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OCTOBER 2008

Keeping the Torch Lit

ACS Celebrates National Chemistry Week

"Having a Ball with Chemistry"—The Chemistry of Sports

QUESTION FROM THE CLASSROOM

By Bob Becker

Q. I hear that many athletes, right before they are about to compete, will spend a few weeks training way up in the mountains, and that it's supposed to improve their performance when they return. Is that true? And if so, how does it work?

A. What you are referring to is called altitude training. Although some research indicates that it does indeed help enhance an athlete's speed and endurance, some other research shows that there is no real benefit.

Down at sea level, on a typical day, the air exerts a total pressure of about 760 torr, and oxygen, being about 21% of that air, exerts a partial pressure of about 160 torr.

Most proponents of altitude training recommend that such training take place between 2100 and 2400 meters above sea level. At an elevation of 2100 meters (6900 feet), the air still contains about 21% oxygen (Fig. 1), but since the total air pressure is only about 590 torr, oxygen's partial pressure is only 123 torr.

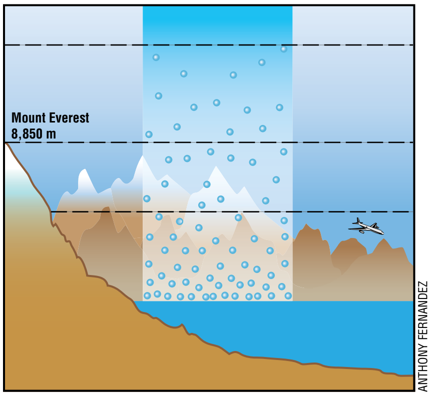

Figure 1. The air contains more oxygen molecules (blue circles) at sea level than at high altitude.

It is important to consider the partial pressure of oxygen because it determines how quickly oxygen can be absorbed through your lungs into the bloodstream. The faster oxygen can get into your blood, the faster it can be used by your muscles.

If you have ever tried to exercise at a high elevation, you will find yourself unable to run as fast or work out as long as you would at sea level. And yet, everyone who lives at high elevation seems to have no trouble running and working out because their bodies have become used to these hypoxic (low oxygen) conditions.

This happens because the body is producing an additional amount of the hormone erythropoietin. This elevated level of erythropoietin triggers the bone marrow to produce more red blood cells, which will then carry more oxygen to the muscles and tissues through a molecule called hemoglobin (Fig. 2).

The body also becomes used to low oxygen levels by making more enzymes—such as citrate synthase—which help muscles use oxygen. But all of these changes don't happen overnight. Generally, it takes three to four weeks for the body to change this way.

When acclimated athletes return to lower elevations, their higher than normal red blood cell levels make them feel energized. Rather than feeling drained and out of breath—as they did when they first went up into the mountains—each normal breath they take delivers more oxygen to the muscles and allows them to do things they could not have done before.

After about two weeks, the body starts to acclimate back to its original red blood cell level. But during these two weeks, any athlete will have a distinct advantage in competition.

Or at least that's what advocates of altitude training have long argued. Although there is no denying the supercharged feeling that these athletes experience when they return to low altitudes, their actual performance is not always better than it was before they started their altitude training.

Most researchers attribute this poorer performance to the loss of training that occurs when they are at high altitudes. With the reduced oxygen levels, athletes simply cannot get as rigorous a workout as they would at sea level. All that time spent having their bodies adapt was time wasted in terms of their training.

This has led some trainers to adopt a new motto: "Live high, train low." Eating, sleeping, and hanging out in high altitude conditions still trigger the body to make more red blood cells, but then returning each day to lower elevations to train keeps the workouts rigorous and the muscles well tuned.

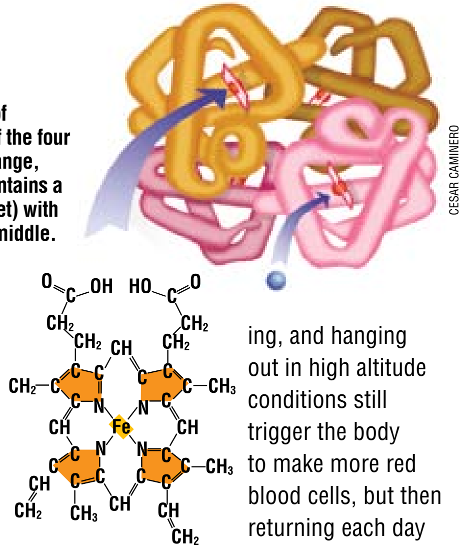

Figure 2. Structure of hemoglobin. Each of the four subunits (brown, orange, purple, and pink) contains a heme molecule (inset) with an iron atom in the middle. Blue sphere, oxygen molecule (O_2).

Unfortunately, there are not too many places on Earth that have high enough mountains and low enough valleys in close proximity to make this feasible for most athletes. But there are some ways to simulate this effect. One of them is to remain at high elevations but, while training, simulate lower elevation by breathing oxygen-enriched air, either though an oxygen mask or in an oxygenated training facility.

A less costly alternative—which seems to be gaining popularity among athletes—is to remain at lower elevations but, when not training, to breathe in air that has been partially deoxygenated. Decreasing the oxygen level from about 21% to 15% causes the same oxygen levels that would be present at an elevation of 2500 meters (8200 feet). One way to do this is by moving into a deoxygenated house! So far, there is only one such house, developed by Heikki Rusko, professor of exercise physiology at the University of Jyvaskyla in Jyvaskyla, Finland.

Unfortunately, the jury is still out on whether altitude training—real or simulated—does work. In sports where success depends as much on mental attitude as on physical ability, maybe altitude training should be regarded like a lucky pair of socks. If the athletes are convinced that they will perform better, far be it for science to tell them otherwise.

