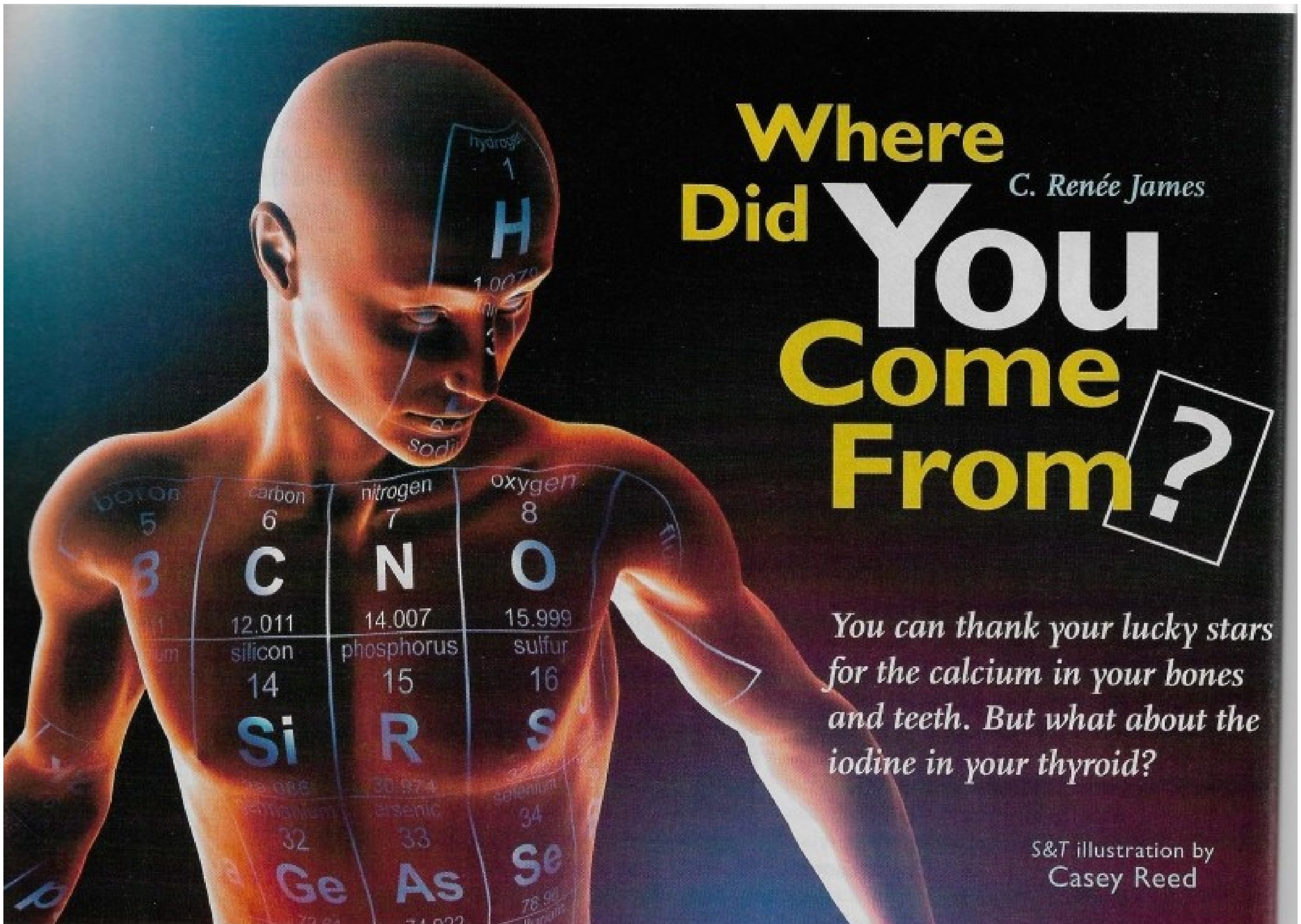
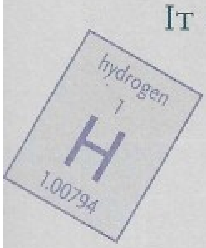


Where Did You Come From?

C. Renée James

You can thank your lucky stars for the calcium in your bones and teeth. But what about the iodine in your thyroid?

S&T illustration by Casey Reed



IT FINALLY HAPPENED in our house: The Dreaded Question. "Where do babies come from?" After some stuttering and blushing, we decided to give our son the truth about his newborn sister: She's a child of the universe.

In fact, most of her atoms — and yours — have been riding unchanged through the universe since its birth in the Big Bang 13.7 billion years ago. The most abundant element in the universe, hydrogen, is also the most abundant element in you. Making up some 90% of the atoms outside you and 62% of the atoms within you, hydrogen — with just one proton and one electron — was the easiest element for the nascent universe to put together.

The Big Bang also created plenty of helium, with two protons, two electrons, and two neutrons. But except for the helium you might inhale to make a funny voice, you have none of this element in you. As a noble (inert) gas, it doesn't bond to form molecules necessary for life.

