwater. The process is called reverse osmosis because pressure forces the water to flow from an area where the concentration of ions is higher to an area when the concentration is lower.

In the past, the membranes used during reverse osmosis were extremely expensive and wore out quickly. In addition, they caught only about 85% of the salt. But recently, scientists have developed sturdier membranes that last three times longer and cost 20% less than older models. The new membranes also filter out nearly all of the salt.

These improvements have led many American communities to take a serious look at how desalination technology may help solve their water problems. In Florida, the Tampa Bay Water Authority is currently constructing the largest desalinated seawater facility in North America. When the plant is completed in December 2002, it will be able to process 25 million gallons of ocean water per day—about 10% of the daily volume for the region. ▲

Melissa Stewart is a science writer living in Marlborough, MA. She has written more than 30 books for children and young adults.

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2. Dissolve 1 tablespoon of salt (sodium chloride) into the water in the large beaker. This now represents the saltwater in the Earth's oceans—unfit for drinking.

The water in the small beaker A represents all the Earth's freshwater.

3. Pour 6.5 mL of water from Beaker A into another beaker labeled "B".

Now the water in Beaker A represents inaccessible freshwater tied up in glaciers and polar ice caps. You can make this more dramatic by placing Beaker A into a freezer, turning its contents into ice.

The water in Beaker B represents the remaining freshwater.

4. Pour 3.4 mL of water from Beaker B into another small beaker, labeled "C".

Now the water remaining in Beaker B represents inaccessible groundwater.

The water in Beaker C represents the entire supply of freshwater on Earth. But much of this accessible freshwater is either polluted or otherwise unavailable for use.

5. Finally, use the dropper to remove 5 drops of water from Beaker C and place them on the piece of wax paper.

These five drops are a reasonable estimate of how much drinkable water is actually available from the original 1 liter of water you started with!

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Up in Smoke

How cleaner cooking could help the environment—and save millions of lives

BY MARA GRUNBAUM | FOR *SCIENCE WORLD* MAGAZINE

As a teenager in India, Veerabhadran Ramanathan used to visit his grandparents in the summer. They lived in a small village, and his grandmother cooked on a traditional stove made of dried mud.

The firewood and dried cow dung that she burned as fuel would fill the kitchen with smoke. After hours of breathing the dirty air, his grandmother would go outside and try to clear her lungs. "She'd be coughing for up to an hour," he says.

That was more than 50 years ago. But today, many people in India and other countries still cook the way Ramanathan's grandmother did. According to the World Health Organization (WHO), nearly 3 billion people worldwide use open fires or crude stoves that burn wood, dung, or other biomass.

That's a huge problem, says Ramanathan, who's now a climate scientist at the University of California in San Diego. The soot from the stoves damages people's lungs and can eventually cause serious or even fatal diseases. It creates air pollution in areas where burning biomass is common. It's also a major contributor to global climate change, scientists confirmed last year. Now scientists like Ramanathan are trying to change all that—starting with people like his grandmother.

BURNING UP

The problem with traditional biomass stoves boils down to basic chemistry. To make a fire, you first need fuel—a material that stores energy, such as charcoal, gas, wood, or dung. Burning the fuel releases the energy in the form of heat and light. But this chemical reaction, called combustion, requires oxygen to work.

Many homemade stoves are poorly ventilated, which means that not enough oxygen-rich air can get inside. The air that does get in doesn't mix easily with a solid material such as firewood or dung, says Alessandro Gomez, a combustion scientist at Yale University in Connecticut.

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When there isn't enough oxygen, the fuel doesn't burn completely. This incomplete combustion produces gases such as carbon monoxide that are dangerous to breathe. It also creates soot—tiny particles of partially burned material that float up in the hot, rising air. Scientists call the soot black carbon.

Many things that burn fuel produce black carbon, from campfires and barbecues to jet airplanes and diesel trucks. Any time you see dark smoke coming from a fire or an exhaust pipe, "that indicates that combustion is incomplete," says David Fahey, a climate scientist at the National Oceanic and Atmospheric Administration in Colorado. "That [dark] material is black carbon."

A DARK CLOUD

Though there are many sources of black carbon, cookstoves are a particularly bad problem because people spend so much time around them, and the smoke is so hazardous to their health. Soot particles are tiny enough to lodge deep within a person's lungs, eventually leading to diseases like pneumonia and lung cancer. The WHO estimates that smoke from biomass-burning stoves kills 2 million people worldwide every year.

Black carbon also takes a toll on the environment. In regions like south Asia, soot from millions of crude stoves rises into the atmosphere and forms huge brown clouds over the area. The dark soot absorbs heat from the sun, like a black T-shirt on a hot day. Then that heat gets trapped in the atmosphere by carbon dioxide and other greenhouse gases, raising the average temperature of the planet.

Around the world, black carbon from stoves and other sources is the second-largest human-made contributor to climate change after carbon dioxide, Fahey and other researchers determined last year. That's a much bigger role than many scientists had expected. But for Ramanathan, it also presents an opportunity.

"If I could solve my grandmother's problem," he says, "I could solve this one major climate problem too."

CLEANER COOKING

Several years ago, Ramanathan teamed up with engineers to design a cookstove that burns biomass without producing so much soot. In 2009, they began distributing them in Indian villages.

