

Ay 105 Lab Experiment #2: Geometric optics

Purpose

In the first week's lab you used a very simple optical set up to produce collimated light which was then focused on to (part A) or overilluminating (part B) a detector. In this lab, you will start with a similar collimated light source but increase the complexity of the optics, incorporating both mirrors and lenses. You will study the properties of telescopes, eyepieces, and field lenses used in multiple element optical systems. A main goal is to learn how to relate angular and linear quantities.

Unlike the first week, there are no drawings given to you in this week's lab instructions, nor is the equipment and its setup described in as much detail. You are learning how to figure things out yourselves! However, as initial help, there may be some equipment set up on each bench. You will spend the first day with one setup (Part A or B), then switch places for the second day.

Pre-lab Work

- Read the entire lab and be familiar with the note on test pattern.
- Review optics concepts of focal length, magnification, focus, pupil planes, chief ray, etc.
- Remind yourself of how a regular old fashioned camera lens works.

Background

Telescopes and their instruments consist of a sequence of mirrors and lenses. They inject photons originating at a distance of essentially infinity, capturing them first with the primary mirror, then image and re-image the light, eventually on to a detector.

Equipment List

QTH lamp
Lens (50 mm Diameter, 260 mm FL or approximation)
6" Maksutov-Cassegrain Telescope
2 White Opal Glass Diffusers
USAF Resolution Test Target
Periscope-like (z motion) stage
10x power Micrometer Eyepiece
40 mm Eyepiece
15 mm Eyepiece

10.8 mm Eyepiece
(or any 3 eyepieces with different properties)

2 QTH lamps or 2 HeNe Lasers
Power Supplies
Red or Blue filter
Diffuser (optional)
Spatial Filters
Shear Plate
Nikon Lens
Air-Spaced Triplet Lens (f/2.8, 80 mm EFL)
Plano-Convex Field Lens (33 mm Diameter, 57 mm FL)
Double Convex Field Lens (36 mm Diam, 41 mm FL)
White Screen or Wall

Experiment

Part A : Telescope imaging

Part A Configuration. The preliminary setup here features a 50 mm diameter, 260 mm focal length achromatic doublet collimator (you could also use one of the 63 mm diameter, 356 mm lenses) sending light from a test target into a 6-inch aperture Maksutov-Cassegrain telescope arranged near the end of optical table. The test target should be mounted on a periscope-like “z stage” so that you can move different parts of the pattern in to the telescope field of view. To achieve field of view control in the other direction, just pivot the telescope left and right. The test target is illuminated by the QTH lamp from lab #1, but with a white opal glass diffuser between the lamp and the target for more even illumination. Note that the collimated beam should be both large enough and appropriately pointed such that it reaches the telescope primary e.g. not so small or directed such that e.g. all of the light hits the back of the telescope’s secondary mirror. The telescope has several knobs and you are asked below to explore their uses. The experimental set up should include a micrometer eyepiece that contains a moving crosshair. This should be mounted on a post or post+plate and positioned at the normal location of a telescope lens. The micrometer will be used to measure the size of image features in the telescope focal plane. In addition to this write-up, there is also a handout describing the pattern element line spacings for the USAF resolution test target. Turn on the QTH lamp and produce a collimated beam that enables you to view the test target in focus through the micrometer eye piece. Note that underneath the telescope at the eyepiece end is a small knob intended to be used for focus. The telescope has a very narrow range of focus but do not worry too much about it as, in fact it may not be doing much; instead achieve test target focus by moving the collimating lens. If you are having serious problems you can consider taking the telescope out into the hallway and pointing down the corridor to find the focus at infinity.

Part A Measurements. Experiment with how to read the test target patterns by having one member of your group move the blocking source around in front of the lamp. Once you are comfortable, use the micrometer eyepiece to measure the sizes of an element (one “line pair”) in each group that is visible, albeit perhaps faint. You know from the “Line Pairs Per Millimeter” chart in the handout the actual sizes of each feature measured in the focal plane of the achromat lens, so from your measurements you can determine the effective focal length (EFL) for the 6-inch telescope. Make all of your micrometer measurements at a single focus setting.

