Building a Helium — Neon Gas Laser
Lab Manual
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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 4 primary parts: two mirrors, a gain medium, and 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:

![Figure 1: Trapped Photons](image)

The process of dropping the photons into the system is known as pumping it a glowing gas discharge tube 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. 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. See Figure 2 above.

Since no photons can escape the system, and more photons are being constantly emitted, there is a net increase in the number of photons between the mirrors it is said to be lasing (LASER is an acronym for Light Amplification by the Stimulated Emission of Radiation). Now, imagine that one of the mirrors is only partially reflective (i.e. perhaps 1 photon in 100 is transmitted and not reflected); thus, some of the light escapes from the system. This partially reflecting mirror is called an output coupler, constituting the end of the cavity from which the laser beam emerges. See Figure 3 on the following page.
What are transverse modes?

Making a laser with flat planar mirrors as shown above is very difficult, so slightly curved mirrors will be used instead. Such a set-up also makes it easier to understand the concept of transverse modes. (Note: the photon path is the focus of this explanation, so the gain medium is not shown; however, for lasing to occur, the gain medium must indeed be present)

Imagine you begin with a perfectly aligned laser cavity with curved mirrors on either end, as drawn below:

![Figure 3: Output coupler allows a few photons to escape to form beam.](image)

**Figure 3:** Output coupler allows a few photons to escape to form beam.

![Resonant Laser Cavity TEM 00](image)

**Figure 4:** A typical laser output beam, in the TEM 00 mode.
Now, change the alignment of those mirrors slightly so that instead of oscillating perfectly along the z-axis, there is some deviation (see Figure 5).

![Resonant Laser Cavity](image)

**Figure 5: Laser Cavity Modes**

Such a configuration would cause multiple laser spots to emerge from the cavity, not just one (your textbook has excellent pictures of these modes). Classically, you are creating standing waves in directions not parallel to the axis of the laser (the standing waves which are parallel to the axis are the longitudinal modes); the bright spots are intensity maxima and the dark spots are minima (or nodes). Because these modes are approximately normal to the z-axis (direction of the cavity), they are called Transverse Electric and Magnetic (TEM) modes. They are denoted as TEM$_{mn}$ modes, where m and n represent the number of nodes in the horizontal and vertical directions (see your textbook for examples).

The most useful transverse mode is the 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 these other modes. Though the drawings above depict a cavity with two curved mirrors, transverse modes may occur in any laser cavity configuration.
What is the wavelength of this laser?

The wavelength of a red He-Ne laser is 632.8 nm. In order to measure the wavelength of your laser, you will replicate Young’s 2-slit interference experiment. Recall that Young used a pinhole to create a spatially coherent beam of sunlight that then passed through two more, closely-spaced pinholes. As the light leaves these pinholes, it propagates in a spherical manner, as if each pinhole was a point source. Because the light is coherent, or in phase, in the places where these spherical waves overlap the principle of superposition indicates that they will add constructively or destructively. This produced a system of alternating bright (constructive) and dark (destructive) bands known as interference fringes (see the figure below).

Figure 6:
The Original Setup for Young’s Two Slit Experiment


In this lab, the laser that you build will provide the coherent light beam and you will use two narrow slits instead of two pinholes. When the primary wavefront coming from the laser arrives at the two slits, its segments will be exactly in-phase. Thus, the two wavefronts that emerge from the slits can be considered two coherent secondary sources. Where these two waves overlap, interference will occur. At the points where the two waves are exactly in-phase, bright bands (maxima) are created. In contrast, at the points where the two waves are exactly out-of-phase, the dark bands (minima) arise.
By simple geometry and trigonometry, you should be able to derive an expression for the wavelength of your laser by calculating the spacing of these interference fringes. The figure below shows the important geometrical factors in this relationship: P represents the location of the $m$th maxima; $y_m$ the distance between the central maxima and $m$th order one; $a$, the slit spacing; $r_1$ and $r_2$ the distances from each slit to the point P; $s$, the slit to screen distance; and $\theta_m$, the angle between the shortest path, $s$, and the path from the slits to the point P.

