Building a Helium – Neon Gas Laser
Lab Manual

Shialing Kwa '01 and Shane Smith '02
revised Michael Sturge, Oct 2001

Purpose:

The goal of this lab is to build a fully functioning laser from the ground up. During the process, you will also familiarize yourself with related phenomena such as transverse laser modes and interference fringes. Through the intensely hands-on approach, you will begin to develop a fundamental understanding of laser science, and thus expand your intuition for modern optics.

Reference:

Optics, Hecht, Ch. 13, Section 13.1-3 *The Laser*.

Introduction:

How does a laser operate?

Before you can begin to build your own laser, you will need to know the fundamentals of how a laser works. A laser consists of two primary parts: a cavity consisting of at least two mirrors, and a "gain medium" with a means of establishing a "population inversion" (in this case, a gas discharge tube). Imagine aligning two parallel mirrors opposite each other and dropping some photons into the system, as in the picture below:

The process of dropping the photons into the system is known as pumping it—a glowing gas discharge tube, in which electrons are accelerated by a high electric field and excite the gas atoms, is used in this lab for this purpose. Assuming the mirrors are perfectly reflective, photons traveling perpendicular to the planes of the mirrors will be reflected back and forth infinitely in between the mirrors (the laser cavity), unable to escape if one neglects diffraction. This direction defines the cavity axis, called the z-axis.

Now imagine that inside that cavity you put some material—called a gain medium—that will amplify the number of photons that are put in; that is, for example, for every one photon which passes into the substance, two others leave it. Normally, this one initial photon is just as likely to be absorbed, causing an atom to make a transition up to a higher electron state, as it is to stimulate the emission of another photon, causing the excited atom to make a downward transition and emit a photon. If there were more atoms in the excited state than in the ground state (a population inversion), the overall probability of stimulated emission would be higher. The gain medium (helium-neon gas in this lab) creates this population inversion so that the initial photons stimulate the emission of more photons, all in phase with one another, to create extremely coherent, highly directional, and monochromatic light.

The most useful transverse mode is the on-axis TEM_{00} mode—the single, Gaussian, bright spot that you usually associate with a laser beam. However, since you will be creating your own laser, you will have the opportunity to find and observe some of the off-axis modes. These can be identified by the number of nodes: the TEM_{nm} mode has n nodes in the x-direction and m in the y. You will sometimes see lasing in more than one mode simultaneously: for example the "donut" mode which is an incoherent combination of the TEM_{10} and TEM_{01} modes.

Pre-lab calculation

The laser has the full confocal configuration with concave mirrors of 50 cm focal length separated by 50 cm. The wavelength produced is 633 nm. Calculate the beam waist parameter w_o and the angular divergence of the beam in far field.

Apparatus: (see figs. 9-13)
1 low power red He-Ne laser w/ mount (alignment laser)
1 optical breadboard
13 bases (1 wide base)
13 post holders
8 posts
13 spring-loaded screws
2 beam blocks
1 iris
9 collars
2 small steerable flat mirror mounts
2 1" dia. large steerable mirror mounts
1 filter
1 filter holder
2 flat mirrors for beam steering
1 high-reflecting concave mirror (99.7% for appropriate wavelength, r = .5 m)
1 high-energy partially reflective concave mirror (99 % for appropriate wavelength, r = .5 m)
Various screws and washers for making assemblies and attaching them to the breadboard
1 ball driver (3/16 inch)
1 gas laser tube (see spec. sheet)
2 laser tube mounts
1 translating stage
1 high voltage power supply for tube model
1 high voltage cable
1 short connector cable
1 ballast resistor with terminal connections
1 laser power meter
1 slit plate with stand
1 piece of foam-core board with stand
safety goggles
1 index card
2 flashlights

In this lab, you will be using a variety of equipment with which you may not be familiar. Thus, below you will find a brief description of some of the equipment that will be part of this lab. In this description, figure numbers refer to last year's lab write up, a copy of which is in the lab.

The entire lab will be performed atop an optical breadboard—a large metal plate that is covered with screw holes at regularly spaced intervals. The breadboard makes keeping the set-up stable and aligned much easier than if you were to attempt to have elements randomly set up on a standard tabletop. All the screws in the setup have a hexagonal hole in the top of them, instead of a flat or crossed pattern; you will use special "ball drivers" with these hex screws.

