

The Projecting Microscope

Purpose

The purpose of the experiment is to design, build, and test a projecting microscope with a magnification of 400. A He-Ne laser beam illuminates the object, producing a highly magnified image on a screen about seven feet away, similar to the picture from a 35 mm projector. The experiment introduces the laser, the optics of lenses, and the optical bench with its mechanical lens-holding devices; also introduced are the basic procedures for aligning and adjusting lenses to make the system work

WARNING-CAUTION

1. The laser beam can cause serious damage to the retina of your eye. Learn the precautions you should take to avoid this risk. **Remember: Never look into the beam!** Always use a card held in the beam to see where it is. Be aware that the beam may be unexpectedly reflected off of shiny surfaces.
2. Learn how to handle and clean optical components so that they are not damaged.

Introduction

The projecting microscope forms a highly enlarged real image of some small object on a distant screen. It differs from the viewing microscope with which the viewer sees a virtual image, located in the same plane as the object at a distance of 25 cm from the eye - the closest distance of distinct vision. In both microscopes (see Figure 2.0), the objective lens (L1) focuses light from the Object (O) to produce a magnified real intermediate image (I1). This image, I1, serves as an object, or source of light, for the second lens (L2). This second lens will be the eyepiece on the viewing microscope, or a projecting lens in the projecting microscope. A viewing microscope can be converted to a projecting microscope by increasing the separation of the lenses L1 and L2, since the first principal focus (F2) of the lens L2 lies to the right of image I1 in the projector, whereas F2 is to the left of I1 in the viewing microscope.

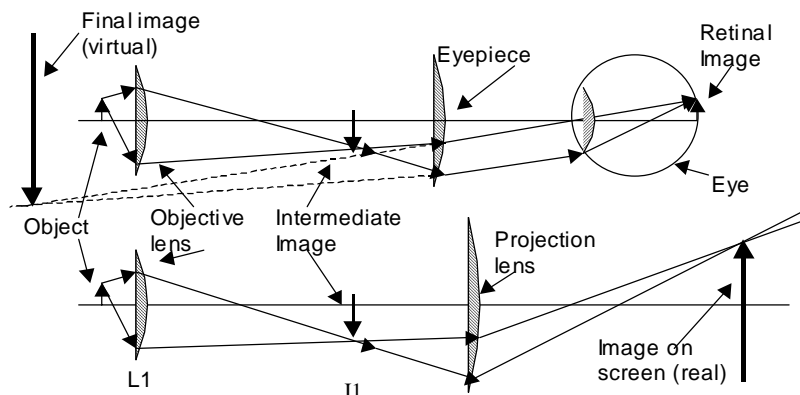


Figure 2.0 Comparison of viewing and projection microscopes.

The complete layout for the projecting microscope is shown in Figure 2.1. The He-Ne laser beam illuminates the object to make the final image as bright as possible. A laser beam is typically 1mm diameter. If this beam is too narrow to illuminate the full area of the object, a beam expander (lenses Lx1 and Lx2) can be inserted to enlarge the beam up to the size of the object. The factor by which the beam is expanded is equal to the ratio of the focal lengths of the lenses i.e., $D2/D1=f_{x2}/f_{x1}$ (see discussion on page 2.10).

The first lens (L1) of the microscope, the objective lens, produces a magnified real image (I1) of our object (O). This intermediate image serves as the object or source for the second lens of the microscope, the projector lens (L2). The light diverging to the right from I1, is refocused by the lens (L2) to produce a final image (I2) on the screen (E).

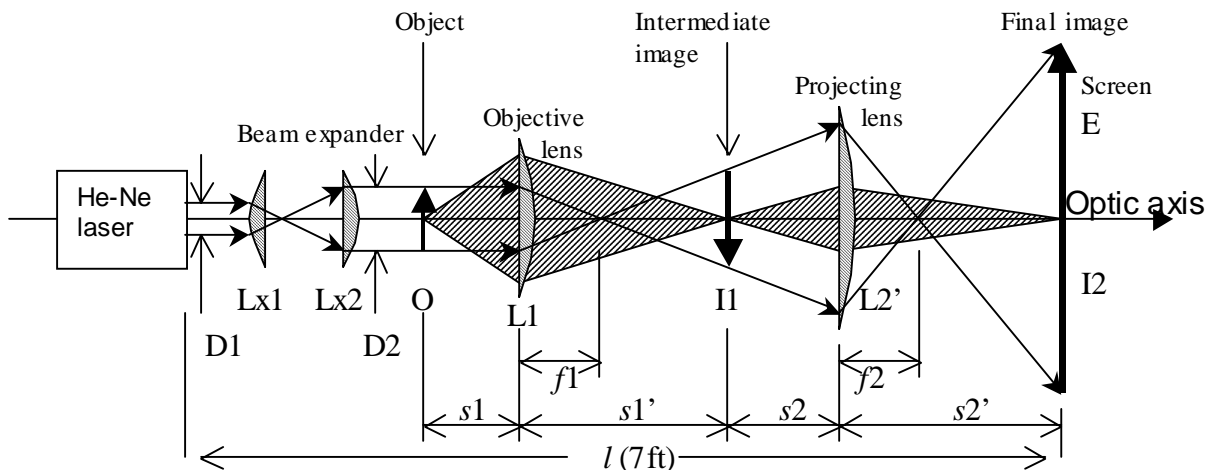


Figure 2.1. Projecting microscope with laser illumination.

