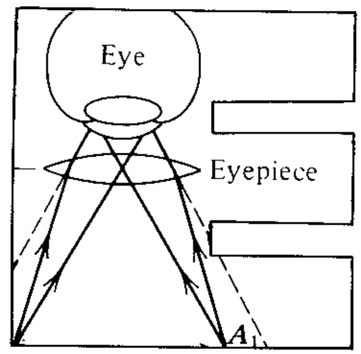

OPTICAL INSTRUMENTS EMPLOYING TWO LENSES

SPECIAL APPARATUS:

Two meter sticks, two rulers, two optical-bench supports, light source, object screen, cardboard screen, screen holder, five lenses (convex with foci of 5, 10, 15, and 30 cm, respectively, and concave with focus of 10 cm), three lens holders

GENERAL APPARATUS:

Electric lamp.

THE PURPOSE OF THIS EXPERIMENT

is to observe the operation of microscopes and telescopes when set up with simple lenses, and to measure their magnifying power.

INTRODUCTION

As the term is generally used, an optical instrument is an instrument designed to form on the retina of the eye an image of the object larger than would be formed if the object were viewed with the naked eye. The magnifying power is defined as the ratio of the angle subtended at the eye by the enlarged image of the object when viewed through the instrument to the angle subtended at the eye by the object when viewed directly. In this calculation, the angles should be expressed in radians.

The *compound microscope* consists essentially of a short-focal-length objective lens and a longer-focal-length eyepiece lens (Figure 41-1), both lenses being convex. The object AB, just outside the principal focus F_0, of the objective, gives a real enlarged image A_1B_1 just inside the principal focus F_e of the eyepiece. This real image serves as an object to give a magnified virtual image A_2B_2, which is viewed by the eye at the distance of most distinct vision.

The magnifying power M_0 of the objective lens is the ratio A_1B_1/AB, which is also given by

$$M_0 = \frac{D_i}{D_0} \quad [1]$$

where D_i and D_0 are the distances of the lens from A_1B_1 and AB, respectively. If we treat the image A_1B_1 (Figure 41-1) as an object being viewed through a simple magnifier (the eyepiece), the normal eye sees the virtual image A_2B_2 most distinctly at some distance d, usually about 25 cm from the eye (or lens). Since the eye sees a virtual image, d is negative, and, if we use $d = -25$ cm in the general lens equation, it takes the form

$$\frac{1}{D_0} - \frac{1}{25} = \frac{1}{f_e} \quad \text{or} \quad \frac{25}{D_0} - 1 = \frac{25}{f_e}$$

But the magnifying power of the eyepiece is

$$M_e = \frac{D_i}{D_0} = \frac{25}{D_0}.$$

When this value of M_e is substituted in the above equation, it takes the form

$$M_e = \frac{25}{f_e} + 1 \quad \text{or} \quad M_e = \frac{d}{f_e} + 1 \quad [2]$$

