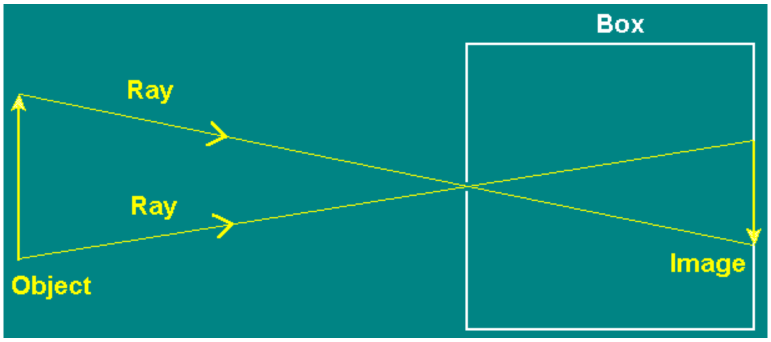
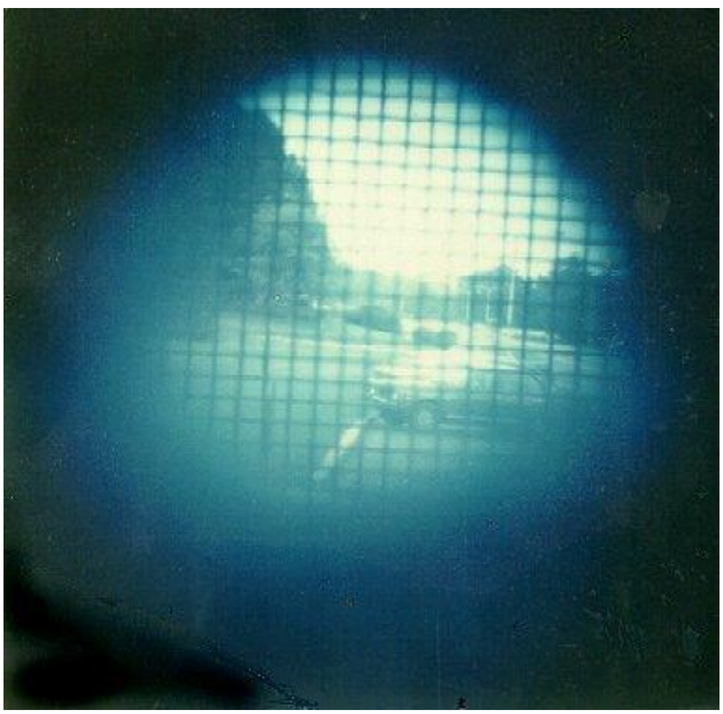
Modern Optics, Prof. Ruiz, UNCA **doctorphys.com**
Chapter J. Microscopes, Telescopes, Eclipses
OR Optical Instruments. **This Chapter is dedicated to Inventors.**

J1. The Pinhole Camera.



Pinhole Photo of Doc (c. 1985)

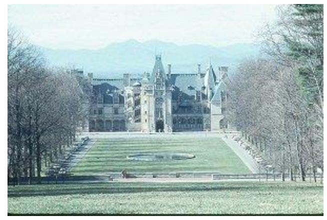
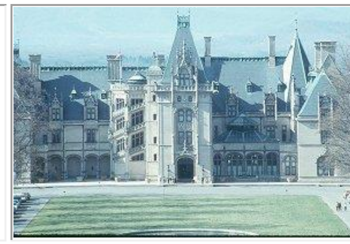
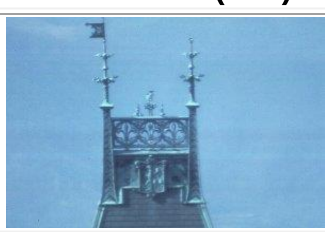
Here we have an actual photograph made by a pinhole camera. Many years ago, I "ripped off" a Polaroid camera from my sister-in-law, "smashed out the lens," and replaced it with a pinhole. For over 20 years, this same camera has been used to take pinhole-photos in class. The photos were then developed in one minute and passed around the class. The photo here is of me in my younger days, taken in then Rhoades 105, where we used to meet for the Light course at UNCA before the Robinson addition was built. If I appear a little fuzzy, remember that due to the small amount of light entering the pinhole, this guy had to sit still for over a minute - something nearly almost impossible for him.



For our next photo, I set the camera on my window in my first office in Rhoades Hall, before our Robinson Hall addition was built. Today there is a machine shop where my old office was. Notice how the screen is "in focus" and also the cars. With a pinhole camera, everything is "in focus." Yet the pinhole focuses nothing. The light simply enters and does not need to be focused. As we have noted, in photographic jargon, we say that the pinhole camera has an infinite ***depth of field***.

J2. The Camera. We have studied the camera as an optical instrument, along with its many accessory lenses.

