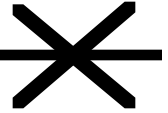


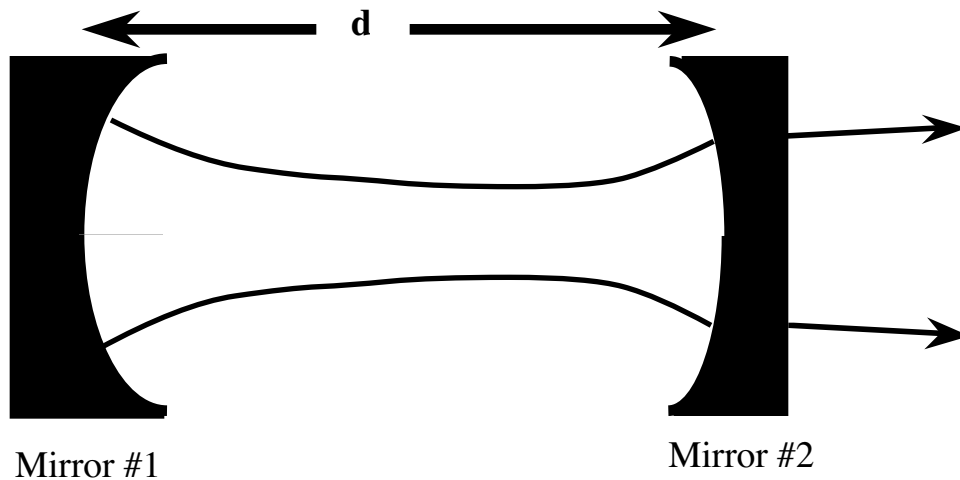
OPTICS AND LASER PHYSICS LABORATORY #10  
INSIDE A LASER CAVITY -- EXPLORING STABILITY,  
POLARIZATION, AND MODES

with Mark Chawla and Chris Baird



**What is a laser cavity and how is it deemed to be stable?**

Most laser cavities are made up of a surprisingly small number of optical components -- two mirrors and a gain medium. They may also include additional mirrors (to fold the cavity into a smaller physical space or to focus into a gain medium), apertures for controlling radial mode structure, a dispersing component for wavelength selection, and/or apparatus to create a pulsed output rather than a continuous wave output. Lasers which do not follow this general prescription include diode lasers, micro-lasers, and free-electron lasers. A simple laser resonator is pictured below (Figure 1).



**Figure 1:** Simple laser cavity.

In order for a cavity to be stable, it must be physically arranged in such a manner that a Gaussian beam traveling back and forth inside the cavity will be repeated on each round trip. In other words, a "mode" is produced within the cavity. The ability to form this mode can be determined by a simple study of the radius of curvature of the mirrors comprising the cavity and the distance between the mirrors.

The stability inequality condition for optical resonators with a cavity of length,  $d$ , having one mirror with a radius of curvature  $R_1$  and a second mirror with a radius of curvature  $R_2$  is

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$$0 \leq \left(1 \pm \frac{d}{R_1}\right) \left(1 \pm \frac{d}{R_2}\right) \leq 1. \quad \text{Eq. 1}$$

If one of the mirrors is a flat mirror ( $R_1 = \infty$ ), the stability condition reduces to

$$0 \leq \left(1 \pm \frac{d}{R_2}\right) \leq 1. \quad \text{Eq. 2}$$

This new condition indicates that a stable cavity must have  $R_2$  greater than  $d$ . This laboratory exercise will investigate the stability condition for optical resonators both with a computer-generated simulation in PARAXIA and with a helium neon laser whose cavity parameters can be altered.

### **Computer Simulation of Optical Resonators using PARAXIA**

The Macintosh program, PARAXIA, will be used to investigate the implications of Equation 1. Assuming the computer has just been turned **ON**, PARAXIA may be loaded by **double clicking** (with the mouse) on the SE/30 block that appears on the screen. Then one must **double click** on the PARAXIA folder, the ABCD folder, and then the ABCD block in succession. Under the File header, **select New**. Under the Define header, **select System** and **change overall ABCD** to Round Trip. Also under Define, **select Input** and **change** the input to Eigenmode. Under Graphs, **select Beam Propagation**. Now **click** the mouse somewhere near the Delay Update box to be able to begin to input elements of the laser cavity.

