Laser Physics I (PHYC/ECE 464)

FALL 2022

OPTICAL SCIENCE & ENGINEERING
University of New Mexico

Midterm Exam, Closed Book, Closed Notes

Time: 4:30 – 6:30 pm

NAME ....
last *first*

Score

Total= 100 points

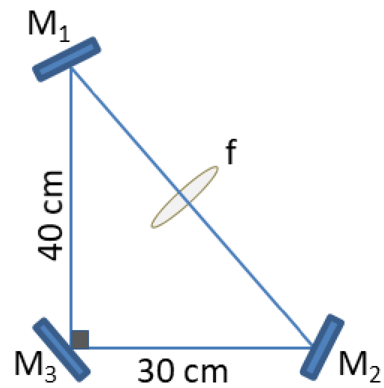
Please staple and return these pages with your exam.

Instructor: M. Sheik-Bahae

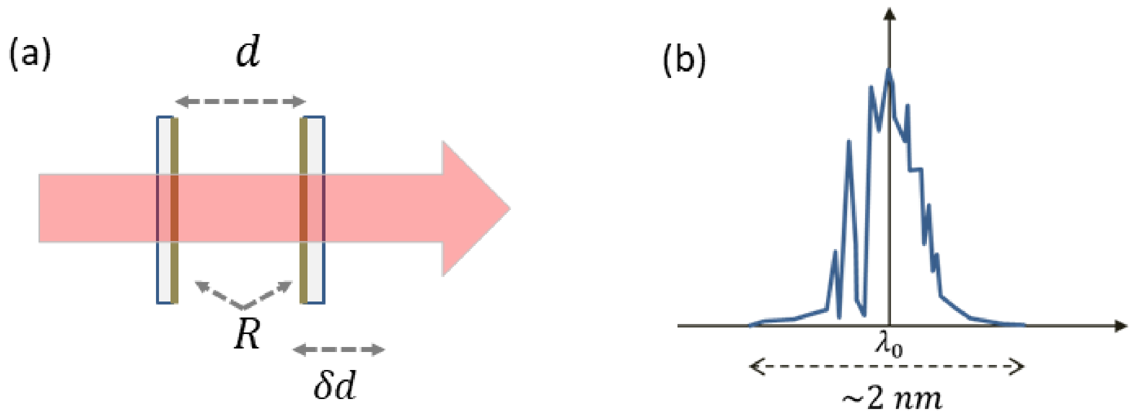
1. *(25 points)* Consider the ring cavity below consisting of 3 flat mirrors (forming a *right-angle triangle*), and a lens (focal length **f**) placed *half-way* between M_1 and M_2.

(a) Derive the range of **f (in cm)** that make this cavity stable.

(b) Find the position and the size of the minimum beam waist $\boldsymbol{w_0}$ as a function of **f** assuming a wavelength $\boldsymbol{\lambda_0}$. Mark the position of the beam waist(s) on the cavity diagram below.



2. (25 points) Design a *scanning* Fabry-Perot interferometer, as shown in Fig. 2.a, formed by two mirrors with reflectivity **R** separated by a distance **d** *in air*,. This device should be capable of analyzing the spectrum of a laser at $\boldsymbol{\lambda_0 = 1\ \mu m}$ that is roughly **2 nm** wide, as shown in Fig. 2.b.

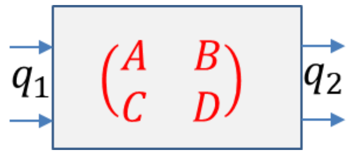


(a) Discuss the condition (range) for the separation distance **d** needed to analyze the above spectrum. What is the required scanning range ($\boldsymbol{\delta d}$)? Explain.

(b) Estimate the minimum mirror reflectivity **R** required if the desired spectral resolution is $\boldsymbol{\Delta\nu = 1\ GHz}$. Express this resolution in $\boldsymbol{\Delta\lambda\ (nm)}$.

(c) If $\boldsymbol{d}$ is fixed at 200 μm (i.e. non-scanning **δd=0**), the tuning can be achieved by varying the angle of incidence $\boldsymbol{\phi}$. Obtain the required range ($\boldsymbol{\delta\phi}$) needed for part (a). (Make approximations where applicable).

3. (25 points) Consider a refractive optical element with its corresponding **ABCD** matrix, as shown below. A *collimated* Gaussian beam is incident on this element at its *waist* ($\boldsymbol{q_1} = \boldsymbol{iz_{01}}$).



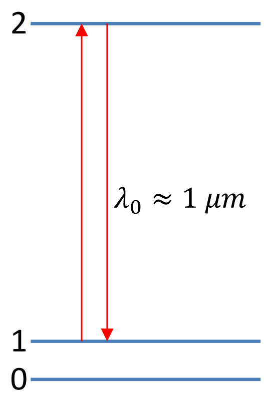
(a) What is the condition (i.e. the relations between the matrix elements and z_{01}) so that the exiting beam is also *collimated* (i.e. has a flat phase front)? This corresponds to a telescopic lens system.

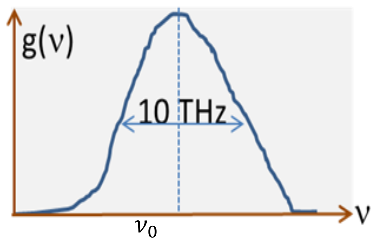
(b) What is the exiting beam's Rayleigh range ($\boldsymbol{z_{02}}$) in part (a) in terms of **A, B, C and D** of the system?

(c) Using this device as a beam expander, derive a simple expression for the magnification $\boldsymbol{M = w_{02}/w_{01}}$ (from part (a) & (b)) in terms of **A, B, C and D**.

4. (25 points) A homogenously broadened solid-state laser transition is described by the following properties:

- *Spontaneous emission lifetime:* τ_{sp}**=2 ms**
- *Homogeneous linewidth* $\Delta\nu_h$**=10 THz** *(THz=10^{12} Hz)*
- *Line center wavelength:* λ_0**= 1 μm**
- *Refractive index* **n=1.45**
- *Total density of active ions (concentration):* $N_t = 2\times10^{21}$ **cm^{-3}**
- *Non-degeneracy factors:* g_1**=2,** g_2**=2**





(a) What is the absorption/gain cross section at the line center (λ_0)?

At a given temperature, the total density N_t (= N_1+N_0) is equilibrated between levels 0 and 1 following the Boltzmann statistics; i.e. $N_1/N_0 = e^{-(E_1-E_0)/kT}$ where $E_1 - E_0 = 480\ cm^{-1}$.

(b) What are the absorption coefficient $\alpha(\lambda_0)$ (between levels 1 and 2) at room temperature (**T=300K**), and at **T=100K?** (Assume all the other parameters remain constant with temperature).