Now move the (micrometer or other, e.g. the Celestron) eyepiece out of the way and perhaps the eyepiece holder which may be threaded into the telescope tube. Likewise remove from the end of the telescope the threaded cap in the center. Describe in your notebook the function of the two knobs at the back end of the telescope. Is the lens carried into position below the eyepiece a positive or negative lens? What will be the effect of this lens on the effective focal length of the telescope? Return the knobs to their original positions, and replace the parts you have removed. Move the knob that controls the motion of the lens inside the tube, and observe the result by looking into the eyepiece. Move the knob that controls the motion of the lens, and observe the result by looking into the eyepiece (turning the focus knob for sharpest focus). Does the result confirm your expectation? Using the micrometer eyepiece again, re-measure at least one line pair spacing on the target to re-determine the effective focal length of the telescope plus lens.

Replace the micrometer eyepiece with various other eyepiece lenses. If you can find them, use the 40 mm, 15 mm, and 10.8 mm effective focal length eyepieces, but if not the power 2.5x, 7x and 10x eyepiece lenses will suffice. Record the target appearance for each. What is the outermost group on the test target that you can see, what is the smallest element you can resolve with your eye, etc. Note that you may need to refocus the telescope for different eyepieces. Again, the narrow range of focus of the telescope means that such focus moves should be made intelligently.

Turn off the QTH lamp and put a white screen in front of the entrance to the telescope; room light should illuminate the side of the screen facing the telescope. With a second opal glass or ground glass diffuser, locate the exit pupil formed by each of the eyepieces and measure the diameter of this exit pupil as accurately as you can.

Part A Analysis. For each of your USAF test target measurements, calculate the angle subtended by a line pair in the focal plane of the 260 mm lens and use this angle together with your micrometer measurement to determine the EFL of the telescope. Use your error estimates to compute a weighted mean average for the telescope EFL. When the full 6-inch aperture of the telescope is used, what is the effective f /ratio of the telescope? What happens to the EFL and f /ratio when the small lens is inserted into the beam beneath the eyepiece holder?

Calculate the angular magnifications achieved with the 40 mm, 15 mm, and

10.8 mm eyepieces. Dividing the 6-inch aperture by the magnification, predict the exit pupil diameter and compare the values you measured. What angular magnifications and pupil diameters would you have found if the additional lens were used?

Part B : Reimaging Systems and Pupils

Part B Configuration. This part of the lab can be done using collimated light of either two QTH lamps, or two HeNe laser, spatial filter, and 50 mm diameter laser collimator combinations (as you may have tried to set up in Lab 1).

At the end of your alignment process, you will have one beam aligned with the long optical rail and thus it will be “on-axis” for any optics on the the rail. The other collimated beam is at the same height above the table but is aligned at an “off-axis” angle with respect to the long rail. You will want the angle between the rails to be as small as physically possible.

If using QTH lamps, work using the methods you developed in Lab 1 to produce two collimated beams.

If using lasers, the first step is to make certain that each 50 mm diameter laser beam is precisely collimated (parallel light). During Lab #1, you used various approximations to crudely collimate optical beams, but for this lab you can try to use a “shear plate” to do this precisely. An additional handout describes the design and use of shear plate collimation testers. After reading these pages, slide the mounted shear plate onto the rail and turn on the laser. You should see fringes on the ground glass screen on the shear plate box. Adjusting the laser collimator lens focus will vary the tilt of the shear plate interference fringes. Align the fringes with the reference line for precise collimation. Turn off the green laser and (gently!) turn on the red laser; fine-tune the red laser spatial filter/collimator as you did for the green laser, and use the shear plate tester for the off-axis beam. Note that you’ll need to locate the shear plate unit at the location where the red beam crosses the axis of the long rail, and you’ll also need to rotate the shear plate unit so that its input port faces the direction towards the red laser. Once collimated, you can remove the shear plate unit and carrier, and turn both lasers on.