The Biltmore House, Asheville, NC with Different Focal Lengths

		
f = 50 mm (40°)	**f = 100 mm (20°)**	**f = 200 mm (10°)**
		
f = 300 mm (7°)	**f = 400 mm (5°)**	**f = 400 mm (Raising the Camera)**
		
f = 500 mm (4°)	**f = 600 mm (3.4°)**	**f = 800 mm (2.6°)**
		
f = 900 mm (2.3°)	**f = 1200 mm (1.7°)**	**f = 1500 mm (1.7°)**
		
f = 1800 mm (1.4°)	**f = 8 mm (132°)**	

J3. The Eye. We have also studied the eye as an optical system.

The Red Eye. If a bright light is flashed at a human eye, some light will return from the back of the eye. It will appear red due to blood flow. The photo below illustrates this reflection. Note the additional small white refection of the flash from the convex cornea in the midst of the red. This surface reflection is not red since the light did not penetrate into the eye.

Reflection from Cornea and Back of Eye

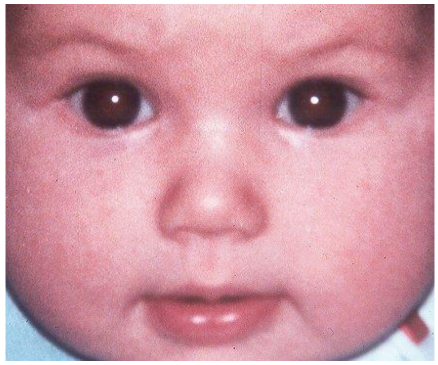


Photo by Doc c. 1984 of Daughter Frances Claire

Professional photographers often remove the flash units from their professional cameras and direct the flash at an angle so that the light doesn't hit the eye directly and bounce right back. Unlike your instructor who tries to get the red eye intentionally, most people want to avoid it. See the triple red-eye effect in the photo below - all three children with red eyes.

Red Eyes in Three Children

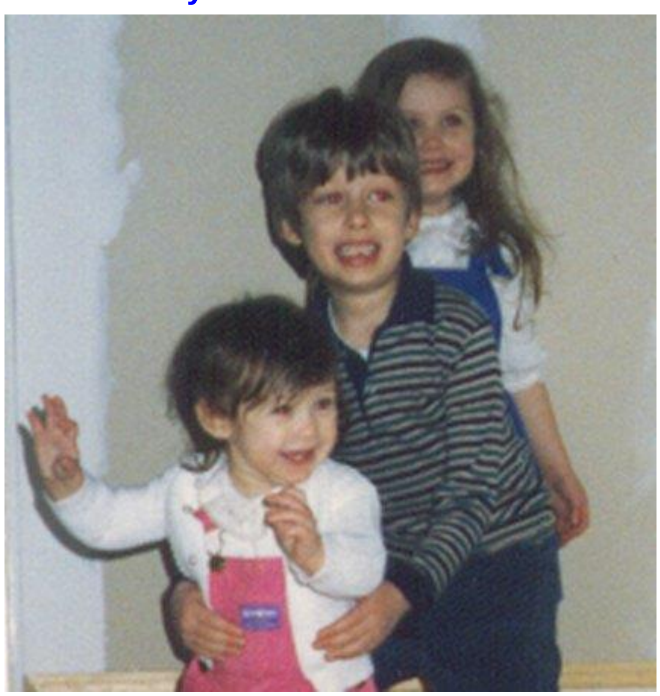


Photo by Prof. Ruiz (c. 1988): Christa, Evan, and Frances

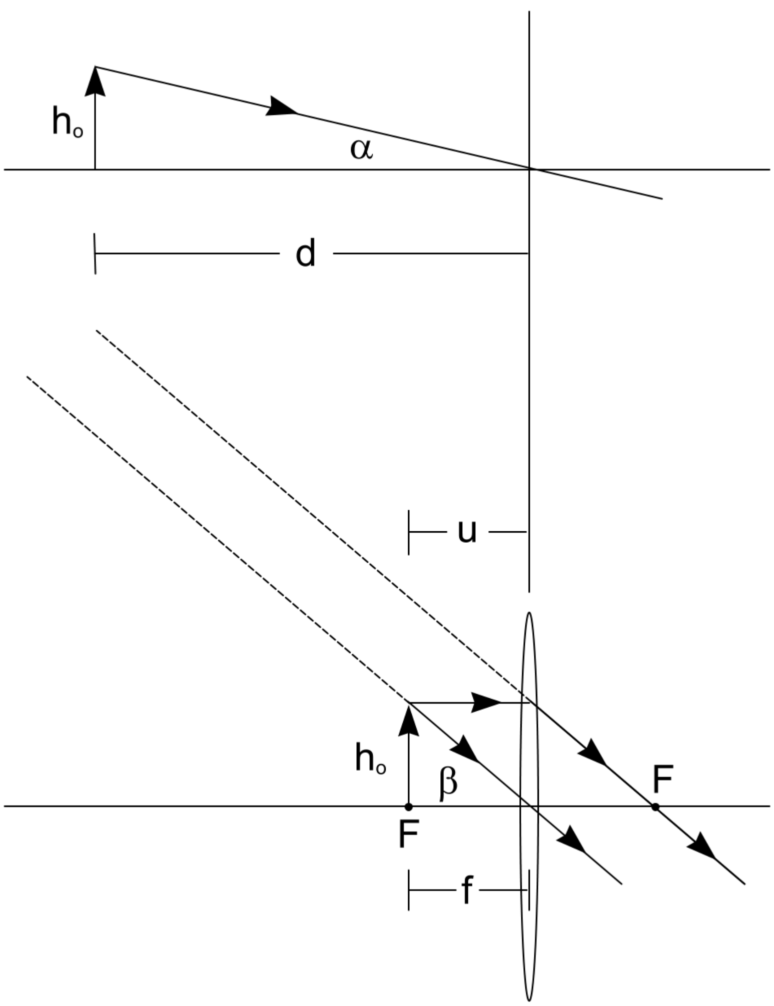
J4. The Magnifying Glass.

