

Astrobiology 101

**Where did all the Elements
come from?**

WHERE DID ALL THE ELEMENTS COME FROM??

In the very beginning, both space and time were created in the [Big Bang](#). It happened 13.7 billion years ago. Afterwards, the universe was a very hot, expanding soup of fundamental particles. The universe expanded rapidly during [inflation](#) and expands at a more or less constant rate now. As it grows, it cools.

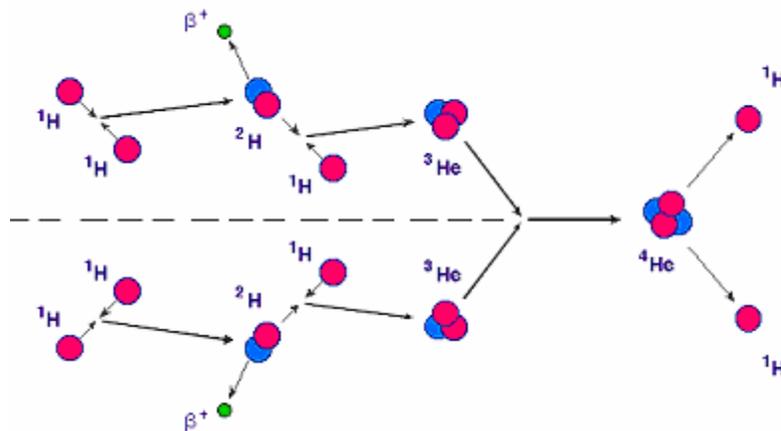
At first, the universe was dominated by radiation. Soon, [quarks](#) combined together to form [baryons](#) (protons and neutrons). When the universe was 3 minutes old, it had cooled enough for these protons and neutrons to combine into nuclei. This is known as the time of nucleosynthesis. Hydrogen, helium, lithium, and beryllium were produced. Today, about 90% of the universe is still hydrogen. Remember that only the nuclei of these atoms were created at this time. The universe was still far too hot to allow these nuclei to attract electrons and form atoms. That didn't happen for another 300,000 years, at the time of recombination.

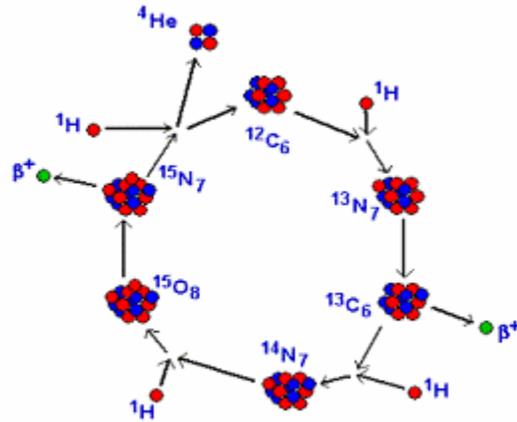
At this time the universe had cooled sufficiently for atoms to exist. Echoes from these first atoms can still be seen in the [Cosmic Microwave Background](#). But this process only created the lightest four elements. How did the other 88 natural elements come about? To understand this, we need to understand fusion.

All protons have positive charge and therefore repel one other. How then, can they be packed tightly into a nucleus? What holds them there? The answer is another force, the [strong force](#). When protons collide with enough energy, their electric repulsion can be overwhelmed by this new force and they will be bound together. Similar processes take place between neutrons and protons and between small nuclei. This building up of heavier nuclei is called nuclear fusion.

Three important fusion processes are: the [proton-proton chain](#) which details how helium is made in our sun, the [CNO cycle](#) which explains how hydrogen is fused in hotter stars, and the [triple alpha process](#) which accounts for the helium fusing that occurs in mature stars. Sketches of these three processes are shown below. In each case, the sketch is incomplete. These reactions occur in chains with more than one possible path. Only the most probable paths are shown below.

