AST 515 – ISM and Star Formation – Fall 2015
Homework #1 Due: Wednesday September 09

1. Hydrogen Problems.

   (a) Suppose an electron recombines into the n=5, l=4 level of hydrogen. What is the probability that an Hα photon will be emitted during the radiative cascade starting from (n,l) = (5,4)?

   (b) Radio Recombination Lines (RRLs) are a dust extinction free way to probe physical conditions in a H plasma. When an electron recombines, it can do so in a very high principle quantum number in rarefied plasmas. The notation Hnα is shorthand for a transition of Hydrogen ("H") from n+ Δn $\rightarrow$ n where α implies Δn = 1, β implies Δn =2, γ implies Δn =3, etc. Which radio recombination line Hnα transition is closest in frequency to the HI hyperfine transitions (what is n)? What is the frequency of that RRL?

2. The ground state of neutral Carbon (CI) is $1s^2$ $2s^2$ $2p^2$.

   (a) The lowest energy ground state fine structure transition is observable at submm wavelengths. What are the terms for the transitions and which radiation multipole best describes this transition?

   (b) If one of the p electrons becomes excited into the 3s orbital, what are the electronic terms of this state?

   (c) Order the terms in increasing energy

   (d) What is the parity of the electronic terms in the ground electronic state and the excited electronic state in part (a)

   (e) Which resonance transitions are allowed between the excited electronic state energy levels and the ground electronic state lowest energy levels (^3P_J)? Explain using the selection rules for electric dipole transitions.

   (f) Calculate the Einstein A for the lowest energy ground state fine structure transition of CI. [Hint: Check out Sections 2.8 and 5.5 of Quantum Mechanics in Astrophysics by Neal Evans (link on class webpage).]

3. Molecular Spin Statistics

(a) Which rotational energy levels are allowed for the linear molecular CO_2 by spin statistics in the ground electronic state? [Hint: the inversion symmetry of the ground electronic state is even.]

(b) Which rotational levels of the CO molecule are ortho and para? Explain.

4. Ozone (O_3) is a bent, asymmetric top molecule that is a minor species in the Earth's atmosphere.

(a) In the ALMA 1mm band (216-275 GHz), which frequencies (list quantum numbers and frequencies in GHz) might have a contribution from terrestrial O_3? [Hint: Only consider transitions with E_u <~ 300 K.]

(b) Given the quantum numbers for allowed transitions, which inertial axis (A, B, or C) must the electric dipole moment lie along?

(c) Check out the online "CSO atmospheric transmission plotter" – are most of the absorption features in the transmission curve due to O_3 in this band?

(d) Do ozone rotational lines have hyperfine splitting? Explain.

5. Observations of shocked H_2 in Orion via infrared ro-vibrational emission have the following intensities:

$I = 6.9 \times 10^{-3}$ erg s^{-1} cm^{-2} sr^{-1} for v = 1-0 S(1)
$I = 5.7 \times 10^{-4}$ erg s^{-1} cm^{-2} sr^{-1} for v = 2-1 S(1)

(a) Give the full quantum numbers for each observed transition and calculate their total statistical weights.

(b) Using the values of the Einstein A's found in Turner et al. 1977, ApJS, 35, 281 and the energy levels in Black & van Dishoeck 1987 ApJ, 322, 412, compute the gas kinetic temperature of the emitting region. You may assume that the emission is optically thin, isotropic, and thermalized. [Hint: Boltzmann is your friend.]