PHYS Light Visual Phenomena

A course for the general student covering basic optics with applications in the areas of photography, vision, color, and art.

A converging lens produces a magnified virtual image if the object is between the focal point and the lens. The object may even be placed at the focal point, producing parallel rays, which rays allow the eye to relax its ciliary muscles.

In either case, after the magnifying glass converges the rays to some extent, the eye takes care of the rest, forming the final image on the retina. For an object at the focal point, the image is enlarged (infinitely) and sent to infinity.



In the top case an observer is viewing the object at a distance d, which we can take to be the observer's near point so that the object is as close as possible to the observer. For the average eye, d = 25 cm.

Below, the observer is viewing the object through a magnifying glass. Linear magnification is not useful here since the image is infinitely large. So we go with angular magnification.

$$M = \frac{\beta}{\alpha}$$

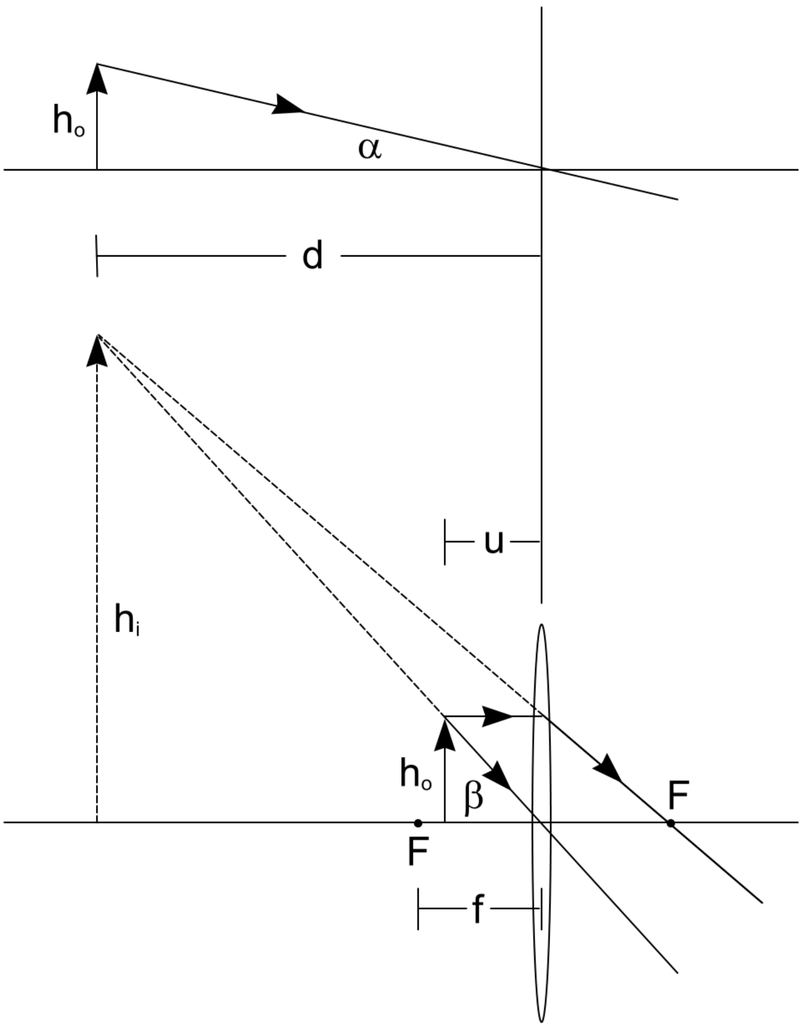
Using the usual paraxial angle approximation:

$$\alpha \approx \tan\alpha = \frac{h_o}{d}$$

$$\beta \approx \tan\beta = \frac{h_o}{f} .$$

Therefore, $M = \dfrac{\beta}{\alpha} = \dfrac{h_o / f}{h_o / d} = \dfrac{d}{f}$. Summary: $\boxed{M = \dfrac{d}{f}}$.