The unshaded light cones represent the envelope of the laser beam as it propagates through the lens system in the absence of an object. The lens apertures must be large enough that the laser can illuminate the whole of the desired image space on the screen. The shaded light cone originating from the center of the object is light that has been diffracted by the fine details of the object's structure. This is the light that carries detailed information about the structure to the image on the screen. Recall that the angular half-width, α , of the central diffraction maximum from a source element of width (a) is given by: $a \sin \alpha = \lambda$ where $\sin \alpha = d_1/2s_1$. Thus, the diameter (d_1) of the objective lens (L1) is the determining factor in the fineness of detail transmitted when the detail is limited by diffraction. Unfortunately, the improved diffraction performance of large diameter lenses is offset by the increase of spherical aberrations for larger diameters. You can reduce aberrations by making the proper choice of lens shape and orientation. Figure 2.1 shows the best lenses for this application are planar-convex (PCX) with the planar sides facing the most strongly divergent (or convergent) beams.

The best performance can only be obtained by using multi-element compound lenses, such as the commercial microscope objective. We would like you to see how well you can do

with ordinary lenses this week. Since these may be the only ones available if you must make a quick setup for an experiment in progress. For the remainder of the semester, you will use various types of commercial compound lenses such as the 35 mm projector lens, whenever the application makes it appropriate.

Outline of the Experiment

1. Preliminary laboratory work

- Identify optical and mechanical components on the optical bench.
- Measure the line spacing (d) of the Ronchi grating to 1% accuracy with the measuring microscope. The Ronchi is your 'fine' scale.
- Define the optic axis by two pinholes on the optic bench.
- Align the laser beam with the optic axis.

2. Check the laser beam characteristics

- Measure the laser wavelength (λ) to 1% by diffraction with the Ronchi grating, using the grating formula: $d \sin \theta_N = N\lambda$.
- Verify that the laser beam is diffraction limited by measuring its diameter (D_0) and the divergence (θ_0). It should satisfy the diffraction formula ($D_0\theta_0 \approx \lambda$).
- Measure the total laser beam power (P_L , mW).
- Set up a beam expander to give a parallel output beam of about 4 mm diameter.

3. Measure the focal lengths of the microscope lenses.

4. Set up the projecting microscope.

- Place a test transparency (the Ronchi for example) in object position O.
- Insert a beam diffuser just in front of the object, close up.
- Install objective lens (L1), and a white card in a fixed position at the predicted distance of image I1. Adjust the lens (L1) position to give a sharp image on the card.
- Set up projecting lens (L2) and adjust its position to produce a sharp image (I2) on screen (E) attached to the wall.
- Increase the image brightness by removing the diffuser and beam expander.

5. Test the microscope

- Verify the overall magnification (M) is 400.
- Estimate the resolution of the instrument. (the smallest distance between two distinguishable points in the object (O)).
- Observe the effect of reducing the objective aperture with an iris. Estimate the width of

the fuzziness introduced into the previously sharp edges in the image. Compare with the predictions of diffraction theory.

OPTIONAL:

6. Install a zoom lens (L2 and L3) in place of the projector (L2)
 - Adjust it to give magnifications M of 200 and 800.
7. Examine and report on a few tiny objects of interest to you.

Problems

(It will help to read the lab and the textbook sections before attempting the problems.)

1. Design a beam expander that will increase the beam diameter from approximately 1 mm at the laser output to 4 mm for illuminating the object. What is the value of the characteristic length for the 1 mm beam? What is the diameter of the waist (narrowest part of the beam) between the two lenses of the expander? What is its characteristic length?
2. Design a projecting microscope with an overall magnification of 400. The maximum available distance between laser and the screen is about 7 ft. Draw a topologically correct ray diagram for the instrument showing the chief, parallel and focal rays. Also, mark the principal foci of the lenses L1 and L2. Calculate suitable focal lengths for the objective L1 and projecting lens L2 in Figure 2.1, and their positions. The shortest focal length lens that we have is about 15 mm. Choose lenses of a shape to minimize spherical aberrations. Note that there is not a unique design, but some choices are better than others.
3. Consider the illumination: Room light intensity is typically 0.05 mW/cm^2 . We might expect that the projected image is easily visible for one fifth of this intensity, say 0.01 mW/cm^2 intensity. What is the maximum diameter that image I2 can have if all of the light from a 10 mW laser is spread over it? What is the diameter of an object whose image (I2) has the diameter just calculated? What diameter of laser beam do you need? Draw rays that define the envelope of the laser beam as it passes through the system when there is no object in the beam. Calculate the minimum diameter that the lens L2 must have so that it transmits all of the laser light to the screen.
4. Design a zoom lens that will give overall magnification of 200 and 800 by adjustment of the positions of the same pair of lenses (L2 and L3).

