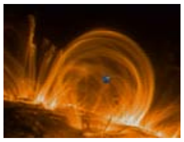
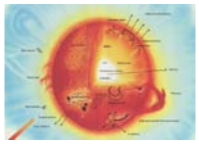
The Sun





The Sun

- Closest Star
- Source of light and heat on earth
- Next closest - Alpha Centauri 4.3 light years away
- Sun - 8 minutes away
- Easiest to study
- Want to Understand the sun to understand other stars in the universe

Sun Fact Sheet

The Sun is a normal G2 star, one of more than 100 billion stars in our galaxy.

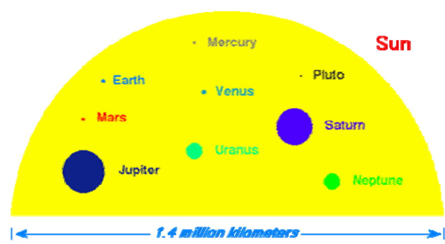
Diameter: **1,390,000 km** (Earth 12,742 km or nearly 100 times smaller)
Mass: **1.1989 x 10^{30} kg** (333,000 times Earth's mass)

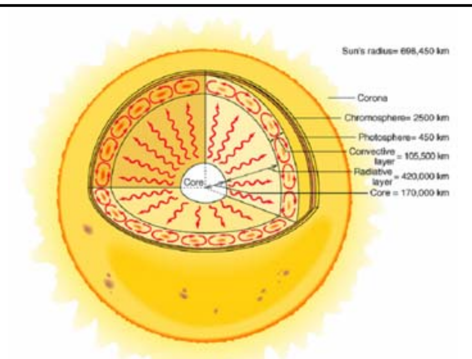
Temperature: **5800 K** (surface) **15,600,000 K** (core)

The Sun contains more than **99.8%** of the total mass of the Solar System (Jupiter contains most of the rest).

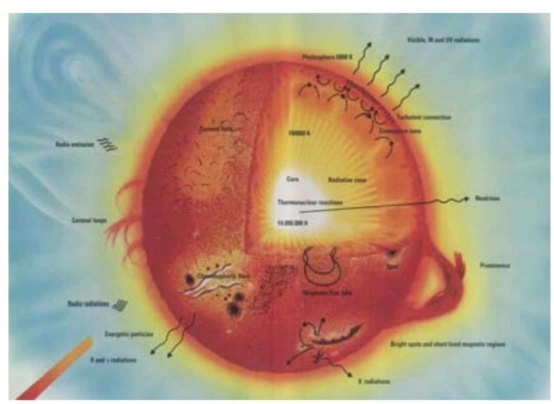
Chemical composition:
Hydrogen **92.1%**
Helium **7.8%**
Rest of the other 90 naturally occurring elements: **0.1%**

The Sun and its Planets to Scale





Energy is created in the core when hydrogen is fused to helium. This energy flows out from the core by radiation through the radiative layer, by convection through the convective layer, and by radiation from the surface of the photosphere, which is the portion of the Sun we see.

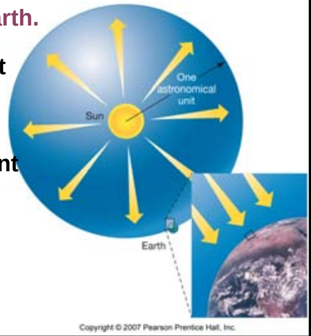


Luminosity – total energy radiated by the Sun – can be calculated from the fraction of that energy that reaches Earth.

Measure as energy unit per square meter (with detection device)

Solar constant – amount of energy per second

About 1400 W/m^2

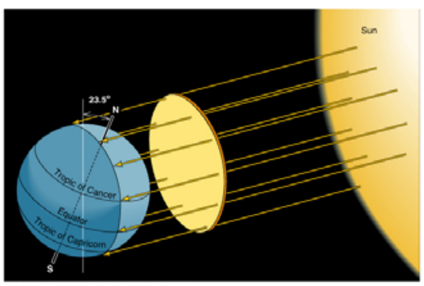


How much solar energy is received by a sunbather who has a surface area of .5m^2 ?

