General Astronomy (29:61)
Fall 2012
Lecture 22 Notes, October 22, 2012

1 The Sun as a Solar System Object, Continued

1.1 The opacity in the photosphere

What causes the opacity in the solar photosphere? Opacity can occur via atoms or molecules absorbing a photon and changing energy level, or by becoming unbound as a result of the absorption. There are also processes by which a free electron (not bound in an atom or molecule) can absorb a photon.

The problem in understanding the opacity of the photosphere was that no one could think of a transition of an atom or molecule which would provide the opacity of the photosphere over the entire visible spectrum.

It was finally deduced in 1943 by the famous physicist S. Chandrasekhar. The opacity is due to absorption by the H^- ion. The H^- ion consists of one proton and two electrons. You might not think such a thing could exist (you didn't hear about it in high school chemistry), but it doesn't. As you might expect, the ion is not very tightly bound. Its *ionization potential* $\chi = 0.75$ eV. The opacity in the photosphere is provided by

$$H^- + h\nu \rightarrow H + e \tag{1}$$

and H^- is reformed by

$$H + e \rightarrow H^- + h\nu \tag{2}$$

The H^- ion exists in a fairly narrow range of temperatures; in cooler gas, there are not enough electrons around to form a significant number of ions. At higher temperatures, the electron thermal speeds are too fast to permit the formation of this flimsy ion. The density also has to be high enough so that the replenishment of H^- ion can occur fast enough. This ceases to be the case at the top of the photosphere. However, there are enough of these ions in the photosphere to make it opaque.

1.2 Limb darkening

There is an interesting phenomenon that is readily noticeable when you look at the disk of the Sun. The regions near the edge appear noticeably darker than the center of the disk ($\longrightarrow$ look at pictures in the online notes.). This is the phenomenon of limb darkening. This is another consequence of the fact that the temperature in the photosphere drops as you go higher. The idea is illustrated graphically in Figure 7.2. Since the path through the atmosphere is longer for lines of sight near the limb, the gas becomes optically thick higher in the atmosphere where the gas is cooler. A law of blackbody radiation is that a hot blackbody is brighter than a cool blackbody at all wavelengths.

2 Solar Convection

The energy generation in the Sun occurs through nuclear fusion reactions in the center of the Sun, where the temperature is of order 15 million K (yea, we're sure about this). For the Sun to shine, this energy has to flow out from the center of the Sun to the surface where it is emitted to space.

In most of the interior of the Sun, this heat flow occurs via *radiation*. However, in the last 20 % of so, it occurs by *convection*, the buoyant overturning of cool fluid by hot fluid. ($\longrightarrow$ look at pictures in the online notes.)

An observational demonstration of this convection is the phenomenon of *granulation* or *granules*. These can be seen in small solar telescopes.

3 Solar Rotation

The Sun rotates on its axis. This is very easily seen by observing the passage of sunspots across the disk of the Sun. The rotation period of the Sun is 27 days. An interesting feature that since the Sun is not a rigid body, all parts of it don't have to rotate together, and they don't. The rotation period is several days longer at the solar poles. This latitude-dependent rotation is called *differential rotation*.

The combination of differential rotation and convection is fundamental for the origin of the solar magnetic field, which underlies solar activity.

4 Other Parts of the Solar Atmosphere

4.1 The Solar Chromosphere

During a solar eclipse, one can see a reddish glow in the solar atmosphere, and sometimes what seem to be glowing red clouds.

($\longrightarrow$ look at pictures in the online notes.) These are at higher altitudes than the photosphere, and the gas is deduced to have higher temperature than the photosphere

(Didn't I tell you the temperature went down as you go up in the solar atmosphere?) As your book states, the chromosphere is also the place where the element helium was discovered in 1868. You also get a view of the corona in solar telescopes that observe in the Balmer Alpha line of hydrogen. The Physics and Astronomy department has several of these telescopes.

4.2 The Solar Corona

During total solar eclipses, one can see a glow around the Sun. This is visible to the naked eye at those times ($\longrightarrow$ look at pictures in the online notes.). With the SOHO spacecraft, an instrument called LASCO allows us to see the solar corona all the time (look at SOHO URL on the course web site. If often shows structure and detail. The intensity of the light of the corona is measured in units of 10^{-6} of the brightness of the solar disk.

In the 19th century, astronomers took spectra of the corona during eclipses. An example of an eclipse spectrum is in the online notes. Many of the spectra lines were identified, such as the Balmer Alpha line of hydrogen or lines of helium. However, two bright lines, the "red line" and the "green line" were not identified. This was a big mystery in astronomy until the 1930s, when they were identified as lines from highly ionized ions of iron, FeX and FeXIV.

4.3 Question for the Scholarly Assembly

. What does this mean? What is the significance of emission lines of highly stripped ions from the solar corona? What does it tell us about physical conditions in the corona?