to form atoms with more than one proton (all the other elements).

The nuclei of atoms must come very close together before they can fuse. Nuclear fusion is extremely difficult because the nuclei are positively charged, and similarly charged particles strongly repel each other.

Extremely high temperature and pressure in the sun and stars cause atoms to move and collide such that their nuclei come close enough to fuse and become the heavier elements. In the sun (about 15 million °C), about 657 million tons of hydrogen atoms (1 proton each) fuse to make about 653 million tons of helium atoms (2 protons each) per second:

2 Hydrogen atoms (1 proton each)

$$\xrightarrow{\text{Nuclear Fusion}}$$

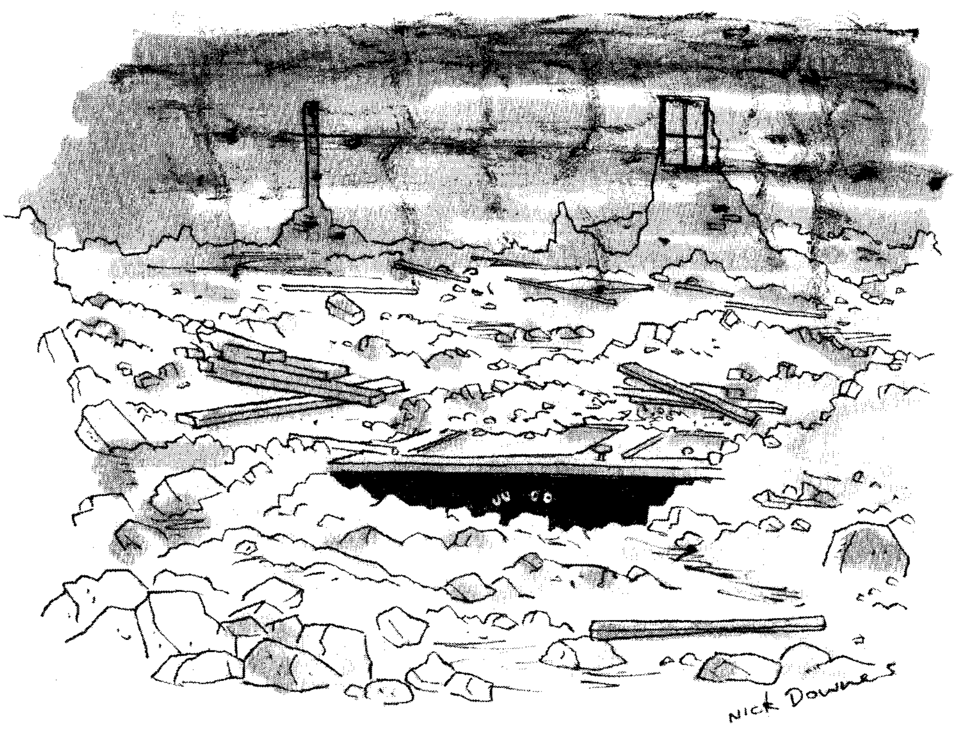
1 Helium atom (2 protons) + Energy

The atomic weight of a helium atom is slightly less than that of two hydrogen atoms. The "missing mass" of 4 million tons is converted into the heat and energy that sustains life on earth. Mass is converted to energy according to Einstein's famous equation: $\boxed{\mathbf{E = mc^2}}$ (E = energy, m = mass, c = the speed of light.) This conversion of mass to energy is what keeps the sun shining, a discovery that led to a 1967 Nobel prize for Hans Bethe. Yes, the sun will eventually burn itself out, but not for billions of years.

All the heavy elements (carbon, oxygen, calcium, etc.) were—and still are—made by nuclear fusion in stars and in the extreme conditions that exist when stars explode. We are truly made in heaven—every atom in our bodies was once inside a star that exploded (a supernova explosion).

Hydrogen is the most abundant element on earth and a potential source of virtually unlimited energy. The hydrogen bomb, first exploded in 1952, works by uncontrolled **fusion** of hydrogen atoms (the atomic bomb dropped over Hiroshima in 1945 released energy by splitting very heavy atoms—nuclear **fission**). For decades, physicists have been trying to fuse hydrogen atoms in a controlled way to provide a sustained source of energy. They try to create conditions like those in the sun (*hot fusion)* using contraptions that are huge, complex, and expensive—quite unlike "cold fusion in a jar" (see Chap. 2).