Kit of tools for lens problems

A. Definitions

OA = Optical axis (symmetry axis of lens)

l = distance from object to image

s = object distance, + to left implies a real object

s' = image distance, + to right implies a real image

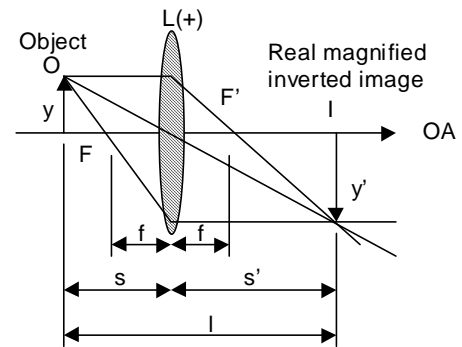
$l = s + s'$

f = focal length (+) is a converging lens (convex)
(-) is a diverging lens (concave)

y = object height

y' = image height

$m = y'/y =$ magnification



B. Gauss' Lens Formulae

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

$$m = \frac{y'}{y} = -\frac{s'}{s}$$

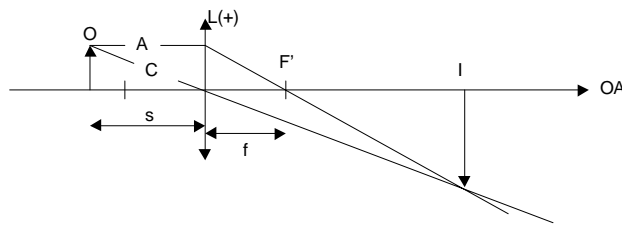
C. Analysis of a given lens system:

- Given object distance (s) and focal length (f).
- Find image distance (s') and magnification (m)

$$s' = \frac{sf}{s - f}$$

$$s = \frac{s'f}{s' - f}$$

$$m = \left(1 - \frac{s'}{f}\right) = \frac{f}{f - s}$$



The image (I) lies at the intersection of parallel ray (A) with the Chief Ray (C).

D. Design to meet given specifications:

- We require magnification (m) with fixed spacing (l).
- Find focal length (f) and position (s or s') of lens.

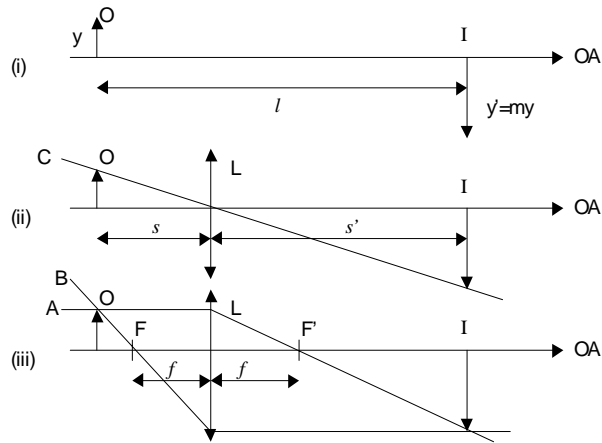
$$f = \frac{l}{2 - m - 1/m}$$

$$s = f(1 - 1/m)$$

$$s' = f(1 - m)$$

Rules for construction of a Ray Diagram.

- i. Draw data showing O and I with given magnification and separation.
- ii. Draw chief ray (C) from tip of O to tip of I. Lens lies at intersection of chief ray with optic axis.
- iii. Draw parallel ray (A) from the tip of O to plane of lens (L). Then connect to tip of image I.



The intersection of rays A and B with optic axis gives the locations of principal foci F and F'.

Stages in designing the projection microscope

In the following sections, we show an example of the design of a projection microscope to meet example specifications. As we stated above, there are many choices of optical components that could meet the particular specifications. We will make certain choices, with the reasoning explained briefly. The result is a 'middle of the road' design. The final design could be different depending upon additional specifications such as requirements on spherical or chromatic aberrations.

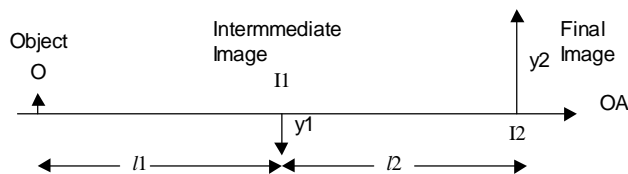
SPECIFICATIONS:

Total magnification	$M = m_1 m_2$
Total length	l (mm)
Power of laser	P_L (mW)
Light intensity on screen	I_E (mW/cm ²)

EXAMPLE:	$M = 100X,$	$l = 2 \text{ m},$	$P_L = 10 \text{ mW},$	$I_E = 1 \mu\text{W}/\text{cm}^2$
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a. Initial choices

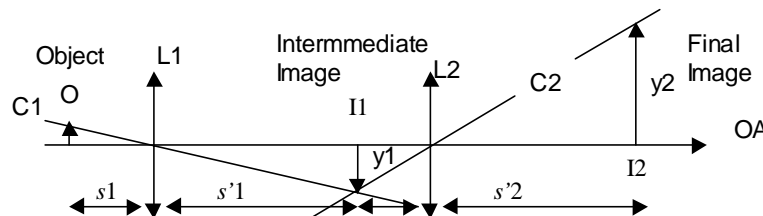
We first choose the magnifications of the two stages to be equal ($m_1 = m_2$) to minimize aberrations



(both spherical and chromatic).

