ChemMatters®

DEMYSTIFYING EVERYDAY CHEMISTRY

DECEMBER 2011

The Flavor of Food: It's All Relative! p. 6

Can Meat Substitutes Really Replace Meat?, p. 9

Your Body Under Construction, p. 14

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American Chemical Society ChemClub

NEWS

Flash! Boom! Bang! Ask almost any student in high school chemistry what they would like to see more often in class, and you will probably hear, "explosions." For some reason, many of you like to see things blow up!

One common demonstration you might have seen in a chemistry show is the explosion of balloons filled with various gases. The results can be fairly low key—as in the case of a balloon filled with helium, an inert gas—or loud and dramatic, as in the case of balloons filled with more reactive gases such as hydrogen, oxygen, or a combination of both.

COREY BROMAN-FULKS, WWW.EMORY.EDU/ESCIENCECOMMONS

Setting flame to a balloon filled with hydrogen results in a loud explosion.

Another demonstration is to submerge different objects, such as inflated balloons, racquetballs, flowers, and more, in liquid nitrogen (see photo). We inhale nitrogen in gaseous form every time we take a breath. However, you wouldn't want to come in direct contact with nitrogen in its liquid form—it is so cold that at atmospheric pressure, it boils at –196 °C. The demonstrator submerges an inflated balloon in liquid nitrogen, so the temperature of the gas molecules in the balloon is decreased. The molecules move more slowly and push on the sides of the balloon less, resulting in lower pressure, and the balloon shrinks. Once the balloon is pulled out of the liquid nitrogen and the temperature of the gas molecules increases, the balloon returns to its original size.

SANDRA SMITH, PALMER HIGH SCHOOL, COLORADO SPRINGS, CO

Two ACS ChemClub members show how a balloon that was immersed in liquid nitrogen shrinks in size (left) compared to a similar balloon that was not immersed in liquid nitrogen (right).

One more demonstration uses dry ice, a solid form of carbon dioxide that is slightly warmer—at atmospheric pressure, it turns from a solid to a gas at –78.5 °C. A demonstrator can create soap bubbles filled with clouds of water vapor and carbon dioxide gas generated from dry ice (see photo). The bubbles can even be held by someone wearing soft knit gloves.

SANDRA SMITH, PALMER HIGH SCHOOL, COLORADO SPRINGS, CO

Two ACS ChemClub members show how to make "boo bubbles"—bubbles filled with clouds of water vapor and carbon dioxide.

A favorite activity of many American Chemical Society (ACS) ChemClubs is to travel to their local elementary and middle schools and perform chemistry demonstration shows for younger students. These demonstrations get students excited about chemistry and allow them to learn about the science behind the demonstrations.

There are tons of great demonstrations that can be included in chemistry shows. With proper preparation and safety precautions, you could demonstrate chemistry to other students just like ACS ChemClub members do and help spread the word that chemistry is cool! For more information about ACS ChemClubs, please visit: www.acs.org/chemclub.

—Erica K. Jacobsen

CHEMMATTERS®
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Check out the video podcasts on flavorful food at: www.acs.org/chemmatters

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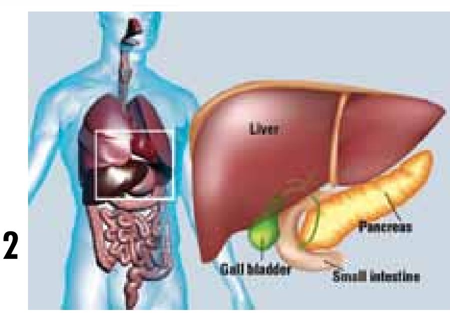

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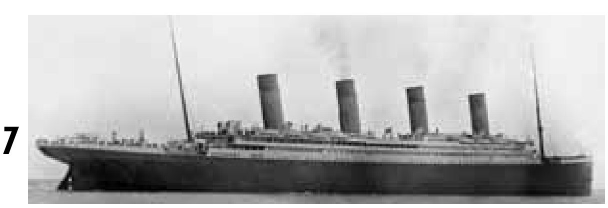
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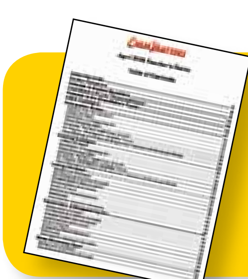

TEACHERS! find your complete **teacher's guide** for this issue at: www.acs.org/chemmatters

DID YOU KNOW?...

Structure of Matter: How Cotton Candy Is Made

It's fascinating to watch cotton candy being made, and it's fun to eat. For many people, a trip to the fair would not be the same without it. But have you ever wondered how cotton candy becomes a colorful, tasty treat?

Cotton candy is actually just a form of sugar that gets its look and feel after being run through a machine that melts the sugar and spins it through little holes.

Spun sugar has been popular for centuries, but in 1897, two candy makers in Nashville. Tenn., William Morrison and John C. Wharton, invented an electric machine that allowed melted sugar to form thread-like filaments in a spinning vessel.

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Their machine was first used in public at the 1904 World's Fair in St. Louis, Mo., and Morrison and Wharton called their product "fairy floss." It would take at least another 15 years before the term "cotton candy" would be used to describe this spun sugar.

The ingredients that make up this sweet and sticky substance are simple: table sugar, also known as sucrose ($C_{12}H_{22}O_{11}$); boiling water; cream of tartar; and food coloring.

While cotton candy machines have been upgraded, the process essentially remains the same. The center consists of a small bowl, where the sugar and food coloring are inserted. The heaters near the rim melt the sugar, which is spun through a series of tiny holes.

Table sugar melts at 186 °C, but in the machine, cotton candy is heated to 160 °C so it does not turn into caramel. Then, a large bowl catches it, and the operator twirls a cone or stick around the rim of the bowl to pick up the cotton candy.

What's interesting is that although the volume occupied by the sugar increases, its mass does not change because none of the ingredients evaporates away significantly. The amorphous solid that it forms is like glass (see article titled "Glass: An Amorphous Solid" in the Oct. 1998 issue of *ChemMatters*).

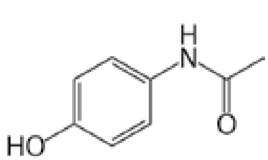
When the sugar leaves the small bowl in the middle, it cools down and becomes solid again, but it cannot recrystallize fast enough. The melted sugar leaves the bowl through tiny holes, solidifying as it is squeezed out to fom glassy threads. When the threads are gathered together, they form loosely packed bundles that make up the familiar fluffy cotton candy.

Next time you are enjoying cotton candy, remember that you have Tennessee candy makers to thank!

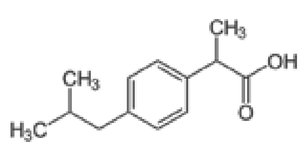
—*Sherry Karabin*

Organic Chemistry/Proteins: New Type of Painkiller from Sea Snails

Most painkillers—such as Tylenol or Ibuprofen—consist of relatively small molecules. But during the past few decades, scientists have found an entirely different family of painkillers made of long chain-like molecules called peptides. Peptides consist of a chain of amino acids, which are also the building blocks of proteins—molecules commonly found in meat, milk, eggs, and legumes.



Tylenol



Ibuprofen

The first painkiller peptide was discovered by Baldomero Olivera, a scientist from the Philippines who began studying deadly toxins produced by a cone snail—a type of venomous sea snail—in the late 1960s. Then, a student in his laboratory discovered the peptide toxin that was later developed into this painkiller.

Olivera and his research team produced a synthetic version of the toxin, which was tested on nerve cells. A biotechnology company then tested it on animals. It took three decades before this painkiller was approved by the U.S. Food and Drug Administration in 2004. Unlike all the other painkillers known at the time, this painkiller was a peptide. It is now sold under the brand name Prialt, or the generic name Ziconotide.

Prialt consists of 25 amino acids (structure below, where Ala=Alanine, Arg=Arginine, Asp=Aspartic Acid, Cys=Cysteine, Gly=Glycine, Leu=Leucine, Lys=Lysine, Met=Methionine, Ser=Serine, and Thr=Threonine; the structures of each of these amino acids are provided in your chemistry textbook):

Cys-Lys-Gly-Lys-Gly-Ala-Lys-Cys-Ser-Arg-Leu-Met-Tyr-Asp-Cys-Cys-Thr-Gly-Ser-Cys-Arg-Ser-Gly-Lys-Cys-NH_2

Prialt works by blocking specific pores in the membranes of nerve cells. These pores, called calcium channels, allow calcium ions to flow in and out of the cell. When a person is in pain, the nerve cells that relay the sensation of pain release chemicals in the brain. Prialt blocks specific calcium channels, so the pain signal cannot be sent to the brain, and a person cannot feel the pain sensation anymore.

This painkiller has helped many people around the world suffering from debilitating and chronic pain that even morphine, a relatively potent painkiller, could not relieve. Thanks to the work of Olivera and other scientists, more types of painkillers should be available in the future.

—*Sherry Karabin*

OPEN FOR DISCUSSION

By Barbara Sitzman and Regis Goode

Hand Sanitizers, Soaps, and Antibacterial Agents: The Dirt on Getting Clean

Regis: Flu season is upon us! Doctors tell us to keep our hands clean to prevent the spread of disease. My students ask what method will best clean their hands.

Barbara: Flu and colds are both caused by viruses. So, the first line of defense is a flu shot. After that there are two general approaches to eliminating viruses from your hands, but each involves complications. One way is using hand sanitizers; the other is just washing with old-fashioned soap and water.