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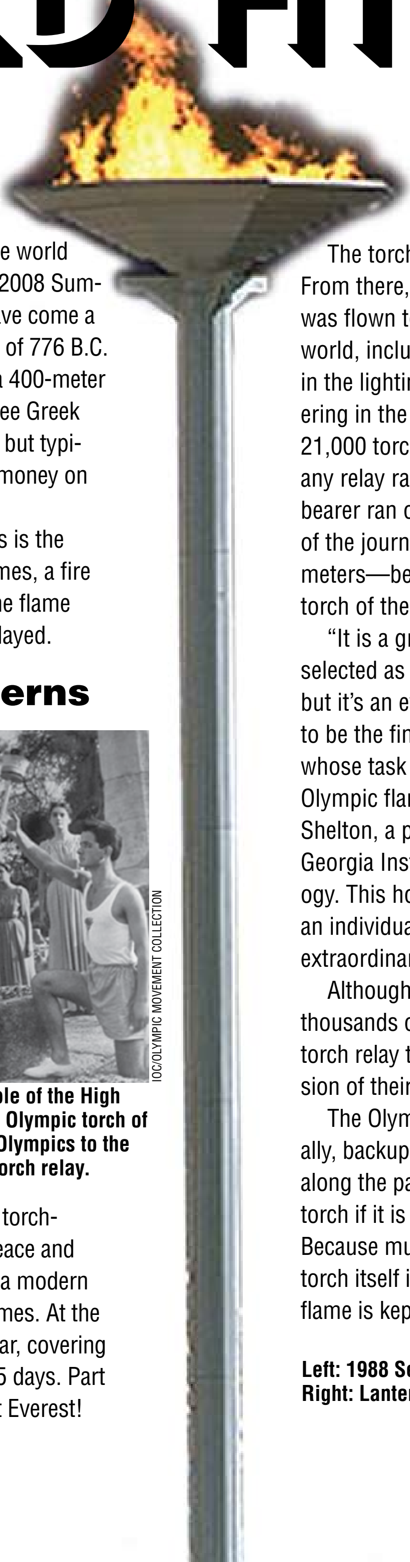
The Olympic Flame
CHEMISTRY HELD HIGH



By Brian Rohrig

This past summer, the best athletes in the world gathered in Beijing to participate in the 2008 Summer Olympic Games. Today's games have come a long way since the first Olympic games of 776 B.C. Back then, there was only one event—a 400-meter sprint. To participate, you had to be a free Greek man. The prize for winning was not a precious medal, but typically an olive branch. You didn't have to spend much money on uniforms, either, as the athletes often ran naked!

One similarity between those early games and ours is the tradition of the Olympic flame. During the ancient games, a fire burned throughout the competition. The lighting of the flame has always signaled that the games are ready to be played.

Flame, torches, and lanterns

Today's Olympic flame is lit in the same way as it was in ancient Greece. Every four years, an elaborate ceremony is held at the site of the first Olympics in Olympia, Greece. An actress representing a high priestess holds an unlit torch above the center of a large, bowl-like mirror. The sun's rays are reflected off the curved surface of this mirror, converging at a single point on the torch. This generates enough heat to ignite a flame on the torch.

IOC/OLYMPIC MOVEMENT COLLECTION

An actress in the role of the High Priestess gives the Olympic torch of the 1956 Summer Olympics to the first runner in the torch relay.

After its lighting, the flame is passed on to the first torchbearer, beginning the torch relay, which symbolizes peace and brotherhood throughout the competition. The relay is a modern invention, beginning with the 1936 Berlin Olympic Games. At the Beijing Olympic Games, the relay was the longest so far, covering five continents over 137,000 km (85,000 miles) in 135 days. Part of the journey even included a trip to the top of Mount Everest!

The torch relay started on March 24 in Olympia, Greece. From there, it traveled within Greece for five days and then was flown to Beijing, where it continued its journey around the world, including Mount Everest on May 8. The relay culminated in the lighting of the Olympic flame in Beijing on August 8, ushering in the start of the competition. There were a total of over 21,000 torchbearers. Just like any relay race, each torchbearer ran only a small leg of the journey—at least 400 meters—before lighting the torch of the next runner.

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One of the members of the Mount Everest climbing team ignites the torch for the first torchbearer of a 30-meter relay on the tallest peak in the world.

"It is a great honor to be selected as a torchbearer, but it's an even greater honor to be the final torchbearer, whose task is to light up the Olympic flame," says Sam Shelton, a professor at the Georgia Institute of Technology. This honor is given to an individual who personifies the Olympic spirit by extraordinary athletic or humanitarian efforts.

Although there is only one Olympic flame, there are thousands of Olympic torches. The members of the torch relay team can purchase their torch at the conclusion of their leg of the journey.

The Olympic flame is carried in a lantern. Additionally, backup lanterns are carried inside guarded vehicles along the parade route and can be used to relight the torch if it is accidentally or intentionally extinguished. Because much of the flame's journey is done by air, the torch itself is extinguished most of the time, but the flame is kept alive thanks to the lanterns.

IOC/OLYMPIC MOVEMENT COLLECTION

Left: 1988 Seoul Olympics Cauldron.
Right: Lantern carrying the 2008 Beijing Olympic torch.

Chemical composition

The Olympic torch is a marvel of chemistry, engineering, and art. The 2008 Beijing Olympic torch was made of a mixture of aluminum and magnesium. These metals were chosen because they are very lightweight, yet durable. Also, both metals have relatively low densities, yet are exceptionally strong. Weighing about one kilogram (two pounds), the torch was also designed to withstand 65 kilometers/hour winds, rainfall, and temperatures as low as –40°C!

In past Olympic torches, substances used for fuel have included ammonia, formaldehyde, olive oil, gunpowder, and naphthalene (the active ingredient in moth balls). Many of these early components were smoky, smelly, and downright dangerous. During the 1956 torch relay, burning bits of magnesium and aluminum erupted from the torch, no doubt thrilling the spectators yet severely burning one runner's arms.

Many of these early torches were intentionally designed to release soot, producing a more visible, yellow flame. Unfortunately, the soot that forms is made of carbon particles that can produce a lot of smoke.