The stoves have an enclosed ceramic combustion chamber that keeps heat from escaping, so they need less fuel. A solar-powered fan draws air into the chamber to provide plenty of oxygen, so less black carbon forms. Ramanathan and his colleagues gave the villagers tools to monitor the soot levels in their homes, and they found that the new stoves cut emissions by almost 90 percent.

Gomez at Yale and many others are also designing cleaner stoves for people in India, Africa, and other regions where biomass burning is common. And the United Nations recently announced that it wants to help 100 million households switch to cleaner cookstoves by 2020.

That won't be easy, says Gomez. Many people who use traditional stoves earn only a few dollars per day and may not be able to afford a new one, and some may not want to change the way they cook. But if the effort is successful, it could save millions of lives—and help the environment too.

"The challenges are enormous," says Gomez. "But the difference would be dramatic

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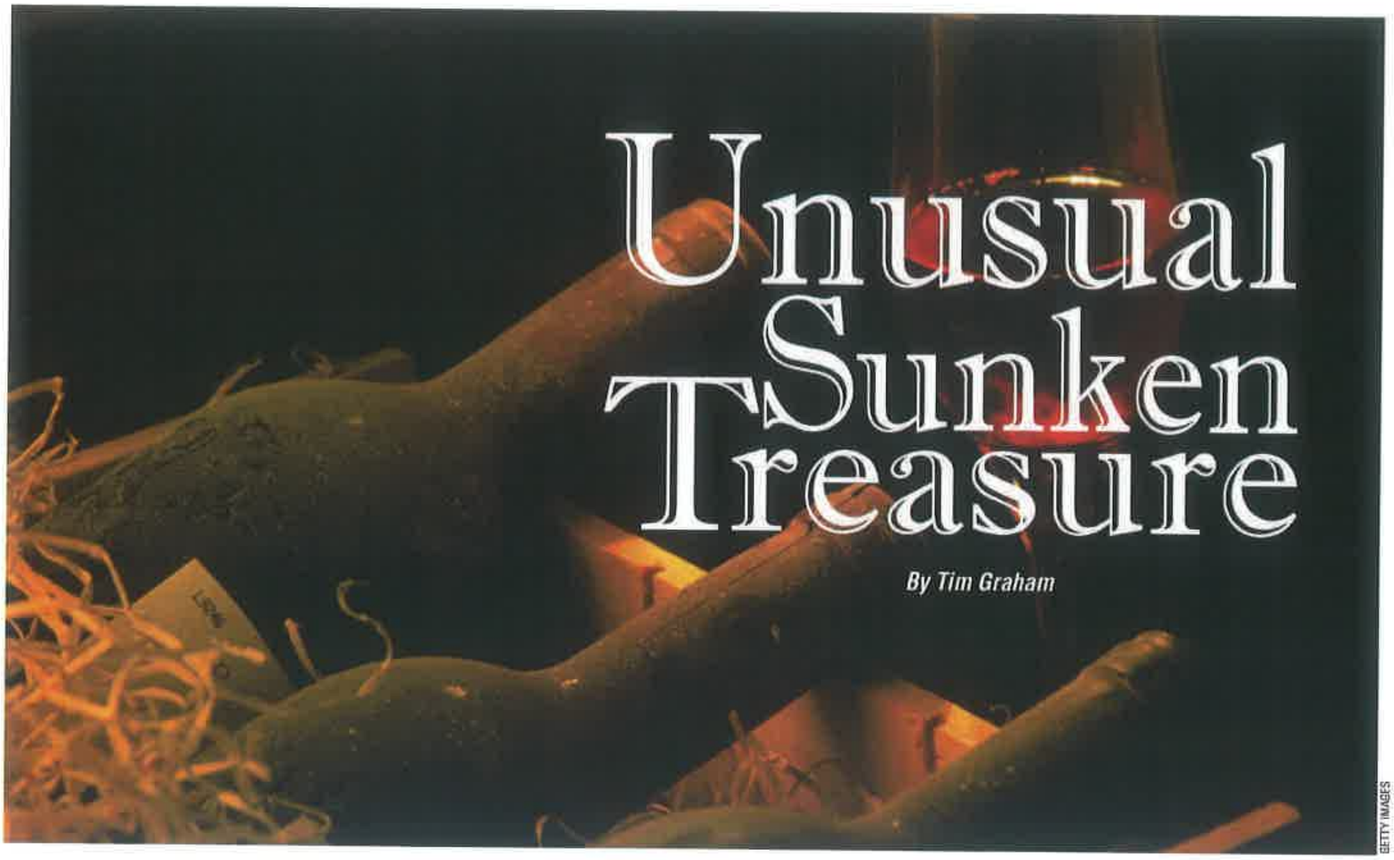


GETTY IMAGES

Unusual Sunken Treasure

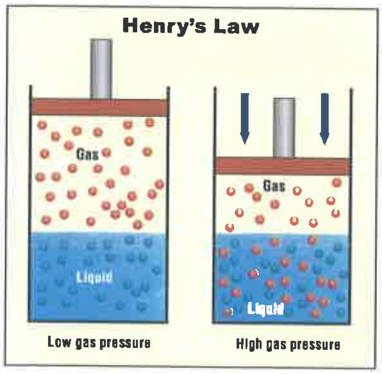
By Tim Graham

During 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 Heidsieck 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-