R: Soap and water are not always available, but you can easily carry a hand sanitizer. Commercial sanitizers often contain alcohol and other chemicals that effectively kill most viruses. To be effective, the active ingredients should include at least 60% alcohol.

B: Be wary of recipes for homemade sanitizers on the Internet. Is the following example really a good, inexpensive solution?

Bubble Gum Sanitizer

1/2 cup of aloe vera gel + bubble gum essence
1/4 cup of 99% rubbing alcohol isopropanol

Let's do the math: 99% of ¼ cup of alcohol = .2475 cup of alcohol/.75 cup of solution x 100% = 33% alcohol! While the scent may be appealing, this gel does not contain enough alcohol to kill viruses. Unfortunately, in addition to their effect on viruses, alcohol-based sanitizers kill all bacteria, not just pathogens. Some bacteria are beneficial and actually strengthen our immune systems.

R: Also popular is washing with antibacterial soaps. However, they do not kill viruses, the cause of the flu and colds. You may be surprised by the number of products that contain the antibacterial agent triclosan (Fig. 1), a chemical that slows bacterial growth (antibacterial

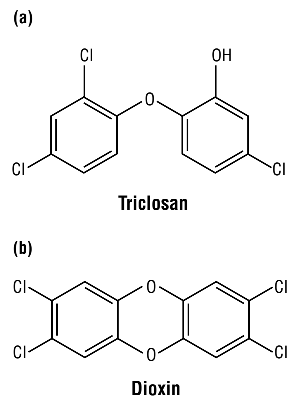


Figure 1. Chemical structures of (a) triclosan and (b) dioxin (or 2,3,7,8-tetrachlorodibenzodioxin)

soaps); prevents dental disease (toothpaste); controls growth of odor-causing bacteria (socks); prevents bacterial degradation (baby pacifiers); and acts as a preservative (cosmetics).

B: Even in low concentrations, triclosan increases thyroid production of hormones that control development of the body, brain, and immune system. When it gets into wastewater, only 4% is removed at the treatment plant, leaving the rest to impact our aquatic environment. In water exposed to sunlight, 1–12% of triclosan converts into extremely toxic dioxins. Note the similarities of the two structures (Fig. 2).

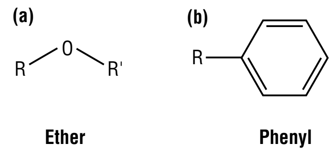


Figure 2. Chemical structures of two functional groups: (a) ether and (b) phenyl

Both contain ether (oxygen atom bonded between two carbon atoms) and phenyl (benzene ring) functional groups. As predicted by its structure, triclosan is only slightly soluble in water (.012g/L at 20 °C) but is fat-soluble, so it accumulates in human body fat.

R: Americans overwhelmingly want to use antibacterial products. Have you tried to purchase liquid soap that is not antibacterial? Currently, 75% of liquid soaps on the market are antibacterial, and many contain triclosan.

B: These popular products do not kill flu and cold viruses. Overuse promotes antibiotic resistance in bacteria and encourages viruses to mutate. Just washing and drying your hands removes many viruses. This also reduces disease-causing bacteria which tend to be on the surface, while leaving those that are essential to our well being.

R: While this is true, consider the environmental impact. If you use a paper towel to dry your hands, in effect you are chopping down trees and sending more paper to landfills.

B: The use of antibacterial cleaners also impacts the environment. In a 2008 study by the

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Centers for Disease Control and Prevention (CDC), triclosan was found in the urine of 75% of the population. The American Medical Association advises against household use, and the Environmental Protection Agency plans a triclosan review in 2013.

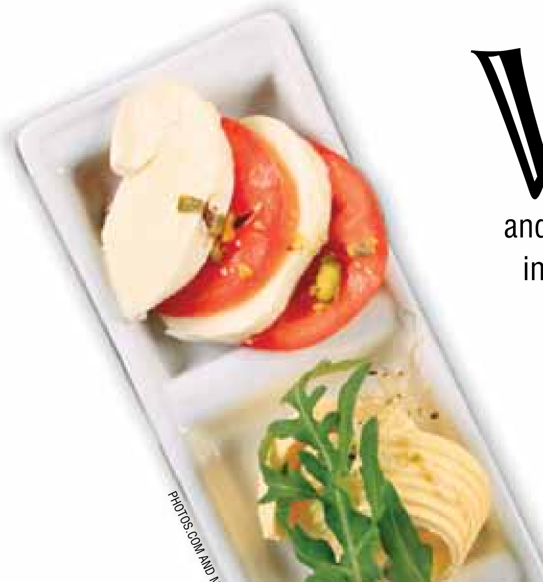
R: Antibacterial products in hospitals are effective in reducing the spread of many serious infections. The CDC suggests washing your hands for at least 20 seconds with soap or a dime-sized dollop of an alcohol sanitizer for 30 seconds. It is important to let hand sanitizer dry to avoid spreading infection.

B: The needs in hospitals differ from those in the home; should we consider restrictions on home use? The ultimate effectiveness of all soaps, gels, and foams depends on the behavior of the user. Sanitizers are ineffective when hands are soiled or when used by people preparing food. I will reserve hand sanitizers for times when soap and water are unavailable.

R: Some decisions are not easy. Should we restrict the use of alcohol-based sanitizers and ban the use of triclosan from over-the-counter products? Will you choose to limit the use of hand sanitizing products in your home? Send us your ideas at: chemmatters@acs.org *CM*

Mmmm… Flavorful Food!

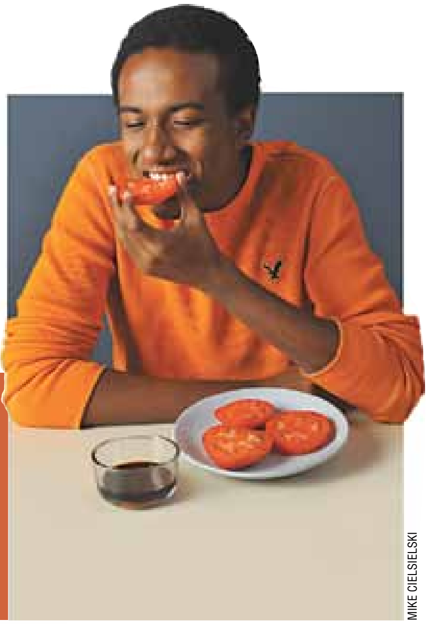
By Renée Heiss



PHOTOS.COM AND MIKE CIESIELSKI

Why do people have different reactions to the same food? One person may love chocolate while another may find it too sweet. Some people love cheese while others find its taste and smell unappealing. And some people always want vanilla in their ice cream while others would rather avoid vanilla and choose another flavor instead.

The reason for these differences is due, in large part, to the taste of food, but there are other factors, too. The smell of food, its texture, its color, and its temperature also contribute to what is more generally known as the "flavor" of food. The combination of all of these factors tells us whether food is delicious, good, unpleasant, or downright disgusting.



MIKE CIELSIELSKI

Why we enjoy food

The flavor of food is due mostly to how it tastes and smells. When you eat, the most immediate sensation is taste. But you actually smell food, too. If you hold your nose while you eat, you will notice that some foods will taste different.

There are five taste sensations: sweet, bitter, sour, salty, and umami. The umami taste was formally recognized in 1985 after scientists debated for a long time about whether umami was a basic taste. In 1985, they agreed that umami was the fifth basic taste. It is associated with savory foods, which include meat, tomatoes, and a food additive called monosodium glutamate.

Smell is as important if not more important than taste. For instance, when people who have a head cold try to taste salsa and chips, they feel the textural crunch of the chips and the tingle of the hot peppers on their tongues, but they cannot taste the flavor-rich salsa with its onions, tomatoes, and peppers because they cannot smell it.

When we chew, aromas are released that activate our sense of smell by way of a special channel that connects the back of the throat to the nose. If this channel is blocked, such as when our noses are stuffed up by a cold or flu, odors cannot reach sensory cells in the nose that are stimulated by smell. So, we don't enjoy foods the same way. Without smell, foods tend to taste bland and have no flavor.

MIKE CIESIELSKI

Smelling food is different from smelling roses. To smell a rose, you would bring the flower close to your nose and inhale the flowery scent. To smell food, the aromas either go directly through your nose or enter the back of your nose—as you chew and swallow food, in which case the aromas add to the flavor of food.

Taste and smell contribute only partially to the flavor of food—other factors include texture (crunchy or soft food) and temperature (hot or cold food). For instance, some people like to put fruit in the fridge and eat it cold while others prefer to eat fruit at room temperature. And some people would only eat cooked carrots while others like to eat them raw.

Also, the color of food can affect its flavor. Dark red beverages need less sugar to achieve an acceptable level of sweetness because people perceive dark beverages to be naturally sweeter. In this case, what you expect influences the taste of food.

In a classic experiment, French researchers colored a white wine red with an odorless dye and asked a panel of wine experts to describe its taste. The experts described the wine using typical red wine descriptors rather than terms they would use to evaluate white wine, suggesting that the color played a significant role in the way they perceived the drink.

The flavor of food also changes depending on how it is prepared or cooked. Take tomatoes, which have a soft texture and are bought in the store at room temperature. Add garlic, oregano, salt, and pepper, cook them for a while, and you have spaghetti sauce. Dry the tomatoes, and you get crunchy sun-dried tomatoes. Refrigerate them, and you can chop them into a salad. The possibilities are endless, and the flavor is different each time.