"There is one advantage to a dirty yellow flame, though," says Shelton, who was the chief designer of the 1996 Atlanta Olympic torch. "A yellow flame is much more visible than a blue flame, especially from a distance." The soot particles produce the very visible flame through incandescence, which is the emission of light due to heating.

The 1996 Olympic torches were especially visible, because they used a mixture of propylene (C_3H_6) and propane (C_3H_8). The unique fuel mixture produced a bright yellow smokeless flame clearly visible in sunlight and under windy conditions.

Since 1972, liquid hydrocarbons have been exclusively used as the Olympic torches' fuel because they are relatively safe and produce little odor when burning. The Beijing Olympic torches used pure propane (C_3H_8) as a fuel. Propane is the bottled gas used in gas grills that burns very cleanly. The only drawback is that it is not as bright as previous flames. But the flame can burn yellow by adjusting the fuel-to-oxygen ratio. Propane reacts with oxygen by producing carbon dioxide (CO_2) and water (H_2O) as follows:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Inside Beijing's Olympic torch

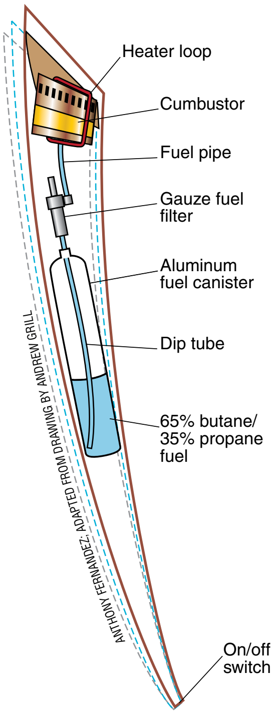
The burning system of this year's Olympic torch was designed by the state-owned China Aerospace Science and Industry Corporation. Within the handle of the torch is a small canister of liquid propane. When the torch is turned on, the sudden pressure drop causes the propane to vaporize.


IOC/OLYMPIC MOVEMENT COLLECTION

The propane gas flows through tiny holes at the top of the torch that ensure that the gas comes out. Then, once the propane hits the atmosphere, it combines with oxygen and burns. Each torch has a 25- to 30-centimeter flame under good conditions and can stay lit for about 15 minutes, which is more than enough time for a typical 400-meter journey.

Recent Olympic torches worked on the same principle as the 2008 Beijing torch. For example, the inside structure of the 2000 Sydney Olympic torch is shown in Fig. 1.

But for the journey up Mount Everest—the tallest peak in the world—solid fuel instead of propane was used. The combustion of propane relies entirely on outside oxygen. But on top of Mount Everest, the atmospheric pressure is only about one-third of that at sea level. To burn effectively, the oxygen is supplied by a compound called an internal oxidizer that releases oxygen during combustion.



ANTHONY FERNANDEZ, ADAPTED FROM DRAWING BY ANDREW GRILL

Figure 1. The inside structure of the 2000 Sydney Olympic torch (left) works on the same principle as the 2008 Beijing torch.


ADAM PRETTY/ALLSPORT/GETTY IMAGES

Marine biologist Wendy Craig-Duncan carries the 2000 Olympic torch under water at Agincourt Reef, Queensland, Australia.


IOC/OLYMPIC MOVEMENT COLLECTION

"The oxidizer component of the torch provides enough oxygen so that the fuel continues to burn, even when the amount of atmospheric oxygen is greatly reduced, such as on Mount Everest," says Paul Smith, a pyrotechnic expert and a lecture demonstrator at Purdue University, West Lafayette, Ind. "An oxidizer was also used for the 2000 Sydney Olympics torch, which was taken under water by a SCUBA diver to cross Australia's Great Barrier Reef!"

The solid fuel used in the torches is similar to the solid rocket boosters used to launch the space shuttle. These rocket boosters use ammonium perchlorate (NH_4ClO_4) as the internal oxidizer and aluminum as the fuel. The oxygen comes from the decomposition of ammonium perchlorate at 200 °C as follows:

$$2\ NH_4ClO_4 \rightarrow N_2 + 3\ H_2O + 2\ HCl + 2.5\ O_2$$

The Olympic flame is one of the most enduring symbols of the Olympic Games. The torches that carry the flame leading up to the games serve to heighten the anticipation for athletes and spectators alike. "By being lit directly from the sun, the Olympic flame vividly shows that the sun is an important source of energy for life on Earth," Shelton says. "The same energy that ignites the flame fuels the body of each Olympic athlete."

Brian Rohrig teaches at Jonathan Alder High School in Plain City (near Columbus), OH. His most recent *ChemMatters* article, "The Chemistry of Arson Investigation," appeared in the April 2008 issue.

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The Chemistry of Marathon Running

By Brian Rohrig

As the starting gun sounds, a sea of runners slowly surges forward. The 2007 Columbus Marathon has officially started. Over 3,000 runners begin a journey that will alternate between exhaustion and exhilaration, not to mention downright pain.

This is my fifth marathon, and my goal today is to qualify for the Boston Marathon. At 45 years of age, a time of 3 hours and 30 minutes gets me in. I am running with the 8-minute mile pace team. Eight-minute miles will get me to Boston.

First few miles

The first mile is slow—but that's not a bad thing. In past marathons, I have made the mistake of starting out too fast. For every minute that I go out too fast in the first half, I will lose four minutes in the second half.

Right now, my adrenalin is pumping. This hormone, secreted by the adrenal glands, which are located on top of the kidneys, works by putting more sugar into my blood and by breaking down fat. The release of adrenalin is like flooring the accelerator in a car. You get a little boost now, but you run out of gas sooner. Fortunately, this adrenalin rush is short-lived, and the elbow-to-elbow press of bodies prevents me from using up too much energy at the beginning.