Elements that, like hydrogen, *do* bond well to form complex molecules are oxygen, carbon, and nitrogen, which respectively comprise about 24%, 12%, and 1% the atoms in your body. These weren't made in the Bi Bang; they were forged by the generations of stars tha preceded the Sun's formation. Their story is told in "O gin of the Elements of Life" on page 26.

The Other 1%

Look at a multivitamin label, and you'll see that huma life requires far more elements than hydrogen, oxygen carbon, and nitrogen. Some you've never even heard of Take molybdenum. You might not be able to pronounc (*muh-LIB-deh-num*), but if you want your body to make the enzymes crucial for metabolism, you need to cons 75 micrograms of this element each day.

Containing 42 protons and typically 54 neutrons, molybdenum makes up only about 1 in a billion of your atoms. Strikingly, this minuscule concentration far exceeds its abundance in space. In the solar system, molybdenum makes up fewer than 1 in 10 billion atoms.

So where did this vital but obscure element arise? Our current understanding is that molybdenum is manufactured by stars more massive than the Sun during their late stages of stellar evolution.

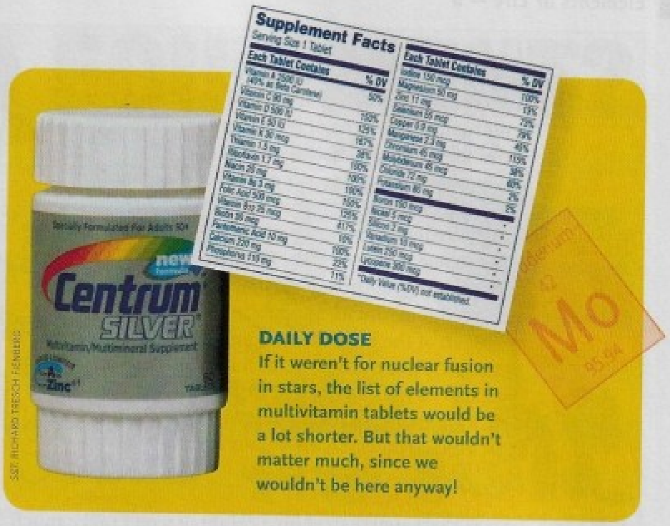
Slow Cookers

When such a star empties the hydrogen fuel tank in its core, it has to find alternative energy sources to avoid collapsing under its own weight. An intermediate-mass star — one with about 1 to 8 solar masses — begins to pulsate. As it contracts, it heats up, eventually igniting a new round of nuclear burning. This in turn causes the star to expand and cool down, and then the cycle repeats.

During these thermal pulsations huge numbers of carbon-13 nuclei (6 protons and 7 neutrons) fuse with helium-4 (2 protons and 2 neutrons). Each such reaction produces a nucleus of the familiar oxygen-16 (8 protons and 8 neutrons) that makes up about a quarter of your atoms — plus a leftover neutron.

In more massive stars, with their denser and hotter interiors, the fusion of neon-22 with helium-4 also yields a leftover neutron, along with magnesium-25, trace amounts of which are essential to protein synthesis, muscle contraction, and the transmission of nerve impulses.

All these excess neutrons are kicked into the hot, dense stellar cauldron, where they can attach to heavy "seed" nuclei. For example, when an iron nucleus captures a neutron, it becomes a new isotope of iron, one whose proton number is 26 — as is true for every iron atom — but whose neutron number has just increased by one (from, say, 30 to 31).

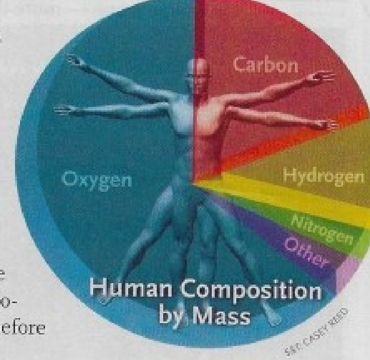


DAILY DOSE If it weren't for nuclear fusion in stars, the list of elements in multivitamin tablets would be a lot shorter. But that wouldn't matter much, since we wouldn't be here anyway!

S&T: RICHARD TRESCH FIENBERG

Sometimes a heavy nucleus is fine with an extra neutron (such as iron-57), but sometimes it's not. Too many neutrons can make a nucleus unstable, in which case one neutron converts itself into a proton by ejecting an electron. This process is called *beta decay* (electrons are also known as beta particles), and when it occurs — *voilà!* — the nucleus advances one square on the periodic table.

During the thermal-pulsation phase of a middleweight star's evolution, some 100 million neutrons are buzzing through each cubic centimeter of its core, bombarding potential seed nuclei. Astrophysically speaking, this is a very low neutron density. It means each newly formed isotope has plenty of time to stabilize itself with a neutron-to-proton conversion, if necessary, before being hit with another neutron.



