ChemMatters®

DEMYSTIFYING EVERYDAY CHEMISTRY

DECEMBER 2012

Food Smarts: Figuring Out Nutrition Labels

p. 6

You Better Cook Twice! p. 9

Like That Smell? p. 12

ACS Chemistry for Life™

www.acs.org/chemmatters

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

Subscriber Information
Prices to the United States, Canada, and Mexico: $16 per subscription. Inquire about bulk, other foreign rates, and back issues at the ACS Office of Society Services, 1155 16th St., NW, Washington, DC 20036; 800-227-5558 or 202-872-6067 (fax). Information is also available online at: www.acs.org/chemmatters.

American Chemical Society ChemClub

NEWS

Bond with Someone New!

Bond. What comes to mind when you read that word? Well, you are reading a magazine about chemistry, so you might think about the attraction between atoms. Maybe you saw the latest James Bond movie this fall, and Agent 007 pops into your head. An American Chemical Society (ACS) ChemClub poster designed by ChemClub members from T. Wingate Andrews High School in High Point, N.C., suggests a third idea. Its tagline: "Try ChemClub and bond with someone new!"

SALLY MITCHELL

ChemClubs from New York State participated in a 5K run to raise money and awareness for breast cancer research.

SEEMA AHUJA

ChemClub students in Houston, Texas, designed a holiday tree made of aluminum cans to encourage students to recycle.

ChemClubs give members the chance to get together and bond outside the chemistry laboratory. Since the start of the program in 2005, ChemClub members have been working together to accomplish projects in their own school districts, in surrounding communities, and for others across the world.

ChemClubs from three high schools in New York State, along with the Syracuse ACS Local Section, participated in the Carol Baldwin "A Run for Their Life" 5K run to raise money and awareness for breast cancer research. The run was on Mole Day, Oct. 23, 2011, so the students—from **high schools in East Syracuse–Minoa, Fayetteville–Manlius, and Jordan–Elbridge**—made 1,023 "moleasses" cookies to give away, while sharing information about the health benefits of ginger.

In December 2011, ChemClub students at **Jefferson Davis High School in Houston, Texas,** designed a holiday tree to display in its school commons. The tree was made of aluminum cans the Club collected for recycling and was decorated in the school colors. It reminded all students to recycle.

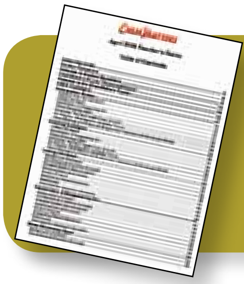
During the summer of 2011, students at two ChemClubs in Puerto Rico—**Radians High School in Cayey,** and **Escuela San Germán Interamericana in San Germán**—helped to clean up their beaches. Removing trash and debris made these beaches more welcoming to tourists and local residents and reduced the chances that people and animals who live near the beaches would face health hazards from litter.

ESCUELA SAN GERMAN INTERAMERICANA CHEMCLUB

ChemClub students in Puerto Rico helped to clean up their beaches.

This year, the ChemClubs will participate in a project to help provide clean water for people around the world. For more information, go to the ChemClub Web site: **http://www.acs.org/chemclub** and the ChemClub Facebook page: **https://www.facebook.com/acschemclubs**.

—Erica K. Jacobsen



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

ChemMatters®

Vol. 30, No. 4 DECEMBER 2012

DEPARTMENTS

FEATURES

5

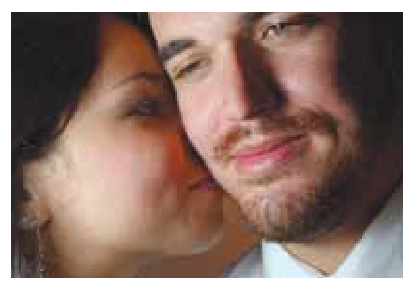
AP IMAGES

PHOTOS.COM

6

Check out the video podcast on nutrition labels at: www.acs.org/chemmatters

12



PHOTOS.COM

MIKE CIESIELSKI

15

ON THE COVER: MIKE CIESIELSKI PHOTOGRAPHY AND SHUTTERSTOCK PHOTOGRAPHY

DID YOU KNOW?...

DID YOU KNOW?...

PHOTOS.COM

Photochemistry: Artificial Leaves to the Rescue

Gasoline comes mostly from fossil fuels—oil, coal, and natural gas. But fossil fuels cause air pollution when they are processed to make gasoline. Also, the current reserves of fossil fuels will be depleted sometime in the future.

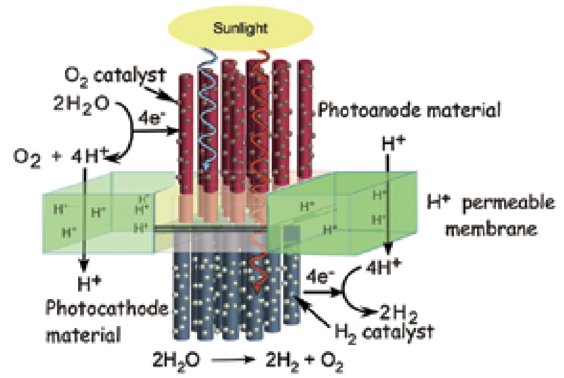
So scientists are trying to find an alternative to gasoline that is cost-efficient and reliable. Materials that work like leaves, called synthetic leaves, could be such an alternative. Plant leaves use sunlight to make their own food—in the form of compounds called carbohydrates—through a process known as photosynthesis. One common carbohydrate produced by plants is glucose ($C_6H_{12}O_6$), which results from the reaction of carbon dioxide and water from the air:

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

An artificial leaf would also use sunlight and water to create hydrogen and oxygen. The hydrogen created through this process could serve as a source of energy that would ultimately replace gasoline. When used as a car fuel, hydrogen combines with the oxygen in the air and releases energy along with water:

$$2\ H_2 + O_2 \rightarrow 2\ H_2O + \text{energy}$$

The artificial leaf that Nate Lewis, a chemist at the California Institute of Technology in Pasadena, and colleagues have developed consists of a membrane that produces hydrogen in two steps. First, catalysts in the membrane help to form oxygen from water, releasing protons (H^+) and electrons, as follows:



ELISABETH SANTORI, PHD, CALTECH, 2012

An artificial leaf does not look like a leaf, but it does the same work: It splits water into oxygen and hydrogen according to the redox reactions shown here.

$$2\ H_2O + \text{energy from sunlight} \rightarrow O_2 + 4\ H^+ + 4\ e^-$$

Then, the electrons combine with protons to form hydrogen gas, as follows:

$$4\ H^+ + 4\ e^- \rightarrow 2\ H_2$$

The artificial leaf produced in Lewis's laboratory looks more like a small spherical structure than a leaf. Such small structures could be arranged in the form of a layer that could look like bubble wrap and could be rolled out on the rooftop of a house, Lewis says. By absorbing sunlight and water from the air, this material would generate hydrogen that could be collected into a tank and converted later into gasoline.

—*Sherry Karabin*

Electromagnetic Spectrum/Light Absorption: What Does Urine Color Tell Us?

Where does the color of urine come from? Urine is usually light yellow, which is due to a pigment called **urobilin** that is produced in the body from the breakdown of hemoglobin in old red blood cells. Urobilin only absorbs light in the blue-violet wavelengths, so it appears yellow (the complementary color of violet).

Urine can turn red after eating beets. An estimated 10–15% of U.S. adults experience this harmless effect, called beeturia, which is caused by betalain pigments, the most common of which is betanin.

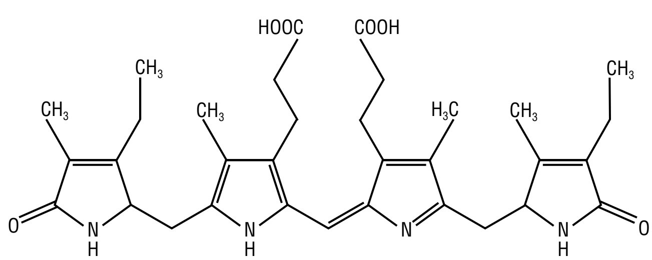
In most people, betanins are decolorized by processes in the stomach and colon. Acidity appears to play some role in accelerating the decolorization of betanin, so people with low stomach acidity may have a better chance of having the betanin pass through the stomach unchanged and enter the blood intact as a red pigment. It is then filtered into the urine, turning the urine red.

Another interesting urine color is green. For some people, when they take vitamin supplements or eat asparagus, their urine takes on a fluorescent yellow/greenish color that comes from excess vitamin B, especially riboflavin (vitamin B_2).

Daily recommendations range from 1–1.5 mg of riboflavin, depending on age and activity level. But once the body has the amount of riboflavin that it needs, the rest is excreted, and the yellow/greenish color of riboflavin shows up in urine.

