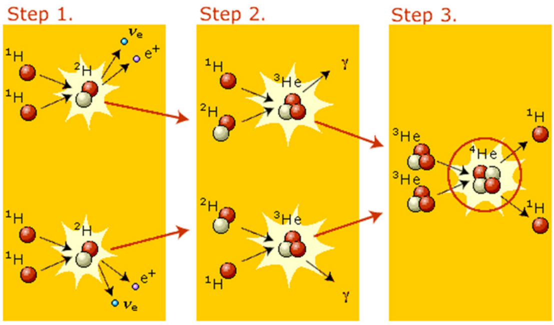
Sun – Part 15 - energy production 2

Fred Hoyle



Proton-proton chain reaction

Hans Bethe

A decade after Gamow's work, in 1938, Hans Bethe, a German-American physicist, published an analysis of different possibilities for reactions by which hydrogen is fused into helium. In it, he described the first of two processes proposed to be the source of energy in stars. What he and his colleague Charles Critchfield derived was the proton-proton chain reaction, the dominant energy source in stars with low masses up to about a solar mass. A year later, he independently developed the carbon-nitrogen-oxygen (CNO) cycle, positing that, in larger, hotter stars, this was the means by which hydrogen was converted to helium, with the associated release of large amounts of energy. These two nuclear reaction routes were, at first, speculative, but other physicists checked the equations and confirmed that they were viable. Bethe was awarded the Nobel prize for physics in 1967 for his work on stellar nucleosynthesis.

Bethe did not address creation of heavier nuclei. The original work on this was undertaken by the English astrophysicist Fred Hoyle. In 1946, he argued that a collection of very hot nuclei would assemble into iron. He explained the production of all heavier elements, starting from hydrogen in 1954, describing how advanced fusion stages within stars would synthesise elements between carbon and iron in mass. As part of his work, he proposed that hydrogen is continuously created in the Universe from vacuum and energy without need for a universal beginning. Hoyle derided the Big Bang theory and Big Bang nucleosynthesis, not realising that Lemaitre's Big Bang model was needed to explain the existence of deuterium and nuclides between helium and carbon, as well as the fundamentally high amount of helium present both in stars and the interstellar medium.

The first proof that nucleosynthesis occurs in stars was observations that interstellar gas has become enriched with heavy elements as time has passed. Stars born later in the Milky Way formed with much higher initial heavy element abundances than those which formed earlier. It was the 1952 detection by spectroscopy of the element technetium in the atmosphere of a red giant star which provided first direct evidence of nuclear activity within stars. Because technetium is radioactive, with a half life much less than the age of the star, its abundance must reflect its recent creation within the star.

In 1957, a review paper by Eleanor and Ronald Burbridge, William Fowler and Hoyle (B2FH) collected and refined earlier research into processes for transformation of one heavy nucleus into others within stars. It gave promise of accounting for the observed relative abundances of the elements, but did not enlarge on Hoyle's 1954 picture for the origin of primary nuclei as much as was often assumed, except in the understanding of nucleosynthesis of those elements heavier than iron. Empiric evidence for the processes described by Bethe and Hoyle could be, and was, documented by astronomers. During the

1960s, Fowler, Alastair Cameron and Donald Clayton expanded Hoyle's explanations, followed by many others.

Processes The prime energy producer in the Sun is fusion of hydrogen to form helium in the core at temperatures around 14 million K. Later in the star's life, fusion reactions will also move into the shells surrounding the core. The initial reaction involved in the chain reactions involved in nuclear fusion is hydrogen burning. It occurs via the proton-proton (p-p) chain or the CNO cycle. Processes following hydrogen burning are helium burning (via the triple-alpha process), carbon burning, neon burning, oxygen burning and silicon burning. These processes are able to create elements up to and including iron and nickel.

In smaller stars with core temperatures under 18 million K, the p-p chain reaction dominates. Essentially, the process involves fusion of four hydrogen protons into a helium-4 nucleus. This occurs through a sequence of chain reactions that begins with fusion of two hydrogen atom (protons) to form a nucleus of deuterium. Isotopes of lithium, beryllium and boron are also produced during the intermediate stages.

The subsequent process of deuterium burning consumes any pre-existing deuterium found at the core. Energy is released at different stages of the p-p chain process. The process is relatively insensitive to temperature, so the hydrogen burning process can occur in up to a third of the star's radius and occupy half its mass.

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