Natural and artificial flavors

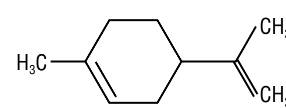
Lots of chemical compounds contribute to the flavor of food. Chocolate, for instance, is a mixture of some 300 flavor compounds; vanilla comes from about 300 chemicals mixed together; and coffee beans contain more than 800 chemicals. Identifying these chemicals can help create a variety of artificial flavors that are used in nearly every food product available in a grocery store, including potato chips, ice cream, chewing gum, and soft drinks.

MIKE CIESIELSKI

MIKE CIESIELSKI

Chemists create artificial flavors from the chemical compounds present in plants and animals. They use them in their natural state, or they process them to make new flavors. They also create concentrates by extracting the juice of fruits, such as oranges and lemons. They remove the water from the juice, and the concentrated orange or lemon juice goes into cans. You can later add water to reconstitute the juice.

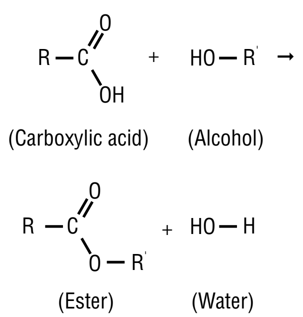
What's interesting is that we don't need all the flavor compounds in a given food to re-create its flavor. For instance, an orange contains 250 flavor chemicals, which all combine to create an orange flavor. But artificially flavored Tang, a powdered drink mix, contains only six aromatic chemicals, yet it has an orange-like taste. So, we can re-create a good orange flavor by combining only a handful of the most abundant or most strongly flavored compounds present in an orange.



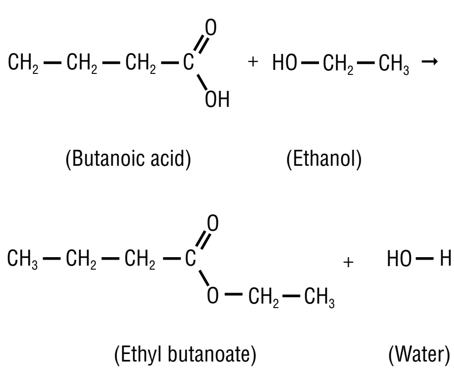
Limonene

Also, the same flavor may not work in different types of food and beverages. For instance, the lemon-lime flavor that works in candy might not work in a soft drink. A lemon-lime candy might contain lemon and lime oils, which are extracted from the skin of lemon and lime. These substances are 90% limonene. But limonene cannot be used to make lemon-lime soda, because it is not soluble in water. So, lemon-lime soda contains a mix of different flavor chemicals that also give it a lemon-lime flavor.

Artificial flavors get their characteristic odor from various compounds, particularly esters—chemical compounds formed by the chemical reaction of an alcohol with a carboxylic acid. An alcohol is an organic compound with the general formula R–OH, in which R is a hydrocarbon group and –OH is a hydroxyl group. A carboxylic acid is a compound with the general formula R–COOH. The formation of an ester molecule occurs through the following reaction:



For example, the formation of ethyl butanoate, one of the compounds that give pineapple its flavor, is produced through the reaction of butanoic acid with ethanol, as follows:



If you use different alcohols and different acids, you can obtain different flavors. You can compare that to combining two colors of paint. When you combine red with yellow, you get orange. Similarly, when you combine pentanol with acetic acid, you get pentyl acetate, an ester that smells like a banana. Table 1 lists some of the many acids and alcohols that are present in a fruit salad that contains pineapples, oranges, grapes, and pears.

But wait. Isn't ethanol the type of alcohol found in alcoholic beverages? It sure is, but when it combines with the acid, it loses the characteristics of drinking alcohol. Likewise, acetic acid is the main component in vinegar. Yet, when it reacts with an alcohol, the flavor changes dramatically. When two compounds react to form a new compound, the properties of the new compound are not a simple combination of those in the original one. They are completely different.

Flavor chemists combine many chemicals to achieve a desired scent. Day after day, they test different combinations before settling on the one that will achieve the desired result. To achieve what they perceive to be the smell of pineapple, chemists combine different acids and alcohols.

But don't expect to take a tour of a flavor and fragrances factory. Those companies carefully guard their secret ingredients unless you do the following. First, you will need a degree in organic chemistry and a successful job application. Then, you train for 5 years to learn how to synthesize flavor chemicals, but still without learning the secret flavor ingredients. At the end of those 5 years, you must pass a test to become a junior flavor chemist for 2 years. When you complete your apprenticeship, you take another test, and when you successfully pass that test, you finally become a senior flavorist. At that point, you will finally learn the secrets of the company that hired you 7 years earlier.

When you combine pentanol with acetic acid, you get pentyl acetate, an ester that smells like a banana.

Check out the video podcasts on flavorful food at: www.acs.org/chemmatters

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Alcohol	Acid	Ester	Odor
Ethanol	Butanoic acid	Ethyl butanoate	Pineapple
Octanol	Acetic acid	Octyl acetate	Orange
Ethanol	Heptanoic acid	Ethyl heptanoate	Grape
Pentanol	Butanoic acid	Pentyl butanoate	Pear

Table 1. Flavor compounds present in a fruit salad.

Where else do you find esters?

Esters are not only responsible for the flavor of food but also for the smell of everyday products. At home, you may have washed your hands with pomegranate-scented soap. Maybe you chewed peach-flavored gum on your way to school. Perhaps the carpets at school were vacuumed with melon-scented powder. And then maybe one of your female classmates wore perfume that day that smelled like apple. These are all examples of esters in action!

So, as you go through your day, take some time to smell the soap, the hand cream, and the fruits and vegetables at lunch. These flavors are actually an important part of our daily lives, even if we don't realize it! *CM*

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Renée Heiss is a science writer who lives in Tabernacle, N.J. This is her first article in *ChemMatters*.

Hold the Meat!

Meat-Free Food Takes a Seat at the Table

By Beth Nolte

I used to love cheeseburgers. In my family, a steak dinner meant it was time to celebrate. While I don't miss eating meat, the hardest thing about becoming a vegetarian has been saying "No" when people want to share their food. Sometimes, it was easier to just eat what was offered. As I became more confident about my decision not to eat meat, I was eventually able to say "No thanks." It also helps that I'm not alone.

More and more people are becoming vegetarians in the United States. According to one poll, 7.3 million adults are vegetarian (3.2% of the population), and an additional one-fifth of Americans intend to reduce their meat consumption in the next year. More teenagers are also choosing vegetarian diets. It is estimated that one in every 200 teens is a vegetarian.

Instead of eating meat—traditionally a major source of protein—vegetarians consume various meat-free products that can provide all the proteins needed by the body.

Why we need proteins

Proteins are abundant not only in meat but also in milk, eggs, and legumes. When we eat any of these food groups, our body breaks them down during digestion, and proteins are broken down into their basic components, which are called amino acids. Meat, for instance, contains a protein called collagen that gives meat its fibrous texture. Collagen consists of three long chains of amino acids called polypeptides that coil around each other to form long fibers (Fig. 1).

ALL PHOTOS BY MIKE CIESIELSKI

Amino acids (Fig. 2 on next page) are nutritionally important for building new proteins that you need for growth, immune function, tissue repair, and manufacturing of enzymes and hormones. Also, the nitrogen provided by amino acids plays a role in your genetics, as a part of molecules called nucleic acids, such as deoxyribonucleic acid (DNA).

Living beings on Earth—plants, animals, bacteria, and so forth—can produce 20 different types of amino acids, but humans can synthesize only 11 of these 20 amino acids. The other nine, called *essential amino acids,* cannot be made in our bodies and must come from the food we eat.

The proteins in our bodies are made of different types of amino acids, but any given protein may not contain all 20 amino acids. Nutritionists used to recommend combining foods, especially in vegetarian diets, so that all essential amino acids were present at once. Scientists now know that people do not have to eat all essential amino acids together in one meal. What's important is to eat a balanced amount of proteins with different types of essential amino acids during the day.

Plant-based proteins tend to contain a lower amount of essential amino acids than animal proteins. But by eating a variety of legumes, grains, nuts, fruits, and vegetables, the body's amino acid needs are easily met.

In fact, according to the World Health Organization, the average American consumes double the amount of protein needed for healthy bodily function. You can estimate the amount of protein you need per day in grams by multiplying your body weight in pounds by 0.36 for teenagers or 0.4 for an active adult.

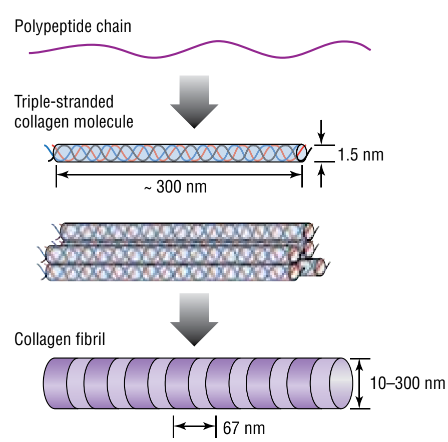

Figure 1. Meat contains collagen, a tough substance that consists of a series of amino acid chains coiled in many tube-like structures that ultimately form fibers whose diameters range between 10 and 300 nanometers.