Solar Constant x Surface area

About 700 watts (7 - 100 watt lightbulbs per second)

How much energy does the sun transfer to earth?



Consider that Energy from the Sun passes through an imaginary disc that has a diameter equal to the Earth's diameter.

Now we calculate all energy sun emits by considering the diameter of earth compared to its distance to the sun.

We now can consider the imaginary sphere around sun

Area of Sphere $=4\pi r^2$

Calculate Area….

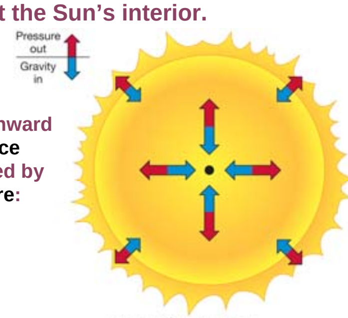
Multiply by Luminosity

Total luminosity is about **4 * 10^{26} W** – the equivalent of 10 billion 1-megaton nuclear bombs per second.

The Solar Interior

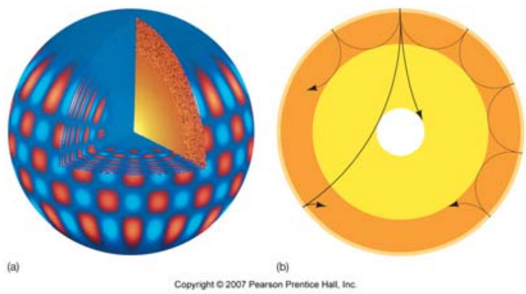
Mathematical models, consistent with observation and physical principles, provide information about the Sun's interior.

In **equilibrium**, inward **gravitational force** must be balanced by outward **pressure**:



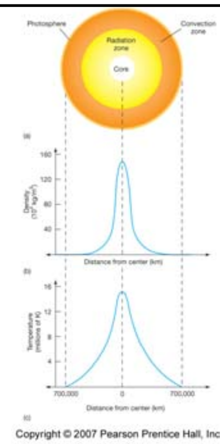
The Solar Interior

Doppler shifts of solar spectral lines indicate a complex pattern of **vibrations**:

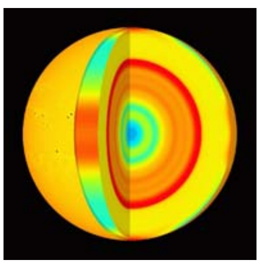


The Solar Interior

Solar **density** and **temperature**, according to the standard solar model:



Internal Rotation



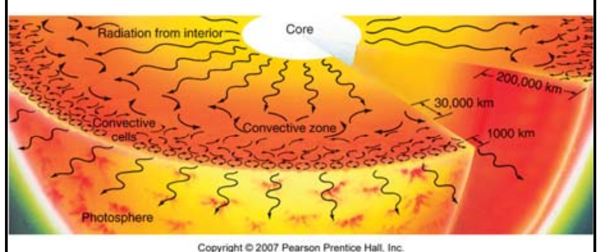
False color image showing a theoretical model of hotter (red) and colder (blue) regions

The red layer may be a shear region between the radiative and convective zones, powering a dynamo that gives rise to the Sun's magnetic field.

The Solar Interior

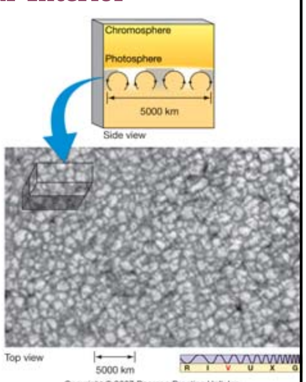
Energy transport

The **radiation zone** is relatively transparent; the cooler **convection zone** is opaque:

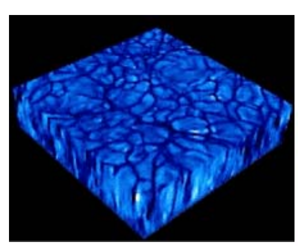


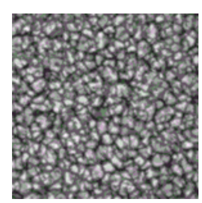
The Solar Interior

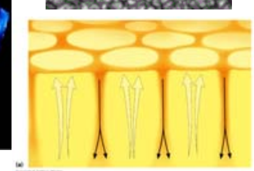
The visible top layer of the convection zone is **granulated**, with areas of upwelling material surrounded by areas of sinking material:



Granules

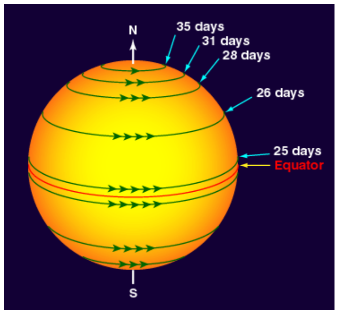






Energy rises to the surface as gas wells up in the cores of the granules, and cool gas sinks around their edges.

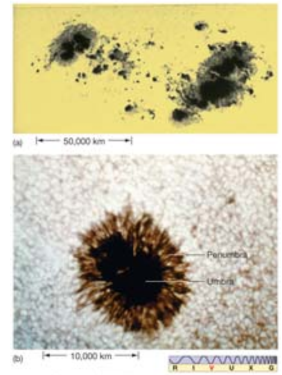
differential rotation



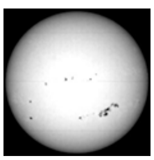
Sun does not rotate as a rigid sphere. The equator of the Sun rotates faster than the poles of the Sun.. Sunspots and many other solar activities are due to this differential rotation.

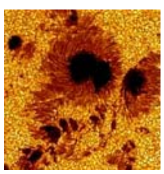
9.4 The Active Sun

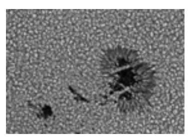
Sunspots: appear dark because slightly cooler than surroundings:



Sunspots





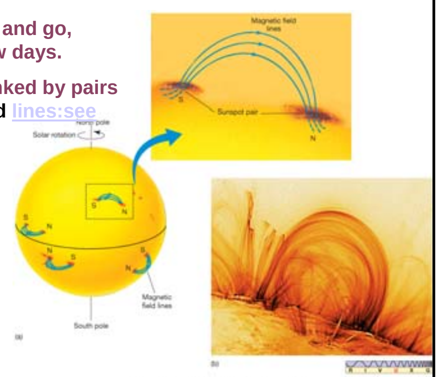


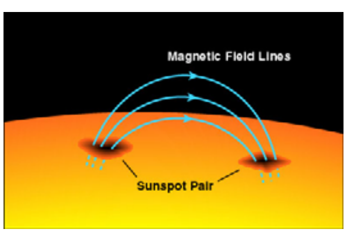
Sunspots appear as dark spots on the surface of the Sun. Temperatures in the dark centers of sunspots drop to about 3700 K (compared to 5700 K for the surrounding photosphere). They typically last for several days, although very large ones may live for several weeks.

9.4 The Active Sun

Sunspots come and go, typically in a few days.

Sunspots are linked by pairs of magnetic field lines:see magnets





- have strong magnetic field, about 1000 times stronger than the Sun's average.
- usually appear in pairs.
- two sunspots of a pair have different polarities, one would be a magnetic north and the other is a magnetic south, joined by magnetic field lines.
- magnetic field locks the gas of the photosphere in places and inhibits the hotter gas below to rise
- As a result, the sunspots are cooler.
- Sunspots appear to coincide with changes in the climate of the Earth. Studies show that during the last ice age, there were very few sunspots

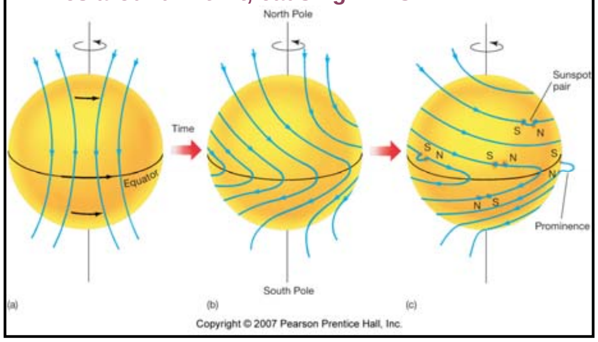
Sun’s Magnetic Field

The Sun's corona is threaded with a complex network of magnetic fields. Solar storms and flares result from changes in the structure and connections of these fields.