However, it is easier to see the workings of the magnifying glass by considering a case where the object is between the focal point and the lens, like the one illustrated below. Here we make the eye do extra work in accommodation, the ciliary muscles becoming tense to some extent in order to focus the image on the retina.



The magnifying glass allows the observer to bring the object closer to the eye than the normal 25-cm near point. Whenever an object is closer to the eye, it produces a greater retinal image. Without the magnifying glass the closest viewing distance is taken to be the d = 25 cm near point. See the upper figure.

$$\alpha \approx \tan\alpha = \frac{h_o}{d}$$

The magnifying glass here is placing the magnified image at d = 25 cm, the closest that the observer can focus on.

$$\beta \approx \tan\beta = \frac{h_o}{u}$$

Now the angular magnification is

$$M = \frac{\beta}{\alpha} = \frac{d}{u}.$$

The familiar equation $\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$ can be used where $s_o = u$ and $s_i = -d$.

Note that $s_i < 0$ since the image is in negative image space.

Then

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} \text{ becomes } \frac{1}{f} = \frac{1}{u} + \frac{1}{(-d)}$$

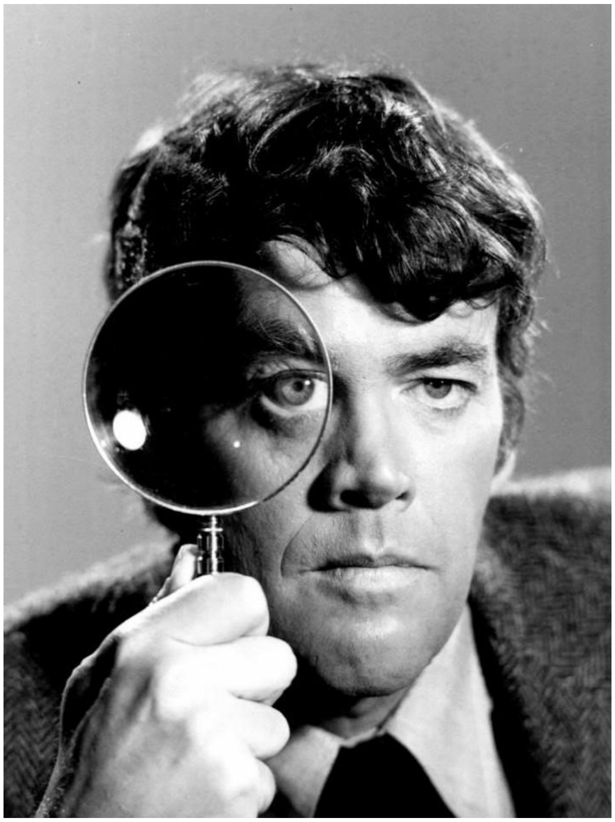
$$\frac{1}{u} = \frac{1}{f} + \frac{1}{d}$$

$$M = \frac{\beta}{\alpha} = \frac{d}{u} = d\left[\frac{1}{f} + \frac{1}{d}\right] \quad \text{and} \quad M = \frac{d}{f} + \frac{d}{d}$$

$$M = \frac{d}{f} + 1$$

$$\boxed{M = 1 + \frac{d}{f}}$$

Before, we found $M = \frac{d}{f}$.

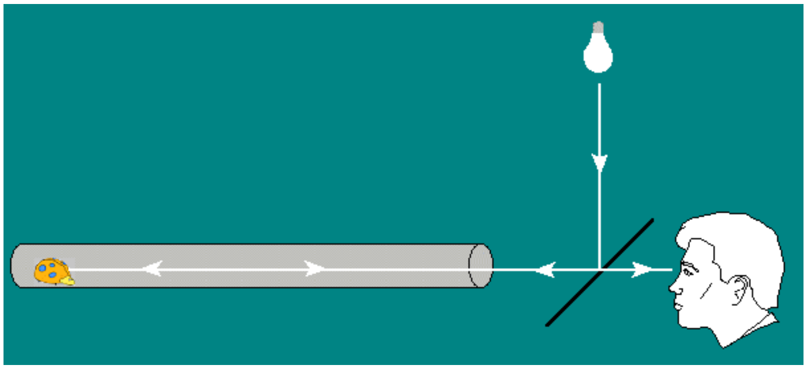


Jim Hutton from TV (1970s).
Wikipedia: Detective Ellery Queen

J5. The Ophthalmoscope. In 1847, Charles Babbage (1791-1871), the multi-talented British mathematician and inventor built the first device to look into the eye, called the ***ophthalmoscope***. However, the invention is often credited to Hermann von Helmholtz (1821-1894), of Young-Helmholtz color-vision fame, who devised one four years later in 1851. Babbage was also a computer pioneer being the first to establish the theoretical overall structure of a computer: input, central processing unit (CPU), memory, and output. However, the construction of the computer had to await another century.

