SESSION THIRTEEN: THE SUN

A. <u>Physical parameters of the sun</u>: Students should read the sections in Session 14 titled the Nature of Light, Principals of Spectroscopy, and Magnetic Fields in Session Seven.

Radius	6/9599(7) x 10^{10} cm / 432,480 miles
Surface area	6.087 x 10^{22} cm^2
Radius of Earth	6.37103 x 10^8 cm / 3958.4 miles
Elemental abundances **Hydrogen** **Helium** **Oxygen** **Carbon** **Nitrogen**	 **1,000,000 atoms… All atoms are compared to Hydrogen** **50,000** **670** **350** **110**
Mass	1.98892 × 10^{33} gm = 333,000 Earths
Volume	1.4122 x 10^{33} cm^3
Mean density	1.408 gm/cm^3
Core/Surface (Photosphere) Temp.	16 million K/5800 K
Acceleration at surface (photosphere)	2.7398(4) x 10^4 cm/sec^2
Rotation	differential
Equator	24.5 days
+-30° latitude/+/-45° latitude	26.5 days/27.8 days
+-60° latitude/+-poles	32.0 days/36.5 days
Luminosity	3.839×10^{33} erg/sec
Horizontal parallax of Earth from sun	8.79418 sec of arc
Radius of sun at 1 AU	9.5963 x 10^2 sec of arc or diameter = 31.99 minute
Solar constant	1.388 x 10^6 erg/cm^2 sec
Astronomical unit	1.495979(1) x 10^{13} cm or 9.29558 x 10^7 miles

One dyne equals the amount of force necessary to accelerate a mass of 1gm 1cm/sec^2.
The erg is a unit of work or energy equivalent to a dyne's worth of force exerted through a distance of 1cm or 1gm 1cm/sec^2 x 1cm = 1gm $1cm^2/sec^2$.

B. **<u>Understanding the Sun's Interior</u>:** We gain knowledge about the sun's interior through our understanding of mathematical models, solar surface vibrations, and solar neutrinos.

1. **<u>Mathematical models</u>** examine temperature, pressure, and density changes with depth to predict the size, structure, and rate of energy production in the sun.
2. **<u>Helioseismology</u>:** Interprets the sun's wave motion at its surface to better understand and predict conditions of motion in the solar interior. The process is similar to seismologists' study of earthquakes, but more complicated.
3. **<u>Neutrinos</u>** are nearly massless subatomic particles which have a very low probability of interacting with the matter that we see. They are produced when matter is converted into energy in the cores of stars. Stopping a neutrino would require a slab of lead one light year in thickness. About 2 x 10^{14} neutrinos pass through your body every second.

a. **The low probability of neutrinos interacting with matter** and their near light speeds offers astronomers a real time method of understanding what is happening in the sun's core.
b. **By observing neutrino capture** in certain substances which possess a higher probability of interacting with them, it has been possible to understand the rate of nuclear fusion within the sun.
c. **Neutrino Deficit:** A deficiency of neutrinos was observed at the specific energy level predicted by theory (Ray Davis experiment-1960s). This problem was rectified by understanding that neutrinos come in different flavors. Although the sun produces one type of neutrino, called an electron neutrino, these spontaneously change into muon neutrinos and tau neutrinos many times on their way to Earth. Neutrino detectors were only designed to detect electron neutrinos. When neutrino detectors were designed to detect all three types of neutrinos, no discrepancy between theory and observation was found (Sudbury— Canada— Neutrino Collector).

C. **Core:** The central region of the sun where thermonuclear fusion occurs. The temperature is about 15 million K. The minimum temperature for the proton-proton reaction to complete a cycle is 10 million K.

1. **Matter is being destroyed, energy created:** $E = mc^2$… mass in grams x the speed of light in cm^2. Speed of light = 3×10^{10} cm/sec; speed of light squared = $9 \times 10^{20}\ cm^2/sec^2$.
2. **Four Hydrogen Protons Fuse to Form one He Nucleus:** The atomic mass of the resulting He nucleus is less massive than the four hydrogen protons.
   a. Atomic mass of H is 1.0089 x 4 = 4.0320
   b. Atomic mass of He = 4.0030
   c. Mass loss = 0.0290/4.0320 = 0.007 x 100 = 0.7%
   d. Amount of H needed to produce one gm of mass loss = 0.007(x)= 1
      x = 1/0.007 = 143gm
   e. Essentially 143 gm of H yields 142 gm of He. One gram of matter is converted into energy
      $E = mc^2$; $E = 1gm\ (3 \times 10^{10}\ cm/sec)^2$; $E = 1gm\ (9 \times 10^{20}\ cm^2/sec^2)$
      E = approximately 1×10^{21} ergs 1 erg = 1 dyne cm = $1gm\ cm^2/sec^2$
      An average atomic bomb delivers about 10^{22} ergs worth of energy which is equal to 10 gm of mass or about 1/3 of a (30 gm) granola bar.
3. **How much energy is released during one Proton-Proton reaction?:**
   Single proton's mass = 1.6726×10^{-24}gm. Four protons equal 6.690×10^{-24}gm.
   A single helium-4 nucleus has a mass of 6.643×10^{-24}gm.
   Mass loss in a single proton-proton reaction =
   $6.690 \times 10^{-24}gm - 6.643 \times 10^{-24}gm = 0.047 \times 10^{-24}gm$
   Fractional mass loss in one proton-proton reaction = $\dfrac{0.047 \times 10^{-24}gm}{6.690 \times 10^{-24}gm}$ =
   0.007 x 100 or 0.7% of the original hydrogen mass is converted into energy.

4. **<u>Proton-Proton Reaction</u>:**

(2) $\mathbf{{}_1H^1 + {}_1H^1 \longrightarrow {}_1D^2 + e^+ + v + 0.42\ MeV}$ (energy carried away by neutrinos)

(2) $\mathbf{e^- + e^+ \longrightarrow 2\gamma + 1.02}$ **MeV** (energy carried away by gamma radiation)

(2) $\mathbf{{}_1D^2 + {}_1H^1 \longrightarrow {}_2He^3 + \gamma + 5.49\ MeV}$ (energy carried away by gamma radiation)

$\mathbf{{}_2He^3 + {}_2He^3 \longrightarrow {}_2He^4 + 2{}_1H^1 + 12.86\ MeV}$ (increase in kinetic energy of particles)

Where H = hydrogen
D = deuterium (heavy hydrogen)
He = helium
$\mathbf{e^+}$ **= positron**
V = neutrino
$\boldsymbol{\gamma}$ **= gamma ray**
MeV = million electron volts

5. **<u>Sun's mass loss per second</u>** if its energy emission = 3.8×10^{33} erg/sec?
$E = mc^2$ or $m = E/c^2$. **See a more detailed problem of mass loss at the end of this chapter.**

$$m = \frac{3.8 \times 10^{33}\,\text{erg/sec}}{(3.0 \times 10^{10}\,\text{cm/sec})^2} = \frac{3.8 \times 10^{33}\,\frac{\text{dyne cm}}{\text{sec}}}{9.0 \times 10^{20}\,\frac{\text{cm}^2}{\text{sec}^2}} = \frac{3.8 \times 10^{33}\,\frac{(\text{gm cm})}{\text{sec}^2}\frac{\text{cm}}{\text{sec}}}{9.0 \times 10^{20}\,\frac{\text{cm}^2}{\text{sec}^2}}$$

$$m = 0.42 \times 10^{13}\ \text{gm/sec} = 4.2 \times 10^{12}\,\frac{\text{gm}}{\text{sec}}\ \frac{1\text{kg}}{1 \times 10^3\ \text{gm}} \times \frac{1\text{mt}}{10^3\ \text{kg}} = 4.2 \times 10^6\,\frac{\text{mt}}{\text{sec}}$$

$$4.2 \times 10^6\ \text{metric tons/sec}\ \ \frac{1.1\ \text{English tons}}{1\ \ \text{metric ton}} = 4.65\ \text{English tons/sec}$$

6. **<u>Sun's Mass Loss is from a Change in Binding Energies</u>:** Because the nuclear bonds (**<u>strong nuclear force</u>**) which are produced in the solar fusion process are stronger than their unit components, energy is released. The concept is similar to an electron that moves from a higher orbital to a lower orbital. In that transition, energy is released (**<u>electromagnetic force</u>**). When two protons bind to form deuterium, the **<u>weak nuclear force</u>** governs the release of the neutrino and the positron. An average proton in the sun's core encounters another proton millions of times each second, but it takes on average billions of years before the collision of two protons is hard enough to overcome the **<u>Coulomb barrier</u>** which is necessary for fusion to take place.
7. **<u>Sun's Mass Loss over its Lifetime is Insignificant</u>:** One Earth mass is equal to approximately 50 million years of solar energy production. Twenty Earth masses equal one billion years of solar fusion. Since the beginning of the solar system,

4.6 billion years ago the sun has lost only 20 Earth masses/billion years x 4.6 billion years = 92. During the sun's entire life history of 10 billion years it will only lose 200 Earth masses or 200/333,000 = 2/3330 = 1/1665 of its total mass. Helium production is 142 times greater = 200 x 142 = 28,400 Earth masses = 28,400/333,000 = 0.086 x 100 = 8.6% more He than when fusion started.

