

Lab 1 - Lenses and Simple Lens Systems

I. Objective :

To give the student an introduction to the properties of simple lenses and lens systems.

II. Theory:

Positive lenses form a real inverted image of an object placed outside the object focal point. Parallel rays incident upon the lens will converge at the image focal point.

Two positive lenses may be used to expand or contract a laser beam. While the beam may be expanded almost indefinitely, there is a limit to how small it may be focused. A process called diffraction is responsible for this. Put very simply, diffraction is the effect of an aperture (i.e. lens, iris, or size of laser beam) on the wavefronts that make up light. This illustrates a limitation of geometrical optics. It can be shown that a laser beam of spot size a_o (Figure 3) with infinite radius of curvature (all light rays parallel) will expand (diffract) over a typical distance of $z = \frac{pw_o^2}{\lambda}$ where λ is the wavelength of light.

III. Procedure :

Part A – “Laser Telescope”

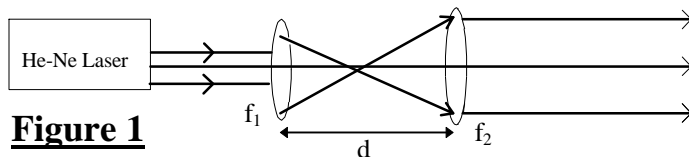


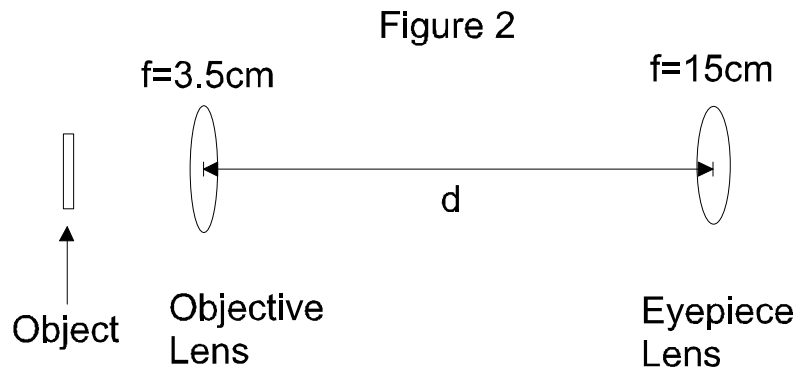
Figure 1

- 1) As shown in Figure 1, place two positive lenses a distance “d” apart such that the beam is expanded and collimated. Put the shorter focal length lens first. To check if the beam is collimated block the beam with an index card. Place it close to the second lens on the image side. Move the index card over some significant distance, (i.e. ~ 0.5 m) and check to see that the beam stays the same size. You might find it helpful to draw a small circle on the index card. In Figure 1 $f_1 = 35$ mm and $f_2 = 150$ mm.
- 2) Estimate the size of the beam before and after the expander. You may use either an aperture or graph paper to estimate the size of the beam. If you use graph paper, you may need to attenuate the light so that your eye is not saturated. Compare to the ratio of the focal lengths f_2/f_1 . Do the experimental values for d and m match the values of (2)?

- 3) Interchange the two lenses – what happens? Repeat step (2) and (3) for the ratio f_1/f_2 . How do you account for any discrepancy?
- 4) One possible explanation for any discrepancy is the diffraction of light. Use the theoretical beam size of procedure I.2 and I.3 with $Z = \frac{pw_o^2}{\lambda}$ to determine the distance Z over which diffraction becomes important (see Figure 3). Based on these numbers can the discrepancy between the theoretical and experimentally determined beam sizes be due to diffraction? Why or why not?
- 5) Using the BEAM2 ray tracing software, confirm that the appropriate distance d of Figure 1 must be such that $f_1+f_2=d$. With BEAM2, open the optics file (lab1-a.opt) and the ray file (lab1-a.ray). These files as written correspond to a correctly designed beam expander. Use the IN/OUT command under the RUN menu of BEAM2 and then the LAYOUT command. The resulting optical component layout will appear on the screen. Either print the screen or copy it to a WORD file to be included in your laboratory report.
- 6) Modify the optics file to move the second lens 5cm closer to the first lens. Run IN/OUT and LAYOUT. Print or copy the result. Repeat the process with the second lens 5cm further away from the first lens.

Part B - Compound Microscope

- 1) Arrange the lenses as in Figure 2. Let the lens with the shorter focal length be the objective. Use an index card with an asymmetric crosshair on it for your object (a business card with typing on it will do). Make sure that $d > f_1 + f_2$. For example, try $d = 300$ mm the first time. With d fixed, place your eye right up against the eyepiece lens. Move the index card until the image is focus. The microscope is properly aligned when the image remains in focus as you move your eye away from the eyepiece. At this point, the image rays emerge from the eyepiece roughly parallel.
- 2) Use the formula for the magnification of a simple compound microscope, $M = \frac{-s*25cm}{f_1 * f_2}$, where $s = d - (f_1 + f_2)$.
- 3) and compare it to a direct measurement of the image. To measure the magnification, place a meter stick in between the two lenses. Adjust the position of the meter stick until both the meter stick and the magnified image are in focus at the same time. Ideally, the distance between the meter stick and



the eyepiece should be the focal length of the eyepiece. Change d (use either 20cm or 40cm) and repeat one time. The interested student can consult Hecht *Optics* Chapter 5.75, Page 216 for the details of the derivation of the formula for magnification.

- 4) Comment on the nature (real or virtual) and orientation (inverted or erect) of image.
- 5) Using the BEAM2 ray tracing software, open the optics file (lb1_3x.opt) and the ray file (lbl_3x.ray). These files as written correspond to a microscope with objective of 35mm and an eye piece of 150mm. Print out a copy of the ray tracing layout and label the eyepiece, objective, object, a location of the image of the object through the objective. Does the ray tracing confirm the observations of III.B.4? (HINT: use the F8 and F7 function keys to zoom in/out on the layout. Either print the screen or copy it to a WORD file to be included in your laboratory report.)

IV. Discussion:

- 1) Using the BEAM2 plots, compare the ray tracing for the $f_1+f_2 < d$, $f_1+f_2 = d$, and $f_1+f_2 > d$ plots. If the distance between the lenses is not optimal, what is the effect on the expanded/collimated beam?
- 2) For the optimal plot (eg. $f_1+f_2 = d$), verify graphically that the magnification is given by the ratio of the focal lengths.
- 3) As a thought experiment, explain what would happen if you tried to collimate an incandescent source instead of a laser. HINT: Does it matter how far the first lens is from the light source? What are the differences between an incandescent source and a laser?

