The interior of the Sun

Space Physics - Project

by

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October 17, 2006

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1 Introduction

Before 5 billion years the sun was formed out of a contractive cloud of matter. The main matter was Hydrogen. With increasing pressure and density the temperature in the core was increasing. That caused to the start of fusion reaction at 15 million Kelvin in the sun. The Hydrogen firing starts and the sun begins to glow.

The important mechanism of fusion is the Proton-Proton-Cycle (chapter 2.6.1), where 4 Hydrogen ions fuse to a Helium core.

$$4^1H \rightarrow^4 He + 2e^+ + 2\nu + 26.2\,MeV$$

In the following chapters I will describe the structure of the interior of the sun (chapter 2) and how the energy is generate.

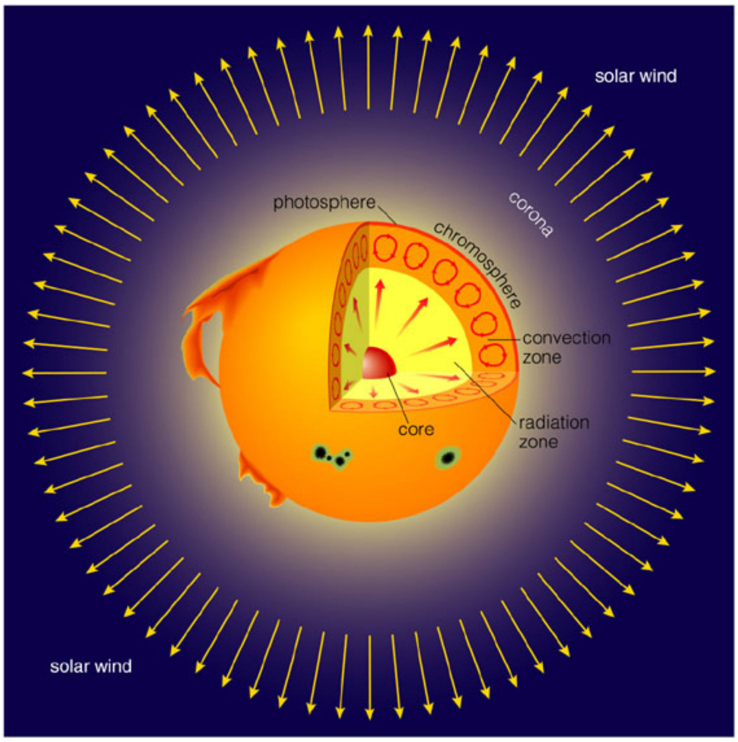

Figure 1: The structure of the sun [7]

2 The Structure of the Sun

The sun and its atmosphere consists of several zones or layers. Describing from the outside to the interior the sun's atmosphere is made up of the corona, the chromosphere, and the photosphere. The interior of the sun consists of the convection zone, the radiative zone, and the core.

2.1 The Corona

The Corona is the part of the sun's atmosphere whose average temperature is greater than 500,000 K. The temperature rises from the sun's surface in about 3000 km to 10^6 K. The corona is hotter than the next two interior layers. It is assumed that the high temperature is caused by the magnetic filed of the sun and not by radiation.
The Corona is visible during a total eclipse. It emits most of its radiation in UV and X-ray wavelength because of the ionized gas due to the high temperature.

2.2 The Chromosphere

Astronomers first detected the chromosphere's spectrum during total eclipses of the sun. The spectrum is visible after the moon covers the photosphere, but before it covers the chromosphere. This period lasts only a few seconds. The emission lines in the spectrum seem to flash suddenly into visibility (red hydrogen line), so the spectrum is known as the flash spectrum.
The chromosphere is about 2500 km thick and across the layer the density decreases from $10^{-5}\,\frac{kg}{m^3}$ to $10^{-10}\,\frac{kg}{m^3}$ while the particle temperature increases from 4300 K to 40000 K. In the upper part the magnetic force dominate the particle pressure forces.

2.3 The Photosphere

The photosphere is the visible surface of the sun and the lowest layer of the atmosphere. It is a thin layer of about 500 km and emits the light that we see. Hence the sun becomes opaque to visible light. The temperature is about 4400 K to 6400 K on the top. It's spectrum is approximately that of a black body at 5800 K. The interaction of free electrons in that layer form the continuous spectrum of light.

2.4 The Convection Zone

The area outside $0.8\,R_\odot$ to $1.0\,R_\odot$ is called the convection zone. This zone consists of the boiling convection cells. Hot gas, heated at the bottom of the convection zone, is rising and cooler gas is falling down in cause of being cooled at the solar surface. It makes up about 66 percent of the sun's volume but only slightly more than 2 percent of its mass. At the top of the zone, the density is near zero, and the temperature is about $5800K$. At the bottom the temperature is about $2 \cdot 10^6\,K$.
Astronomers have observed two main kinds of convection cells, granulation and super granulation. Granulation cells are about 1000 kilometers across. Super granulation cells reach a diameter of about 30000 kilometers.
The energy transport through this layer takes places via convetction.

