ASTR 1020

Look over Chapter 14

Good things to Know

- Radiative Zone
- Convection Zone
- Granulation
- Corona
- Nuclear Fusion
- Strong Nuclear Force
- Isotopes
- Solar Seismology Sunspots
- Prominence
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The Sun

The Sun is a star, a dazzling luminous ball of gas, more then 100 times bigger in diameter then the Earth.

The Sun’s Temperature

The Sun’s surface temperature is around a hundred times hotter then the surface of the Earth (about 9900 F).

At the Sun’s center (its core) the temperature is about 3 hundred thousands times hotter then the Earth (≈27 million F).

The Sun’s Interior

When we look at the Sun we see through the low density gasses of its outer atmosphere.

The layers where the Sun’s gases change from transparent to opaque form what is called the Photosphere, the visible surface of the Sun.

The Sun’s Fuel

The Sun radiates the energy of 100 billion nuclear bombs into space from its surface every second.

This energy is provided by the fusion of hydrogen in its core.

Fortunately, the Sun has a plentiful supply of hydrogen. The Sun is about 71% hydrogen, 27% helium, and 2% vaporized heavier elements.

Energy Transport

Near the Sun's core, the energy moves by radiation carried by photons through what is called the Radiative Zone.

Even though photons travel at the speed of light between absorptions, it takes them 100,000 years to move from the core to the surface.

Convection Zone

Rising and sinking gas brings heat up to the photosphere in the Convection Zone.

We can infer the gas's motion from the numerous tiny, bright regions surrounded by narrow darker zones, called Granulation.

The Sun's Atmosphere

Astronomers refer to the extremely low density gases that lie above the atmosphere as the Sun's atmosphere.

Immediately above the photosphere the temperature decreases, but at higher altitudes the gas grows hotter, reaching temperatures of several millions degrees.

The Chromosphere

The Sun's atmosphere consists of two main regions. Immediately above the photosphere lies the chromosphere, the Sun's lower atmosphere.

Spicules

With a telescope, you can see that the chromosphere contains millions of thin columns called Spicules each a jet of hot gas thousands of kilometers long.

Corona

The **Corona** is the Sun's outer atmosphere.

The corona's extremely hot gas has such a low density that under most conditions we look right through it.

The corona contains huge regions of cooler gas called Coronal Holes through which gas may escape from the Sun into space.

How the Sun Works

The structure of the Sun depends on a balance between its internal forces. One force holds the Sun together. A second force prevents the Sun from collapsing. This balance is called **Hydrostatic Equilibrium**.

Pressure in The Sun

Pressure in a gas comes from collisions among its atoms and molecules.

The strength of the pressure depends on on how often and how hard the collisions occur.

The Idea Gas Law

So the strength of the pressure is proportional to the temperature and inversely proportional to volume.

$$P = \frac{NRT}{V}$$

R = a Constant

N = # of atoms

T = Temperature

V = Volume

This is the Idea gas Law.

Powering The Sun

Energy that leaves the core eventually escapes into space as sunshine: heat and light.

That heat loss must be replaced, or the Sun's internal pressure would drop, and the Sun would begin to shrink under the force of its own gravity.

Is It Coal?

Early astronomers believed that the Sun might burn ordinary fuel such as coal.

Is It Gravity?

At the end of the last century two physicist proposed that the Sun is not in hydrostatic equilibrium but that gravity slowly compresses it making it shrink. In their theory, compression heats the gas and makes the Sun shine.

$E=mc^2$

In 1899, T.C. Chamberlin suggested that subatomic energy—energy from the reactions of atomic nuclei—might power stars.

In 1905, Einstein proposed that energy might come from an objects mass as:

$$E = mc^2$$

where *m*=mass and *c*=speed of light 3×10^{8} *m/s*.

Nuclear Fusion

In the 1930's the physicists Hans Bethe and Carl Weizsacker showed that the Sun generates its energy by converting hydrogen into helium by a process called **Nuclear Fusion**, a process that bounds two or more nuclei into a single, heavier one.

The Strong Force

Under normal conditions, hydrogen nuclei repel each other, pushed apart by the electrical charge of the protons.

If the nuclei is moving fast enough then the nuclei may get close enough together so that the **Strong Nuclear Force** can over come the repulsion and hold the nuclei together.

Isotopes

Hydrogen consists of one proton and an orbiting electron, and helium consists of two protons, two neutrons, and two orbiting electrons.

Hydrogen and helium always have one and two protons respectively, but they have other forms called Isotopes with different numbers of neutrons.

The Proton-Proton Chain

Hydrogen fusion in the Sun occurs in these steps called the Proton-Proton Chain.