8. **<u>Combustion vs. Nuclear Synthesis</u>:** If the sun were composed of gasoline, it would take about 10,000 years for it to be consumed via combustion. If a gallon of gasoline was dropped into the sun from Pluto, its released gravitational potential energy would be thousands of times greater than the energy released through combustion.
9. **<u>Hydrostatic Equilibrium (Dynamic Equilibrium)</u>:** The amount of energy being produced by the sun is stabilized by the sun's mass wanting to collapse the star. This balance keeps the sun shining at nearly a constant rate.
10. **<u>Sun Brightens over its Lifetime</u>**: During the sun's existence, "He ash" will squeeze into the center of the core leaving fewer H ions to partake in fusion reactions. The net effect will be to compress the core, causing the fusion rate to increase, the sun to expand, and cool slightly. The sun's luminosity will also increase to some extent.

D. **<u>Radiative Zone</u>:** 0.2-0.7 of the sun's distance from its center… Energy transport (radiative diffusion) takes place via high energy gamma ray photons which are scattered or "bounced around" by the densely packed plasma in the radiative zone. Near the core, distances traveled between absorptions are well under a millimeter. Since the scattering takes place in random directions, the movement of photons towards the surface is very slow and convoluted (a random walk). Their decrease in energy is also equally slow, taking hundreds of thousands of years to millions of years for a gamma ray photo to reach the surface as many photons of visible light or other electromagnetic radiation.

E. **<u>Convective Zone</u>:** 29 percent of solar radius… At about 2 million K, the nuclei of atoms begin to become less ionized. The decreasing plasma begins to absorb photons rather than scatter them. This slows down or backs up the energy flow because photons are now starting to be captured. The medium begins to become opaque to "light" causing the mechanism of energy transport to change from radiation to convection. Parcels of hotter solar plasma move as a single unit towards the sun's photosphere because they are less dense. At the top of this zone, energy radiates away as the light we see coming from the sun (see photosphere). The cooler, denser solar material sinks back into the convective zone to be reheated and then rise again in a never-ending cycle (**<u>Granulation</u>**).

1. **<u>Helioseismology/Solar Seismology</u>**, the study of the wave motion on the sun's surface, gives astronomers an indication that this convective layer is at a minimum depth of 117,000 miles (190,000 km) or 27 percent of the sun's radius). It also indicates that the sun is rotating differentially in its interior. The process is similar to geophysics attempt to understand what lies beneath the Earth's surface through the study of earthquakes (Seismology), but much more complex.

2. **<u>Adiabatic Heating/Cooling</u>:** An adiabatic process is one in which no heat is gained or lost by the system. Compressing a gas causes it to heat while expanding a gas causes it to cool. It is the manner in which the internal temperature of the sun is determined.

F. **<u>Atmospheric Structure and Features of the Sun:</u>** Solar activity visible in the photosphere is also seen in areas of higher elevation such as the chromosphere and in the corona. All visible features are grounded in magnetic interactions.

1. **<u>Photosphere</u>:** It is the light emitting region of the sun and it is extremely tenuous. A density of solar material equal to the air breathed at sea level is not reached until 10,000 miles below the photosphere (15,000 km).
    a. **<u>Depth</u>:** About 200 miles (300 km). It is the uppermost region of the sun's convective zone. It is here that the energy generated in the core finally can escape from the sun.. The sun is opaque beneath the photosphere because any radiation given off at these depths is immediately absorbed by the atoms and ions in that region.
    b. **<u>Negative Hydrogen Ion Produces the Continuous Spectrum</u>:** Gas pressure is too low to obey Kirchhoff's first law (A solid, liquid, or gas [under high pressure] when heated and made to incandesce will produce a continuous spectrum in which all wavelengths are represented). The light that is emitted from the photosphere is the result of the formation of negative hydrogen atom. A second electron can briefly attach itself to a neutral hydrogen atom because the single electron allows a slightly positive charge to be felt opposite to its position. The ionization potential averages 0.75 eV, but there are virtually an infinite number of energy levels to which the electron can become attached. Emission results when the electron briefly attaches itself to form the negative hydrogen ion. The emission at various energy levels results in the creation of the continuous spectrum for the sun, where all of the wavelengths of light are represented. Most absorption lines form in the photosphere, but there are some that form in the chromosphere (Balmer series of hydrogen) and in the Corona.
    c. **<u>Average Temperature</u>:** 5800 K (10,500^{o} F.), roughly that of an iron welding arc.
        1) 4000-4500 K at the photosphere-chromosphere boundary
        2. 6300 K at a depth of 200 mi (300 km) into the photosphere when viewing the center of the sun's disk.
    d. **<u>Density of photosphere</u>:** 1/10,000 (10^{-4}) of Earth's atmosphere.
    <u>Pressure of photosphere</u>: Two percent of Earth's sea level atmospheric pressure. Pressures are greater than expected because of higher the temperatures.
2. **<u>Solar Features in the Photosphere</u>**
    a. **<u>Limb Darkening</u>:** Correctly exposed white-light images of the sun show the edge (limb) of the solar disk to be darker than the center. Views of the center of the disk penetrate into deeper, hotter (brighter) layers of the photosphere. Observations of the solar limb are more tangential, so only the upper, cooler (less bright) regions of the photosphere are seen.

b. **Granulation**: Bright and irregularly shaped cellular formations which are found on the photosphere. They are created by the convective motions of photospheric gases. Average sizes are about 700 km (400+ miles). Brighter central regions indicate rising gases while darker borders indicate cooler, sinking gases.

c. **Sunspots:** An intense magnetic region in and above the photosphere which appears darker because it is cooler than the surrounding photospheric area.
   1) **Magnetic fields inhibit convective** movements of gases which cause the region to become cooler and therefore darker.
   2) **Field strength varies** between 1000 and 4000 gauss. The normal field strength of Earth is about 0.3 to 0.5 gauss.
   3) **Sunspots are bipolar** and hence they appear in pairs, or as groups or areas of opposite magnetic polarity. Regions surrounding sunspot activity are referred to as **bipolar magnetic regions**, BMR's for short.
   4) **Sunspots evolve from small pores** which are larger than normal dark regions in the granules. Pores generally persist for a few hours, but they can mature into spots as large as 100,000 miles (1.6 x 10^5 km) and remain visible for two solar rotations.
   5) **Structure and temperature of sunspots:**
      a) **Umbra:** It is the spot's central darker region, and is found at a temperature of 4200K or 8000^o F. This area is emitting about 30 percent of the light intensity of the photosphere. The striations found in the umbra (and penumbra) represent outward flowing gases following magnetic flux lines
      b) **Penumbra:** It is the lighter region surrounding the umbra. It is emitting about 80 percent of the photospheric intensity. The temperature of the penumbra is about 5000 K (9000^o F).

d. **Differential Rotation of sun** was detected through the motion of sunspots at different latitudes. The rotation of the sun is slower at higher latitudes. The sun's rotational period at the equator is 24.5 days while at 45^o N/S latitude the rotation slows to 27.8 days.

e. **Eleven year sunspot cycle is only an average:**
   1) **Discovered by Heinrich Samuel Schwabe** (1789-1875) a German apothecary who was making systematic observations of the sun looking for a planet inside the orbit of Mercury called Vulcan.
   2) **The magnetic field which drives sunspot production** is created in the convective layer of the sun through the motion of plasma.
   3) **Bipolar Nature:** Sunspots have a leading and trailing area of magnetism of different polarities. The leading spot or region in the opposite hemisphere has the opposite magnetic polarity of the northern hemisphere.