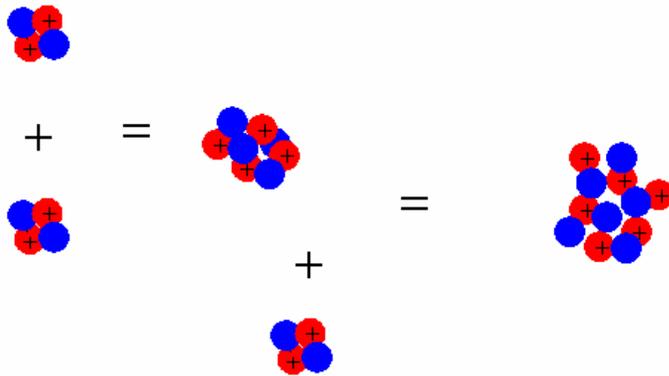
Proton-proton chain





Triple alpha process

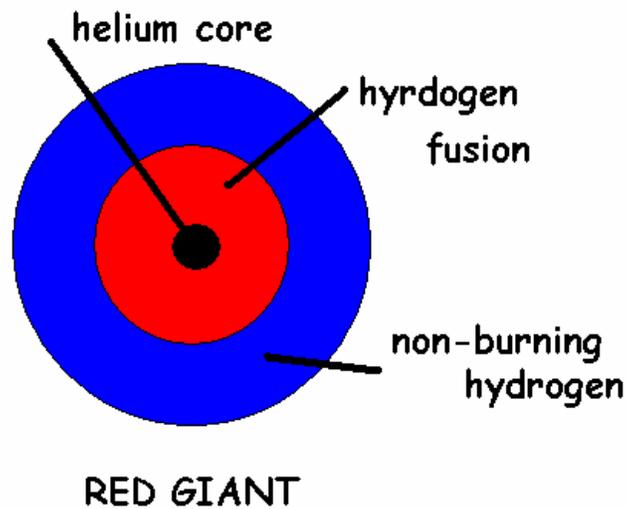
Thanks to Michael Richmond for the following image



Another important concept is the behavior of an ideal gas. When a gas is compressed, its temperature increases. When a gas expands, its temperature drops. This is why a bike pump warms up when in use. It is also why air rushing out of a balloon feels cool. Now back to our story.

The atoms left over by the big bang were gravitationally attracted to one another and condensed into huge clouds. The gravitational pressure on the centers of these clouds heated them to temperatures of millions of degrees.

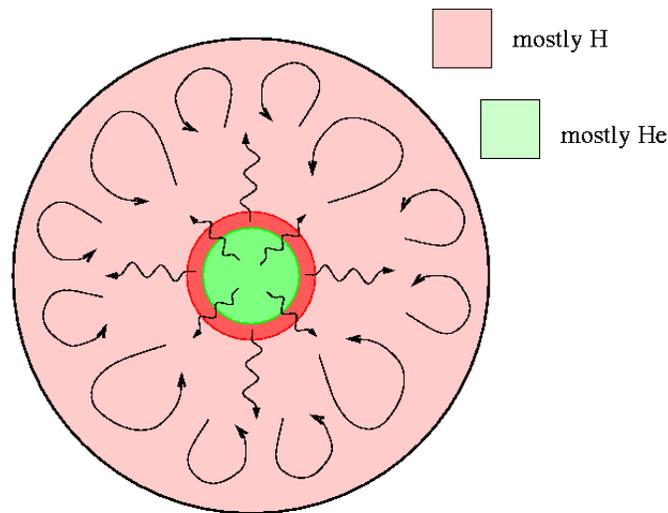
This led to the fusion of hydrogen into helium. Stars were born. As the fuel in their cores is used up, the cores shrink and warm. This causes hydrogen fusing to occur in the outer parts of the star, its shell. This new source of energy causes the star to expand and cool, turning it into a [red giant](#).



Once all the hydrogen in the core has been used up, helium is fused into **carbon, nitrogen and oxygen**. This causes the core to expand and cool once again. The shell, which is still fusing hydrogen, also cools. When all the helium has been used, the core contracts and warms. This heats up the shell which now starts fusing helium. The star enters a second red giant phase.

