

## LAB 4: THE SIMPLE MAGNIFIER EYEPIECES

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An eyepiece functions as a magnifying glass, or simple magnifier. In effect, your eye looks into the eyepiece, and in turn the eyepiece looks into the optical system—be it a compound microscope, a spotting scope, telescope, or binocular. In all cases, the eyepiece doesn't view an actual object, but rather some intermediate image formed by the "front" part of the optical system. This intermediate image is usually real, but could be virtual. In either case, the function of the eyepiece is to form a virtual, magnified image located at  $\infty$  for your eye to view.

### The Simple Magnifier:

We begin by considering how a simple magnifier works. For this we use a large single lens similar to what Sherlock Holmes made famous. Our magnifier could just as well be the lens or system of lenses (eyepiece) used in microscopes or telescopes. As already stated, a magnifying lens is used to form a *virtual, magnified* image for your eye to view.

The magnification of the image depends on where the image is located. When viewing the image with your eye, we will consider two special locations of the image and the corresponding magnifications. Figure 4.2 shows a lens used to magnify an object placed in front of the lens, for an eye located immediately behind the lens. In 4.2 (a), the object is located at the front focal point  $F$  of the lens, placing the image at infinity. In 4.2 (b), the object is located at the spot inside the front focal point to position the image at the near point (N.P.) of the eye. The near point, located 25 cm in front of the eye, is the closest comfortable viewing distance of the (average) human eye.

The magnification of the image is given by the following equations:

For the image at infinity:

$$M_{\theta}(\infty) = \frac{25 \text{ cm}}{f_e} \quad (4.1)$$

For the image at the near point, with your eye positioned just behind the magnifier:

$$M_{\theta}(NP) = \frac{25 \text{ cm}}{f_e} + 1 \quad (4.2)$$

where  $f_e$  is the effective focal length of the lens (magnifier).

Note that in both cases, it is assumed that the eye is (properly) positioned directly behind the magnifying lens. In this manner, the ray angle at the eye is (essentially) the same as the chief ray angle  $\bar{u}$  at the lens. This has an important implication for how to properly use a simple magnifier:

**FIRST HOLD THE LENS UP TO YOUR EYE, AND THEN BRING THE OBJECT UP TO THE LENS UNTIL IT IS IN FOCUS FOR COMFORTABLE VIEWING.**

- (1) Take the lens out into the lobby and form a real image of the outside world on the wall.
- (2) Measure the distance between the center of the lens and the wall. Assuming the magnifier to be a thin lens, this is the effective focal length,  $f_e$ .
- (3) Take the magnifier lens and use it to form a magnified, virtual image of a flat 2-D object such as a piece of paper. Form the image while viewing it with your eye relaxed (i.e. while looking at infinity).
- (4) At the same time, have a lab partner measure the distance between the lens and the object. Assuming the magnifier to be a thin lens, this is the object distance,  $z$ .

**Q1** Calculate where the virtual image is located. Is it closer to your near point, or  $\infty$ ?

**Q2** Calculate  $M_\theta(\infty)$ . Calculate  $M_\theta(NP)$ . Is the magnification that you observed close to either of these two values?

Learn how to use the 10X optical comparator, also known as a “loupe”:

- Hold up the comparator in front of a blank white background (paper, the wall, etc.) and look through it.
- Twist the ring around the eyelens until you see the scale in focus.
- Place the bottom side of the comparator (with the glass reticle) against the flat surface to be measured.
- Looking through the eyelens, compare the size of the object to the tick markings on the scale.

**Q3** Compare the tick marks on the reticle to known tick marks on a ruler. What is the scale of the reticle (i.e. how far apart are the numbered marks)?