While your textbook has an excellent geometrical analysis of the set-up which you should now read (chapter 9, section 9.3.1) and make sure that you understand, the most important result and the one that you will use is the relation:

$$a \sin \theta_m = m \lambda$$

In the lab, you will use the geometry in Figure 8 to determine what measurements to make to determine the wavelength of your laser.
**Apparatus:**
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
2 irises
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.

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 setup stable and aligned much easier than if you were to attempt to have random elements 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 the picture below) 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, 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 ease in establishing the 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 these mirrors are very sensitive to dust and scratches, so you should take great care to never touch them; 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 and Brewster windows on the outside, 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). The electronics inside protrude through the glass and leave an anode and cathode to be connected on the outside. When operating,
these electronics make the tube produce an electromagnetic discharge, very similar to that in a neon sign. **The electrical connections will be connected to a high voltage power source, so use caution.**

**Procedure**

**Part I: Building the HeNe Laser**

1. Assemble 13 base-and-post-holder combinations using the ball driver by screwing one of the short screws through the base into the bottom of the post-holder. Of these 12 bases, only one wide base should be used (this will hold the alignment laser).
2. Place the breadboard on the table so that you are facing its longest side. The alignment laser will be positioned parallel to this longest edge and on the side of the breadboard furthest from you.
3. Attach the base to hold the alignment laser to the breadboard, so that the laser 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. (See Figure 15) 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**

![Diagram of Gas Laser Tube components](image)

**Figure 14:** The Basic Alignment Beam Setup

![Diagram of Placement of the alignment laser](image)

**Figure 15:** Placement of the alignment laser
breadboard to avoid scratching the base. And unless otherwise noted, make sure they are screwed in as tightly as possible.

4. Place the alignment laser into its post-holder and tighten the screw on the post-holder. Plug in the alignment laser and turn it on. The screw on the bottom of the laser can be used to adjust the beam so that it is no longer parallel with the breadboard. **For this purpose of this lab, the beam should be as parallel to the breadboard as possible,** so you should hold the 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. If it is not, then use the screw on the bottom of the laser platform to adjust the beam until you can repeat this test successfully.

5. Take one of the base-and-post combinations and place it in front of the alignment laser so that there are 5 holes between the bases on the breadboard. Attach the base loosely as you will be making adjustments later. This base, as with the majority of the bases you will be using, should be attached perpendicular to the path of the laser beam. (See Figure 16) Attach the filter-holder to a post and put the filter into the filter-holder. Then place the post into the post-holder that you have just attached to the breadboard. Swivel the post in its holder, adjust its height in the post-holder, and adjust the base position on the breadboard so that the filter is approximately 45 degrees to the path of the laser beam. Then tighten the screws in the post-holder and base so that the filter can no longer move in any direction. This filter is going to reduce the intensity of the laser beam, but you should still be careful to not look into the beam or its reflections. This is especially important now because, in passing through the filter at this angle, the laser beam has been split into two beams: one due to the transmission through the filter and the other due to the reflection from the filter. You should use your foam-core board to determine the spatial positions of both of these beams.

6. Attach a beam block to a post and place this post into one of the post-holders. Position this assembly on the breadboard and adjust it so that the reflected beam from the filter falls on the beam block. The base should be attached as close to the filter as possible due to the limited size of the breadboard, but the orientation of the base is not relevant. Be sure to tighten all screws in the post-holder and base so that the position of the beam block is fixed, thus blocking the reflected beam. (See Figure 17)
7. Attach one of the beam-steering mirror holders to a post and put that post into one of the post holders. Place this assembly in front of the filter so that there are 10 open holes between the base of the mirror assembly and the base of the filter. Adjust the mirror assembly so that the beam strikes the approximate center of the mirror and is then reflected perpendicular to the original path in the direction towards you. Ensure that the reflected beam is parallel to the breadboard. 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 are for steering purposes only and should not be adjusted at this time.**

8. Attach the second beam-steering mirror holder to a post and put that post into one of the post holders. Place this assembly on the breadboard so that there are 6 open holes between its base and the base of the mirror assembly in Step 7. These two bases are lying along the same row of holes, parallel to the path of the reflected beam from the first mirror. Adjust the second mirror assembly so that the reflected beam from the first mirror strikes this second mirror and is then reflected anti-parallel to the path of the beam originating from the alignment laser. **Important: 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.** Ensure that the reflected beam is parallel to the breadboard. Once you have established the correct position, tighten all screws in your mirror assembly to fix this position. Once again, do not adjust the two steering screws on the mirror mount itself.