2.5 The Radiative Zone

Surrounding the core, between $0.25\,R_.$ and $0.8\,R_.$, is a huge shell known as the radiation zone. The energy produced in the sun's core is transported by photons in that zone. Generally by radiation, that's the fact of theirs name. The radiation zone makes up 32 percent of the sun's volume and 48 percent of it's mass. The scattering rate is so high that it takes million of years for a photon to pass through the zone. At the bottom of the zone the density is $22\,\frac{g}{m^3}$, about twice that of lead, and the temperature is about 8 million K. At the top, the density is $0.2\,\frac{g}{m^3}$ and the temperature is 2 million K. The composition of the radiative zone has remained much the same since the sun's birth. The percentages of the elements are nearly the same from the top of the radiative zone to the solar surface.

2.6 The Core

The core extends from the center of the sun about one-fourth of the way to the surface. The core has about 2 percent of the sun's volume, but it contains almost half the sun's mass. The temperature is about 15 million K and its density reaches $1.6 \cdot 10^5\,\frac{kg}{m^3}$, 15 times the density of lead.
The sun gets the energy by fusion. Each second about $5.7 \cdot 10^{11} kg$ of hydrogen is converted to helium, with a mass loss of $4.3 \cdot 10^9\,kg$. The energy which is produced is about $3.86 \cdot 10^{26}\,W$.
Almost all the fusion in the sun takes place in the core. Like the rest of the sun, the core's initial composition, by mass, was 72 percent hydrogen, 26 percent helium, and 2 percent heavier elements. Nuclear fusion has gradually changed the core's contents. Hydrogen now makes up about 35 percent of

the mass in the center of the core and 65 percent at its outer boundary.
The two main processes of fusion are the pp - chain, and the CNO - cycle. In the first, the energy is created by fusion of four protons and in the second the energy comes from the interaction of four protons with help of catalysts (Carbon, Nitrogen, Oxygen).

2.6.1 pp - Chain

The pp - chain takes about 99 percent of the fusion in the sun. Four protons were fused to a helium core by sending out 2 positrons, 2 neutrinos and 2 γ-rays. The two positrons will also produce energy in the form of γ-rays after being annihilated by electrons. The total energy released in the formation of a helium nucleus is then 26.7 MeV. But some energy is take away by the neutrinos. The pp - chain needs a temperature of $5 \cdot 10^6$ K to $15 \cdot 10^6$ K.

$$^1_1p +^1_1 p +^1_1 p +^1_1 p \rightarrow^4_2 He^{2+} + 2e^+ + 2\nu_e + 2\gamma$$

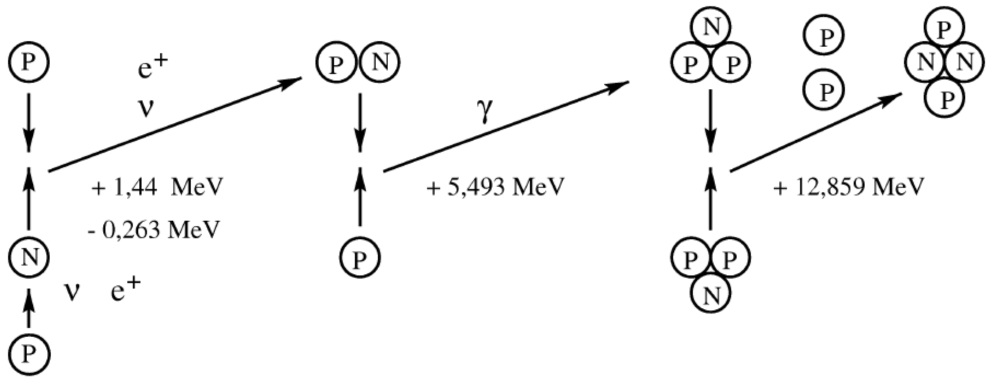

Figure 2: The pp Chain [6]

2.6.2 CNO - Cycle

The CNO - cycle, or Bethe Bloch Cycle, is involved in energy generation in the sun by only 1 percent. Four protons were fused to a helium nucleus by sending out 2 positrons and 2 neutrinos requiring a catalyst. In figure 3 the cycle of energy creation is shown. The generated energy is about 25 MeV. Thy CNO cycle needs a temperature of about 15 to $50 \cdot 10^6$ K.

