Telescopes

Background

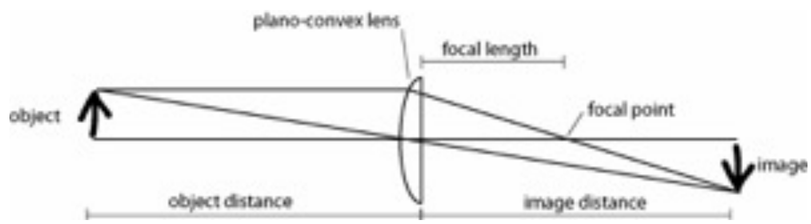
In this exercise you will learn about the components of a telescope and about how a telescope works. There are two main types of telescopes: *reflecting telescopes* use mirrors and *refracting telescopes* use lenses. You will construct a refracting telescope in this exercise.

Astronomical telescopes are generally used to observe things in the night sky. To do this effectively, a telescope must be able to do four things:

1. Form an image
2. Gather light – astronomical objects are usually pretty faint
3. See fine detail – the more resolution the better
4. Magnify – besides being faint, astronomical objects are also pretty small

The first property is most important because without an image, the other items wouldn't matter much. You will construct a small refracting telescope from the lenses in your kit, but first you will see how images can be formed, without a lens, in a pinhole camera.

You will also determine some of the properties of the individual lenses. Lenses are characterized by their shape (convex, concave, and planar) and by their focal length.



The focal length of a lens can easily be measured by holding the lens up to a screen of some kind (a wall does nicely), and adjusting the distance between the lens and the screen until the image is in focus. If the object is far away, then the distance from the lens to the image is the focal length.

The next two properties in the list (gather light and see fine detail) are also very important. Both of these properties are determined by the *aperture* of the telescope. Aperture is pretty much just the size of the main lens (or mirror) of the telescope, which we call the *objective lens* (or mirror). The size, or more precisely, the *area* of the objective determines how much light can get into the telescope thus determining the light gathering power. You will measure the lenses in your telescope kit and find their areas. You will also compare this with your own light gathering device, the pupil of your eye.

Aperture also determines how well a telescope can resolve fine detail. But instead of depending on the area of the objective, resolution depends on the *diameter* of the objective. You will measure the resolution of your own eye and calculate the resolution of which your telescope should be capable.

The objective lens determines a property of the telescope known as the f-ratio ($f \cdot ratio = \frac{f.l._{objective}}{diameter_{objective}}$). Altering the f-ratio (by changing either the diameter or focal length of the objective lens) will alter properties such as the brightness and sharpness of the image.

Making the image of the object larger, or magnification, is the fourth task of a telescope. Although still important and necessary, magnification is less important than the other properties because if an image is faint and blurry, making it larger is not going to improve things! Magnification is the job of the second lens (the smaller one) in your kit, which is called the *eyepiece* or *eye lens*. The eyepiece magnifies the image that is created by the objective lens. One can calculate the theoretical magnification of a telescope by taking the ratio of the focal lengths of the objective and eye lenses (i.e. $mag_{theoretical} = \frac{f.l._{objective}}{f.l._{eyepiece}}$).

1. Pinhole camera

Use the tubes from your telescope (i.e. without the lenses in place) to construct a pinhole camera. First mark gradations on the smaller (inner) tube with 1 cm separation and then fit the tubes together. A piece of aluminum foil should be pulled taut over one end of the tube and fastened with a rubber band and a piece of tracing paper should be pulled taut over the other end of the tube. Carefully poke a hole in the centre of the aluminum foil taking care to keep it small and circular.

Place the cardboard mask in front of the light source on an overhead projector. The **F** shape cut into the cardboard is your object. Point your pinhole camera at the object and adjust the position so that you get the image of the **F** on your screen. The distance from the pinhole to the cardboard **F** is your object distance and you will make measurements at two different distances. Watch your units!

	Object Size (OS) (mm)	Object Distance (OD) (mm)	OS/OD	Image Size (IS) (mm)	Image Distance (ID) (mm)	IS/ID
1						
2						
3						
4						
5						
6						

Answer the following on a separate sheet of paper.

a. Compare the ratios Object Size/Object Distance and Image Size/Image Distance
b. What happens to the brightness of the image as it gets larger?
c. Compare the image observed in the pinhole camera to the object you are observing (Is the image inverted top-bottom? Is it flipped left-right?)
d. Draw a ray diagram to illustrate how light travels in the pinhole camera.

2. Lenses

Before constructing the telescope, you will measure some properties of the individual lenses. You should have two lenses; the larger lens is called the *objective lens* and the smaller one is called the *eye lens*. Be sure to watch your units! Where calculations are required, be sure to show your work (use a separate sheet of paper if you need more space).

i. Light gathering power

a. *Measure* the diameter of the objective lens ________________ (mm)
b. *Calculate* the light gathering power of the objective lens ________________
c. *Measure* the diameter of the eye lens ________________ (mm)
d. *Calculate* the light gathering power of the eye lens ________________
e. *Estimate* the diameter of your dark adapted pupil ________________ (mm)
f. How much more light can the objective lens gather compared to your eye? ________________
g. **BONUS**: If you can detect a 5th magnitude star with your naked eye, what magnitude should you be able to detect using the telescope? (show your work!
HINT: $2.5\log(flux) = \Delta m$) ________________

ii. Focal length

h. *Measure* the focal length of the objective lens ______________ (mm)

i. *Measure* the focal length of the eye lens ______________ (mm)

iii. Magnification

j. *Estimate* the magnification of the *eye lens* ______________

k. *Calculate* the theoretical magnification of the *eye lens* ______________

3. Telescope

Use the lenses and the tubes to construct your telescope.

a. *Measure* the size of the exit pupil ______________ (mm)

b. *Calculate* the telescope's f-ratio ______________

c. *Estimate* the magnification of the *telescope* ______________

d. *Calculate* the theoretical magnification of the *telescope* ______________

Answer the following on a separate sheet of paper:

e. How does the size of the exit pupil compare to the diameter of your dark adapted eye? How large should the exit pupil be in a telescope to achieve optimum views? What happens when it is larger than this? When it is smaller?

f. How can one change the f-ratio of a telescope? What happens to the image as the f-ratio gets larger? smaller? Comment on the brightness and sharpness of the image.

g. Compare the image observed in the telescope to the object you are observing. How is it similar or different to the image observed in the pinhole camera?

h. Observe a bright white light source through the telescope and comment on the appearance of the edges.

