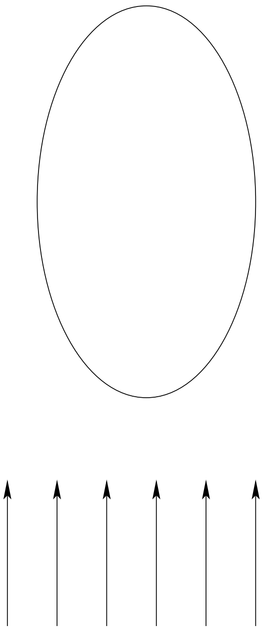
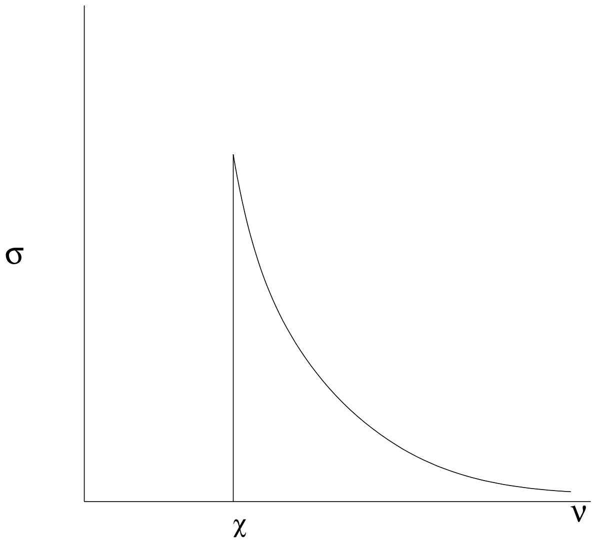
A311, 2005-09-28

1. The spectrum of the Sun looks like a blackbody modified by absorption lines. Explain this spectrum in terms of the *temperature of the effective emitting gas you are seeing at each wavelength*, invoking the concept of optical depth.

2. A cloud (picture below, left) is being illuminated from one side by a hard spectrum of ionizing (UV and X-ray) radiation. The cloud is optically thick to radiation with just enough energy to ionize Hydrogen. Given that the cross section for photoionization is largest right at the "ionization edge" and drops after that (picture below, right), draw and explain the structure of the cloud. It includes H_2, HI, and HII regions.





3. Consider the cloud above. Suppose that the ionizing radiation is actually thermal. The dissociation energy for H_2 is lower (but close to) than the ionization potential for atomic H. The cross section for photodissociation of H_2 is qualitatively similar to the photoionization cross section of HI.

Take the distribution of electrons in the *molecular* gas which have just been knocked off of a H_2 molecule. Take *just* those electrons which have yet to collide and termalize with the rest of the molecular gas. If you assign an average temperature for those electrons such that $\frac{3}{2}kT = < \frac{1}{2}mv^2 >$, and you assume that the star has a temperature such that the peak of the blackbody is at wavelengths longer than the wavlength of light able to photodissociate H_2, how does this bizarrely defined average electron temperature compare to the star's temperature? Explain.

How does this bizarrely defined average electron temperature compare to the temperature of the thermalized molecular gas?

4. An O6 and B1 star both maintain a region of ionized gas around them. There is a balance between ionizations caused by UV photons emitted by these stars and recombinations caused by collisions between ions and electrons.

Would the flux ratio of [OIII]/Hβ be higher in the region around the O6 star, or around the B1 star? Explain. Ask for any data you think you might need.

. . . continued on reverse. . .

5. **(a)** HI has an ionization potential of 13.6eV. At what gas temperature do you expect substantial amounts of HI to be collisionally ionized?

(b) The Cosmic Microwave Background is emission from gas in the early Universe that has just become transparent. Before that emission, the Universe was opaque, so photons and the plasma was in equilibrium. At the time of "recombination", protons captured electrons to make Hydrogen atoms, and the Universe became transparent, giving us a snapshot of the thermal photon spectrum at that moment. After correcting for the redshift, we find that that temperature is about 3000K (to one significant figure).

How does this temperature compare to the temperature in (a)? How can you reconicile this difference?

(c) At the time of recombination, the density of the Universe was about 3000 cm^{-3}. The number of recombinations per second per volume can be given by $n_e\, n_p\, \alpha$, where n_p and n_e are the proton and electron number densities, and α is a "recombination coefficient" (which has a value of approximately $5 \times 10^{-13}\,\text{cm}^3\,\text{s}^{-1}$).

Given these data and the temperature you have from (b), calculate the ratio of the number of photons to the number of protons in the Universe.