The twelve small squares on the left of the main window represent the different elements you may use to build an optical system. Some of these elements include: free space, neutral medium, thin and thick lenses, and flat and curved mirrors. Clicking a box will place it in the optical system. (The delete key may be used to eliminate a previously chosen element.) For all of the elements, except the flat mirror, the user must then choose the specific parameters for that element. (Remember, all lengths are in centimeters.) Single clicking on a box in the main window will allow you to see its individual ABCD matrix on the far right sub box, and double clicking on the same box will allow you to change the parameters for that element.

Before starting, measure the length of the helium neon tube that you will be using in the experimental section of the lab and check the radius of curvature of all the mirrors you have available to you, as well as the total length of travel the optical rail will allow the mirror mount to move. You will

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need this information to model the system you will be testing. You will now build a number of laser cavities and test them for stability in PARAXIA.

Remember that the bottom window labeled Beam Propagation displays information about the optical system and the propagation of the Gaussian beam through the system. Information about the beam at various places in the system can be selected by clicking between the different elements in the main window. If the system you design is unstable, the beam will not be displayed in the Propagation window.

**Practice Systems:**

For each of the systems listed below calculate the stability criteria for each cavity and then run them in PARAXIA answering the following questions from the computer simulation.

Is it stable? What is its minimum spot size? What is the spotsizes at each mirror? Where is the location of the waist?

- a) Try a cavity in which  $R1 = 50$  cm,  $R2 = 100$  cm, and  $d = 25$  cm.
- b) Try a cavity in which  $R1 = 76$  cm,  $R2 = 38$  cm, and  $d = 76$  cm.
- c) Change the parameters in the above system by small amounts and see how this affects the cavity stability and spotsizes/locations.
- d) Try a cavity with  $R1 = 76$  cm,  $R2 = 304$  cm, and  $d = 152$  cm.
- e) Try a cavity with  $R1 = 1000$ ,  $R2 = 25$  cm, and  $d = 40$  cm.
- f) Build a cavity in which the waist is found in the middle of the cavity.
- g) Change the parameters in the above system by small amounts and see how this affects the cavity stability and spotsizes/locations.
- h) A cavity is set up as follows,  $R1 = 250$  cm,  $R2 = -300$  cm, and  $d = 150$  cm.
- i) Build an optical resonator in which the waist (minimum spot size) is found at one mirror.
- j) Build one cavity that you know will be stable and one you know will be unstable. Record the values of the cavity parameters you chose.

**Experimental System Modeled with PARAXIA:**

a) Model the experimental set found in the lab (see Figure 2 below), and then test the cavity's stability for different cavity lengths and mirror curvatures. Record the values in your notebook for testing with the actual cavity. Remember, the beam's spotsizes must be small enough to fit within the plasma tube of the HeNe.

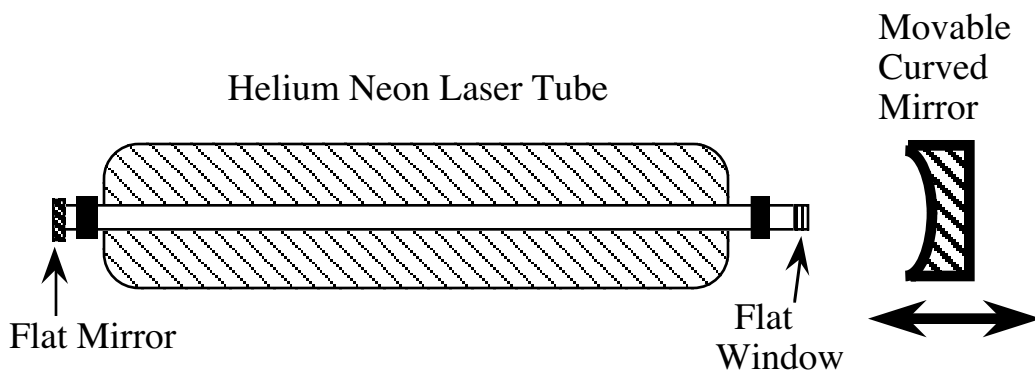
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As discussed earlier, if  $d$  is less than  $R_2$ , the resonator should be stable and if  $d$  is greater than  $R_2$ , the resonator should be unstable. Use PARAXIA to verify these claims. Using the information section be sure that the size of the beam at the opening of the laser plasma tube is smaller than the hole for your chosen  $d$  values. Now use  $d$  values that are only slightly greater or less than  $R_2$  (e.g.  $R_2 \pm 0.000001$ ). Record your observations.