Producing energy in a controlled manner by nuclear fusion would be revolutionary. Unlike the burning of fossil fuels (e.g., coal, gas), we'd have a virtually unlimited supply of energy, without climate-changing consequences. For example,



"I always get it confused. Was that an example of fusion or fission?"

they have more fat and mitochondria. Red fibers are also rich in myoglobin, which is similar to the hemoglobin in red blood cells.

Both myoglobin and hemoglobin are proteins that contain heme (which contains iron) and carry oxygen. Myoglobin in muscle holds oxygen that can be used when oxygen from blood is restricted (as when muscle contractions squeeze the capillaries). Muscles of seals and whales are exceptionally rich in myoglobin, to provide oxygen to generate ATP when they dive and swim under water.

Studies show that muscle fibers in the relevant muscles of elite strength-and-power athletes are more than 70% white, whereas those of elite endurance athletes are more than 70% red. These proportions seem to be genetic. (Quarter horses and greyhounds are bred for speed; the fibers in their leg muscles are about 95% white.) For athletes intending to break world records, heredity could well be destiny. Training, however, can markedly enhance the aerobic (and possibly the anaerobic) capacity of both types of fibers.

The iron-containing heme in myoglobin (and hemoglobin) is red, giving a reddish color to muscles rich in red fibers. People are already familiar with these muscle fibers in their preference for either dark or white meat in the Thanksgiving turkey.

The dark meat of the turkey leg is mostly red fibers, and is thus well adapted to turkeys running around (endurance). The white breast meat is mostly white fibers, needed for the burst of power that turkeys use to flap their wings in making a fast move. (In contrast, the breast of migratory birds is dark meat, needed for the endurance of long, nonstop flights.) As a food, this makes dark turkey meat higher in fat and iron than white meat.*

The flesh of fish is mostly white fibers. Survival depends a lot on a fish's ability to make quick movements—to catch prey, or avoid being one. Fish don't need much power to cruise the waters; for this, fish have thin bands of red fibers just under their skin and/or near their fins. (The flesh of salmon is actually white, but looks pink, because of pigments from insects and such that salmon feed on.)

Oxygen delivery: Endurance athletes need a steady production of ATP over a long time—more ATP than glycogen (glucose) stores can provide. But even the leanest athlete has more than enough body fat to fuel a marathon. Oxygen is needed to "burn" fat, so the amount of oxygen available to the muscles is what becomes limiting. Endurance athletes work for cardiovascular fitness (to deliver oxygen and remove carbon dioxide and lactic acid as fast as possible), and they train to enhance the aerobic capacity of their muscles. Also, as discussed in Chapter 7, some endurance athletes attempt to boost the amount of red blood cells (i.e., the oxygen-carrying capacity) in their blood.

Glucose supply: Aerobic metabolism is sluggish when glucose is scarce. In other words, a muscle doesn't "burn" fatty acids as well if it runs out of glucose. Endurance athletes often use a technique called *carbohydrate-loading* to temporarily increase glycogen (the storage form of glucose) in the relevant muscles.† The extra supply of glycogen delays muscle fatigue.

Endurance athletes also work to "spare" the use of glucose so it won't run out as fast. Drinking carbohydrate-containing beverages during events of more than 90 minutes helps (Chap. 4). Caffeine can also help, because it promotes the use of fatty acids as fuel, thus sparing

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*Looking for good sources of iron in the diet, we can make a visual appraisal of the heme-iron content of meat (Chap. 7). Myoglobin in muscle has the red iron-containing heme, so the redder meats generally have more heme iron. Beef liver has more iron than hamburger, which has more iron than chicken or fish. Whale and seal meat is very dark and rich in iron because it's so rich in myoglobin.

†About a week before competition, athletes train hard and then taper training, resting on the day before the event. For 3 days before the event, they eat a high-carbohydrate diet. The intense exercise depletes the muscles of glycogen. Upon repletion with a high-carb diet, there's a rebound effect, and glycogen stores are temporarily raised to higher-than-normal levels in time for the event.

