PH 481/581 **Physical Optics** **Winter 2014**

Laboratory #1 Week of January 13

Read: Handout (Introduction & Projects #2 & 3 from Newport Project in Optics Workbook), pp.150-170 of "Optics" by Hecht

Do:

1. Experiment I.1: Thin Lenses (Project #2)
2. Experiment I.2: Alignment Project
3. Experiment I.3: Expanding Laser Beams (Project #3)
4. Experiment I.4: Familiarization with Lab Equipment

Experiment I.1 Thin Lenses:

Newport's Projects in Optics **#1-12** on pp. 52-53. Use the optical rail on your table. A target on a photographic slide is provided. A piece of cardboard with a slide sized hole cut in it will help to reduce stray light reaching your image plane.

Experiment I.2 Alignment project:

For many situations, it is convenient if the laser beam is parallel to the top of the optical table and above a line of holes on the table. This will make insertion and adjustment of other components much easier. The Newport Project in Optics Workbook describes experiments where a "U" shape geometry is used. To make life easy, *we will modify their experiments so that we do everything in the last arm of the "U."* In addition, we will use an optical rail in this last arm. This rail is bolted to the table and has carriages that ride on the rail. Components can be mounted on the carriages so that they can be easily moved along the optical axis defined by the rail.

The first two arms of this U geometry are already set up. We want to ensure that the laser beam is along the optical axis - parallel to the rail and parallel to the table top. Mount the second beam steering mirror (BSM) on the optical table and position it close to the beginning of the optical rail such that the center of the mirror is above the center line of the rail and is at a height greater than 14.5 cm above the table (**this height will ensure that the beam will pass through the center of components like lenses mounted on the rail – check that it does!**). Set up two irises on each end of the optical rail. Adjust the iris heights (again > 14.5 cm) to be as nearly equal as you can using a ruler. We now want to direct the laser beam through these two holes which define our optical axis.

Close the irises down. Use the knobs on the back of the first BSM to reflect the beam off the second BSM and through the first iris. Now adjust the second BSM so the beam passes through the second iris (note that this adjustment should do little to perturb your first adjustment since the first iris is so close to the second BSM). That is the trick! You should repeat this procedure until you can open both irises to clip the outside of the beam and see a clean symmetric halo on each iris. You may have to open the irises some to start and iterate a few times to get it just right, but the procedure should converge very rapidly. Note how the beams move and play with this arrangement enough so that you can quickly and correctly determine which knob needs to be adjusted and which direction the knob must be turned to move the beam the correct direction (left, right, up, or down). Note the kinematic construction of the mirror mount; there are two orthogonal pivots about a single point.

This procedure can be done with one iris as well – simply move the iris between the two positions on the optical rail. Using one iris will more accurately level the beam to the tabletop, while two irises accurately align the beam along the rail.

Leave the laser beam aligned so that you can use it in Part 3.

Do not remove the irises from their posts; they can easily be damaged. If you need another post to mount something else, ask and you shall receive.

Experiment I.3: Expanding Laser Beams (Project 3):

Newport's Projects in Optics **#5-10** on pp. 57-58 and **#1-3** on p. 58. Place all lenses on optical rail. Use a third mirror at the end of the rail to reflect the expanded beam back toward the laser. Be sure that your telescopes do not clip the size of the beam! Do not measure the divergence here! Focus on measuring the magnification of each telescope and comparing with theory.

Experiment I.4: Familiarization with Lab Equipment:

For this section you will need to go to the back room in the lab and collect the following items:

USB Camera – Camera and USB Cable

Connect the camera to the computer through a USB port. On your desktop you will find the camera's program IC Capture 2.1. The program should automatically recognize the camera when you open the program. *Do not take pictures of the laser unless you have decreased the laser intensity.* With the lens you measured earlier in front of the camera take a picture of an illuminated ruler in focus. Measure the object and image distances to acquire the magnification. Now open your image in the program ImageJ. Using the rectangular highlighter tool, highlight a portion of the image and look at its profile by clicking "Analyze → Plot Profile". Explain what this function does. Now use the measure function to determine the size of one pixel. *Save this value somewhere special, you will need it for future labs!*

USB Stages – Translational stage, Rotational Stage, Control Box, Power Cable, USB Cable

Connect the translational stage to control box and the control box to the computer using the USB cable. Open the program APT User on the desk top. The program should automatically recognize the stage when you open the program. Play around with the stage. What is the minimum speed at which the will travel? What is the range of the stage?