9. Take your foam-core board and place it between the filter and the first alignment mirror so that it is perpendicular to the breadboard and to the path of the laser beam. Using a pencil or pen, make a mark in the center of the laser spot on the board. Then place the board between the two alignment mirrors, making sure the foam-core board is still perpendicular to the breadboard and to the path of the beam. Use the steering knobs on the first alignment mirror to adjust the height of the beam until it falls on the mark you made earlier. Once you have
established that the beam hits the same mark when it is placed between the filter and first mirror and between the first and second mirror, move the foam-core board to the far end of the breadboard opposite the second mirror (along the path of the beam) and check to see that the beam height still hits the same mark. Position the foam-core board relative to the laser beam following the same steps used above. Use the steering knobs on the second mirror to adjust the beam until it hits the mark, and reposition the foam-core board between the filter and first mirror and between the first and second mirror to make sure that the beam hits the same mark at all three locations. **You must continue making 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.** Once you have established that the beam is level all through the set-up, attach collars to the posts of both alignment mirrors. This fixes the height of the mirrors, but still allows for rotation of the posts.

10. Along the path of the laser beam coming from the second mirror, you will loosely screw down four of your base-and-post-holder assemblies from Step 1 in a row. Space the first base so that there are 8 holes between it and the base of the second mirror. Space the second base so that there are 3 holes between it and the first base, space the third base so there are 4 holes between it and the second base, and space the fourth base so that there are 3 holes between it and the third base. You are going to be aligning all of the elements that go in these bases so that the beam passes straight through them, thus 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.

11. Take your foam-core board and place it between the second mirror assembly and the first base that you have just attached to the breadboard. The board should be held perpendicular to the breadboard and to the path of the laser beam; you may use a row of holes as a guide to establish this perpendicularity (see Figure 20). Align the edge of your foam-core board with the near edge of the breadboard. Using a pencil, mark the location of the beam on the foam-core board. Then move the foam-core board to the end of the breadboard and make sure that the edge of the board lines up once again with the edge of the breadboard and that the foam-core board is still held perpendicular to the breadboard. Most likely, the laser beam will not strike the same mark that it did before. You will need to use the second steering mirror to align the beam with that mark. This is done by using the steering knobs on the mirror mounts. You should observe how turning these knobs affects the beam because you will later use knobs like these to make much finer adjustments when creating the laser cavity. Use the knobs on the second mirror mount to align the laser beam with the pencil mark on the foam-core board. Once it is aligned, bring the board back in between the second mirror and the first base and check to see if the beam still strikes the mark since the alignment has now been changed. If it does not strike the mark (which will most likely be the case), use the
steering knobs to adjust the beam until it does align and repeat these steps (moving the foam-core board from between the mirror and base to the far end of the breadboard and back again) until the laser beam strikes the same mark when the board is placed at both locations. This will let you know that the beam is now level and will pass perpendicularly through the elements that will be placed in the 4 bases you have attached.

