Laboratory 12: Optical Instruments – Prelab

1 Magnifier

A magnifier consists of a single lens. The magnifier must produce an enlarged upright image from any object. Describe what type of lens (convex, concave) must be used and where the object must be in relation to the focal point in order to accomplish this. Explain your answer.

2 Telescope

A telescope consists of two convex lenses. The telescope is used to view a star that is effectively infinitely far from the first lens. Where will the image of the star formed by this lens be located? Explain your answer.

Laboratory 12: Optical Instruments – Activity

Lenses can be used alone or in combination to produce enhanced images. This laboratory introduces you to two examples: a simple magnifier and a telescope.

1 Simple Magnifier

A simple magnifier consists of a single convex lens placed so that the object is between the lens and its focal point. The image is viewed by looking into the lens from the opposite side. This is illustrated in Fig. 1.

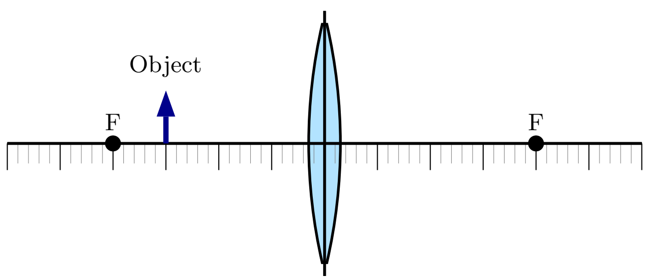

Figure 1: Operation of a magnifier. The focal points are labeled F. The object is placed between the lens and its focal point.

a) Mount one of the grid sheets, attached to the end of this package, to the screen. This will be the "object" that you will view through the lens. Place the 100 mm focal length lens about 3 cm from the grid and look into the lens. Is a clear image of the grid visible? Is the image larger or smaller than the object? Is the image upright or inverted (you can mark the grid to determine this)?

b) Starting with your eye about 30 cm from the lens, move it toward the lens while viewing the image. Does the apparent size of the image change while you do this? You should be able to feel whether your eyes have to adjust or not to view the image (if you do the same thing while looking at a page in a book you should be able to feel your eyes working to adjust). Did you notice this? Does the image become blurred when your eye is close enough to the lens?

c) Use the illustration to trace rays as accurately as possible to indicate how the magnifier forms its image. Where does it predict that the image will be formed? Does it predict that the image will be larger or smaller than the object?

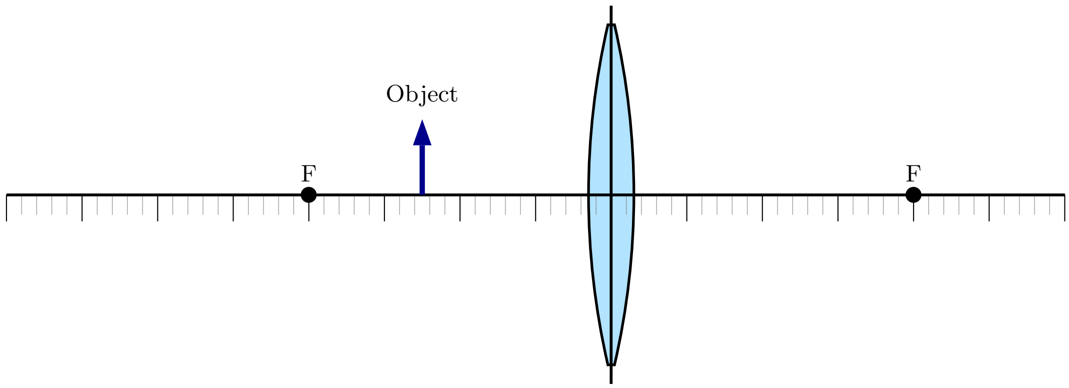

Figure 2: Magnifier with an object between the lens and focal point.

d) Using the thin lens equation and magnification equations, determine the location and height of the image produced by the lens.

The eye views the image produced by the lens. If the image is fairly close to the eye, then when you move your head back and forth the distance between your eye and the image changes appreciably. Your eye's lens has to adjust to form a clear image; this is the work that you should have noticed. If the image is very far from the lens, then moving your eye a small distance in and out does not make a noticeable difference; you will not notice your eyes working in this case.

e) Move the lens as close as possible to the grid. Keeping your eye the same distance from the grid, slowly slide the lens away from the grid until the grid coincides with the focal point of the lens. As you do this what happens to the size of the image? What happens to the magnification?

f) Determine the distance between the grid and lens when the maximum magnification is attained. How does this compare (substantially larger, smaller or similar to) to the focal length of the lens?

g) Using the thin lens equation, predict where the image formed by the lens is when the grid is located at the focal point of the lens.

h) With the grid just within the focal point of the lens, perform the following observation. Move your head toward the lens, starting from a distance of about 30 cm from the lens. When you do this does the size of the image appear to change or not?

i) Does the image ever become blurred as you move your eye closer? Use that fact that your eye has a **near point**, which is the closest point at which you can see any object clearly, to explain why your observations now differ from those when the grid was closer to the lens (part b)).

j) The magnification can be determined by simultaneously viewing the image of the grid and the original grid. You should be able to see how many of the original grid squares fit vertically within one grid square of the original grid. Use this to determine the largest magnification possible while keeping the grid between the lens and its focal point. Record the distance from your eye to the original grid at this stage. **Note:** this will depend on the distance from your eyes to the actual grid, and for the same lens, will vary depending on where you locate your eye.

The maximum magnification for usual magnifier use (object at focal point) is

$$M = \frac{s_{\text{near}}}{f} \tag{1}$$

where f is the focal length of the lens and s_{near} is the viewer's near point. The actual magnification that you will attain should be

$$M = \frac{s}{f} \tag{2}$$

where s is the distance from your eye to the original grid.

k) Determine the theoretical magnification using Eq. (2).

