The Sun

Why study the Sun?

• It is the main object in Solar system.
• It is the source of almost all the energy we use on Earth.
• We cannot understand our origins without first understanding the Sun.
• It is a classic example of a star.
Distance to the Sun

- The distance is from the Earth to the Sun is defined as 1 Astronomical Unit (A.U.)
- One A.U. is about $1.5 \times 10^{11}$ meters or nearly 93 million miles

Diameter of the Sun

- The Sun has an angular diameter of about $\frac{1}{2}$ a degree
- The actual diameter is $1.4 \times 10^9$ meters, which is about 1 million miles
  - Over 100 times the Earth’s diameter.
Mass & Density

- We get the mass of the Sun by applying Newton's law of gravity to the orbits of the planets.
- The mass is about $2 \times 10^{30}$ kilograms, which is about $2 \times 10^{27}$ tons (one million times the mass of the Earth).
- The mass of the Sun is much more than all the planets put together.
- From here we can get its density:
  - It is about 1.4 times the density of water.
  - This is lighter than rock or metal.
  - This is an important clue to what the Sun might be made of.

The Solar Spectrum

An absorption spectrum!
The Absorption Spectrum – Revisited!

- Therefore, we can deduce that the temperature of the Sun must decrease outward.

The Sun’s Emission Spectrum

- During a solar eclipse we can see emission lines from the Sun’s lower atmosphere.
- This layer is sometimes called the chromosphere.
Temperature (Outside)

- Recall that from Wien's law we can deduce that the surface temperature of the Sun is about 5800 K.

Composition

- First, we note that 5800 K is so hot that all known solids melt and all known liquids boil.
- Second, almost all molecules break up at this temperature.
- Third, the temperature is so high that the gas must be ionized.

Therefore, the Sun must be a hot ball of ionized gas.

- We can then analyze the absorption line pattern (composition) and shading (abundance).
- The Sun is about 71% hydrogen, 27% helium, and 2% of the rest of the known atoms (by mass).
Interior of the Sun

- Balance between gravity (pulling in) and pressure (pushing out)

By using Newton’s Law of Gravity we’re able to determine the gravity at the center and thus the pressure.

- Since pressure and temperature are related...we can calculate the temperature of the Sun’s core.

- This temperature to be about 15 million Kelvin (~27 million °F).

- The density is 158 times the density of water.

- Compare this with rocks (~3), gold (~20), and air (~0.001).
Nuclear Reactions

- The Sun is radiating about $4 \times 10^{26}$ Watts of power into space
- It would quickly cool down unless the energy is replaced from some source
- The source of this power lies in the science of nuclear physics
- Nuclear physics is the science of how nuclei (including protons and neutrons) interact with each other directly
  - In nuclear physics you change the elements
  - Unlike chemistry where the atoms remain unchanged
- Nuclear reactions are generally uncommon on Earth
The Sun’s Nuclear Power

• The type of nuclear reaction taking place on the Sun is called **thermonuclear fusion**
• Thermonuclear fusion occurs when light elements of low atomic number combine to make an element of higher atomic number
• In the Sun this is:

  6 hydrogen nuclei (protons) and 2 free electrons ($e^-$) combine through various steps to produce 1 helium-4 nucleus ($^4$He), 2 protons, 2 positrons ($e^+$), 2 neutrinos ($\nu$), and energy in the form of gamma rays ($\gamma$)

• This is referred to as a proton-proton chain reaction!
This happens first...

Then this...

This is the main energy producing reaction!
And finally this...