Step #1

In the first step, two ^{1}H nuclei collide and fuse to form the isotope of hydrogen ^{2}H. In the collision, one proton becomes a neutron by ejecting two particles: a Positron (e^{+}) and a neutrino (v).

$$^{1}\mathrm{H} + {}^{1}\mathrm{H} \rightarrow {}^{2}\mathrm{H} + e^{+} + v + \mathrm{Energy}$$

Step #2

In the second step, the ^2H nucleus collides with a third ^1H to make the isotope of helium containing a single neutron, ^3He. This process releases a high-energy photon (a gamma ray) ɣ.

$$^1H + {}^2H \rightarrow {}^3He + \gamma + \text{Energy}$$

Step #3

The third and final step is the collision and fusion of two ^3He nuclei. Here, the fusion results not in a single particle, but rather one ^4He and two ^1H nuclei.

$$^3He + {}^3He \rightarrow {}^4He + 2\,{}^1H + \text{Energy}$$

Follow the Chain

The Energy Released

We find the quantity of energy released by comparing the initial and final masses and using the mass–energy relationship $E=mc^2$.

$$\begin{aligned} 4\times 1 \text{ Hydrogen} &= 6.693\times 10^{-27}\,kg \\ -1 \text{ Helium} &= \underline{6.645\times 10^{-27}\,kg} \\ \text{Mass lost} &= 0.048\times 10^{-27}\,kg \end{aligned}$$

$$E=\left(0.048\times 10^{-27}\,kg\right)\left(3\times 10^{8}\right)^{2}=4.3\times 10^{-12}\,J$$

Solar Neutrinos

Counting neutrinos is extremely difficult. Neutrinos have no electric charge and only a tiny mass, which gives them enormous penetrating power.

They escape from the Sun's core through its outer 700,000 km and into space like bullets through wet Kleenex.

The elusiveness that allows neutrinos to slip so easily through the Sun makes them slip with equal ease through detectors on Earth.

Neutrino Detectors

Neutrino Detectors contain Large amounts of water.

The detectors are buried to shield them from the many other kinds of particles besides neutrinos that constantly bombard the Earth.

Super–Kamiokonde detector

One of the largest neutrino detectors is the Super–Kamiokonde detector located deep in a zinc mine west of Tokyo.

Missing Neutrinos

When astronomers examine the results of the neutrino detectors, they find that the number of neutrinos is about three times smaller then predicted.

There are at least two explanations for the discrepancy seen in the detectors:

1) The model of the Sun is wrong.
2) Neutrinos have properties that are not understood.

Helioseismology or Solar Seismology

Solar Seismology is the study of the Sun's interior by analyzing waves in the Sun's atmosphere.

The rising and falling surface gas makes a regular pattern which can be detected as a Doppler shift of the moving material.

Solar Magnetic Activity

A wide class of dramatic phenomena on the Sun are caused by its magnetic field.

Sunspots

Sunspots are the most common type of solar magnetic activity.

They are large, dark appearing regions that contain strong magnetic fields.

Solar Magnetic Fields

The magnetic field of sunspots is more then a thousand times stronger then the Sun's normal magnetic field.

Because of the strong magnetic field, particles are forced to follow the magnetic field as they spiral in it.

Magnetic Fields and Sunspots

In the Sun, the magnetic field slows the ascent of hot gas in the convection zone and, starved of heat from below, the surface cools and becomes darker, making a sunspot.

Solar Prominences

A Prominence is a huge plume of glowing gas that jutes from the lower chromosphere into the corona.

Prominences form where the Sun's magnetic field reduces heat flow to a region.

Solar Flares

Sunspots also give birth to , brief but bright eruptions of hot gas in the chromosphere.

One theory suggests that the magnetic field near a sunspot gets twisted by gas motion.

But the field can only be twisted so far before it supply readjust, whipping the gas in its vicinity into a new configuration. The sudden motion heats the gas, and it expands explosively.

Heat and the Chromosphere

Although the Sun's magnetic field cools Sunspots and prominences, it heats the chromosphere and corona.

A speedup occurs in the Sun's atmosphere when magnetic waves form in the photosphere move into the corona along the Sun's field lines. As the atmospheric gas thins, the wave energy is imparted to even smaller numbers of atoms making them move faster. But "faster" in this case means hotter.

The Solar Wind

The corona's high temperature gives its atoms enough energy to escape the Sun's gravity. As these atoms stream into space, they form the Solar Winds, a tenuous flow of mainly hydrogen and helium that sweeps across the Solar System.

Heliopause

The Heliopause is the last boundary where interstellar space takes over.

The Heliosheath represents a mixing bowl-region in which smaller amounts of solar wind mix with gas from outside our solar system.

The Solar Cycle

Sunspots and flare activity change from year to year in what is called the **Solar Cycle**.

The number of Sunspots clearly rise and fall approximately every 11 years.

Cause of the Solar Cycle

As the Sun rotates, gas near its equator circles the Sun faster then gas near its poles: that is, it spins differentially, property common in gaseous objects.

Winding up the Sun

Because the magnetic field and gas are tightly connected differential rotation causes gas at the equator, which is moving faster then the gas at the poles, to drag the magnetic field with it so that a field, initially straight north to south is wound into two subsurface loops.

The Kinks

As the loops are wound tighter, they develop kinks, as when you twist a rubber band to tight.

The cycle ends when the field twist too "tightly" and collapses, and the process repeats.

Pairs of Spots

Each kink breaks the photosphere in two places-one where it leaves and one where it enters. We therefore expect that spots will occur in pairs or paired groups.

Maunder Minimum

Although this hypothesis cannot be verified yet, many scientists think that Solar activity affects our climate.