12. Take one of the posts with an iris and place it in the base furthest from the second mirror. Make sure the iris is closed and adjust the height of the iris (use the spring-loaded screw to make fine adjustments) and the positioning of the base so that the beam falls on the exact center of the iris. The iris should be perpendicular to the path of the beam. 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.**

13. Place the second post that has an iris into the empty post holder closest to the second alignment mirror and adjust it following the same procedure described in Step 12. **However, you should only be adjusting the iris assembly itself and should no longer adjust the alignment mirrors.** Adjusting the alignment mirrors would cause the beam to not strike the center of the far iris. If no adjustments to the base positioning of the iris closest to the alignment mirror will allow the beam to strike its center, remove both irises and return to Step 11 to ensure that the beam is passing directly over the row of bases. **When you have correctly positioned both irises, you should be able to fully close both irises and still see a spot on the foam board when it is placed at the far end of the breadboard.** Furthermore, leaving the iris closest to the second mirror closed, you should be able to open and close the other iris without disturbing the spot on the board. Once you have established correct iris positions on the iris posts. **Turn off the alignment laser.**

14. Take the laser tube assembly and carefully remove the Brewster window covers. **Remember not to touch the surfaces of the Brewster windows.** You are now going to place the laser tube assembly in the two remaining post holders on the breadboard, a process that requires two people. **Figure 20: Making Alignment Beam Level**
should support the tube; however the tube holders do not have an extremely firm grip on the tube so the other person should hold the tube firmly in the center taking care to touch neither the Brewster windows nor the electric connections. Now lift the assembly and position it over the two empty post holders on the breadboard. While the person holding the tube keeps a firm grip on it to support it, the one holding the posts with the mounts should slide them gently along the tube until the posts will fit into the post holders such that the tube will sit without the Brewster windows touching either iris. Once the posts are in the post holders and are resting securely within them, it may be necessary to adjust the position of the tube in the mounts. With one person still holding the tube, the other person should loosen one of the screws on both mounts and the tube should be adjusted to rest exactly between the two irises. Also, make sure the cathodes are approximately parallel to the breadboard and the anode approximately perpendicular to the breadboard, pointing down towards it. Then tighten the mounts on the laser tube.

16. **Make sure the alignment laser is turned off for this step.** Partially tighten the screws on the post holders for the laser tube so the height of the tube can still be adjusted. The goal of alignment is to have the laser beam from the alignment laser pass directly through the center of the first iris, through the center of the laser tube, and out the center of the second iris. Slightly open the second iris and lower your head so that you are looking through the opening of the iris and such that your line of sight is parallel to the breadboard. Remove the second alignment mirror from its post holder. Note that if you don’t change the position of the collar on the post, you will be able to replace the mirror in the post holder and rotate it to achieve the alignment that you established earlier. Another person should be looking into the other end of the laser tube through the opening of the first iris. Now each person should adjust his/her end of the laser tube so that it is centered in the opening of the iris. Remember that the bases holding the laser tube are not fully tightened so they can be slid on the surface of the breadboard. The spring-loaded screws also allow for fine height adjustments. Opening or closing the iris as you look through it to the tube may help with determining whether the tube is centered properly. Once each person has his/her end of the tube centered in the opening, tighten the screws on the base and on the post holder.

17. Now turn the alignment laser back on and replace the second alignment mirror back into its post holder. Make sure the first iris is closed and slowly rotate the second alignment mirror, watching until you line the laser beam with the center of the first iris. Once you have the mirror properly lined up again, tighten the screw on the post holder of the alignment mirror. Place the foam-core board at the far end of the breadboard so that the laser beam coming out from the second iris hits it perpendicularly. If you have lined up the laser tube properly, you should see a red spot on the foam-core board. If this is not the case, turn off the laser and repeat Step 15 to align the laser tube properly. Once you do have the laser beam passing through and hitting the foam-core board, you’ll most likely notice that the spot is not symmetric and that there is a pattern of rings positioned asymmetrically around a central point of light. This indicates that the beam is partially obstructed when passing through the
laser tube. It is striking an internal part and then internally reflecting within the tube. To avoid this effect, you will have to adjust the position of the laser tube while watching the beam on the foam-core board. With both irises open, slightly loosen the screw in the post holder of the laser tube that is closest to the foam-core board and adjust the height until you have eliminated as much of the pattern of rings as possible. Slightly loosen the screw on the other post holder and the screws on the bases of both laser tube post holders and make more small adjustments until the spot on the foam-core board is as small as possible. You should be able to eliminate nearly all of the ring pattern. The ultimate test is to close first one, then both irises and observe little to no change in the spot on the foam-core board. Once this has been achieved, tighten all screws and place collars on the two posts. Then turn off the alignment laser.

