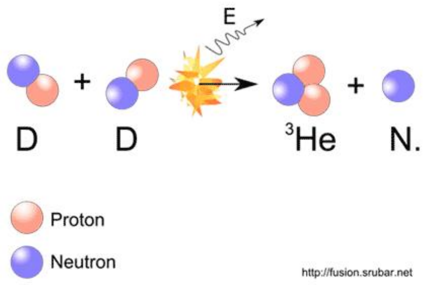
Ever since the beginning of life on Earth, the Sun has sent the energy needed to keep its inhabitants alive. Solar rays light the days, warm the soil, and provide plants with the raw energy they need to make food. We know the Earth's energy comes from the Sun, but from where does the Sun's energy come? Only one force is powerful enough to fuel our sun and all the other stars for billions of years: nuclear fusion, the process in which small atoms combine to form larger ones.

What is Nuclear Fusion?

Nuclear fusion occurs when the nuclei of two atoms combine to form the nucleus of a larger atom. Naturally, this can occur easily only with the smallest of elements, hydrogen, which has only one proton, and, in some cases, helium, which has two. Also, nuclear fusion can take place only when the atoms are under high pressure and high temperature. In fact, they must be hot enough to take on a state known as plasma, in which the electrons are completely stripped away from the nuclei. According to Nick Strobel, "At high temperatures the nuclei move fast enough to be driven close enough together to fuse. The high densities ensure that there are enough nuclei within a small volume for the collisions to take place at all. The only place these extreme conditions occur naturally is in the cores of stars." As a result of these collisions, enormous amounts of energy are released.

When it occurs, nuclear fusion has many forms. Even though hydrogen is by far the most likely element to undergo fusion, there are times where helium and, sometimes, larger elements reach high enough temperatures and pressures to fuse. More important, though, is the fact that hydrogen fusion itself can take on different forms. According to Craig Freudenrich of Howstuffworks, there are three common kinds of hydrogen fusion. This is because there are three isotopes, or forms based on number of neutrons per nucleus, of hydrogen. The proton-proton chain, the form of fusion that takes place in stars, is a complicated reaction in which free protons (also known as protium, an isotope of hydrogen with no neutrons) follow a sequence of fusing into larger atoms and decaying back into smaller ones until they form helium-4 (a helium isotope with two neutrons per atom). In a deuterium-deuterium reaction, two deuterium (hydrogen isotope with one proton and one neutron) atoms combine to form helium-3 (helium with one neutron) and give off a free neutron (see Figure 1). In a



http://fusion.srubar.net

Figure 1: Diagram of deuterium-deuterium fusion.

deuterium-tritium reaction, a deuterium nucleus and a tritium nucleus (hydrogen with two neutrons) combine to form a helium-4 nucleus and a free neutron. All three reactions give off great amounts of energy, but proton-proton chains take place in stars while the other two reactions can only be produced with man-made reactors (sec. 2).

The Sun (and Other Stars)

To understand how nuclear fusion powers stars such as the sun, it is important to know of what these stars are made, what they do, and how this process works.

What the sun "looks" like

The Solar and Heliospheric Observatory, a NASA and ESA collaboration dedicated to studying the sun, describes stars as being divided into six layers. From the innermost, these layers are the core, radiative zone, convective zone, photosphere, chromosphere, and corona (see Figure 2). The core of the sun is where nuclear fusion takes place, and the energy produced by the fusion must be carried outward through the other five layers before escaping into the solar system. The radiative zone, which surrounds the core like a shell, is made up of incredibly dense plasma; energy must zigzag through this area for hundreds of thousands of years! In the convective zone, energy is carried through in "convection currents" and bubbles of hot plasma. The photosphere, chromosphere, and corona make up the sun's visible surface, where energy travels through more easily. The photosphere is much cooler than the inner core and outer corona. The chromosphere appears red, and helps give the sun its orange color. The corona, also known as the "atmosphere" of the sun, is its final layer. This is where the solar cycle, an 11-year cycle of activity caused by the sun's magnetic field, takes place. During certain points in the solar cycle, occurrences such as sunspots (visibly cooler areas) and solar flares (sudden bursts and releases of energy) become more or less common.

