1a. Consider a resonator constructed using a two concave (R>0) mirrors of equal radius of curvature separated by a distance L. Write the two stability parameters for this two-mirror arrangement (1pt). What are the limits on L such that we have a stable resonator (4pts)?

1b. We similarly saw in class that we could use ABCD matrices to arrive at the same stability criteria. Draw a simple two mirror cavity and write down, in appropriate order, the ABCD matrices that will lead us to the famous (A+D+2)/4 stability result (1pt). (Note: you are not being asked to multiply the matrices.) The following two matrices may be of assistance:

$$\begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix}, \qquad \begin{pmatrix} 1 & 0 \\ -\frac{2}{R} & 1 \end{pmatrix}$$

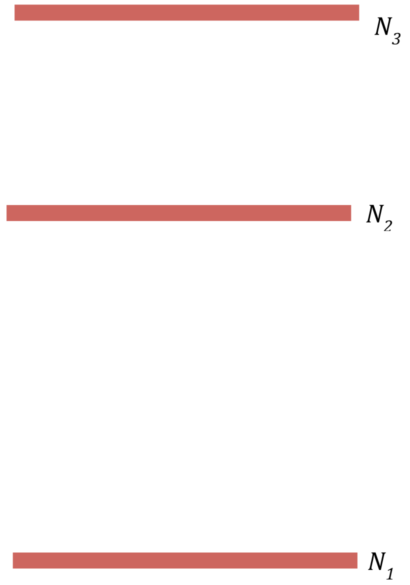
1c. The waste size in a resonator is given by the following expression:

$$w_0^2 = \frac{\lambda L}{\pi} \frac{\sqrt{(1-g_1 g_2) g_1 g_2}}{g_1 + g_2 - 2 g_1 g_2}$$

Find an approximate expression for the beam waste of a confocal resonator (g_i=0) (2pts).

1d. Using the expression for the beam waste given in question 1, find an expression for the waste size at the mirror position (3pts) (The definitions of problem 1 may be of assistance.)

2a



Consider this three level lasing system. Write down the rate equations for the three levels, without considering the lasing transition and energy density in the cavity. In doing so, consider all the mechanisms that result in transfer of populations from one level to another. Label them in the figure (3pts).

2b. The population inversion in such a three level laser system can be calculated based on the above equations to be:

$$\Delta N = N\frac{\left(1-\frac{\gamma_{32}}{\gamma_{21}}\frac{\Gamma/\gamma_{32}}{1+\Gamma/\gamma_{32}}\right)}{1+\frac{\Gamma/\gamma_{32}}{1+\Gamma/\gamma_{32}}\left(\frac{\gamma_{32}}{\gamma_{21}}+1\right)}$$

The threshold population inversion is then a complicated function of both the various relaxation rates and the pumping rate Γ. Find an expression for the pumping rate that leads to a population inversion (3pts). (note the population inversion in our notations is when $\Delta N<0$)

2c. Sketch a couple of curves for the population ΔN in this three level system. Consider a few cases of

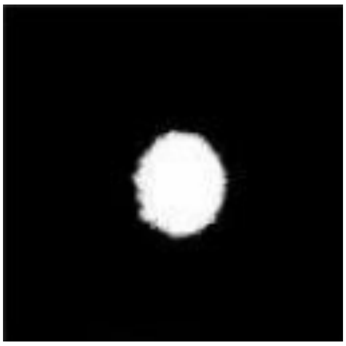
$$\frac{\gamma_{32}}{\gamma_{21}}$$

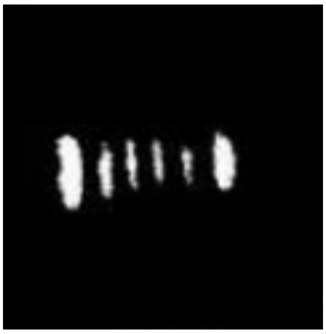
and sketch them as a function of Γ/γ_{32} (2pts).