There is more to urine than its color. Knowing what foods you ate can tell you the color that your urine will take. But if your urine has an unusual color, it could mean that something else is going on, and you may need to call your doctor. Who knew the color of urine could be so important?

—*Beth Nolte*



ANTHONY FERNANDEZ

Chemical structure of urobilin

By Barbara Sitzman and Regis Goode

TATTOOS

Thinking about tattoos?

Once popularized by cartoon characters, tattoos are everywhere now. Just look at the reality show Miami Ink, magazine advertisements for Calvin Klein, or celebrities such as David Beckham, Johnny Depp, and Katy Perry. Have you also noticed inked torsos during basketball and football seasons? The Pew Research Center reports that **38% of young adults ages 18 to 29 have tattoos.**

AP IMAGES.COM

How are tattoos made?

Needles puncture through two layers of skin, injecting droplets of ink. Jabs are repeated close together, forming a pattern. Since the ink is inserted deeply into the second layer of skin, it remains stable, so the tattoo is essentially permanent.

If you decide to ink, **do it safely by seeing an expert.** Ask if the tattoo artists are licensed, wear gloves, and sterilize their instruments. Since a new tattoo is a wound, treat it like one. Infection and diseases are potential problems.

PHOTOS.COM

What's in the ink?

Most tattoo inks are pigments suspended in a carrier solution that keeps the color pigments evenly distributed for smooth application. Salts of heavy metals are usually the source of color for the inks (Table 1). The heavy metals mercury, lead, and cadmium are known to cause brain damage, birth defects, and other serious medical problems.

When ink is carefully and safely deposited in the skin, it usually does not cause a problem, but if the body has an allergic reaction to the ink or carrier, chemical changes can occur that lead to an itchy rash or small bumps.

COLORS	METALS (symbol)
Black	Iron (Fe), Carbon (C)
Brown	Iron (Fe) rust
Red	Mercury (Mg), Cadmium (Cd)
Orange	Cadmium (Cd)
Yellow	Zinc (Zn), Cadmium (Cd)
Green	Chromium (Cr), Copper (Cu), Lead (Pb), Aluminum (Al)
Blue	Cobalt (Co), Copper (Cu), Iron (Fe)
Violet	Manganese (Mn), Aluminum (Al)
White	Lead (Pb), Titanium (Ti), Barium (Ba), Zinc (Zn)

Table 1. Typical metals used as pigments in tattoos

Can tattoos be removed?

You can't just cut or rub away a tattoo. Consider a tattoo as a lifelong decoration. Sometimes tattoos can be removed by repeated laser treatments performed by a doctor. When the laser's intense light energy is focused on a tattoo, **the ink pigments break into tiny, nanosized particles that are gradually absorbed by the body.** This is a painfully slow and expensive process, costing $1,000, or more, depending on the tattoo.

AP IMAGES.COM

Why not experiment with alternatives?

With all the cost, pain, and risks involved, why not do a trial tattoo first? This can be fun. Ink your body temporarily before attempting the real thing. You can order supplies online and host a glittery tattoo party at your home. If you decide to ink, do the research, and then look at the data to make an informed decision.

PHOTOS.COM

PHOTOS.COM

The Big Reveal
What's Behind Nutrition Labels

By Michael Tinnesand

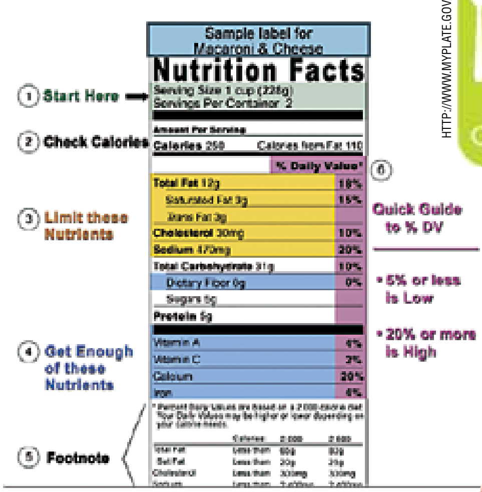
Nearly all of the foods we eat have a nutrition label that presents the essential values foods contain. The label starts with a serving size and the number of calories per serving, followed by a list of key nutrients, including total fat, carbohydrates, and proteins. Other values may be included, such as calories from fat, saturated fat, trans fat, dietary fiber, sugars, and various vitamins.

But what do all these values mean, and how are they measured? How does this information help us stay healthy?

Calories

Nearly all of us can be casual about the type and amount of food we consume. I recently stopped at a fast food restaurant and ordered a large caramel coffee frappé. I noticed a brochure near the counter and, as I finished my drink, I read that it contained 680 Calories!

I happen to know that in order to burn 680 Calories at the gym, I would need to spend at least an hour on a stationary bicycle, spinning at high speed. Given that just three of these drinks would exceed my daily limit of total energy required (2,000 Calories), this forced me to pay close attention to the nutritional values of what I eat. But where to begin?



Let's start with calories. Actually, the word "Calorie" (uppercase C) is what chemists call a "kilocalorie," or 1,000 calories (lowercase c). To distinguish between the two, the nutritional calorie is sometimes written as a Calorie—as in this article—as opposed to a calorie. More specifically, one Calorie (kilocalorie) is the amount of energy it takes to raise 1 kilogram of water 1 °C at sea level.

The calorie content of food was determined in the late 1800s by **Wilbur O. Atwater,** an agricultural chemist. He built a device called a respiration calorimeter to make direct measurements of heat released by humans from the food they consumed. At 4 feet by 8 feet, Atwater's calorimeter was big enough to allow a person to step into it. The device measured the amount of heat released by that person, along with the amount of oxygen consumed and carbon dioxide given off.

Using this device, Atwater was able to measure the precise amount of energy contained in thousands of food items. He found that carbohydrates and proteins were worth 4 Calories per gram and fats about 9 Calories per gram. This 4–9–4 system is how labels are determined today. In some cases, dietary fiber is subtracted from the total carbohydrate count because it is assumed that it provides no nutritional calories. Also, alcohol, if present, is accounted for as 7 Calories per gram.

HTTP://WWW.MYPLATE.GOV/

MIKE CIESIELSKI

Calories in, calories out

In case you wonder how many calories you need every day, the answer varies depending on your gender, your age, and your activity level (Table 1).

The calories we need for our daily activities come from a process called metabolism that occurs in the body's cells. Metabolism is a series of chemical reactions that occur when food is broken down in smaller pieces, which also releases energy.

This released energy can also be stored in body tissues for later use. When we consume more calories than our bodies need, calories are stored, primarily as fat.

Gender	Age (years)	Activity Level		
		Sedentary	Moderately Active	Active
Female	4–8	1,200	1,400–1,600	1,400–1,800
	9–13	1,600	1,600–2,000	1,800–2,200
	14–18	1,800	2,000	2,400
	19–30	2,000	2,000–2,200	2,400
	31–50	1,800	2,000	2,200
	51+	1,600	1,800	2,000–2,200
Male	4–8	1,400	1,400–1,600	1,600–2,000
	9–13	1,800	1,800–2,200	2,000–2,600
	14–18	2,200	2,400–2,800	2,800–3,200
	19–30	2,400	2,600–2,800	3,000
	31–50	2,200	2,400–2,600	2,800–3,000
	51+	2,000	2,200–2,400	2,400–2,800

Table 1. Calorie needs by gender, age, and activity level

HTTP://WWW.SPORTSCI.ORG/NEWS/HISTORY/ATWATER.HTML

This exercise machine, called an ergometer, was used in the laboratory of Wilbur Olin Atwater to measure the amount of calories released by exercising.

But how calories are produced and used—that is, our metabolism—varies from person to person and is mostly affected by how much a person exercises, the amount of fat and muscle in his or her body, and the person's basal metabolic rate—the rate at which a person's body uses energy while at rest.

The basal metabolic rate is responsible for up to 70% of the calories used by our bodies, so it can play a role in a person's tendency to gain weight. For example, a person with a low basal metabolic rate will not use as much energy as a person with a high metabolic rate for the same amount of food.

To a certain extent, the basal metabolic rate is inherited, but it also depends on the amount of muscle and fat present; people with more muscle and less fat generally have a higher basal metabolic rate. Also, people can change their basal metabolic rate by exercising or practicing a sport, which, in the long run, increases the basal metabolic rates of the heart, lungs, kidneys, liver, and the brain. Some outdoor activities can burn a substantial amount of calories (Table 2).

Proteins in food

In addition to calories, the nutrition label also displays the amount of the three main nutrients: proteins, fat, and carbohydrates. Proteins are found in meat, beans, milk, and nuts. Fat is present in vegetable oil, dairy products, and fish. Carbohydrates are found in fruits, vegetables, and cereals.