4. Angular Resolution

Attach the fan diagram to a wall and stand, facing the diagram, about 10 meters away. Have a partner cover the diagram, starting at the top, until you reach the point where the fan lines blur together and read off the height (marked on the diagram).

a. Measure your distance to the fan diagram (watch units!) ______________ (mm)

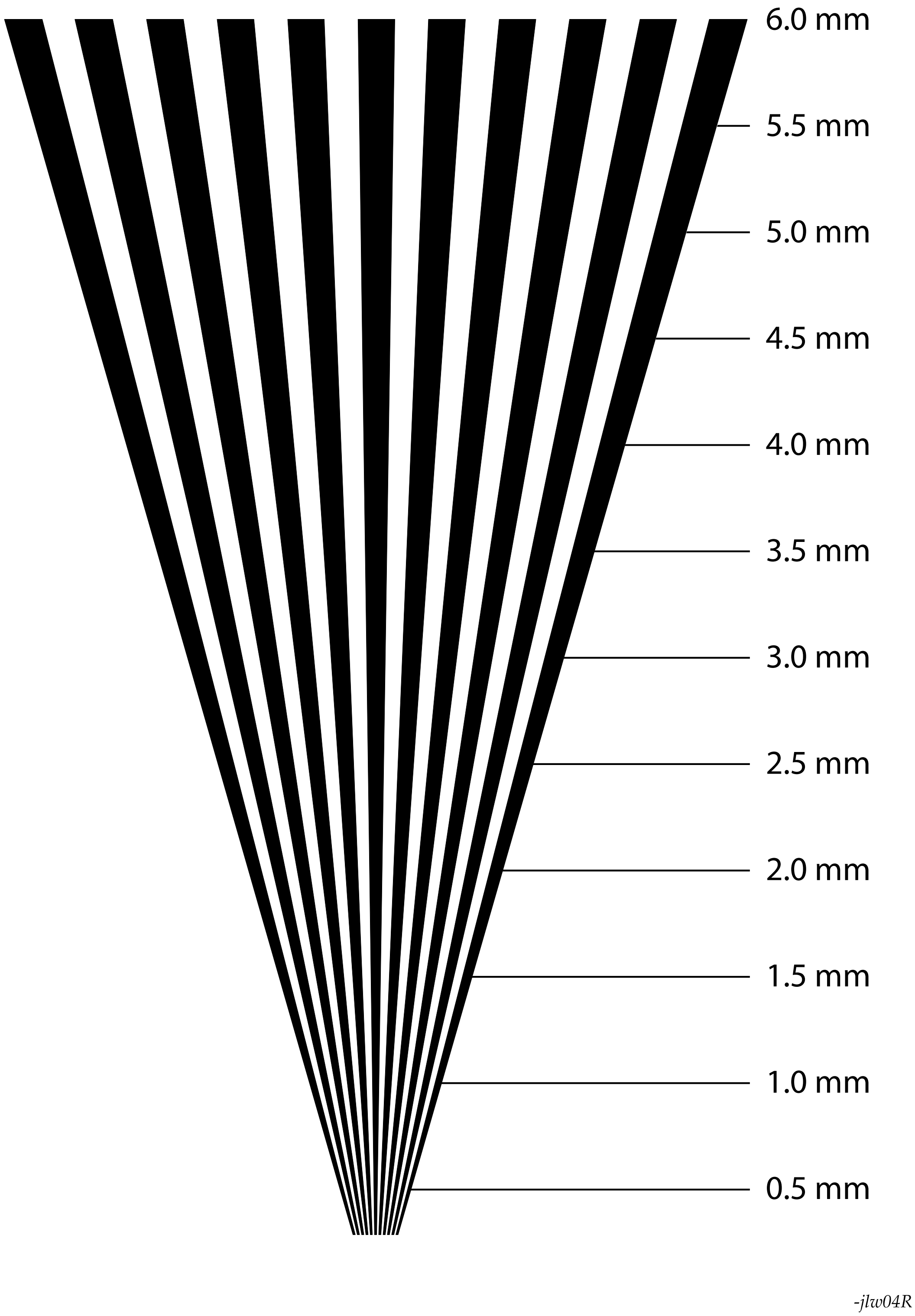
b. Height at which the fan lines blur together ______________ (mm)

c. Ratio (height/distance).
This is the angular resolution of your eye in radians. ______________ (rad)

d. Calculate the angular resolution of your eye in arc minutes ______________ (arcmin)

e. From the same distance, use the telescope to look at the fan diagram. You will probably need to steady yourself against a wall in order to find the diagram through the telescope. On a separate sheet of paper describe the appearance of the diagram through the telescope.

f. Calculate the resolution you should be able to achieve when looking through the telescope $\left(\frac{\text{Diameter}_{\text{pupil}}}{\text{Diameter}_{\text{objective}}} * \text{Resolution}_{\text{eye}}\right)$ ______________ (arcmin)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