**Actual Laboratory HeNe Cavity Tests:**

Next, you will experimentally investigate the conditions for the stability of an optical resonator using the HeNe tube. Place the movable mirror ( $R_2$ ) at a distance  $d$



**Figure 2:** Experimental HeNe Laser Cavity

from the flat mirror (the back of the HeNe tube) that was found to produce a stable resonator using the computer. After getting the system to lase, proceed to increase  $d$  while making the necessary adjustments to keep the system lasing. Determine the distance at which the system is no longer stable and compare this distance to the distance determined using PARAXIA.

Some adjustments must be made to the system before it will be able to lase. (WARNING!!!! BE CAREFUL NOT TO TOUCH THE ELECTRODES AT THE ENDS OF THE HE-NE TUBE. HIGH VOLTAGE) Using the coarse adjustment of the sliding base which the mirror is resting on, the desired distance between the two mirrors may be achieved. Now the HeNe tube should be placed parallel to the ground and directly in line with the movable mirror, so that the beam may resonate along a straight path. These adjustments may be made using the fine vertical and horizontal adjustment knobs located on the HeNe tube holder. Next, the fluorescence from the tube should be centered on

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the mirror. Vertical adjustments may be made using the coarse adjustment of the tube holder and the translator holding the mirror mount. Horizontal adjustments may be made using the translator on which the device holding the HeNe tube is attached.

The beam reflected from the movable mirror must now be aimed back into the HeNe tube. An opaque piece of computer card with a small hole to allow a portion of the fluorescence through is attached to the rail. By looking back at the card (toward the tube) the portion of the beam which is reflected by the movable mirror can be directed back into the hole in the card. At this point the laser should be lasing or at least flickering!!

There are two properties of a laser cavity that you can now explore in addition to cavity stability. One property that you can investigate is the transverse mode structure of the laser. See if the beam is in the TEM<sub>00</sub> mode or not. If not, an iris aperture placed inside the cavity can be closed until the higher order mode is no longer viable, and the TEM<sub>00</sub> mode is lasing. Record the various modes you are able to attain. Try using a 3x5 card to cut off the beam from one side. What happens? The second property to study involves the polarization of the light in the laser. Using dichroic sheets, determine the polarization of the output light. Use a glass plate to alter the polarization. Predict your results before actually testing your experimental plan.

**With PARAXIA:**

- 1) If a cavity were set up as follows,  $R_1 = 450$  cm,  $R_2 = -50$  cm, and  $d = 150$  cm, is it stable? What additional optical element could you add to the cavity in order to make the cavity stable? Try to create a stable cavity.
  
- 2) Build a cavity that is on the "edge" of stability and test which parameters have the most influence over making the cavity stable. i.e. By how little do you need to change each parameter in order to observe a stable cavity.
  
- 3) How would the index of refraction of HeNe change the experimental results? (using a CRC or optics catalog find  $n$  and see what PARAXIA predicts.

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**With HeNe Tube:**

- 4) By how much can you move the mirror and keep the laser lasing?
  
- 5) How difficult is it to get the laser to lase? What adjustment has the most effect on the ability of the cavity to lase?
  
- 6) Do your laboratory observations support that this cavity is one in which the rear mirror is flat? Why or why not?