So how are these nutrients measured? Let's look at proteins first: The standard method for determining the amount of protein in food is called the Kjeldahl (pronounced: Kel-daal) method. Measuring the protein content of food is similar to measuring its nitrogen content because nitrogen in food is contained mostly in proteins.

The Kjeldahl method consists of three steps (summarized in Fig. 1):

1. A sample of food is heated in boiling sulfuric acid (H_2SO_4), which leads to ammonium sulfate [$(NH_4)_2SO_4$], among other products:

$$\text{Sample} + H_2SO_4 \rightarrow (NH_4)_2SO_4\,(aq) + CO_2\,(g) + SO_2\,(g) + H_2O\,(g)$$

Ammonium sulfate is made of ammonium ions (NH_4^+) and sulfate ions (SO_4^{2-}). The ammonium ions contain the nitrogen that was initially present in the sample.

2. The ammonium ions are then converted into ammonia gas (NH_3) by adding sodium hydroxide (NaOH) to the solution of ammonium sulfate:

$$(NH_4)_2SO_4\,(aq) + 2\,NaOH \rightarrow Na_2SO_4\,(aq) + 2\,H_2O\,(l) + 2\,NH_3\,(g)$$

3. The ammonia gas goes inside a condenser and ends up in a flask that contains a solution of boric acid. The ammonia is neutralized by the boric acid, as follows:

$$B(OH)_3 + H_2O + NH_3 \rightarrow NH_4^+ + B(OH)_4^-$$

When all the ammonia has reacted with the boric acid, the amount of borate ions [$B(OH)_4^-$] is determined by titration with a strong acid:

$$B(OH)_4^- + H^+ \rightarrow B(OH)_3 + H_2O$$

The amount of acid needed corresponds to the amount of ammonia that was present. The amount of ammonia is the same as the amount of nitrogen initially present in the sample, which is then used to determine the amount of protein present in the sample.

How much protein do we need every day? The Institute of Medicine recommends that adults consume a minimum of 0.36 grams of protein for every pound of body weight per day. That's about 58 grams for a 160-pound adult.

Fat content of food

The standard method for measuring fat content is called the **Soxhlet extraction**. In this method, food is ground up and continuously

Exercise	Calories per hour
Walking (*3 mph*)	280+
Tennis	350+
Bicycling (*moderate*)	450+
Swimming (*active*)	500+
Hiking	500+
Power walking	600+
Running	700+

Table 2. Calorie-burning chart for various activities

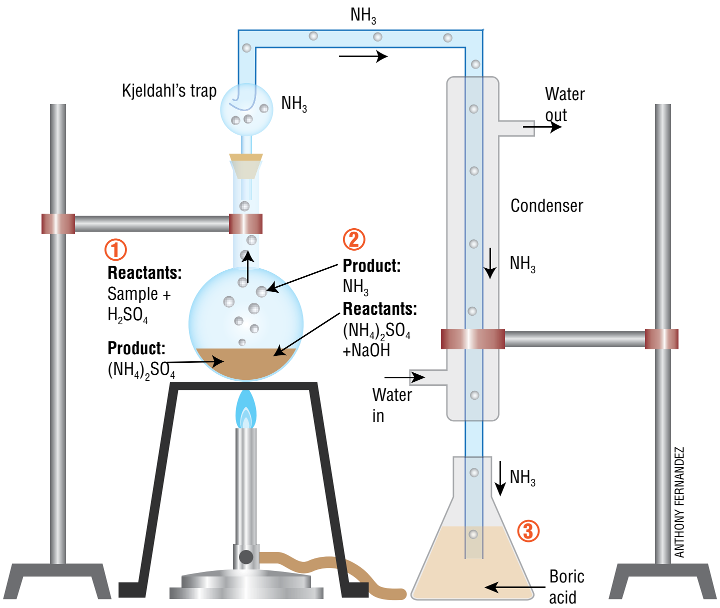


Figure 1. Schematic representation of the apparatus used to estimate the amount of proteins in food by using the Kjeldahl method.

washed with an organic solvent, dissolving only the fat. Although the Soxhlet extraction method has been used for more than 100 years, it is slow and complicated. It can take 6 hours or longer to remove all of the fat.

A new method uses a technique, called nuclear magnetic resonance, to measure fat. Here is how it works: The sample is placed in a strong magnetic field and is bombarded with a pulse of radio frequency. This causes the magnetic moments of the hydrogen nuclei to flip. After the pulse ends, the magnetic moments of the nuclei oscillate, but the magnetic moments of nuclei in fat oscillate at a slightly different frequency than the magnetic moments of nuclei in other substances. So the signal generated by nuclei in fat can be separated from the signals generated by nuclei in other substances present in the sample, and the amount of fat can be determined.

THINKSTOCK.COM

PHOTOS.COM

When eating out, watch portion sizes and choose meals that contain a balance of proteins, fruits and vegetables, and whole grains. A garden salad provides fiber, vitamins, and minerals without a lot of calories or fat.

How much fat should we consume? Experts agree that 30% of our daily calories should come from fat. If you consume 2,000 Calories in a day, that means no more than 600 Calories should come from fat. One way to consume 600 Calories from fat is to eat foods that have a total of 67 grams of fat (fat=9 calories per gram, see p. 6).

Carbohydrate content of food

The amount of total carbohydrates in food has traditionally been calculated rather than measured. Other components of food—such as protein, fat, and water—are measured and added together. This sum is subtracted from the total, and the difference is assumed to be the amount of total carbohydrates.

One problem with calculating the amount of total carbohydrates is that it does not distinguish between carbohydrates used by our bodies to produce energy—such as sugars—and carbohydrates that we cannot digest and are, therefore, excreted, such as fiber.

About half of the calories that you consume should come from carbohydrates. This means that if you consume 2,000 Calories per day, 1,000 Calories should be from carbohydrates. Because each gram of carbohydrate has 4 kilocalories, you would need no more than 250 grams of carbohydrates per day.

Staying healthy

Knowing about calories, proteins, fats, and carbohydrates can help people make informed decisions about the foods they buy and eat, especially if they are overweight or obese. According to the U.S. Centers for Disease Control and Prevention, the percentage of obese U.S. children ages 6 to 11 increased from 7% in 1980 to nearly 20% in 2008, and the percentage of obese U.S. adolescents ages 12 to 19 increased from 5% to 18% during the same period.

The average American diet is high in fat and sugar, so many teenagers consume too much sugar, mainly in the form of sugar-sweetened drinks, such as soft drinks, sports drinks, and energy drinks, along with high-fat foods such as chips, fries, and burgers.

By looking at the nutrition label on food products, you may gain a better understanding of what you are eating and what to include in your diet. *CM*

SELECTED REFERENCES

How to Understand and Use the Nutrition Facts Label, U.S. Food and Drug Administration: http://www.fda.gov/Food/ResourcesForYou/Consumers/NFLPM/ucm274593.htm [accessed Oct 2012].

Food and Fitness, TeensHealth: http://kidshealth.org/teen/food_fitness/ [accessed Oct 2012].

McArdle, W. D.; Katch, F.; Katch, V. L. Exercise and Sports Nutrition, 4th ed., Lippincott Williams & Wilkins: Baltimore, 2013.

Fast Food Facts: http://www.foodfacts.info/ [accessed Oct 2012].

Michael Tinnesand is a science writer and education consultant who lives in Portland, Ore. His latest *ChemMatters* article, "Graphene: The Next Wonder Material?" appeared in the October 2012 issue.

Check out the video podcasts on nutrition labels at: www.acs.org/chemmatters

A friend of mine used to toast his bread at medium setting, which makes it crispy on the outside but soft in the middle. But when he would add butter, sometimes the toast would become soggy in the middle. I showed him that if he toasted his bread twice at a low setting, he would notice that the bread would be crisp right through. So, he did, and when he scraped the toast with a knife covered with butter, the butter spread throughout without being soggy. When he ate it, he noticed that it tasted better, too!

Try it yourself: Toast a piece of bread at a high setting (say, 6) and then toast another piece of bread twice at a lower setting (say, 3). Will you notice a difference?

Several types of food taste better when they are cooked or heated twice. Not only is toast crispier, but cookies are both crunchy and soft and meat is more flavorful. Why is that? In all of these cases, because of the chemical reactions and transformations that occur inside the food, two is better than one.

Two Is Better than One

By Tom Husband

Super-crispy toast

Toasted bread tasted different in the two toasting scenarios because of two processes: the vaporization of water and a series of chemical reactions called the Maillard (pronounced: may-yar) reactions. The vaporization of water makes sense because water is already present in bread, and when the bread is heated, the water vaporizes.