You will use the two beams, either QTH or laser generated, to simulate on-axis and off-axis ray bundles to study focal planes, field lenses, and pupils.

For tracking the beams more easily, you can also place different filters in front of the lamps (for example, a “green” filter for the “on-axis” beam and a “red” filter for the “off-axis” one). You can set these up as in Lab 1.

Part B Measurements. Begin by observing the collimated beams as they intersect and move apart. Estimate the rail scale reading that corresponds to the point of intersection. Install the **small** AF Nikon lens and carrier so that the two beams

intersect in the middle of the lens body. In your lab notebook, record the focal length of the lens (written around the front of the lens), and set the f/stop ring of the lens to a focal ratio of f/5.6. You should feel the lens click into this stop position; you may need to rotate part of the lens if it is mounted by the f/stop ring. Set the lens focus to ∞ .

Locate the focal plane of the lens. Now measure the separation between the “on-axis” and “off-axis” image in the focal plane by using the ruler as a screen. Also take the reading on the rail scale corresponding to the focal plane. Remember to estimate your errors.

Turn your attention next to the patterns on the wall. Use the ruler to extrapolate the optical rail scale reading to the wall, and record the reading that corresponds to the wall position. Recall from lecture the discussion of the “chief ray” that passes through the center of the aperture stop, and therefore is located at the center of the ray bundles. Measure the distance on the wall separating the chief rays of the on-axis and off-axis beams. Also measure the diameters of the two patches on the wall.

Calculate Δx between your optical rail scale readings for the focal plane and the wall, and the Δy between the separations of the foci and the patches on the wall. Make a scale layout in your lab notebook of the xy -plane and draw rays between the foci and the wall patches, then extrapolate backwards the off-axis chief ray and the optical axis until they intersect. Describe what occurs at (and what name is given to) this intersection point. Calculate the x -coordinate of this location where $\Delta y = 0$.

Now install the EFL = 80 mm mounted f/2.8 air-spaced triplet lens behind the Nikon lens, and focus to reimage the foci onto the wall. What happens to the off-axis beam? Record the EFL = 80 mm lens carrier scale reading where the on-axis beam is focused on the wall, and also record your observations pertaining to the off-axis beam.

Next locate a 33 mm diameter, 57 mm focal length plano-convex “field lens” at the Nikon lens focus. Move the 80 mm focal length triplet out of the way, and observe the behavior of the on- and off-axis ray bundles following the field lens. Return the 80 mm focal length f/2.8 triplet to a position where images are focused on the wall, and record the lens carrier scale reading. Measure also the y -separation between the red and green images on the wall, and sketch these in your notebook. Finally, substitute the 36 mm diameter, 41 mm focal length double-convex “field lens” in place of the 33x57 lens in the Nikon lens focal plane and repeat the measurements in this paragraph.

Part B Analysis. Determine the angular separation of the green and red beams as they enter the Nikon lens, and again as they leave (in this case, the angle between the optical axis as defined by the center of the green cone of light and the off-axis chief ray defined by the center of the red cone of light). Where inside the Nikon lens is the aperture stop as viewed from the focal plane, and what diameter is this aperture stop? Do your calculations based on the 57 mm and 41 mm field lenses agree for the location

and diameter of the aperture stop inside the Nikon lens? What are the angles between the optical axis and the off-axis chief ray following each of the field lenses?

Discussion

Summarize what you've learned in this lab about image scales, aperture stops, entrance and exit pupils. How as an optical re-imaging instrument designer you can exert control over the location and direction of off-axis ray bundles. What are some of the penalties for ill-placed pupils in a re-imaging instrument? Provide examples to illustrate your points.

(If you find yourself lacking an example, consider the Palomar 200-inch diameter Hale Telescope, which has a Cassegrain f /ratio of $f/16$, and say you wanted to reimage the $f/16$ focal plane onto a CCD detector array that is 2048 by 4096 pixels on a side with $15\ \mu\text{m}$ square pixels. In the reimaged focal plane you want 3 pixels per arcsecond on the sky. Think about pupil positions and sizes, and what effect a field lens would have.)