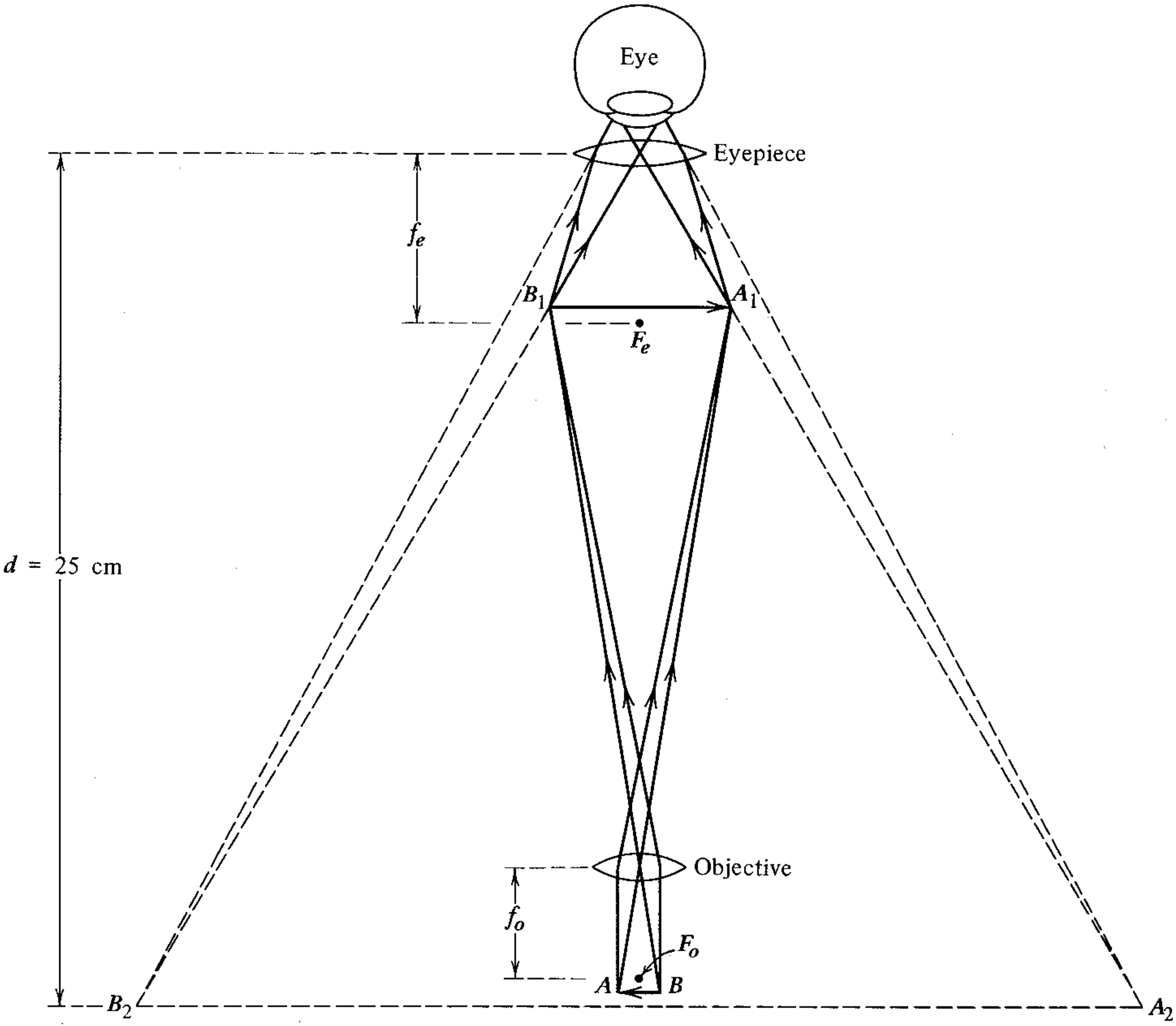

Figure 41–1 Compound Microscope.

where d is the distance of most distinct vision, and f_e is the focal length of the eyepiece. Hence, the total magnifying power of the microscope is

$$M = (M_0)(M_e) = \frac{D_i}{D_0}\left(\frac{d}{f_e} + 1\right). \qquad [3]$$

The objective of a *simple telescope* gathers light from a distant object and gives a real, inverted image AB (Figure 41–2) very near the principal focus of the objective. This real image, which is just slightly inside the principal focus of the eyepiece, acts as the object for the eyepiece, which gives an enlarged virtual image A_1B_1. The angle α is half of the angle subtended at the eye by the image, and β half of that subtended by the original object, assuming that the eye is at the objective when viewing the object directly. In practice the angles are quite small so that the magnifying power, which is by definition the ratio of the angles, may be considered equal to tan α/tan β. By examination of Figure 41–2, it may be seen that this ratio gives the magnifying power as

$$M = f_0/f_e \qquad [4]$$

where f_0 and f_e are the focal lengths of the objective and eyepiece, respectively. This does not mean that the image is actually larger than the object. The image is merely brought close to the eye and is larger than the object appears to be when viewing it from a great distance.

