Lab #1
Lenses and Imaging

(1 week)

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1. **Optics Lab Safety**

The first rule for safe conduct in any laboratory is to know the hazards. In most optics labs the hazards consist of electrical shock hazard, optical radiation hazard (from intense optical beams) and chemical exposure. As optics labs go, the teaching lab is a pretty safe place. The lasers we are using are low power, minimizing the risk of eye injury as well as the electrical shock hazard. We currently have very few chemicals in the lab as well. Nonetheless, you can get hurt in this lab! Know where the hazards are, and what to do and where to seek help if someone is injured.

Electrical Shock Hazard

Currently the only high voltage in the lab is the power supplies for the HeNe lasers. These voltage supplies may reach 10 kV during start-up, during which the plasma is established in the tube, and then idle at a few kV. After turning the laser off, this voltage may remain at the tube for some time. **Do not disconnect the laser head from the power supply. Seek assistance from the lab instructor if the laser is not functioning properly.** If you disconnect the laser tube from the power supply, the plug terminals may have several kV potential between them. Whenever necessary to unplug the laser tube from the power supply (**in this class, only the instructor should do this**) you should follow these steps:

1. Turn off and unplug the laser power supply from the wall.
2. Carefully unplug the laser tube from the power supply, being careful not to touch the exposed ends of the connector.
3. Short the connector leads together on a metal surface such as the optical table. NEVER LEAVE A PLASMA TUBE UNPLUGGED WITHOUT SHORTING THE CONNECTOR LEADS!!

This is like leaving a large capacitor with a voltage on it – the next person to grab it won't appreciate it.

Occasionally we may bring other high voltage sources into the lab. The risks will be identified when that happens.

Radiation Hazard: risk of eye injury

The Helium Neon lasers used in this lab are class 3R (3A in the old system), meaning they are less than 5 mW output power. Scattered light from diffuse reflections is safe for the unprotected eye, but direct intra-beam viewing (staring into the laser beam) can cause eye damage. Direct viewing of a beam reflected from a polished surface can also cause damage. Your blink response offers some measure of protection. Know where the beam is at all times, and don't put your eye at the level of the beam on the table. Please remove jewelry when working around the laser beam. **Don't let your beam create a hazard for others in the lab: block the beam before it leaves your workspace.**

Chemical Hazard:

The chemicals you will encounter in the lab are Isopropanol and Methanol, used for cleaning optical surfaces. We have MSDS (material safety data sheets) available for viewing on the web, and copies are kept in the lab as well.

2. **New Tools** introduced in this lab

- Helium Neon laser
- Various optical mounts and positioners

3. Lens focal length measurement

Objective: In this exercise you will investigate two methods for determining the focal length of a lens in the laboratory.

a) Image test

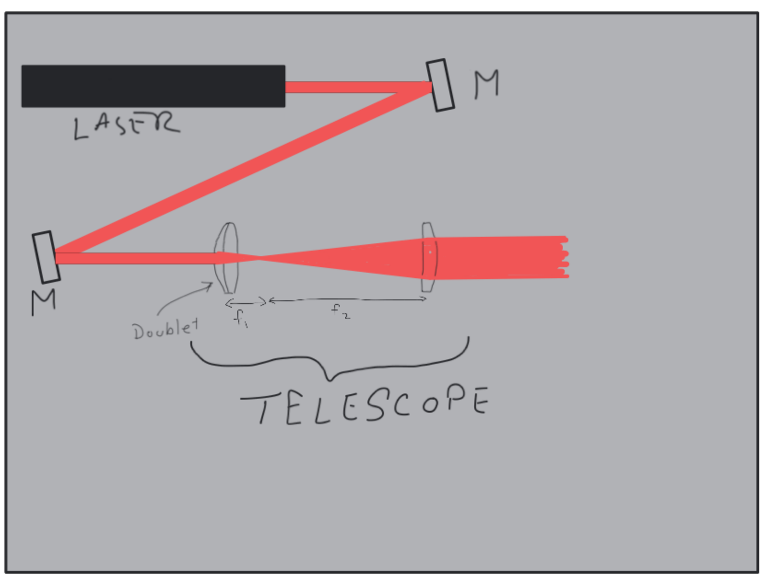
Procedure: Image a scene at infinity (a long distance compared to the focal length of the lens) onto a white piece of paper, and measure the distance from the lens to the image. (Overhead fluorescent bulbs can be a convenient object.)

1) Select two positive lenses with different apparent focal lengths and estimate the focal length of each using the image test.
2) What do you expect is the error in your estimation? Why?

b) Knife edge test

Preliminary setup: To best see the effect and usefulness of the knife edge test, you will want to expand the beam from the laser. Construct a Keplerian telescope beam expander (two positive lenses, separated by the sum of their focal lengths). You should use a short focal length achromatic doublet lens for the first element (approx. $f = 25$ mm) and a longer focal length lens (achromatic doublet or plano-convex singlet is fine for this lens) for the second element (approx. $f = 250$ mm for 10x beam expansion). Use the telescope to expand the beam from the Helium Neon laser.

We'll use the telescope again in part 5 below, so you will want to build it with room to make those measurements without bumping into things. The following sketch is a suggestion for effective use of your optical table space for this lab. This way you only need to build your telescope once, and can use it now and later in the lab.