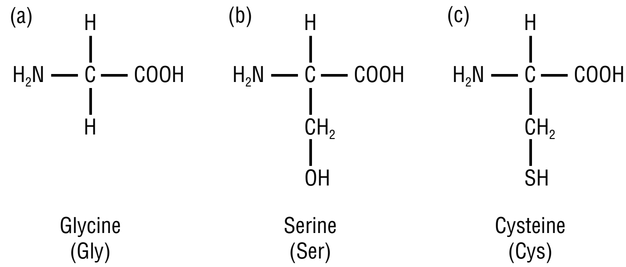

Figure 2. Examples of three amino acids: (a) glycine, (b) serine, and (c) cysteine. All amino acids have two functional groups, the amino group (–NH_2) and the carboxyl group (–COOH), both of which are covalently bonded to a central carbon atom. The central carbon atom is also bound to a hydrogen atom and a group that varies depending on the amino acid.

Making meat-free mainstream

Four meat-free products are widely available: tofu (TOE-foo), tempeh (TEM-pay), seitan (SAY-tan), and Tofurky. The proteins in these products come from plants, either soybean (tofu and tempeh) or wheat (seitan), while Tofurky is a mix of both. With the rise of vegetarian eating, more and more of these products are available in the grocery store, often in the "health food" section.

Tofu

Tofu is a common and convenient meat substitute. It has a subtle, somewhat earthy flavor and a spongy texture that easily soaks up marinades and sauce. Tofu is versatile—it can be fried, baked, broiled, steamed, or sautéed.

Tofu

Tofu is made from soybean, which has all the essential amino acids. Ninety percent of soy proteins are globulins, a class of proteins found in milk and plant seeds. True to their name, a globulin is folded into a globular form (Fig. 3).

To begin the transformation into tofu, soybeans are soaked and then ground into soy milk. Next the milk is boiled and coagulated—the process of forming solid lumps in a liquid. Milk contains proteins that are dissolved in it. But when milk is heated and when salts are added, the milk proteins start to unravel into long chains. Instead of sticking to themselves, they stick randomly to each other, aggregating into large clumps and precipitating from the solution.

During this process, the weaker bonds holding the protein are broken, so the protein unfolds. The negatively charged amino acids within the protein are now able to react with the positively charged magnesium or calcium

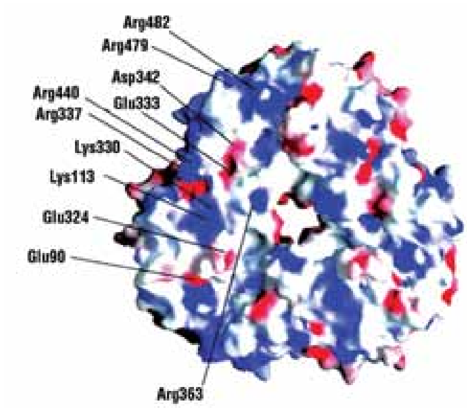

Figure 3. Structure of the protein globulin. Shown here are some of the amino acids present: arginine (Arg), aspartic acid (Asp), glutamic acid (Glu), and lysine (Lys). The numbers refer to the positions of the amino acids in the protein.

ions from the salts. This causes the proteins to precipitate and form curds. These curds are pressed into a block so that excess fluid is removed. Freezing and thawing the tofu further removes the moisture, giving it a "meatier" texture.

Tempeh

It took being a vegetarian for a while before I had the courage to buy tempeh to cook it at home. This strange-looking meat-like stuff, comes in packages, is often flavored, and sometimes mixed with flax, wild rice, or vegetables. I like to cut it into slices, sauté it, and eat it as a sandwich.

Tempeh

Tempeh is a soybean product that is injected with mold. The added mold causes fermentation of the soybean, making it easier to digest. This process is similar to making cheese or yogurt, in which mold is added and allowed to grow at warm temperature.

In the case of tempeh, mold grows slowly at warm temperature for 20 hours. Then, thin white threads known as hyphae appear and begin to make connections between the soybeans. That's when changes start happening fast. Soon, the surface is covered and spaces between the beans are filled, and the soybeans are bound by the mold into the shape of a cake.

While the mold is growing, enzymes called proteases break down the soy globulins into chains of amino acids called polypeptides and free amino acids that are easily absorbed when eaten. Tempeh reaches its best flavor, texture, and aroma at the peak of mold growth.

Depending on how tempeh is cooked, its texture is either chewy or crumbly.

Seitan

I have recently discovered the joy of making my own seitan, also known as mock meat or wheat meat. The texture is usually chewy, but depending on conditions for protein bonding, it can also be firm and dense.

Seitan

Seitan has all essential amino acids, but is low in an essential amino acid called lysine. It is made from wheat gluten, a protein found in wheat, which is removed in the process of turning grain into flour.

Wheat gluten is sometimes added to bread recipes to make dough more elastic, so the bread is chewy. The gluten traps the air while the bread is baking so that it comes out light and fluffy instead of flat.

To make seitan, wheat gluten is mixed with water and spices. Kneading the dough in the presence of water helps the two proteins that make up gluten—glutenin and gliadin—to come together. When these proteins are bound together, the dough becomes elastic and stretchy.

The dough is then divided into fist-sized pieces, placed in a cold-seasoned broth and simmered for about an hour. A cold liquid makes the gluten contract. With less thermal energy available, the atoms move more slowly, and the molecules fit together more tightly, so seitan becomes denser, less airy, and bread-like.

The finished product can be sliced and either baked or fried. You can create a substitute for chicken pieces by using a vegetarian chicken-flavored broth, giving the slices a light coating of flour and frying them.

Tofurky

MIKE CIESIELSKI

Tofurky

The Tofurky roast was created as a meat-free alternative for the family feast. It is a combination of organic tofu and wheat gluten that are mixed together to create a meat-like texture. The popularity of this strange-sounding food has increased during the past 5 years, as indicated by the 25% growth rate of Turtle Island Foods, the Oregon-based company that produces it.

Jaime Athos, vice president of operations at Turtle Island Foods, attributes Tofurky's success to the open-mindedness of young people. "There are a few decisions that we make as consumers that can have a big impact, and one of them is the food we eat," he says. "The texture and flavor of Tofurky is similar to the texture and flavor of meat, so it is easier to try Tofurky as a substitute to meat."

Soybeans everywhere

Although these meat-free foods may seem foreign to many of us, soybean, their common ingredient—except for seitan, which is made from wheat—is all around us. Before making its way into food, soy protein started as an industrial waste product, commonly used in paper coating, binding ink, paint, and adhesives. Since the 1950s, soy protein has been found in fast food and school lunches to "extend" the amount of ground beef in a hamburger. Soy protein is also present in bread, ice cream, soup, salad dressing, cereal, and lots more.

Eating too much unprocessed soy can cause some problems. Soybeans naturally contain toxins and nutrients that block the enzymes needed for digestion and absorption of essential minerals. But the fermentation of soybean—as in tempeh—eliminates and breaks down the harmful compounds, so we digest the proteins without negative effects.


MIKE CIESIELSKI

Of all the four meat-free products, Tofurky is the closest to simulating the fibrous qualities of meat, like chicken or turkey. None of the other meat-free products—tofu, tempeh, and seitan—will tear into irregular, coarse pieces that you observe with chicken. Many vegetarians don't mind that lack of similarity to meat; all they want is a healthy source of protein.

Vegetarians also want these products to taste good—and that's where the cooking comes in. When meat-free products are cooked under high heat—between 230 °F and 300 °F—carbohydrates break down into simple sugars and the carbon molecules combine with the amino acids in protein to produce a chemical reaction known as the Maillard reaction. This is the browning on the surface of foods that creates the smell that makes your mouth water and the crispy appearance that occurs when you bake or fry.


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Soy protein is extracted from soybeans, shown here in blossom (top) and after they are harvested (left).

Frying and roasting meat-free products also gives them more and different flavors. Depending on which amino acids are present, hundreds of flavor compounds can be created.

When you get down to the molecular level, the carbon, hydrogen, oxygen, and nitrogen is the same, whether it came from actual meat or from a meat substitute. Today, there are scientists trying to grow meat in test tubes that has the correct taste and texture. But we still depend on protein that is either raised or grown. Along with the protein and amino acids, you consume fat, cholesterol, carbohydrates, minerals, vitamins, and whatever else is present. Chemically speaking, the old saying is true, you are what you eat! *CM*


MIKE CIELSIELSKI

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Changing the Course of Diabetes

By Sherry Karabin

Each day, millions of diabetics throughout the world test their blood sugar by pricking their fingers. If their blood sugar level is too high, that means their insulin level is too low, and they need to give themselves an insulin injection. Insulin is a chemical substance that allows cells to take in blood sugar and convert it into energy.

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The reason most diabetics have less-than-normal amounts of insulin is that their immune system destroys their insulin-producing cells, which are located in the pancreas. Not enough insulin in the body means that too much sugar accumulates in the blood and cannot be used to produce energy. High levels of blood sugar can lead to serious problems, such as heart attacks, strokes, kidney problems, and blindness.

To prevent these problems from happening, diabetics try to keep their blood sugar levels as close to normal as possible. To do so, they need to limit the amount of carbohydrates in their diet, and, when needed, they inject insulin through the skin with portable insulin pumps.