$$^{12}C(p, \gamma) \rightarrow^{13} N(e^+, \nu) \rightarrow^{13} C(p, \gamma) \rightarrow^{14} N(p, \gamma) \rightarrow^{15} O(e^+, \nu) \rightarrow^{15} N(p, \alpha) \rightarrow^{12} C$$

$$4(^1H^+) \rightarrow ^4He + 3\gamma + 2e^+ + 2\nu_e + 25.03\,MeV$$

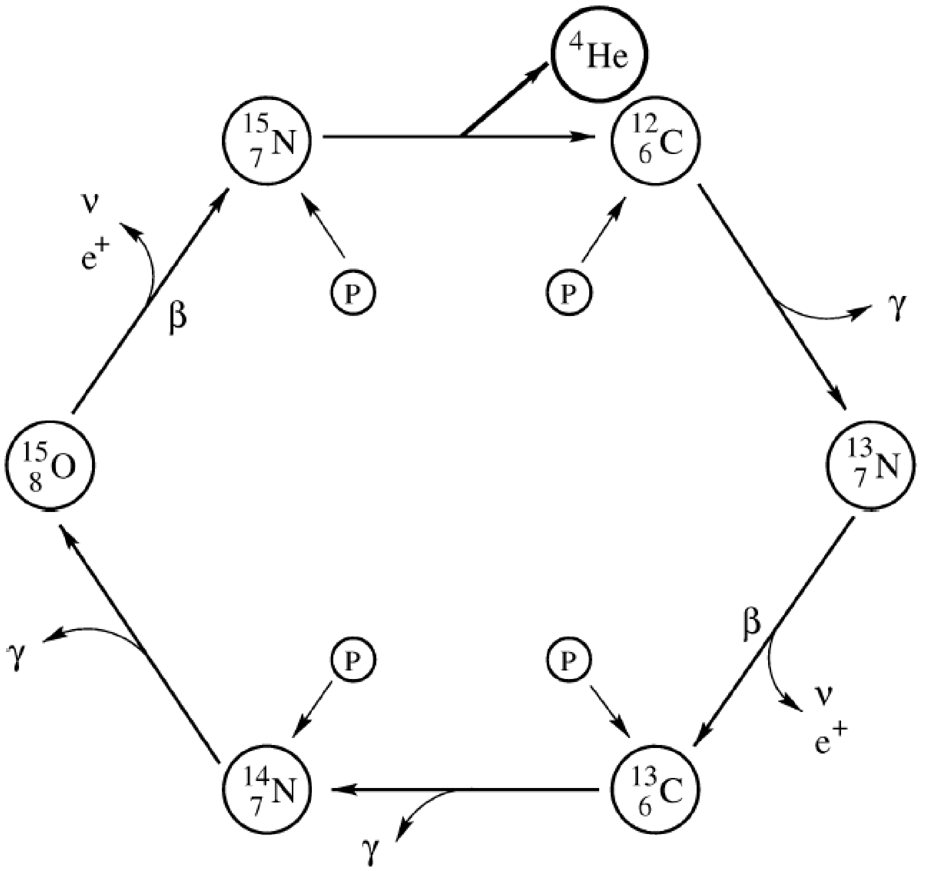

Figure 3: The CNO Cycle [6]

3 Conclusion

The sun is the main cause of all life on earth. In about 5 billion years the sun will run out of Hydrogen and will be transformed into a red star. Than the sun will expand and assimilate Mercury and Venus. After this the sun will blow the outer strata away and a white dwarf will be left.

Hydrogen	73.46 %
Helium	24.85 %
Oxygen	0.77 %
Carbon	0.29 %
Iron	0.16 %
Neon	0.12 %
Nitrogen	0.09 %
Silicon	0.07 %
Magnesium	0.05 %
Sulphur	0.04 %

Table 1: Photo spheric composition of the sun (by mass) [3]

Mean diameter	$1.392 \cdot 10^6\,km$ (109 Earth diameters)
Circumference	$4.373 \cdot 10^6\,km$ (342 Earth diameters)
Surface area	$6.09 \cdot 10^{12}\,km^2$ (11,900 Earths)
Volume	$1.41 \cdot 10^{18}\,km^3$ (1,300,000 Earths)
Mass	$1.988435 \cdot 10^{30}\,kg$ (332,946 Earths)
Density	$1.408\,g/cm^3$
Surface gravity	$273.95\,ms^{-2}$ (27.9 g)
Escape velocity from the surface	$617.54\,km/s$ (55 Earths)
Surface temperature	$5785\,K$
Temperature of corona	$5\,MK$
Core temperature	$\approx 13.6\,MK$
Luminosity	$3.8 \cdot 10^{26}$ watts

Table 2: Physical characteristics of the sun [3]

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