If vaporization was the only process involved, the bread would simply seem stale. Stale bread is mostly dry because it lost its original moisture over time. But if you toast stale bread, you will notice that, like fresh bread, it will become brown and crispy, thanks to the Maillard reactions. These chemical reactions are responsible for the browning of not only toasted bread but a vast array of cooked foods, including french fries and meat.

In the case of toasted bread, the Maillard reactions occur between two substances that are present in the flour used to make bread: starch and gluten. Starch is a long chain of repeating units that belongs to a group of molecules called carbohydrates, and gluten is a protein.

The Maillard reactions produce various chemical compounds that create not just the brown color, but also the complex flavor that we associate with toast and other roasted foods. These compounds number in the hundreds of thousands, but they all come from proteins and carbohydrates (Fig. 1).

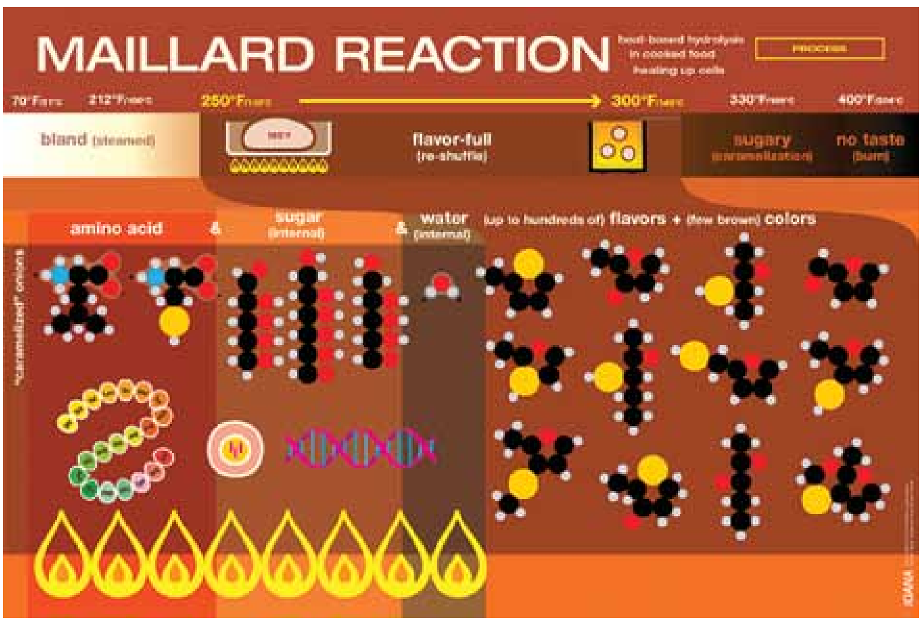
In both toasting scenarios, the Maillard reactions and the vaporization of water take place at the same time, but some water needs

MIKE CIESIELSKI

to vaporize before the Maillard reactions can start, because carbohydrates and proteins cannot react if too much water is present. Also, it takes a different amount of time for water vaporization and the Maillard reactions to occur.

On a medium setting, water at the surface evaporates, the Maillard reactions kick in, and the toast is suitably browned. But because it browned pretty quickly, it is still a bit soggy in the middle. We could continue toasting the bread to allow the remaining water to vaporize, but the toast would also continue browning, and it would be charred black by the time all of the water is gone.

Instead, toasting the bread for a longer time produces brown toast that is dry on the inside because all the water will have vaporized by the time the Maillard reactions are complete.



IOANA URMA; HTTP://IOANACOLOR.COM

Figure 1. The Maillard reactions occur between proteins and carbohydrates—depicted as their basic constituents, amino acids and sugars, respectively (on the left)—and lead to hundreds of compounds (on the right) that contribute to the browning of food, along with its distinctive flavor and color. The Maillard reactions occur at various temperatures (shown above) and, depending on the temperature, the products of these reactions change the way food tastes.

Crispier french fries

Just as toast is crispier if it is cooked twice at a low setting, french fries are crispier if they are fried twice. The best way to do this is first to deep-fry french fries at 140 °C (280 °F) and then to remove them from the heat and allow them to sit for about 10 minutes before frying them a second time at 180 °C (360 °F).

French fries—as well as potatoes, in general—are made of starch, a molecule that consists of repeating units called glucose ($C_6H_{12}O_6$). In potato cells, starch is present in granules—small structures that look like grains of rice but are much smaller (Fig. 2). In each granule, the starch molecules arrange themselves neatly in repeating rows, similar to a crystal. But each granule is not one single crystal; instead, it is made of areas that each contains a separate crystal structure.


MIKE CIESIELSKI

Starch arranges itself into neat, ordered granules because the building blocks of starch are attracted to each other through intermolecular forces—forces between molecules that have slightly positive or negative electric charges. In starch, the oxygen atoms in one unit, which have a slightly negative electric charge, attract the hydrogen atoms in neighboring units, which have a slightly positive electric charge.

When french fries are fried, the high temperature causes the starch granules to collide with surrounding water molecules, which overcome the intermolecular forces holding the starch in its crystalline structure. Starch molecules lose their crystalline structure and become amorphous—meaning they are all disordered.


MIKE CIESIELSKI

For crispier fries, first deep-fry french fries at 140 °C (280 °F). Then remove them from the heat and allow them to sit for about 10 minutes before frying them a second time at 180 °C (360 °F).

More heating causes starch to leak out of the granules, and the granules become coated with starch. This is what happens when potatoes are fried once. But if you remove the french fries from the heat, let them cool down, and fry them again, this time you will see something new that did not occur earlier: The starch that seeped out of the potato granules starts reacting with proteins present in the potato, causing Maillard reactions that give french fries a golden brown, crispy texture.

The temperature needs to be higher this time because even though the Maillard reactions start occurring at 140 °C, they do not produce a noticeable amount of compounds that lead to the browning of french fries at that temperature. The optimum temperature for this to happen is 180 °C.

We can now enjoy superior french fries that are both golden brown and dehydrated!

Perfectly cooked meat?

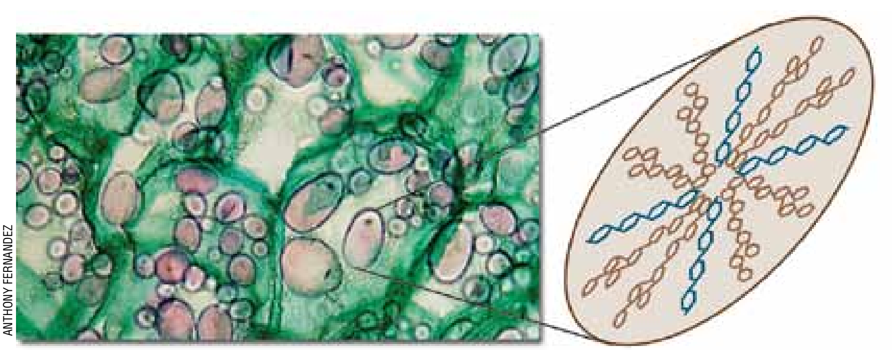
Meat also benefits from being cooked twice, especially when making a stew. The preferred way to cook meat in a stew is first to fry the meat in a frying pan and then to add the meat to some stock, which is the liquid part of a stew, and to let the stew simmer for a couple of hours.

So, why fry the meat first? Hot oil in a frying pan can easily reach a temperature of

180 °C (350 °F), so it can drive the Maillard reactions, which start at 115 °C (230 °F). This would not happen if the meat was added directly to the stock, which is mainly water and has a boiling point of roughly 100 °C.

When we fry meat, the proteins and sugars in the meat react through Maillard reactions that create several hundred different compounds, which add a unique combination of flavors, aroma, and appearance to the meat.

But if we continue to cook the meat this way, it becomes tough and dry, not soft and juicy. The reason for this difference in texture is that the proteins inside the meat are unraveled into long chains and then line up next to each other to form fibers. These fibers squeeze out the juices between them, and the meat dries out. But you can restore juiciness to the meat by adding it to a stock and letting it simmer.



MICHAEL W. DAVIDSON, FLORIDA STATE UNIVERSITY: HTTP://MICRO.MAGNET.FSU.EDU/MICRO/GALLERY/BURGERSNFRIES/BURGERSNFRIES4.HTML. ILLUSTRATION BY ANTHONY FERNANDEZ

Figure 2. Potatoes are made of cells that contain starch granules, which are shown in the middle photo as pink spherical structures). Each starch granule contains two types of carbohydrate molecules called amylose and amylopectin, shown here in blue and brown, respectively.