Repeat for the rotational stage.

Photodiodes – Photodiode, BNC Cable, T-Connector, Resistor Clip, Resistors

Connect the photodiodes to the oscilloscope with a coaxial cable. Make sure to turn off the photodiode when not in use. Measure the intensity of the room lights when pointing the detector at the lights and at the floor. What is the maximum voltage output of the photodiode? Try this with different resistors attached to the clip. What happens?

Equipment needed:

Item	Qty	Source (part #)
Helium-Neon Laser	1	Melles Griot 05 LHP 121
Optical Rail	1	Newport PRL-36
Rail carriage	3	Newport PRC-1
Lamp	1	
Target slide	1	OSU
100 mm lens	1	Newport KPX094
200 mm lens	1	Newport KPX106
25 mm lens	1	Newport KPX076
-25 mm lens	1	Newport KPX043
Index card	2	

Filter holder	2	Thor Labs FH2
Al mirror	3	Newport 10D10ER.1
Iris (adjustable)	2	Thor Labs ID12
Meter stick	1	

Component Assemblies

All ten experiments use a number of similar component assemblies. In order to simplify the experimental set up procedure we have included a section on building these assemblies. This components section contains drawings of each assembly and easy to understand instructions.

The parts are labeled with a single letter in the instructions. The Newport catalog number that appears on some of the items is listed next to the part label. The catalog numbers in parentheses denote metric versions of the same item.

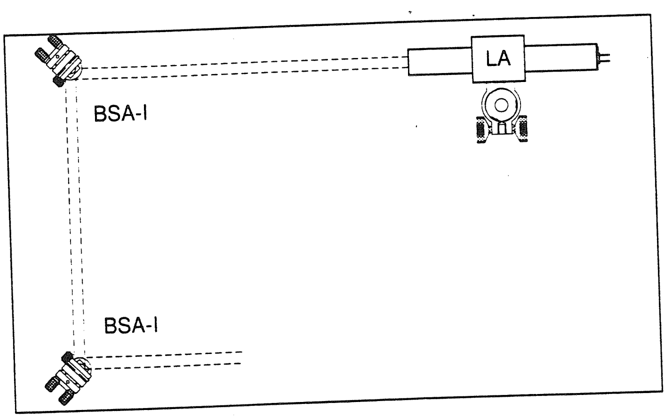
Alignment of Components

All assemblies, except the lens chuck assembly (LCA), are intended to be screwed directly into the rectangular lab bench (sometimes referred to as an optical breadboard, since it can be used to set up optical systems on an experimental basis). Alignment of many of the components is made simpler by directing the optical paths along the screw holes on the surface. To adjust the height or alignment of a component, rotate the assembly in the post holder and reposition the post within the holder.

In a number of the later experiments, you will notice that there are some standard assemblies in the same locations. One particular geometry that is used for all experiments after Project #3, has a U-shaped form: One arm consists of a laser assembly (LA) and beam steering assembly (BSA-I). The side of the "U" is between this BSA-I and a second BSA-1. In some experiments a laser beam expander, described and constructed in Project #3, is located within the arm between the two beam steering assemblies. The third arm consists of any number of components that are specific to the particular experiment. If the experiments are being done in order, then it should be possible to construct the basic U-shaped geometry, LA plus two BSA-I's, and conduct the balance of the experiments without having to tear down after each set of experiments.

Warning

The HeNe laser can cause permanent damage to your vision. Never look directly into the laser tube or at a reflection from a specular surface. Do not wear rings or other shiny jewelry when working with lasers. Use only diffuse (white 3x5 card) reflectors for viewing HeNe laser beam. Protect fellow co-workers from accidental exposure to the laser beam. Always block laser beam close to the laser when the experiment is left unattended.



A Note on Handling Optics

When handling optical components treat the optical surfaces of lenses and mirrors with care. Never touch those surfaces. If there are lens tissues or finger cots available, use them to protect the surfaces from finger oils and contamination. If not, handle the components by their edges. Assemble components over a table surface. (Do not lift components any higher off the table than necessary)

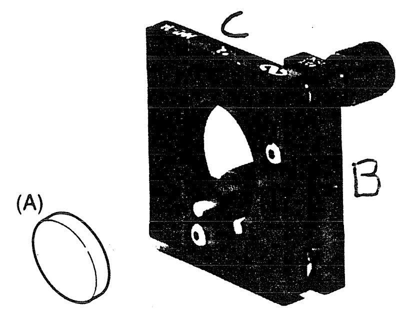
Beam Steering Assembly: (BSA-I)

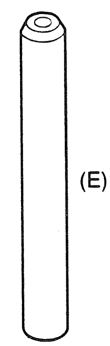
1. Place the 1 inch mirror (A) into the mirror mount (B) and tighten the nylon-tipped set screw (C) to hold the mirror in place. Be careful not to get your fingerprints on the mirror; holding the mirror with lens tissue will help.