18. Next you are going to put together the output coupler assembly and place it at the end of the laser cavity beyond the second iris. Attach the output coupler mirror mount to a post and place this post into one of the post holder/base assemblies. Loosely screw down the base to the breadboard leaving three open holes between it and the base of the second iris; rotate the post so that the mirror coating faces the second iris. Be extremely careful when handling the output coupler and high reflector because their surfaces are extremely sensitive to scratches and dirt. Do not touch the surfaces. Turn on the alignment laser and adjust the height of the output coupler so that the beam from the alignment laser falls approximately in the vertical center of the mirror and partially tighten the screw in the post holder. Then adjust the positioning of the base so that the alignment beam is now perfectly centered in the mirror. Tighten the screws in the base. Looking towards the laser tube from the side of the second iris (closest to the output coupler), and without placing your eyes in the plane of the laser beam, swivel the post of the output coupler in its post holder until the reflected beam falls either directly above or below the opening of the second iris. Then tighten the screw in the post holder and use the steering knobs on the output coupler mirror mount to adjust the reflected beam until it matches up exactly with the opening of the second iris; that is, the alignment beam will be reflected back through the iris and laser tube. 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.

19. Now you will assemble the high reflector and place it at the opposite end of the laser cavity. Attach the high reflector mirror mount to a post and place this post in your one of your remaining post holders. Loosely screw down the base leaving three open holes between it and the base of the first iris so that the mirror coating faces the first iris. Adjust the height of the high reflector so that, from the back of the high reflector, the alignment beam is striking the vertical center of the mirror and partially tighten the screw in the post holder. Then adjust the position of the base on the breadboard 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 back of the high reflector. When the reflected beam strikes the two alignment mirrors in approximately the same places that the original alignment beam strikes, 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. Now the alignment laser is striking the back of the high reflector and traveling backwards through the alignment set-up. Where the beam strikes the filter, another stray beam is being reflected in your direction. Even though the alignment laser will not be used beyond this step, the laser you are creating will also produce a beam that follows this path. **To eliminate this potential hazard, place your second beam block in one of the remaining base-and-post-holder assemblies and attach this base to the breadboard close to the filter. Adjust the height and spacing of the beam block so the stray beam falls into the center of the beam block.** Turn off the alignment laser. You will no longer be using it.

20. 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. 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 end of the resistor connected to the black terminal. The black clip should be attached to the cathode of the laser tube. Then attach one end of the white cable to the side of the resistor connected to the red terminal. The other end of the white cable should be attached 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.** Secure the red cable from the power supply 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. **Before you turn on the power supply, make sure no one is too close to the laser tube set-up because you are working with high voltages.** Make sure both irises are open and place the foam-core board at the far end of the breadboard perpendicular to the path that the laser beam will take so that you will be able to observe the beam. **Put on your safety glasses and turn on the power supply.**

21. Most likely you will notice a pink glow from the tube similar to that of an un-colored neon sign. Ideally, with perfect alignment, a laser spot should be on the foam-core board. However, this is most likely not the case and you will have to make adjustments to the high reflector. Using the steering knobs on the high reflector mirror mount, slightly adjust the mirror while watching the foam-core board. When the laser lases, but you are still moving the mirror, it will flash quickly. 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 working 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 again to realign the two mirrors. Remember, you will need to remove the high reflector in order to reposition the output coupler, so 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!

Part II: Transverse Modes
22. Once you have made a laser, move the foam-core board as far away from the tube as possible
to expand the pattern of the beam on the board. The board should be at least 3 meters away
from the output coupler, but the further the better. Use the steering knobs on both mirrors to
concentrate the beam to one central bright spot.

23. 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 (ex. TEM$_{00}$) in your lab notebook and try to copy one more complicated pattern
that you observe.