While meat simmers, something else happens that softens it. A meat protein, called collagen, reacts with water molecules that break it up into smaller molecules. The result is gelatin, the substance used in Jell-O. Collagen is tough and makes the meat hard to chew, while gelatin is much softer. Collagen is composed of three polypeptide chains, wound together in a tight triple helix, while gelatin is a mixture of peptides and proteins produced by partial hydrolysis of collagen. In hydrolysis, a chemical reaction takes place in which a chemical compound decomposes by reaction with water.

PHOTOS.COM

When gelatin forms in meat, it soaks up the juices from the stew. This adds to the juiciness of the meat. So, in the end, a juicy and tasty meat is the result of chemical changes—the Maillard reactions and the collagen becoming gelatin—and physical changes resulting from the vaporization of juices present in the meat when it was fried.

Twice-cooked food

Cooking, frying, or heating food twice often improves the flavor or texture of food. Toasted bread, french fries, and beef stew are only three examples of how this can be done, but there are many more food items that taste better when they are cooked twice. For example, twice-cooked pork is prepared just like a stew except that the steps are carried out backward. The pork meat is simmered until it is cooked through to the middle and then it cools down before being fried in oil to allow for the browning effects of the Maillard reactions. Another example is a kind of Italian cookie called a *biscotti* that remains true to the meaning of the original French word, "biscuit," which means "twice-cooked."

Although the chemistry differs in each case, there are some common processes. The Maillard reactions usually play an important role in the development of flavor. Also, water dehydration is a key process that can be either desirable—say, when making crispy toast—or undesirable, for example when cooking meat. Another important factor is how the molecules are arranged, which can significantly affect the outcome, for example when starch molecules in french fries are unraveled or when collagen becomes gelatin in meat.

One of the reasons food chemistry is so complicated is that there are many different ways atoms and molecules can rearrange themselves. They can form new bonds, as in the Maillard reactions; they can change phases, such as when water goes from liquid to vapor when it vaporizes; or an existing molecule can change its shape, such as when proteins unravel in meat.

Another twist is that sometimes chemical reactions or changes can only take place because other changes have already occurred. For example, the Maillard reactions produce the crispy, golden coating on french fries only after the starch granules have changed shape and allowed their contents to ooze onto the granules' surface.

The interesting thing about food chemistry is how the slightest change can have a huge impact on the results, which also makes any knowledge of food chemistry invaluable and the mere understanding of these intricate, interwoven processes a reward all its own. CM

SELECTED REFERENCES

McGee, H. On Food and Cooking; Hodder and Stoughton: London, 2004.

Coultate, T. P. Food: The Chemistry of its Components, Royal Society of Chemistry; Cambridge, United Kingdom, 1989.

The Structure of Proteins, Chemguide: http://www.chemguide.co.uk/organicprops/aminoacids/proteinstruct.html [accessed Oct 2012].

Tom Husband is a science writer and chemistry teacher in London, United Kingdom. His latest *ChemMatters* article, "Recycling Aluminum: A Way of Life or a Lifestyle?" appeared in the April 2012 issue.

What's that Smell?

By Chris Eboch

Open a magazine or turn on the television, and it is clear that we are obsessed with smell. Everything from hair products to laundry detergents to kitty litter either covers up bad smells or promises to make you and your surroundings smell better. By smelling nice, product ads imply that you will feel, act, and become more popular.

The science of scent has developed dramatically in the past century. The creation of synthetic aroma chemicals—commonly referred to as "synthetics"—has led to thousands of new fragrance ingredients. New scents both reflect cultural tastes and influence them. Synthetic fragrances have many advantages, but they may not do everything they promise.

Natural or synthetic?

To create a perfume that smells like roses or violets, a perfumer could extract the essence of roses or violets. But extracting fragrance chemicals from plants and flowers is expensive, challenging, and risky, and supplies can be damaged by weather or disease.

An alternative is to make these chemicals in the laboratory, which is typically faster and cheaper. Synthetics, also called aroma chemicals, help re-create natural fragrances and imitate fragrances that are difficult or impossible to extract from plants. The first synthetic fragrances were developed in the 1800s, and the first perfume containing a synthetic chemical was released in 1882.

Since then, synthetics have provided a whole new array of smells. Instead of rose oil or musk, a perfume might include methyl dihydrojasmonate, hydroxy butyl thiazol, or coumarin, for scents that smell "light," "creamy," or "chewy," respectively. The average perfume today contains 80% synthetic elements. But the perfume industry does not like to advertise that fact because much of the public believes "natural" is better.

But there is often no difference. Some of these synthetics are exactly the same as the natural molecules. Scientists will even tell you that synthetics are better than natural scents. A synthetic is always the same, while a natural scent depends on where a plant is grown, the weather conditions, and even the time of day when it is picked. Using synthetics means that your favorite product will smell the same every time you buy it.

Synthetics are better for the environment, too. The sandalwood forests have largely been destroyed; so, many perfumers now refuse to use natural sandalwood, preferring instead synthetics with names such as Santaliff and Javanol. Synthetics also replicate animal products, such as musk from an Asian deer, civet from a small North African mammal, and ambergris from whales, without hurting or killing the animal.

Another advantage of synthetics is that they are less likely to cause an allergic reaction than their natural counterparts. A natural scent may contain hundreds of molecules, while a synthetic version contains only one or a handful. Natural chocolate, for example, contains more than 800 different molecules, while a perfumer can create the same scent with just two types of molecules.

MIKE CIESIELSKI AND PHOTOS.COM

Tools of the trade

To identify the molecules that are responsible for a scent, scientists use a device, called a gas chromatograph-mass spectrometer (GCMS). This device consists of two parts: a gas chromatograph, which separates the components; and a mass spectrometer, which identifies these components and determines their amounts (Fig. 1). GCMS allows scientists to reveal the exact chemical makeup of a natural scent, which they use to create a synthetic version of the scent.

With GCMS, scientists can also capture unusual scents. Some fragrance scientists go to exotic locations searching for new scents. They may hire a guide to take them to remote areas, and they sniff the air for a scent that is unusual and appealing. If they smell something interesting, they explore the area, sometimes climbing trees or crouching in the mud to identify the source, which may be a

PHOTOS.COM

plant, an insect, or simply soil. If the smell is worth capturing, they use GCMS to identify its molecular ingredients.

This type of exploration can be challenging. The scientists may have to make multiple visits to the same location to identify the scents of flowers during different blooming seasons. Also, flowers pollinated by bees release their scent during the day, while those pollinated by moths smell strongest at night. Even light intensity and temperature may affect how a plant smells. Experienced researchers can make some assumptions about the best time to visit, but luck also plays a role. An unexpected rainstorm may also change how things smell.

During these visits, scientists usually capture 10 to 25 new scents, each consisting of a list of ingredients and their respective amounts. But only half of these scents may end up being good enough to be part of a perfume, and the fragrance company would be lucky if even one becomes widely popular.

Discovering something extraordinary is not easy, but GCMS improves the odds. GCMS can even replicate the complex scent of a specific location, such as an individual beach, with all of its separate aromas combined. This allows perfumers to create unlimited new fragrances.

Fragrance companies also create new scents. When a chemist at a fragrance company discovers a new synthetic molecule, the company may use it or sell it to other fragrance companies. But isolating and identifying these molecules is difficult, even with GCMS, and not all are unique or pleasant. For every 1,000 molecules a fragrance manufacturer creates, maybe one will be usable.

The art of mixing chemicals

Even with the help of chemistry, creating perfume is not easy. The main challenge is to mix ingredients in a way that produces a stable and long-lasting fragrance. The average commercial fragrance has 60 to 100 ingredients, and some have more than 300. For example, Estée Lauder's ***Beautiful*** fragrance has 700 ingredients and a 12-page formula. That's a lot of ingredients that have to work together!

Still, nearly any scent can work in a perfume. Tomato leaf, for instance, is a popular ingredient, and carrot mixes well with other ingredients to provide a sweet, fruity scent. Ethyl vanillin, which smells like vanilla, can provide either the smell of chocolate—when mixed with isobutyl phenylacetate, which smells sweet and flowery—or the smell of cola, when mixed with natural cinnamon, orange, and lime.

Bad smells can turn good when mixed. Blackcurrant smells like cat urine; and civet, a strong musky scent secreted by a cat-like mammal, smells like fecal matter. But when mixed with other ingredients, such as floral essences, these smelly scents can add an impression of richness and intensity.