Into the breadboard you will screw optical element assemblies that consist of a base, post holder, post, and the optical element itself. (see fig 11) The base is screwed to the post holder using a very short screw, and it is screwed down to the breadboard using a longer screw and washer pair on each side. The post—a simple stainless steel rod with a screw protruding from the top—simply slides into the post holder from the top when the thumbscrew is loosened. The thumbscrew is the one that screws in perpendicularly to the post holder; it will hold the post in the orientation (with respect to the base) that you specify. At this point, you should notice that the thumbscrews are actually loaded with a small metal sphere that is pressed outwards by a small spring. In the course of positioning, you will often find it helpful to tighten the thumbscrew partially, so that the spring is pressing the sphere against the post, yet the post is still somewhat free to move and make fine adjustments. However, once a post is in precisely the right position, you will want to go ahead and finish tightening the thumbscrew to lock it into position. Once the permanent height of the post has been established, you will attach a collar to the post; this is sort of metal clamp that is positioned on the post and slid all the way down it, flush with the post holder. In the event that you need to rotate the post, or remove it completely from the post holder, the collar will preserve the height that you have established, so that repositioning is as easy as rotation of the post in the holder.

Atop the post, you will attach a variety of optical elements that are necessary for the experimentation. Sometimes, these elements will be as simple as a filter holder, but others are surprisingly complicated. A beam block is essentially a stack of razor blades that is bundled together and used to absorb stray laser beams. Mirror mounts do just that—hold the mirror atop the post; however, the ones you will be using all have adjustable knobs on their backs which allow for fine movement of the mirrors in both an x and y direction. Irises consists of a metal outer ring, an array of small woven metal pieces on the inside, and an adjustment lever; when the lever is used to open or close the iris, it acts as the iris in your eye, expanding and contracting to let more or less light through.

There are two basic types of mirrors that you will end up using during this lab. One type is a simple, flat, front silvered mirror that you will use to steer your alignment beam into the appropriate position. The other type is much more highly specialized and will be used to form the ends of the laser cavity. These mirrors are slightly curved, to form a confocal laser cavity. They are coated with special thin films that make them highly reflective for the exact wavelength of the laser that you will be making; in fact, the high reflecting mirror is about 99.7 percent reflective and the output coupler (a fancy name for a mirror that less highly reflecting and thus allows a bit of light to pass through) is about 99 percent reflective. **The coatings on all these mirrors are very sensitive to dust and scratches, so you should take great care to never touch them. This applies to the front surface mirrors too. Once dust has got on the mirrors it is difficult to get off, so always cover them when not in use. If you have questions about handling them, ask your TA.**

The star of the setup is the helium-neon laser tube, for which you will find the specs sheet attached. The tube is a sealed, blown glass cylinder that has electrical connections on the sides and Brewster windows on the ends, and is filled with a specific ratio of helium and neon gases. The Brewster windows are simply pieces of glass that seal the tube on either end—the points where the light enters and leaves the gas. These "windows" are tilted at precisely the Brewster angle for the interface, to maximize the transmittance of the light through the glass and minimize the reflection loss (**as with the mirrors, dirt or scratches on these windows can easily ruin them, so be sure never to touch the window itself**). One electrical connection to the anode and two (on opposite sides of the tube) to the cathode protrude through the glass and will be connected to the power supply. A high voltage applied to thes electrodes produces an electric discharge in the tube, very similar to that in a neon sign. **The electrical connections will be connected to a high voltage power source, so use caution.** Keep your hands away from any exposed conductor when the voltage is on, and **NEVER turn on the power supply without first warning your colleague(s) and checking that no one is at risk of shock.**

Procedure

CAUTION! NEVER look into the beam of the alignment laser or of the laser you are building, or their reflections. Also make sure that no beams from your set-up can be seen by others in the lab, who cannot be expected to watch out for what you are up to.