4) **<u>Sunspot Cycle is Nonsymmetrical</u>:** Time period from minimum to maximum is shorter than the time between maximum to minimum. The reason is unknown.
5) **<u>Butterfly Diagram</u>:** A graphical plot of time versus latitude which details how sunspots change their position of formation over an 11-year solar cycle. As a sunspot cycle matures, spots appear at latitudes closer to the solar equator.
    a) **<u>Beginning of a Sunspot Cycle</u>:** Cycle begins with spots appearing at 40 degrees N/S latitude. As the sunspot cycle progresses, successive groups of spots appear at lower latitudes. The latitude of greatest frequency at sunspot maximum is 15º N/S.
    b) **<u>End of a Sunspot Cycle</u>:** Spots appear at 5º N/S latitude, while spots of the next cycle begin to form at latitudes of 40º N/S.
6) **<u>During sunspot maximum the sun is releasing more energy</u>** than during sunspot minimum. This is accomplished in denser, hotter, and brighter regions of the photosphere called **faculae**. The light intensity is about 103 percent of the normal photosphere. Faculae are generally associated with magnetically active regions on the sun such as sunspots. They help to create a thermal balance between the sunspots which are radiating less energy, but in actuality their total output overcompensates for the darker, cooler spots.

f. **<u>Formation of sunspots/22-year magnetic cycle</u>:** Proposed by Horace W. Babcock (American astronomer, 1912-2003) in 1961.
1) **<u>The sun can be considered similar to a dipole magnet</u>**, in that it contains a north and south pole.
2) **<u>Differential Rotation</u>:** The sun rotates fastest at the equator and more slowly towards the poles.
3) **<u>Onset of a 22-Year Cycle:</u>** Magnetic field lines are positioned in straight lines between the north and south poles.
4) **<u>Differential rotation</u>** causes the field lines near the solar equator to move ahead of the field lines at higher latitudes. After a year or so, the field lines at the sun's equator have completed many more circuits around the sun than those flux lines at higher latitudes.
5) **<u>Magnetic flux lines begin to bunch</u>** and twist between 30-40 degrees N/S latitude. The twisting is caused by the rising and falling currents in the convection zone. It has also been suggested that the density of the solar material near these flux lines decreases, creating a condition of magnetic buoyancy.
6) **<u>As the twisted field lines rise to the surface</u>,** they inhibit the convective flow of gases, thus cooling that region of the sun. The gases radiate less energy and appear cooler/darker than the surrounding gases. A sunspot with its area of higher magnetic intensity has been formed.

7) **Sunspot maximum** corresponds to the time of greatest field strength over the largest latitude band.
8) **Equatorial Migration:** Differential rotation causes the tangled field lines to migrate towards the equator where the areas of opposite polarity cancel each other.
9) **The opposite ends of the bipolar magnetic regions migrate northward** where they neutralize the existing field and reverse the magnetic polarity to initiate the second half of the 22-year solar cycle. Leading spots now have the opposite polarity of the previous 11-year cycle.

3. **Chromosphere:** The layer of the solar atmosphere which occurs immediately above the photosphere.
   a. **Visible** as an emission spectrum with a pinkish hue against the black sky (Kirchhoff's second law) just before and after a total solar eclipse. The color is due to the fluorescence of hydrogen in the chromosphere with the dominant wavelength at 6563 Å, hydrogen alpha. The hydrogen absorption lines are produced in the chromosphere.
   b. **Temperature** increases rapidly with height from a low of 4500 K at the photosphere-chromosphere boundary, called the **reversing layer**, to about 140,000K at the transition of the chromosphere with the corona.
   c. **Chromospheric thickness** is about 5000-6000 miles (8000-10,000 km).
   d. **Density** is about 10^{-8} gm/cm^3 at the photospheric boundary, thinning to 10^{-12} gm/cm^3 at the boundary with the corona. That is 10,000 to one billion times less dense than the air breathed at the Earth's surface (1.225×10^{-3} gm/cm^3).
   e. **Chromospheric Structure:**
      1) **Supergranulation**: Large scale 20,000 miles (30,000 km) cells of outward flowing chromospheric material. The flow follows along magnetic lines of force. They are similar to granulation in the photosphere but on a much larger scale.
      2) **Spicules** are tenuous pointed jets of glowing gas which lie in the chromosphere, but poke into the corona. They are about 6000 miles high (10,000 km), 300-600 miles (500-1500 km) wide and last for about 15 minutes. Spicules are found along the boundaries of supergranules and may through magnetic agitation transfer energy from the cooler chromosphere to the much warmer corona. Turbulence below the photosphere seems to flick the spicules (magnetic loops) back and forth heating the corona. The transition zone where temperatures rise from 10^4 to 10^5 K is less than 12 miles (20 km) in thickness.

f. **Observing the Chromosphere**
   1) **The chromosphere is optically transparent**, but it can be observed through specific absorption lines such as hydrogen alpha which are formed with its boundaries.
   2) **Coronagraph:** A specially designed telescope which employs an occulting disk at the focal plane of the instrument to occult the photosphere to reveal the chromosphere and the corona.

4. **Corona:** Latin for crown… Outermost layer of the sun's atmosphere. It is visible in a coronagraph or during a total solar eclipse as a pearly striated white halo extending several solar diameters from the sun's limb. Coronal densities are about one hundred million to one billion (10^8 to 10^9) atoms/cm^3 (Earth air at sea level has 3 x 10^{19} molecules/cm^3). The K and F coronas (see below) can be easily separated from each other because dust and electrons differ greatly in the way they polarize the light that they scatter.
   a. **K-Corona:** (K for kontinuierlich, "continuous" in German). It is also called the inner corona.
      1) **Predominates near the sun** and results from photospheric light scattered by rapidly moving electrons. Electrons constitute more than half of the particle number density in the K-corona.
      2) **Exhibits a continuous spectrum** because Doppler broadening created by the kinetic energy (motion) of the plasma virtually washes out any absorption line features.
      3) **Temperature:** reaches an average of 2,000,000 K. (3.6 x 10^6 F.) due to magnetic agitation (see above). The temperature of the K-corona is determined from the spectrographic analysis of highly excited ions.
      4) **Brightness** is about that of a full moon.
      5) **The K-Corona is Affected by Solar Activity:** Bulbous shape of coronal streamers results from solar magnetic fields and the expulsive force of the solar wind.
         a) **Sunspot Minimum:** 1,000,000 K (1.8 x 10^6 F) Corona extends farther in the equatorial regions than at the poles. Polar plums or brushes are visible.
         b) **Sunspot Maximum:** 4-6,000,000 K (7.2—11 x 10^6 F) Corona is uniform and bright around the entire solar disk.
      6) **X-ray observations of the K-Corona** show it to be composed almost entirely of loops of fluorescing gas, loosely laced between regions of opposite magnetic polarity.
         a) **Light:** Radiation comes from the particles trapped in these higher density magnetic regions.
         b) **Coronal Bright Points:** Bright specks in the X-ray corona mark locations of concentrated, dipolar magnetic fields. Coronal bright points are smaller than sunspots and they exist everywhere including the solar poles and in coronal holes. At least 100 can be seen on the sun at anytime. Coronal bright points seem to increase in number as other

signs of solar activity, such as sunspots decrease, as though to balance the entire magnetic "budget" of the sun.

c) **Coronal Holes:** Revealed in X-ray observations coronal holes are quiet area from which the solar wind flows freely into space along open magnetic field lines.

d) **Coronal Mass Ejections (CMEs):** Large magnetic storms which have their origins in solar flares and active sunspot regions. They eject large quantities of plasma into space. The ejection process may be caused by magnetic reconnection where boundaries of opposite polarity reconnect to become boundaries of similar polarities. This forces material of the opposite polarity into space.

b. **F-Corona:** Also known as the Fraunhofer corona or outer corona.