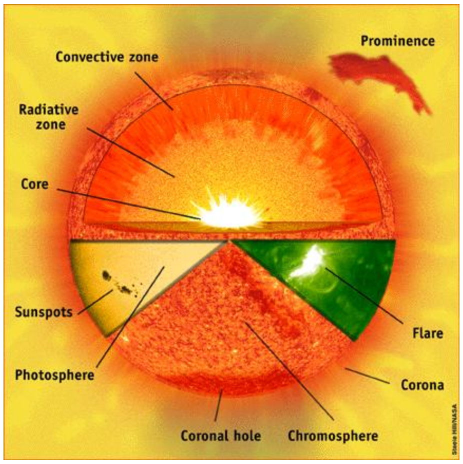


Figure 2: Cross-section diagram of the sun's layers and some of its features

Life of the star

There are many kinds of “life cycles” through which a star may go. Which kind of life cycle the star takes depends on its size.

Every star begins as a cloud of hydrogen and helium gas, called a nebula. An anomaly such as a supernova explosion causes this gas cloud to collapse, or draw into itself. As the nebula collapses, the speed of the gases increases until the nebula gives off light, at which time it is called a protostar. The particles of the protostar continue to increase in speed and heat until the nuclear fusion of hydrogen begins. At this time, the protostar becomes a fully-formed main sequence star. For billions of years, or about ninety percent of the star’s life, this nuclear fusion keeps the star powered. Eventually, however, the core runs out of hydrogen, which has all been converted to helium. When this happens, the star begins to collapse again, further increasing the temperature, until the “shell” of the radiative zone becomes hot enough to begin nuclear fusion. As this happens, the star begins to expand and gives off a red color, so that it is known as a red giant. Meanwhile, the helium core increases in temperature until it is hot enough to begin the nuclear fusion of helium (this requires a much higher temperature than the fusion of hydrogen). This stabilizes the star once again. Eventually, however, the helium runs out in the core, and the star begins to collapse once more. The radiative zone shell, now composed of helium, increases in temperature until it reaches the point of helium fusion. This causes the star to expand as a red giant again, and the core (now composed of elements like carbon and oxygen) is too heavy to reach a temperature capable of causing nuclear fusion. Eventually, the outer layers of the star expand so much that they are released from the core’s gravity and float off into space. The floating gases are known as a planetary nebula, and the core is known as a white dwarf (Marquard).

Nuclear Fusion and Power

There may be a way for humans to use artificially generated nuclear fusion for personal benefit in the future. Nuclear fusion, which gives off a very large amount of energy, could have some adaptations for producing electricity. Already, there are power plants that generate power through nuclear fission, the counterpart of nuclear fusion. In nuclear fission, very heavy atoms such as uranium are split into lighter ones. Nuclear fission, however, has some serious downsides; because the elements involved are so heavy, they are radioactive and can produce dangerous wastes. Deadly radioactive spills, in fact, are not completely unheard of in nuclear power plants. The use of nuclear fusion, however, could have many benefits over nuclear fission and other forms of generating electricity, such as burning fossil fuels. For example, because the atoms involved in fusion are hydrogen and helium, there is very little danger of problems with radioactivity. Because hydrogen is present in water, it would also be simple to use chemical reactions to isolate it for use in creating power. Also, nuclear fusion produces almost no waste products other than helium, so its use would cause clean, as well as effective, energy.