The prevalence of sickle cell trait in Africa suggests a selective advantage. Malaria is prevalent in Africa and is caused by a parasite that multiplies in red blood cells. Sickle cell trait protects against the most lethal form of malaria. The likely explanation for the prevalence of this mutation is that those who have it tend to survive malaria, enabling them to pass the mutation on to their descendants. This mutation was a mixed bag. It caused severe anemia, yet it gave people a better chance of surviving the most lethal form of malaria.*

In 2010, another "mixed bag" mutation was discovered that increases the risk of kidney disease and protects against sleeping sickness (trypanosomiasis) caused by tsetse flies infected with a particular parasite. These flies and parasite are found in sub-Saharan Africa. African-Americans have higher rates of kidney disease; about 30% of African-Americans carry this mutation.

Some mutations are much more one-sided. Mutations in certain genes cause cancer.† At the other extreme, there's a mutation that causes extremely high HDL-cholesterol (Chap. 8). This seems to increase longevity without any drawbacks. But genetic mutations that, say, extend life expectancy from age 75 to 95 don't tend to become widespread. In contrast, the mutation for sickle cell anemia helps children survive malaria, allowing them to make it to the childbearing years and pass on the mutation. "Longevity genes" could be propagated by letting men only over age 90 father children!

Spontaneous Mutations

The public tends to think of mutations as something caused by environmental insults. While these can certainly cause mutations, mutations also occur as copying errors. Each time a cell divides, the two strands of DNA separate, and copies of the original DNA are duplicated in the two new cells (Fig. 10-2).

A "spontaneous" mutation occurs if, for example, the wrong base is inserted in the process of making a matching strand—a copying error. In humans, copying errors are unusual because when our DNA is duplicated, the two strands are carefully checked to make sure that the bases are paired correctly. For a copying error to occur, it has to slip by the cell's diligent proofreader. But copying errors do slip by, and are more likely the more times something is copied, i.e., the more times a cell divides.

Spontaneous mutations are especially unusual in sperm and ova—DNA we pass on. As such, the number of mutations is used as an evolutionary clock. Molecular paleontologists compare DNA from animals to estimate when they branched apart from a common ancestor. They estimate how many mutations would have had to occur to account for the DNA differences between the animals and their common ancestor (e.g., 1000 mutations), estimate the rate of spontaneous mutations (e.g., 1 per 100 years), then estimate how long ago the animals branched apart [(1000 mutations)/(1 mutation/ 100 yrs) = 100,000 years].

Spontaneous mutations are common in microbes, allowing them to adapt easily. Suppose that disease-causing bacteria are flourishing in an environment that is then changed by introducing an antibiotic. If the antibiotic quickly kills all the bacteria, the assault is a success. If the antibiotic doesn't quite do its job (e.g., dose is too low or isn't taken long enough), the bacteria have an opportunity to adapt.

If even a single bacterium becomes resistant to the antibiotic because of a spontaneous mutation, that bacterium will flourish in the new environment and become the new, antibiotic-resistant strain. Such bacteria can then transfer thus antibiotic resistance to other bacteria.

Abortions following prenatal diagnosis of genetic diseases tend to lessen the perpetuation of a mutated gene. Some conditions tend to perpetuate

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*Thalassemia is also a disease caused by a mutation that both protects against malaria and causes anemia. Worldwide, it's one of the most common inherited diseases. It's more common among those from Mediterranean areas, Africa, and Southeast Asia.

†These genes regulate normal growth of a cell. Harold Varmus and J. Michael Bishop won the Nobel prize in 1989 for discovering these genes and their connection to cancer.

Bone

We tend to think of our bones as dry—a Halloween skeleton-chalky, dead tissue. But bone is well supplied with blood, and minerals constantly move in and out. Some bones contain red marrow, which makes red blood cells, some white blood cells, and platelets. The skeleton is very much alive.