1) **Light:** Results from the scattering of electromagnetic energy by very small meteoric dust particles which are falling into the sun. It shows the characteristic Fraunhofer (dark absorption) lines of the photosphere

2) **Extends outward** from about 500,000 miles (800,000 km) above the photosphere.

5. **Other types of solar activity** affecting the chromosphere and the corona.

a. **Plages** (also called **flocculi**) are the chromospheric equivalent of faculae in the photosphere. They are found above the regions where faculae occur.

b. **Prominences:** Arched lines of magnetic force made visible by chromospheric and coronal gases. They are usually connected to a magnetically active region of the sun such as a sunspot. Although prominences may appear to be moving away from the sun as they develop, the motion of the gases within their structure appear to move downward along the magnetic flux lines which originate in lower layers of the sun. What makes a prominence especially intriguing is that the gases within it are fluorescing in a magnetic bottle at a temperature of 10,000 K in a region of the sun which is at a temperature of several million Kelvin.

1) **Filaments** are prominences extending into the corona which are seen in silhouette against the photosphere when viewed at a specific wavelengths of light such as hydrogen alpha. These transitions are temperature dependent.

2) **Quiescent (quiet) prominences** appear like descending curtains and may last for weeks. They emerge between the two poles of a bipolar magnetic region.

3) **Active prominences** are short duration phenomena with loops or surges of gas descending along the magnetic field lines joining a bipolar magnetic region.

c. **Flares** are extremely energetic outbursts of solar material along lines of magnetic force of opposite polarity. When these fields connect and cancel each other in what astronomers call **reconnection events**, energy is released in the form of X-ray and ultraviolet photons, as well as high energy protons and electrons.

1) **Flares spray plasma into space**, which is in the form of energetic electrons, protons, and atomic nuclei in proportion to the elemental composition of the sun.
2) **Time Frame of Interaction:** When a large flare occurs in the direction of Earth, the most energetic plasma can reach the magnetosphere of the Earth in as little as 30 minutes. The bulk of the material arrives in a time frame of about 24 hours. Flares can produce very beautiful and very active auroral displays.
3) **Visible Light Limited:** Only about one percent of the electromagnetic radiation released while a flare is in progress is in the visible spectrum, so they are difficult to detect in visible light.

d. **The Solar wind is plasma ejected by the sun** due to the high temperature of the corona which produces sufficient pressures to blow away material from the sun.

1) **Coronal Holes:** The "wind" moves outward along lines of magnetic force, escaping from coronal holes, areas of weak magnetic flux which can be observed in X-rays as darker regions.
2) **Solar wind velocities** at 1 AU vary between 400 to 800 km/sec (250 to 500 miles per second). Gusts can have velocities of 1000 km/sec (600 miles/sec) and are time dependent with the solar rotation period. This discovery established a direct link to geomagnetic disturbances on Earth with the sun's coronal holes acting in a similar manner to the rotation of a garden sprinkler.
3) **Solar Wind Composition:** protons, electrons and the nuclei of helium atoms and other atomic nuclei in proportion to the solar composition. Since the sun is almost totally made up of hydrogen, the protons and electrons escaping from the sun are virtually in equal numbers.
4) **The density of solar wind** is on average is about 10 particles/cm^3 at one AU. Extremes can vary between 1-50 particles/cm^3.
5) **Aurora Borealis/Australis (Northern/Southern lights)** are caused by the capture of plasma escaping the sun, by Earth's magnetosphere. Most of the solar wind escapes capture, but those particles that penetrate Earth's magnetosphere are eventually drawn into the atmosphere in a torus surrounding the N/S magnetic poles. The aurora is created by a direct current of electricity which moves though the atmosphere causing it to fluoresce.

G. **<u>Solar Constant</u>:** 1.94 cal/cm^2 min. The average amount of solar radiation which falls on a square centimeter held perpendicular to the sun outside the Earth's atmosphere at a distance of one AU from the sun. This is equivalent to 1.366 kW/m^2 min. or 0.1366 W/cm^2 min. or (1.388 x 10^6 erg/cm^2 sec) 8.328 x 10^7 ergs/cm^2 min. Solar constant fluctuations measured from numerous spacecraft have shown changes of 0.1 percent (0.001) over intervals of several days up to one week.

1. **<u>One calorie equals</u>** the amount of heat necessary to raise the temperature of one gram of water from 14.5^o C to 15.5^o C at standard pressure.
2. **<u>Bolometer</u>:** A device which measures solar radiation by the means of two blackened strips of platinum, one exposed to the sun, the other kept isolated from the solar radiation. As the exposed strip heats, the electrical resistance of the platinum changes, giving an effective measure of insolation.
3. **<u>Importance of Measuring the Solar Constant</u>:** A fluctuation of only one percent in the solar constant would affect the Earth's average temperature by 1-2^o C. During the last Ice Age, the average temperature of Earth was approximately 5^o C cooler than at present. A drop of 10^o C would completely snowball the Earth and require a 50 percent change in the solar constant to correct the energy deficit.
   a. **<u>Maunder Minimum</u>:** Named after Edward W. Maunder (British astronomer, 1851-1928)… The Maunder minimum represents a period of time between 1645 and 1715 when few sunspots were recorded on the sun. The Earth became about 1^o C cooler. When total solar eclipses occurred, the corona was absent and there were no aurora displays. During this time Europe experienced a cooler climate with bitterly cold winters which has been called the Little Ice Age.
   b. **<u>The Dalton Minimum</u>** (1790-1820), was also a period of fewer sunspots. Consider winter in London as described by Charles Dickens in the Christmas Carol (December 1843). It was cold and snowy. During that time the Themes River froze. The sun is slightly cooler when fewer sunspots are present.

H. **<u>Some important considerations when discussing the sun and other stars</u>**

1. **<u>Kirchhoff's Three Laws of Spectroscopy</u>:**
   a. **<u>Continuous Spectrum (Law I)</u>:** A solid, liquid or gas (under high pressure) when heated to incandescence will emit light at all wavelengths, producing a continuous spectrum.
   b. **<u>Emission Spectrum (Law II)</u>:** A rarefied gas when made to incandesce will produce a spectrum that will show bright lines at wavelengths specific to its chemical composition.
   c. **<u>Absorption Spectrum (Law III)</u>:** If light from a continuous source is allowed to pass through a gas, the gas will subtract certain wavelengths of energy specific to the gas' atomic structure. This is known as an absorption spectrum.
2. **<u>Black Body</u>:** A hypothetical body that is a perfect absorber of all radiation incident upon it. No energy is reflected from it. Perfect absorbers are also perfect emitters.

3. **Black Body Radiation:** The thermal radiation which would be emitted from a black body at a particular temperature. It has a continuous distribution of wavelengths and is known as a black body curve.
4. **Planck's Law:** A formula that derives the intensity of radiation at various wavelengths emitted by a black body. Three concepts are of particular interest.
    a. A perfect radiator at any temperature emits some radiation at all wavelengths, but not in equal amounts.
    b. A hotter black body emits more radiation (per square centimeter) at all wavelengths than does a cooler black body.
    c. A hotter black body emits the largest proportion of its energy at shorter wavelengths than a cooler black body. This is why hot stars appear blue and cool stars appear red.
    d. **Planck's Law:** $E = h\nu$ where E = the energy of the photo
       h = Planck's constant
       6.624×10^{-27} erg sec
       ν = frequency of the radiation or the number of wave crests passing a given point per second

5. **Stefan's Law or the Stefan-Boltzmann Law:** The total energy emitted per unit area per second from a black body is proportional to the fourth power of the temperature.