But there is hope in sight. In the future, diabetics may not have to prick their fingers or make drastic changes to their diet. Scientists around the world are working on an artificial pancreas that may one day replace the defective pancreas of diabetics. At The University of Akron, Ohio, for instance, scientists have been working on such a device for the past 15 years. Their artificial pancreas is now showing promising results.

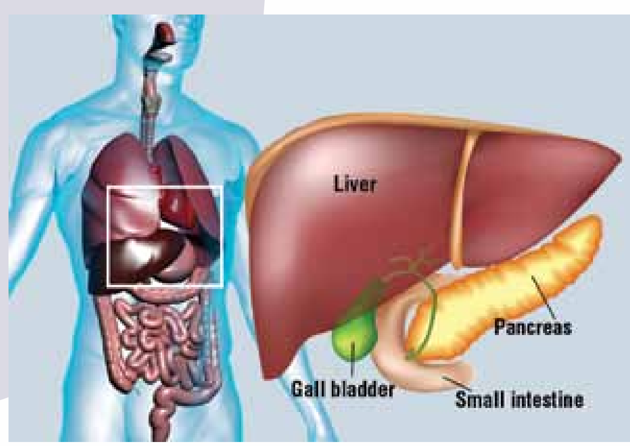
The artificial pancreas developed by the UA scientists looks like a tube that contains healthy pancreatic cells. The main materials used to make this tube are polymers—materials that consist of long chain-like molecules and that have an extraordinary range of properties.

Polymers are present in practically every product that surrounds us, including plastic containers, packaging materials, nonstick cooking pans, clothes, and automobile parts. Polymers are also used in a number of medical applications, such as heart valves, dental fillings, replacement joints, and prosthetic devices. So, it is no surprise that the UA scientists decided to use a polymer to create an artificial pancreas.

"Polymers are very important for medical devices because their properties can be 'tuned' to deliver precisely the function that is needed for various demanding clinical applications," says Joseph P. Kennedy, leader of the team of UA scientists.

Long, chain-like molecules

Many of the polymers that we use in our everyday products are industrially made, but polymers are also present in nature. Actually, polymers are one of the most important molecules in nature because they are essential to life. Our genetic code, for example, is contained in a long molecule, called deoxyribonucleic acid (DNA), which consists of two polymers that are facing each other (Fig. 1).



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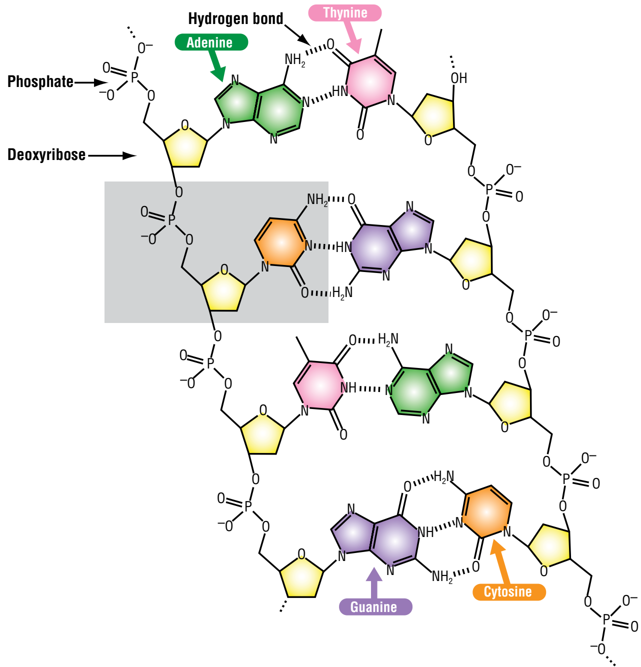


Figure 1. DNA consists of two chain-like molecules facing each other that consist of repeating units, each composed of three parts: a phosphate group, a deoxyribose sugar, and a nucleobase (adenine, thymine, guanine, or cytosine). The repeating unit highlighted in gray contains the nucleic acid cytosine.

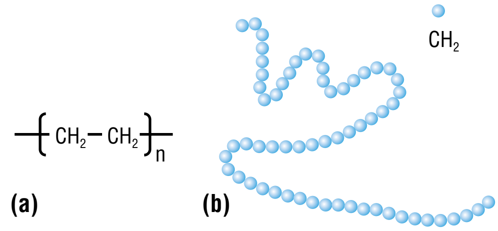
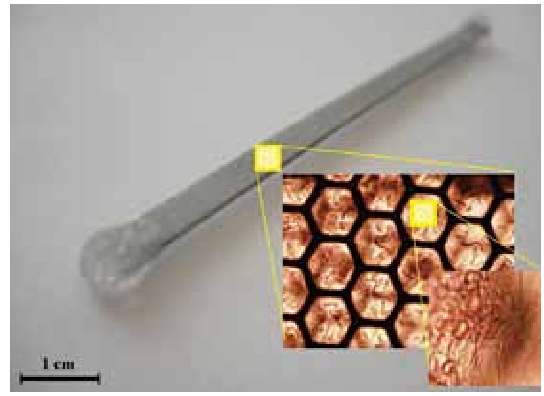


Figure 2. (a) Chemical structure of polyethylene (n is a very large number); (b) model of a polyethylene molecule.



JOSEPH P. KENNEDY

Figure 3. The artificial pancreas created by scientists at The University of Akron and a close-up of its polymer membrane coating, and the healthy pancreatic cells inside.

FIGURES BY ANTHONY FERNANDEZ

Proteins are an essential natural polymer that participates in virtually every biochemical reaction in our bodies and are an important food group. Carbohydrates are another group of natural polymers that are used to store energy in our bodies and are structural components of cells. They are also another important food group.

While natural polymers form the basis of life—and have been on Earth as long as life itself—synthetic polymers were discovered only a century and a half ago. One of the simplest synthetic polymers is polyethylene (Fig. 2), which consists of a long chain of ethylene monomers bonded together.

Synthetic polymers are usually arranged in a random structure, giving them unique properties, such as elasticity and flow that make them useful in a wide variety of applications.

Making an artificial pancreas

Kennedy and his team have been developing a prototype for an artificial pancreas for the past 15 years. The prototype consists of a 7-centimeter-long metallic tube (Fig. 3) coated with a polymer membrane made up of poly(dimethylacrylamide) and polydimethylsiloxane (Fig. 4). What makes this membrane so successful is that it is semipermeable: It allows certain substances to pass through.

The device was designed to protect the pancreatic cells from being destroyed by the molecules in the immune system called antibodies—which is the main problem faced by diabetics. To prevent this from happening, the holes in the polymer membrane are small enough to keep antibodies out but large enough to allow nutrients and oxygen to come in from the outside. The size of these holes is also large enough to allow insulin produced by the pancreatic cells to come out of the tube.

The device detects the amount of glucose in the blood and delivers insulin accordingly. This way, the concentration of insulin in the body is precisely controlled, and patients do not have to perform painful daily testing or self-injections to maintain proper insulin levels. In other words, the artificial pancreas is allowing these patients to live their lives as if they did not have the medical condition.

The device is currently being tested on lab rats. Gabor Erdodi, a member of the UA team of scientists, says the next step is to work on larger animals in an effort to conduct clinical trials on human patients and ultimately receive approval from the U.S. Food and Drug Administration to make it commercially available.

Should the scientists succeed, it will still be at least 10 years before the device is on the market, Erdodi adds. But the invention would certainly help to alleviate a health crisis that is expected to get worse. The World Health Organization estimates that there are more than 180 million diabetics worldwide, and those numbers are expected to double by 2030, especially because the rate of obesity—the leading cause of diabetes—is also increasing. *CM*

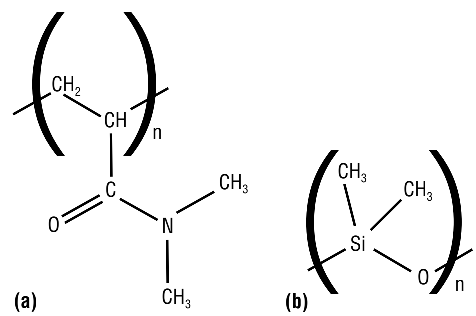


Figure 4. Chemical structure of (a) poly(dimethylacrylamide) and (b) polydimethylsiloxane (n is a very large number).