Today is perfect marathon weather—sunny and in the low 50s. Before I reach the 1-mile mark, I am already hot. So I discard the old sweatshirt that kept me warm at the starting line. Just like a car burns fuel to move, my body burns fuel to run. At 155 pounds, for every mile I run, I burn about 100 kilocalories. (What we commonly refer to as Calories—with a capital C—are actually kilocalories.)

If I maintain my present pace, I will have burned over 3,000 kilocalories during the marathon, which is equivalent to losing one pound. That's a lot of work to lose just one pound!

Where does my energy come from?

I am breathing heavier than usual to increase my oxygen intake. Right now, my body combines this oxygen with fuel to produce energy. The fuel comes from the three main food nutrients: protein, fat, and carbohydrates (which are mostly starch and sugars).

Protein typically accounts for only 2% to 5% of the body's total energy expenditure, perhaps rising to as high as 8% during the marathon. Fat contributes to 60% of the energy produced when our bodies are at rest, but when we run, only 15% of the energy that we need comes from fat. So for the next few hours, my body will receive the bulk of its energy from glucose ($C_6H_{12}O_6$), a simple sugar resulting from the breakdown of most carbohydrates (Fig. 1).

The body's preferred fuels for marathon running are glucose, fat, or both, depending on the intensity of a runner's pace and the time point in the race.

During aerobic respiration, glucose combines with oxygen to form energy as follows:

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

For runners, the most efficient source of glucose is a large molecule called glycogen that is stored in the liver and muscles (Fig. 2). The average person has about 2,000 kilocalories worth of glycogen stored up, which is enough to run about 20 miles.

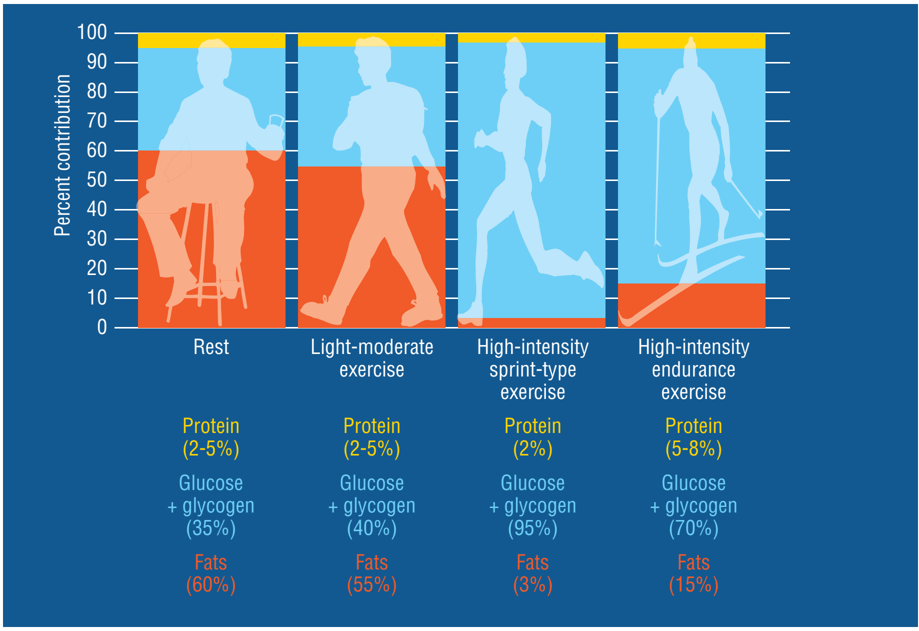
Early in the race, my body is getting most of its glucose from glycogen in my muscles. Then, as muscle glycogen becomes low, more glucose will come from liver glycogen. To increase my glycogen stores, three days before the race, I ate a lot of carbohydrates—such as pasta, bread, and cereals—while training very hard. This combination of diet and training stimulated the production of glycogen in my muscles.

As I am running, my energy also comes from a process that doesn't use oxygen. Called anaerobic respiration, this process breaks down glucose into lactic acid ($C_3H_6O_3$) and energy as follows:

$$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3 + \text{energy}$$

As I am warming up, most of my energy comes from the anaerobic process. But after a few miles, as my heart rate increases and my blood receives more oxygen, the aerobic process becomes the predominant source of energy. Throughout the whole race, though, my energy will come from both processes, with the aerobic process dominating as I hit a steady state.

During these first few easy miles, it is tempting to want to go faster. I feel like I could run all day at this pace. The many miles of training make it seem easy so far, but the farthest I ran during training was 20 miles three weeks ago. After that, I tapered off to allow my body to recover. So I prefer to run at a steady pace to preserve my glycogen reserves and burn fat more efficiently.



ANTHONY FERNANDEZ

Illustration of the contribution of carbohydrates (blue), fat (pink), and protein (yellow) to energy metabolism during various intensities of excercise.

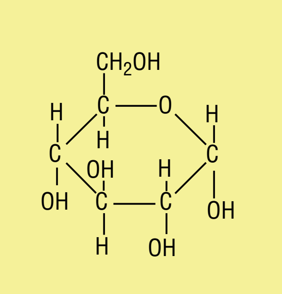


Figure 1. Structure of glucose.

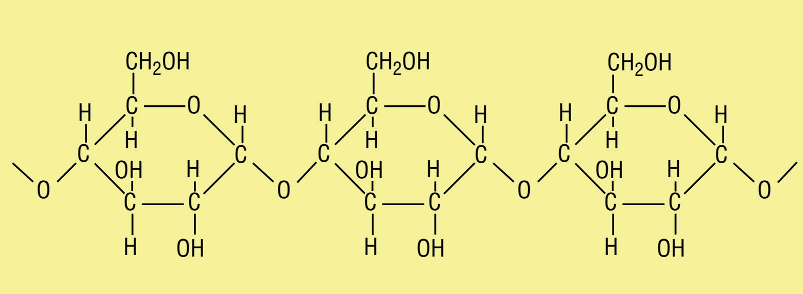


Figure 2 Stucture of glycogen.

