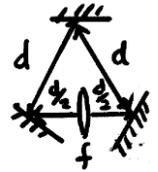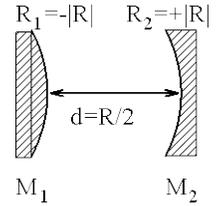1) Consider the ring laser cavity in problem 4 of HW4. What are the values of d/f that make it a stable cavity? (5 points)
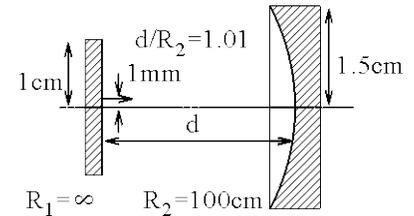
2) Examine the stability of the cavity shown on the diagram on the right by the following steps:
   a) Draw an equivalent lens diagram.
   b) Identify a unit cell starts on the right side of M_1.
   c) Find the ray matrix for the unit cell.
   d) Apply the stability criterion. (10 points)

3) Consider the obviously unstable cavity shown in the accompanying diagram. Suppose that a ray starts out at the flat mirror with a zero slope and at position that is one tenth of the radius of the mirror. (10 points)
   a) Show the equivalent lens diagram. Indentify two unit cells, one starting at the flat mirror and the second starting just before the spherical mirror.
   b) Since the cavity is unstable, we should return to the second order difference equation (e.g. the recurrence relation (1.4-23), on page 30 of the text book) to obtain a solution of the form (for unit cell 1 starting at the flat mirror) $r_m = r_a(F_1)^m + r_b(F_2)^m$
      i) What are the values of F_1 and F_2? (determined by the elements of the ray matrix)
      ii) What are the values of r_a and r_b? (determined by initial position (m=0) and position for m=1)
   c) How many passes through the cavity does the ray make before it misses the flat mirror?

4) A He-Ne laser is quite sensitive to changes in cavity length L. Assume a laser cavity is made of quartz (with a thermal expansion coefficient in fractional change in length per degree Celsius $\left(\dfrac{1}{L}\dfrac{dL}{dT}\right) = 5.5 \times 10^{-7}$ $(^{\circ}C^{-1})$ and calculate how much the resonant peaks of the modes move (in frequency) as the laser warms from $T=25^{\circ}C$ to $T=50^{\circ}C$. Assume the cavity is 25cm long, the laser wavelength is at 632.8nm and the index of refraction is 1. Express your answer in terms of fractions of the free spectral range (for example, 0.35FSR $(0.35\,v_F)$ or 0.2FSR $(0.2\,v_F)$. (10 points) (Hint: From $v_q = q\dfrac{c_o}{2nL}$, you need to find the integer q that gives the frequency matching closest to the laser wavelength, Using the same equation, you can see that $\dfrac{\Delta L}{L} = -\dfrac{\Delta v}{v}$ which is similar to the relationship between bandwidth and linewidth with the negative sign denoting the increasing of frequency with the decrease in length. Notice that v is a generic symbol representing frequency, i.e. the equation can be applied to ratio of bandwidth and frequency for v_q or v_F.)

Regular problem for graduate students (bonus for undergraduate students)
6) For question 3, we continue to investigate:
   d) Where does the ray leave the cavity: at the flat mirror or at the curved one? How many passes does it make? (To answer this, you will have to repeart b) and c) for the 2nd unit cell and then decide.)
   e) If the beam associated with this ray started with 1µW of power and the power gain per pass G=5, what is the power leaving the cavity? (Assume that the mirrors are perfectly reflective.)

Extra Credit
7) It is rare for a mode of an etalon to exactly match frequency of one of the modes of the laser. However, twisting the etalon slightly will change the optical path length and allow modes to overlap. Consider an etalon 2.5mm thick. Assume that it will be used in a 488 mm laser, has an index of refraction of n=1.58 and has both surface coasted so that they have reflectances of 90%. Use a computer program to generate serval plots of the transmittance spectrum for this Fabry-Perot etalon. Construct the plot so that all the transmittance spectra can be seen and compared (the plot should be similar to http://scylla.ceas.uwm.edu/890/summary/pdf/resonat.pdf). Generate spectra for $\theta_t = 0$ radian, $\theta_t = 0.004$ radians, $\theta_t = 0.008$ radians, and $\theta_t = 0.012$ radians. Put transmittance (T) on the y-axis and wavelength on the x-axis and all curves on the same plot.