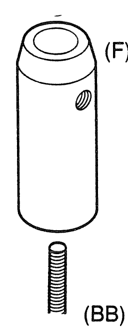
2. Attach the mirror mount (B) to the 1/2" post (E) by screwing the 8-32 set screw (CC) on the post into the base of mirror mount.

3. The post holder (F) can be fixed to the table or the rail in several manners. You can bolt it directly to the table or rail carriage by using a 1/4-20 set screw (BB). Another possible option is shown here (see Lens Chuck Assembly).

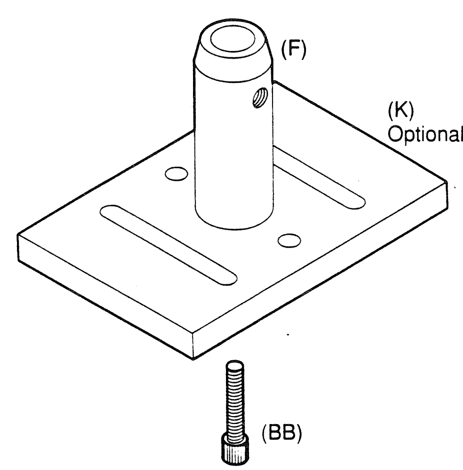
4. Place the post assembly in the holder and tighten the side screw sufficiently to hold the unit together. The posts fit quite well so you needn't tighten too much.







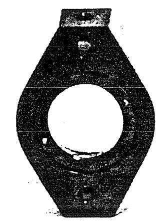
Optional Base Set-up



Lens Chuck Assembly: (LCA)

1. Remove the delrin retaining ring from the lens mount (J). Place the 1 inch diameter lens in the holder and screw the retaining ring down snugly, but not too tight. Be careful not to get your fingerprints on the lens. To turn the retaining ring, use a pointed object (e.g., ball point pen) that will fit in one of the holes on the ring, but that won't go all the way through the hole and scratch the lens.

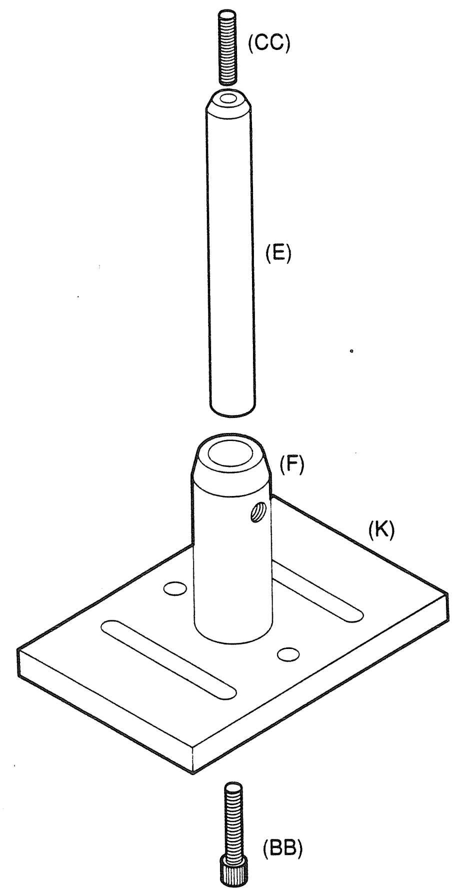
J



2. Screw the 8-32 set screw (CC) which is in the end of the post (E) into the bottom of the lens mount. **Note that there seem to be two possibilities here. However, one end of the lens mount is marked with an M, signifying that this end has a METRIC hole. Use the other end!!!**

3. Place the post holder (F) over the center hole in the base plate (K), insert a 3/8" long 1/4-20 screw through the base plate and tighten until the postholder is securely attached to the base plate.

4. Insert the lens mount-post combination into the post holder and tighten the thumb screw by hand to hold the complete assembly together.