Staying hydrated

I bypass the first of the aid stations and then try to drink about 0.2 liter every 2 miles. I prefer Gatorade to water, since it provides sugar—in the form of sucrose and glucose—that gives me a continued energy boost. After just a few minutes, the sugar will pass through the stomach and into the small intestine, where it will be absorbed into the bloodstream.

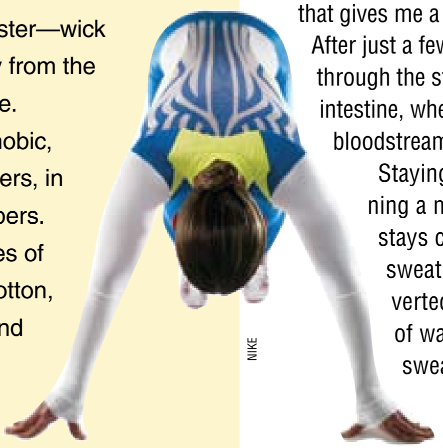
Staying hydrated is essential to running a marathon because the body stays cool by the evaporation of sweat. As carbohydrates are converted into energy, up to 0.5 liter of water per hour are lost through sweating. So I need to drink at least that much per hour to maintain good hydration.

Running Apparel that Wicks Away Sweat

One of the cardinal rules of running is "ABC," or "anything but cotton." Cotton tends to hold in sweat, adding weight. Since a shirt remains wet for a long time, it is difficult for sweat to evaporate, which could cause a runner to overheat.

Instead, nearly all synthetic fabrics—such as nylon and polyester—wick away sweat and keep you dry. They work by drawing water away from the interior of the fabric to the outside, where it can quickly evaporate.

Synthetic fabrics are made of very thin fibers that are hydrophobic, that is, they repel water. These fabrics consist of a network of fibers, in which water can easily travel through the spaces between the fibers. As a result, water quickly and efficiently travels along the surfaces of these fibers without being absorbed by the fibers themselves. Cotton, on the other hand, is hydrophilic, which is why it attracts water and tightly absorbs it. — *Brian Rohrig*



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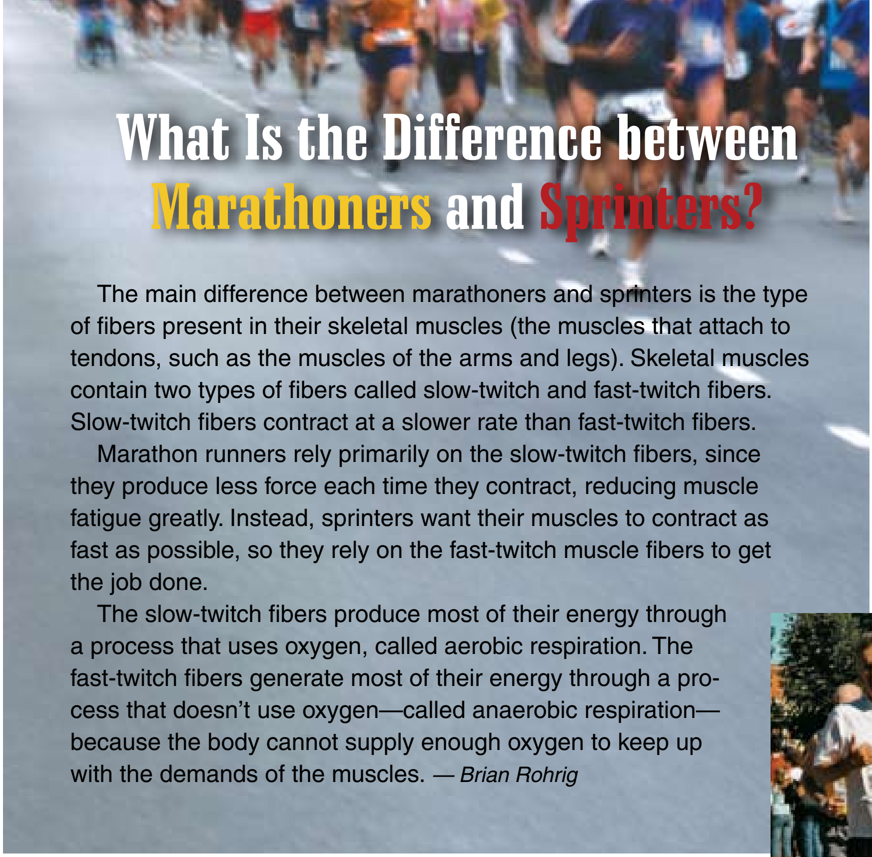

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What Is the Difference between Marathoners and Sprinters?

The main difference between marathoners and sprinters is the type of fibers present in their skeletal muscles (the muscles that attach to tendons, such as the muscles of the arms and legs). Skeletal muscles contain two types of fibers called slow-twitch and fast-twitch fibers. Slow-twitch fibers contract at a slower rate than fast-twitch fibers.

Marathon runners rely primarily on the slow-twitch fibers, since they produce less force each time they contract, reducing muscle fatigue greatly. Instead, sprinters want their muscles to contract as fast as possible, so they rely on the fast-twitch muscle fibers to get the job done.

The slow-twitch fibers produce most of their energy through a process that uses oxygen, called aerobic respiration. The fast-twitch fibers generate most of their energy through a process that doesn't use oxygen—called anaerobic respiration—because the body cannot supply enough oxygen to keep up with the demands of the muscles. — *Brian Rohrig*

Hitting wall after wall

Around mile 9, I am given a little packet of energy gel. These gels contain a mixture of simple carbohydrates (made of one or two sugar molecules) and complex carbohydrates (made of long chains of glucose molecules), which give you an energy boost. This energy boost will likely start to kick in around mile 10 or 11.

The midpoint of the race arrives. My time is 1 hour and 44 minutes—right on pace. The streets of downtown Columbus are lined with cheering spectators. This gives me a little energy boost—probably that adrenalin kicking in again. Since it draws from my glycogen reserves, it is best to not let my adrenalin get too out of hand. My glycogen levels are running dangerously low, as I am about to find out.