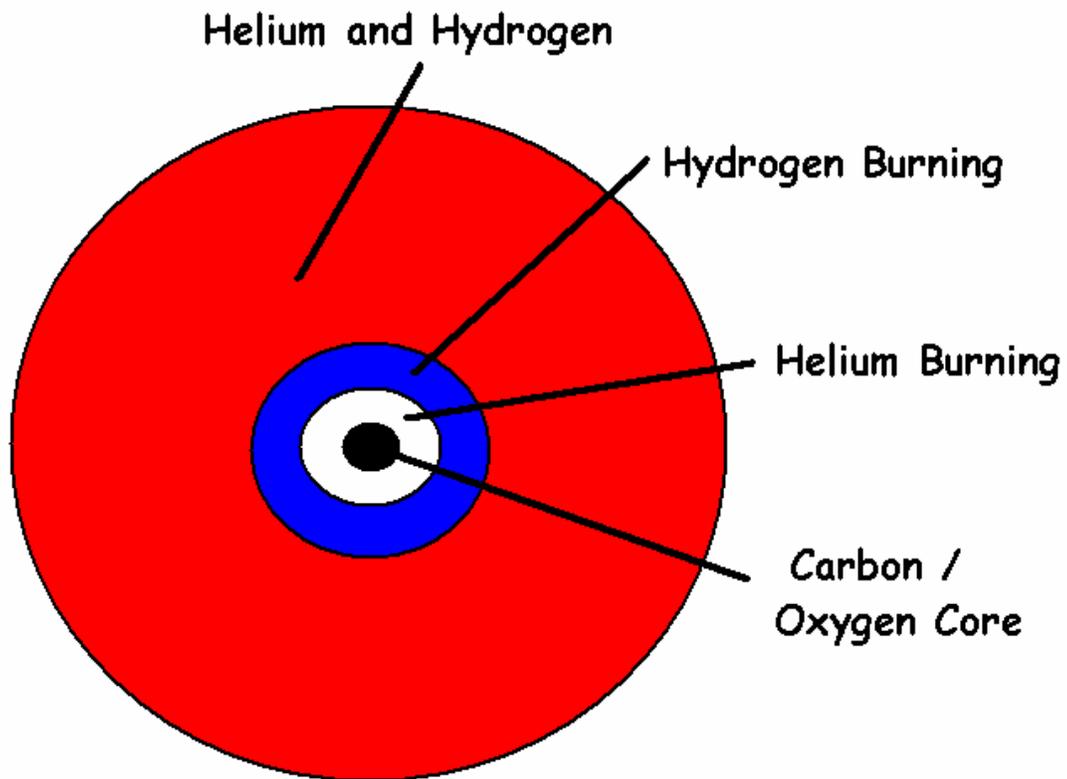
During these cycles, convection within the star increases. After hydrogen fusing is stopped, the first dredge-up carries oxygen, nitrogen, and carbon from the CNO process to the surface of the star. After helium fusing stops, a second dredge-up carries more of these elements from the triple alpha reactions to the surface. If the star has a mass greater than 2 solar masses, a third dredge-up can occur. This time mostly carbon and carbon molecules are brought to the surface. These stars are called AGB or carbon stars. They have very active solar winds and are typically surrounded by a sooty planetary nebula.