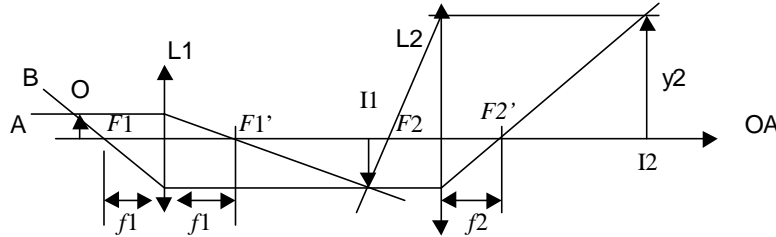
- $m_1 = m_2 = -\sqrt{M} = -10$
- $l_1 = l_2 = l/2 = 1000 \text{ mm}$

- b. Locate the lenses by drawing the chief rays. The first is C1 from the tip of the object to the tip of I1. The second is C2 from the tip of I1 to the tip of I2. The lenses are located where the chief rays intersect the optic axis. Now you know where to place the lenses.



- c. Determine the focal lengths of the lenses, L1 and L2. Draw the parallel ray (A) from the tip of the object to the tip of I1. The principal focus, F1', is located where this ray crosses the optic axis. Similarly, use the focal ray (B) to find F1. Each is located a focal length to

either side of L1. Similarly, continue rays A and B through the image I1, lens L2, to image I2. These rays cross the optical axis at points F2 and F2'. These are located a focal length from lens L2.



You can cross check your graphical results for the lens positions and the focal lengths by applying the lens equations listed in the tool kit:

$$f_1 = \frac{l_1}{(2 - m_1 - 1/m_1)} = \frac{1000 \text{ mm}}{(2 - (-10) - (1/(-10)))} = 83 \text{ mm}$$

$$s_1 = f_1 \left(1 - \frac{1}{m_1} \right) = 83 \text{ mm} \left(1 - \frac{1}{-10} \right) = 91 \text{ mm}$$

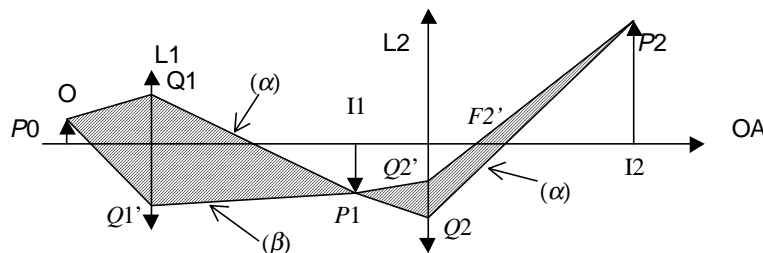
$$s_1' = f_1 (1 - m_1) = 83 \text{ mm} (1 - (-10)) = 909 \text{ mm}$$

The two lens systems are identical. Therefore, we also have:

$$f_2 = 83 \text{ mm} ; s_2 = 91 \text{ mm}$$

Hint: You won't be able to find lenses in the lab with the exact f_1 that you calculate. Choose lenses with the closest f you can find that is smaller than your calculated result, as the bench is less than 2m in length.

- d. Construction of any other rays: Draw planes of the lenses L1 and L2, and the position and heights of the object, O, and the images I1 and I2. When drawing the rays, remember that light rays bend only at the lenses and follow straight lines between them. Any ray from the tip of O must pass through the corresponding point in every image of O, specifically, I1 and I2 in our case. Thus, ray (α) is the line connecting the points $P_0Q_1P_1Q_2P_2$. The shaded area between rays α and β is the pencil of light between them.



- e. Choose the size of final image for adequate brightness.

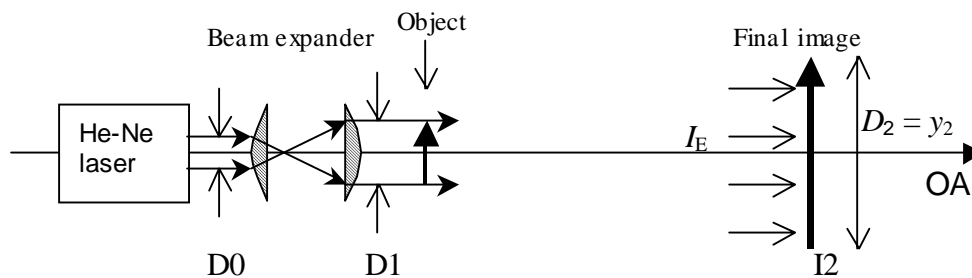
The total power available from the laser is fixed at roughly 10 mW. We design for the intensity on the screen to be $10 \mu\text{W}/\text{cm}^2$, or one fifth of room light intensity. Therefore, the diameter of the final image is determined via:

$$I_E = \frac{\text{Laser power}}{\text{area of image}} = \frac{P_L}{\pi D_2^2/4}$$

or

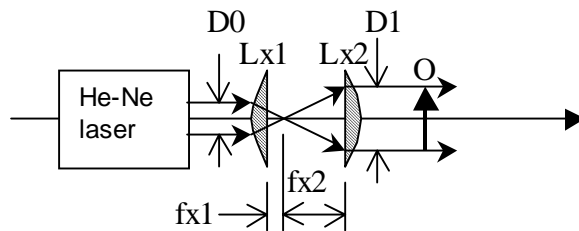
$$D_2 = y_2 = \sqrt{\frac{4P_L}{\pi I_E}} = \sqrt{\frac{4(10mW)}{\pi(0.01mW/cm^2)}} = 36 \text{ cm}$$

The diameter of that part of the object, O, which will be displayed on the screen is $y_0 = y_2/M = D_2/M = 360mm/100 = 3.6mm$. This is the diameter of that part of the object to be illuminated by the laser beam. Therefore, the laser beam diameter must be expanded to 3.6 mm.



f. Design the laser beam expander.