SHUTTERSTOCK

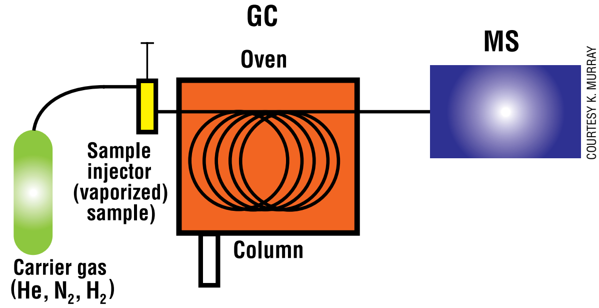
Experience and memory

Personal taste affects how we react to a fragrance. A scent that smells great on our friend may not suit us. It's not so much that the smell has changed, but that it does not fit our perception of ourselves. A floral scent may be perfect for a friend you see as sweet, gentle, and romantic. But that same fragrance would probably be inappropriate for another friend who is tough and athletic.

Experience plays a part, as well. More than any of our other senses, smell triggers memory. In seconds, an odor can bring back detailed memories from years before. You may like a citrusy scent if you associate it with happy summer days of drinking lemonade after running through the sprinkler in the yard. Not so much if you associate it with the cleaning products you had to use during tedious chores.

Also, if you happened to be sick after eating a particular food, just the smell of that food may turn your stomach for years afterward. It does not matter that your brain knows the food was not responsible for your illness—your body tells you to avoid it. It's an instinctive reaction that harkens back to the days when our ancestors may have tried a new food in the wild and found it poisonous. That instinct works so well that if a smell has negative associations, you may never be able to enjoy that smell, even if others find it pleasant.

Some perfumers try to draw on positive associations by creating fragrances that smell like popular products—such as a vanilla latté—or places, such as the ocean. The "marine" scent may remind potential buyers of vacations at the shore. Demeter Fragrances even marketed products with names such as Eau de Birthday Cake, Sushi, and Play-Doh.



COURTESY K. MURRAY

Figure 1. A gas chromatograph mass spectrometer (GCMS) consists of two parts: a gas chromatograph (GC) and a mass spectrometer (MS). After a sample is heated to a temperature hot enough to vaporize it, the resulting gas is injected into the GC. Some molecules from the sample travel faster than others in the GC, so the various molecules present in the sample enter the MS at different times, where they are identified based on their mass.

Test Your Sense of Smell

You can experiment with essential oils, which may be available at grocery stores, drugstores, health food stores, and bath and beauty shops. Start with a work surface that will be easy to clean, and cover it with newspaper. You may want to wear an apron or old shirt, as well. It can be very difficult to get spilled fragrances out of fabric!

To test your sense of smell, dip a toothpick in each of the oils and place it, scented end up, in a foam cup. Label the fragrance on the inside of the cup.

Mix all of your fragrance samples and then try to identify them by smell only. If you want to train your nose, try making notes about each scent, perhaps connecting it to a memory, a food, or a familiar product, such as toothpaste.

To avoid "nose fatigue," which can affect your sense of smell, take frequent breaks or sniff freshly ground coffee beans to cleanse your olfactory senses.

Now, label the outside of the cup with the fragrance name. Then you can tip the cups and bring two or more toothpicks close together to test various scent combinations. You may want to add more of one type of oil to make that scent more prominent. Just dip another toothpick in the oil and add it to the same cup. Keep adding toothpicks until you find a blend you like, and note the percentages of each ingredient.

If you want to create that fragrance blend for personal use, measure the correct percentages using a spoon or eyedropper. Be sure to use a metal measuring spoon, glass eyedropper, measuring cup, and bottle, because essential oils can damage plastic, and plastic can absorb fragrances. Be careful not to cross-contaminate your essential oils, and clean your equipment with rubbing alcohol after each use.

Most fragrances have alcohol as a base, but you can use unscented Aloe Vera gel instead and create a gel fragrance (do not use rubbing alcohol, which will affect the scent). To make the essential oils last, you need a fixative such as jojoba oil or tincture of benzoin. Aloe Vera gel and tincture of benzoin may be available in the First-Aid section of a drugstore.

Plan to use about 10 drops of jojoba oil or three drops of tincture benzoin for one ounce of Aloe Vera gel and 15 to 40 total drops of essential oil.

Warning: Do not taste essential oils. Some are poisonous. Store them out of the reach of young children. Essential oils may cause an allergic reaction on the skin, so test a small drop before using it widely.

The Difference between Perfume, Cologne, Splash...

A perfume is only one of many products used to make you smell nice. Here is the difference between them:

Fragrance: Any pleasing scent. In the perfume industry a fragrance is a mix of oils and other additives in a solution that is 75% to 95% alcohol.

Perfume: The most concentrated fragrance, with at least 22% oils.

Eau de Toilette: Half as strong as perfume.

Cologne: One-quarter as strong as perfume.

Splash: One-eighth as strong as perfume, the lightest fragrance.

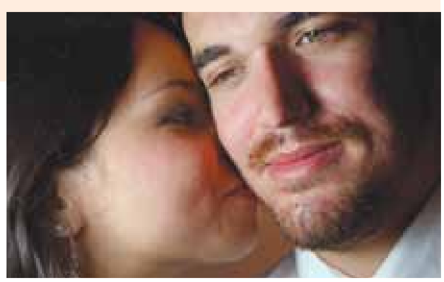
ALL IMAGES FROM PHOTOS.COM

Cultural preferences make a difference in scent perception, too. Frying bacon and Christmas trees are popular scents in the United States and Britain. You would not expect to find that in Muslim countries where they don't eat pork products or celebrate Christmas. Americans like wintergreen, which is mostly used in gum and candy in the United States. But the British dislike it, associating it with medications such as rub-on analgesics.

Scent of attraction?

Now, how about those ads for "pheromone cologne," which promise to attract the opposite sex? Can a smell really change your sex appeal?

Pheromones are chemical substances released by an animal that can affect the function or behavior of other animals of the same species. This form of chemical communication is most commonly used by social insects such as termites. Some mammals may use pheromones to signal that they are ready for reproduction, or "in heat." Because of this association, the fragrance industry has tried to find chemicals that would help humans attract potential partners.



But pheromones are not odors, even though they may have a smell. In fact, pheromones are usually not processed by the olfactory system at all. Instead, they affect a separate structure called the vomeronasal organ. Humans do not appear to have a functioning vomeronasal organ.

For now, pheromone perfumes are just marketing hype, as there is no evidence that they actually work on a chemical level. Still, knowing you smell good can increase your confidence and make you feel more flirtatious. And maybe your scent will linger after you're gone, reminding someone of you.

The art of perfume has changed dramatically over the past 130 years. Synthetic aroma chemicals and tools such as GCMS have enabled perfumers to develop thousands of new fragrances to appeal to every taste, while helping to protect the environment. Because of individual chemistry and personal experiences, no two people will experience scents exactly the same way, but fragrance can be one way we express our individuality. *CM*

SELECTED REFERENCES

Fragrance Knowledge, The Fragrance Foundation: http://www.fragrance.org/fragrance-knowledge.php [accessed Oct 2012].

Nasr, S. L., How Perfume Works, HowStuffWorks.com: http://science.howstuffworks.com/perfume.htm [accessed Oct 2012].

Burr, C. The Perfect Scent: A Year Inside the Perfume Industry in Paris and New York; Henry Holt: New York, 2008.

Herz, R. The Scent of Desire: Discovering Our Enigmatic Sense of Smell; William Morrow/Harper Collins: New York, 2007.

Chris Eboch is a science writer who lives in Socorro, NM. This is her first article in *ChemMatters*.

Mascara

What combination of chemicals can beautify your eyes, even the morning after an all-night study session? What cosmetic can make faint, short lashes darker, longer, and thicker? Mascara does it all! Whether you go for a natural-looking once-over or dramatic layers of lushness, mascara is almost guaranteed to make a woman look more glamorous.

Unless, of course, the product makes your eyes look like those of a raccoon—or possibly a panda. You might even have an allergic reaction to mascara, such as itchy and swollen eyes. It's all in the formulation, and a few other things. Chemistry plays a giant role, especially with the burning question: Is there bat excrement in your mascara? More about that later.

The basic recipe for mascara is simple: a pigment for color and an oil to hold it in place. In the past, women used to make mascara by combining graphite (pure carbon) with castor oil in a small dish. They would stir the mixture and apply it directly to their eyelashes with a small, stiff brush.

It would not be a good idea to try this recipe because this mixture may irritate your eyes. But back then, mascara was not available in stores as it is today. Also, this do-it-yourself cosmetic has disadvantages. Without thickeners, it smears easily, resulting in raccoon rings, and without preservatives to keep out mold and bacteria, the mixture needed to be freshly made every day.

The different chemicals listed on a mascara container address these and other issues. Want extra eyelash length? Volume? Fancy color? Mix in more chemicals! At this point, it is time to let the cosmetic chemists take over.

That Lush Look You Love!

By Gail Kay Haines

A mix of chemicals

In addition to oil and water, mascara contains three types of ingredients: pigments, emollients, and thickeners.