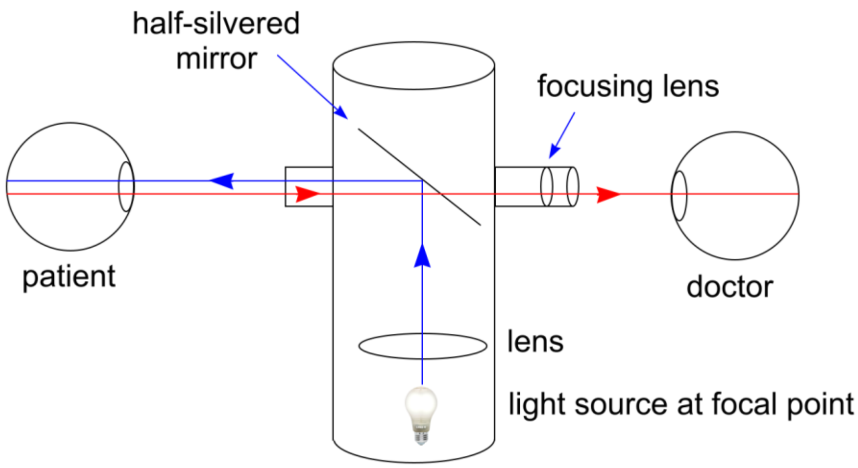
Remember our earlier challenge in seeing a bug down a dark tube? The arrangement of the light, half-silvered mirror, and observer as illustrated below lets the observer see the bug. The light from the mirror hits the half-silvered mirror, where half of the light is reflected to the left to proceed into the tube and the other half passes through the mirror straight down (light ray not shown in the figure). This transmitted light is lost and not used. Light returning from the bug likewise splits at the mirror with some traveling up toward the bulb (again not shown and not used), while the rest passes on to the observer.

Principle of the Ophthalmoscope



The figure below illustrates how the ophthalmoscope works. Note the similarity in the two physical situations.

Half-Silvered Mirror (Two Way) and Ophthalmoscope



J6. The Slide Projector.

Courtesy Wikipedia: Steve Morgan. [Creative Commons License]

Project a 36 mm x 24 mm slide to a wall 40 feet away, like in Robinson Hall 125. You will need a special lens since 40 ft is far. See projected slide below.