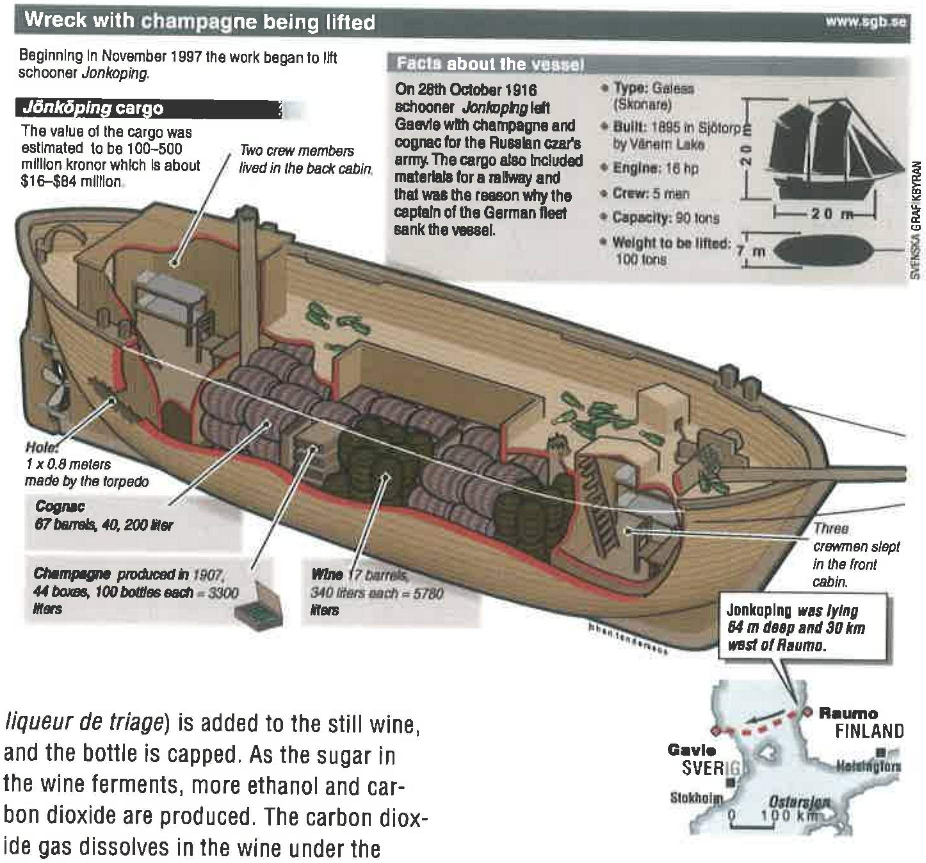
CESAR CAMINERO

In accordance with Henry's law, as the pressure on the corks decreases, more CO_2 will come out of solution.

SVENSKA GRAFIKBYRAN

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.

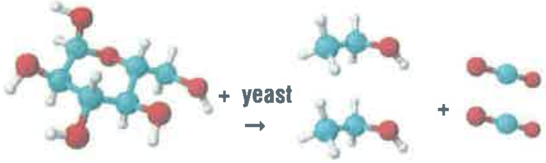


Chemistry of champagne

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 (CH_3CH_2OH, also called ethyl alcohol) and 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 *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 CO_2 and water.



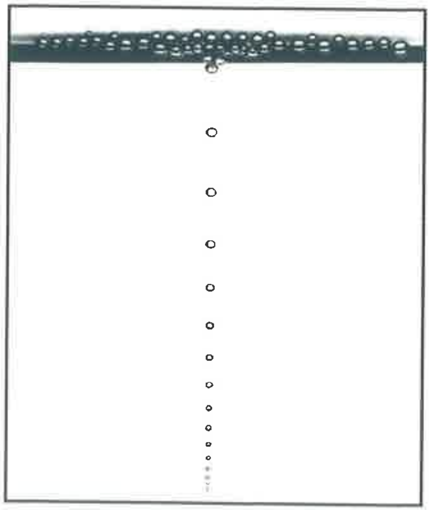
$$C_6H_{12}O_6 + \text{yeast} \rightarrow 2\,CH_3CH_2OH + 2\,CO_2$$

The formation of 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).

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 CO_2 to come out of solution, it first needs a place where microscopic vapor bubbles can congregate until they form a buoyant bubble. Called a nucleation site, it may be an imperfection in the glass, some dust or any other deposit that prompt the 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



COURTESY OF GÉRARD LIGER-BELAIR, UNIVERSITY OF REIMS, FRANCE.

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

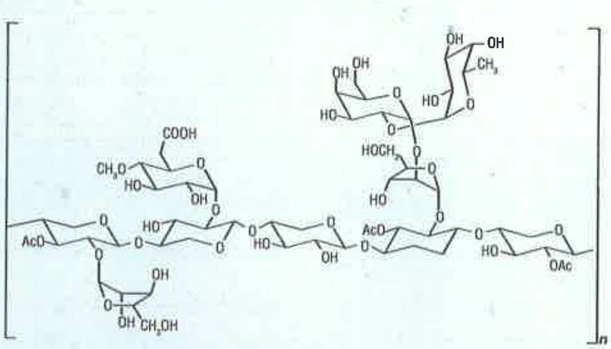
Sunken treasure can also be found in the Great Lakes of North America. No gold doubloons or precious jewels from sunken pirate ships, but treasure nonetheless. The Great Lakes are currently being mined for valuable submerged lumber! Sonar equipment is being used to locate and salvage logs that were lost 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 hemicelllulose.