The beam emerging from the laser has a diameter, D_0 , of roughly 1 mm. It must be increased to D_1 . The short focus converging lens Lx_1 produces a nearly point image at distance f_{x1} . Lens Lx_2 transforms the expanding beam to a parallel beam of diameter D_1 . Our shortest focal length lens has a 15 mm focal length. Then, by similar triangles:

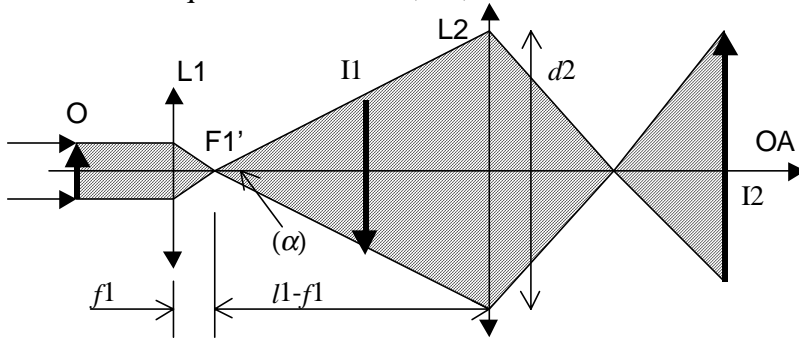


$$f_{x2} = f_{x1} \frac{D_1}{D_0} = 15mm \frac{3.6}{1} = 54 \text{ mm}$$

g. Illumination profile through the system. (Determine the minimum diameter of L_2)

Draw the envelope of the expanded laser beam as it propagates through the lens system. The marginal ray RM passes through the tip of O , is bent by L_1 to pass through the principal focus F_1' , touches the tip of I_1 , and is bent by L_2 to arrive at the tip of I_2 , the final image. There is a corresponding ray through the base of O . The shaded area represents the cone of illumination passing through the system. The minimum diameter of

lens L2 equals the diameter, d_2 , of the beam at L2.



$$d_2 = \alpha(l_1 - f_1)$$

but

$$\alpha \approx \frac{D_1}{f_1}$$

$$d_2 = \frac{D_1}{f_1}(l_1 - f_1)$$

$$= \frac{3.6}{83}(1000 - 83)$$

$$= 40 \text{ mm}$$

h. Characteristics of laser beams.

The properties of laser beams depend upon the details of the laser construction and mode of operation. A complete treatment of laser beam properties is quite involved, requiring at least Maxwell's equations, and often quantum electrodynamics, to understand beam diffraction effects and laser photon properties. However, most situations we will encounter involve small diffraction angles, bright beams, and beams with approximately Gaussian intensity profiles. Under these conditions, a good description of the diffraction effects is provided by small angle approximations and Gaussian optics. Then, the Helium-Neon lasers in the lab have beams that are:

- Monochromatic (single wavelength, λ)
- Coherent (all the photons have the same phase)
- Diffraction limited. The angular divergence of the beam, θ_0 , is about equal to that due to diffraction of incident plane waves by a circular aperture of diameter D_0 , the exit aperture of the laser. The precise small angle relation for the laser is:

$$D_0 \theta_0 = \frac{4}{\pi} \lambda$$

The characteristic length, L_L , is the distance for which the beam remains almost parallel. Specifically, the beam diameter has increased by $\sqrt{2}$ at distance, L_L .

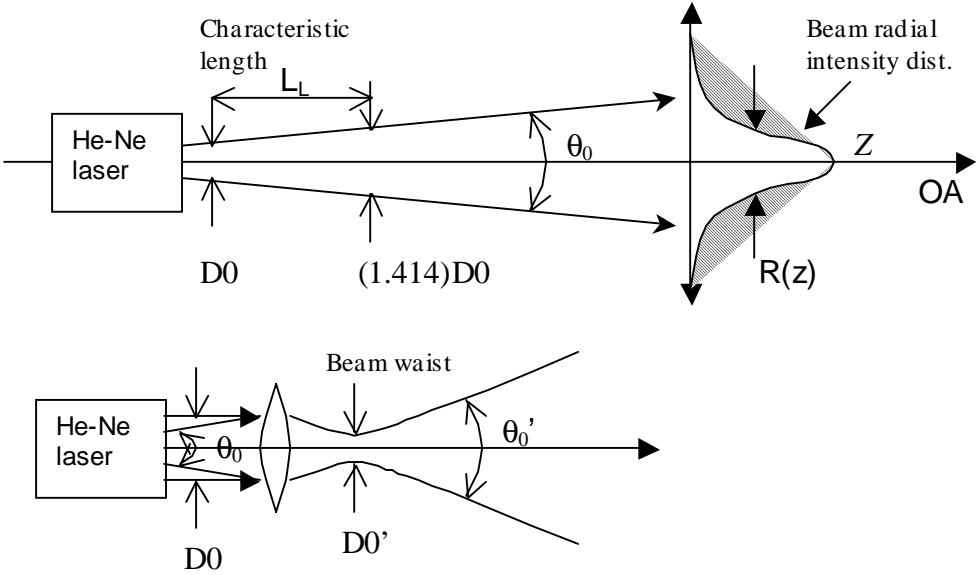
- Has a Gaussian intensity distribution across the beam.

$$I(r) = I_0 \exp\left(-\frac{r^2}{R^2}\right) \text{ where } R(z) = \frac{D_0}{2} \sqrt{1 + \frac{z^2}{L_L^2}}$$

In this description the length, z , is measured from the front of the laser and in the direction of laser beam propagation. The quantity, $2R$, is approximately the diameter you see. A local minimum in diameter of the beam is called a waist.