24. 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. 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 first 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 one of the
irises, then try this and note your results. Is this the same or different from the experiments
involving placing a sheet of paper 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?

Part III: Young's 2-slit experiment
25. Next you're going to measure the wavelength of your laser using Young's Two Slit method.
Place the slit plate in the path of the laser beam coming from the output coupler so that it is
as close to the output coupler as possible without touching it or disturbing the set-up in any
way. Orient the slit plate so that the laser beam passes through a single slit. Describe the
pattern that you see on the foam-core board (you should draw it in your lab book) and write
down observations regarding intensity and the spatial positioning of the pattern along with
relative sizes. Then pass the laser through a pair of slits and record your observations,
comparing them to what you saw with the single slit. What differences do you notice?
Explain these differences.
26. Making sure that the beam is passing through a set of slits for which you know the slit-spacing, make appropriate distance measurements so that you can calculate the wavelength of your laser (look at the diagram from the introduction).

**Part IV: Laser Power**

27. Now you're going to measure the power of your laser beam. First, make sure that the beam is organized into the lowest order mode (TEM$_{00}$). Take the mounted detector of the laser power meter 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 there are only two open rows of holes between it's base and the base of the output coupler. 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.

28. Position 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 until you achieve the maximum power output; record this maximum power value.

29. 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). Note the mode of the laser at this maximum power configuration (if it is easily distinguishable) and sketch the mode in your lab notebook. Replace the detector in its base and try slightly moving the position of the detector, noting what slight adjustments in this position do to your power measurements.

30. Measure the power of two more, easily distinguishable modes that you create by adjusting the laser cavity mirrors. Sketch the mode patterns in your notebook and note the power of the laser for each mode. 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. With the detector temporarily out of the setup, adjust the mirrors of the cavity so that when the beam is projected onto the foam-core board it is as faint as possible, but your eyes can still detect it. Measure and note the power of this cavity configuration by replacing the detector in the setup. Sketch the mode and label it if you can see it well enough. Remove the power meter from your laser setup and replace the foam-core board as far away as possible, so that you can easily see the laser spot.

**Part V: Cavity Length**
31. Return your laser to the brightest but most compact TEM$_{00}$ mode. As painful as it might seem, you’re now going to remove the high reflector and put it on a base that will allow you to translate the mirror, thus altering the length of the laser cavity. First, turn off the laser, unscrew the base of the high reflector from the breadboard, and set it aside. Translate the stage so that the top platform is displaced as much as possible in one direction. You’re going to attach it to the table so that the overhanging edge of the platform faces the laser tube. 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 into the row of holes that is aligned with the center line of your setup, leaving three empty holes between the translating stage and the base of the first iris. The base for the high reflector will eventually be attached to the row of holes that is partially overhanging the bottom platform; with the stage in this fully forward position, this set-up should place the high reflector in a position similar to its original one.

32. Translate the stage backwards fully until the rear hole is clear so that another screw can be used to attach the stage to the breadboard; put a table screw in this hole, firmly anchoring the stage to the breadboard. Attach the post holder base of the high reflector to the row of holes on the upper stage of the translator closest to the laser cavity, and translate the stage fully forward so that (as mentioned earlier) the high reflector is in the same approximate position as when the laser was previously operational. **Turn the laser back on, follow the steps given previously to align the high reflector using the alignment laser, and obtain a laser spot (unless you have moved the output coupler, the only realignment necessary should be that of the high reflector) in the TEM$_{00}$ mode.**

33. Slowly translate the high reflector backwards from the cavity and note how your laser spot changes. If the mode changes, identify and sketch it. Also note how the intensity changes. Now translate the high reflector until it returns to the position closest to the laser cavity. Adjust the high reflector so that you locate one distinct mode pattern that you can identify and sketch this pattern. Then, slowly translate the mirror away from the cavity and note your observations with mode labels, sketches, and intensities. Repeat this for at least one other starting mode. Finally, establish a mode with the high reflector translated as far away from the cavity as possible, and observe the mode changes in the same way by translating the mirror towards the cavity.