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. ▲

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Additional references can be found in the Teacher's Guide for this issue.

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

ICE, Cream... and Chemistry

By Brian Rohrig

There is perhaps no fonder childhood memory than the local ice cream truck driving through the neighborhood, music blaring from its tinny speakers, beckoning all to partake of its frosty delights. But ice cream is not just for kids. **U.S. residents consume 1.5 billion gallons of ice cream each year; that's roughly 5 gallons (19 liters) per person!** The ice cream we all enjoy is the result of years of experimentation involving—you guessed it—*chemistry*!

Air is important!

If you have ever made ice cream, you already know what goes into it, ingredients such as milk, cream, and sugar. But there is one main ingredient that you may not have thought about, probably because you can't see it—*air*.

Why is air so important? If you have ever had a bowl of ice cream melt, and then refroze it and tried to eat it later, it probably did not taste very good. If you set a whole container of ice cream on the table and let it melt, the volume of the ice cream would simply go down. **Air makes up between 30% and 50% of the total volume of ice cream.**

ISTO[illegible] PHOTOS.COM, SHUTTERSTOCK

To get an idea of the effect of air on ice cream, think of whipped cream. If you whip air into cream, you get whipped cream. Whipped cream has a different texture and taste than plain cream. Plain cream tastes sweeter than whipped cream. Just like ice cream without air, pure cream has a sickly, overly sweet taste. This is because the structure of a substance can have a big effect on how it tastes. The structure often controls the rate at which flavor molecules are released into the mouth. The larger the structure (of ice cream, in this case), the longer it takes for flavor molecules to be released. Flavor molecules trigger receptors on the mouth and tongue.

The amount of air added to ice cream is known as overrun. If the volume of ice cream is doubled by adding air, then the overrun is 100%, which is the maximum allowable amount of air that can be added to commercial ice cream. The less expensive brands usually contain more air than the premium brands. One side effect of adding a lot of air to ice cream is that it tends to melt more quickly than ice cream with less air.

The amount of air also has a huge effect on the density of the ice cream. A gallon (3.8 liters) of ice cream must weigh at least 4.5 pounds, making the minimum density 0.54 gram per milliliter (or 540 grams per liter). Better brands have higher densities—up to 0.9 grams per milliliter. The next time you visit a grocery store, compare cheaper and more expensive brands by holding a container in each hand—you should be able to notice a difference. Then read the net weight on the label to confirm your observation. Due to the high fat content of ice cream, however, and because fat is less dense than water, any ice cream will always be less dense than any aqueous solution. Otherwise, you would not be able to make root beer float! **Ice cream is an emul-**

The amount of air, known as overrun, in the dish of soft-serve ice cream on the left is 65%, versus 35% on the right.

ELECTRO FREEZE/H.C. DUKE & SON, LLC

sion—a combination of two liquids that do not normally mix together. Instead, one of the liquids is dispersed throughout the other. In ice cream, liquid particles of fat—called fat globules—are spread throughout a mixture of water, sugar, and ice, along with air bubbles (Fig. 1). If you examine ice cream closely, you can see that the structure is porous. A typical air pocket in ice cream will be about one-tenth of a millimeter across. The presence of air means that ice cream is also a foam. Other examples of foams are whipped cream, marshmallows, and meringue (as in lemon meringue pie).


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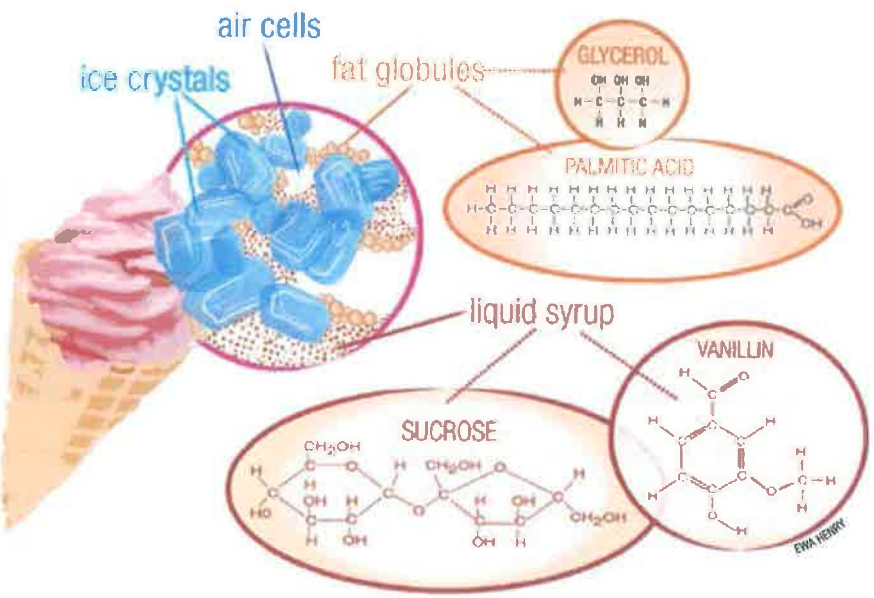
A close look at ice cream shows its porous structure.