When the beam is focused by a lens, another waist is formed which may have a different diameter, D_0' , and angle, θ_0' . However, the product is an invariant for a given wavelength with the value:

$$D_0\theta_0 = D_0'\theta_0' = \dots = \frac{4}{\pi} \lambda$$



Mechanical and optical components

1. The optic bench and mechanical components

The optical components include lenses, mirrors, beam splitters, diffraction gratings, Polaroid filters, and various optical crystals. Other components inserted in the beam include object transparencies, slits, pinholes, intermediate focusing screens, and photodiodes or other light detectors.

The mechanical part of an optical system enables each optical component to be centered on the optic axis and then translated along the optic axis e.g., to focus a lens, while maintaining its centered position.

Most optical components are mounted on black aluminum slides that are interchangeable with 35 mm photographic slides. Larger components are mounted on 3' by 3' slides. The slide holders enable experiments to be quickly set up and modified. Sensitive optical components can be handled without touching the surfaces, once they have been mounted in the slides.

The screws that hold the system together are now restricted to just two thread sizes, which are standards in the US optical industry: 8-32, meaning 1/8" diameter with 32 threads per inch, and 1/4-20, meaning 1/4" diameter by 20 threads per inch. The screws with heads are called cap screws, while set screws have no head and are used for making inaccessible connections.

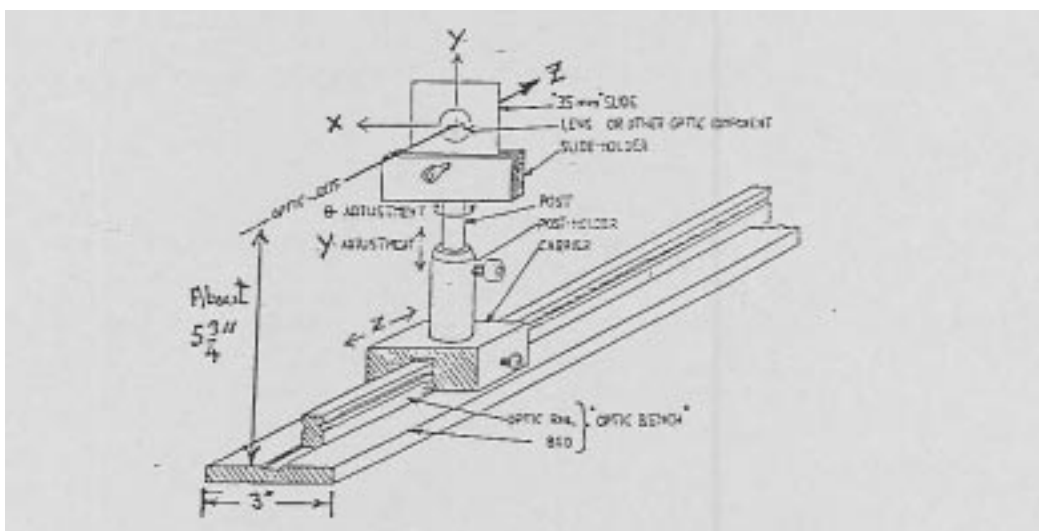


Figure 2.2. Optic bench, showing parts needed to hold a 35 mm slide.

Figure 2.2 shows the optic bench and the assembly used to hold an optic component.

- Each slide fits snugly into a groove in the top of a slide holder. The horizontal position is adjusted by moving the slide along the groove and tightening a screw to lock it in position when properly set.
- The slide holder is attached to the top of a steel post (2" or 3" long). The vertical position is adjusted by moving the post up or down in the post holder. The height may be set, leaving the post free to rotate, by tightening the screw on a collar (not shown) that rests on the top of the post holder. All movement of the post can be frozen by tightening a 1/4-20 screw through the side of the post holder.
- The post holder is rigidly attached to a carrier by a hidden 1/4-20 set screw.
- The carrier slides along the optic bench guided by a rail that is strictly parallel to the optic axis. The optic axis is set for convenience at 5-3/4" above the surface of the rail bed. This height gives the greatest flexibility in combining different components.
- A typical experiment may have several carriers spaced at intervals along the optic bench. They may hold a laser or other light source, lenses, etc. A beam stop must be fixed securely at the end of your optic bench for safety reasons if the beam is not directed at a nearby wall.

CAUTION CONCERNING SCREWS

Screws that lock an adjustable component in place do so by bearing down on a smooth underlying surface. Locking screws should be only finger tight. Never use an Allen wrench or pliers. Such use causes the screws to bite into and damage the underlying surface. A roughened surface may cause the interface to seize up, preventing the movements needed for adjustment.

2. Optical components

For lenses, 1" in diameter or smaller, choose a blank 2" by 2" slide with a hole of diameter a little less than the lens. Attach it to the holder with 3 tiny dollops of adhesive wax, less than one mm³ each. Gently press the edges of the lens into the wax. For 1-1/2 inch lenses and larger, use the 3" by 3" slides.