The next 3 miles begin a gradual uphill incline, hardly noticeable at first, but it begins to take a toll on my body. Around mile 14, the balloons that my pace group carry begin to recede in the distance. I never catch up with them again. Around mile 15, I feel like I have hit a wall. This is a bad sign, since it shouldn't happen until at least mile 20, due to my training routine.

This is where my glycogen reserves probably run very low, and my body has to rely on other fuels to get by. It's probably not really "the" wall or I may not have made it another 11 miles. Around mile 18, I feel like I hit another wall, so I receive another dose of energy gel, which I greedily gobble down. At mile 20, I feel like I hit yet another wall. Past mile 20, it's pretty much pure pain.

Carbohydrates to the rescue

At any point of the marathon, I am using both glucose and fat as my fuel. At the beginning of the marathon, about 75% of my fuel is due to glucose metabolism and 25% is due to fat. As the race progresses, this ratio reverses. By mile 20, I feel as though I have no glycogen left in my body. In fact, glycogen never really runs out—it just runs low. I am hitting every aid station now, and it's the only thing that keeps me going. I gulp down Gatorade as if it were gold, coveting the few precious carbohydrates it supplies.

Once glycogen reserves are very low, my body relies on the next best thing to burn for energy—fat. At first glance, it may seem like fat is a far better energy source: It supplies 9 kilocalories per gram, while carbohydrates provide 4 kilocalories per gram. But the body likes its fat and is not ready to give it up quite so readily.

Even the skinniest runner has enough fat on his body to run 600 miles. Why then am I having trouble running these last six? The reason is that although a given amount of fat produces more than twice as much energy as the same amount of glucose, to break down each molecule of fat requires four times as many oxygen molecules than to break down each molecule of glucose. So my body simply can't take in oxygen and transport it fast enough to convert enough fat into energy.

MARATHONFOTO.COM

Brian Rohrig runs the last miles of the Columbus Marathon.

The final stretch

Somehow, I make it through the last few miles. I try to put out of my mind thoughts of the very first marathon runner of ancient Greece, who dropped dead after finishing the world's first marathon. The last mile is lined by cheering spectators, and I even manage to pull out a respectable sprint over the last 0.2 mile. My final time is 3 hours, 46 minutes, and 41 seconds, not good enough for the Boston Marathon, but still my best marathon time ever!

I am given a lightweight shiny blanket, which reflects my body heat back into me, keeping me from getting chilled. Although my joints are stiff and I ache all over, I feel both exhausted and exhilarated. I grab a bagel, a banana, and some Gatorade. I am afraid to sit down for fear I will never get up again. Whereas a few miles back I was vowing never to do this again, I am already planning my next marathon. Boston, here I come!

Brian Rohrig teaches at Jonathan Alder High School in Plain City (near Columbus), OH. His most recent *ChemMatters* article, "The Chemistry of Arson Investigation," appeared in the April 2008 issue.

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NATURAL, BRAIDED, BLEACHED, COLORED, STRAIGHT, AND CURLY HAIR ... Thanks to Chemistry

By Lois Fruen

The way you style your hair can make a bold statement about who you are. There are lots of different styling products that can give you the look you want, and those products are all formulated by chemists. Many of these products also help repair potential damage caused by blow-drying, coloring, and straightening your hair.

Below is an overview of hair products that you can find in your favorite store. You will discover some of the chemicals they contain and how some of them interact with your hair.

Conditioners

To add moisture to hair and smooth the cells on its surface—collectively called the hair cuticle—most people use hair conditioners, which help untangle and improve hair appearance, prevents hair from getting dry and brittle, and makes locks easy to brush.

"Stripped of its natural oils, hair feels dry and raspy," says Anita Grahn, a cosmetic chemist at Aveda Corporation. "This is because strands of negatively charged hair repel each other, causing so-called 'flyaway hair.'"

Hair conditioners usually contain positively charged molecules called quaternary ammonium compounds, such as stearalkonium chloride (Fig. 1), which bind strongly to the hair surface and then act as the new hair surface. Conditioners usually also contain molecules called amino silicones that fill in the splits, cracks, and chips present on the surface of damaged strands.

HEADLINE PHOTOS FROM JUPITERIMAGES
ALL STUDENT PHOTOS BY JACOB MILLER

Both ingredients work together to add weight to the hair, make it easier to comb, and restore the essential oils needed to make hair healthy. A hair strand that was exposed to a conditioner is shown in Fig. 2.

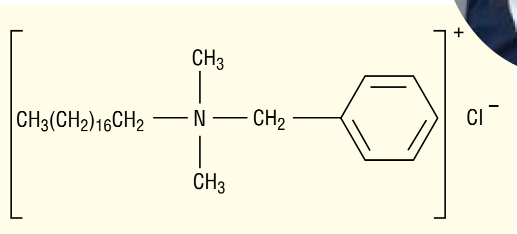
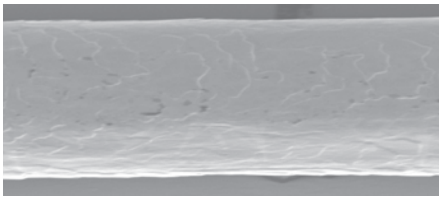


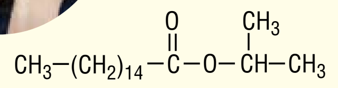
Figure 1. Stearalkonium chloride



COURTESY OF AVEDA

Figure 2. Hair strand with conditioner.

Christine uses an antihumectant to give her hair high gloss and sheen and protect her hair from the heat of her straightening iron.



$$CH_3{-}(CH_2)_{14}{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}O{-}\overset{\overset{\displaystyle CH_3}{|}}{CH}{-}CH_3$$

Figure 3. Isopropyl palmitate

Antihumectants

If your hair frizzes in humid weather, you can use an antihumectant pomade, which contains chemicals free of water.

