Phys 532 Midterm Exam Due March 17

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 you should not expect to need anything more than a calculator.

The first half of the exam consists of short-answer questions, which should require very little calculation. The second half has three more complex problems dealing with a particular laser system. Partial credit will be given on the extended problems, but not on the short questions. You will get more credit if I can understand what you are doing, so be sure to explain your methods and copy your solution out clearly.

Short Answer 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 2.5 cm and a center-to-center length of 5 cm, what is the resulting longitudinal mode spacing?

3. Consider a laser medium consisting of ordinary glass ($n = 1.5$) doped with erbium (Er) ions. The ions have a strong absorption line at a vacuum wavelength of 980 nm, with a peak absorption coefficient of 10 cm^{-1}. What are the real and imaginary parts of the electric susceptibility χ at the very center of the line?

4. 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 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.

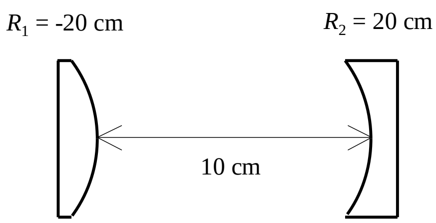
5. Suppose a CW gas laser contains a gain medium which is pumped strongly enough to provide a small signal gain of 10% per pass. The laser cavity itself has a loss of 2% per pass, with 1% due to internal losses and 1% due to the transmission of the output coupling mirror. In operation, what is the actual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

Extended Problem:

6. (15 pts) Consider an optical cavity constructed as shown. The two mirrors have equal and opposite radii of curvature $R_1 = -20$ cm and $R_2 = 20$ cm. The mirror spacing is $d = 10$ cm. For the fundamental Gaussian mode at a wavelength of 700 nm, find

(a) the location and spot size of the focus

(b) the spot sizes at each mirror.



7. (20 pts) Suppose you wish to construct a solid-state laser using the cavity of the previous problem. Your gain medium is a 1-cm long crystal that you don't know very much about, but you observe that it absorbs light at 532 nm with an absorption coefficient of 1 cm^{-1}. Once excited, it fluoresces in the near infrared at $\lambda = 700$ nm. From your experiments, you determine that the system acts like an ideal four-level scheme with equal degeneracies. The decay on the 700 nm laser transition seems to be purely radiative with a lifetime of 10 ns, which is much longer than the lower state lifetime. The lasing transition has an inhomogeneous linewidth of 300 cm$^{-1} \approx 10^{13}$ Hz and a coherence time $T_2 = 10$ ps. The host index of refraction of the crystal is $n = 2$.

You plan to optically pump the crystal with an 8 W laser running at 532 nm. The cavity mirrors transmit the pump light efficiently, so you will direct the pump beam axially through the cavity with a beam waist chosen to match that of the cavity mode. Neglecting the fact that there will be some absorption of the pump beam as it passes through the crystal, what is the small signal gain (per round trip) you can expect to achieve? Assume you place the crystal near mirror 2 of the cavity. (If you didn't get problem 6, take a beam waist of 300 μm.)

8. (15 pts) For the laser described in problem 8:

(a) Estimate the output power for a single oscillating mode, assuming an internal cavity loss of 0.5% per round trip and optimum output coupling.

(b) Since the gain medium is inhomogeneously broadened, several modes could potentially oscillate at once. Assuming the gain profile to be flat across the entire linewidth, estimate the number of modes that can oscillate and the total output power achieved. (If you didn't get problem 7, take the small-signal round-trip gain to be $g_0 = 0.04$.)