When some of the Sun's magnetic field lines are filled with hot gas, we see a *magnetic loop*.

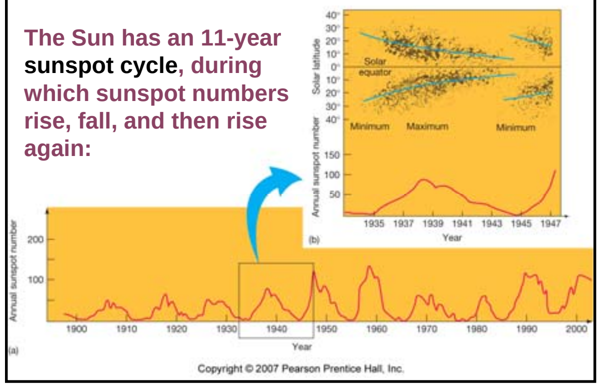
9.4 The Active Sun

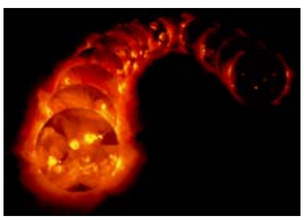
The rotation of the Sun drags magnetic field lines around with it, causing kinks



9.4 The Active Sun

The Sun has an 11-year **sunspot cycle**, during which sunspot numbers rise, fall, and then rise again:





X-ray images of the Sun taken by the Yohkoh spacecraft, showing changes in the corona in 1991 (left) at a solar maximum to 1995, a solar minimum (right).

The most rapid changes to the Sun's magnetic field occur locally, in restricted regions of the magnetic field.

However, the entire structure of the Sun's *global* magnetic field changes on an 11 year cycle. Every 11 years, the Sun moves through a period of fewer, smaller sunspots, prominences, and flares - called a "**solar minimum**" - and a period of more, larger sunspots, prominences and flares - called a "**solar maximum**."

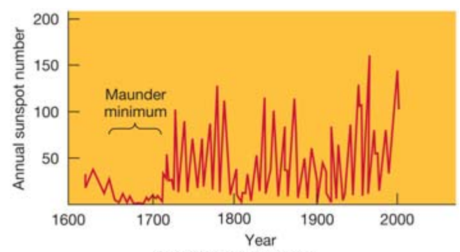
After 11 years, when the next cycle starts, the magnetic field poles are reversed.

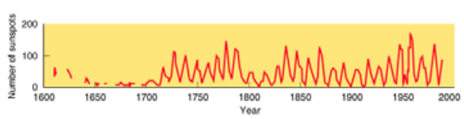
The last solar minimum was in 2006

9.4 The Active Sun

This is really a 22-year cycle, because the spots switch **polarities** between the northern and southern hemispheres every 11 years.

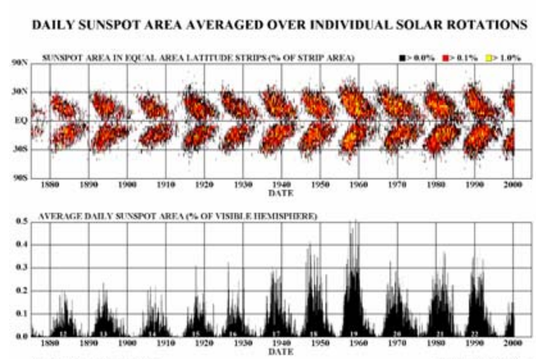
Maunder minimum: few, if any, sunspots:





The sunspot cycle over the past 400 years. Note the period before 1700, when, for reasons that are not understood, very few sunspots were observed. Sunspots have reached a maximum about every 11 years since 1700, and there is also a suggestion of some sort of cycle on a 55- to 57-year time scale.

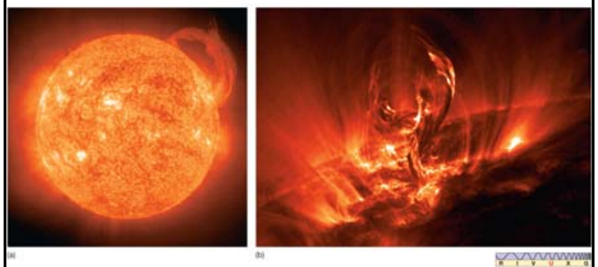
Because the pre-1700 period of low sunspot activity coincides with a prolonged cool period that is sometimes called the Little Ice Age, some scientists have speculated that sunspot activity and climate are connected somehow.