Substances that repel water often feel oily or greasy, which is unappealing. But most antihumectants are not greasy, yet they repel water. The reason is that most atoms in greasy substances have nonpolar bonds with their neighboring atoms, that is, they share electrons equally. Instead, antihumectants contain a molecule called isopropyl palmitate (Fig. 3), in which some atoms have nonpolar bonds with their neighbors, while other atoms have polar bonds, in which electrons are unequally shared with neighboring atoms. This doesn't make the antihumectant greasy, yet it repels water.

In addition to isopropyl palmitate, antihumectants also contain phenyl trimethicone, which acts like a lubricant to add shine and makes hair easier to brush. These ingredients are dissolved in a solvent, such as cyclopentasiloxane, which evaporates readily and prevents the ingredients from feeling heavy or oily.

Styling products

Once your hair is conditioned and defrizzed, you can use one of many styling products. For example, styling gels prevent fine hair from falling flat and make it shine with a substance called a film former that forms a coating around the strands of hair as the gel dries.

In these gels, molecules called polymers, which contain a chain of identical units, make a film that steps in between hair strands, drawing them together. When the gel dries, it forms a firm connection between the hair strands which can be immediately undone by brushing or washing.

Styling gels are usually used to make hair stand out. This way, you can try to make a Mohawk spike—like the British punk-rock band G.B.H. or *American Idol* finalist Sanjaya Malakar—or a fauxhawk—like the British soccer player David Beckham.

"Some of these styling products are really sticky to start, but they dry down to a nice film," Grahn says.

The chemicals at work in these products have exotic names, such as polyvinylpyrrolidone (PVP) and a molecule called a copolymer made of a chain of smaller molecules called methyl methacrylate, octyl acrylamide, propylene glycol monomethacrylate, butylaminoethylmethacrylate, and acrylic acid (Fig. 4). In the copolymer, some of these molecules are positively charged, while others are negatively charged, making the copolymer soluble in water, so that it can be removed with a shampoo.

You may also want to give your hair a gritty, messy look. You can try a product that uses grit wax, which works by coating the hair with powdered starch for separation. But if you prefer lacquered spikes, you can try polyurethane products.

ALL STUDENT PHOTOS BY JACOB MILLER. PHOTO OF OSIE BY ACS STAFF

Jan styles his hair with boosters that contain polyvinylpyrrolidone and methacrylate copolymers.

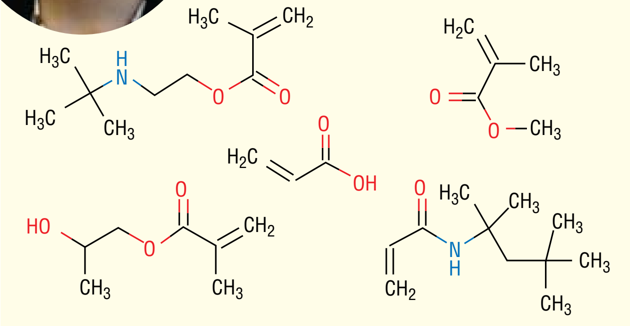


Figure 4. The monomers used to make the copolymer are (clockwise from top right): methyl methacrylate, octyl acrylamide, propylene glycol monomethacrylate, butylaminoethylmethacrylate, and (center) acrylic acid.

To style his dreadlocks, Osie uses a conditioner and shampoo for dreadlocks. After the hair is twisted, he uses a locking wax that holds the hair in place, and then he dries it with a blow dryer.

$$CH_3-CH(OH)-CH_2(OH)$$

Figure 5. 1,2-propylene glycol.

ISTOCK PHOTO

Mary Ann likes soft, nonfrizzy curls, so she uses products with polyquaternium-11

Styling products for dreadlocks can make extremely thick gels in water, helping to wash hair and keep a twisted rope styling. Such products contain a dye called D&C Yellow 11 and a thick oily liquid called 1,2-propylene glycol (Fig. 5).

Frizzy and springy hair benefits from moisturizing products that soften the curls while fighting frizz. Such products contain polyquaternium-11, a molecule that reduces frizz while softening the curls.

Emily lightens her hair with products that contain *p*-aminophenol.

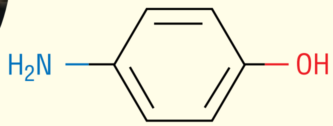


Figure 6. *p*-aminophenol

Hair dyes

You can also change the color of your hair. You can do it in one of three ways: temporarily, semipermanently, and permanently. Dyes used for temporary hair color contain pigment molecules that are large and, therefore, don't penetrate the cuticle layer. Instead, they coat the cuticle and may be removed by shampooing.

Semipermanent hair dyes deposit color on the hair shaft but don't remove the hair pigments. These dyes contain small molecules that penetrate the hair shaft.

The third type of dyes first removes the hair pigments with a chemical called hydrogen peroxide (H_2O_2). This process is called lightening, since it gives hair a lighter color. Then other chemicals such as *p*-aminophenol (Fig. 6) penetrate the hair and give it a new color.

You can also do highlights, which consist of selecting small or thick strands of hair and giving them a color that is at least two

What Does

Anita Grahn is a cosmetic chemist who works for Aveda Corporation. She uses her degrees in chemistry and biology to formulate new products and to monitor her formulations for quality and safety.

Grahn likes to use for herself the products that she and her team have developed. She likes to give body to her hair, so she uses Pure Abundance, which gives some volume to her hair.

"I designed Pure Abundance to rough up my hair cuticles, which are the cells located on the surface of each hair," she says. "Most hair products are designed to keep cuticles lying flat, but Pure Abundance makes cuticles flare out without damaging them, which gives hair a fuller look."

ISTOCK PHOTO

Madia straightens her hair with phenyl trimethicone and a flat iron.

