How to Make an Element

"The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of star stuff."—Carl Sagan

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Almost all of the elements in the universe originated in the high-pressure hearts of stars or during a star's violent death. But some elements are not "star stuff." Hydrogen and helium trace their lineage back to the big bang. Other elements, like francium and plutonium, are only produced in trace amounts by the decay of uranium—and by trace amounts, I mean that if you gathered all the naturally occurring plutonium in the world, you'd have roughly 0.05 grams of it.
In fact, the periodic table might well have ended after plutonium if scientists had not picked up where nature left off. In the last 75 years, scientists have added an additional 24 elements to the periodic table and created several others that are so rare we can only speculate about their existence in nature. We have redefined matter and are perhaps the only planet that has ever seen elements heavier than plutonium. But how much further can we go?

To answer this question, it is important to understand the anatomy of an element. Everyone has heard of the periodic table of elements, or at least seen it hanging on the wall of a high school science classroom. This infamous table classifies all the atoms in the universe into 118 different types, known as elements. An atom is composed of two parts: a nucleus and an electron cloud. The nucleus is in the heart of an atom and composed of positive particles called protons and neutral particles called neutrons. Negatively charged electrons buzz around the nucleus in the electron cloud.

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An atom looks a little like the picture above—except atoms are a thousand-million times smaller than you see them here. (If this were the real size of an atom, you would be roughly the size of the sun.) Even though all the components of an atom are important, the periodic table ignores the number of neutrons and electrons and defines an atom based solely on the number of protons it has in its nucleus. All atoms with six protons are carbon, regardless of how many neutrons or electrons they have. Nitrogen is element seven because it has seven protons, and so on until we reach ununoctium with 118 protons.

So creating a brand new element requires loading an atom's nucleus with more protons. Stars create new elements in their cores by squeezing elements together in a process called nuclear fusion. First, stars fuse hydrogen atoms into helium. Helium atoms then fuse to create beryllium, and so on, until fusion in the star's core has created every element up to iron. Iron is the last element stars create in their cores, and a kiss of death for any star with the the mass to make it to this point. As astronomer Robert Kirshner of the Harvard-Smithsonian Center for Astrophysics describes it, "Once a star has built an iron core, there is no way it can generate energy by fusion. The star, radiating energy at a prodigious rate, becomes like a teenager with a credit card. Using resources much faster than can be replenished, it is perched on the edge of disaster."

But the edge of disaster for these massive stars is the threshold of life for the rest of the periodic table. In a star's last second of life, its core compacts so tightly that it becomes as dense as an atomic nucleus. When no more matter can squeeze into the core, the star explodes with the energy of an octillion (10^{27}) atomic bombs. In this violent explosion, more than half the elements on the periodic table are born. Intense heat from the explosion catalyzes nuclear reactions that were not possible in the core. Escaping elements are bombarded with neutrons, which split inside the nucleus into protons and electrons, generating new unique elements. Iron turns into gold, gold turns into lead, and so on until uranium, the heaviest naturally star-born element, is forged from the ashes.

This spectacular shower of life and death creates everything. Well, *almost* everything. There are another 27 elements on the periodic table after uranium that were not created by stars. Some elements are produced in trace amounts by the decay of other elements. But even the long radioactive decay chain is not enough to produce the ultra-heavy elements at the end of the periodic table. The periodic table would have ended altogether if scientists had not pushed the boundaries of natural physics and ventured deeper into the world of super heavy elements.

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To make new elements, scientists borrowed some advice from the heavens. The transuranium elements (elements 95 through 100) were forged by bombarding uranium with neutrons and waiting for the impregnated nucleus to become radioactive and convert its extra neutron into a proton, electron, and a charge-less, nearly massless, antineutrino. But after fermium (element 100), the irradiate-and-wait technique stops working. Particle physicists "stepped up their game" and upgraded their atomic fodder from neutrons to other elements. The trick was to get the nuclei of the two atoms to fuse into one giant nucleus, generating an entirely unique atom. Scientists started small—firing helium (2) at einsteinium (99) to beget mendelevium (101); launching neon (10) at uranium (92) to engender nobelium (102). Eventually, scientists busted out the big guns and bombarded lead (82) with zinc (30) to beget copernicium (112) and californium (98) with calcium (20) to produce element 118, provisionally called ununoctium.

But why do scientists succeed where the stars fail? The truth is, the stars don't fail. In the storm of their deaths, some stars probably do forge super heavy elements—even elements heavier than we've created—but these elements don't survive long in the turbulent chaos of a supernova. Super-heavy elements are so fragile they live only a matter of microseconds before they decay into a jumble of atomic scrap metal.

There is a limit to the number of protons and neutrons that can squeeze inside an atomic nucleus, but we haven't found it yet. Protons are positively charged, and because like-charges repel, the protons are in a continuous "this nucleus ain't big enough for the both of us" duel. The neutrons have no charge and quell some of the tension by weaseling between the protons. The entire nucleus is held together by the strong force—a mysterious force that acts like a bungee cord and pulls everything together. But eventually, the proton's repulsion overwhelms the strong force, and not even the neutral neutrons can prevent the emigration of alpha particles (two neutrons and two protons) from the nucleus. So the real question is: How big can we go?

As we close the gap between what does exist and what can exist, the laws of physics will eventually stop us from venturing deeper into the world of synthetic matter. Scientists will continue to push the limit of "physically possible," but for now it appears the periodic table is nearing its completion.