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:

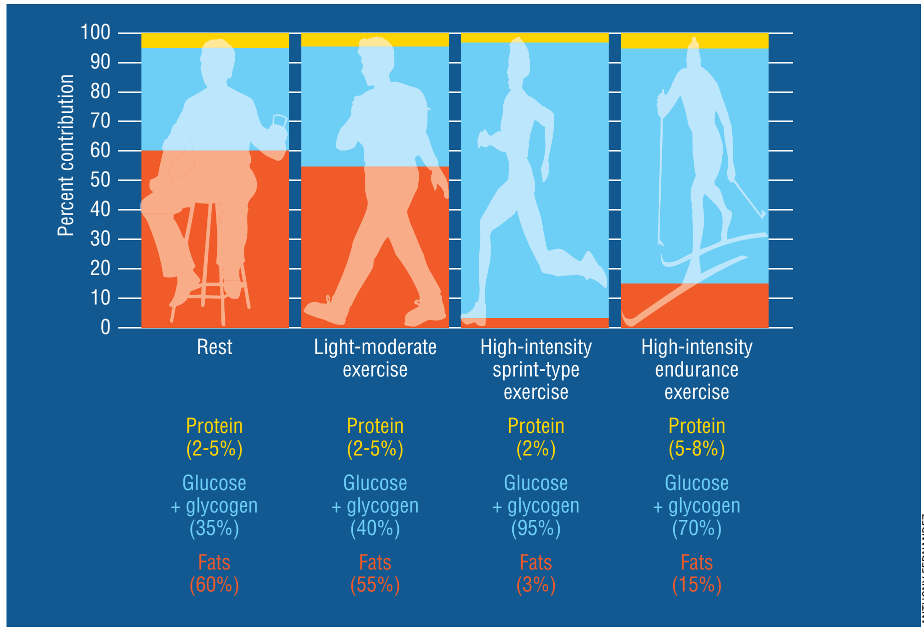
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

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:

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



ANTHONY FERNANDEZ

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

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.

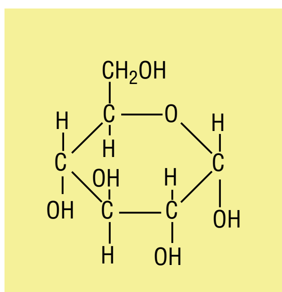


Figure 1. Structure of glucose.

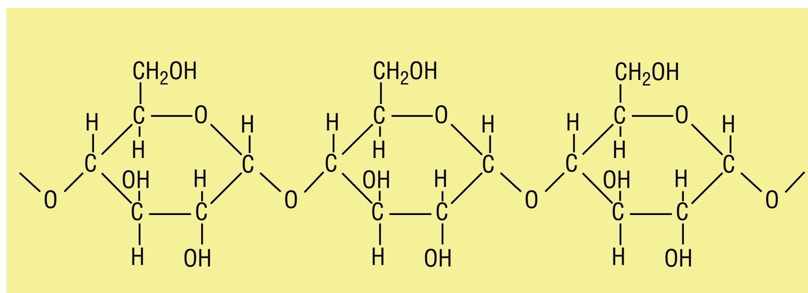


Figure 2 Stucture of glycogen.

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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.

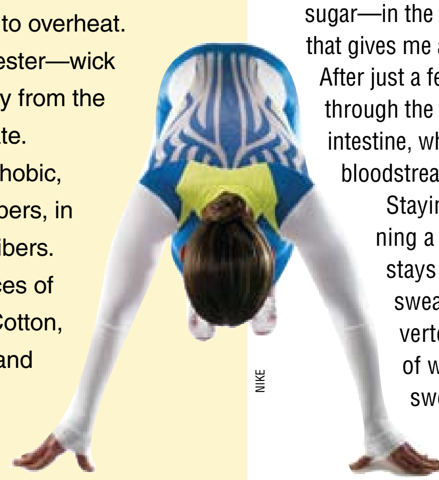
Staying hydrated is essential to running a marathon because the body stays cool by the evaporation of sweat. As carbohydrates are converted into energy, up to 0.5 liter of water per hour are lost through sweating. So I need to drink at least that much per hour to maintain good hydration.

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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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*

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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.

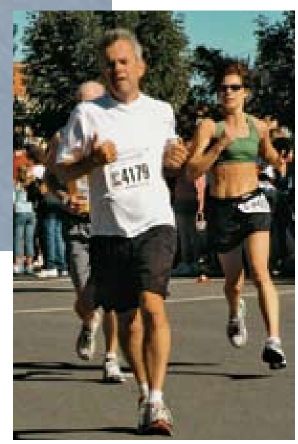
This is where my glycogen reserves probably run very low, and my body has to rely on other fuels to get by. It's probably not really "the" wall or I may not have made it another 11 miles. Around mile 18, I feel like I hit another wall, so I receive another dose of energy gel, which I greedily gobble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



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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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