EWA HENRY

Figure 1. Some of the most common ingredients in ice cream include ice crystals, air, fat globules, sugar (sucrose), and flavoring agents (such as vanillin).

Sugar and fat

Milk naturally contains lactose, or milk sugar, which is not very sweet. Ice cream makers need to add a lot more sugar than you probably realize—usually, sucrose or glucose. Cold tends to numb the taste buds, making them less sensitive. So, more sugar needs to be added to produce the desired effect at the low temperatures at which ice cream is usually served. If you taste ice cream at room temperature, it will taste overly sweet. You may have noticed this same effect with carbonated soft drinks. If consumed warm, they taste sickly sweet. In parts of the world where soft drinks are normally consumed warm, there is less added sugar. If these same soft drinks were served cold, they would not taste sweet enough.

A big reason why ice cream tastes so good is because of its high fat content. Unless it is labeled as light, low-fat, or non-fat ice cream must contain at least 10% fat, and this fat must come from milk. (You cannot use lard when making ice cream!) Before milk is homogenized, a thick layer of cream rises to the top. This cream has a high-fat concentration—up to 50%—and supplies most of the fat in ice cream.


ACS STAFF

Premium ice creams may have up to 20% fat, which gives it a velvety, rich texture. Reduced-fat ice cream does not taste as good as the real thing, and tends to lack the creamy texture. Although fat is frequently vilified, it has its purpose. Most foods that taste delicious probably contain fat. Fat fills you up, so you don't have to eat as much to feel full.

The problem with using fat as an ingredient in any food is that it does not mix well with a lot of other substances. Fat is nonpolar, meaning positive and negative charges within the fat molecule are equally dispersed. A polar substance, such as water, has separate regions of positive and negative charges—one end of a polar molecule has a partial positive charge, and the other end has a partial negative charge. Polar and nonpolar substances do not mix. Just like oil floats to the top of water, the fat content of ice cream has a tendency to separate out, as well.

Keeping it all together

Because ice cream is an emulsion, you would expect that the fat droplets that are present in the mixture would separate after some time, similar to a bottle of salad dressing in which the oil separates from the rest of the dressing. When you shake a bottle of salad dressing, the two parts come together. But after a few minutes, they begin to separate. That's because the oil droplets interact with one another, a process called coalescence.

In the case of milk, each fat droplet is coated with a layer of milk proteins that prevents the fat droplets from interacting with one another. These milk proteins act as "emulsifiers"—substances that stabilize emulsions and allow the liquid droplets present in the emulsion to remain dispersed, instead of clumping together. Because these milk proteins have a nonpolar side, and because like dissolves like, the nonpolar sides of the proteins are attracted to the nonpolar fat globules. This is good in milk, but not so good in ice cream, in which the fat droplets should coalesce to trap air.

So another emulsifier is added to allow the fat droplets to coalesce. This emulsifier replaces milk proteins on the surface of the fat droplets, leading to a thinner membrane, which is more likely to coalesce during whipping. A common emulsifier is lecithin, found in egg yolks. Lecithin is a generic term that refers to a group of molecules that consist of long chains of fatty acids linked to a glycerol molecule, along with choline and a phosphate group (Fig. 2).

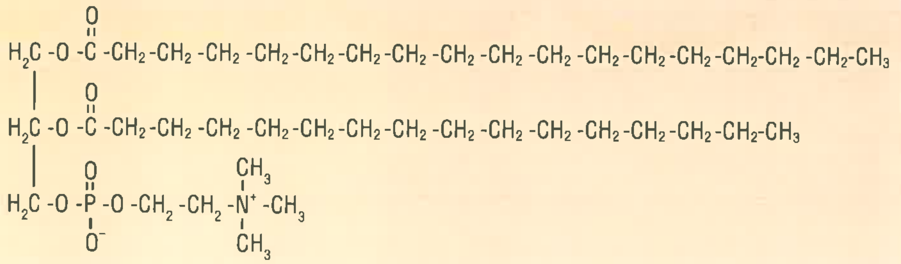


Figure 2. Chemical structure of a type of lecithin called phosphatidylcholine

Lecithin inserts itself between the fat globules, which helps the fat globules to stay together and, as a result, the air bubbles that are present in the mix are trapped by this partially coalesced fat. This adds firmness and texture to the ice cream, enabling it to retain its shape.

Closely related to emulsifiers are stabilizers, which make the texture creamy. Stabilizers have two roles: First, they prevent large crystal formation. In the presence of stabilizers, ice cream contains small ice crystals, which melt more slowly than larger ice crystals, due to the insulating effect of fats surrounding small crystals. Second, emulsifiers act like a sponge by absorbing, and then locking into place, any liquid in the ice cream.

Common stabilizers are proteins, such as gelatin and egg whites. Guar gum, locust bean gum, and xanthan gum can also be used. **Look for carrageenan and sodium alginate on the ingredients' label of your ice cream container. Both are derived from seaweed! Without these stabilizers, ice cream might look like a milkshake.**

Once you get all of the ingredients together in a mixture, you need to freeze the mixture to form ice cream. The dissolved solutes (mostly sugar) in the liquid portion of the mixture lower its freezing point. A freezing point depression of 1.86 °C occurs for every mole of solute added to 1 kilogram (kg) of water. In other words, if you dissolve one mole of sugar in 1 kg of water, water will no longer freeze at 0 °C, but rather will freeze at –1.86 °C.