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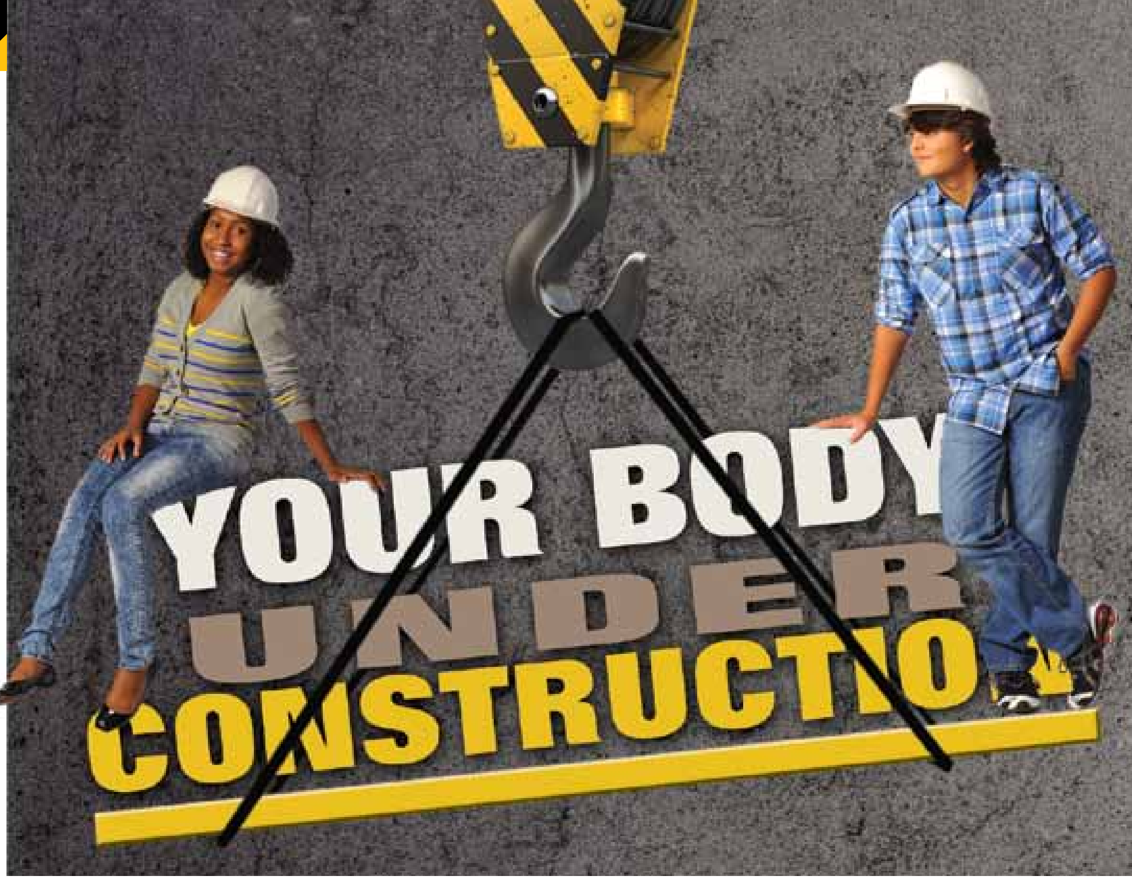

PHOTOS.COM AND MIKE CIESIELSKI

By Michael Tinnesand

Upon reaching the age of 12, boys in the Brazilian Satere-Mawe tribe face a terrifying test as a rite of passage into manhood. The boys take part in a ceremony where they must put their hands inside a pair of gloves loaded with bullet ants. It is a rite that could make the most courageous of young boys tremble with fear.

The bullet ant inflicts one of the most painful bites of any insect, some 30 times as painful as a bee sting. Their hands are only in the gloves for 10 minutes, but the burning, throbbing pain lasts for 24 hours. And what happens after they survive this ceremony? They must repeat it 19 more times before they are considered true adults in the tribe.

Rites of passage occur in nearly every culture around the world, although most of them are nowhere near as painful or dramatic as the bullet ant initiation. In Jewish culture, the Bar Mitzvah (for boys) and Bat Mitzvah (for girls) ceremonies mark their coming of age as adults at ages 13 and 12, respectively. Christians celebrate with confirmation or, in some cases, baptism. In many parts of Latin America, the Quinceañera at age 15 marks the transition for girls from childhood to womanhood.

Our bodies as chemical factories

What is it about the early teenage years that inspires this wide range of ceremonies, marking the change from childhood to adulthood? The answer lies in the basic chemistry of human growth and development.

Beginning with the teenage years, the body begins its own "rite of passage" called puberty. The word comes from the Latin *puberatum*, meaning "age of maturity" or "manhood." The effects on the human body are relatively quick and substantial. Boys develop facial and pubic hair, voices deepen and muscles grow. Girls develop breasts and their body composition includes a higher percentage of fat which, along with skeletal changes, gives the classic feminine "hour glass" shape to their bodies.


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But what causes these remarkable changes? The answer lies in chemical substances called hormones. It is of little surprise that the control of our growth and development is based on chemicals. Although there is little evidence in our everyday lives to make us think so, our entire existence is based on millions and millions of chemical reactions.

Our bodies are amazing chemical factories that build up and tear down body parts constantly. Chemists can keep track of our metabolism by labeling atoms with radioactive material. They discovered that every year, 98% of the atoms in our bodies have been exchanged for new ones. We are always "under construction." Chemical reactions allow us to get energy and building materials from the food we eat. Chemical reactions control how we move, respond, and heal. There is very little that happens inside our bodies that does not involve a chemical reaction.

Hormones are defined by their action. They are generally produced by small organs called glands and are carried through the bloodstream to other cells where they cause changes. One remarkable feature of hormones is that they can have significant effects on our bodies in doses as small as a few millionths of a gram (micrograms).

In contrast, most of the substances that affect our bodies are taken in large quantities. Think about the food we eat. We consume several kilograms of food each week, but the short-term effect on our body shapes is small. (The long-term effect is a different story!) The daily dose of required vitamins ranges from a few micrograms to several hundred milligrams. But only relatively small amounts of hormones have noticeable effects.

Physical changes in males

Although we know hormones are the cause of changes in our bodies at puberty, we still don't know why it starts all of a sudden in the teenage years. In males, it is all about the hormone called testosterone. This hormone is produced in male testes, which are also known to make sperm.

At the onset of puberty, the testes begin pumping out more and more testosterone. As the level of testosterone increases, the effects on the body begin to take shape. Testosterone is an androgen—meaning it is responsible for the development of male characteristics. These include stimulating growth of the sex organs that make up the male reproductive system, thickening of the skin, beard, and muscle growth.

These effects are part of the body's *anabolism*—processes that build up our bodies. Testosterone is one of a class of hormones called steroid hormones, which are derived from the dietary fat cholesterol (Fig. 1). A

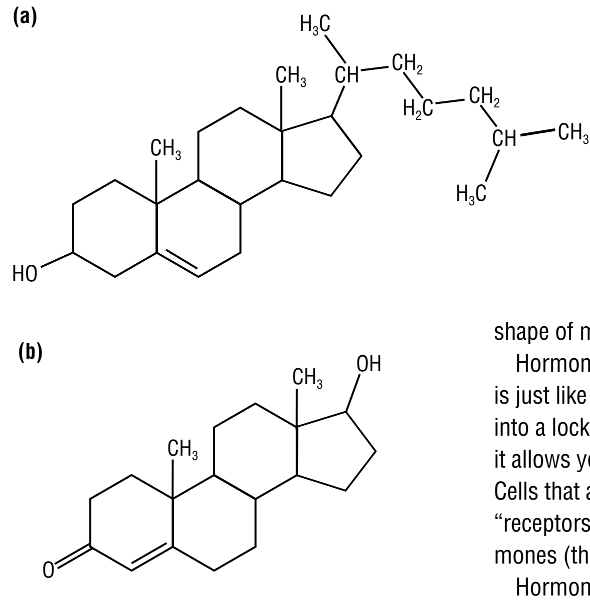
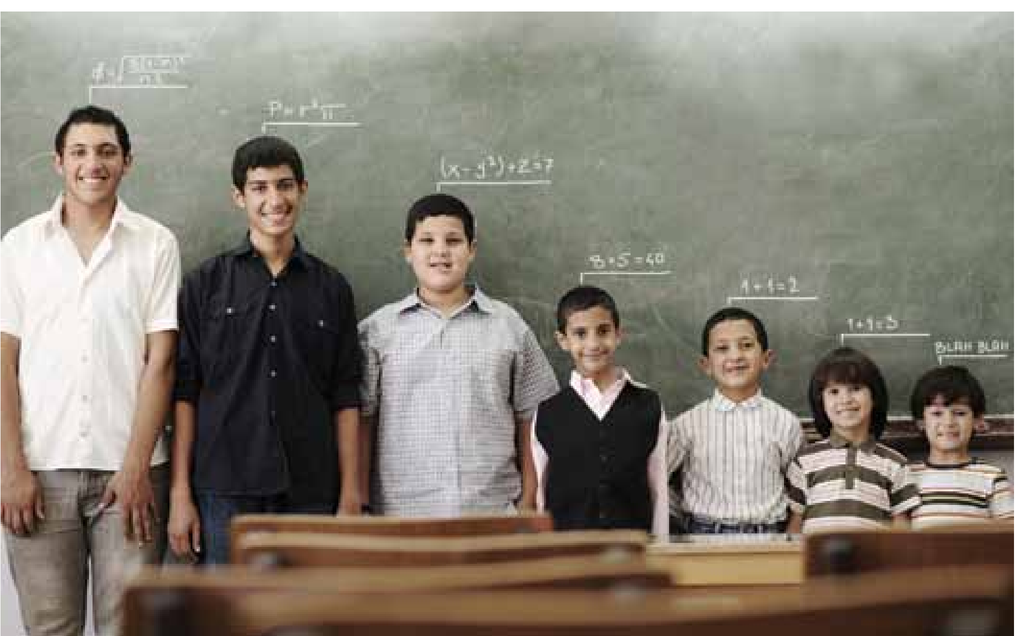


Figure 1. Chemical structures of (a) cholesterol and (b) testosterone

steroid is an organic compound that contains four rings that are joined to each other in a particular arrangement.

Anabolic steroids are very effective in stimulating muscle growth, which has tempted some athletes to take supplements that contain large doses of these androgens to improve their athletic performance. In addition to the unethical nature of its use, the potential harmful health effects of androgen steroid use is well established. High concentration of steroids from supplements can prevent the release of natural hormones necessary in the production of sperm and can lead to temporary infertility. Excess amounts of supplemental testosterone also leads to its conversion to a female hormone, causing breast enlargement.