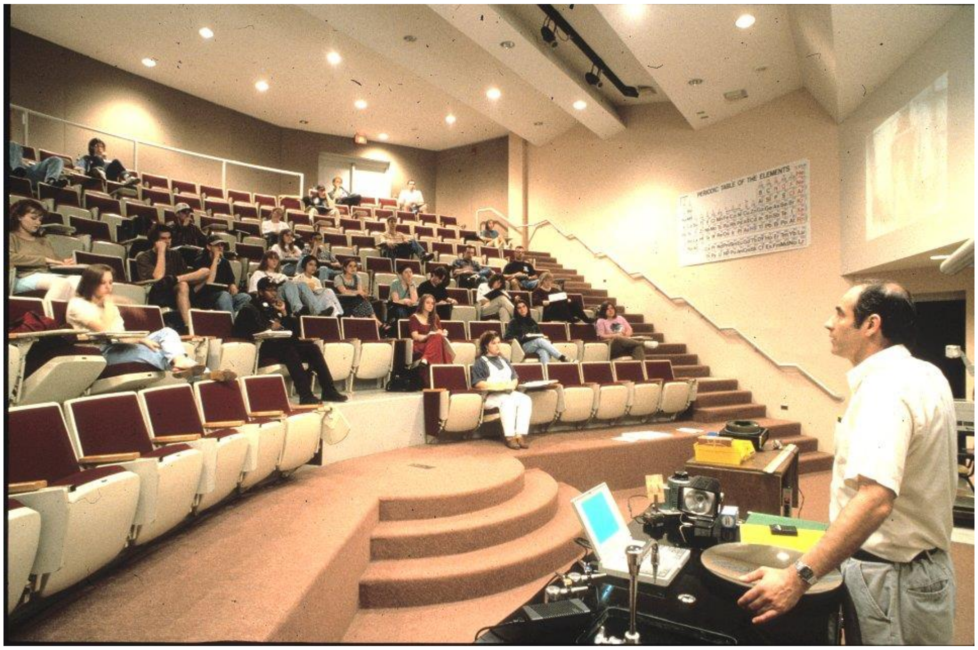
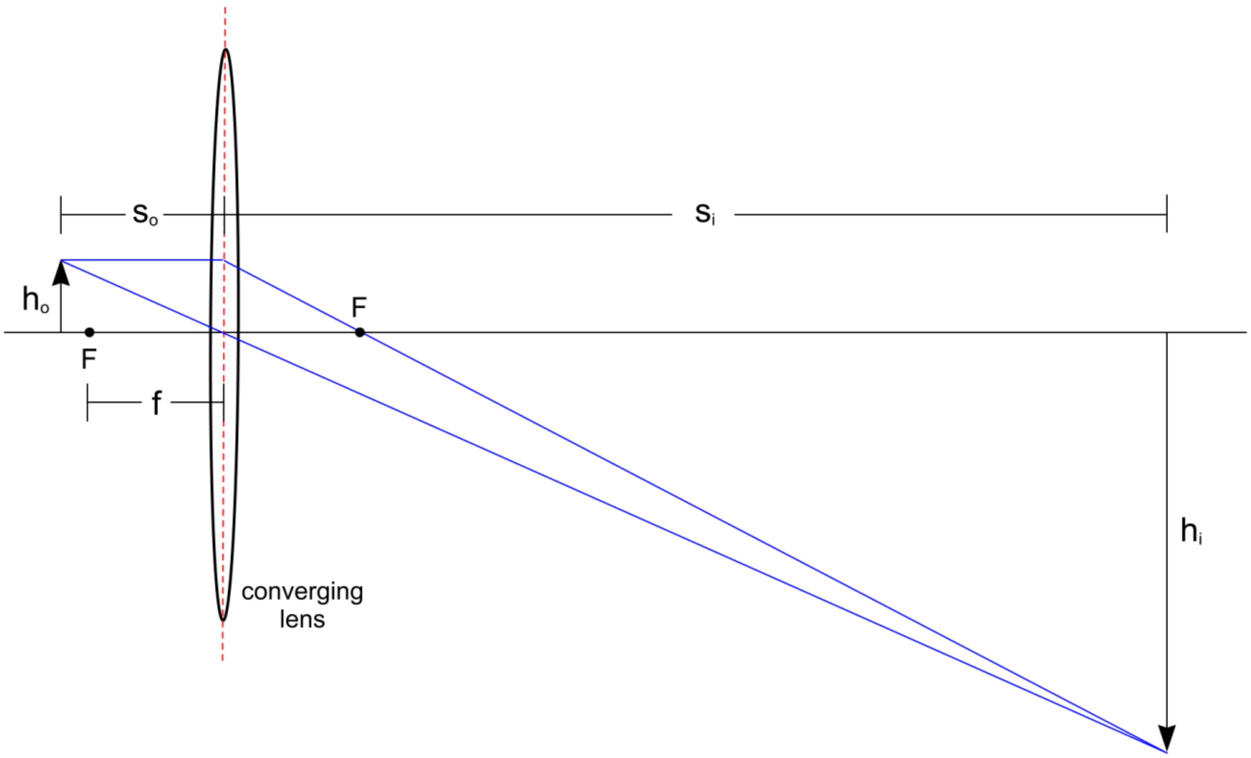


Photo by John Warner. Slide projector is just out of view at the upper left back.

The slides are 2 inches x 2 inches when you include the frame. From the above photo of the slides and projector with lens, you can estimate s_o = 8 inches = 20 cm. The distance from the projector in the back of the auditorium to the panel at the right is s_i = 40 feet = 12 m = 1200 cm.



$$M = -\frac{s_i}{s_o} = -\frac{1200}{20} = -60$$

The wall panel that receives the image must be 60 times the slide picture dimensions.

$$60 \times 36 \text{ mm} = 2160 \text{ mm} = 2.2 \text{ m}$$

$$60 \times 24 \text{ mm} = 1440 \text{ mm} = 1.4 \text{ m}$$

To be safe, better have a width of $2.5 \text{ m} = 8 \text{ ft}$ and height $1.5 \text{ m} = 5 \text{ ft}$. Find f.

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} \quad \Rightarrow \quad \frac{1}{f} = \frac{1}{20} + \frac{1}{1200} \quad \Rightarrow \quad \frac{1}{f} = \frac{1200+20}{(20)(1200)}$$

$$\frac{1}{f} = \frac{1220}{(20)(1200)} = \frac{61}{1200} \quad \Rightarrow \quad f = \frac{1200}{61} = 19.67 \text{ cm} \approx 200 \text{ mm}$$