**Q4** Explain why the reticle is very close to the surface on which you are making comparison measurements.

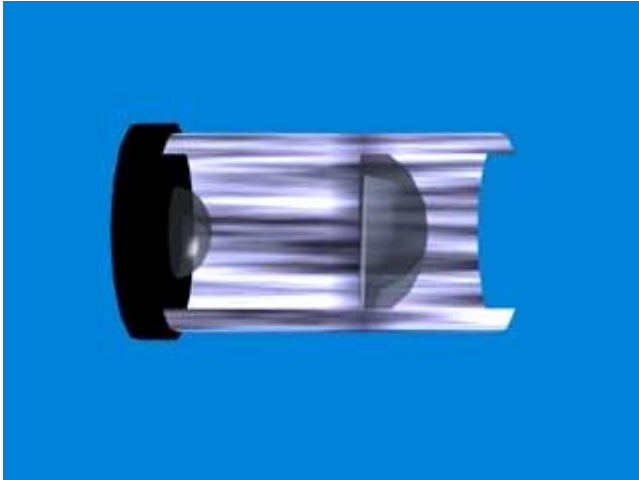
**Q5** Explain why the reticle is not in direct contact to the surface on which you are making comparison measurements!

## **Eyepieces:**

The following information is borrowed from:

<http://www.astro-tom.com/telescopes/eyepieces.htm> (an excellent website on eyepieces).

### Huygens



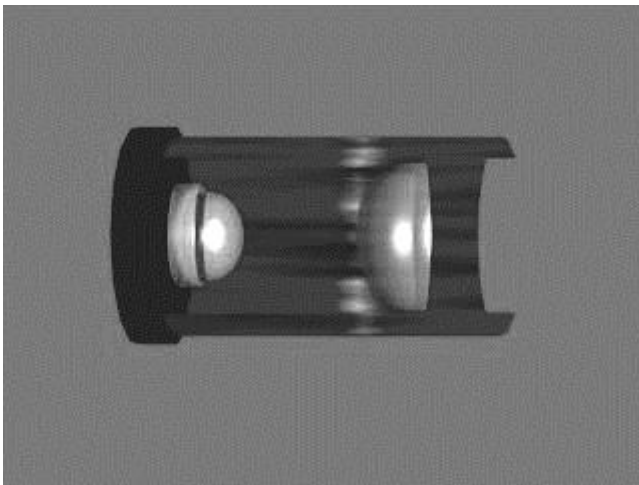
“Christian Huygens developed the first compound eyepiece in 1703. A pair of plano-convex elements contain both spherical and chromatic aberrations. Long ago, Huygens eyepieces were standard equipment with telescopes of  $f/15$  or greater telescopes. At the longer focal ratios, these eyepieces perform marginally well, although their field of view is very narrow. They lack an overall sharpness and are considered to have poor image quality.

Huygens eyepieces are generally the least costly eyepieces on the market. Huygens eyepieces incorporate two optical elements. They perform quite well on long focus refracting telescopes, but they can show image distortion as the telescope's focal length becomes shorter. Huygens are very good for projection of solar images since they don't use cement to hold the lens elements.”

### Ramsden

“It was Christian Ramsden who invented this eyepiece in 1783. It is similar to a Huygens in that it consists of two plano-convex lenses, except both of the convex surfaces have identical focal lengths and they face each other. In most cases the lenses are separated by two-thirds to three-quarters of their common focal length, which represents a severe compromise between eye relief and aberrations. This design was an improvement, albeit a small one, in the history of eyepiece design.”

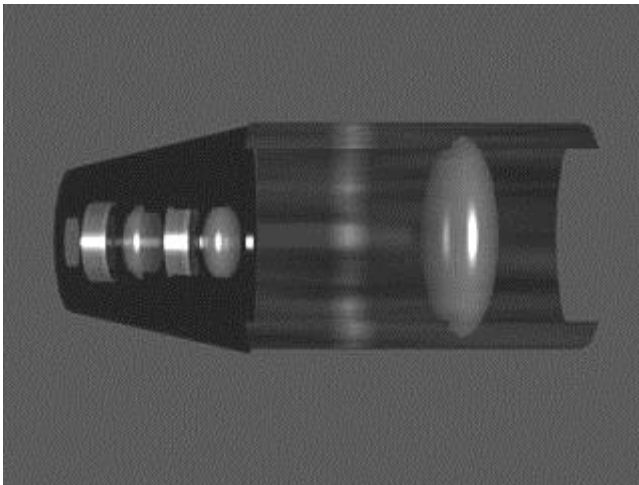
### Kellner



“About 65 years after the Ramsden eyepiece was developed, Carl Kellner introduced the first achromatic eyepiece in 1849. He placed a cemented two element achromat lens in place of the eye lens of the Ramsden. He also used flint glass closest to the observer's eye and crown glass in the other elements.