Project #2

The Thin Lens Equation:

While the idea of creating images with lenses is easy to grasp, understanding of location, magnification and orientation of an image usually comes from working with lenses. This project is more than a verification of the thin lens equation. It is also a study in the sizes and orientations of images and in the effect of combination of lenses and their equivalent focal length.

In this experiment you will apply the Gaussian form of the thin lens equation:

$$1/f = 1/s_o + 1/s_i \qquad (2\text{-}1)$$

to determine the focal length of a lens or a combination of lenses. By careful measurements of object distances (s_o) and image distances (s_i) (**Fig. 2-1**) it is possible to calculate the focal length (f) of an unknown lens to less than a percent of the true focal length. To use this equation requires that the thickness of the lens be small relative to its focal length. If the lens is "too thick", the lens equation breaks down and a more complicated calculation is required to determine the image distance and magnification (see references).

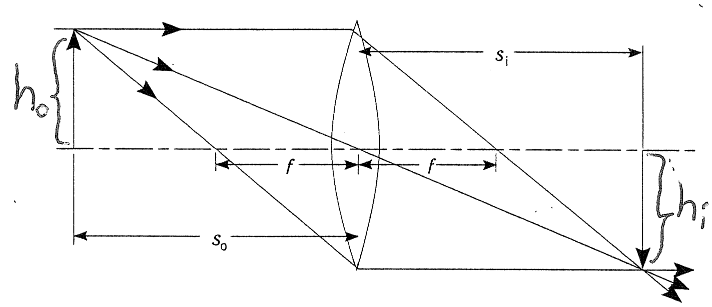


Figure 2-1. Definition of lens parameters.

Since a negative lens alone cannot produce a real image, a combination of a positive lens and a negative lens is used to determine the focal length of the negative lens.

The relation between object and image location is taken for granted once you are given the Gaussian form of the thin lens equation. But it is usually forgotten that some approximations have gone into deriving the equation. As a method of rapidly laying out the location and focal lengths of various lenses, it has some use, but as a means of doing optical engineering, it cannot provide the precision required for serious calculations of optical performance. Still, as a means of exploring the nature of imaging, experiments involving the thin lens equation can be most useful.

Newport Equipment Required:

Part	Cat #	Qty	Description
TA-I		1	Target Assembly
TA-II		1	Target Assembly
LCA		2	Lens Chuck Assembly
LKIT-2		1	Lens kit, as noted below
LP1	KPX094	1	100 mm focal length lens
LP2	KPX106	1	200 mm focal length lens
LP3	KPX076	1	25.4 mm focal length lens
LN1	KPC043	1	-25.4 mm focal length lens

Additional Equipment Required:

Part	Qty	Description
QW	1	Meterstick or tape measure
QI	1	Index card
QT	1	Target
QQ	1	High intensity lamp

Table 2.1 - Required Equipment

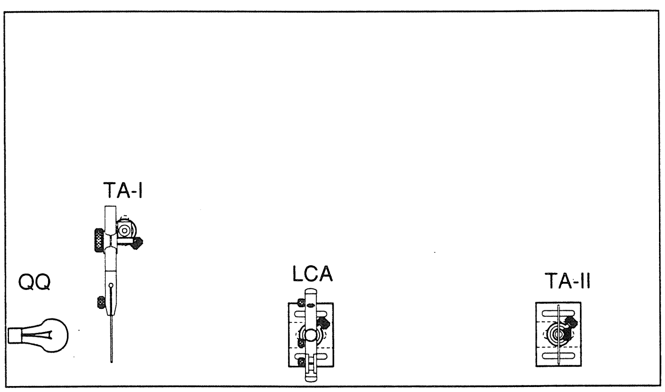


Figure 2-2. Project #2, Positive lens set up.

Experimental Set Up:

1. Construct a target (QT) on an index card by ruling a square grid of lines 5 mm apart. This will serve as your object. You can compare the size of the images you generate to this object to determine the magnification. Add some arrows to enable you to determine if the images are upside down or right side up. Mount this in a target assembly (TA-I) close to the edge of the breadboard (**Fig. 2-2**).

2. Unroll the tape measure along the breadboard edge so that the start of the tape is directly under the target. Place a high intensity lamp approximately 2 inches behind and at the same height as the target.

Positive Lens

3. Read the note on handling lenses in the components assembly section if you have not done so already. Take a positive 100 mm focal length lens from the lens kit and mount it in a lens chuck component assembly (LCA).

4. Place the lens about 125 mm from the target and record in your notebook, the exact distance between the lens and the target. This is the first object distance.