First, the pigments. Carbon black, which is essentially pure carbon, is the most common pigment in eye makeup, while iron oxides provide earth-toned shades of brown. Pigments of carbon and iron oxides are generally derived from a plant or mineral source, not coal or tar. (U.S. federal law prohibits the use of coal or tar in cosmetics for the eyes.) Ultramarine blue, which comes from a sulfur-containing clay, gives a stunning, elegant look.

Next are emollients, which are substances that soften and soothe the eyelashes. Mascara usually contains carnauba wax, which comes from Brazilian palm trees, and beeswax. Mineral oil, almond oil, castor oil, and sesame oil are also used.

The other important ingredient is the thickener, a substance that makes the solution firmer. You don't want runny black streaks down your face, which is why mascara contains rice proteins, tapioca starch, microfibers of nylon and cellulose, and even cashmere. These substances are the reason why mascara can adhere between and at the ends of the lashes, to add length and thickness, for that lush look fashion models wear.

Another ingredient, called guanine ($C_5H_5N_5O$), imparts a gorgeous luster to the lashes. Here is where bat excrement comes in. Even though this substance is found in bat and bird droppings, there is no excrement—or chemicals extracted from excrement—in any commercial mascara, no matter what tales you have heard. The guanine used in cosmetics is typically extracted from fish scales, although it can also be synthesized chemically.

ALL IMAGES FROM PHOTOS.COM

Mascara and cancer

When looking for mascara, you will notice many products labeled "paraben-free." Parabens are preservatives that keep mascara—and other cosmetics—free of molds and microbes. But parabens have been found in breast cancer tumors, and they can slightly mimic estrogen, a hormone that plays a role in breast cancer. As a result, many cosmetic manufacturers have removed parabens from their products.

Parabens are esters of *para-hydroxybenzoic* acid ($HCOOC_6H_4OH$), which is why they are called *parabens* (Fig. 1). An ester is a compound with the structure RCOOR', where R and R' are carbon chains. In the case of parabens, R' is C_6H_4OH. Parabens include various compounds, which differ by their R group (Fig. 2).

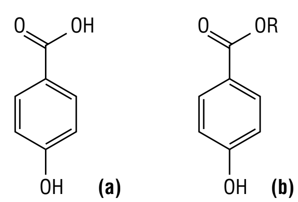
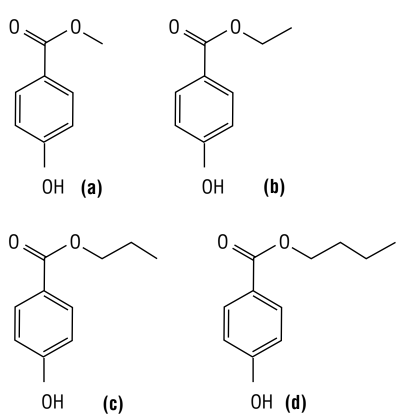


Figure 1. Chemical structures of (a) para-hydroxybenzoic acid and (b) paraben



ANTHONY FERNANDEZ

Figure 2. Chemical structures of (a) methyl-, (b) ethyl-, (c) propyl-, and (d) butyl-parabens

Synthetic parabens have long been the favorite preservative in mascara, because they resist molds and bacteria and are considered safe in foods and drugs. But some studies have found that parabens may cause cancer and hormonal imbalance. However, no direct connection between the occurrence of cancer and hormonal imbalance and any one cosmetic or cosmetic ingredient has been established.

Mascara for the millennia

As a cosmetic product, mascara is more than 5,000 years old. Egyptian tomb paintings show queens Nefertiti and Hatshepsut—long before Cleopatra—rimming their eyes and coating their lashes with a thick black substance. Male Pharaohs wore it, too. Some wearers believed that, in addition to adding glamour, mascara had magical properties that protected against disease.

Chemists have analyzed the residue left in ancient pots, and the substance has similarities to mascara today: Kohl, for color, and honey—instead of oil—to make it stick. Kohl was a chemical hodgepodge, with ingredients ranging from sooty burnt almonds, powdered lead(II) sulfide (PbS), and green malachite—a mineral of copper carbonate hydroxide ($Cu_2CO_3(OH)_2$)—to crocodile dung.

Smudge-Proof Mascara

It's a marvel of chemical engineering! Smudge-proof mascara contains fibers—typically rayon or nylon—that are stuck to the lashes by various binders. You can wash these fibers away with cleanser and warm water.

Three years ago, French scientists uncovered a surprise: Mascara may have actually protected from disease. The scientists found that some ancient Egyptian mascara contained several unusual lead chlorides. Compounds of lead are generally assumed to be toxic, but the team of scientists found that those particular lead-based ingredients actually helped the body protect against eye infections by stimulating the body's production of nitric oxide (NO). Excess nitric oxide tells the body to rev up its immune system to combat infection.

After millennia of early use, mascara went out of fashion for more than 1,000 years to reappear in industrial-age Europe. Then, industrial chemists took over. Eugene Rimmel, a French perfumer working in England in the 19th century, sold the first commercial mascara. In 1913, in Chicago, Ill., T. L. Williams adapted and marketed an eyelash product made with Vaseline, which was originally created by his sister Maybel. Actors of the silent film era—the forerunners of movies—popularized the look, and modern mascara was launched. Rimmel and Maybelline, the companies the two men founded, respectively, are still making mascara today.

MIKE CIESIELSKI

MIKE CIESIELSKI

Mascara goes on right atop your eyes, so it should contain the best and safest ingredients. Checking out the chemicals is one way to learn more. If you find a mascara you really love—or one that bothers your eyes—find out what's inside. Choosing a good cosmetic brand and reading online reviews are other ways to be sure you pick the best mascara for you. *CM*

SELECTED REFERENCES

D'Amore, J. What is Mascara Made Of? About.com: http://video.about.com/makeup/What-Is-Mascara-Made-Of-.htm [accessed Oct 2012].

Goins, L. The Makeup of Makeup: Decoding Mascara, WebMD: http://www.webmd.com/healthy-beauty/features/makeup-decoding-mascara [accessed Oct 2012].

The Chemistry of Cosmetics, HowStuffWorks.com: http://science.howstuffworks.com/the-chemistry-of-cosmetics-info4.htm [accessed Oct 2012].

Gail Kay Haines is a science writer and book author from Olympia, Wash. Her most recent *ChemMatters* article, "Chance Favors the Prepared Mind: Great Discoveries in Chemistry," appeared in the October 2012 issue.

Dirty Business: Laundry Comes Clean with Chemistry

By Brian Rohrig

It won't be long until you leave home and head off to college. One rite of passage for every freshman is doing laundry. If not done correctly, every article of clothing you own will have a pinkish hue. This article will not tell you how to actually *do* your laundry—but will discuss how laundry detergent cleans your clothes. If you take a close look at the label on your laundry package, you will notice a list of ingredients that may not seem too familiar. But as you will discover in this article, what they do is nothing more than putting chemistry into action.

Surfactants to the rescue

The most basic ingredient in doing laundry is, of course, water. But if you used only water, your clothes would not come out clean, and most stains would remain. And that sweaty shirt that has been in the bottom of your gym bag for the past month? Chances are water would do little to get rid of *that* odor.

The reason water alone cannot remove stains from clothes is that water molecules tend to attract other water molecules but not molecules of oil or grease that are present in most stains. This is due to a key difference between water and oil, called polarity. Water is polar, while oil is nonpolar.

A polar molecule contains regions of partial positive and negative charge that are due to the uneven distribution of electrical charge. In a water molecule, the electrons in the covalent bonds between oxygen and hydrogen are more strongly drawn to the oxygen side, giving it a slightly negative charge, while both hydrogen sides have a slightly positive charge.

When two water molecules are next to each other, the slightly positive end of one molecule is attracted to the slightly negative end of the other molecule through so-called intermolecular forces. The attraction of water molecules to one another contributes to the enormous surface tension of water—the force that holds the molecules in a liquid together.

MIKE CIESIELSKI AND PHOTOS.COM

Laundry detergents contain substances called surfactants that reduce water's surface tension. These substances help water to spread on the surface of fabrics allowing fabrics to absorb water faster (Fig. 1).

Surfactants are also the cleaning agents in detergent. A typical surfactant molecule has two parts—a polar and a nonpolar part. The polar part is attracted to water and is called hydrophilic, and the nonpolar part repels water but is attracted to a molecule of grease or oil.

After water has spread out on the surface of a piece of clothing, the surfactant molecules bind to molecules of grease or oil present on the surface of the fabric. The nonpolar ends of the surfactant molecules bind to the nonpolar oil molecules present in the stain. Then, the surfactant molecules surround the stain, forming a cluster of molecules called a micelle. Fig. 2 shows how the stain at the center of a micelle is surrounded by surfactant molecules. This way, stains are removed from dirty clothes.

