ASTR 311 STELLAR ASTROPHYSICS
Take-Home Exam #2 due by 2:00 PM on 4 November 2011

Clearly indicate your final answers, but ***show all your work*** *(partial credit will be given). Be careful, complete, and consistent with units. Please be neat. [20 points per problem]*

You may use any textbook and the class notes. If you use ANY other reference, printed or on-line, you must cite it clearly. You may not discuss any aspect of this exam with ANYONE except me (no other living beings, whether they are in the class or not; well, I guess you can discuss it with your dog or cat, but that's all) until after 2 PM on 4 November. If you have mastered the material, you should be able to complete this exam within 2 hours. In no case should it take you more than 5 hours. If it seems more complicated than that, you are probably making the problems harder than they should be.

1) The H-alpha line of neutral Hydrogen has a wavelength of 6563 Angstroms and results from a transition between the n=3 and n=2 levels.

- **a)** Assuming no electromagnetic fields or multi-electron interactions, how many "degenerate" energy levels are there for the upper and lower levels?
- **b)** Make a table or diagram showing all possible combinations of the 4 quantum numbers (n, l, m_l, m_s) for each of these two levels. To save time, just break it down explicitly into unique values of l and then list the allowed values of m_l and m_s for each l.
- **c)** Now assume that we can concoct some field that will split all of these energy levels apart [note: this is not terribly physical, but it should demonstrate your understanding of energy level degeneracies and selection rules]. Instead of one H-alpha line, we will now see several at slightly different wavelengths. To figure out how many, you need to apply only the Δl selection rule. What is this selection rule, and why does it arise?
- **d)** Identify the allowed Balmer-alpha transitions on your table or diagram from part (b). How many allowed lines are there?

2) In this problem, assume the Bohr Model holds for Hydrogen-Like Atoms.

- **a)** Write down the formula that permits you to determine the wavelengths corresponding to transitions between electron excitation levels in a Hydrogen-like atom (i.e. one-electron, any number of protons). Define *all* the terms. *[hints: 1) include atomic number and the reduced mass in your formula; 2) the simpler you can make this expression, the easier it will be to do the calculations below]*.
- **b)** Determine the wavelength of the He II Lyman-alpha line in Angstroms. How does it compare to the wavelength of the H I Lyman-alpha line (explain the difference)?
- **c)** Determine the wavelength of the "Balmer limit" for hydrogenic Lithium (Li III).
- **d)** What kind of telescope, detector, and observing location you would need to observe the Lyman-series transitions of the hydrogen-like ions of the astrophysically important elements Carbon, Nitrogen, and Oxygen.

[continued]

3) Assume the Sun's atmosphere consists of pure hydrogen in thermal equilibrium at T=5800 K with $n_e=10^{16}\ cm^{-3}$
   a) What fraction of the atoms have an electron in the first excited state (compared to the number of atoms in their ground state)?
   b) What fraction of the Hydrogen atoms are ionized? Explain why you can assume $Z_{II}=1$ and $Z_I=2$.
   c) If the temperature were increased by 2500 K, how would the strength of the line produced by the n=2 to n=3 transition change? Does the changing excitation (Boltzmann) or the changing ionization (Saha) dominate the change in line strength?

4) For the hydrogen gas in the solar atmosphere (i.e., use values from previous question)
   a) calculate the most probable speed for a Hydrogen atom
   b) estimate a collision cross section, and explain how you derived it
   c) calculate the mean free path of a hydrogen atom
   d) calculate the collision frequency (collisions per second)
   e) If this gas were suddenly thrown out of equilibrium, estimate how long it would take for elastic collisions between hydrogen atoms to return to a Maxwellian speed distribution.

5) In a single, succinct paragraph, define "Thermal Equilibrium", how it is attained, and why it is important in stellar astrophysics. Then, in 2 pages or less, describe all the microscopic processes occurring in a gas in thermal equilibrium (gas processes and radiative processes). This is free form! You should be able to think of at least 10 important "facts" about a thermal equilibrium gas and be able to write a few sentences about each.