How does the result compare to the magnification that you measured?

2 Telescope

A telescope uses two lenses to produce images of distant objects with an enhanced angular size. The configuration is illustrated in Fig. 3.

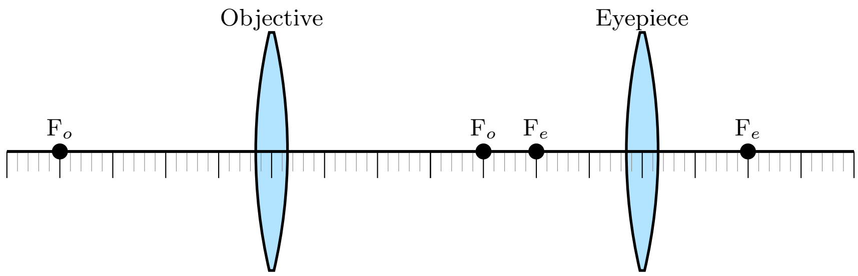

Figure 3: Configuration of a telescope indicating focal points for both lenses. The object will be situated to the left of the objective lens. The viewing eye looks leftward into the eyepiece.

The idea is to use the eyepiece as a simple magnifier. Alone it could not be used to view distant objects, since a magnifier is used by placing the object at the lens focal point and to attain any reasonable magnification, a short focal length is required. A distant object would be far beyond the focal point of any lens that would give a worthwhile magnification. The purpose of the objective is to produce an intermediate image (of the distant object) very close to the focal point of the eyepiece. The eyepiece lens then views this intermediate object.

a) In a telescope the objective lens has a longer focal length than the eyepiece lens. Using this information and the scheme of Fig. 3, arrange the 200 mm and 100 mm focal length lenses on the optics track to form a telescope. Initially place the lenses about 25 cm apart.

b) View a distant object (the further away the better) through the eyepiece lens. To check that the lenses are in the correct order, reverse the telescope and view the same distant object. The correct order gives the largest apparent image size. Is the image inverted or upright?

c) While looking through the eyepiece, slowly slide the eyepiece lens away from the objective lens. What happens to the apparent size of the image as you do this?

d) Continue sliding the eyepiece away from the objective until the image becomes as large as possible without becoming blurred. Keeping your eye the same distance from the lens, move your head left and right. Does the image move compared to the background when you move your head left to right?

The apparent motion (relative to some background objects) of the image when you move your eyes left to right is called **parallax.** You can easily notice this by looking at your finger at arms length. If you move your head left to right your finger appears to move relative to the background. This occurs when you view an object that is closer to you than the background. Many optical instruments are configured so that the lens closest to the eye produces an image that is infinitely far from this lens. The eye is then viewing an infinitely distant image. At this stage **parallax should be eliminated.** Additionally the eye muscles should not have to work to view the image when the eye is moved away or toward the lens. Aside from alignment issues associated with the small aperture of the lens, it should always feel easy on the eye to view the image when the optical elements in the system are correctly aligned.

e) Determine the distance between the lenses in the maximum image size situation.

f) When an infinitely distant object is viewed, the objective lens produces an image at the focal point of the objective. The optimum magnification is produced when the eyepiece is located so that its focal point is at the intermediate image produced by the objective.

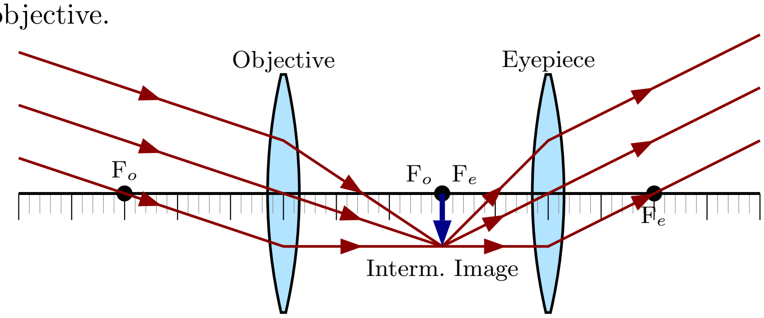

Figure 4: Configuration of a telescope for viewing an infinitely distant object. The object is located at an infinite distance to the left of the objective.

Based on the scheme of Fig. 4 and the given focal lengths of the lenses, determine a (theoretical) value for the separation between the lenses when the optimum magnification is attained. How does this compare to the separation measured in part e)? Explain your answer.

g) Theory predicts that the optimum angular magnification for viewing a very distant object is

$$M = -\frac{f_o}{f_e} \tag{3}$$

Determine this for your telescope.

h) View the grid on the wall with your telescope, and adjust the lenses to attain maximum magnification. Determine the magnification using the same "split viewing", technique as for the magnifier. Record your result. How does it compare to the theoretical magnification as predicted by Eq. (3)?

3 Beam Expander

A beam expander consists of two lenses that are designed increase the width of a narrow beam of light, such as that emitted by a laser. You will demonstrate this for a laser. **NOTE: Do not look into the laser beam during this part of the laboratory.**

a) Place the two lenses on the track. Shine the laser beam through the two lenses, with the light entering the 100 mm lens first. Intercept the beam with a piece of paper prior to it hitting the first lens. Does it appear to expand as it passes from the laser to the lens?

b) Intercept the beam between the lenses. Does the beam width vary along the gap between the lenses?

c) Intercept the beam beyond the second lens. Adjust the spacing between the lenses so that the beam width after it leaves the second lens is the same at all locations along the beam. The lenses are then functioning as a beam expander. How is the spacing between the lenses related to the focal lengths of the lenses? By what factor has the width of the beam increased? How does this relate to the focal lengths of the lenses?