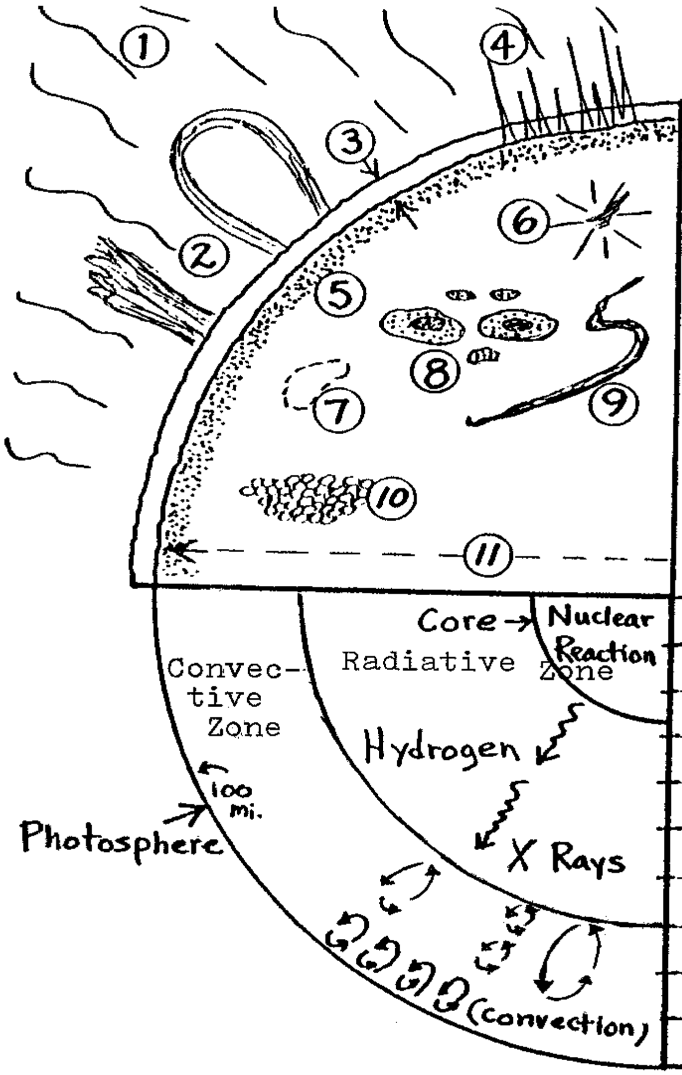
   Energy = sigma (temp)^4 $E = \sigma T^4$

   Where E = total energy
   σ = Stefan-Boltzmann constant = 5.670400×10^{-5} erg/cm^2 K^4 sec
   = 5.670400×10^{-8} j/m^2 K^4 sec
   It relates the total energy emitted to the temperature of the star.

6. **Wien's Law:** A formula which relates the temperature of a black body to the wavelength at which it emits the greatest intensity of radiation.
   Maximum wavelength = $\lambda_{max} = \dfrac{2.898 \times 10^8 \text{ Å T}}{\text{Temperature}}$

   Where the maximum wavelength being emitted by a black body is measured in Angstroms (Å) and the temperature (T) is measured in degrees Kelvin. One Angstrom equal 10^{-8} centimeters.

A SOLAR MODEL



Radius X 1000 Mi.	Temp. X Million °K	% of Mass	Density g/cm³
0	15	1	158
21	14	8	128
43	12	10	84
65	11	15	59
86	9	27	36 Pt(21)
128	7	18	13 Pb(11)
173	5	15	3
259	3	4	2 H_2O(1)
346	1	0.5	0.2
432	(6000°K)	0.5	0

1. Corona
2. Prominences
3. Chromosphere
4. Spicules
5. Limb Darkening
6. Flare
7. Facula
8. Sunspots
9. Filament
10. Granulation
11. Sun's Radius

MASS LOSS WITHIN THE SUN

$E = mc^2$ where E = energy, m = mass, and c = the speed of light in a vacuum

$m = \dfrac{E}{c^2}$ $\quad m = \dfrac{\frac{ergs}{sec}}{\frac{cm^2}{sec^2}}$ $\quad m = \dfrac{\frac{dyne\ cm}{sec}}{\frac{cm^2}{sec^2}}$

erg = work/energy = a dynes worth of force exerted over a distance of one cm.

dyne = force necessary to accelerate $\dfrac{1gm\ 1cm}{sec^2}$

$m = \dfrac{\frac{gm\ cm\ cm}{sec\ sec^2}}{\frac{cm^2}{sec^2}}$ $\quad m = \dfrac{\frac{gm\ cm^2}{sec^3}}{\frac{cm^2}{sec^2}}$ $\quad m = \dfrac{gm}{sec}$

<u>What is the solar constant</u>? It is the amount of incoming solar electromagnetic energy.

$= 1.388 \times 10^6 \dfrac{ergs}{cm^2\ sec}$

<u>The solar constant is then multiplied</u> by the number of cm^2 contained on a sphere (πd^2) with a radius one AU = $2.766 \times 10^{27}\ cm^2 \times 1.388 \times 10^6 \dfrac{ergs}{cm^2\ sec} = 3.839 \times 10^{33} \dfrac{ergs}{sec}$

$m = \dfrac{E}{c^2}$ Speed of light equals $299{,}792 \dfrac{km}{sec} = 2.99792 \times 10^5 \dfrac{km}{sec} \times 10^3 \dfrac{m}{km} \times 10^2 \dfrac{cm}{m}$

$= 2.99792 \times 10^{10} \dfrac{cm}{sec}$

Speed of light squared = $(2.99792 \times 10^{10}\ cm/sec)^2 = 8.98752 \times 10^{20} \dfrac{cm^2}{sec^2} = 8.988 \times 10^{20} \dfrac{cm^2}{sec^2}$

$$m = \frac{E}{c^2} = \frac{3.839 \times 10^{33} \frac{ergs}{sec}}{8.988 \times 10^{20} \frac{cm^2}{sec^2}}$$

$$m = 4.271 \times 10^{12} \frac{gm}{sec}$$

$$m = 4.271 \times 10^{12} \frac{\text{gm}}{\text{sec}} \times \frac{1\text{kg}}{10^3\text{ gm}} \times \frac{1\text{ metric ton}}{10^3\text{ kg}} = \frac{4.271 \times 10^{12}\text{ metric tons}}{10^6\text{ sec}} =$$

$$= 4.271 \times 10^6 \frac{\text{metric tons}}{\text{sec}}$$

$$= 4{,}271{,}000 \frac{\text{metric tons}}{\text{sec}}$$

What is the mass loss in English tons? 1 kg = 2.20462262 lb
1 metric ton = 1000 kg = 2,205 lb or 2.205×10^3 lb

$$= 4.271 \times 10^6 \frac{\text{metric tons}}{\text{sec}} \times \frac{2.205 \times 10^3\text{ lb}}{\text{metric ton}} \times \frac{1\text{ English ton}}{2.000 \times 10^3\text{ lb}} = 4.709 \times 10^6 \frac{\text{English tons}}{\text{sec}}$$

Mass consumption of the sun each second =

$$4.271 \times 10^6 \frac{\text{metric tons}}{\text{sec}}$$

$$4.709 \times 10^6 \frac{\text{English tons}}{\text{sec}}$$

Many DVD programs state that the mass loss of the sun is 4.5 tons/sec while other program tout that the sun's mass loss is 5 tons/sec without indicated which system of units is being used. This must be where this discrepancy originates.