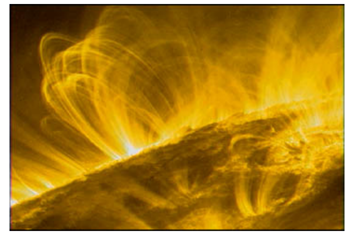
9.4 The Active Sun

Areas around sunspots are active; large eruptions may occur in photosphere.

Solar prominence is large sheet of ejected gas:



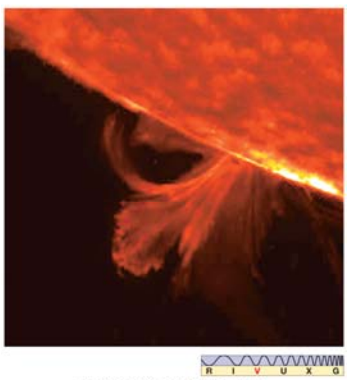
Solar Prominences



Prominences are dense clouds of material suspended above the surface of the Sun by loops of magnetic field. Prominences can remain in a quiet or quiescent state for days or weeks. However, as the magnetic loops that support them slowly change, prominences can erupt and rise off of the Sun over the course of a few minutes or hours

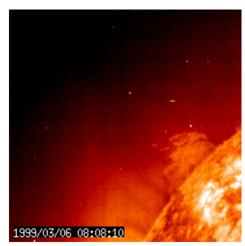
9.4 The Active Sun

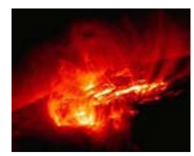
Solar flare is a large explosion on Sun's surface, emitting a similar amount of energy to a prominence, but in seconds or minutes rather than days or weeks:



Solar Flares

Solar flares are tremendous explosions on the surface of the Sun. In a matter of just a few minutes they heat material to many millions of degrees and release as much energy as a billion megatons of TNT. They occur near sunspots, usually along the dividing line (neutral line) between areas of oppositely directed magnetic fields.



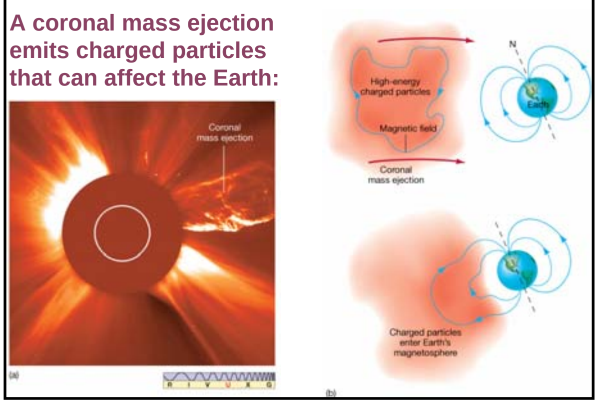


Images from SOHO*

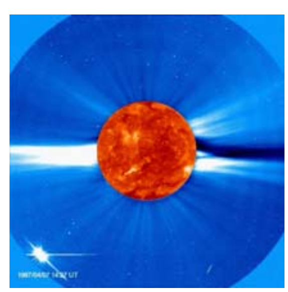
*NASA/ESA Solar and Heliospheric Observatory spacecraft

9.4 The Active Sun

A coronal mass ejection emits charged particles that can affect the Earth:

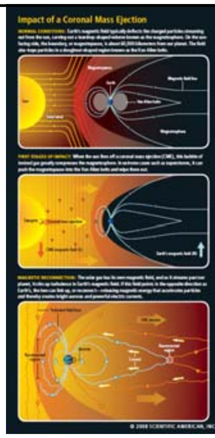


Coronal Mass Ejections (CMEs)



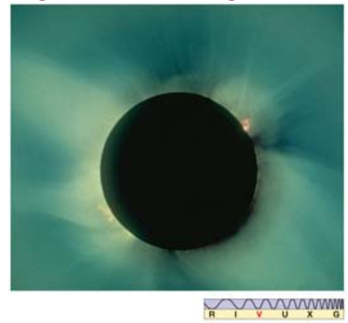
Coronal mass ejections (CMEs) are huge bubbles of gas threaded with magnetic field lines that are ejected from the Sun over the course of several hours.

