Geometric Optics Lab 2

Building a Keplerian Telescope

Light source with arrow, optical bench, carriages and lens mounts, lenses, screen, frosted microscope slide.

Procedure 1

1. Place the light source on one side of the laboratory. This will act as a “star”.
2. On the opposite side of the laboratory, place a lens (having a focal length of approximately 30 or 40 cm) in a lens holder atop an optical table or rail. This will serve as our objective lens. On the side of the lens opposite the constellation, place a small rigid white screen. Move the screen forward or backwards until an image of the constellation is focused on the screen. The distance between the lens and the screen is called the image distance; since the object distance is very far, the image distance should be approximately equal to the focal length of the lens.
3. Carefully inspect the image on the screen. Is it larger or smaller than the actual objects being observed? Calculate the magnification.
4. When you are near an object, it appears large; when it is distant, it appears small. This is because when it is near, it takes up a larger portion of your field of view: it occupies a larger solid angle (more on this later). Now: you can try to make the image of the star that appears on the screen larger by moving your head very close to it. Try this. How close can you get your eye before it looks blurry? This is distance is called your ``near point”.
5. Your near point is set by the ability of the ciliary muscles of your eye to squeeze the lens in your eye so as to focus light on the retina in the rear of your eye. This physiological limitation can be overcome by using a magnifying glass to inspect the image on the screen formed by the objective lens. In this way, the image formed by the objective lens acts as the object for the magnifying glass. So select another lens having a focal length between 5 and 10 cm. We will call this magnifying glass the eyepiece lens. What do you see?
6. What problems do you run into when trying to look through the eyepiece lens at the screen? It would probably be much easier to inspect the image from behind the screen; this way your head will not block the light from the star. Unfortunately, the screen is opaque, so let’s replace it with a semi-transparent sheet of glass, such as a partially frosted microscope slide.
7. Focus the image of the star on the frosted glass using your objective lens. Incidentally, this image is called a real image, as opposed to a virtual image; a virtual image is one formed at an apparent location at which no light rays are actually converging—for instance the image formed behind a mirror.
8. Now mount your eyepiece lens in a holder on the side of the frosted glass opposite the objective lens. Move the eyepiece lens until you can look through it and see a focused image of the constellation on the frosted glass slide. How is the distance between the image and the eyepiece related to the focal length of the eyepiece lens? In particular, is the distance from the frosted slide to the eyepiece lens larger or smaller than the focal length of the eyepiece lens? You might need to do a quick measurement to figure out the focal length of your eyepiece lens to be sure.
9. Importantly: you can now remove the frosted glass slide and still use your telescope to view distant objects. Do it. Does this surprise you?
10. Congratulations! You have now built a Keplerian telescope. Try to use your telescope to observe distant objects, such as shapes drawn on a board on the opposite side of the laboratory.

11. What is the magnification of your telescope? In order to determine the magnification, use the method described by Galileo. Galileo observed two objects simultaneously, one through the telescope and the other with the unaided eye. This is a bit tricky, but give it a try. Draw a small square (about an inch across) on the chalkboard and look at it through your telescope from the other side of the room. It will look magnified. Now, have your lab partner stand next to the small square on the chalk board. While looking with one eye through the scope, look through the other eye past the lenses. Have your lab partner try to draw another square on the board that looks to be the same size as the magnified square. The ratio of the sizes of these two squares is the magnification of your telescope.
12. How do the magnification, field of view, image brightness, and image sharpness depend upon the focal lengths of the objective and eyepiece lenses? Does the approximate formula (Magnification) = (objective focal length) / (eyepiece focal length) work?

Refracting telescope theory

1. A refracting telescope uses two lenses, an objective and an eyepiece. Light from a distant object first passes through the objective lens. The objective lens forms a real inverted image which is somewhat smaller than the object itself. Sketch this optical arrangement in your lab book.
2. The image produced by the objective then acts as the object for the eyepiece. In a refracting telescope, the image produced by the objective lies at, or just inside, the focal point of the eyepiece lens. Add this to your sketch.
3. If the focal length of the eyepiece is much less than the user's near point, then he or she can use the eyepiece as a magnifying glass to inspect this image up close without straining his or her eye. What is the relationship between the focal lengths of the objective and eyepiece lenses and the total length of your telescope?
4. What is the relationship between the focal lengths of the two lenses and the magnification of your telescope? Why is this the case? Challenge: can you explain this geometrically, using light ray diagrams?

Angular width

1. The perceived size of an object is determined by its angular width. What is the angular width of your fingernail, in degrees and in radians, when held at arm's length? You will need to measure the linear width of your fingernail and the distance from your eye to your fingernail to compute the angular width.
2. Now move your fingernail closer to your eye; it appears bigger and bigger. Eventually, however, you will reach your “near point,” closer than which you will be unable to focus on your finger nail. What is your near point? What is the angular width of your fingernail at your near point? This is the largest angular width of your fingernail achievable without using a magnifying glass.
3. Now place a short focal length lens between your fingernail and your eye. Can you move your fingernail closer than the near point of your eye now? If so, see if you can determine the angular width of your fingernail when viewed through the lens.
4. Compare the angular width of your fingernail at your near point (your initial measurement) and the angular width of your fingernail when it is viewed through your magnifying glass. The ratio of these two quantities is the angular magnification of the magnifying glass.