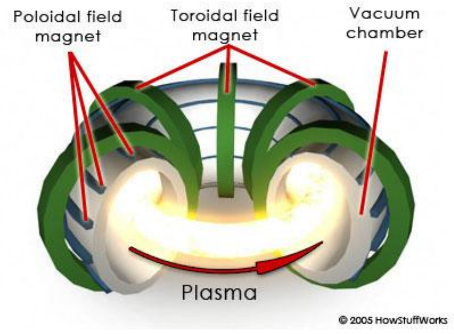


Figure 3: Diagram of a Tokamak, a type of nuclear fusion reactor

So why don't scientists use nuclear fusion for electricity now? The main problem with this almost ideal alternative is cost. With our current technology, it is incredibly difficult to create the intense heat and pressure necessary for hydrogen nuclei to fuse. It is therefore far too expensive to use nuclear fusion commercially as a power source, because much more money would be lost than gained through generating the power. Also, reactors for generating nuclear fusion are still being tested and reworked for improvement (see Figure 3). Anne Trafton of the Massachusetts Institute of Technology news office describes the current usage of one nuclear fusion reactor: "For about six months of the year, bursts of a hot, electrically charged gas, or plasma… [help] scientists learn more about a potential energy source… engineers make upgrades that will help them achieve their goal of making fusion a viable energy source." Meanwhile, it must be remembered that, even with all the benefits working nuclear fusion reactors will have, there will still be some drawbacks. There is still a small danger of nuclear radiation in these reactors, and the possibility of fires breaking out is clearly evident when temperatures must be high enough for hydrogen gas to become plasma. However, if the idea of nuclear fusion as a power source ever becomes a reality, it will certainly become an admirable resource.

Conclusion

Nuclear fusion plays a key role in the life of the sun and other stars. It is a force that helps hold stars together, and it generates the energy we see as light and feel as heat. Nuclear fusion is present throughout most of a star's life and takes place in its very core. In addition, manmade nuclear fusion may one day be used to generate abundant, clean power. Nuclear fusion is, indeed, the fuel of not only the stars, but of the energy required for life itself.

References

Beschizza, Rob. "Fusion Experiments Show Nuclear Power's Softer Side." Wired Magazine. Wired.com. 29 Mar. 2007. Wired. 11 Oct. 2007 <http://www.wired.com/science/discoveries/news/2007/03/fusion_0329>.

Freudenrich, Craig. "How Nuclear Fusion Reactors Work." Howstuffworks. 11 Oct. 2007 <http://science.howstuffworks.com/fusion-reactor1.htm>.

Freudenrich, Craig. "How Nuclear Fusion Reactors Work." Howstuffworks. 11 Oct. 2007 <http://science.howstuffworks.com/fusion-reactor2.htm>.

Marquard, Paul J. "The Life Cycle of a Sun-Like Star." Paul Marquard's Astronomy. 28 June 2001. NASA Space Grant College and Fellowship Program and the Wyoming Space Grant Planetary & Space Science Center, NASA. 1 Oct. 2007 <http://wind.caspercollege.edu/~marquard/astronomy/sunlike.htm>.

"Nuclear Fusion." Cartage.org. 7 Dec. 2007 <http://www.cartage.org.lb/en/themes/sciences/Chemistry/NuclearChemistry/NuclearReactions/NuclearFusion/NuclearFusion.htm>.

"Our Star the Sun." Solar and Heliospheric Observatory. 25 Sept. 2007. 1 Oct. 2007 <http://sohowww.nascom.nasa.gov/explore/sun101.html>.

Saunders, Nigel. "Atoms Everywhere!" Hydrogen. The Periodic Table. Chicago: Heinemann Library, 2004. 10-11.

Strobel, Nick. "The Sun's Power Source." Astronomy Notes. 24 May 2001. 8 Oct. 2007 <http://www.astronomynotes.com/starsun/s3/htm>.

Trafton, Anne. "Reactor Upgrades Help Researchers Study Nuclear Fusion as Energy Source." MIT - Massachusetts Institute of Technology. 15 Feb. 2007. 11 Oct. 2007 <http://web.mit.edu/newsoffice/2007/alcator.html>.

Picture References

Freudenrich, Craig. "How Nuclear Fusion Reactors Work." Howstuffworks. 11 Oct. 2007 <http://science.howstuffworks.com/fusion-reactor3.htm>.

"Our Star the Sun." Solar and Heliospheric Observatory. 25 Sept. 2007. 1 Oct. 2007 <http://sohowww.nascom.nasa.gov/explore/sun101.html>.

Šrubař, Martin. "Principles of Nuclear Fusion." Nuclear Fusion. 11 Oct. 2007 <http://fusion.srubar.net/principles-of-nuclear-fusion.html>.