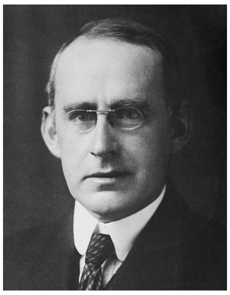
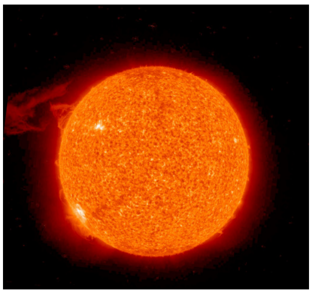
Sun – Part 14 - energy production 1


Arthur Eddington Solar energy George Gamow

Stars like the Sun are thermonuclear furnaces. The process of nucleosynthesis which occurs in stars creates new atomic nuclei (elements) from pre-existing nucleons by nuclear reactions. Apart from hydrogen and helium, which were created soon after the Big Bang, it is the means by which the natural abundances of chemical elements in stars are both created and vary due to nuclear fusion reactions in the cores and overlying stellar mantles.

The life cycle of stars is inextricably linked with changes in the relative abundances of their elements. Changes in nucleosynthetic processes initiate the stages which occur during the latter stages of a star's life. The younger Sun consists almost entirely of hydrogen (73%) and helium (24%) and it is the conversion of hydrogen to helium which is the primary energy source of the star for billions of years. Core fusion of lighter hydrogen to heavier helium increases the atomic weight of gaseous elements, causing pressure loss and contraction of the core, accompanied by temperature increases.

Later in their lives, in low-mass stars like the Sun, as temperatures increase progressively as the composition of the core evolves, the nuclear reactor will produce elements up to and including iron, elements which are released into the interstellar medium when the dying star ejects matter as its outer layers blow away. It is this stellar nucleosynthesis which is responsible for the galactic abundance of elements from carbon to iron and nickel (The elements heavier than these are released when larger stars die in extremely hot supernova explosions).

History of nucleosynthesis theory The goal of this theory is to explain the vastly differing abundances of chemical elements and their isotopes in the Universe. Those abundances, when plotted on a graph as a function of atomic number of elements, have a jagged sawtooth shape that varies by factors of tens of millions. This suggested a natural process other than random distribution. The first ideas were simply that chemical elements were created at the beginning of the Universe, but no rational physical scenario for this assumption could be identified. It gradually became clear that hydrogen and helium are much more abundant than any other elements. In fact, all the rest form less than 2% of the mass in the cosmos. In addition, it was found that oxygen and carbon were the next two most common elements. Also, there was a general trend towards high abundances of the light elements, esp those composed of whole numbers of helium-4 nuclei.

The predominance of hydrogen and helium in the Universe, and stars like the Sun is a result of events which occurred within three minutes of the beginning of the Universe. Although helium continues to be produced by stellar fusion and alpha decays, and trace amounts of hydrogen continue to be produced by spallation (the process which reduces the atomic weight of interstellar mater by impact with cosmic rays, to produce some of the lightest elements present in the Universe) and certain types of radioactive decay, most of the hydrogen and helium in the Universe is accepted to have been produced by the Big Bang via so-called Big Bang nucleosynthesis, Because only about twenty minutes passed before this process was stopped by expansion and cooling, no elements heavier than beryllium, or possibly boron, could be formed. Elements formed in this time were in the plasma state and did not cool to the state of neutral atoms until much later.

Another stimulus to the development of a coherent nucleosynthesis theory was development was realisation that the energy released from nuclear fusion reactions accounts for the longevity of the Sun as a source of heat and light. It was also realised that the process of fusion of nuclei in a star, starting from its initial hydrogen and helium abundance, also synthesises new nuclei as a by-product of that fusion process. Furthermore, fusion product nuclei are restricted to those only slightly heavier that the fusing nuclei, meaning that they do not contribute heavily to the natural abundances of the heavier elements.

It was the English astrophysicist Arthur Eddington who, in 1920, on basis of Aston's precise measurements of atomic masses, proposed that stars obtain their energy through nuclear fusion of hydrogen into helium. He also raised the possibility that the heavier elements may also form in stars, but his ideas were not generally accepted, as the nuclear mechanism was unknown.

In the 1920s, the Russian-American George Gamow applied his early training in nuclear physics to astrophysics. In 1928, he derived the Gamow factor, a quantum-mechanical formula that gave the probability of bringing two nuclei sufficiently close for the strong nuclear force to overcome the Coulomb barrier. He and other scientists used this factor to derive the rate at which nuclear reactions should proceed a the high temperatures s believed to exist inside stars.

Sources: Ridpath, I (Ed) (2012) Oxford dictionary of astronomy 2nd ed rev, Singh, S (2004) Big Bang, www.en.wikipedia.org