Freezing point depression is a colligative property, meaning that the effect is observed regardless of the specific identity of the solute—all that matters is how many moles are dissolved. A typical batch of ice cream will freeze at –3 °C (27 °F), due to the presence of all the dissolved solutes.

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BrAiN FReEZe!!!

MIKE CIESIELSKI

When ice cream touches the roof of your mouth, it may trigger a cold headache. The cause is a dilation of blood vessels in your head located above the roof of your mouth. When this nerve center gets cold, it seems to overreact and tries to heat your brain.

Ice Cream True or False?

Many myths and half-truths are floating around about ice cream. Test your ice cream knowledge by deciding whether each of the following is true or false:

1. **Margaret Thatcher,** former prime minister of the United Kingdom, helped to develop the formula for soft-serve ice cream before she entered politics, while working as a chemist in the food science industry.
2. **Soft-serve ice cream was born on Memorial Day in 1934** when an ice cream truck broke down, and the salesman had to sell his melting ice cream, which was a big hit.
3. Modern-day ice cream was accidentally discovered **in 1782 by Martha Washington,** wife of the first U.S. president, who left a bowl of cream on the back steps of her home one night and, in the morning, found that it had hardened into ice cream.

4. The infamous **Roman emperor Nero** had slaves who would bring ice from the mountains so he could enjoy chilled desserts by pouring fruit juice and honey over the ice.
5. **Ice cream sundaes** were invented in the late 1800s in New York to circumvent a law prohibiting the serving of ice cream on Sunday, hence the name.
6. Eskimo pies were originally called **"I Scream Bars."**
7. **Explorer Marco Polo** was the first person to bring ice cream to the New World, bringing the recipe from China.
8. **The ice cream cone** was invented in 1904, during the St. Louis Exposition in Missouri, when an ice cream vendor ran out of bowls and substituted rolled up waffles instead.
9. The ice cream sandwich was invented by **the Earl of Sandwich** in England.

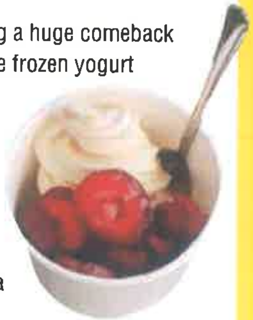
Types of ice cream

Soft-serve ice cream, frozen custard, and frozen yogurt. What is the difference?

Regular ice cream is typically served at −12 °C, while **soft-serve ice cream** is served at −6 °C. This higher temperature is responsible for a softer product. Soft-serve ice cream, or soft serve, for short, contains less fat and more air than regular ice cream. Soft serve with insufficient air will have a yellowish color. The whiter the soft serve, the better the quality. As ice cream melts, you may have noticed this yellow color, which is simply the actual color of the ingredients used to make it. By adding air and fluffing it up, ice cream is better able to reflect white light, producing the white color. This is because the molecules in ice cream are large enough to reflect visible light (whereas, for example, water molecules are too small to reflect visible light, because the size of a water molecule is smaller than the wavelengths of visible light).

Frozen custard differs from ice cream in that it contains at least 1.4% egg yolks. Egg yolks are made of lecithin, an excellent emulsifier. The result is a product with a smoother, creamier texture. Another difference is that frozen custard contains much less air than ice cream. No air is mixed during its manufacture; instead, air is introduced during mechanical agitation as the frozen custard is being made. It is churned more slowly during its manufacture to minimize the amount of introduced air. Less air leads to a thicker, denser product. Frozen custard is typically made fresh each day in the store. It is frozen quickly to prevent large crystals—of water, lactose, or any added sugar—from forming.

Frozen yogurt is making a huge comeback these days, with self-serve frozen yogurt shops offering a plethora of toppings popping up seemingly on every corner. Frozen yogurt is viewed as a healthier alternative to ice cream, unless you top it off with a generous helping of gummy bears! It contains less fat, but that means you can eat more without feeling full. And to compensate for less fat, often a lot of sugar is added. The biggest difference is that instead of cream, yogurt is added as the primary dairy product. From there, the process is similar to making regular ice cream.



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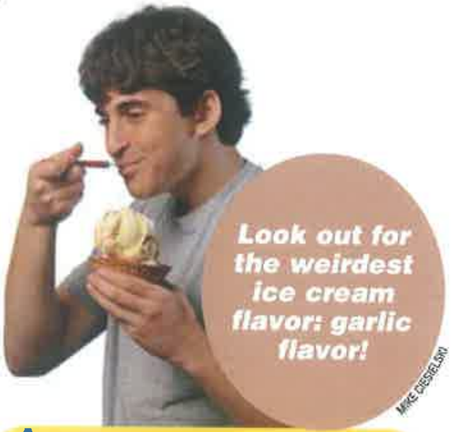
A recent trend is ice cream made with liquid nitrogen. One shop in San Francisco, Calif., aptly named Smitten Ice Cream, has a viewing area where customers can watch ice cream being made with liquid nitrogen, accompanied by the impressive plume of fog that is released. Liquid nitrogen, which boils at −196 °C, will freeze ice cream almost instantly. Because the ice cream freezes so quickly, the size of the crystals is small, resulting in a creamy texture. And because it boils when it hits the mixture, the ice cream is aerated during the process. The popular Dippin' Dots are also made using liquid nitrogen. It is no exaggeration to say that ice cream made with liquid nitrogen is the coolest ice cream around! *CM*

ADAM LOWE, COURTESY OF SMITTEN ICE CREAM

Ice cream shops serving desserts made with liquid nitrogen are unique and very popular.