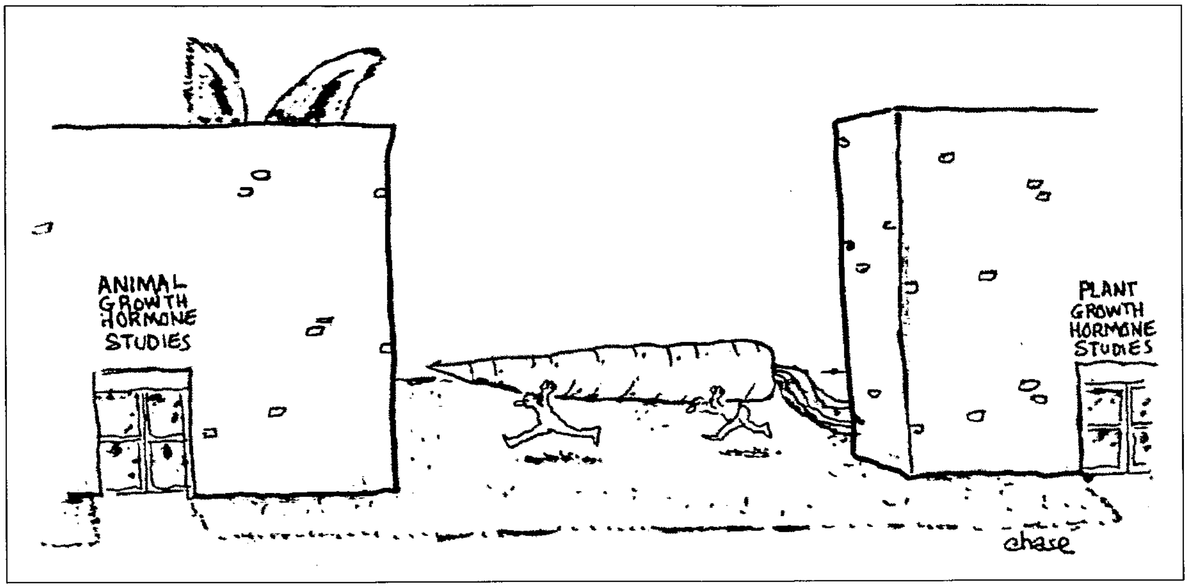
Besides its use as support, protection, movement, and blood-cell production, bone is a mineral reserve. About 99% of the body's calcium, 85% of the body's phosphorus, and 60% of the body's magnesium are in bone. These minerals are crucial to body chemistry. Without calcium, blood can't clot, muscle can't contract, and a nerve cell can't send its message. Phosphorus is a key part of ATP (adenosine tri*phosphate), and* magnesium is needed to regenerate ATP. Very small amounts of calcium, phosphorus, and magnesium are needed for these uses, but their presence is crucial, and the body is assured of never running out. Bone minerals are readily mobilized to make up for any shortfall.

Bone is about 30% protein (collagen) and about 70% minerals. It's sort of like reinforced concrete—protein for tensile strength, and minerals for compressional strength. Taking out the minerals is a popular experiment in a child's science class: Put a chicken bone in vinegar; the acid (acetic acid in vinegar) dissolves the minerals; after a few weeks, only the protein is left—demonstrated by bending the bone in half.*

When a bone is said to be dense, it's dense with minerals. Bones aren't really solid. The outside is smooth and compact, but the inside is porous, much like styrofoam. It's well engineered. The outer hardness of a leg bone provides the strength of a tube (a tube is almost as strong as a solid rod of the same diameter). The porous inside adds strength without adding much weight. The protein gives it some flexibility.

Stimulated by growth hormone, bone grows fast during childhood and adolescence. Bone density increases until about age 30, but most of that density is acquired before age 20. Generally speaking, bone density stays the same from age 30 to 50 and then falls. A key factor in the development of osteoporosis is the amount of bone a person has in early adulthood when bone mass reaches its peak (peak *bone density*).

In dwarfism, the pituitary gland doesn't make enough growth hormone during childhood, and the person is abnormally short. Growth hormone (a protein) used to be extracted from human pituitary glands, and the limited supply was



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*When soup bones are boiled, collagen dissolves, forming gelatin. This is why soup stock gels when refrigerated. Gelatin (for Jell-O, etc.) is typically made by extracting it from pig skin.