2d. Describe how we obtain a population inversion in a three level lasing system. Your description should include a discussion about the relative transition rates and how one achieves an inverted population between the lasing levels (2pts).

Q3 (Topic 3: Resonators & Gaussian Beams)

a) In class and in the practicum we saw that the solution to the parabolic equation can be constructed from Hermite Polynomials. Identify the following two modes you may have seen in the practicum (2pts).





b) Using the stability criteria for a stable resonator, find the range of stable separations between two mirrors of radii infinity (plain mirror) and 1m (concave).

1) Draw the resonator (1pt).

2) What range of mirror separations results in a stable configuration (2pt)?

3) Draw the g_1g_2 stability diagram for the two-mirror configuration. Draw a line representing the location of the resonator on this stability curve as the mirrors are separated between the extrema of the stability criteria (3pts).

c) What is the Gouy phase shift (1pt)? Identify in the equation below the term responsible for this shift (1pt).

$$u(x,y,z)=\frac{-Ai}{\frac{ikw_0^2}{2}+z}\cdot\exp\left(-\frac{r^2}{w^2(z)}\right)\cdot\exp\left[-ikz\left(1+\frac{2r^2}{k^2w_0^4+4z^2}\right)\right]$$

Q4 (Topic 4: Steady State & Transient Operation)

$$\frac{dN_2}{dt} = \Phi_2 - \gamma_2 N_2 - (N_2 - N_1)B(\omega)U \qquad (1)$$

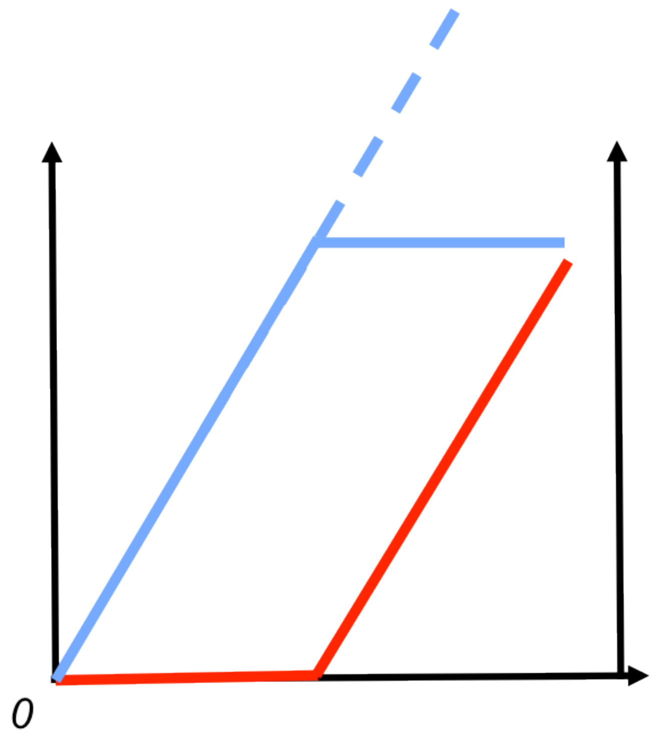
$$\frac{dN_1}{dt} = \Phi_1 - \gamma_1 N_1 + (N_2 - N_1)B(\omega)U \qquad (2)$$

$$\frac{dU}{dt} = -2\eta U + \hbar\omega(N_2 - N_1)B(\omega)U \qquad (3)$$

a) The term "steady state" was used in class to refer to what property of laser operation (1pt). Describe (mathematically or in words) steady state operation of a laser with reference to energy density and population dynamics (1pt).

b) In the above expressions for population and energy density dynamics which parameters do we, as users, have control over (1pt)? How does one control these (1pt)?

c) The following curve represents the population inversion as well as the steady state power of a laser system. Label the various lines and also the axes (3pts).



d) Q-switching is a technologically important type of laser operation. Describe the phenomena of Q-switching (2pts). You may do so with graphs or words.

e) Q-swich can generate high pulse energies and pulselengths commonly measured in (1pt):

- Femtoseconds
- Picoseconds
- Nanoseconds