Thanks to Michael Richmond for the following image

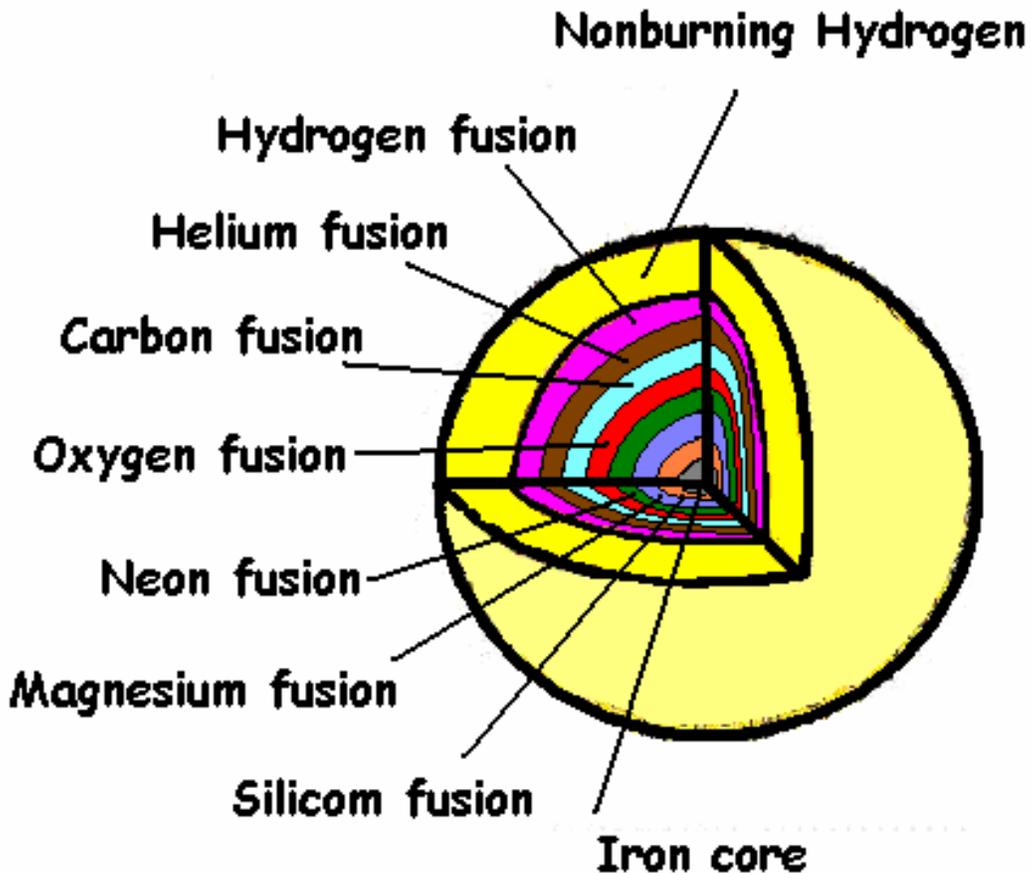


At this point, low-mass stars (below 8 solar masses) eject their outer layers and evolve into [white dwarfs](#). White dwarfs are carbon-oxygen-rich and made of super-dense matter. Most of their hydrogen and helium are lost to the stellar wind. These stars are so dense that they form a new type of “degenerate” or nuclear matter.

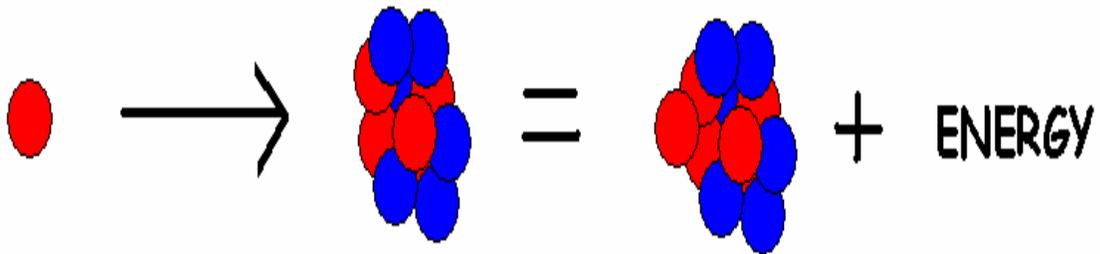
High-mass stars do not evolve into white-dwarves. The gravitational pressure on these stars does not allow their cores to expand and cool. Their gravity is so great that not even the degenerate electron pressure in the core can cool it. After helium fusing ends in these stars, carbon fusing begins creating **oxygen, neon, sodium, and magnesium**.



If the star has a mass of more than 8 solar masses (called a [supergiant](#)) its gravity is strong enough to fuse neon after it has finished fusing carbon. This forms more oxygen and magnesium. Afterwards, oxygen will be fused into sulfur, silicon, phosphorus, and magnesium. Then silicon will be fused to new **elements as heavy as iron**. Each stage burns more quickly, at a higher temperature, and at a greater density. As each new stage begins, the earlier stages continue their reactions in onion-like shells about the core. The star heats up and expands as each new phase begins. It constantly loses mass to its stellar wind.



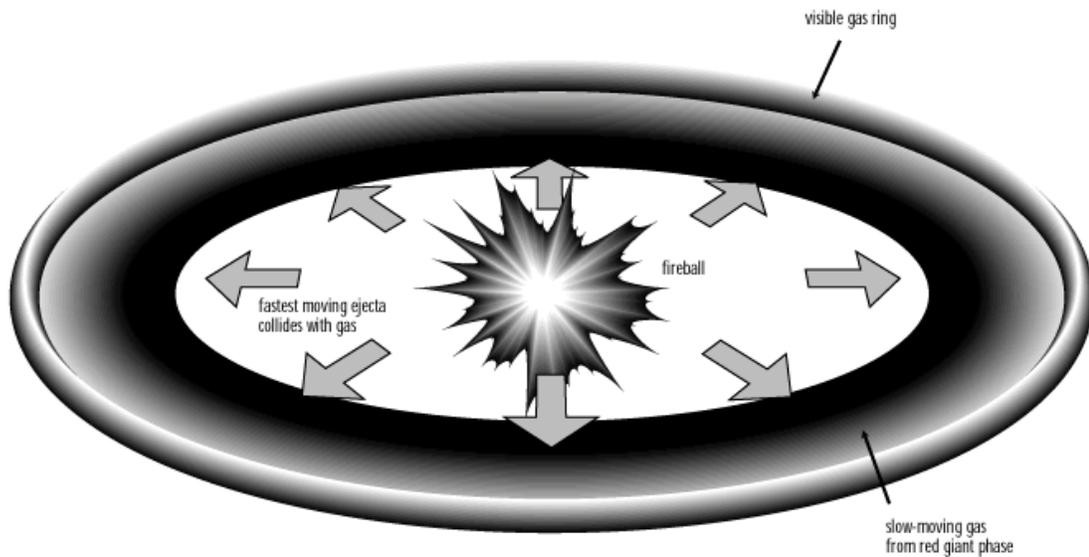
Some of the reactions which lead to the creation of these new elements also produce neutrons. These neutrons are captured by some of the new atoms to form different isotopes. This process cannot create a nucleus with more than 26 protons (iron) because at that point the energy it takes to overcome the electric repulsion is greater than the energy released by the strong force. Creating elements heavier than iron requires energy, it doesn't release energy.