All of these steps take more than 1 Billion years to complete. However, because there are so many hydrogen atoms in the core, at any one instant many are undergoing the reactions
• The pressure and temperature are so high (IN THE CORE) that the protons can blast their way through the force of the electric repulsion to fuse together
• The energy given off comes from the destruction of about 0.7% of the mass of the hydrogen

[Diagram: 
4 protons → 1 He nucleus (2 protons + 2 neutrons) → released energy]

• The energy is converted according to Einstein's formula:

\[ E=mc^2 \]

• Each second 4 million tons of the Sun is turned into energy; causing the mass of the Sun to decrease with time
  – This too defines its age and lifetime!
• These properties and processes define our Sun as the classic example of a star
Energy Transport

- The energy from the core comes out in the form of gamma ray photons

- Gamma rays take millions of years to reach the surface, despite traveling at the speed of light

Convection

- Towards the outer regions the energy travels by convection
Atmosphere of the Sun

- There is no hard edge to the Sun
- The density tails off to zero in the same way that the Earth’s atmosphere does
- What we actually see is the atmosphere of the Sun
- We do not see into the Sun directly at all

The Photosphere

- We often talk loosely about the "surface" of the Sun
- The photosphere is the layer of the sun from which light reaches us directly
- Below the photosphere the Sun is opaque
Granulation

- Granulation is the changing appearance of the solar surface, caused by rising (hot) and falling (cool) material in convective cells just below the photosphere.

Temperature Profile

- The temperature of the gas in the photosphere (5800 K) is lower than that of the core (15M K)
  - This is why you see absorption lines.
The Solar Corona

• This is the outer layer of the Sun's atmosphere just above the chromosphere
• It spreads out farther than the diameter of the Sun.
• It is very hot, about 1 million degrees, but we do not know exactly why.

• At this temperature, the corona emits x-ray radiation
Coronal holes

- Corona sections that appear dark
  - An X-ray and extreme ultraviolet void
- Magnetic field lines emerging from the holes extend indefinitely into space rather than looping back into the photosphere
- This allows charged particles to escape from the Sun and results in coronal holes being the primary source of the solar wind

Sunspots

- Dark regions found on the surface of the Sun
- Sunspots can last for days/weeks on the surface of the Sun.
  - Sunspots are dark because they are relatively cool (typically 4200 instead of 5800 K)
  - They are caused by variations in the magnetic field of the Sun (we’ll not get into these details)

1947: The largest sunspot group was recorded.
It was estimated at 7 billion square miles.
• Sunspots are the easiest way to study the rotation of the Sun, which is approximately 1 month.

• The Sun, however, does not rotate as a solid body which causes the equator to rotate faster than the poles.

![Diagram of sunspots and rotation]

The Sunspot Cycle

• The fairly regular pattern that the number and distribution of sunspots follows

• The average number of spots reaches a maximum every 11 or so years, then falls off to almost zero

• Sometimes they go away completely, as with the "Maunder Minimum" at the end of the 17th century

![Graph of yearly averaged sunspot numbers 1610-2000]
The Solar Wind

- Fast moving charged particles from the solar corona

- When they reach the Earth's upper atmosphere they can cause Auroras (i.e. The Northern Lights) near the Earth's magnetic poles

Prominences

- Loops or sheets of glowing gas ejected from an active region on the solar surface
- They move under the influence of the Sun's magnetic field
Flares

- Very explosive events on the Sun's surface
- Flares can erupt for a few minutes and eject vast numbers of particles into space.
- The energy = ten million times the energy released from a volcanic explosion

Results of a Solar Flare

- The Earth's upper atmosphere becomes more ionized and expands.
- Long distance radio signals can be disrupted
- A satellite's orbit around the Earth can be disturbed by the enhanced drag on the satellite from the expanded atmosphere
- Satellites' electronic components can be damaged
Solar Energy

- The energy from the Sun that is converted into thermal or electrical energy.
- The amount of energy falling on the Earth is given by a solar constant, but depending on clouds and latitude (how far we are from the equator) we get about 1000 - 3000 Watts per square meter of energy from the Sun at the surface.
Types of Solar Energy

- Direct heating (such as for hot water)
- Solar cells for electricity
- Absorption by plants for food
- Absorption by plants for wood fuel
- Absorption by plants for fossil fuel (oil, coal)
- Movement of atmosphere (wind power)
- Evaporation of water (hydroelectric power)

- There are also types of non-Solar energy we use:
  - nuclear energy
  - geothermal energy
  - tidal energy

End Topic

The Sun