Controlled Thermo-nuclear Fusion

What Is Nuclear Fusion , What Makes It Happen ?

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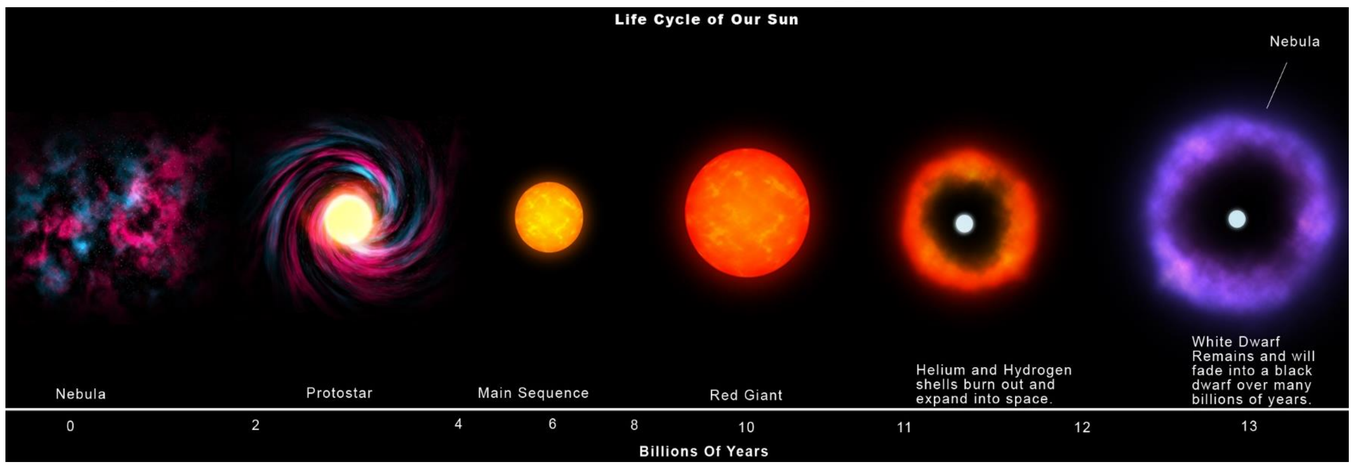
The life cycle of stars helps explaining the process of Nuclear fusion: How does it happen, what makes it possible and why it is tough to replicate on earth !

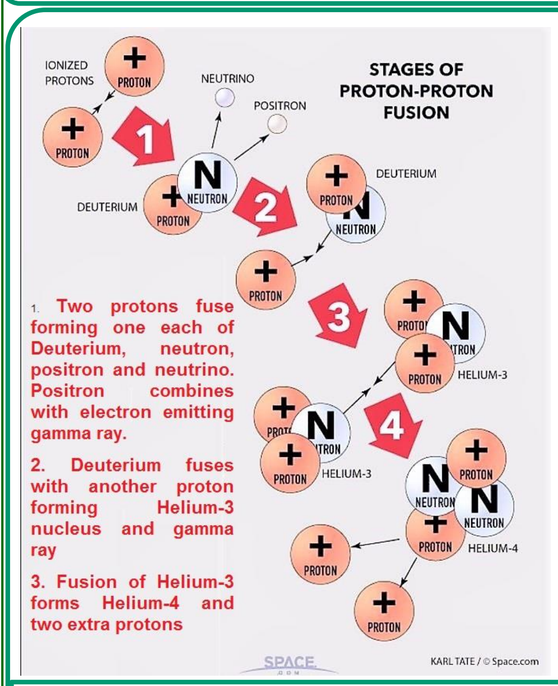
1.The process starts with the collapse of giant clouds of gas and dust (Nebula) **under the influence of massive gravity**. Friction while on their movement towards the centre make them hot and glow forming the **Protostar**.



4. Fusion stops at core once Hydrogen is finished and the gravity crushes it further. Tremendous temperature and pressure **fuses helium into carbon**. Fusion continues in the shell and photosphere expands. Star turns to **Red Giants**, where **Helium-Helium Fusion** (AGB STAGE) and become a White Dwarf and ultimately die as a Black Dwarf.

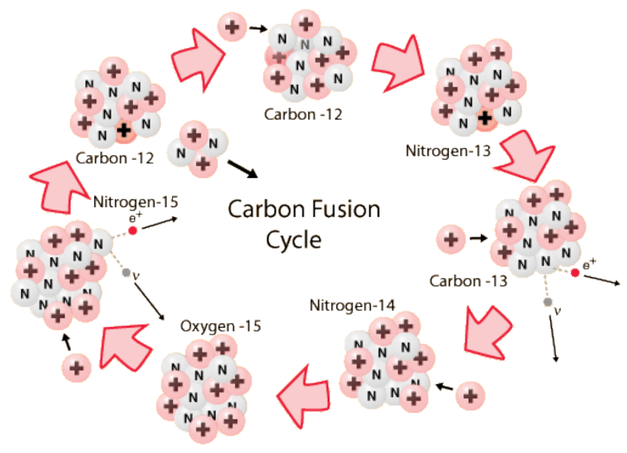
2. The star is born when further **squeezing of this red hot mix so tightly that the temperature and pressure rise to such extreme levels that the proton to proton repulsion is overcome** igniting the thermonuclear **fusion of hydrogen atoms** into helium generating light/gamma rays.