The design reduced most of the aberrations in Huygens and Ramsden eyepieces and had fairly good color correction and edge sharpness. They also had good field of views (about 40 to 50 degrees).

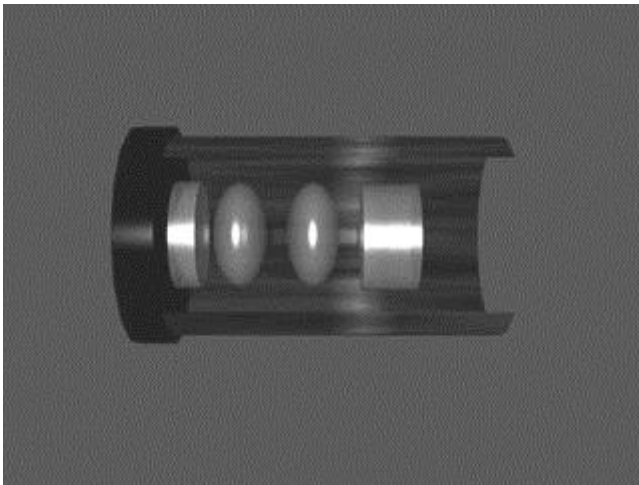
The biggest problem that plagues the Kellner design is internal reflections. Today's anti-reflection coatings make these usable, economical choices for small to medium aperture telescopes at low to medium powers.”

Erfler

“The original wide field eyepiece was developed for the military in 1917. Because it has field of views between 60 and 75 degrees, the amateur astronomers quickly adopted it. Erflers have either five or six elements, with either two achromats with a double convex lens in between or with three achromats.

Erfler are designed to give a very wide field of view, usually from 60-70°. The Erfler is usually less expensive than the plossl's. However they can suffer from considerable image distortion near the edge of the field of view when used at high magnification. They are most useful for observing deep sky objects.

Erflers can give panoramic views of the night sky, but at the expense of image sharpness with astigmatism at the edge of the field. This design doesn't work well for lunar or planetary observations that use higher powers. They work exceptionally well at low power, wide angles.”

Plossl

“An optician named G. S. Plossl, living in Vienna, Austria, developed this excellent eyepiece in 1860. After a hundred years of relative obscurity, the design finally caught on and has resulted in one of the most highly regarded eyepiece designs around. Excellent on all criteria, it features twin close-set pairs of doublets for the eye lens and the field lens.

Plossl's incorporate at least 4 optical elements. The Plossl design is a very well designed eyepiece, I would highly recommend them if you are using a Newtonian telescope with a very short focal length. Plossl's are very costly to make and hence a lot more expensive than the other designs mentioned so far. Inexpensive Plossl's usually exhibit some degree of internal reflection, which is not present in the more expensive models. Plossls generally have a wide field of view and generous eye relief. If there is such a thing as a good all around eye piece for observing then these are it: planet viewing, lunar observing or for deep sky objects.

In 1980, Al Nagler, owner of Tele Vue Optics, Inc., introduced a line of Plossls that are considered almost legendary today. This set up a cascade of companies that developed and marketed their own line of outstanding Plossls. Some are better than others and it's fair to say that you get what you pay for. Things to look for when purchasing Plossls include, fully multi-coated optics, blackened lens edges, and anti-reflection threads for filters.”

**Lab Exercises:**

We will characterize the following basic properties

- Focal length
- Back focal distance (BFD)
- Eye relief (the distance from the rear vertex to the exit pupil)
- Aberrations (spherical, chromatic, coma and astigmatism)

of 2 different eyepieces:

- a 25mm f.l. Kellner
- a 25mm f.l. Plossl.