If there are no metal slides available, make one from the black cardboard that is 0.05" thick. Holes may be punched in the cardboard with a hammer and punch tool. Do this on top of a lead brick, not the bench!

Slides without holes are available for mounting mirrors.

Lens surfaces and especially front surface mirrors are very vulnerable to touch with the fingers. Be careful NOT to touch the optical surfaces. If you DO accidentally touch an optical surface, immediate cleaning as discussed below can usually remove the finger oils and acids before permanent damage occurs.

Lift lenses only at the edge, and set down on lens tissue. Forceps with soft coating may be used also, or use polyethylene lab gloves if you have much work to do. Skin acids leave permanent marks on the surface, causing unsightly optical noise in the coherent light beams that the lasers generate.

For cleaning, use mild neutral soap (1% in water), distilled water, alcohol, and acetone in that sequence. Petri dishes make convenient containers. Use only lens tissue for swabbing.

3. Laser Safety

Remember never to look into the beam, even if it is not apparently there. Always use a card held in the beam to see where it is. Be aware that the laser beam may be unexpectedly reflected off a shiny surface. Use blackened surfaces or dull white for materials that the beam might hit.

The Experiment

1. Preliminary Work

- a. Identify the parts in your kit (see Appendix 1).
- b. Measure the period of your Ronchi grating to 1% accuracy with the measuring microscope. This Ronchi grating will be your standard of length whenever you need a small scale.
- c. Define the optic axis of your system at 5-3/4" above the wider surface of the optical rail using two black cards with a pinhole in the center of each.
- d. Turn on the laser and align the beam with the optic axis such that it passes through both pinholes.

2. Verify the characteristics of the laser beam

- a. Measure the wavelength, λ , to 1 or 2% using diffraction by the Ronchi grating.
- b. Estimate the diameter, D_0 , of the laser beam at the exit port and the angle of

divergence, θ_0 . Verify that the beam is diffraction limited by seeing if your data satisfy the equation: $D_0\theta_0 = (4/\pi)\lambda$.

- c. Measure the beam power (mW) with the laser power meter.
- d. Set up the beam expander.

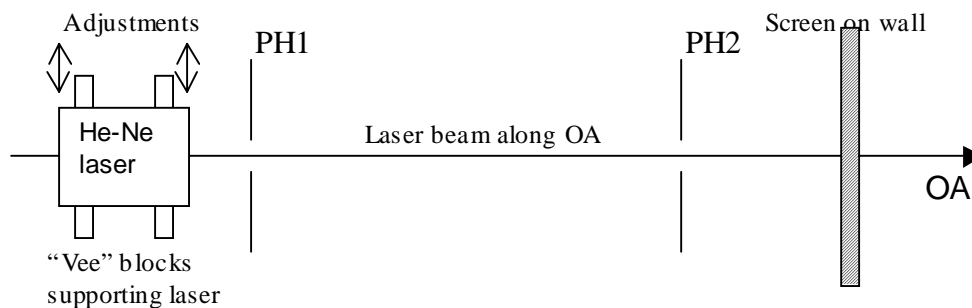
Some details:

1. (d) Aligning the laser beam with the optic axis

Take two pieces of black cardboard, 2" square and make a pinhole at the center of each, about 1 mm in diameter. With white ink, mark X and Y axes centered on the hole. Mount each in the complete carrier assembly and place them close together on the optic bench near the exit window of the laser.

Adjust the height of the first pinhole, PH1, to be 5-3/4 inches above the optic bench and center it horizontally by eye. We will define the optic axis to be the line through this pinhole that is parallel to the rail.

Place the laser in the cradle and turn it on. Adjust the cradle so that the laser beam passes through PH1, pointing in about the right direction. Center the second pinhole in the beam and slide it to the far end of the bench. The line through both pinholes should now represent the optic axis. Your setup should look like the sketch below. Adjust the laser position and direction to make the beam pass through both pinholes. Mark the spot where the beam hits the screen. The beam now follows the optic axis. The laser mount locking screws should now be tightened, and left fixed for the duration of the experiment.

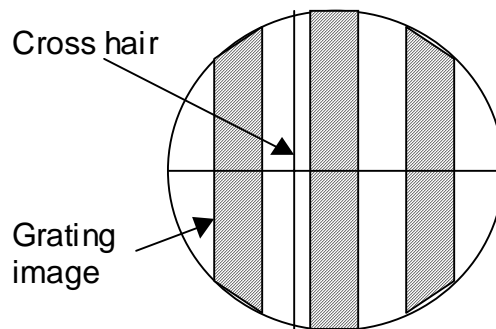


The process of aligning the laser and lenses can be extraordinarily time consuming if the individual adjustments are done at random or in an improper sequence. For example, consider the alignment of the laser beam with the optic axis. A quickly convergent

procedure is to adjust the front of the laser (number 1 holder) with PH1 very close, until the beam passes through. The beam is probably following the wrong direction, so your next adjustment is to the rear end of the laser to steer the beam closer to PH2. This adjustment will cause a small alignment error to appear at the front end, which is corrected by appropriate adjustment. About three or four iterations of this kind should bring the beam into alignment. This process takes perhaps 5 minutes, perhaps longer the first time.