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Form and function

So, how do these powerful molecules work? They follow the concept of form and function, the principle that the shape of molecules determines how they work. Many chemical mechanisms depend on the shape of molecules for their activity.

Hormones are examples of this concept. It is just like what happens when you put the key into a lock. If the shape of the key is just right, it allows you to turn the key and open the lock. Cells that are affected by a hormone contain "receptors," which act as locks to which hormones (the "keys") bind.

Hormone receptors are either on the surface of the cells or on the surface of the nucleus inside the cell. When a given hormone fits into a specific receptor, they are like two jigsaw pieces fitting together.

What happens next depends on the type of hormone. In the case of testosterone the receptors are found in the nucleus of the target cell. When the testosterone binds to its receptor, it causes the receptor to change shape. This shape change then allows the receptor to attach to a strand of DNA in the nucleus. DNA, or deoxyribonucleic acid, is the chemical responsible for the genetic information that controls the function of the cell.

Binding to specific sites on the strand of DNA causes the production of messenger RNA (mRNA), which carries the genetic information that directs the synthesis of proteins. Since proteins are the main structural materials of our body (muscles, hair, skin, organs), any change in protein production can have a big impact on how we look.

Females also produce testosterone, but only about a tenth as much. Females begin their rite of passage in puberty with other hormones.

Physical changes in females

In girls, puberty starts when their ovaries produce larger amounts of a type of hormone called estrogen. Estrogen is actually a group of compounds such as estradiol (Fig. 2 on next page).

The ovaries are the center of the female reproduction process. They not only produce the hormones associated with puberty and fertility, they also shelter and nourish some 500,000 egg cells.

An interesting side note: Although males begin producing sperm at puberty and continue their whole life, a female is born with all the eggs she will ever have. These eggs are stored in the ovaries and released one at a time, in a monthly cycle controlled by hormones.

Like testosterone, estrogen molecules also belong to a class of hormones called steroid hormones. Estrogen molecules are similar to testosterone, in that it affects the appearance and function of the body in many ways. It promotes the layering of fat beneath the skin and accounts for the fact that women tend to have more body fat than men. This accumulation of body fat is particularly true in the breasts and hip areas. It is thought that this is an evolutionary development, as young women begin to become fertile and ready to have babies, it is important they have an adequate amount of stored energy, in the form of fat, to be able to nourish their babies.

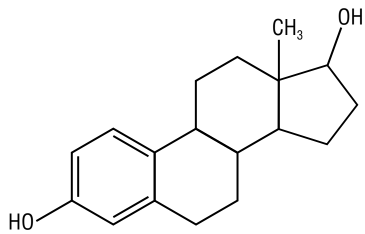
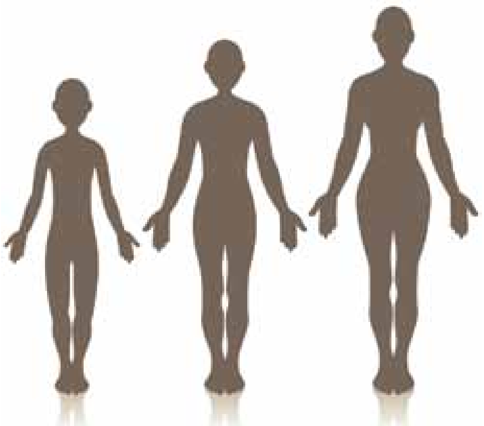


Figure 2. Chemical structure of estradiol, a type of estrogen

Estrogen also makes the skin smoother and thinner. It has an inhibiting effect on bone growth, accounting for the fact that on average, women are shorter than men. Curiously, estrogen has the opposite effect on the bones of the pelvis, causing them to become wider than in men. Again, this is a change that makes it easier for women to give birth.

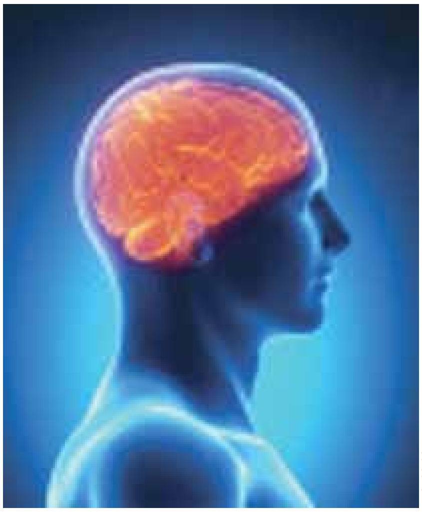


This last observation raises some interesting questions. How can the same chemical messenger cause bones in one part of the body to grow and in other parts to slow down? Testosterone has similar contradictory effects. It stimulates hair growth on the face and body, but can cause baldness on top of the head. How can this be?

The answer is not well understood, but likely has to do with the genetics of individual cells. Variations among hormone receptors in individual cells could change everything in the way the hormone alters the cell behavior. We have only looked at a few hormones. There are many other hormones that influence how cells behave.

Hormones and the brain

Hormones can also affect the brain. The changed anatomy of the male brain is significant enough that it can be seen in medical imaging techniques. Two behaviors influenced by testosterone are sex drive and aggression. This kind of behavior is observed all the time in the animal world. The largest and most aggressive wolf in a pack is more likely to breed with females, and have its genes passed on to the next generation



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Likewise, estrogen affects female behavior. It has an influence on sexual arousal and can also affect food intake. High levels of estrogen tend to suppress appetite in females, while low levels have the opposite effect. This increase and reduction in appetite seems to be related to pregnancy, ensuring there is adequate nutrition for growing babies.

There is some evidence that links estrogen levels to eating disorders such as anorexia nervosa or bulimia. Also, if a female becomes very lean from dieting, exercise, or starvation, her reproductive cycle will be inhibited. This again seems to be a natural safeguard that prevents pregnancy when there does not seem to be enough body fat to nourish a baby during pregnancy.

The hormones associated with puberty and sexual development are filling just one of the many roles hormones play in human metabolism. There are many examples of basic human systems that are under the control of hormones.

The hormone insulin is a great example. Insulin is essential in the ability of cells to take in glucose molecules that provide energy to our cells. Lack of adequate insulin restricts the cells' ability to take in glucose, which results in a medical condition called diabetes. (See the article titled "Changing the Course of Diabetes" on p. 12 in this issue.)

Other hormones regulate blood pressure and heart rate, and a whole class of hormones serves to regulate other hormones. It is a complex and elegant system.

Anyone who has experienced puberty can attest to the power and influence of hormones. Fortunately, the changes that accompany it don't happen overnight, giving teenagers time to adjust. After all, it could be worse: We could be walking around wearing gloves full of stinging ants! *CM*

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Was It Doomed By Chemistry?

TITANIC

By Brian Rohrig

In a few months, the world will observe the 100th anniversary of the sinking of the Titanic. Believe it or not, there is still a lot of debate over what caused the ship to sink. New evidence is still being uncovered—with chemistry playing a starring role.

On the morning of April 10, 1912, the Titanic embarked on its maiden voyage from Southampton, England, to New York. At 52,310 tons, it was the heaviest ship at the time to ever set out to sea. It was as large as four city blocks and as high as an 11-story building. No expense was spared in making the Titanic the most luxurious ship ever built. The roster of the ship's passengers read like a "Who's Who" of the world's rich and famous. A first-class ticket cost $4,700—equivalent to $50,000 in today's money!

The makers of the ship claimed that the Titanic was virtually unsinkable, due to its many safety features—especially a double layer of steel along the bottom of the hull. The hollow, lowermost portion of the ship was divided into 16 watertight compartments, separated by 15 vertical partitions. This design made the ship very difficult to sink, because even if four of the first compartments became flooded, the ship could still stay afloat. The ship's owners were so confident about its safety that they only carried 20 lifeboats on board—enough for about half of its passengers.

Disaster at sea

All was well until April 14. That day, at 9 a.m., the Titanic received a message from another ship, the Cunarder Caronia, announcing the presence of small icebergs and field ice in the area. It was followed by six more messages from other ships in the area warning of the presence of icebergs and field ice. All of these messages were dismissed by the captain of the ship, Edward John Smith.

At 11 p.m., the Titanic was traveling close to its top speed of 22 knots (25 mph). It was a calm and moonless night, making icebergs very difficult to see.

At 11:40 p.m., the two crew members on duty saw a large iceberg right in front of them. To avoid it, the ship attempted to turn, but it was too late. The front right side of the ship grazed the iceberg. Eyewitnesses described the impact as a slight jarring—strong enough to be felt but not enough to worry about. By hitting the iceberg on the side, extensive damage was made to the hull, rupturing five of its compartments (Fig. 1 on next page).

Experts determined later that icebergs in the area had been in the process of melting, so the surface of the melting ice acted like a mirror, reflecting light from the sky and water around it, which made the iceberg difficult to see. The experts also concluded that if the ship had hit the iceberg head-on, it may not have sunk, since only one or two of the 16 watertight compartments would have ruptured.