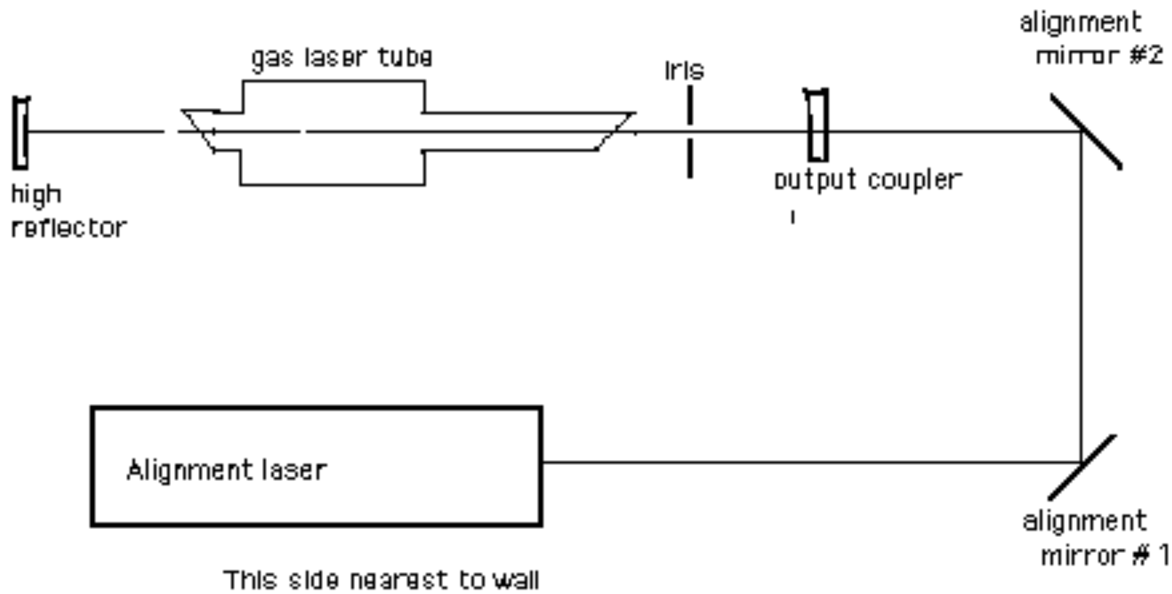
I: Building the HeNe Laser

The overall arrangment on the breadboard is shown on the next page. Since the holes in the breadboard are 1 inch apart, distances in these instructions will be given in inches.

1. Before you start, cut a rectangular piece of white foam core board about 21x8", with two sides accurately at right angles to each other, and find 8 base-postholder combinations . If necesssary assemble these by screwing one of the short screws through the base into the bottom of the post-holder One of these bases should be a wide base to hold the alignment laser.

3. Place the breadboard on the table with its longest side parallel to the wall. The alignment laser should parallel to this longest edge and on the side of the breadboard furthest from you as shown on the next page.

4. Attach the wide base (for the alignment laser) to the breadboard, so that it is about 6 inches away from the furthest edge. The base should also be about one-third of the way down the breadboard from its shortest, right edge. Use two screws and two washers to attach the wide base (with its post-holder in place) to the breadboard. **Make sure you use washers when screwing all bases into the breadboard to avoid scratching the base**. **And unless otherwise noted, make sure they are screwed in as tightly as possible.**



SET UP FOR ALIGNMENT (not to scale)

5 Put the alignment laser into its post-holder and tighten the screw on the post-holder (see fig. 16). Plug in the alignment laser and turn it on. The screw on the bottom of the laser is to tilt it, but for this purpose of this lab, the beam should be horizontal. Put your piece of foam-core board vertically in front of the laser and mark the position of the beam. Then, move the board close to the end of the breadboard and verify that the beam is at the same approximate height and distance from the edge of the breadboard. If it is not, then use the screw on the bottom of the laser platform and turn the post in its holder to adjust the beam.

6. Attach the beam-steering ("alignment") mirror holders to posts and put the posts into the post holders. Place the two mirrors on the breadboard as shown above (see also fig. 17- ignore the extra component close to the laser in this figure). They should be separated by 10", be 8" from the short edge of the breadboard , and set at 45deg to it. Adjust the first mirror's position so that the beam strikes its approximate center, then adjust the orientation of the post in its holder so that the reflected beam strikes the second mirror in its center. Adjust the second mirror so that the beam goes approximately parallel to the side of the breadboard. **Make sure that the laser beam that is reflected from the second mirror falls directly over a row of holes because this will make the alignment of the remaining pieces of equipment much easier**. You can check this with your foam core board. Once you have established the correct position, tighten all screws in your mirror assembly to fix this position. **Note that the two screws on the mirror mount itself should be near the middle of their range and should not be adjusted at this time**.