WORD LIST FOR THE SUN

1. **Adiabatic:** A process of heating or cooling in which energy in neither inputted or extracted from the system.
2. **Aurora Borealis/Australis:** Emission in the upper atmosphere of Earth triggered by the capture of plasma by Earth's magnetic field. The plasma can result from a coronal mass ejection or the solar wind.
3. **Binding Energy:** The energy stored within an atom's nucleus. It is responsible for the majority of energy produced in the Proton-Proton reaction. A tighter nuclear structure indicates less bonding energy.
4. **Bipolar Magnetic Field:** A magnetic field that has a north and a south pole.
5. **Butterfly Diagram:** A graph which plots the latitude of sunspot occurrences against time. It shows that sunspot formation decrease in latitude during a solar cycle.
6. **Corona:** The sun's outermost and thinnest atmospheric layer. Temperatures reach to one million K. Most of the sun's X-rays are emitted from this region.
7. **Coronal Holes:** Quiet regions in the corona where plasma can move (spiral) away from the sun along magnetic field lines which are open.
8. **Coronal Mass Ejections:** Energetic releases of plasma in the corona propelled by the forces of opposite magnetic fields in close proximity canceling each other.
9. **Chromosphere:** The transition layer between the photosphere and the corona where prominences originate and the mechanism for heating the corona occurs. Temperatures vary between 4500 K (reversing layer) to over 100,000 K (chromosphere-corona boundary). Its pinkish light when seen edgewise just before totality in a solar eclipse results from the fluorescence of hydrogen. Its thickness is about 1,250 mi (2,000 km).
10. **Convective Zone:** A layer from the sun's surface inward (125,000 mi—29% of the solar radius) where conditions are cool enough to allow some atoms to lose their ionization. Here, hotter columns of thermal energy rise en mass to the sun's surface, dissipate their energy, and sink back into the convective zone to be reheated and rise.
11. **Core:** The innermost region of the sun (0-0.25 of the solar radius) where energy production occurs via the Proton-Proton reaction. Densities are as high as 150 gm/cm^3 and temperatures with temperatures at 16 million K. In this area matter is being converted into energy at the prodigious rate of 4.2 million metric tons/sec.
12. **$E=mc^2$:** The equation which expresses the amount of energy obtainable from a specific quantity of matter.
13. **Electron Volt:** The amount of energy gained by the charge of a single electron moved across an electric potential difference of one volt. It is equal to 1.602×10^{-19} joule or 1×10^{-12} erg.
14. **Faculae:** Brighter white light regions in the photosphere near sunspots. These areas compensate for the spot's cooler temperature by allowing a greater energy outflow. They are hotter than the surrounding photosphere and therefore appear brighter. They lie below plages.
15. **Field:** A condition of matter which produces a force that goes beyond the boundary of the matter creating it. Magnetic fields result when the spin axes of atom point in similar directions or there is a flow of changed particles along a flux lines.
16. **Filaments:** Prominences seen at a specific wavelength of light projecting against the disk of the sun.

17. **Flare:** A very energetic outburst of plasma and radiation trigged by a reconnection event where magnetic fields of opposite polarity neutralize each other.
18. **Gravitational Contraction**: The first scientific explanation for understanding the sun's energy output. As a gas contracts it heats. The sun's energy output was maintained by its slow contraction.
19. **Granulation**: A rice grain appearance to the surface of the sun created by areas of ascending gases (brighter) and boundaries, where cooler, darker gases are descending.
20. **Helioseismology:** An area of research in solar physics where oscillations are observed at the sun's surface to interpret conditions within the sun. Helioseismology has shown that the interior of the sun rotates differentially.
21. **Hydrostatic Equilibrium**: The balance between gravitational contraction (inward) and energy production (outward) which maintains the sun as a stable star.
22. **Limb Darkening**: The dimming of the sun near its limb. The increasingly tangential line of sight near the limb permits the observer to only view only higher/cooler layers of the photosphere. Because the photospheric layers are cooler they make the limb of the sun look darker.
23. **Magnetic Flux Lines**: Stronger areas of magnetic intensity within a magnetic field.
24. **Maunder/Dalton Minimums:** Periods where sunspot activity radically decreased and the Earth's climate cooled.
25. **Negative Hydrogen Ion:** It occurs when an electron attaches itself loosely to a hydrogen atom. The attachment of the electron releases the energies that we see as visible light coming from the sun.
26. **Neutrinos:** A small, virtually massless particle that possesses an extremely low probability of interacting with matter.
27. **Nuclear Fission:** The process by which the nucleus of an atom is split apart into two smaller nuclei. Nuclear power plants derive their power from the fissioning of Uranium 236 and Plutonium. When fission occurs, the nuclei of the daughter particles are smaller and more tightly bound. This release in binding energy produces high energy photons.
28. **Nuclear Fusion**: The process by which the nuclei of atoms are combined to form heavier nuclei with greater numbers of protons, neutrons or both. The sun's energy output is sustained through the fusing of hydrogen into helium. Binding energy is released because the nucleus of a helium atom is more tightly bound than the binding energy of the individual protons which contribute to the synthesis. See the Proton-Proton reaction…
29. **Penumbra**: The lighter membrane region of a sunspot surrounding the umbra. It represents an outflow of gases along magnetic field lines emanating from the spot's center.
30. **Photosphere**: The visible layer, about 200 miles (300 km) thick, where visible light can finally escape. Its temperature is about 5800 K. It is the location of sunspots. The density of the photosphere is much less than the density of the air that we breathe.
31. **Plages**: Regions in the chromosphere near sunspots where energy output is greater. They lie over faculae and show that active regions permeate many different solar layers.
32. **Plasma**: The most common elemental phase of the gases in the sun and in all stars. It is a hot gas composed mostly of positively charged ions and electrons. In the light emitting layer of the sun, many of the hydrogen ions are negatively charged.
33. **Prominences**: Projections of coalescing plasma seen against the limb of the sun. They are associated with sunspots, originate in the chromosphere, and maintain more or less chromospheric temperatures in a magnetic bubble as they project into the corona.

34. **Proton-Proton Reaction:** The main energy source of the sun. It accounts for 98 percent of the sun's energy production. The process involves $2{}_1H^1$ yields ${}_1H^2$; ${}_1H^2 + {}_1H^1$ yields ${}_2He^3$; $2{}_2He3$ yields ${}_2He^4 + 2{}_1H^1$
35. **Radiative Zone**: The area between the sun's core and convective zone (0.25 to 0.7 of the sun's radius) where energy is being transported mainly by photons which are being scattered by electron and absorbed and reemitted by ions of H and He. Since absorption and emissions occur in random directions, it takes hundreds of thousands to millions of years for a photon to escape from this region. Gamma rays which are being produced in the sun's core are reduced gradually to mostly visible light in a ratio of 1:2000 by the time they reach the photosphere.
36. **Solar Activity**: The wide variety of phenomena that can be seen from the sun's "surface" and throughout its atmosphere.
37. **Solar constant:** The average amount of solar radiation that falls on an area held perpendicular to the sun outside the Earth's atmosphere at a distance of one AU from the sun. It is equal to 1.388×10^6 erg/cm^2 sec.
38. **Solar Wind**: The flow of plasma away from the sun along open magnetic field lines.
39. **Spicules**: Brush-like structures in the chromosphere which magnetically lash at and heat the corona.
40. **Sun**: Earth's self-luminous daystar which sustains itself through the thermonuclear fusion of H to He in its core.
41. **Sunspots**: Regions of intense magnetic activity where upward convection is stifled. Sunspots appear darker against a brighter photosphere because they are cooler.
42. **Supergranulation**: Large scale 20,000 miles (30,000 km) cells of outward flowing chromospheric material. At their boundaries are found the spicules.
43. **Umbra**: The darker region of a sunspot (8000^o F or 4300 K).

NOTES

CAN YOU ANSWER THE FOLLOWING QUESTIONS/STATEMENTS ABOUT THE SUN?

INTRODUCING THE SUN

1. Supply the following information about the sun:
   a. distance from Earth .... ________________
   b. diameter .... ________________
   c. volume (in comparison to Earth) .... ________________
   d. mass (in comparison to Earth) .... ________________
   e. density .... ________________
   f. "surface" temperature .... ________________
   g. core temperature .... ________________

ENERGY PRODUCTION WITHIN THE SUN

2. The two most abundant elements which are contained within the sun are ________________ and ________________. Those elements with an atomic number greater than two can be collectively referred to as ________________.

3. All elements contained within the sun are found in the ________________ state. In fact most of the material is in the form of a ________________.

4. The sun powers itself through a conversion of ________________ into ________________. Albert ________________ laid the foundation for astrophysicists to speculate upon how the sun produces its own energy.

5. The nuclear reaction which powers the sun is referred to as the _______________ reaction.

6. Essentially, during this process four ________________ (atoms) fuse via a distinct series of t______________ reactions to produce a helium nucleus. Since a helium nucleus, which is composed of two ________________ and two ________________, weighs MORE/LESS (circle one) than four hydrogen protons, some ________________ has been converted into ________________. The amount of matter converted into energy is 0.7 percent per reaction.