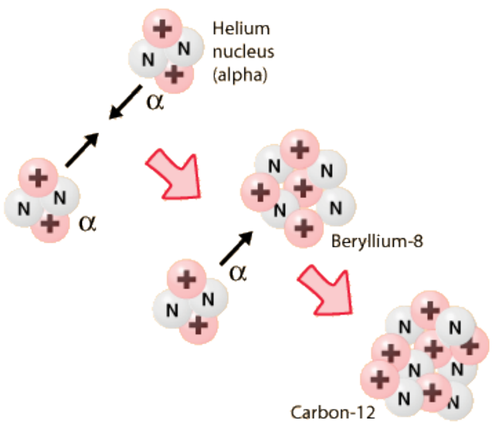
3. The extremely high outward pressure due to nuclear fusion is balanced by the enormous pressure of gravity and the star remains in a steady state called **Hydrostatic equilibrium.**



Proton Proton nuclear fusion is the process that fuels the Sun and other stars which have core temperatures **below 15 million Kelvin yielding about about 25 MeV** of energy per cycle. The gamma ray takes millions of years to come out of the sun from the inner core while the neutrino takes only 2 seconds. **Quantum tunnelling**, the process where particle tunnels through a potential barrier which it cannot overcome in classical concept, plays an important role in nuclear fusion in PP fusion in stars.

The Stars like Sirius , which is twice the mass of sun and temperature greater than 15 million Kelvin , are powered by **Carbon Cycle** which yields 26.72 Mev per every helium nucleus.

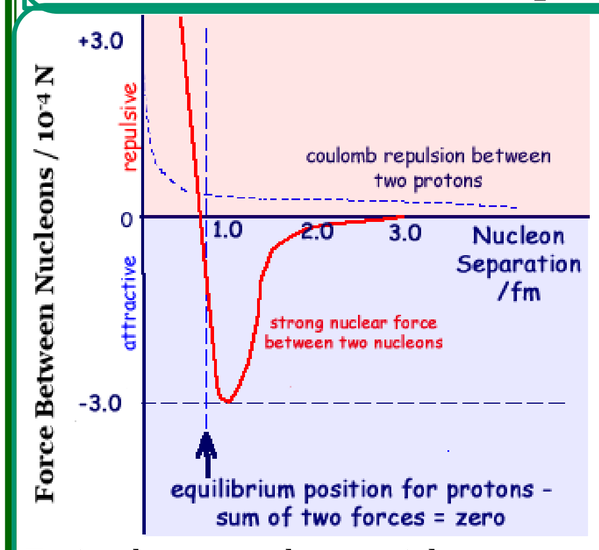




Helium Helium fusion forming beryllium and then Carbon happens when temperature exceeds 100 m k and is the process in the last phase of life cycle in star as red supergiant.

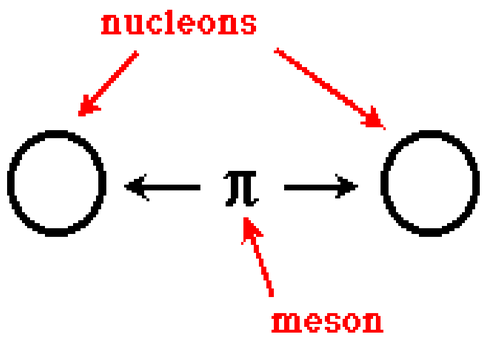
Sun, *330000 times heavier than the earth with mostly hydrogen and helium with core temperature at 15 Million °C , is the primary source of energy for everything on earth since 4 billion years and expected to do so for as many billion years to come. It consumes 620 million metric tons of hydrogen every second to forming Helium.*

Is it possible to achieve the conditions required to replicate this fusion process on earth ?



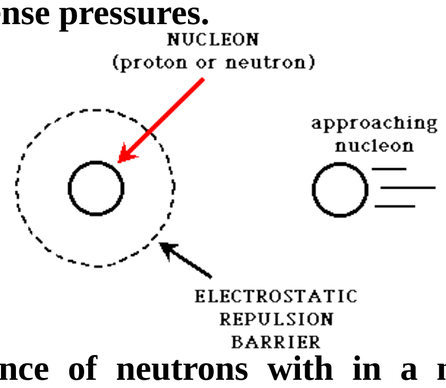
Fusion happens when particles **overcome the electrostatic repulsion** to come close enough so that attractive nuclear strong force take over and fuse it.

The short range Nuclear Strong Force is derived from **Binding Energy**; the energy released when nucleus is assembled **(fusion)** from the nucleons or when they are pulled apart **(Fission).** This energy which is held within the bonds of the atoms is given by $\mathbf{E = \Delta mc^2}$ where **m** is mass difference in the mass of the protons of the nucleus of an atom from the total mass of its constituents.