Removing the toughest stains

Many clothes that go in the wash have tough stains from sweat, grease, or food. To remove these stains, a little more kick is needed. Most laundry detergents contain enzymes, which are catalysts that work by speeding up the rate of a reaction without themselves being changed in the process.

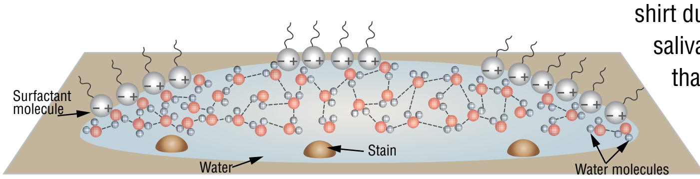


Figure 1. Surfactant molecules decrease the surface tension of a drop of water on a surface by spreading it on the surface.

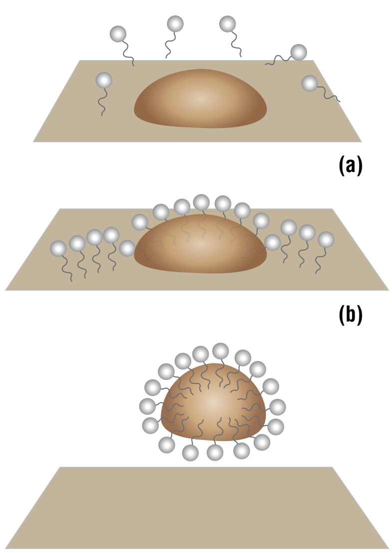
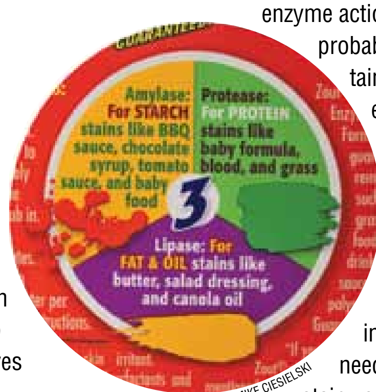


Figure 2. A stain on a piece of fabric is removed by surfactant molecules in three steps: (a) The nonpolar side of the surfactant molecules (their tails) are attracted to nonpolar oil molecules present in the stain; (b) the surfactant molecules surround the outside part of the stain; (c) the surfactant molecules completely surround the stain and lift it out of the surface of the fabric.

ANTHONY FERNANDEZ

If you look at the list of ingredients on the laundry detergent label, you might notice one of the following enzymes: proteases, which attack protein stains; lipases, which attack lipids (fats); and amylases, which remove starch. If a stain remover advertises "triple-enzyme action," it probably contains all three enzymes.



MIKE CIESIELSKI

Incidentally, your saliva contains many of these same enzymes; so, if you find yourself in a pinch and you need to remove that stain you got on your white shirt during lunch, a little saliva may be more effective than just plain water.

Enzymes break down over time. So, if a detergent contains enzymes, its shelf life is between six months and one year. After this time, the detergent may become less effective.

More than chemicals

Chemical processes are only one aspect of cleaning clothes. Mechanical processes are also involved. The agitation of your washing machine provides mechanical energy to remove dirt from clothes. You can't just let your clothes soak in water. In the old days, people would beat clothes with rocks or use an old-fashioned wash board.

PHOTOS.COM

Another key ingredient for doing laundry is heat, which is provided by hot water. In addition to speeding up the rates of chemical reactions and providing the necessary temperature for enzymes to work, thermal energy is an essential part of the washing process. Substances dissolve more readily in hot water than in cold, helping to lift dirt and stains.

Even though every container of laundry detergent contains quite an array of chemicals, there are still even more amazing products on the horizon. Chemists have begun developing technologies that may make today's laundry detergents obsolete. Through the use of nanoparticles, for instance, your clothes may soon be able to clean themselves!

A nanoparticle is any particle whose diameter is between a few nanometers and 100 nanometers. (A nanometer is one-billionth of a meter.) Nanoparticles have been incorporated into fabrics that repel stains—meaning the clothes will never need to be washed. One amazing such product, called Neverwet, can be sprayed on clothing, and any type of liquid will just roll right off (see photo).

As exciting as these new technologies sound, your traditional laundry detergent is probably not going away anytime soon. So when your dirty and smelly clothes come out of the washer smelling fresh and clean, remember it's only possible due to the wonders of chemistry! *CM*

HTTP://WWW.TECHEBLOG.COM/INDEX.PHP/TECH-GADGET/INCREDIBLE-NEVERWET-SUPER-HYDROPHOBIC-SPRAY-LETS-CHOCOLATE-SYRUP-SLIDE-RIGHT-OFF-YOUR-SHOES

A shoe that has been sprayed with a substance called Neverwet lets chocolate syrup slide right off of it. Neverwet was developed so that clothes and shoes repel water and other liquids, thus becoming stain-free.

SELECTED REFERENCES

Waldron, K. *The Chemistry of Everything;* Pearson Prentice Hall: Upper Saddle River, NJ, 2007.

How Laundry Detergent Works, HowStuffWorks.com: http://home.howstuffworks.com/laundry-detergent.htm [accessed Oct 2012].

Knapp, A. Nanotechnology May Lead to the End of Laundry, Forbes.com: http://www.forbes.com/sites/alexknapp/2011/12/15/nanotechnology-may-lead-to-the-end-of-laundry/ [accessed Oct 2012].

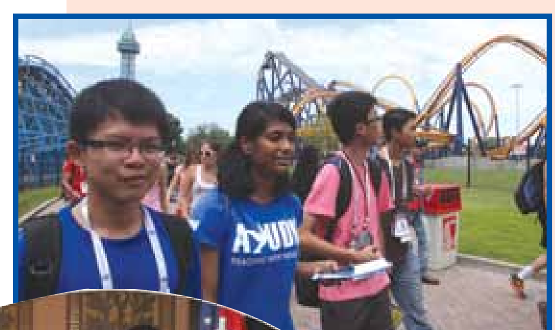
Brian Rohrig teaches chemistry at Jonathan Alder High School in Plain City (near Columbus), Ohio. His most recent *ChemMatters* article, "Weather Folklore: Fact or Fiction?" appeared in the October 2012 issue.

Highlights from the International Chemistry Olympiad

This summer, the United States served as host to the International Chemistry Olympiad, a competition that brings together the world's most talented high school students to test their knowledge and skills in chemistry. Almost 300 students, representing 72 countries, spent 10 days in the Washington, D.C., area, touring the city and its surroundings, experiencing U.S. culture, and getting to know each other.

The students stayed on the campus of the University of Maryland, College Park, Md., where they took a five-hour theoretical exam and laboratory work for two days as part of the competition. The students also visited NASA, toured Annapolis and Washington's monuments and museums, and visited Baltimore's Aquarium and Science Museum. Whether on campus, during meals, or on buses, the students made new friends, exchanged gifts from their countries, and shared stories. This year, Team USA won one gold and three silver medals.

U.S. high school students are invited to participate in the next U.S. National Chemistry Olympiad program, which will determine the students who will represent the United States at next year's International Chemistry Olympiad, to be held in Moscow, Russia. Read about the U.S. National Chemistry Olympiad program at: www.acs.org/olympiad or send an e-mail for more information to: USNCO@acs.org.



PETER CUTTS PHOTOGRAPHY

CM Demystifying Everyday Chemistry

1155 Sixteenth Street, NW
Washington, DC 20036-4800

www.acs.org/chemmatters

ACS
Chemistry for Life™
American Chemical Society

Statement of Ownership, Management, and Circulation for *ChemMatters* Magazine

ChemMatters is published quarterly by the American Chemical Society, 1155 16th St., NW, Washington, DC 20036. Both the office of publication and the general business office are at the American Chemical Society, 1155 16th St., NW, Washington, DC 20036. Administrative Editor: Marta Gmurczyk. Owner: American Chemical Society. There are no other known bondholders, mortgages, or other security holders. The purpose, function, and nonprofit status of this organization and its exempt status for federal income tax purposes have not changed in the past 12 months. A total of 32,000 copies of each magazine issue are printed. The average circulation during the past 12 months was 12,281.The circulation closest to the filing date was 10,702. There are no paid in-county subscriptions, no sales through dealers or vendors, and no other USPS mailings at other classes. There is no free distribution of *ChemMatters*. During the past 12 months, an average of 19,719 magazines per issue was not distributed. For the most recent issue with available subscription data (October 2012), 27,298 magazines were not distributed. This statement was filed according to Section E216.3.0 of the USPS Domestic Mail Manual on October 31, 2012, by Marta Gmurczyk, Administrative Editor.