PHY 689-01, Spring 2009
Laser Spectroscopy of Atomic Systems
Midterm Exam

23 February 2009

Answer any 4 of the following 6 questions.

1. For the neutral potassium atom (K I), the D_1 transition ($4^2P_{1/2} \rightarrow 4^2S_{1/2}$) has a frequency of 12985.170 cm^{-1}.

   a) What is the wavelength of the spectral line?

   b) Calculate the decay time for a classical dipole oscillator radiating at this frequency.

   c) What is the expected natural linewidth for this spectral line?

2. The mass of the potassium atom is 39 a.m.u.

   a) Find the Doppler width of the potassium D_1 line at room temperature.

   b) At what temperature is the Doppler width equal to the natural linewidth (from question 1)?

   c) Give three possible reasons why a measurement of the absorption line width, using a weak tunable laser, may give a larger width than the calculated Doppler width?

3. A cell contains neutral K atoms in a buffer gas of Ar at 50 Torr, and $T = 300\ K$. Assume the density of K atoms to be negligible with respect to the Ar atom density.

   a) Under the conditions stated above, which type of collisions do you expect to be more significant for the K, D_1 line: *quenching* collisions or *phase-perturbing* collisions? Give a reason for your answer.

   b) The experimental broadening parameter for the full width of the K, D_1 line, for K-Ar collisions, is 2.6×10^{-20} cm^{-1}/cm^{-3}. Determine the total *homogeneous broadening* of the line.

   c) The experimental shift parameter of the K, D_1 line for K-Ar collisions is -1.2×10^{-20} cm^{-1}/cm^{-3}. Determine the frequency shift of the peak of the line in units of MHz. Is the peak shifted to the red side or the blue side of the unperturbed line?

4. To within a normalization constant, $\mathcal{N}$, the Maxwell-Boltzmann probability density function for the speed of an atom in thermal equilibrium is given by

$$f(v) = \mathcal{N} v^2 e^{-\left(\frac{v}{v_p}\right)^2}$$

   a) Show that the most probable speed of an atom is v_p.
   b) Determine the constant, $\mathcal{N}$, in terms of v_p, by requiring that the total probability for all possible speeds be unity.

5. Starting from the expression for the energy density of an abritrary electromagnetic field in free space, derive the relation between the time-averaged intensity and the electric field amplitude of a monochromatic plane wave:

$$I = \frac{1}{2} c \epsilon_0 {E_0}^2$$

6. A classical dipole oscillator is driven near resonance by a monochromatic plane wave. The detuning from resonance is Δ, and the damping rate is γ.

   a) Write the expressions, in the long-time limit ($t \gg \frac{1}{\gamma}$), for the oscillator amplitude, $A(t, \Delta)$, and oscillator phase shift, $\phi(t, \Delta)$.
   b) Show that the phase shift goes to zero at large detunings.
   c) Relative to on-resonance ($\Delta = 0$), by what factor is the amplitude, A, decreased at a detuning of $\Delta = \gamma$?
   d) How does the absorption coefficient, α, scale with the oscillator amplitude, A, and, therefore, how much of a decrease in the absorption coefficient is expected at a detuning of γ, relative to α_0?