5. Mount the white card in a second target assembly mount (TA-II). Place the TA-II at the end of the breadboard and slowly move it toward the lens until an image is seen. Continue moving the TA-II until the image starts to become blurred. Move it away from the lens until the image is again seen. Move the TA-II to produce the sharpest image and mark this position. The distance from the lens to the card is the image distance. Record this value along with object distance.

6. Mark on the white card two points on the image that represent the distance between a specific number of grid lines and, either now or later, measure the distance between these points. Measure the distance between the corresponding points on the object grid. Record the values in your notebook along with the image and object distances.

7. Redo steps 4 through 6 with the object distance set close to the values of 150, 200, 400, and 600 mm. Record the object and image distances and the distance between two points on the image. This will give you sufficient data to make a good determination of the focal length of the lens.

8. Using the relationship for lens focal length, object distance and image distance, $1/f = 1/s_o + 1/s_i$, calculate the focal length of the lens using each of the sets of data. Find the average of the results and compare this value to that specified in the lens kit. Also calculate the magnification of the image for each object distance from the distances marked and measured on the white card divided by the corresponding distance on QT. Compare these to the ratio of the image distance divided by the object distance. (See **Eq. 0-6** in the Primer.)

$$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o}$$

9. Return to the first lens placement with an object distance of 125 mm. Verify that the image is located at the point that you recorded it earlier by moving the TA-II into the correct position. Now, keeping the TA-II fixed, move the lens toward it until you get an image on the index card. Measure the new image and object distances and compute the magnification. Do they bear any relation to the earlier measurements?

Negative Lens

Bi-concave lenses have negative focal lengths and the image they form is virtual. Since only image distances for real images can be directly measured, the technique that uses an auxiliary positive lens of known focal length, described in **Section 0.2** of the Primer, is used to determine the focal length of a negative lens.

10. Place a negative focal length lens (LN1) in an LCA with its concave side facing the object and measure the distance from the object to the lens.

11. Next place the positive lens whose focal length you have just measured more than 100 mm beyond the negative lens. Obtain a sharp image and measure the image distance from the positive lens.

12. Since you know the focal length of the positive lens and you have measured the image distance, you can calculate the object distance that would be required for this image distance if only a positive lens were present. The image of the negative lens is the object for the positive lens (Rule #5 in **Section 0.1**). Subtract the calculated object distance for the positive lens from the spacing between the two lenses. This is the image distance for the negative lens and will be negative. See **Fig 0-9** in the Primer to help you visualize this. Recalculate the focal length from the lens formula above (remember to use the correct signs on the image and object distances). Compare this to the value in the lens kit guide.

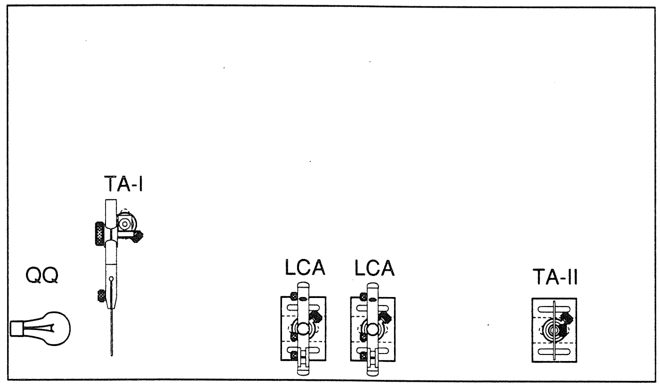


Figure 2-3. Project #2, Negative lens set-up.

Project #3
Expanding Laser Beams:

Many times when a laser is used in an optical system, there is a requirement for either a larger beam or a beam that has a small divergence (doesn't change size over the length of the experiment). In some cases the size of the beam becomes critical, for example; when measuring the distance from the Earth to the Moon, a beam one meter in diameter travels to the Moon where it has expanded to several hundreds of meters in diameter and when the return beam intersects the Earth's surface it is several kilometers in diameter. The signal returned from this expansion is millions of times smaller than the original signal, so that the divergence of a laser beam must be reduced to produce strong, detectable signals. Even in the case of earthbound experiments, higher degrees of collimation are required for many applications including some of the projects in this manual.

