The Image Between the Lenses: Activities with a Telescope and a Microscope

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Perhaps the simplest optical instruments are the Keplerian (or astronomical) telescope and the compound microscope since they consist of only two converging lenses. Physics textbooks at a variety of levels describe the operation of both instruments in remarkably similar ways: The objective lens forms a real image which is then magnified by the eyepiece.[1] We describe a set of activities designed to demonstrate to students that there actually is a real image between the lenses. These activities are primarily intended for liberal-arts physics courses, but they also may be useful for other physics, astronomy, and perhaps even biology courses. The telescope and the microscope discussed are intended to illustrate principles, not to be practical instruments.[2]

Our activities are carried out with inexpensive "meterstick" optical benches and a set of converging lenses with focal lengths of 50 mm, 100 mm, and 500 mm.[3] These benches have the advantage that they can easily be lifted up and pointed when they are used to make a telescope. We have found that Scotch "Magic"® tape is ideal for making a screen upon which to project images, because it is less opaque than ground glass or waxed paper. Multiple strips of tape are attached across a frame made of thin cardboard with an opening of approximately 3 by 3 in.

Before constructing the telescope and the microscope, our students experiment with image formation using the 500-mm lens. For distant objects, an inverted, real image appears on the screen at approximately the focal length. As the object gets closer to the lens, the distance to and the size of the real, inverted image both increase. When the object is closer than the focal length, there is no longer a real image but an upright, magnified, virtual image can be seen by looking through the lens. Most students recognize that this final configuration is how a converging lens is used as a magnifying glass. They also experiment with the 50-mm lens held close to the eye as a simple magnifier[4] to see that it produces greater angular magnification.

For the telescope activities, students work inside a darkened room and observe a brightly illuminated, distant object outside. They form a real image of the distant object on the screen using the long focal-length lens (f = 500 mm). The real image is easily observable on the back side of the translucent screen. Next, students position a short focal-length lens (f = 100 mm or 50 mm) as an eyepiece magnifier to "inspect" the real image from the back side of the screen. At this point, an interesting telescope has been constructed in that the real image is formed and then observed on an intermediated screen. Finally, while the students are viewing the image on the screen, they remove the screen and observe the distant object directly through the two lenses of the telescope. The lightweight telescope can be picked up and used to look at a variety of objects. The eyepiece with a 50-mm focal length gives greater angular magnification, but the one with a 100-mm focal length is less sensitive to placement. Chromatic aberration is very apparent with either eyepiece. This telescope produces an inverted image, which is why it is primarily used for astronomical rather than terrestrial observations.

We have the students compare and discuss the per-

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formance of the telescope with and without the screen. The use of the screen serves to confirm that there is an intermediate real image formed by the objective lens, which is then observed close up using the eyepiece as a magnifier. Interestingly, the field of view is greatly increased when the screen is in place as compared to when it is removed from the telescope. The screen makes it possible to observe parts of the image that are formed by rays that would miss the eye if the screen did not scatter them. Of course, this scattering also slightly blurs the image. These observations can lead to a discussion of how a screen performs a similar function in a rear-projection television.

For the microscope activities, we begin with the room darkened. Small black text (a font size of four works well) on a white background is used as the object. The page with the text is placed in a screen holder and illuminated with a desk lamp. Using the 50-mm lens as an objective lens, an image distance of about 30 cm works well. For convenience, students first position the screen at the appropriate distance from the lens, then move the object until a magnified real image is focused on the screen. They position an eyepiece (f = 100 mm) to inspect the real image from the back side of the screen as was done with the telescope. Finally, while the students are looking at the image on the screen, they remove the screen and observe the object directly through the two lenses of the microscope.

Students often ask what the difference is between the telescope and the microscope since they both "magnify" objects using two lenses. These activities help to clarify some of the differences between the two. Telescopes have long focal-length objective lenses, while microscopes have short focal-length objective lenses. For the telescope, a large object is far away so the objective lens produces a real image much smaller than the object. However, the image is brought much closer so that it can be magnified by the eyepiece. For the microscope, a small object is near the objective lens, which produces a real image larger than the object. The eyepiece of the microscope then provides further magnification. In addition to providing angular magnification, telescopes have large objectives to collect the maximum amount of light from distant objects to make them more visible.

We have found that these hands-on activities help students understand and remember how the Keplerian telescope and the compound microscope work. They could be followed by more quantitative discussion of the instruments if desired.

References

1. See, for example, W.T. Griffith, *The Physics of Everyday Phenomena: A Conceptual Introduction to Physics,* 3rd ed. (McGraw-Hill, New York, 2001), pp. 328–330; D. Halliday, R. Resnick, and J. Walker, *Fundamentals of Physics*, 6th ed. (Wiley, New York, 2001), pp. 850–852; F.L. Pedrotti and L.S. Pedrotti, *Introduction to Optics,* 2nd ed. (Prentice Hall, New York, 1987), pp. 135–140.
2. Those interested in building a simple but useful telescope can see, for example, M.K. Gainer, "Construction of a 17th century telescope: An experiment in the history of astronomy," *Phys. Teach.* **19**, 22–25 (Jan. 1981).
3. We purchased the following from Sargent-Welch, P.O. Box 5229, Buffalo Grove, IL 60099 (http://www.sargentwelch.com), but similar equipment is also available from other suppliers: one metal support set, WL3602A; two large lens supports, WL3606A; two screen supports, WL3610B; one f = 50 mm double convex lens, WL3411; one f = 100 mm double convex lens, WL3411A; and one f = 500 mm double convex lens, WL3414.
4. F.L. Pedrotti and L.S. Pedrotti, *Introduction to Optics,* 2nd ed. (Prentice Hall, New York, 1987), p. 131.

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