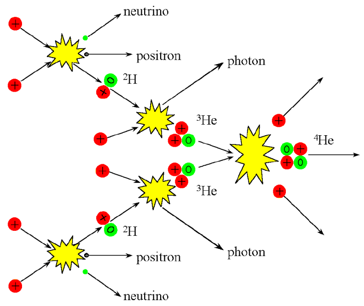
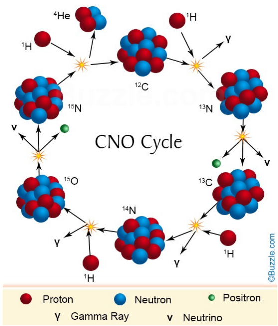
Sun – Part 16 - energy production 3



Proton-proton chain reaction



Carbon-nitrogen-oxygen (CNO) reaction

The carbon-nitrogen-oxygen (CNO) cycle dominates in higher mass stars and in the later life of smaller stars like the Sun as their core temperature rises. It is a 6- stage catalytic cycle that uses the nuclei of carbon, nitrogen, and oxygen as intermediaries to produce a helium nucleus. Unit energy production is slightly lower than that of the proton-pproton (p-p) chain reaction, this difference in energy being accounted for by energy lost through neutrino emission.

The CNO cycle is very sensitive to temperature, so is strongly concentrated at the core. About 90% of the cycle's energy generation occurs within inner 15% of the star's mass. This results in an intense outward energy flux that cannot be sustained by radiative transfer, as is the case in the p-p chain. As a result, the core becomes a convective zone which stirs the hydrogen burning regions, keeping it well mixed with the surrounding proton-rich region. This core convection occurs in stars when CNO cycle contributes more than 20% of the total energy. As the star ages and the core temperature increases, the region occupied by convection zone slowly shrinks from 20% of mass down to the inner 8% of mass.

The type of hydrogen burning that dominates inside a star is determined by temperature dependency differences between the two reactions. The p-p chain reaction starts at temperatures around 14 million K, making it the dominant mechanism in smaller stars, like the Sun. A self-maintaining CNO cycle requires a higher temperature of approximately 15 million K, but, thereafter, it increases more rapidly in efficiency than the p-p chain as the temperature increases. Above approx 17 million K, the CNO cycle becomes the dominant source of energy. This temperature is achieved in cores of main-sequence stars with at least 1.3 times the Sun's mass.

The Sun has a core temperature of around 15 million K and only 0.8% of energy produced in it is from CNO cycle. As a main-sequence star, like the Sun, ages, its core temperature rises, resulting in steadily increasing contribution from its CNO cycle.

Once a star with about 0.5-10 times the Sun's mass has consumed nearly all the hydrogen at its core, it begins to experience helium burning and evolve up the red giant branch of its life cycle. Helium burning occurs in a shell surrounding an inert helium core until the steadily increasing core temp exceeds a billion K. At this point, helium burning begins with a thermal runaway process, the helium flash, with hydrogen burning continuing in a thin shell surrounding the now active helium core.

Once the Sun reaches the red giant stage is will be producing energy via the triple-alpha process whereby three helium nuclei are fused to form carbon. It is also known as the

Salpeter process, for the American astrophysicist Edwin Salpeter. This process requires temperatures of at least 100 million K. It operates in stars only larger than about 0.4 solar masses and only when all the hydrogen has been converted into helium.

Carbon creation is important because its formation form helium is a bottleneck in the entire process. It is produced by the triple-alpha process in all stars. Its formation is the key to production of heavier elements in stars. In very large stars, it is the main element causing release of free neutrons which, give rise to the s-process in which the slow absorption of neutrons converts iron into elements heaver than iron or nickel. In lower mas stars, like the Sun, nucleosynthesis is able to produce elements up to and including iron and nickel, but not any heavier elements.

The products of stellar nucleosynthesis are generally dispersed into the interstellar gas through mass loss episodes and the stellar winds of low mass stars. Stars lose most of their mass when it is ejected later in their stellar lifetimes. Mass loss events occur in the planetary nebula phase of low-mass star evolution like that of the Sun, and the explosive ending of stars more than eight solar masses as supernovas. These processes increase the abundance of elements heavier than in the interstellar medium

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