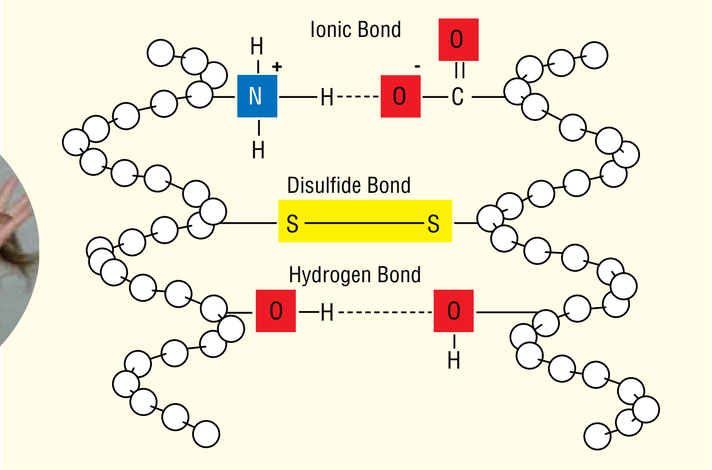


Figure 7. The three main types of bonds between proteins (white chains on right and left) inside a strand of hair: ionic, disulfide, and hydrogen bonds.

Elliot uses hydrogen peroxide to remove his hair pigments before dying his hair with a hair cream, and then he styles his hair with polyvinylpyrrolidone.

shades lighter than the rest of your hair. Hair creams that contain acetic acid, cetearyl alcohol, and a dye called D&C Red 33 can give you funky burnt-orange and pink streaks.

Straightening your hair

Maybe you are looking for straighter hair. You can temporarily straighten your hair with a hot ceramic flat iron that works at temperatures between 170°C and 230°C. The flat iron realigns bonds between proteins inside each hair strand.

Each strand of hair is made up of millions of long chains of proteins cross-linked with each other by three different types of bonds called hydrogen, salt, and disulfide bonds (Fig. 7). When you apply heat to your hair, these bonds are the first to break, but they can easily reform by drying or cooling your hair.

But heat from the iron can also frizz your hair, so be sure to use a defrizzing product. Such products use a variety of silicones, such as phenyl trimethicone, along with cyclopentasiloxane for lightness. All of these chemicals handle the heat of the iron to make hair shiny and leave it soft after straightening.

To permanently straighten your hair, you can use a lotion or cream that relaxes hair curls called a relaxer. This product permeates the protein structure of the hair and weakens its internal bonds, causing the natural curls to loosen out. Some relaxers use potassium hydroxide (KOH), lithium hydroxide ($LiOH$), or a combination of calcium hydroxide ($Ca(OH)_2$) and a solution of guanidine carbonate.

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Lois Fruen teaches chemistry at Breck School in Minneapolis, Minn. Her most recent *ChemMatters* article, "Real of Fake? The James Ossuary Case," appeared in the February 2006 issue.

a Cosmetic Chemist Do?

LOIS FRUEN

Anita Grahn, Director of Hair Care Research at Aveda Corporation.

During her 16 years at Aveda, Grahn has prepared a number of the company's most popular hair products, such as Custom Control and Rosemary Mint Shampoo. Her team of eight chemists also has prepared many of the hair products that are sold in Aveda shops, including Be Curly, Brilliant Anti-humectants Pomade, and Hang Straight.

Grahn's team is now working on a new shampoo plus conditioner that will be launched soon. The scientists are also working to find alternatives to petrochemicals that are still used to prepare some products. "My team is currently experimenting with plant waxes that hold hair in place using viscosity," she says.

Grahn also works with many other scientists, including microbiologists who ensure that products are free from bacteria; formulators who find ways to use raw materials in new and innovative ways; perfumers who formulate aromas; color chemists who make products appealing to consumers; and chemical engineers and technicians who test products on hair.

—*Lois Fruen*

National Chemistry Week Poster Contest

Theme: "Having a Ball with Chemistry" – The Chemistry of Sports

As part of the **National Chemistry Week (NCW) 2008** celebration, the American Chemical Society (ACS) is sponsoring a poster contest for students in Kindergarten–Grade 12.

Students are invited to create a poster that celebrates the theme **"Having a Ball with Chemistry—The Chemistry of Sports."** The poster should be fun, motivational, and inspire students to discover the connections between chemistry and sports.

Consider how science/chemistry is used in sports. For example:

- Importance of an active lifestyle for physical well-being
- Connections to the 2008 Olympic Games
- Chemistry in materials used for sports
- Improvements in sporting equipment made possible through chemistry (e.g. improve safety or allow for "extreme sports")
- Chemistry and sports nutrition

National Chemistry Week

Judging:

Entries will be evaluated based on the following:

1. Artistic Merit (use of color, quality of drawing, poster design, and layout)
2. Poster Message (should be fun, motivational, and capable of inspiring students to pursue a career with an emphasis on chemistry.)
3. Originality and Creativity (unique, clever, and/or creative design)
4. Neatness (free of spelling and grammatical errors and/or stray marks)

Contest Rules:

- All entries must be original works without aid from others.
- Posters must be no larger than 14 × 22 inches.
- Entries on foam board will not be accepted.
- Entries must be hand-drawn using crayons, paint, colored pencils, or markers.
- Posters must be sent to the ACS Local Section NCW Coordinator. Contact the coordinator in your area via the "Coordinator Lookup" at www.acs.org/ncw. ***NOTE: Posters received directly from schools/ students will not be eligible for the contest.***
- Posters must be submitted to NCW Coordinators in time for the local contest (deadlines will vary).

Prizes...Prizes...Prizes:

First and second place in each of the following categories: **K–2, 3–4, 5–8, 9–12**

First Place: $250, Second Place: $150

All entries must have the following information included on the back of the poster: student's name, grade, name of school, school address, teacher's name, school telephone number, and student/ teacher e-mail address. Home-schooled students are eligible for the contest and should include the name of any home-school group with which they are associated.

Entries lacking complete and legible information will be disqualified.

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