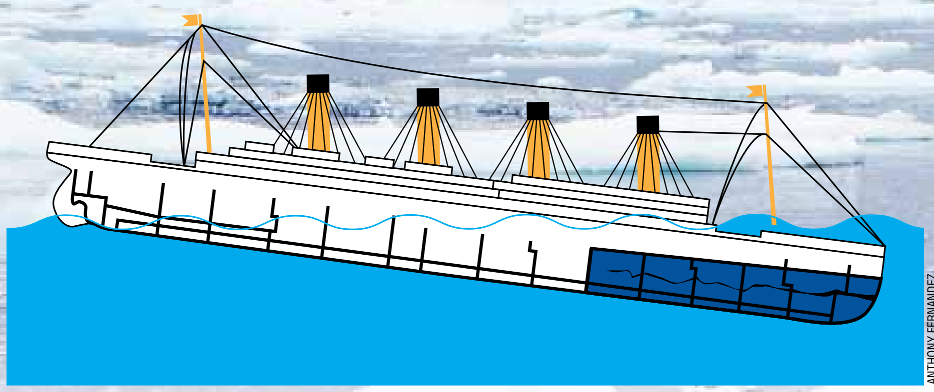

Figure 1. When the Titanic collided with an iceberg, it caused five of its 16 compartment to rupture.

The damage occurred 20 feet (6 meters) below the water line. At this depth, the water pressure was higher than if the damage had been closer to the surface, causing water to rush into the ship at a rate of 7 tons per second! As it filled with water, the ship tipped forward, flooding more of the forward compartments with water. Eventually, the ship became heavy and too dense to stay afloat. Less than 3 hours after hitting the iceberg, the Titanic would sink, plunging 12,600 feet (3840 meters) into the icy waters of the North Atlantic Ocean.

Of the 2,228 people aboard the ship, only 705 survived. The temperature of the water was 31 °F (–1 °C), close to water's freezing temperature (32 °F, or 0 °C). A number of people died of hypothermia after spending the night in the frigid water. Hypothermia occurs when the body's temperature drops to the point when the normal functions of the body are impaired, which can be deadly.

The next morning, when the survivors were rescued, more than 300 dead bodies were recovered from the water, still in their life jackets.

What happened to the Titanic?

After the Titanic's encounter with the iceberg, it started taking on water. As the ship's compartments filled with water, its mass increased. As a result, its density—the ratio of its mass to its volume—increased as well. This caused the ship to be too dense to stay afloat and it sank.

This brings the question: Why do ships float in the first place? An object sinks if its density is greater than the density of the water around it and floats if its density is less. The Titanic was made of steel, a material far denser than water, and weighed more than 46,000 tons. How did it manage to stay afloat? Actually, much of the area enclosed by the ship's metal hull is just air, and the average density of the total combination of metal, air, and cargo is less than the density of the water it floats in.

A ship floats due to a force that goes upward called the buoyant force. It was discovered by Archimedes, a Greek mathematician who one day, while taking a bath, noticed that the amount of water he displaced was related to how much space he occupied. This led to a basic definition for why things float: "An object immersed in a fluid is buoyed up by a force equal to the weight of the fluid it displaces." That force is the buoyant force, and it is equal to the weight of the fluid displaced—the amount of water that rises because of the presence of the object in the water.

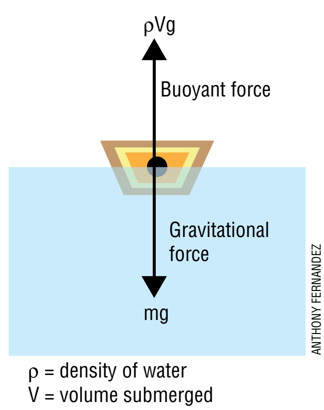

Figure 2. A floating object undergoes two forces: a gravitational force that pulls it downward and an opposite force that pushes it upward. The two forces are equal: the buoyant force (rVg)=the gravitational force (mg), where r is the density of water, V is the volume submerged, g is the acceleration due to gravity (9.8 m/s^2), and m is the mass of the object.

When a ship floats, it undergoes two opposite forces: the force of gravity, which goes downward; and the buoyant force, which goes upward. For a ship to stay afloat, the force of gravity needs to be equal to the buoyant force (Fig. 2). Also, the buoyant force is exerted by the water, not by the ship.

After the Titanic hit the iceberg, the water that filled the ship made it heavier. To stay afloat, the ship needed to displace more water, since a greater buoyant force was needed to keep the heavier ship afloat. If only a little water had seeped in the ship, it would have displaced a little more water but would not have sunk. But once the Titanic was completely submerged, it could not displace any more water, so that its additional weight was not evenly balanced by the buoyant force anymore, causing the ship to sink.

Why the Titanic sank

Although the Titanic was built to be unsinkable, something happened after the collision with the iceberg that caused water to rush in and spread uninterrupted. What exactly happened is still a mystery, but different hypotheses have been proposed by experts, especially after the discovery of the remains of the Titanic in 1985.

The team of scientists who found the Titanic's remains was headed by Robert Ballard, a well-known sea explorer and professor of oceanography at the University of Rhode Island in Kingston. When Ballard and his team analyzed metal samples from the ship, they noticed that this steel had abnormally high sulfur content.

Steel is an alloy—a metal made by combining two or more metallic elements. Steel is an alloy of iron with small amounts of carbon. It is made from iron ore—rocks or minerals that contain iron, usually in a compound form.

To make steel, this iron must be removed from the raw material by a chemical process. A common method, known as the Bessemer process, involves melting the iron ore and blowing oxygen over the molten mixture. The oxygen will react with impurities, such as silicon, manganese, and carbon, producing oxides that can be removed.

Steel consists mostly of iron with 0.2%–2.1% carbon. To make steel harder and more durable, nonmetals such as sulfur are added to iron. Iron by itself is somewhat soft and malleable, so adding a nonmetal makes it harder. But this hardness comes at a price:

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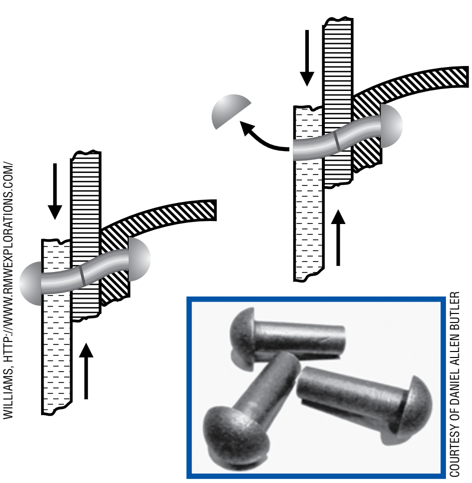
brittleness. Nonmetals tend to be brittle, while metals tend to be malleable.

The iron from the Titanic had high sulfur content. As a result, the Titanic's steel was 10 times more brittle than today's steel. Later, scientists identified the presence of high levels of oxygen and phosphorus, nonmetals that can also add to steel's brittleness.

COURTESY OF CHRISTIAN STENFELT

The water that filled the Titanic made it so heavy that it broke in two before sinking.



DRAWING BY TONY FERNANDEZ; CONCEPT BY ROBERT M. WILLIAMS, HTTP://WWW.RMWEXPLORATIONS.COM/

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Figure 3. The rivets (small gray half-spheres) holding the plates on the sides of the hull of the Titanic may have snapped after the ship collided with an iceberg. (Inset) Photo of rivets used on the ship.

An intriguing new hypothesis about why the Titanic sank was put forth in a book, titled *What Really Sank the Titanic: New Forensic Discoveries,* by Jennifer Hooper McCarthy and Tim Foecke. Both authors, who hold doctoral degrees in materials science, claim that poor-quality rivets were the culprit. Rivets are metal fasteners that hold steel plates together.

When scientists analyzed rivets recovered from the wreckage, they measured abnormally high concentrations of slag—a glassy residue that contains iron, oxygen, and silicon and that is left over from the process that converts iron ore into iron. The amount of slag present in the rivets was about three times the amount expected in today's iron. Too much slag makes metal brittle.

McCarthy and Foecke postulate that when the hull was struck by the iceberg, it pressed inward, stressing some of the rivets and causing their heads to pop off (Fig. 3). A chain reaction then ensued, opening up the seams between the metal plates.

Could it happen again?

The sinking of the Titanic ranks as one of the most remarkable maritime disasters of all time. But as a result of this tragedy, ships today are much safer than they were 100 years ago for four main reasons. First, steel-making techniques have advanced tremendously in the past 100 years. Today's steels are not only tougher but also less brittle, and ships are welded together in sections—not riveted. The hulls are much thicker, and water-tight compartments are typically not linked to one another, preventing water from leaking from one compartment into another.

Second, ships can detect icebergs more readily than they did 100 years ago. When traveling in waters where icebergs are likely to be present, ships today use radar, a high-energy electromagnetic radio wave that bounces off nearly everything and can easily detect obstacles such as icebergs. But this technology is not foolproof. In 1959, a Danish ship, equipped with radar, still struck an iceberg and sank, resulting in 95 deaths.

Third, if you are thinking of embarking on a cruise today, you will notice the presence of enough lifeboats for the passengers and all of the crew members.

Last but not least, advanced satellite communications, modern navigation technology—such as the Global Positioning System—and computerized navigation systems are all in place to protect ships and everyone on board.

Today, the thought of a luxury liner sinking to the bottom of the ocean is virtually unthinkable. But were the passengers of the Titanic any less assured of their safety than we are today? Accidents still happen. A good lesson to learn from the Titanic is that no ship is really unsinkable. Next time you sail the high seas, keep that life jacket handy! CM

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