**Focal Length and BFD**

- (5) Collimate a diffuse pinhole. (The height and rotation of the source and Xerox lens are pre-aligned along the optical rail. Do NOT adjust those.) Adjust only the z-position of the lens along the optical rail to collimate the pinhole!
- (6) Make nodal slide measurements to determine the focal length and BFD of each of the 2 eyepieces.

**Q6** Compare your results for the different eyepieces.

**Eye Relief**

The concept of an exit pupil, when talking about just an eyepiece, is a bit “nebulous.” In practice, we combine the eyepiece with another optical system—afocal (telescopes, binoculars, spotting scopes, etc.) or focal (microscopes). As an example, for refracting telescopes or binoculars, the objective lens is the aperture stop. For reflecting telescopes, the primary mirror is the aperture stop. In turn, the “exit pupil of the eyepiece” will be the exit pupil of the system (where the eyepiece images the aperture stop, the edge of the objective lens or the primary mirror).

- (7) Remove the Xerox lens.
- (8) Replace the pinhole with the large-hole aperture, located about 500mm away from the eyepiece. In reality, this distance is a reasonable value for the focal length of the objective lens or mirror in a small telescope. This hole now becomes (“simulates”) the aperture stop (and therefore the entrance pupil) of our “optical system.”
- (9) Position the microscope behind the eyepiece, and focus it on the image of the aperture stop. This image IS the exit pupil,  $E'$  (the image of the large-hole aperture).

(10) Use the microscope to measure the distance from the exit pupil to the rear vertex for each of the eyepieces. This distance is the eye relief (different for each eyepiece).

**Q7** Compare your results for the 2 different eyepieces.

### **Field of View (FOV)**

Perform the following steps to measure the FOV for the following 3 eyepieces:

- a 25mm f.l. Kellner
- a 25mm f.l. Plossl
- a 12mm f.l. Huygens

(11) Use the microscope to measure the diameter of the field stop.

**Q8** Calculate the FOV (in degrees) for each eyepiece as:

$$FOV = 2 \tan^{-1} \left( \frac{d_{Field\ Stop}}{2f_e} \right)$$

**Q9** Describe why this equation is valid!

### **Aberrations**

(12) Replace the large-hole aperture with the pinhole.

(13) Arrange the Xerox copy lens to produce  $\approx$  a 1:1 image of the pinhole.

(14) Place the 12mm f.l. Huygens eyepiece on the nodal slide.

(15) Describe a scheme (and carry it out) to align the front vertex V of the eyepiece to be directly over the rotation axis of the nodal slide. Hint: think “dust” and “microscope.”

(16) While looking into the eyepiece with a relaxed eye (your eye focused at  $\infty$ ), slide the entire nodal slide back and forth until you see an “in-focus” image of the pinhole.

**Q10** Where is the real image of the pinhole (the point image formed by the Xerox lens) now located?



- (17) Rotate the nodal slide until this point image is centered in the field of view of the eyepiece. Lock down the rotation adjustment of the nodal slide.
- (18) Slowly slide the entire nodal slide back and forth, to move the front focal point of the eyepiece “through focus.” Study the patterns of light that you see, on axis.
- Q11** Make drawings of what you see. Comment on whether or not you see evidence of spherical aberration, and transverse or longitudinal chromatic aberration.
- (19) Unlock the rotation of the nodal slide. Rotate the nodal slide back and forth, effectively moving the point source off-axis of the eyepiece (by the same angle you rotated the nodal slide). Study the patterns of light that you see, now off-axis.
- Q12** Make drawings of what you see. Do you see evidence of coma and/or astigmatism as the image point moves off-axis?
- (20) Rotate the nodal slide until the point image just disappears at one edge of the field of view.
- Q13** When the point image just disappears from the field of view, where is it now located? (Observe its location visually, by looking into the front of the eyepiece!)
- (21) Repeat these observations/measurements for all 3 eyepieces.