

## The Sun: Our Star (Chapter 14)

The source of the Sun's energy has long been a mystery, especially since the great distance between Earth and the Sun was first measured. Geologists argued that Earth's geology needed 100s of millions of years to form, and physicists argued that no energy source could make the Sun shine for that long. The solution was the discovery of  $E=mc^2$  and nuclear reactions.

The Sun's mass is 300,000x Earth's and its radius is 100x Earth's. It rotates every 25 days at the equator and every 30 days at the poles. It is 70% hydrogen, 28% helium, and only 2% of everything else. The solar wind is a stream of protons and electrons blowing continuously away from the Sun. The outermost atmospheric layer, the corona, is 1 million K and is the source of solar X-rays. The intermediate atmospheric layer, the chromosphere, is 10,000 K and is the source of solar UV light. The photosphere, the lowest atmospheric layer, is the visible surface of the Sun. It is 5800 K, marked with sunspots, and vigorously convecting. Below the photosphere is the convection zone, where energy is transported upwards by rising and falling regions of hot and cold plasma. It is above the radiation zone, where energy is transported upwards by X-ray photons that scatter off protons and electrons. The temperature is 2 million K at the top of the radiation zone and 10 million K at the bottom. The core has a temperature of 15 million K and a pressure 200 billion times that at Earth's surface. Hydrogen fuses into helium in the core, releasing energy that takes 100,000 years to reach the Sun's surface.

At the high temperatures and pressure in the Sun's core, protons can come close enough together that the strong nuclear force can overcome their electrical repulsion. Two protons become a joined proton and neutron, called a deuterium nucleus, a positron, and a neutrino. The positron finds an electron and the two annihilate each other into pure energy. Similar processes occur until four protons have turned into two protons and two neutrons, which make a helium nucleus, two positrons, some neutrinos, and some gamma rays. This sequence releases a lot of energy. The rate of energy production inside the core is kept constant by a "thermostat" that increases the rate if it decreases too much and decreases the rate if it increases too much. Energy generated by nuclear fusion keeps the pressure within the Sun high. This supports the weight of the Sun.

It takes 100,000 years for energy to move out through the radiation zone, despite being transported at the speed of light by photons, because the photons continually scatter from electrons in the radiation zone, changing their direction. As you move upwards to the convection zone, the temperature drops, and photons are absorbed, not scattered. Plasma that absorbs photons is heated and rises upwards. When it reaches the photosphere, the plasma's thermal radiation can escape from the Sun, cooling the plasma which falls back down again.

Sunspots are cool regions on the Sun's photosphere where the magnetic field is strong. Energy stored in loops of magnetic field can be suddenly released in a surge of X-rays, a flare, that can also eject blobs of plasma (coronal mass ejections) from the Sun. Sunspots and the Sun's magnetic field vary with an 11-year cycle.