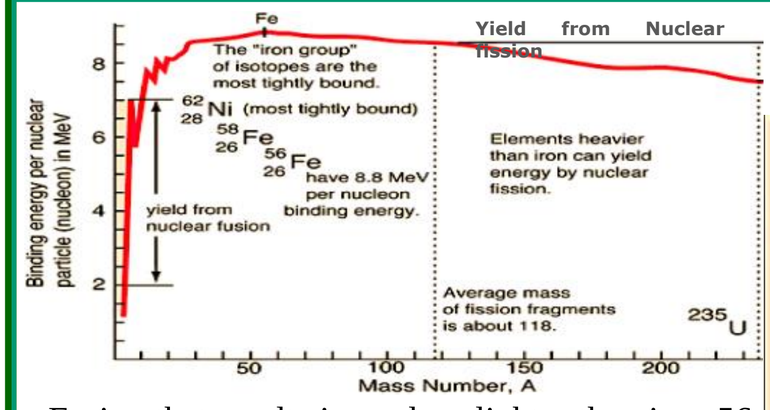


The **exchange of particles called mesons between nucleons**, which happens when extremely close in the order of a size of a proton, is the source of Strong Nuclear Force and as long as it happens the nucleus remains intact.

In order to get 2 protons/nuclei close enough for the meson exchange to happen they **must be moving extremely fast and it happens at sufficiently high temperature and or under immense pressures.**

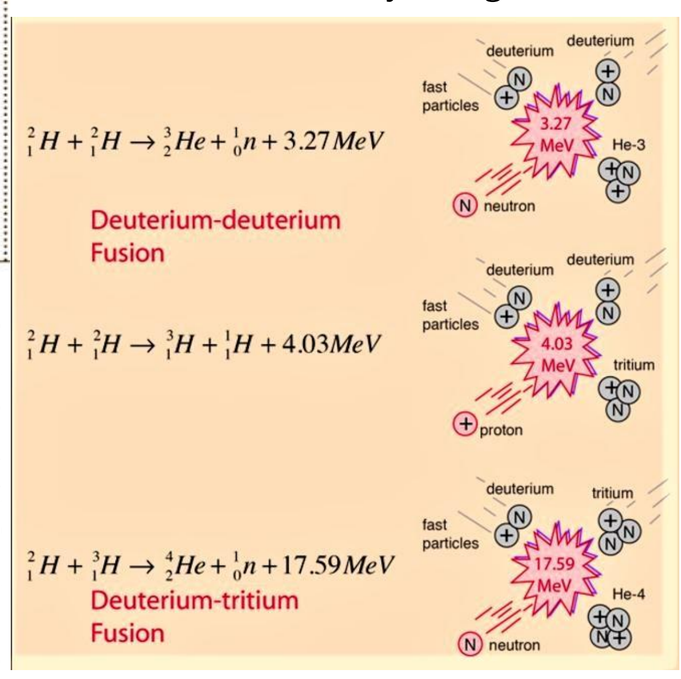


The **presence of neutrons with in a nucleus helps** reduce the repulsion between protons as they keep protons sufficient apart so that they do not face strong repulsion to move far apart. They are also source more binding force as they participate in meson exchange

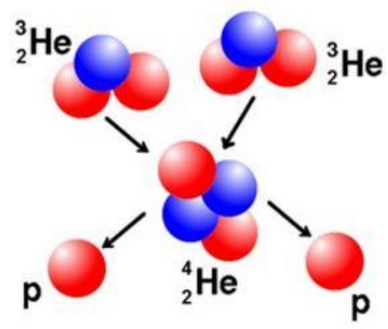


Fusion that results in nucleus lighter than iron-56 or Nickel -62, which have **smallest mass and largest binding energy per nucleon,** are exothermic and releases energy. Heavier than these are endothermic processes. The case is just opposite in the case of fission . Thus **lighter elements like hydrogen and helium are in general fusible** while heavier elements, ones like uranium and plutonium are more fissionable releasing energy.

The conditions where the fuel remains at **extreme temperatures under intense pressure /density confined sufficiently enough time** to sustain fusion as in stars are impossible to recreate on earth .



The **most feasible process under available technologies** is between the isotopes of hydrogen: Deuterium (D) and tritium (T). The D-T reaction event releases 17.6 MeV energy which, on mass basis, is four times of that of Uranium Fusion. The D-D fusion, which require higher temperature, is another hope for future reaction generating 3-4 Mev and also Tritium



Helium-3 fusion is the brightest but futuristic vision on fusion on earth. No neutron is produced and so no radiation . The protons generated are easily containable and energy extractable directly as electricity. Though H-3 is non-existent on earth it is abundant in Moon.

*Ever Since **Prof. Hans Bethe**, in 1937, revealed in detail the nuclear fusion as the secret behind the star power, the controlled version of has been in hottest pursuit and vast amount theoretical and technical advancement have been done towards making it practical. The improvement in reaching the **Lawson Criterion** so far through numerous experiments is more than 100,000 times in the last 30 years and that confirms the gaol of making it real and a common practices not so far in future !*

Illustrations owed to Internet websites and readily available on image search with related keywords

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