As was pointed out in the Primer, the product of the beam waist and the divergence of a lens is a constant:

$$d_o\theta = \frac{4\lambda}{\pi} \tag{3-1}$$

Therefore, if we want a more collimated beam, the divergence θ must be reduced and that can only be done by increasing the beam waist. This process cannot be easily done by a single lens. First, the beam must be diverged with a short focal length lens and then the diverging beam is recollimated with a large beam waist and smaller divergence. The arrangement of the lenses are essentially those of an inverted telescope. It is inverted since the light goes in the eyepiece lens (the shorter focal length lens) and comes out the objective lens. The amount of beam expansion, and therefore divergence reduction, is equal to the power of the telescope, which is simply the ratio of the focal lengths of the telescope lenses. Therefore after passage through a beam expander, the divergence should be equal to the old divergence **divided** by the power of the telescope.

This experiment will demonstrate the design of two types of laser beam expanders — the Galilean and the Keplerian. Each has distinct advantages. From these experiments you will gain experience in the alignment of laser beams and components and learn some simple techniques that make the process of alignment much easier.

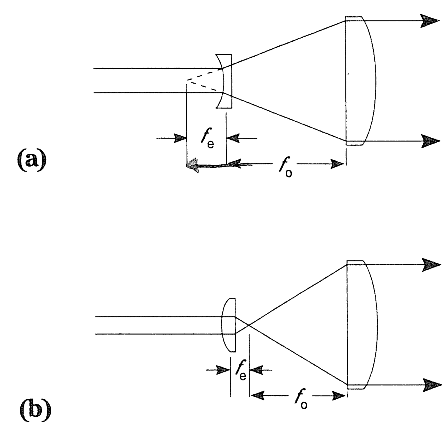


Figure 3-1. Gaussian beam collimation. (a) Galilean telescope. (b) Keplerian telescope. Eyepiece focal length, f_e; objective focal length, f_o.

The set up that you will be constructing in this experiment will be used for a number of other experiments (#4, 6, 7, and 10) that require expanded laser beam illumination. It is worthwhile to write down in your note book anything that helps you to rapidly set up and align the beam expander, since you will be doing this again.

Notes on Alignment of Laser Beams

Tape a card with a hole slightly larger than the laser beam to the output end of the laser, so that the beam will pass through and back reflections from components can be easily seen.

For each lens there are two reflections, one from each surface. When the centers of the two reflections are at the height of the laser beam, the height of the lens is properly adjusted. When they are overlapping, the beam is at the center of the lens. And when they are centered about the laser output, the lens is not tilted with respect to the beam.

In some cases, if the return beam is too strong (as in the case of this experiment), the laser will give an erratic output because vibrations from the outside world can be coupled into the laser. However, in the case of items such as beam expanders, where you do not try to send all the light back into the laser, the small reflections from the components have no measurable effect on the projects described in this manual.

Newport Equipment Required:

Part	Catalog #	Qty	Description
LA		1	Laser Assembly
BSA-I		2	Beam Steering Assy
LCA		2	Lens Chuck Assembly
TA-I		1	Target Assembly
LKIT-2		1	Lens kit, specifically
LP2	KPX106	1	200 mm focal len. lens
LP3	KPX076	1	25.4 mm focal len. lens
LN1	KPC043	1	-25 mm focal len. lens

Additional Equipment Required:

Part	Qty	Description
QI	1	Index card
	1	Tape
	1	Non-shiny, non-metallic ruler or meterstick

Table 3.1 - Required Equipment

Experimental Set Up:

1. Mount a laser assembly (LA) to the rear of the breadboard. Adjust the position of the laser such that the beam is parallel to the edge and on top of a line of tapped holes in the breadboard top. Tape an index card with a small (about 2 mm) hole in it to the front of the laser, so that the laser beam can pass through it. This card will be used as a screen to monitor the reflections from the components as they are inserted in the beam. These reflections, when they are centered about the beam output, indicate that lens is centered in the beam with its optic axis parallel to the beam.

2. Mount a beam steering assembly (BSA-I) approximately 4 inches in from the far corner of the breadboard (**Fig. 3-2**). Adjust the height of the mirror mount until the beam intersects the center of the mirror. Then rotate the post in the post holder until from the laser beam is parallel to the left edge and the surface of the optical breadboard.

3. Place a second beam steering assembly (BSA-I) in line with the laser beam at the lower left corner of the optical breadboard, (**Fig. 3-2**). Adjust the mirror mount until the laser beam is parallel to the front edge and the surface of the optical breadboard.

