# Telescope and Microscope

In this experiment you will examine some basic optical systems: (1) a periscope, a device that translates an image and projects it to a screen without inversion, (2) a telescope, which, in this case, uses your eye as part of the optical system, and (3) a reflection microscope. The microscope is used to examine the resolution of the characters produced by a laser printer. Ideas to be examined are: magnification of objects, the roles of stops and pupils used to limit or block some rays and how they may lead to an improved image, and angular magnification.

Procedure:

Beam Expander

You will measure the degree of collimation, or spreading, of the He-Ne laser beam. The beam can be expanded or contracted with a two-lens telescope. The narrow emission spectrum of the laser eliminates a source of blurring called chromatic aberration. This will allow for more precise measurements. The laser also produces a well-defined beam of light rays.

A. If the beam from the laser is not perfectly collimated, the diverging rays must spread over some angle θ. Aim the beam from the He-Ne laser onto a distant wall and measure the radius of the maximum spot size that can be discerned.
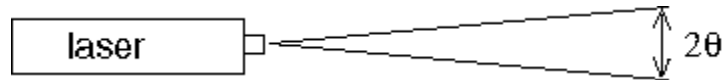
Q1. Is the spot of uniform brightness? Calculate 2θ in degrees and radians.

B. Using the converging and diverging lenses and the equation for a Galilean telescope make a laser beam expander/reducer. Measure the beam diameter before and at several distances beyond the lenses.

Q2. Does the beam diverge? Estimate its divergence angle.

Q3. What is the magnification of the beam? Show whether this is consistent with the two-lens equation.

Periscope/Telescope
  A. Set up the 2f system shown below using two lenses of equal diameter, but not necessarily equal focal lengths. You may find it convenient to replace the screen with a reticle (a glass plate with an inscribed length scale). Construct a bright object by backlighting tracing paper with a halogen lamp. For example, a microscope slide with a stick figure drawn on it. Define the object to have a diameter of 1-2 mm with masking tape. You will need an iris between the lamp and the object to prevent stray light from impinging on the rest of the system. Note that light rays are also limited by the finite diameter of the lenses. Hence, L_1 plays the roles of aperture stop and entrance pupil.
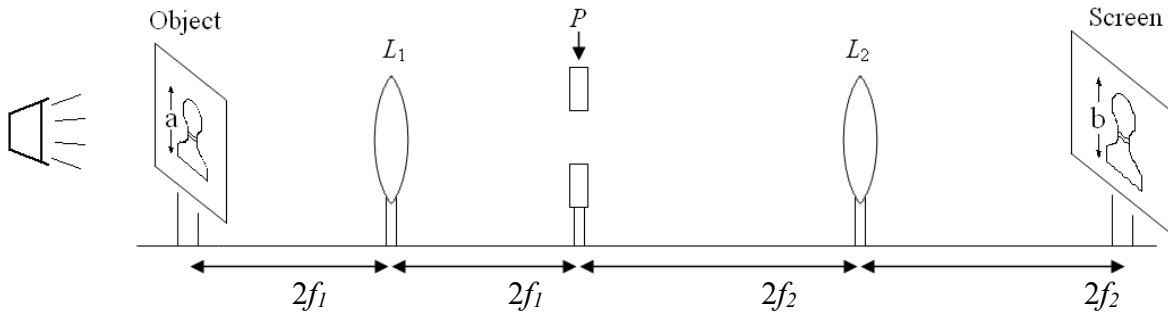
  B. Use Eq. (1) of the Appendix to find the magnification of the periscope $M = b/a$. Measure the object and image sizes to find M (including uncertainty). Give a quantitative comparison between calculation and measurement.

  C. Put a field stop at point P to see whether this eliminates blurred portions of the image.
      Q4. What is the source of the blurring? (Hint: if you placed an object at the position of either lens, would it be in focus on your screen?)
      Q5. Assuming that the blurring is related to the edges of the lenses, can you determine which lens is the culprit? Try putting the field stop at a position other than P.
      Q6. How effective are the alternate positions? Give a rationale for your observations.

  D. The system can now be used as a telescope by turning off the lamp and replacing the screen with your eye. You will find that you cannot immediately focus on the image. Move L_2 towards the object until you are able to see it clearly through the telescope.
      Q7. Why is it necessary to shift L_2? Now estimate the apparent magnification of the object from your current point of view. In other words, compare the angle subtended by the image θ_i to the angle subtended by the distant object θ_o. How does θ_i/θ_o compare to M?
      Q8. Provide an explanation for discrepancies between observations.