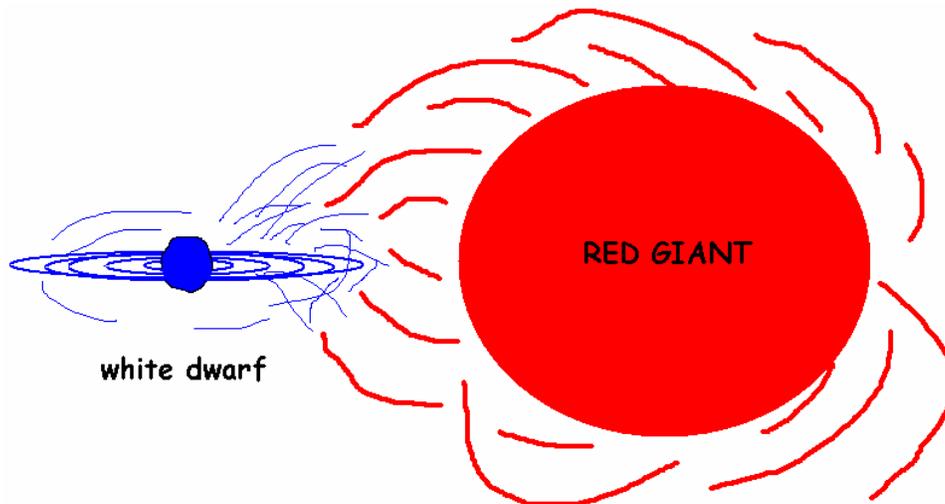
The heaviest elements are created in supernovae, the fantastic death of supergiant stars. As the core of the supergiant becomes saturated with iron, its pressure and temperature increase. Eventually, the [blackbody radiation](#) from the core produces [gamma rays](#) powerful enough to break apart the iron atoms in the core. This further increases the pressure to a point where electrons and protons are fused into neutrons. This releases lots of energy in the form of neutrinos. The core cools and contracts; the inner shells rush to fill the void. As the core reaches nuclear density it becomes rigid and even bounces back a little. When the onrushing material feels this bounce, it creates a wave. As the wave spreads to outer, less-dense regions, it speeds up. Soon it is a shock wave and combines with the wave of neutrinos. The star is doomed. This process blows the star apart releasing 10^{46} joules of energy. This shock wave is the only place hot and dense enough to fuse elements heavier than iron, **elements up to and including uranium.**

Supernova 1987A

Collision Between Explosion Ejecta and Slower Moving Gas



The supernova just described is termed a [type II supernova](#) because it contains the emission lines of metals. [Type I supernovae](#) have no such lines. They are caused by a binary star system with a red giant and a white dwarf (remember that 70% of stars are binary). Matter that flows off the red giant collects on the white dwarf and increases the pressure on its core. Eventually carbon fusing begins in the white dwarf, but this time the star is made of “degenerate” matter and cannot expand to cool off. The result is a runaway reaction which ends in a supernova.



SO THAT'S WHERE THE ELEMENTS COME FROM!!

The first four elements were present after the big bang. Elements up through magnesium were created in red giants. Elements up through iron were created in supergiants and the elements from iron to uranium were created in supernovae.

These atoms can meet one another in nebulae, on dust particles, and even in planets. When they do, chemical reactions take place. These reactions eventually led to life and then . . . us.