7. Even though approximately ________________ million tons of matter are annihilated every second, the chances that a particular hydrogen proton will go into a reaction at any given moment is **extremely** SMALL/LARGE (circle one). It will take about 10 billion years for approximately ________________ percent of the original hydrogen in the core to be converted into helium.

8. The energy created in the core of the sun takes on the order of ____________________ years to travel through its interior and finally escape from the "surface." Thereafter, only about _______________ minutes elapses before that same energy reaches the Earth, 93 million miles (150 million km) away.

9. During its passage from the core to the surface, the energy per photon INCREASES/ DECREASES (circle one). During this same period the number of photons carrying this energy towards the surface INCREASE/DECREASE (circle one).

10. The by-products of the proton-proton reaction are high intensity gamma radiation, positrons (electrons with a positive charge), and n_______________. These latter "particles" have a HIGH/LOW (circle one) probability of reacting with matter and probably possess no mass. Gamma rays are almost immediately absorbed and reemitted as x-rays, while positrons are annihilated on the spot by free electrons and changed into energy.

11. Ray Davis a chemist at the Brookhaven National Laboratory in New York state has built a _______________ detector about one mile underground in the Homestake Gold Mine near Lead, South Dakota. In essence he has filled a 100,000 gallon container with perchloroethylene C_2Cl_4 (dry cleaning fluid) in the hopes of changing an isotope of chlorine (37) into an isotope of (detectable) radioactive argon. The nuclear reaction is triggered by a neutrino which is produced by a variant of the proton-proton reaction in the sun. Based upon the rate of energy escaping from the sun, it is possible to calculate the amount of matter being annihilated, and therefore the number of neutrinos being produced, as well as the probability that these neutrinos will react with the fluid in the tank. Davis' results have consistently shown that the number of radioactive argon atoms being produced in his tank
____
____

12. The sun is a stable star because throughout its various layers the force of gravity created by its mass balances the outward pressures resulting from its energy production. This is termed ____________________________.

ENERGY TRANSPORTATION WITHIN THE SUN

13. The temperature of an object is a direct function of the average ____________________ (½mv^2) which the atoms and molecules of that body possess. At absolute zero, all _______________ motion ceases. The absolute scale for measuring temperature is called the _______________ scale and each degree equals _______________ Fahrenheit degrees.

14. The three types of energy transportation mechanisms are known as _______________, _______________, and _______________.

15. When warmer gases or fluids move in bulk into cooler regions, that type of energy transfer is said to be ________________. The warmer gases or fluids are less dense than the surrounding medium. This makes them ________________ (Think of a direction of movement) because they obtain buoyancy with respect to their surrounding medium.

16. The handle of a metal spoon in a pot of soup soon becomes warm because heat is transferred through physical contact from one atom to another atom along the length of the spoon via ________________.

17. Energy which is transferred across a space from an emitter to an absorber without affecting the matter in between is ________________ to that position. When you are warmed by a fire or the sun, the energy being absorbed warms the skin by causing an increase in its molecular motion. Virtually no energy goes into heating the matter in the space between you and the source.

18. The light that we see, as well as all of the energy of the electromagnetic spectrum, can be described as being either a ________________ or a ________________. For the purposes of energy transfer within the sun, it is best to think of the radiation traveling through this star as a ________________.

19. The three interior layers of the sun through which a photon of light must pass prior to escaping into space are called the ________________, the ________________ zone, and the ________________ zone. The sun produces its energy in the ________________ which comprises about 25 percent of its radius.

20. From the center of the sun's core through about 70 percent of its radius, the mechanism of energy transport is ________________.

21. Throughout this zone mentioned in the last statement, energy is transported via the s_______________ of photons by electrons and the _____________________ (the detachment) of electrons from ions by photons.

22. Throughout the last 30 percent of the solar interior, the dominant energy transportation mechanism becomes ________________. *The transition results from lower temperatures which allow electrons to begin to attach themselves onto the nuclei of atoms. Upcoming radiation excites and ionizes these atoms again with energy being absorbed in the process. This causes heat to be trapped at this level and temperatures to drop more slowly. The result is an increase in the temperature gradient above this level to the point where convection can occur.

23. At the sun's "surface" energy escapes and heads into space via the process of ________________.

THE SUN AS A MAGNETIC DYNAMO

If you have not done so already, read the section entitled "Magnetic Fields" in Session Five and answer the questions pertaining to magnetic fields in Session Six before proceeding.

24. All of the visible effects which can be seen on the sun are directly related to ____________________.

25. The solar magnetic field probably originates in the CORE/RADIATIVE ZONE/ CONVECTIVE ZONE (circle one) of the sun's interior. It results from the flow of _______________ currents within this region and the _______________ of the sun, which may be more rapid than what is observed at the surface.

26. TRUE OR FALSE (circle one): The planets of our solar system all lie within the magnetic influences of the sun.

VIEWING THE SUN IN WHITE LIGHT

27. The light-emitting region of the sun, about 100 miles (160 km) in thickness is called the _______________. Above this layer, is a 1300 mile (2000 km) region of increasing temperatures called the _______________. This area emits light at certain discrete wavelengths, predominately as a result of the hydrogen atom. The least dense, but hottest portion of the solar atmosphere, easily visible during totality in a solar eclipse, is called the _______________.

28. Through a telescope, the edge of the sun appears less bright than the center of the disk. This is termed ____________________ and results from our ability, to view only the upper regions of the sun's photosphere near the solar limb. These areas appear darker because they are WARMER/COOLER (circle one) than the lower levels of the photosphere.

29. Describe one safe method by which the sun can be observed in white light.
____
____

30. When viewing the sun through a telescope, it is considered foolish to use a dark absorbing filter. Telescopes _____________ the light of the sun and focus this hot, bright image near the position of the dark filter causing it to become hot. If the filter _______________, the observer is likely to suffer permanent eye damage or even blindness. If you own one of these accessories, THROW IT AWAY!!!

31. A highly resolved view of the photosphere reveals a speckled "surface" which is termed ________________. This phenomenon represents the end of the line for the energy transportation mechanism known as ________________. The brighter regions of these cells represent warmer gases which are moving _________________, while the darker cell boundaries are composed of cooler gases drifting ________________.

SUNSPOTS

32. TRUE OR FALSE (circle one): Sunspots are considered to be storms on the photosphere of the sun.

33. In the convective layer of the sun ______________________ can become tangled and intensified. When this happens they can rise to the surface and cause a slowing of the convection in that region. This WARMS/COOLS (circle one) that area causing it to EMIT MORE/LESS (circle one) energy. This makes the area appear LIGHTER/DARKER (circle one) than the surrounding region.

34. This phenomenon as noted in the last statement is called a ________________. Their numbers vary in a mysterious ________________ year cycle, which, if all magnetic considerations are taken into account, is really a ________________ year period.

35. Sunspots can last from ________________ to _______________ and in more mature examples possess a darker, central region called the ________________ and a lighter region termed the ________________. Temperatures are lower by about 2000 K (3600° F) in the darker regions.

36. Sunspots near the equator of the sun circuit the sun in a SHORTER/LONGER (circle one) period of time compared to sunspots at higher latitudes. The motion of sunspots proves not only that the sun is ________________, but at different speeds depending upon the latitude at which the spot is found. This difference in the rate of spin of the sun at various latitudes is called ________________ rotation.

37. According to Babcock (1960) the ________________ rotation of the sun causes the magnetic field lines to become stretched around the sun many times. Entanglement of the field occurs between 30 and 40 degrees north and south latitude. The field here becomes intensified and buoyant, causing it to rise to the surface, creating the ________________ that we see. Over a period of years, the regions of highest magnetic intensity gradually migrate towards the ______________ as the solar rotation winds up the field. The opposite fields eventually come together near the equator and are neutralized.

38. A sunspot group usually appears in two clumps. This indicates that they are bipolar which means that they normally contain regions of ________________ magnetic polarity.