Look out for the weirdest ice cream flavor: garlic flavor!

MIKE CIESIELSKI

Answers to True or False

1. Probably false. While Thatcher did work as a chemist for a company that developed soft-serve ice cream, her actual role in developing the product was likely minimal, if at all.
2. Likely true, but may not be the first.
3. False.
4. Probably true.
5. Possibly true, but there are several other equally compelling stories about to the origin of the sundae.
6. True.
7. Story likely true, but may not be the first.
8. Story likely true, but may not be the first.
9. False. Don't mistake the ice cream sandwich for the actual sandwich, which was invented by the Earl of Sandwich.

Note: If you are concerned about the ambiguity of these answers, now you know why ice cream historians are still arguing about the origins of ice cream!

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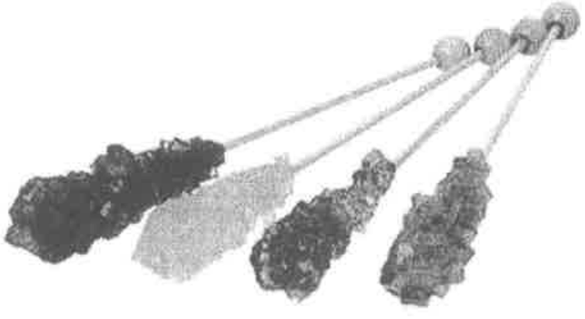
Brian Rohrig teaches chemistry at Metro Early College High School in Columbus, Ohio. His most recent *ChemMatters* article, "Hot Peppers: Muy Caliente!" appeared in the December 2013 issue.

ROCK CANDY

Rock Candy is the product of further refining, by recrystallization of pure cane sugar. It is the purest form of sugar available, because all impurities are excluded as the large crystals form. Rock Candy uses the same process that produces quartz and diamonds. It is made by busting apart the sugar (sucrose) molecular crystal lattice, and then allowing it to reform in conditions that produce larger, purer crystals.

Homemade rock candy is commonly formed by allowing a supersaturated solution of sugar and water to crystallize onto a string or some other surface suitable for crystal nucleation. Heating the water before adding the sugar allows more sugar to dissolve and thus produces larger crystals. Crystals form after several days. Food coloring is often added to the mixture to produce colored candy as well as flavoring.



Rock candy is a different product from British rock, also called seaside rock, which more closely resembles a candy cane. The word "candy" is less frequently used for confectionery in the UK.

For centuries Rock Candy has been recognized as having therapeutic and preservative qualities. In the past, sugar was used only as a medicine or preservative until the 18th century. The earliest known date that white sugar was refined was about 200 C.E

There are several references to 'Rock Candy' in literature, such as the poems of the Persian poet Jalal-ad-Din Rumi who lived inTurkey in the middle 1200's. One English reference in 1584 sums up the virtues of Rock Candy, "White sugar is not so good for phlegume, as that which is called Sugar Candie." Shakespeare in Henry IV (1596) referred to its therapeutic value as a throat soother for long winded talkers.

During the late 1800's there were several Rock Candy companies in the USA. They supplied various forms of crystals and syrups as cough-cold remedies, soda fountain syrups and confections. It was also used in saloons and bars (Rock & Rye - Rock Candy dissolved in rye whiskey) and it was thought to cure the common cold. Or maybe if you drank enough of the Rock & Rye; you wouldn't remember that you had a cold!

Rock sugar is used in Chinese cuisine as well as traditional Chinese medicine. It is used to sweeten tong sui (sweet soups) and chrysanthemum tea, as well as various medicinal preparations and Chinese liquors.

Rock candy is called 'Mishri' in Hindi and is widely used in India with aniseed (Saunf in Hindi) as a mouth freshener, especially after meals. One can find these being offered along with the check/bill, at most restaurants in India. Rock candy is called 'Kalkandu' in Tamil and is commonly used in Tamil Cuisine especially in Jaffna (Northern Sri lanka).

It was also used in Thailand as money, for it was easily accessed and distributed. You could bet the candy on many things, and bet pieces or pounds.

Rock candy was also used in Mexico to make Sugar Skulls on the celebration of the Day of the Dead. Children would make the rock candy in the shapes of skulls by special strings and then decorate them with icing and jewels. These were eaten after the fiesta.
By the 19th Century the Rock Candy industry was almost entirely gone, since soda manufacturers switched to cheap corn syrups and medicated cough drops replaced the sugar crystals. However; in the 1960s Rock Candy made a comeback, and was sold on a stick, and in the 1970s colors and flavors were added to the process.

What is Sugar?

In non-scientific use, the term sugar refers to sucrose (also called "table sugar" or "saccharose") - a white crystalline solid disaccharide. Humans most commonly use sucrose as their sugar of choice for altering the flavor and properties (such as mouthfeel, preservation, and texture) of beverages and food. Commercially-produced table sugar comes either from sugar cane or from sugar beet. Manufacturing and preparing food may involve other sugars, including palm sugar and fructose, generally obtained from corn (maize) or fruit.