CMEs disrupt the flow of the solar wind and produce disturbances that strike the Earth with sometimes catastrophic results.

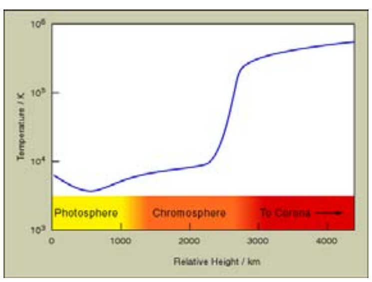


9.4 The Active Sun

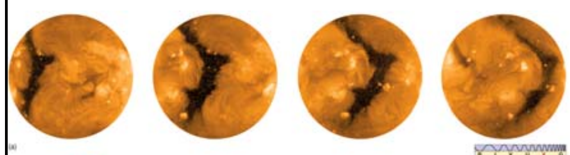
Solar corona changes along with sunspot cycle; is much larger and more irregular at sunspot peak:

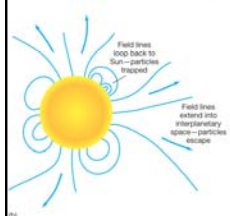


Temperature of the Sun's Atmosphere



9.4 The Active Sun





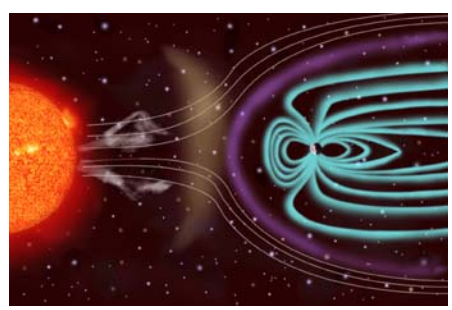
Solar wind escapes Sun mostly through **coronal holes,** which can be seen in X-ray images

Corona and Solar Wind

The Sun's Corona is forever expanding into interplanetary space filling the solar system with a constant flow of solar wind.

Solar wind is the continuous flow of charged particles (ions, electrons, and neutrons) that comes from the Sun in every direction.

Solar wind consists of slow and fast components. Slow solar wind is a consequence of the corona's high temperature. The speed of the solar wind varies from less than 300 km/s (about half a million miles per hour) to over 800 km/s.



Solar wind shapes the Earth's magnetosphere and magnetic storms are illustrated here as approaching Earth. These storms, which occur frequently, can disrupt communications and navigational equipment, damage satellites, and even cause blackouts. The white lines represent the solar wind; the purple line is the bow shock line; and the blue lines surrounding the Earth represent its protective magnetosphere.

BBC NEWS Wednesday, 24 September 2008 14:19 UK

Solar wind blows at 50-year low

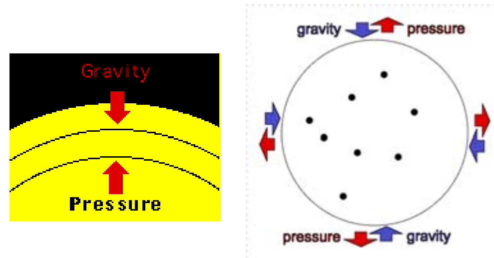
The solar wind - the stream of charged particles billowing away from the Sun - is at its weakest for 50 years.

Scientists made the assessment after studying 18 years of data from the Ulysses satellite which has sampled the space environment all around our star.

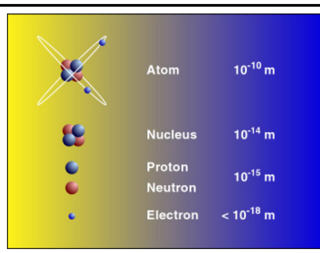
They expect the reduced output to have effects right across the Solar System.