Now you are ready to perform the knife edge test on your lens.

Procedure: Pass the expanded beam from the HeNe laser through the center of a positive lens (this can be one of the lenses you used for part 3(a); note that this is separate from the two lenses you used for the telescope!!) and image the emerging beam onto a viewing card, with the card well beyond the focus. Position a razor blade (affixed to a mount that you can slide along the table) so that it partially obscures the beam near the focus. Translate the razor blade along the beam axis until the shadow of the beam is uniformly dimmed (no asymmetric shadow). This represents the location of the focus.

1) For one of the lenses used in part (a), use the razor blade test to locate the focus of the beam.
2) Describe the image on the card as the razor blade is moved through the focus.
3) With the razor blade at the focus, measure the distance from the lens to the razor blade. What is the new estimate of the focal length?
4) What do you expect is the error in your estimation? What contributes to the error?
5) Can you suggest a way to use a knife edge to aid in the positioning of an imaging device such as a CCD array at the precise focus of a lens? (Hint: consider the image that would be formed on the card in the drawing below, as the **card** is moved through the focus.)

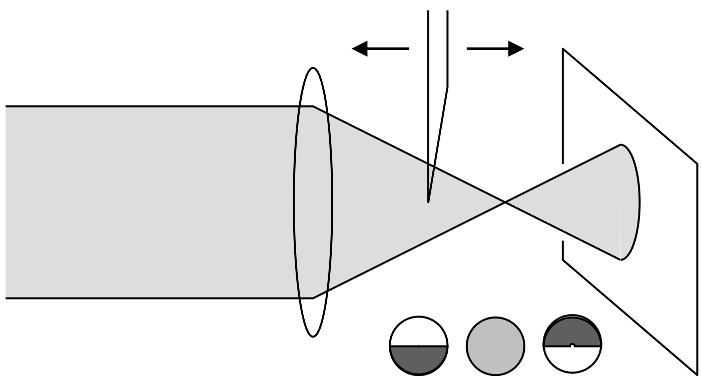


Image on card as knife position is varied.

4. Imaging with a thin lens

Use one of the lenses from part (3). Use a transparent ruler or other convenient transparent item with known feature dimensions as the object to be imaged. You might consider taping the ruler to an optical mount to hold it stationary and allow you to conveniently position it. Illuminate through the ruler (or other object) with a flashlight or desk lamp (or cell phone), and adjust the spacing between the ruler and the lens so that a real image is formed on a piece of paper (a viewing screen) behind the lens. Adjust the separation between the lens and the viewing screen to see a crisp image.

a) Measure the (approximate) lateral magnification of the image for two different lens-object distances (record the distance between object and lens, and between image and lens – in other words measure z_1 and z_2). How does the magnification depend on the location of the object and image?
b) Explain the dependence of the magnification on object and image position, and how the lens imaging law is satisfied.
c) Write down the ABCD matrix for the imaging system, for a general object-lens distance and lens-image distance. Compare your measured magnification and location of object and image planes to the predictions from your ABCD matrix.

5. Beam Expander Telescope

We will use the telescope you constructed in Part 2 for this part of the lab.

a) What is the focal length of the lenses you used, and the resulting beam expansion ratio?

Use your telescope as an imaging lens **system**. Use the test object from part 4 (transparent ruler and a flashlight or desk lamp). Illuminate through the object with a flashlight, and adjust the spacing between the object and the first lens of the telescope so that a real image is formed behind the second lens of the telescope. This may require some fiddling. Be sure that you are imaging using light that passed through **both** lenses. Adjust the separation between the second lens and the viewing screen to see a crisp image.

b) Measure the (approximate) **lateral magnification,** $m = y_2/y_1$, of the image for two different lens-object distances (record the distance between the object and the first lens of the telescope and the distance between the second lens and the image, moving the viewing screen to maintain a sharp image). How does the magnification depend on the location of the object and image?
c) Write down the ABCD matrix for the imaging system, for a general object-lens distance and lens-image distance. Compare your measured magnification and location of object and image planes to the predictions from your ABCD matrix. In other words, what separations z_1 and z_2 would drive element B to zero (the imaging condition)? How does the magnification (element A) depend on these separations?
d) Explain the dependence of the magnification on object and image position, and how the imaging condition is satisfied.

Time permitting:

Consider how to use the laser to measure the angular magnification of your telescope. To do this you can mount one of the turning mirrors on a rotation mount that will permit several degrees rotation of the input beam, relative to the optical axis of the telescope system. Your TA can provide guidance. How might you determine the change in angle of the output beam, corresponding to a change in angle of the input beam? One possibility is a retroreflecting mirror after the telescope, that sends the beam back through the system. Adjusting both the turning mirror and the retroreflecting mirror in tandem, maintaining the counter propagating beam position, can provide a direct measurement of the angular magnification. You may suggest a different method to determine the output beam angle.

e) Measure the angular magnification of the telescope. Describe in detail your measurement technique. (Ask the lab instructor for help with this if needed.)
f) Write the ABCD matrix for your telescope. Does the predicted angular magnification match the measured value? Discuss any discrepancies.