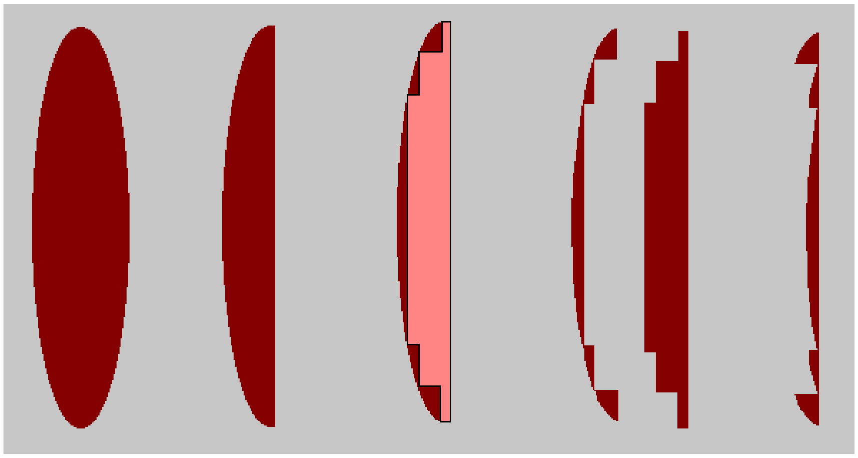
J7. Fresnel Lens. Augustin Jean Fresnel (1788-1827), a mathematician and physicist, made significant contributions to the field of optics in both theoretical and applied areas.

The French Government commissioned Fresnel to develop a more efficient lighthouse. At the time, concave reflectors were the popular design. Fresnel went in a different direction and constructed a large lens from many smaller glass elements. In this way, he could construct a large lens without the bulk associated with a single piece of glass. The lighthouse configurations that emerged were given names such as sixth order, fifth order, up to first order.

Fresnel was not only a practical inventor, but a first-class theoretical physicist. For example, he used advanced mathematics to analyze wave properties of light such as diffraction and his work helped to establish the validity of the wave model of light. Diffraction due to the circular waves emanating from a point light source and passing through an opening or around an obstacle is named after him: ***Fresnel Diffraction***.

The ingenious system of Fresnel builds on an innovative lens design where much weight is reduced. Earlier, Georges-Louis Leclerc de Buffon had suggested in 1748 that a lens constructed with concentric rings could reduce the weight of lenses. This is true since refraction takes place at the surfaces. The bulk of the glass therefore doesn't really contribute much. In designing a lens for a lighthouse, you need a large lens and a heavy lens is just not practical. The sketch below illustrates how you can remove most of the glass and reconfigure the rest to obtain a sturdy structure.

Theoretical Design of a Fresnel Lens



In the above figure, we make a plano-convex lens from the symmetrical converging lens. The plano-convex lens is still converging. We then remove most of the glass. The air-glass interface is now delicate due to the small amount of glass in some areas. We break these and align all the pieces of glass flat against the wall (see far right). We hope that this reconfiguration does not affect the workings of the lens too much. It turns out it doesn't. We have a lightweight lens that does the same thing as the heavy lens. We can also make these from circular molds.

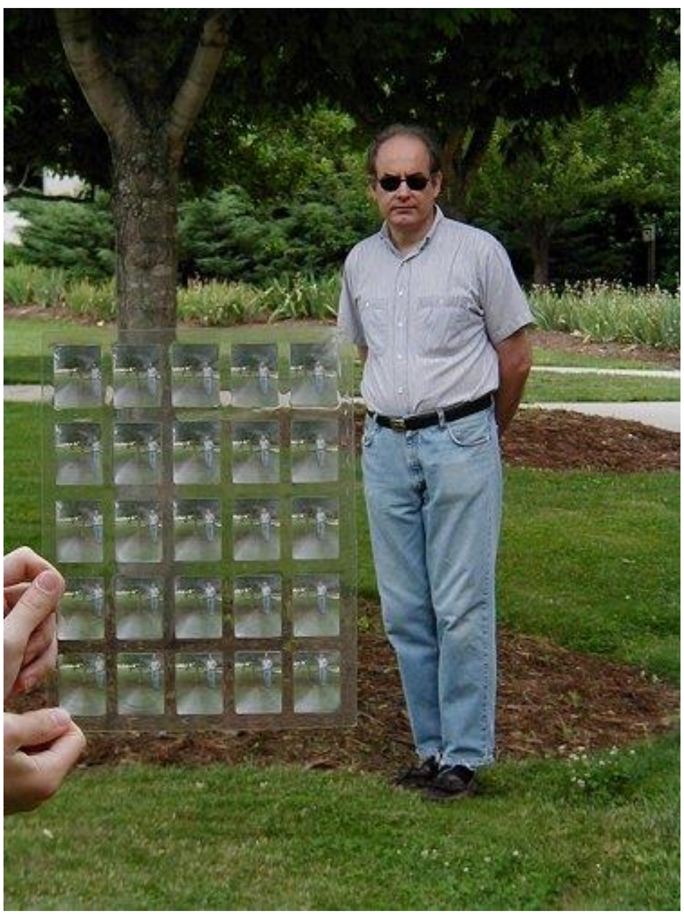
Fresnel Lighthouse Lens. Wikipedia: Frank Schulenburg. [Creative Commons License]

Cape Lookout 163-ft Lighthouse, Harker's Island, NC. Photos by Doc, June 2, 2019.

