PHYC10008 NOTES

Lecture 19: The Sun

How Fusion Start

Nuclear fusion requires extremely high temperatures and densities.

In the Sun, these conditions are found deep in the core.

But how did the Sun become hot enough for fusion to begin in the first place?

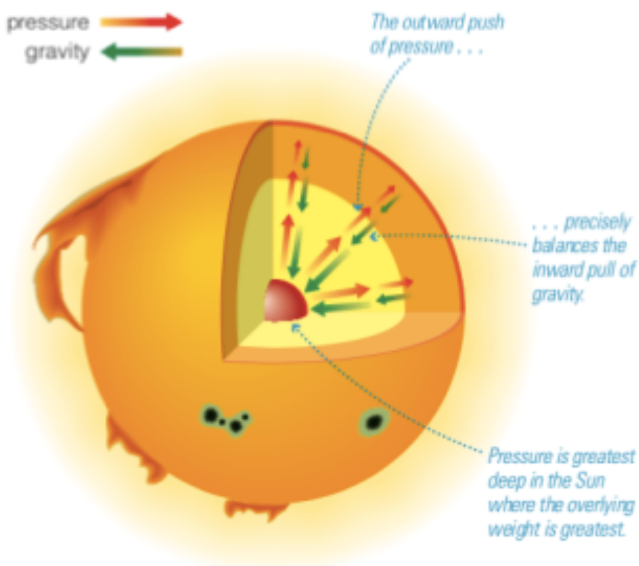
The answer invokes the mechanism of gravitational contraction.

- Recall that our Sun was born about 4.5 billion years ago from a collapsing cloud of interstellar gas.
- The contraction of the cloud released gravitational potential energy, raising the interior temperature and pressure.
- This process continued until the core finally became hot enough to sustain nuclear fusion, because only then did the Sun produce enough energy to give it the stability that it has today.

The Stable Sun

Sun continues to shine steadily today because it has achieved a balance that keep its size and energy output stable.

- The balance, called gravitational equilibrium, is between the outward push of internal gas pressure and the inward pull of gravity.
- Deep in the Sun's core, the pressure makes the gas hot and dense enough to sustain nuclear fusion. The energy released by fusion, in turn, heats the gas and maintains the pressure that keeps the Sun in balance against the inward pull of gravity.



The Sun's Atmosphere

The Sun consists of 3 main atmospheres:

The outermost layer of this atmosphere, is called the corona, which extends several million kilometres above the visible surface of the Sun.

- The temperature of the corona is astonishingly high, about 1 million K explaining why this region emits most of the Sun's X rays.

Nearer the surface, the temperature suddenly drops to about 10,000 K in the chromosphere, the middle layer of the solar atmosphere and the region that radiates most of the Sun's ultraviolet light.

The lowest layer of the atmosphere, photosphere, is the visible surface of the Sun.

- Although the photosphere looks like a well-defined surface from Earth, it consists of gas far less dense than Earth's atmosphere. The temperature of the photosphere averages just under 6000 K.
- The photosphere is also where you'll find sunspots, regions of intense magnetic fields.

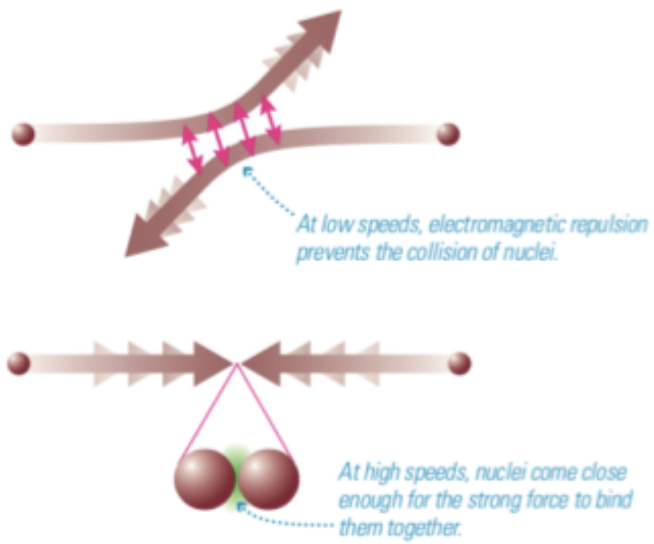
Heliosphere: Extension of solar wind.