4. Use a meter stick or ruler to measure the beam at several distances from the output of the laser. The distances should be up to 10 m, if the room allows it. You will have to estimate the beam size, since, as was discussed in the Primer, the beam irradiance falls off smoothly from the center. Record the beam sizes at various distances about a meter apart. Calculate a divergence for the laser beam. Record the beam sizes at various distances about a meter apart. As indicated in the Primer, the beam diameter varies as

$$d^2(z)=d_0^2+\theta^2 z^2. \qquad (0\text{-}25)$$

Assume that d_0 is the beam diameter measured close to the laser and that z is the distance from the laser, use the above equation to determine the value for θ based upon the measurement at various values of z. You will find the values of θ are more accurate for larger values of z. The average of measured values should be in the neighborhood of 1 milliradian.

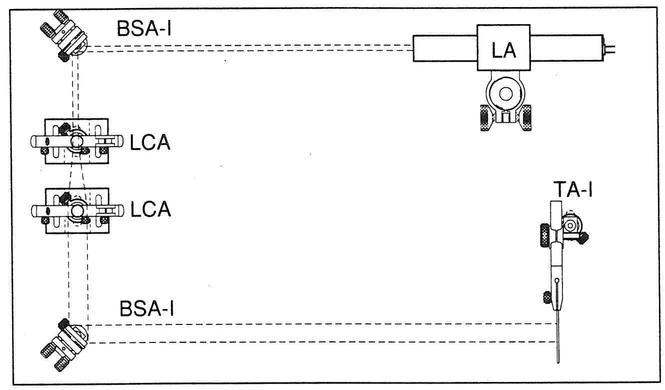


Figure 3-2. Schematic view of Galilean beam expander experiment.

The Galilean Beam Expander

5. Insert a short focal length (-25.4 mm) negative lens (LN1) into a lens chuck assembly (LCA) and mount it five inches from the first beam steering assembly. Align the lens by raising or lowering the post in the post holder and sliding the LCA so that the diverging beam is centered on the mirror of the second beam steering assembly. You can also use the alignment hints given previously.

6. Insert a longer positive focal length (200 mm) lens (LP2) into an LCA and place it about 175 mm (the sum of the focal lengths of the two lenses, remembering the first lens is a negative lens) from the first lens in the diverging laser beam.

Again, center the beam on the mirror of the second BSA and use the reflections off the lens to assist in aligning the beam.

7. Rotate the second BSA such that the beam returns back through the two lenses just to either side of the laser output aperture. (If the return beam enters the output aperture the laser may exhibit intensity fluctuations and you cannot determine the size of the return beam).

8. Carefully adjust the position of the last lens by moving it back and forth along the beam until the returning beam is the same size as the output beam.

9. Rotate the second BSA and shine the laser beam to the end of the room and measure the diameter just after the beam expander and at a number of places along the beam (at least a meter apart). Depending upon the accuracy of your alignment and distance available, it may be difficult to see any divergence at all.

10. As was discussed above, the divergence decreases with increasing beam waist diameter. The beam expander increases the diameter of the beam and as a result decreases the divergence of the beam in the same ratio as the beam expansion. Although it is difficult to be accurate in measuring the divergence, compare the estimate of the divergence of the undiverged beam divided by the power of the telescope. You may wish to try other combinations of lenses. Be sure that you do not choose a lens combination that, at the correct separation, has a beam which overfills the second lens and causes diffraction (See **Project #4**).

The Keplerian Beam Expander:

1. Replace the negative lens (LN1) with a short focal length positive lens (25.4 mm.) (LP3) and use the same adjustments to center the beams in the lenses and the mirror of the second BSA. Adjust the distance between the two lenses to be the sum of their focal lengths (**Fig. 3-2**).

2. Adjust the last beam steering mirror again for the condition of equal spot size at the laser output.

3. Repeat steps 7, 8, and 9 in the Galilean Beam Expander including an estimate of the collimation of the laser beam for this geometry. You are encouraged to try other lens combinations.

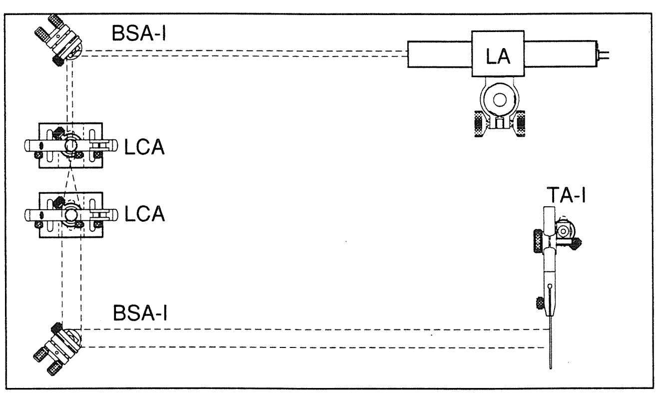


Figure 3-3. Schematic view of Keplerian beam expander experiment.

