MASSACHUSETTS INSTITUTE of TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.161 Modern Optics Project Laboratory
6.637 Optical Signals, Devices & Systems

Problem Set No. 7	**Lasers**	Issued Thrs. 11/14/2024
Fall Term, 2024	**-**	Due Tues. 11/21/2024

Reading recommendation: Class Notes, Chapter 7; Yariv, Chapter 5 - 7. Be neat in your work!

All students are to do all 3 problems.

Problem 1
Consider a specific He-Ne laser that has a Doppler-broadened gain line-width of 1.5 GHz (full width) at the loss line, and its central operating wavelength is 632.8 nm. The radii of curvature of both mirrors is 1 m and the length of the cavity is 25 cm [assume n =1].

(a) Is this cavity stable? (show your calculation).

(b) What is the frequency difference between the longitudinal modes of the cavity?

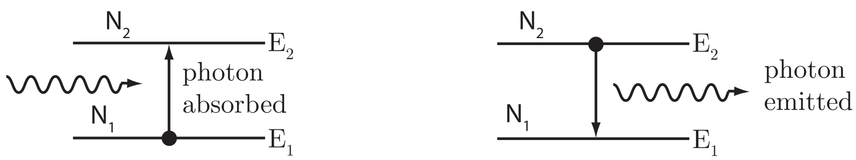
(c) How many longitudinal modes of the laser are active?

(d) What is the maximum resonator length you would have chosen if single-longitudinal-mode operation was desired?

(e) When this laser is mode-locked, what is the temporal separation between the output pulses as would be seen by a detector placed in the output beam?.

Problem 2

A certain two-level laser system is known to have a total of N atoms per unit volume. The ratio of $N_2/N_1 = 1/e$ at room temperature (300 K). Here N_1 and N_2 are the number of atoms per unit volume in state 1 and state 2 respectively. ($h = 6.624 \times 10^{-34} J \cdot s \quad k_B = 1.38 \times 10^{-23} J/K$).



(a) When broadband light is incident on this system, what is the frequency (in Hz) of the photons absorbed or emitted by the system?

(b) What is the wavelength (in μm) of the emitted light?

(c) If the output has a spectral bandwidth of 0.2 $\mathring{A}$, what is the bandwidth in Hz?

(d) Write the rate equations for the system when the system is pumped at a general rate R_p (assume no stimulated transitions occur; i.e., only spontaneous emission).

(e) If specifically, $t_{21} = 0.5 \times 10^{-7}$ s, and the system is being pumped to steady state with $N_2/N_1 = 3$, what is the power density, P_{dr}, (in W/m^3) radiated by the spontaneous emission process in this steady state condition?

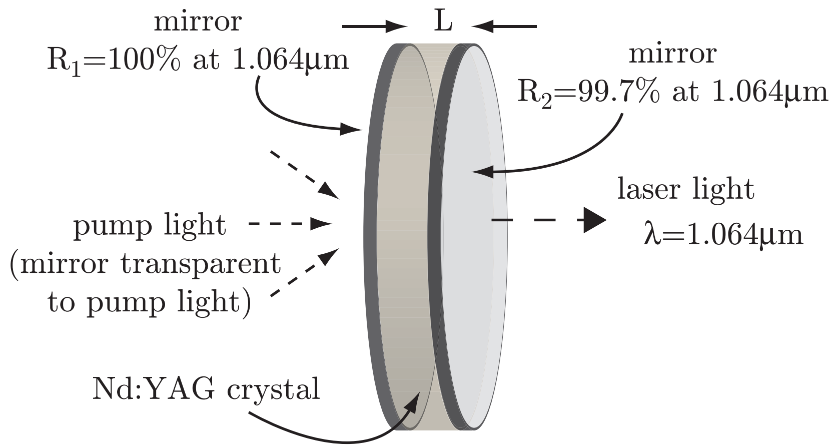
(f) What is the pump power density, P_{da}, (in W/m^3) that is being absorbed to maintain this steady-state condition?

(g) Now, if stimulated transitions are allowed to build in the laser cavity at a rate $R_1(\nu)$, and the pump power is adjusted to keep a steady population inversion rate such that $N_2/N_1 = 3$, what is the new pump power density, P_{da}, (in W/m^3) that is being absorbed to maintain this new steady-state condition?

Note: It is OK to express some answers in terms of N when appropriate.

Problem 3

A Nd:YAG crystal micro-laser is in the form of a disc that is 500 μm thick. The surfaces of the disc are plane-parallel and have mirror coatings with $R_1 = 100\%$ and $R_2 = 99.7\%$ at the Nd:YAG laser wavelength of 1.064 μm. Assume the refractive index of Nd:YAG is 1.82 and its absorption coefficient (absorption loss per unit length) $\alpha = 0.5\text{m}^{-1}$. *Such a disc would normally be optically pumped by a semiconductor laser operating at a wavelength at which the mirror coatings are transparent.*



Assume the lower and upper laser levels (E_1 and E_2 respectively) have an energy separation corresponding to λ=1.064 μm.

(a) What is the energy difference, in eV, between these two levels? ($h = 6.26 \times 10^{-34}$ J $\cdot$ sec $= 4.14 \times 10^{-15}$ eV $\cdot$ sec)

(b) Considering these two levels only, what fraction of the population distribution is in level 2 at 300K?

(c) What is the round-trip optical path length?

(d) What is the round-trip time?

(e) What is the longitudinal mode spacing of this cavity? Do we have single mode operation?

(f) By treating the cavity absorption loss in the same way the mirror reflection losses are treated, using the material in Chapter 3 of the notes, write an expression for the finesse, F, of this cavity. [Hint: Find an identical-mirror resonator that would have the same effective round trip loss]. Do not put the numbers into the equation.

(g) What is the relation between the finesse and the longitudinal mode width? Assuming F = 2617, what is the width of the longitudinal modes (in Hz)?