39. During one sunspot cycle the leading spots of each hemisphere are of the SAME/OPPOSITE (circle one) polarity. During the next cycle, the polarities of the leading spots of each hemisphere reverse themselves, thus making the true magnetic cycle of the sun equal to a period which averages ________________ years.

40. Sunspots may have some relationship to climate. The sun's output of energy is GREATER/SMALLER (circle one) during sunspot maximum and just the opposite during sunspot minimum. During the period between 1645 and 1715 (in regards to sunspot numbers) ____. This has become known as the ________________ minimum. Europe during this period (1400-1850) experienced climatically _____________________________.

THREE LAWS OF SPECTROSCOPY

41. A solid, liquid, or gas (under high pressure) when heated and made to incandesce (glow) produces a ________________ spectrum.

42. A rarefied gas when made to glow produces bright spectral lines at wavelengths distinctive only to that gas. This type of spectrum is called an ________________ spectrum.

43. A cool, rarefied gas found between a continuous source and an observer will produce an ________________ spectrum.

44. The name of the German physicist who formulated the three laws of spectroscopy mentioned above was Gustav **K**________________ (1824-87).

45. According to the man in the previous question, a continuous spectrum can only be produced by a solid, liquid or ________________ (under pressure) which is heated to incandescence. The pressures in the photosphere are HIGH/LOW (circle one) and WILL/WILL NOT (circle one) allow the continuum to be formed in the traditional manner. In the sun it is the loose attachment of an extra electron to the ________________ atom which is responsible for the formation of the continuum. When the extra electron attaches to form a negative ion, energy of varying wavelengths is ABSORBED/GIVEN OFF (circle one). This produces the continuum. When the ion is ionized, just the opposite situation happens.

OBSERVING THE SUN AT OTHER WAVELENGTHS

46. When white light enters a prism, it is dispersed into the rainbow of colors known as the ________________. An astronomical device which creates such an image, but with a high degree of resolution (clarity) is called a ________________.

47. When high resolution is obtained, it is noticed that dark ________________ lines are superimposed on the brighter background known as the ________________. These darker bands represent the fingerprints of the various ________________ which the sun or another star contains.

48. Energy is absorbed by various atoms in the solar (level) ________________. The electrons of these atoms become **ex** ________________, jumping to specific orbital levels which absorb unique amounts of energy. Eventually, when the electron spontaneously returns to a lower energy state, it will **em** ________________ energy at the same intensity of absorption. The energy is absorbed unidirectionally, as it leaves the sun, but emitted randomly with respect to direction when the electron moves down the energy ladder. The result is a(n) ________________ line on the continuous spectrum where the solar energy of that specific wavelength has been subtracted.

49. Although most absorption lines are formed in the ________________ of the sun, a few, such as the hydrogen alpha line (6563 Å), and the H and K lines of ionized calcium are created in the ________________. This latter region is transparent in visible light, but not at the wavelengths of energy which are absorbed in this layer. If the layer is viewed in the light of one of these specific ________________ lines, the region can be isolated for observation. The type of astronomical instrument which can accomplish this is called a ______________________.

50. Satellite observations of the sun made in the **u** ________________ and **x** ________________ portions of the electromagnetic spectrum reveal HOTTER/COOLER (circle one) regions in the outermost solar level called the ________________. These areas are also less dense, so pressures are lower. Magnetic flux lines extend outward into space and carry plasma away from the sun in these regions to create the ______________________. The features themselves are called **c**________________ **h**________________ (two words).   .

51. There IS/IS NOT (circle one) a direct relationship between activity occurring at one level of the sun and activity occurring at a higher or lower level. In other words, does solar activity at one level influence activity in other levels?

MAGNETIC INFLUENCES-- TYING IT ALL TOGETHER

52. Almost all features of the sun can be attributable to the action and interaction of the sun's plasma with its _____________________.

53. A ________________ results when a region of high magnetic intensity breaks into the photosphere to inhibit convection and cool down that region.

54. This magnetic influence extends far into the sun's corona where large arcs of gas can be made to incandesce and travel along the field lines. These features which protrude from the limb of the sun are most easily seen in monochromatic light or during a _______________ eclipse of the sun. These features are called _______________.

55. Along the boundaries of large cells of flowing chromospheric gas, called supergranules, where magnetic fields are intensified, jets of gas called _______________ form. They bob up and down in periods of only a few minutes and (through acoustical vibrations--sound waves) may be responsible for heating the tenuous matter in the sun's _______________ to over one million Kelvin (2-6 million F).

56. Through less energetic regions in the solar corona, known as coronal _______________, plasma may leave the gravitational field of the sun to be swept outward along with the solar magnetic field. This plasma flow is known as the ____________________. Coronal holes appear to be regions where an open magnetic field exists, allowing gases to flow outward along the field lines. This lowers the pressure in the areas where coronal holes regions and therefore _______________ the temperature. Where normal regions of the corona occur, magnetic fields loop back into the corona bottling up this plasma, and preventing its escape. Temperatures and pressures must be _______________.

57. _______________ are the most energetic events which occur on the sun. They are associated with common features in the photosphere known as _______________. They may possibly be created by magnetic field lines which become disconnected and spray energetic plasma into space.

58. If this plasma is directed towards Earth, radio disruptions and spectacular _______________ displays can be the result.

ANSWERS TO SESSION THIRTEEN QUESTIONS

INTRODUCING THE SUN

1. a. 93 million miles (149 million kilometers)
   b. 864,000 miles
   c. 1,000,000 Earths
   d. 333,000 Earths
   e. 1.4 $^{gm}/_{cm^3}$
   f. 10,000° F (5800 K)
   g. 27 million °F (15.0 million K)

ENERGY PRODUCTION WITHIN THE SUN

2. hydrogen, helium, metals (strictly astrophysical jargon)
3. gaseous, plasma
4. mass, energy, Einstein
5. proton-proton
6. protons (hydrogen), thermonuclear, protons, neutrons, LESS, mass, energy
7. five, SMALL, 50 (more like 60 percent--50 is easier to remember)
8. one million, eight
9. DECREASES, INCREASE
10. neutrinos, LOW
11. neutrino, are far fewer than what theory has predicted
12. hydrostatic equilibrium

ENERGY TRANSPORTATION WITHIN THE SUN

13. kinetic energy, atomic (molecular), Kelvin, 1.8 (almost two)
14. conduction, convection, radiation
15. convective, rise
16. conduction
17. radiated
18. wave, bullet (photon), bullet (photon)
19. core, radiative, convective, core
20. radiative
21. scattering, photoionization (ionization)
22. convection
23. radiation

THE SUN AS A MAGNETIC DYNAMO

24. magnetic fields
25. CONVECTIVE ZONE, electrical, rotation
26. TRUE

VIEWING THE SUN IN WHITE LIGHT

27. photosphere, chromosphere, corona
28. limb darkening, COOLER
29. Project the image of the sun onto a screen, using the telescope as a projection system. Filter the sun's light prior to its entering the telescope.
30. concentrate, breaks
31. granulation, convection, upward, downward

SUNSPOTS

32. FALSE
33. magnetic field, COOLS, LESS, DARKER
34. sunspot, 11, 22
35. hours, months, umbra, penumbra
36. SHORTER, rotating, differential
37. differential, sunspots, equator
38. opposite (north/south)
39. OPPOSITE, 22
40. GREATER, there were virtually no sunspots recorded on the sun, Maunder, exceptionally severe winters

THREE LAWS OF SPECTROSCOPY

41. continuous
42. emission
43. absorption
44. Kirchhoff
45. gas, LOW, WILL NOT, hydrogen, GIVEN OFF

OBSERVING THE SUN AT OTHER WAVELENGTHS

46. spectrum, spectrograph (spectroscope)
47. absorption, continuum, elements
48. photosphere, excited, emit, dark (absorption)
49. photosphere, (lower) chromosphere, absorption, spectroheliograph (spectrohelioscope)
50. ultraviolet, x-ray, HOTTER, corona, solar wind, coronal holes
51. IS

MAGNETIC INFLUENCES-- TYING IT ALL TOGETHER

52. magnetic field
53. sunspot
54. total, prominences
55. spicules, corona
56. holes, solar wind, decreases, higher
57. flares, sunspots
58. auroral

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