Microscope
   A. Use the same lenses to set up the following system

   B.

        i. f_1 f_1 L $\leq f_2$
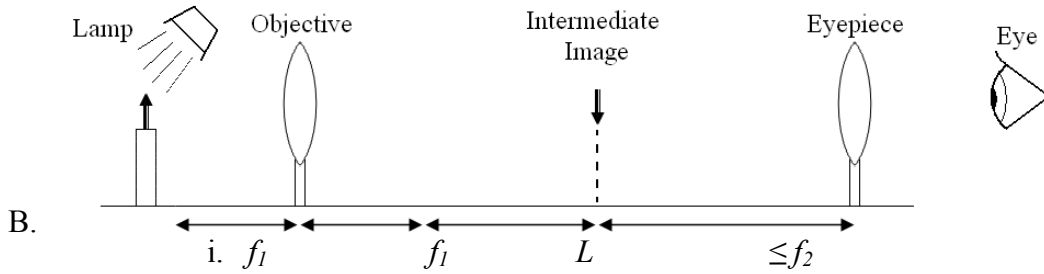
   C. In the above diagram, the object is $1.25\,f_1$ away from the objective lens. Draw a ray diagram for this case; next draw a ray diagram for an object distance of 1.75 f_1, adjusting the placement of the eyepiece accordingly.
      Q9. What is the magnification ratio for the two distances?

   D. Set the object distance to about $1.5\,f_1$ and focus the microscope.
      Q10. How does the image resolution change when you reduce the magnification? Explain this effect. You should find that the border of the field of view is fairly well-defined. If this seems surprising; remember that for the periscope we used a field stop to obtain a sharp border.
   **Q11.** Why is this not necessary in this case?

   E. Situate the camera at the place of your eye and take a picture. Be sure to get the image in focus (you may adjust the position of the eyepiece if necessary). Include the picture in your report. Now that the characters are greatly enlarged, comment on the precision of the printer. Note that the lines and curves do not look perfectly sharp.
      Q12. Are the imperfections consistent with the printer resolution of 1600 dots per inch? If not, what do you think is the origin of the less-than-ideal characters?

Appendix

Description of the optical system:
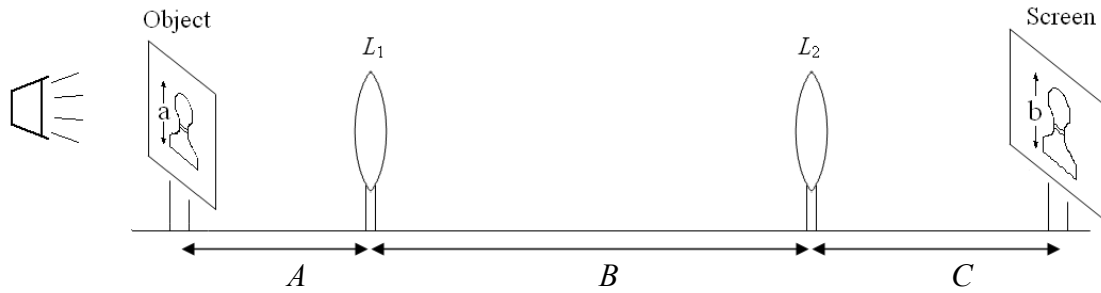
The image produced by the first lens L_1 appears at position $s_1^{'}$ and is given by

$$\frac{1}{A} + \frac{1}{s_1^{'}} = \frac{1}{f_1} \quad \text{so that} \quad s_1^{'} = \frac{Af_1}{A - f_1}.$$

The object is at $B - s_1^{'}$ for the second lens L_2 and the final image is at C so that

$$\frac{1}{C} + \frac{1}{B - s_1^{'}} = \frac{1}{f_2} \qquad \text{so that} \qquad C = \left[\frac{1}{f_2} - \frac{1}{B - \dfrac{Af_1}{A - f_1}} \right]^{-1}.$$

The magnifications $m_1 = \dfrac{-s_1^{'}}{A}$ and $m_2 = \dfrac{-C}{B - s_1^{'}}$, so the total magnification $M = m_1 m_2$ is

$$M = \frac{f_1}{A - f_1} \frac{C - f_2}{f_2} \qquad\qquad (1)$$

For more information, see Hecht, pp. 210-222.