Phys 532/822 Midterm Exam Due March 21

Instructions:

This is a take home unlimited time exam. You may not discuss the problems with other students, but you are free to use the textbook, your notes, and any other reference materials you wish. You may use a computer for numerical calculations if you want, but anything more than a calculator should not be necessary.

The points for each problem is labelled, and partial will be given.

The exam is due at 10:00 AM on Monday March 21 (at the beginning of the class).

Short Questions (10 points each)

1. Suppose you wish to pass a Gaussian laser beam through a small pinhole. You select a lens and try to focus the beam to a spot small enough to fit, but you find the beam coming out is reduced in power and exhibits a series of diffraction rings. Should you try again with a *longer* or *shorter* focal length lens?

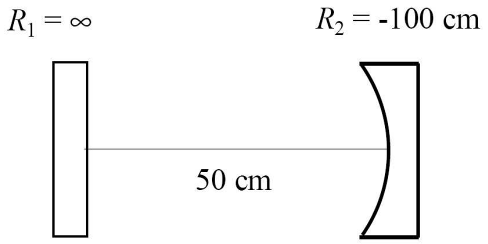
2. An optical cavity can be constructed from a glass (n=1.5) block with polished faces and reflective coatings. If such a cavity has faces with radius of curvature 2.5cm and a center-to-center length of 5 cm, what is the resulting longitudinal mode spacing?

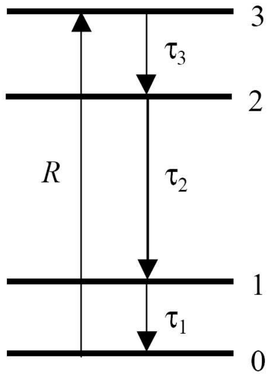
3. Suppose a sample of gas molecules have an ideal four-level structure. State 2 decays to state 1 with a time constant of 1 μs and state 1 decays to state 0 with a time constant of 10 ns. The gas molecules collide with each other once every 10^{-4} s on average. The temperature is such that the mean molecular speed is about 1000 m/s. If the wavelength of the $1 \leftrightarrow 2$ transition is 1 μm, give order-of-magnitude estimates for
(a) the homogeneous linewidth of the $1 \leftrightarrow 2$ transition
(b) the inhomogeneous linewidth of the $1 \leftrightarrow 2$ transition.

4. Suppose a CW gas laser contains a gain medium which is pumped strongly enough to provide a small signal gain of 10% per pass. The laser cavity itself has a loss of 2% per pass, with 1% due to internal losses and 1% due to the transmission of the output coupling mirror. In operation, what is the actual gain per pass provided by the medium?

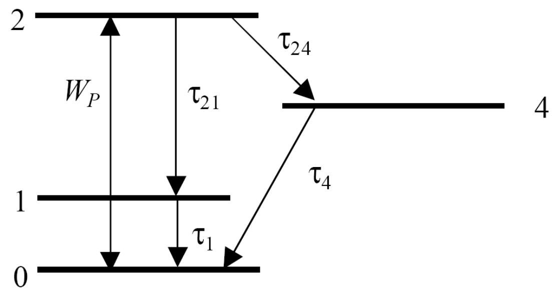
Extended Problems

1. (30 pts) Suppose a laser is constructed using a cavity as shown, with one mirror flat and the other mirror curved with radius R = -100 cm. The spacing between mirrors is d = 50 cm. The curved mirror will serve as the output coupler, and has a transmission T of 2%. Assume that no other cavity losses are present.
   The cavity is filled with a gas having a molecular weight of 200g/mole. The gas pressure is 1 atmosphere, and it is at room temperature. For these conditions, elastic collisions occur at a rate of 10^9 s^{-1}.
   The gas behaves as an ideal four-level laser medium with equal degeneracies. Lasing occurs on the $2 \rightarrow 1$ transition which has a wavelength of 5 μm. The decay times are $\tau_3 = 1$ μs, $\tau_2 = 1$ ms, and $\tau_1 = 1$ μs. The $0 \rightarrow 3$ transition is weakly pumped at a rate $W_p = 10^{-6}$ s^{-1} per atom. Estimate the total output power produced by the laser.





2. (15 pts) Consider a laser medium with energy levels as shown. Here level 4 represents a trapping state: at high pump rates, a large fraction of the atoms can be trapped in level 4, which reduces the available population inversion. You may assume that all levels are equally degenerate. If the $0 \leftrightarrow 2$ transition is pumped at a rate of W_p per atom, calculate the steady-state population inversion $\Delta N = N_2 - N_1$ in terms of the total density N_a.



3. (15 pts) Suppose an ideal four-level laser system (as in problem 1) is operating well above threshold, so the small signal gain g_0 is much larger than the total loss $L+T$. If the spontaneous decay time $t_{sp} = \tau_2$ were suddenly increased by a factor of 2, how would the laser output power change? Assume nothing else about the system changes. (In particular, assume that the laser transition is collisionally or inhomogeneously broadened, as is usually the case.) Similarly, how does the power scale with the transition wavelength λ?