In the informal sense, the word "sugar" principally refers to crystalline sugars; but a great many foods exist which principally contain sugar: these generally appear as syrups, or have specific names such as "honey" or "molasses." Many of these comprise mostly sugar; and sugar may dissolve in water to form a syrup.

Scientifically, sugar refers to any monosaccharide or disaccharide. Monosaccharides (also called "simple sugars"), such as glucose, store chemical energy which biological cells convert to other types of energy. In a list of ingredients, any word that ends with "ose" will likely denote a sugar. Sometimes such words may also refer to any types of carbohydrates soluble in water.

In culinary terms, the foodstuff known as sugar delivers a primary taste sensation of sweetness. Apart from the many forms of sugar and of sugar-containing foodstuffs, alternative non-sugar-based sweeteners exist, and particularly interest people who have problems with their blood sugar level (such as diabetics) and people who wish to limit their calorie-intake. Both natural and synthetic examples exist with no significant carbohydrate (calorie) content, for instance stevia (a herb) and saccharin (produced from naturally occurring but not necessarily naturally edible substances by inducing appropriate chemical reactions).

Chemistry

Biochemists regard sugars as relatively simple carbohydrates. Sugars include monosaccharides, disaccharides, trisaccharides and the oligosaccharides - containing 1, 2, 3, and 4 or more monosaccharide units respectively. Sugars contain either aldehyde groups (-CHO) or ketone groups (C=O), where there are carbon-oxygen double bonds, making the sugars reactive. Most simple sugars (monosaccharides) conform to (CH2O)n where n is between 3 and 7. A notable exception, deoxyribose, as its name suggests, has a "missing" oxygen atom. All saccharides with more than one ring in their structure result from two or more monosaccharides joined by glycosidic bonds with the resultant loss of a molecule of water (H2O) per bond.

As well as using classifications based on their reactive group, chemists may also subdivide sugars according to the number of carbons they contain. Derivatives of trioses (C3H6O3) are intermediates in glycolysis. Pentoses (5-carbon sugars) include ribose and deoxyribose, which form part of nucleic acids. Ribose also forms a component of several chemicals that have importance in the metabolic process, including NADH and ATP. Hexoses (6-carbon sugars) include glucose, a universal substrate for the production of energy in the form of ATP. Through photosynthesis plants produce glucose, which has the formula C6H12O6, and then convert it for storage as an energy-reserve in the form of other carbohydrates such as starch, or (as in cane and beet) as sucrose.

Many pentoses and hexoses can form ring structures. In these closed-chain forms, the aldehyde or ketone group remains unfree, so many of the reactions typical of these groups cannot occur. Glucose in solution exists mostly in the ring form at equilibrium, with less than 0.1% of the molecules in the open-chain form.

Monosaccharides in a closed-chain form can form glycosidic bonds with other monosaccharides, creating disaccharides (such as sucrose) and polysaccharides (such as starch). Enzymes must hydrolyse or otherwise break these glycosidic bonds before such compounds will metabolise. After digestion and absorption the principal monosaccharides present in the blood and internal tissues include glucose, fructose, and galactose.

The prefix "glyco-" indicates the presence of a sugar in an otherwise non-carbohydrate substance. Note for example glycoproteins, proteins with which one or more sugars have connections.

Monosaccharides include fructose, glucose, galactose and mannose. Disaccharides occur most commonly as sucrose (cane or beet sugar - made from one glucose and one fructose), lactose (milk sugar - made from one glucose and one galactose) and maltose (made of two glucoses). These disaccharides have the formula C12H22O11.

Hydrolysis can convert sucrose into a syrup of fructose and glucose, producing invert sugar. This resulting syrup, sweeter than the original sucrose, has uses in making confections because it does not crystallize as easily and thus produces a smoother finished product.

What are Crystals?

In chemistry and mineralogy, a crystal is a solid in which the constituent atoms, molecules, or ions are packed in a regularly ordered, repeating pattern extending in all three spatial dimensions.

The word crystal originates from the Greek word "Krystallos" meaning clear ice, as it was thought to be an especially solid form of water. The word once referred particularly to quartz, or "rock crystal".

Most metals encountered in everyday life are polycrystals. Crystals are often symmetrically intergrown to form crystal twins.

Growing crystals is a slow and careful process because the crystals grow by adding single layers of molecules. It takes millions of individual units of atoms called cells to make a crystal, and these cells repeat themselves in all directions making geometric shapes with flat surfaces called crystal faces. Sugar is an isometric, cubic crystal.

Sugar crystals are grown by disturbing the balance that exists in a sugar and water solution. This is done by lowering the temperature of the solution, however the solution must be saturated. In otherwords; the water has to dissolve all the sugar possible at a given temperature. The warmer the water, the more sugar the water can dissolve. That is why it is important to heat the water first before dissolving the sugar in it.

When the saturated sugar solution is cooled, it becomes supersaturated. The sugar in the solution then begins to crystallize - changing from a liquid to a solid. As the sugar crystals begin to grow; the atoms that make up the sugar align themselves and bond with atoms of the sugar crystal that is growing. Energy is released and the cycle of bonding and growing continues. As each day goes by you will be able to see the crystals getting larger.