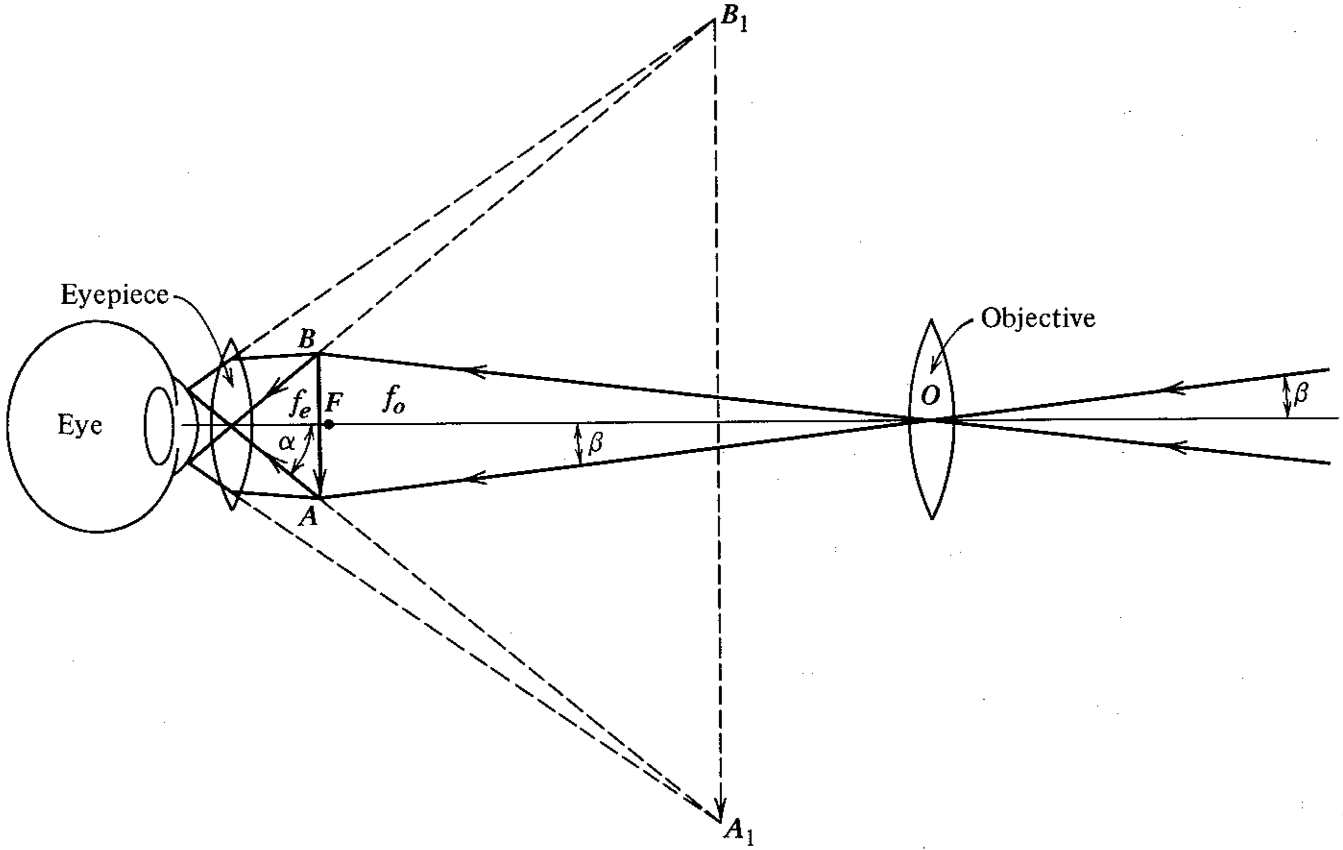

Figure 41–2 Astronomical Telescope.

