Tuesday minilectures on Universe Ch.18, The Sun.

Team 1, Sec. 1, E=mc^2, #27, 28
Team 2, Sec.2-3, Energy transformations, Q9, #34
Team 3, Sec.4-5, Neutrinos and photosphere, Q10, #35
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These will be due the second day of spring quarter.

27. (a) Estimate how many kilograms of hydrogen the Sun has consumed over the past 4.6 billion years, and estimate the amount of mass that the Sun has lost as a result. Assume that the Sun's luminosity has remained constant during that time. (b) In fact, the Sun's luminosity when it first formed was only about 70% of its present value. With this in mind, explain whether your answers to part (a) are an overestimate or an underestimate.

\[ \frac{3.9 \times 10^{26}}{3 \times 10^8} \text{Watts} = \frac{9}{5} \]

Luminosity = Power = Energy / Time

Energy burned = Power \cdot Time = \frac{4.6 \times 10^9 \text{yr}}{\text{yr}} \cdot \frac{2 \times 10^{30} \text{kg}}{3 \times 10^8 \text{yrs}}

\[ \frac{6.3 \times 10^{26}}{2 \times 10^{30}} \text{Kg} = \frac{100}{1000} \text{Mio} \approx 3 \times 10^{-4} \text{Mio} \]

(b) If L was less in the past, then the Sun burned more slowly, and consumed less mass than \( \approx \) a.

28. (a) A positron has the same mass as an electron (see Appendix 7). Calculate the amount of energy released by the annihilation of an electron and positron. (b) The products of this annihilation are two photons, each of equal energy. Calculate the wavelength of each photon, and confirm from Figure 5-7 that this wavelength is the gamma-ray range.

\[ E = 2mc^2 \text{ where } m_p = m_e = m \]

\[ E = 2(0.511 \text{ MeV}) = 1.022 \times 10^6 \text{ eV} \]

\[ \frac{E}{mc^2} = \frac{0.511 \text{ MeV}}{0.511 \times 10^6 \text{ eV}} \]

\[ Z = \frac{hc}{1.24 \times 10^3 \text{ eV} \cdot \mu m} = 2.49 \times 10^{-3} \text{ nm} \quad \text{very short} \]

\[ Wavelength^{\text{short}} \]
34. In a typical solar oscillation, the Sun's surface moves up or down at a maximum speed of 0.1 m/s. An astronomer sets out to measure this speed by detecting the Doppler shift of an absorption line of iron with wavelength 557.6099 nm. What is the maximum wavelength shift that she will observe?

$$\frac{\Delta \lambda}{\lambda} = \frac{v}{c} = \frac{10^{-3}}{3 \times 10^8 \text{ m/s}} = \frac{2}{3} \times 10^{-9}$$

Tiny shift!

$$\Delta \lambda = \frac{\Delta \lambda}{\lambda} \lambda \cdot \lambda = 557.6099 \text{ nm} \left( \frac{1}{3 \times 10^{-9}} \right) = 1.86 \times 10^{-7} \text{ nm}$$

35. The amount of energy required to dislodge the extra electron from a negative hydrogen ion is $1.2 \times 10^{-19}$ J. $= E_{\text{extra}}$

(a) The extra electron can be dislodged if the ion absorbs a photon of sufficiently short wavelength. (Recall from Section 5-5 that the higher the energy of a photon, the shorter its wavelength.) Find the longest wavelength (in nm) that can accomplish this.

(b) In what part of the electromagnetic spectrum does this wavelength lie?

(c) Would a photon of visible light be able to dislodge the extra electron? Explain.

(d) Explain why the photosphere, which contains negative hydrogen ions, is quite opaque to visible light but is less opaque to light with wavelengths longer than the value you calculated in (a).

$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \text{ J} \cdot \text{m}^2}{1.2 \times 10^{-19} \text{ J}} = 1.66 \times 10^{-6} \text{ m} = 1660 \text{ nm}$$

Visible light has $\lambda$ between about 400-700 nm.

Shorter $\lambda$ light can get absorbed by $H^-$ when it dislodges the extra $e^-$. (If there is extra energy, it goes to electron kinetic energy).

Longer $\lambda$ light is not energetic enough to be absorbed in this reaction, so it streams more freely through.
37. Calculate the wavelengths at which the photosphere, chromosphere, and corona emit the most radiation. Explain how the results of your calculations suggest the best way to observe these regions of the solar atmosphere. (Hint: Treat each part of the atmosphere as a perfect blackbody. Assume average temperatures of 50,000 K and 1.5 × 10⁶ K for the chromosphere and corona, respectively.)

Blackbody of temp T has

As peak wavelength at

\[ \lambda = \frac{3 \times 10^{-3} \, \text{m}}{T(\text{K})} \]

(a) Photosphere has \( T = 5800 \, \text{K} \)

\[ \lambda = \frac{3 \times 10^{-3} \, \text{m}}{5800} \approx 5.17 \, \text{nm} \]  

Nice, visible

(b) Chromosphere \( T = 57,000 \, \text{K} \)

\[ \lambda = \frac{3 \times 10^{-3} \, \text{m}}{5 \times 10^4} \approx 600 \, \text{nm} \]

(c) Corona \( T = 1.5 \times 10^6 \, \text{K} \)

\[ \lambda = \frac{3 \times 10^{-3} \, \text{m}}{1.5 \times 10^6} \approx 2 \, \text{nm} \]

40. (a) Find the ratio of the energy flux from a patch of a sunspot's penumbra to the energy flux from an equally large patch of undisturbed photosphere. Which patch is brighter? (b) Find the ratio of the energy flux from a patch of a sunspot's penumbra to the energy flux from an equally large patch of umbral. Again, which patch is brighter?

\[ T_{\text{umbra}} = 4300 \, \text{K} \]
\[ T_{\text{penumbra}} = 5000 \, \text{K} \]
\[ T_{\text{photosphere}} = 5800 \, \text{K} \]

Energy flux \( F = \sigma T^4 \)

\[ \frac{F_{\text{penumbra}}}{F_{\text{photosphere}}} = \frac{\sigma T_{\text{penumbra}}^4}{\sigma T_{\text{photosphere}}^4} = \left( \frac{T_{\text{penumbra}}}{T_{\text{photosphere}}} \right)^4 = \left( \frac{5000}{5800} \right)^4 = \]

\[ \frac{F_{\text{penumbra}}}{F_{\text{umbra}}} = \frac{\sigma T_{\text{penumbra}}^4}{\sigma T_{\text{umbra}}^4} = \left( \frac{T_{\text{penumbra}}}{T_{\text{umbra}}} \right)^4 = \left( \frac{5000}{4300} \right)^4 = \]