Indeed, one impact is to diminish slightly the influence the Sun has over its local environment which extends billions of kilometres into space.

The charged wind particles also carry with them the Sun's magnetic field, and this has a protective role in limiting the number of high-energy cosmic rays that can enter the Solar System. More of them will probably now make their way through.



Thermonuclear fusion heats the inside of the star, creating pressure that stops the collapse and producing a long period of great stability that defines the main sequence.



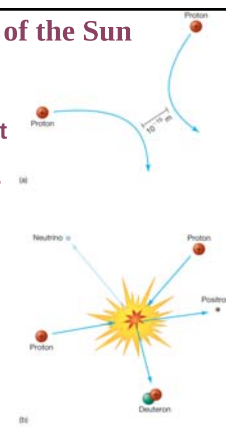
By mass, about 70% of the Sun is hydrogen. The rest is mostly 4He.

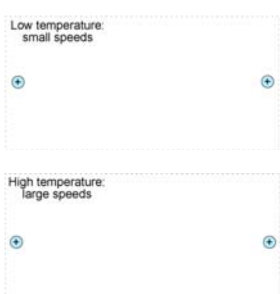
Hydrogen is the fuel of the nuclear reaction in the core of the Sun, and helium is the product. Most of the helium is not produced by the Sun. It was already there when the Sun was formed.

9.5 The Heart of the Sun

Nuclear fusion requires that like-charged nuclei get close enough to each other to fuse.

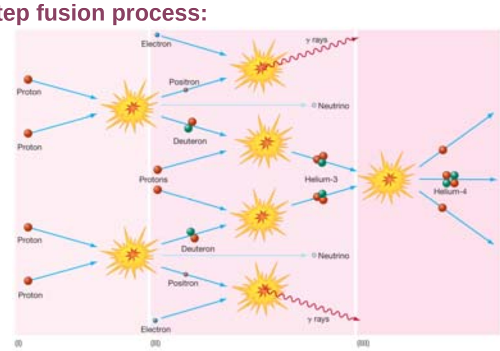
This can happen only if the **temperature** is extremely high – over 10 million K.

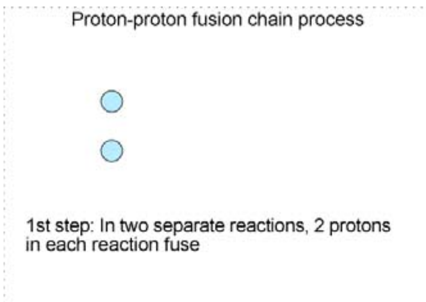




9.5 The Heart of the Sun

The process that powers most stars is a three-step fusion process:





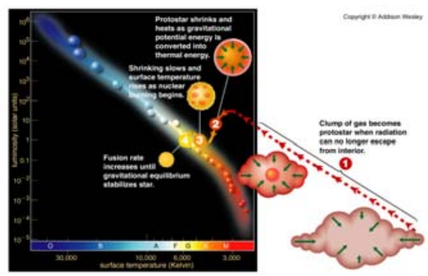
9.5 The Heart of the Sun

Neutrinos are emitted directly from the core of the Sun, and **escape**, interacting with virtually nothing. Being able to observe these neutrinos would give us a **direct picture** of what is happening in the core.

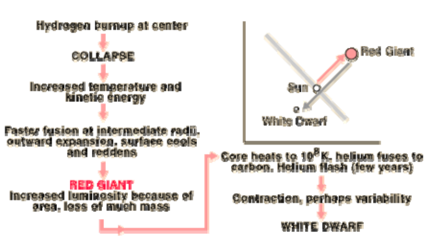
Unfortunately, they are no more likely to interact with Earth-based detectors than they are with the Sun; the only way to spot them is to have a huge **detector volume** and to be able to observe **single interaction events**.

9.5 The Heart of the Sun

The Sudbury neutrino observatory:



Anticipated Future of the Sun



Life Cycle of the Sun

Birth:
Gravitational Collapse of Interstellar Cloud
"Hayashi Contraction" of Protostar

Life:
Stability on Main-Sequence
Long life - energy from nuclear reactions in the core
(E = mc2)

Death:
Lack of fuel, instability, variability expansion (red giant, then white dwarf)