7 Place your foam-core board just after the first alignment mirror so that it is perpendicular to the breadboard and to the path of the reflected laser beam. The beam should strike the board about an inch from the edge. Make a mark in the center of the laser spot on the board. Draw two lines through this point, parallel to the edges that you made perpendicular in step 1. Then place the board in front of the second alignment mirror, making sure that it is still

perpendicular to the breadboard and to the path of the beam (see fig 20). Observe how turning the steering knobs on teach mirror affects the beam because you will later use knobs like these to make much finer adjustments when creating the laser cavity Use the vertical steering knob on the first alignment mirror to adjust the height of the beam until it falls on the horizontal line. Then move the foam-core board to the far end of the breadboard opposite the second mirror (along the path of the beam) and check that the beam height is the same. Be sure to sure a procedure which is convergent. **Continue to make slight adjustments to the mirrors until you achieve this alignment because you must make sure that the laser beam is as level as possible throughout the entire set-up.**

8. Now put the foam-core board parallel to the short edge of the breadboard and just after the second mirror, with the vertical line lined up as precisely as you can with the center of a screw hole. Adjust the first mirror horizontally until the beam falls in the mark where the two lines cross. Move the board to the far end of the bread board, again lining up the vertical line with the center of a screw hole, and use the steering knob on the second mirror to adjust the beam until it hits the beam mark. As before, repeat until the beam hits the mark at both locations.

9. Along the path of the laser beam coming from the second mirror, loosely screw down four base-and-post-holder assemblies from Step 2 in a row, at 6", 8",12", and 20"from the second mirror . You are going to be aligning all of the elements that go in these bases so that the beam passes straight through them, so make sure that the post holders themselves fall approximately along the row of holes that correspond to the path of the beam coming from the second mirror. Screw down the translation stage (see figure 25) on the same row of holes, with its translation direction parallel to the beam, with the nearest edge of its fixed base about $26\frac{1}{2}$ " from the second mirror, and mount a base-postholder assembly on it . To access the mounting holes in the base, translate the stage so that the top platform is displaced as much as possible in one direction. Attach it to the table so that the overhanging edge of the platform faces the laser beam. With the upper platform translated fully forward, one of the screw holes to attach the stage to the table should be open and ready to accept a screw. Through this hole, screw the platform to the breadboard using the row of holes that is aligned with the center line of your set up.

10. Take a post with an iris and place it in the second base from the second mirror, perpendicular to the path of the beam. Make sure the iris is as closed as it can be and adjust its height (use the spring-loaded screw to make fine adjustments) and the position of the base so that the beam falls on the exact center of the iris. You should adjust the position by moving the base slightly since the screws holding the base to the breadboard have not been completely tightened. If the beam is not falling directly over the row of post-holders, you may want to use the steering knobs on the alignment mirrors to adjust the beam's position. **Note: although the alignment of one element in this set-up can be slightly 'off', it is important to remember that errors will be compounded if the alignment of several of these elements is not correct. Do your absolute best to correctly align all elements with the beam.**

11. **When you have correctly positioned the iris, you should be able to almost close it and still see a spot on the foam board when it is placed at the far end of the breadboard.** Furthermore, you should be able to open and close it and see little to no change in the spot on the board. Once you have established this, tighten everything down and put collars on the iris post.

12. Now assemble the high reflector. Make sure it is squarely in its holder, and **be extremely careful when handling high reflector and the output coupler because their surfaces are extremely sensitive to scratches and dirt Do not touch the surfaces; when the mirror is not in its mount handle it only by its edge.** Attach the high reflector in its mirror mount to a post and place this post in the post holder on the translation stage. Initially the flat (uncoated) side of the high reflector should face the beam. Adjust its height so that the alignment beam is striking its vertical center, and partially tighten the screw in the post holder. Attach a collar to keep the height constant. Then adjust the position of the base on the translation stage so that the beam strikes the exact center of the back of the high reflector. Tighten the screws in the base. **Be careful: since these mirrors are curved, stray beams may be reflected. Take care never to place your eyes in the plane of the laser beam**. Now swivel the high reflector post in the post holder until it is perfectly perpendicular to the alignment beam. You can tell when you have achieved this by watching the alignment beam reflected from the high reflector. When it passes through the iris, you have correctly aligned the high reflector**.** Then tighten all screws. Place collars on the posts for both the output coupler and the high reflector.