1. (b) Measure the period of your Ronchi grating to 1% with the measuring microscope.

The grating has approximately 100 lines/inch. Use the measuring microscope to determine the spatial period to 1%. Place the grating on the microscope table and illuminate it from below. First adjust the eyepiece until the cross hairs come into sharp focus. Then adjust the height of the microscope barrel until the grating comes into focus with the objective lens 5 mm above the grating.

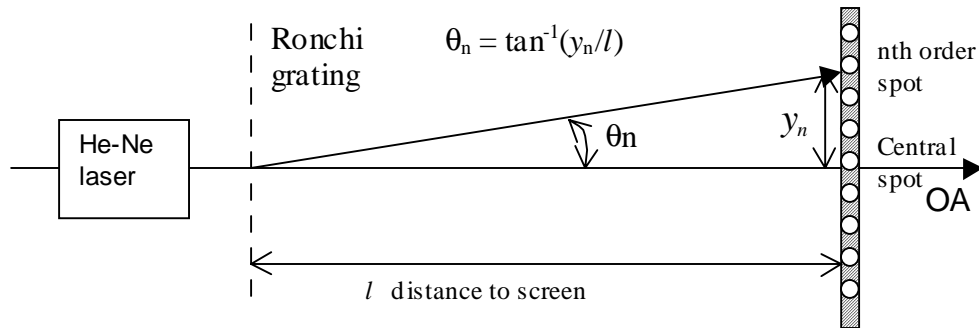


View through the measuring microscope of the Ronchi grating.

Measure the grating by translating the microscope about 10 spatial periods. Read the position via the number of mm on the sliding vernier scale and the decimal fraction of a mm on the drum (large divisions are 0.1 mm, small divisions are 0.01 mm each)

2. (a) Measure the wavelength to 1 or 2% by diffraction with a Ronchi grating.

Set the Ronchi grating about 1 ft. from the laser. Orient the grating normal to the beam (a good criterion is that the back reflected spot is just above or below the exit part on the front face of the laser). Display the diffracted spectrum on a sheet of paper on the wall. There should be up to 20 orders of spectra visible each side of the center. Mark all of these with a pencil on the paper and take it down for careful measurement. Calculate the wavelength from the grating equation: $d \sin \theta_N = N \lambda$.



2. (d) Set up the beam expander to produce a beam about 4 mm diameter.

Center the first lens (shorter focal length) on the beam. Again, the back reflection from the lens is a useful measure of the beam entering normal to the lens surface. Then center and adjust the distance of the second lens (long focal length) to produce a parallel beam centered on the optic axis.

3. Measure the focal lengths of the lenses to be used in your microscope. Many of the lenses are labeled, but the values are only approximate. Here are some suggestions:
 - a. Use the lens to form a sharp image of a distant mercury vapor lamp on a sheet of white paper. The focal length roughly equals the distance of the lens from the paper. When is this approach not valid?
 - b. Set up a 'bull's eye' test slide on the optic bench with a ground glass diffuser on the laser side of it. Adjust the lens (on a lens carrier) to give a sharp image of the bull's eye on a cardboard screen. Measure s and s' , and calculate f .
 - c. For short focus lenses, measure the magnification (m) when the lens is set to give large m . Measure s' (the longer distance) and then calculate focal length using $s' = f(1 - m)$ (remember that m is negative).

4. Build and test the projecting microscope. You may need to use the basic 1 mm diameter laser beam initially (because of the large magnification) while setting up the microscope. Once the instrument is working, reinsert the beam expander to illuminate a larger part of the sample.
 - a. Set up the objective lens section of the microscope.
 - Install the Ronchi grating as the object. Temporarily insert the ground glass diffuser.
 - Set a white cardboard screen at the predicted position of the intermediate image,

I1, with a black cross marking the position of the optic axis.

- Set up the objective lens, L1, in roughly the correct position relative to the object and center it on the optic axis.
 - Slide the lens along the optic axis until you obtain a sharp image of the Ronchi grating on the screen.
 - Find the magnification of the objective, L1, from the ratio of the period in the Ronchi image, I1, to the period in the object itself as measured with the measuring microscope. Compare with your prediction.
- b. Setting up the projector section
- Attach a large white cardboard screen to the wall beyond the end of the optic bench.
 - Install the projector lens, L2, in about the right position.
 - Remove the ground glass from in front of the object slide and remove the screen from the image position, I1.
 - The image, I1, now serves as the object for L2. Adjust the position of L2 until you obtain the sharpest image of the Ronchi on the wall screen.
5. Testing the microscope.
- Determine the overall magnification from the measured period of the final Ronchi image, I2. This should be $M=400$. If it is not 400, adjust the lens positions to make it so.
 - Estimate the resolution of the instrument. In other words, estimate the smallest distance you can distinguish between two points in the object.
 - Install an iris at the aperture stop and estimate the resolution as a function of iris aperture. Does diffraction theory explain your observations?

OPTIONAL:

6. Make the magnification variable by installing a zoom lens. This section is for open investigation.
- Insert a concave lens between the projection lens and the screen
 - Move the projector lens, L2, a little closer to the objective lens, L1, then adjust the new lens position to give a sharp image on the screen.
 - What is the new value of magnification?
 - Can you interpret the magnification you observe with the aid of a ray diagram and a calculation?
7. Examine several small objects that interest you.