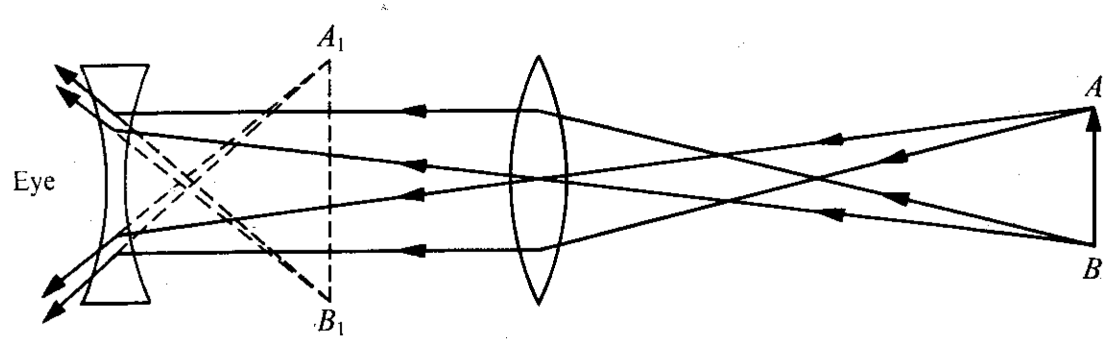

Figure 41–3 Opera Glass (Galilean Telescope).

The *opera glass* (or *Galilean telescope*) (Figure 41–3) employs a concave (diverging) lens as the eyepiece and gives an erect virtual image A_IB_I of the object AB. This instrument is designed to give an enlarged image of a not too distant terrestrial object. Its magnifying power is also given by the relation $M = f_0/f_e$, the same form as for the astronomical telescope.

PROCEDURE

You are to use simple lenses in constructing each of the optical instruments described on the preceding pages. Answer all assigned questions relative to each instrument at the time you are performing the operations. Be sure to put all lenses back in the proper envelope before checking in the equipment.

1. ***Compound Microscope.*** Select a short-focus (about 5 cm) double-convex (converging) lens for the objective and a slightly longer-focus (about 10 cm) double-convex lens for the eyepiece. Check the focal length of each lens by directly viewing a distant object and measuring the image distance on a small screen and use it as the focal length. Then mount the eyepiece a few centimeters from the zero end of a meter stick and, while holding this end vertically down against a printed page of your book, adjust the position of the lens for the most distinct image of the printed matter. Observe the magnification as compared to that of the naked eye.

While viewing printed matter through the center of the lens, also examine the appearance of the letters while looking through the lens near the periphery. Do you notice any difference? Move the lens as necessary to get a better image through the periphery. Which way did you have to move it?

2. Now replace the printed page with a ruler lying flat on a blank sheet of paper. Adjust the lens for a sharp focus on a small portion of the scale at the ruler, then measure and record the distance from the lens to the ruler. Now view the centimeter scale through the lens with one eye, and, while looking with the other eye (unaided) at a nearby section of the blank paper, make two marks on the paper which correspond to the apparent positions of the end points of a centimeter division (or half centimeter) as seen in the eyepiece. Each partner should make at least one trial. The distance between these two marks is the size of the image. Record the size of both object and image and compute the magnification from $M_e = S_i/S_0$ and record. This is the observed magnifying power of your microscope eyepiece.

3. Move the eyepiece upward to about 25 cm above the end of the meter stick, then mount the objective lens at a position slightly more than the focal length above the end of the meter stick. You now have the arrangement for a compound microscope as illustrated in Figure 41–1. With the end of the meter stick against a ruler, adjust the position of both lenses for the most distinct image of the ruler scale. Now select some number of scale divisions within the field of view of your microscope and, by following the procedure in Step 2, measure the magnifying power and record the observed value.