13. Put two tube holders (the rings with three adjustable radial bars) in the two remaining post holders on the breadboard. Adjust their height and position so that the alignment beam is roughly central in the circle. Loosen the screws on the radial bars . Temporarily block the alignment laser. Take the laser tube out of its box and **carefully** remove the Brewster window covers. **Remember not to touch the surfaces of the Brewster windows.** Carefully slide the tube into the holders, with the narrow end first, towards the iris , so that the tube sits centrally between the mirrors, without the Brewster window touching the iris (see the plan on p.5 above and fig. 21). The two cathode connections should be approximately parallel to the breadboard and the anode connection points down towards it. Then **gently** tighten the mounts on the laser tube. After checking that the red cable is disconnected from the power supply, gently attach the leads to the tube. The black clip should be attached to the cathode of the laser tube. The white wire should connect the red terminal of the resistor to the anode of the laser tube. **Make sure you double-check all of these electric connections and make sure no cables touch the laser tube and that there are no exposed conductors.**

14. The goal of alignment is to have the laser beam from the alignment laser pass directly through the center of the iris and through the center of the laser tube.Partially tighten the screws on the post holders for the laser tube so the height of the tube can still be adjusted. Unblock the alignment laser . Adjust the height of the post nearest to the alignment mirrors until the center of the Brewster window is at the same height as the alignment beam. This is easiest to do with a small card to scatter the beam, but don't let the card touch the window. Then adjust the horizontal position until the beam is central in the window. Adjust the height and

position of the other end so that the beam is centered in that Brewster window. Check the other window and repeat until the beam is centered in both windows.

15. Next put together the output coupler assembly and place it in the postholder nearest the alignment mirror. Adjust the height of the output coupler so that the beam from the alignment laser falls in its vertical center and partially tighten the screw in the post holder. Then adjust the position of the base so that the alignment beam is perfectly centered in the mirror. Tighten the screws in the base. Align the output coupler in its post holder and adjust it until the reflected beam falls centrally on the output face of the alignment laser. **Because the output coupler is only partially reflective, part of the alignment beam will be transmitted through the other side of the output coupler so be careful to keep your eyes out of the plane of the laser beam.** Check that this transmitted beam goes through the iris. If it doesn't, re-center the output coupler on the beam. When it does, turn off the alignment laser, and prop a piece of foam core board against it so that when your laser lases it will illuminate the board. Open the iris wide.

16. You are now ready to attach the power supply to the laser tube. Take the red cable and plug it into the power supply box (see fig. 23- however, the components are now screwed down to the breadboard and insulated with tape). To make the connection complete, you must first push the connector in and twist it clockwise until you hear or feel a click. The red clip should be attached to the black terminal of the resistor. Secure the red cable to the breadboard using the cable-holder and screw provided. Be careful not to tighten the screw too much to avoid cutting the insulation. Plug the power supply into the outlet. **Make sure no one is close to the laser tube set-up because you are working with high voltages. When you have done so, and warned your colleague, turn on the power supply.**

17. After a minute or two the laser tube should light up. If you have done the initial alignment perfectly, you will see a bright red laaer spot on your foam-core board. However, more likely. you will see on the foam core board a pink or whitish glow from the tube, and you will have to make adjustments to the output coupler. Using the steering knobs on the output mirror mount, slightly adjust the mirror while watching the foam-core board carefully. Turn one control **very** slowly through a 1/4 turn, first in one direction, then the other, all the while rapidly sweeping the other control through a 1/4 turn in either direction. Make a note of the initial position of your beam steering screws, and don't let the center point of your sweep move away from this. If you think you've lost this center point, turn on the alignment laser and check the spot reflected from the output mirror. When the laser lases, but you are still moving the mirror, you will see a very brief flash. Look out for it- don't be blinking when it happens!. The spot will look just like that of any other red laser. If you still don't see a laser beam, turn off the power supply and use the alignment laser to reposition the high reflector. Then turn off the alignment laser and turn on the power supply again and now make adjustments to both the high reflector and the output coupler until the laser beam appears. If necessary, two people will have to simultaneously adjust the output coupler and the high reflector. If the laser isn't lasing and you think that you have greatly changed the alignment of the mirrors, don't hesitate to turn off the power supply and use the alignment laser to check this. You should be able to do this without will need to removing the output coupler, but if you do have to make sure you have a collar on its post. You should see a