This pathway to the creation of heavier and heavier nuclei is called the *s-process*, since the rate of neutron capture is *slow* compared to the rate of beta decay. Accordingly, atoms synthesized via this mechanism are called s-process elements. With enough neutron captures and

THE HUMAN ELEMENT Our bodies contain more than three dozen chemical elements, all but a few in trace amounts. *Above:* By mass, we're mostly made of oxygen, carbon, hydrogen, and nitrogen. By number, hydrogen comes first, but because it's so light, it accounts for only about 10% of our body weight.

BIG BANG Some of the chemical elements in our bodies were forged in supernova explosions, among the most violent events in the universe. *Left:* A Type II supernova, the catastrophic disruption of a massive, solitary star, produced the Crab Nebula in Taurus, seen here in an image from the Hubble Space Telescope.

beta decays, an evolved intermediate-mass star will eventually turn some of its iron into the molybdenum you need for optimal metabolism.

But how does this stuff get out of the star? During its dying gasps, the star's interior churns like a lava lamp, dredging the newly manufactured elements from deep inside to the surface. The star eventually sheds its outer layers to form a planetary nebula, dispersing this enriched material into space.

Much of the molybdenum and virtually all of the strontium, yttrium, zirconium, barium, lanthanum, cerium, and lead in your body was made by the s-process in the Sun's ancestors and seeded into the cloud from which the Sun and Earth would eventually form.

Blast Furnaces

But try as a stellar alchemist might, it won't make much gold this way, nor will it produce the iodine you need for proper thyroid function. These elements and many others are created in the extreme conditions of supernova explosions. When stars blow themselves to bits, nuclei don't get a chance to adjust to the presence of a new neutron before being saddled with another. And another. And another.

During a Type II supernova, the death of a massive but otherwise normal star, atoms are relentlessly bombarded with neutrons — more than a hundred billion trillion per cubic centimeter. There's no time for stabilizing beta decays during this *rapid* neutron capture, or *r-process*. Only later, after the neutron flood subsides and the material spreads out a bit, will very heavy, unstable atoms have the opportunity to decay into stable isotopes. The energy released in this process makes the supernova stop dimming — or even brighten — weeks after the explosion.

By the time the dust settles, the r-process has created the silver, gold, and platinum we value in our jewelry along with the iodine our bodies need. A Type II supernova also disperses prodigious amounts of lighter biologically important elements forged during earlier phases in the star's life. Among these are calcium, magnesium, silicon, sulfur, and titanium.

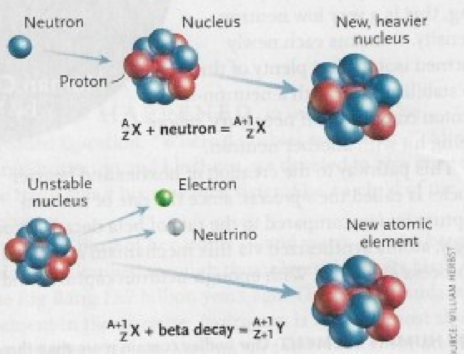
Some elements' birthplaces aren't so easy to pin down. For instance, both the s-process and r-process can make selenium. As far as astronomers can tell, about two-thirds of the selenium you need for a healthy immune system was made in the r-process, the rest in the s-process.

IT'S ELEMENTARY

Atomic elements are defined by the number of positively charged protons in their nuclei: hydrogen (1 proton), helium (2), and so on. Atoms with equal numbers of protons but different numbers of uncharged neutrons are called isotopes of the same element. So, for example, helium-3 (also written ^{3}He) has 2 protons and 1 neutron, while helium-4 (^{4}He) has 2 protons and 2 neutrons. An atomic nucleus is surrounded by a cloud of as many negatively charged electrons as it has protons.

Why do you need chromium, or manganese, or potassium to stay healthy? Find out at www.one-a-day.com/definitions.html.

Neutron Capture



PARTICLE PINBALL **When an atomic nucleus captures an extra neutron, it becomes a heavier isotope of the same atom. (Here *Z* is the number of protons and *A*, the atomic number, is the combined total of protons and neutrons.) If the new isotope is unstable, one of its neutrons may decay into a proton by emitting an electron and an antineutrino, converting the atom into the next element in the periodic table.**

Iron in the Fire

Then there's iron. Type II supernovae blast huge quantities of it into space. But most of the iron in the solar system came not from massive stars, but from the swift conflagrations and explosions of white dwarfs — the compact remnants of Sun-like stars — whose binary companions dumped too much material onto them (*S&T:* July 2007, page 32). About half the mass ejected from this type of supernova, called a Type Ia, is iron, without which we would all suffer fatal cases of anemia.

So forget frogs and snails and puppy-dog tails or sugar and spice and everything nice. Next time you're faced with The Question, try this ditty:

Big Bang creation and thermal pulsations,
r-process, s-process, huge conflagrations.

That's what little boys and girls are *really* made from. ✦

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