4. Without changing the positions of the lenses, set up your system as an optical bench and place an illuminated object at the position on the meter stick occupied by the ruler. By use of a cardboard screen placed between the lenses, adjust its position until you get a distinct real image A_1B_1 (Figure 41–1). Record the object and image distances and compute the magnifying power of your objective lens by use of Equation [1]. Then, from the focal length of the eyepiece and the distance d (Figure 41–1), compute the magnifying power of the eyepiece from Equation [2]. Finally, compute and record the magnifying power of the entire microscope by use of Equation [3]. Show the computation as a part of your report and compare it with the observed value by computing the percent difference.

5. ***The Simple (or Astronomical) Telescope.*** In constructing a simple telescope select a short-focus converging lens (about 5 cm) for the eyepiece and one of about 30-cm focal length for the objective, and mount on a meter stick. While viewing some distant object (a tree or a building), adjust the relative positions of the lenses until a distinct image is seen. Make a general statement concerning the relative size of the image as seen in the instrument and the size of the object as seen with the unaided eye.

To measure the magnifying power, make two horizontal chalk marks on the blackboard about 10 cm apart and focus your telescope on them from across the room. Now, while looking at the marks through the telescope with one eye and at the blackboard nearby with the other eye (unaided), direct your partner to make two marks on the board which appear to coincide with the apparent positions of the images as seen through the telescope. Measure and record the distances between both sets of marks. Exchange places with your partner and make another trial. Record the positions of the lenses and check the focal length of each by direct measurement while viewing a distant object. From the average of the two trials, compute the observed magnifying power and compare with the value obtained by use of Equation [4].

Now focus on some object across the street, such as a brick wall, then substitute a 15-cm-focus lens for the objective and make a comparison of the magnifying power in the two cases. See Question 9.

6. ***The Opera Glass (Galilean Telescope).*** By using the same 30-cm-focus objective as was used with the simple telescope, construct an opera glass by using a 30-cm-focal-length diverging lens as the eyepiece. Repeat Step 5 with the setup in Figure 41–3.

QUESTIONS

The Compound Microscope

1. In using each lens as a reading glass, what relationship do you observe between focal length and magnifying power?
2. What movement of the lens was necessary to get a better image when viewing through the periphery? Explain the reason for this.
3. Describe the imperfections present in the microscope image.
4. What names are given to the defects observed in the images?
5. What is the purpose of an eyepiece in a microscope?
6. In setting up the microscope, where must the object be placed with respect to the objective lens?
7. Where is the image formed by the objective with respect to the eyepiece?
8. What changes could be made to construct an instrument with greater magnifying power?

The Simple Telescope

9. When viewing a distant brick wall or tree, where does the image appear to be with respect to the space between the eye and the object?
10. Did you see any chromatic aberration in the telescope? How can you tell? Which lens is most likely to contribute to it?
11. How does the distance between the two lenses compare with the sum of their focal lengths?
12. If cross hairs are to be put in the telescope, at what point should they be placed? Why?
13. Did you notice any change in magnification when the focal length of the objective was changed? What other change could be made to increase or decrease the magnification?
14. What changes would be necessary in constructing a terrestrial telescope using convex lenses throughout? Construct an image diagram similar to Figure 41–2.
15. What is the advantage of making the objective lens of an astronomical telescope of large diameter?

The Opera Glass (or Galilean Telescope)

16. Is any chromatic aberration observed?
17. How does the magnifying power compare with that of the astronomical telescope?
18. What relation seems to exist between the two focal lengths and the distance between the two lenses? What advantage does this relation give to the instrument which the astronomical telescope does not have?
19. Is there a real image formed in the system? If so, locate its position on a screen.
20. Would an instrument which produces an erect image be of any advantage as an astronomical telescope? Why?