bright red spot on the foam-core board when you have properly aligned the mirrors and the laser is fully functioning. Congratulations!

18. Once you have achieved lasing, remove the first alignment mirror and adjust the second to throw the beam on the the wall. Adjust both mirrors by **very** small amounts, using the steering knobs, to maximize the brightness of the central laser spot.

Part II: Laser Power

19. Now you're going to measure the power of your laser beam. Put the detector of the laser power meter in a lensholder (hold it in place with little sticky wax) and attach it to a post. Place the post in one of the post holders which you have assembled and loosely screw it to the breadboard so that the laser beam reflected from the remaining alignment mirror strikes it.. Adjust the height and base positioning until the laser beam falls exactly into the center of the detector opening; when you have achieved this alignment, tighten all screws to firmly anchor the detector in this position. Place a collar on the post and tighten its screw to establish the correct vertical positioning. Turn the dial on the power meter to the 1 mW setting.

20. Put the meter flat on the breadboard or table, hold the meter's on/off switch in the "on" position, and record the power of the beam. If no power registers, turn the dial on the meter to a lower setting and try again, or reposition the detector if the beam is not properly aligned with it. While holding the meter's power switch in the "on" position, tweak the positioning of the laser cavity mirrors and the cavity length (using the knob on the translation stage) until you achieve the maximum power output; record this maximum power value.

21. Remove the post of the detector from its base (remember the collar will act as a mark for the vertical positioning so that you can easily replace this element of the setup). Check that the mode of the laser is TEM_{00} at this maximum power configuration.

Part III: Transverse Modes

22. Make very fine adjustments using the steering knobs of the high reflector and/or the output coupler and you will observe that the beam breaks into different pieces, sometimes creating elaborate patterns. These are the transverse modes. If you happen to stop your adjustments at a point which is just in between modes, you will notice a changing pattern that makes the light appear to move. Why is this so? Locate at least four simple patterns that you can draw and label (e.g. TEM_{00}) in your lab notebook and try to copy one more complicated pattern that you observe. Measure the power of two of the modes other than the one measured in #21. Sketch the mode patterns in your notebook and note the power of the laser for each mode. Compare the positions of the nodes with what you expect from the theoretical mode pattern. Note that you may have to adjust the spatial position of the detector after these changes so that the laser beam continues to fall exactly into the opening.

23. You're now going to try putting obstacles in the path of the beam at different locations in the setup. These exercises take a very steady hand, so you will want to get into a comfortable position and anchor your body against the table. Mount a card on a post and base so that you

can gently slide it into the beam Focus your beam so that it is in the TEM_{00} mode. Imagine slowly sliding a sheet of paper in the cavity between the second iris and output coupler so that the paper is perpendicular to the beam. In your lab notebook, write what you think this will do to the laser beam; that is, will it be blocked completely, partially obstructed, or unaffected? Explain. Draw a picture of the laser spot and then on the same drawing indicate what your prediction would look like. Do the same for the scenario where the paper is placed between the iris and the high reflector, and where the paper partially obstructs the beam after it has left the laser cavity. Carry out these scenarios and note your results. Were they as you had expected? Explain what is happening in these experiments to cause the beam to be altered as it is. Predict what will happen if you slowly close the iris, then try this and note your results. Is this the same or different from the experiments involving placing a card in the cavity? Repeat these experiments for at least two other mode patterns that you establish by adjusting the cavity mirrors and be sure to note your results. If you were a laser manufacturer and wanted to create a laser which only produced the TEM_{00} mode, what might you consider doing to your laser cavity?

2. In your write-up, include all the techniques, unsuccessful a well as successful , that you tried in aligning the laser, and explain why your successful method worked.