Nuclear Fusion in the Sun

Fusion occurs within the Sun because the 15 million K plasma in the solar core is like a "soup" of hot gas full of bare, positively charged atomic nuclei (and negatively charged electrons) whizzing about at extremely high speeds.

At any one time, some of these nuclei are on high- speed collision courses with each other.

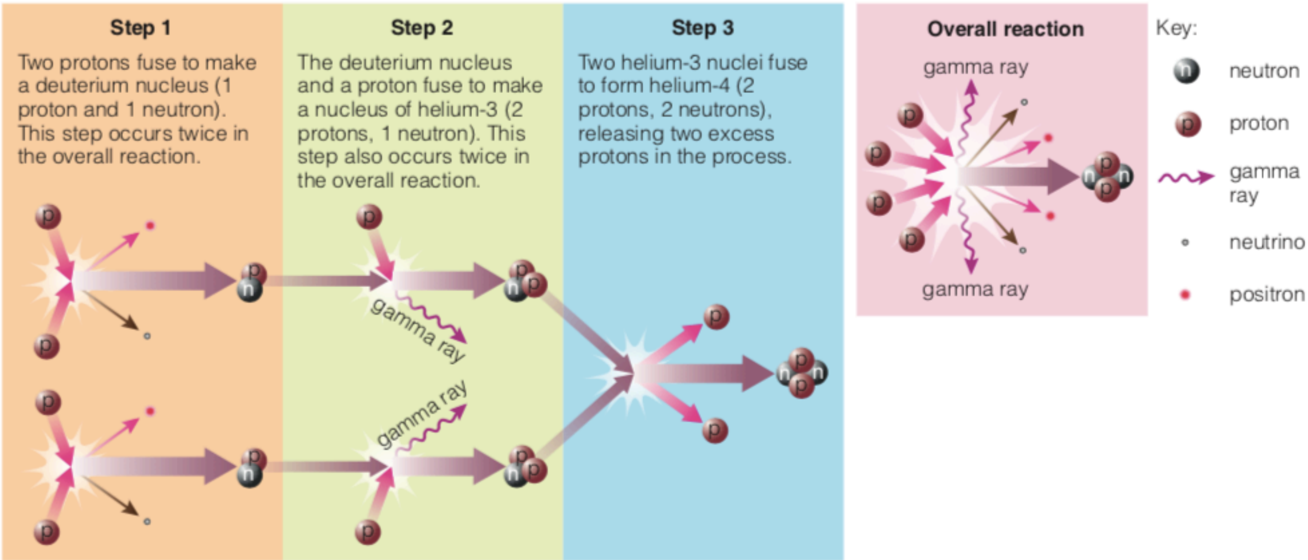
In most cases, electromagnetic forces deflect the nuclei, preventing collisions, because positive charges repel one another. However, if nuclei collide with sufficient energy (speed), they can fuse together to form a heavier nucleus.



The Proton-Proton Chain

Recall that hydrogen nuclei are simply individual protons, while the most common form of helium consists of two protons and two neutrons

The overall hydrogen fusion reaction therefore transforms four individual protons into a helium nucleus containing two protons and two neutrons:



Notice that a total of six protons enter the reaction during Steps 1 and 2, with two coming back out in Step 3.

The overall reaction therefore combines four protons to make one helium nucleus.

- The gamma rays and subatomic particles (neutrinos and positrons) carry off the energy released in the reaction.

Fusion of hydrogen into helium generates energy because a helium nucleus has a mass slightly less (by about 0.7%) than the combined mass of four hydrogen nuclei.

- That is, when four hydrogen nuclei fuse into a helium nucleus, a little bit of mass disappears. The disappearing mass becomes energy.

The Solar Thermostat

If the Sun's core temperature rose very slightly, It would cause the fusion rate to soar as protons in the core collided more frequently and with more energy.

Because energy moves slowly through the Sun's interior, this extra energy would be bottled up in the core, temporarily forcing the Sun out of energy balance and raising the core pressure.

The push of this pressure would temporarily exceed the pull of gravity, causing the core to expand and cool.

This cooling, would cause the fusion rate to drop back down until the core returned to its original size and temperature, restoring both gravitational equilibrium and energy balance.