Note:

Either of these beam expanders can be used in Projects #4, 6, 7, and 10. The beam expander you construct depends more on the required expansion ratio than anything else.

PH 481/581 **Physical Optics** **Winter 2014**

Laboratory Information

The main aim of these labs is to give you real hands-on experience with optical instrumentation and to introduce you to some of the phenomena of physical optics. The laboratory will count for 20% of your total grade in Physics 481 (15 % for PH 581). The labs will start on the second week of classes (week of January 13) and go on until the last week of classes (week of March 10). The lab grade will be based on <u>weekly grading of laboratory reports.</u> See guidelines for lab report preparation. <u>Please prepare for each lab: each lab task will have a reading assignment, which you need to do before the lab. At the beginning of each lab, there will be a short quiz on the reading. If you come to the lab unprepared, you will not be able to finish all experiments you have to do.</u>

Safety:

The primary safety concern in the lab is the laser that is used for most of the experiments. This helium neon laser emits 2 mW of light at 633 nm, which is enough to cause some damage to your eyes. The only safe way to view the beam or any of its reflections is to have it strike a diffuse reflector, such as a card. Take care to keep the beam parallel to the table top and confined within your table area. Remove your watch and other reflective jewelry when working with the lasers, so stray reflections are not produced. Unless absolutely necessary for your experiment, do not let the beam propagate outside of your table. Use the provided beam stops (stack of razor blades, mounted cards, or boxes). Also note that the laser has a shutter on the front which will allow you to turn off the beam without turning off the laser power supply.

Equipment:

- Do your best to preserve the equipment for the future.
- Avoid fingerprints on optical surfaces. The screws used to assemble components are often oily, so clean your hands after using them and before handling optics.
- Do not over tighten screws.
- Use the correct screw for the task at hand. Most of the screws you will need are 1/4-20 (1/4" diameter and 20 threads per inch) or 8-32 (#8 screw with 32 threads per inch). The distinction between the two is obvious; the 1/4-20 is larger. However, some threaded holes or screws in the lab may be metric. Do not force a screw if it feels tight. Most likely the threads are metric or they are damaged. A 1/4-20 screw will go a few turns into an M6 threaded hole (6 mm diameter with 1 thread per mm) and a 8-32 screw will go a few turns into an M4 threaded hole (4 mm diameter with 1 thread per mm); **but don't do it!**

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Documenting work in the lab

Each student is required to maintain a lab notebook and produce lab reports within one week after the completion of each lab.

Lab Notebook: You are expected to write down everything as you go in a laboratory notebook. This means drawings of experimental setups, qualitative observations, quantitative results, and any notes you need to remind you how to do the experiment, such as tricks you learned or deviations from the lab handout. You should perform preliminary analysis of your data immediately so you know if you have made a serious mistake and need to re-take some data. Before you leave the lab, you have to make sure that you have all you need to produce a high-quality lab report. Your lab notebook should be neat enough so that the TA is able to read through and check it off at the end of each lab session.

Lab Reports: to be completed within one week after the lab session and submitted to the TA for grading.

Guidelines for preparation of the Lab Report

Here are the sections that the Report must include:

1) Introduction: describe the goals of the experiment.
2) Theory: discuss theoretical concepts you will be testing experimentally. You do not have to include full derivation of all standard equations used, but you must convey understanding of the material by describing the steps and assumptions used in derivation of the final form of equations.
3) Experiment: describe experimental setup and data acquisition procedures in detail.
4) Results: present experimental results. When applicable, compare to the theory you included in the Theory section.
5) Uncertainty: description of the uncertainty in your lab measurements.
6) Discussion: discuss what your results mean. Did you get a good match with theoretical expectations? If not, why not? Also, in this section, answer questions (if any) in the lab task.
7) Conclusions: briefly summarize your observations and results.

Lab reports should be clearly written: express your thoughts in a concise logical manner, while demonstrating proficiency and understanding of the material. The maximal grade for each lab report is 20 points. The distribution of the points among sections will depend on the lab and is at the discretion of the TA.