Below is a theater Fresnel lens, showing the characteristic circular ridges of Fresnel lenses. Below the theater lens are Fresnel lenses produced by pressing the circular ridges on plastic.

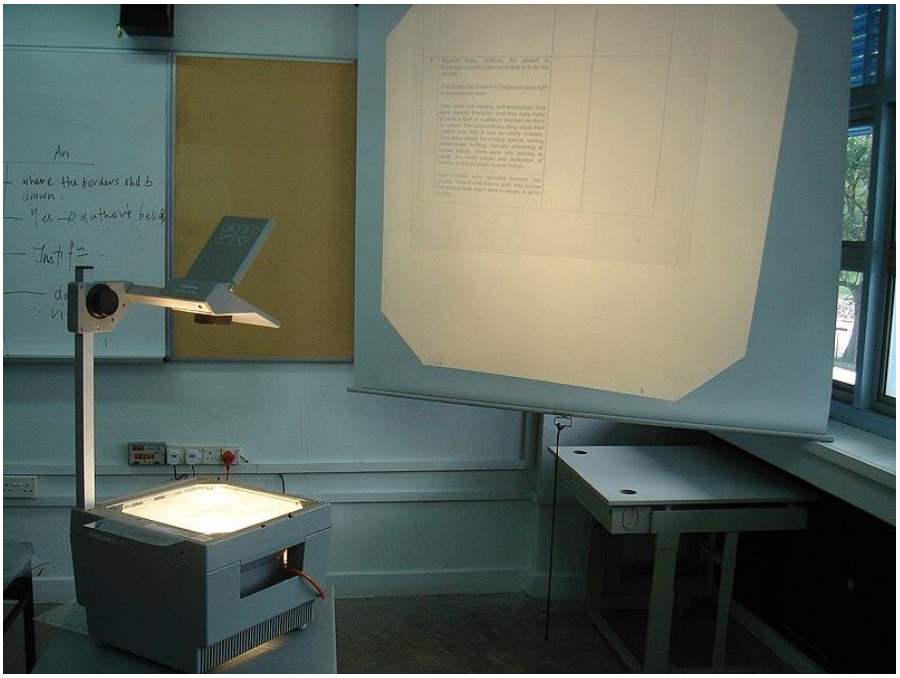
Theater Fresnel Lens

Courtesy Richard E. Berg, Lecture Demonstration Facility, University of Maryland



Pressed Fresnel Lenses. Doc and Daughter Christa. Photo by Wendy Newman.

J8. The Overhead Projector.



Overhead Projector. Wikipedia: mailer_diablo. Creative Commons License

For projecting with an overhead projector, a transparency is placed on a flat Fresnel lens . A lamp underneath with a spherical-type reflector sends light upward through the transparency. The purpose of the Fresnel lens is to take the direct light from the bulb and beam it straight up in order to illuminate the transparency uniformly. A concave mirror in the lower chamber reflects stray light going the wrong way back up toward the transparency. Therefore, the light bulb should be at the focal point for the spherical concave mirror.

Light from the transparency leaves in a variety of directions. You know this since you can look down at a transparency on an overhead and see it from different vantage points. The speaker often looks down at the transparency and may even write on it during the presentation.

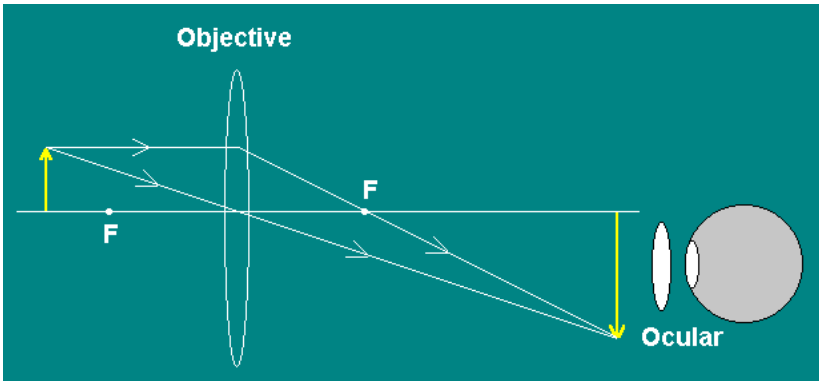
Light from the transparency reaches the upper part of the overhead which houses a converging lens and mirror. The lens focuses the image, which would appear above if it weren't for the mirror. The mirror simply reflects the rays so that the focus can occur on the screen on a wall rather than on the ceiling above the projector. In some projectors, the upper converging lens is placed vertically and to the right of the slanted mirror.

From the above photo estimate

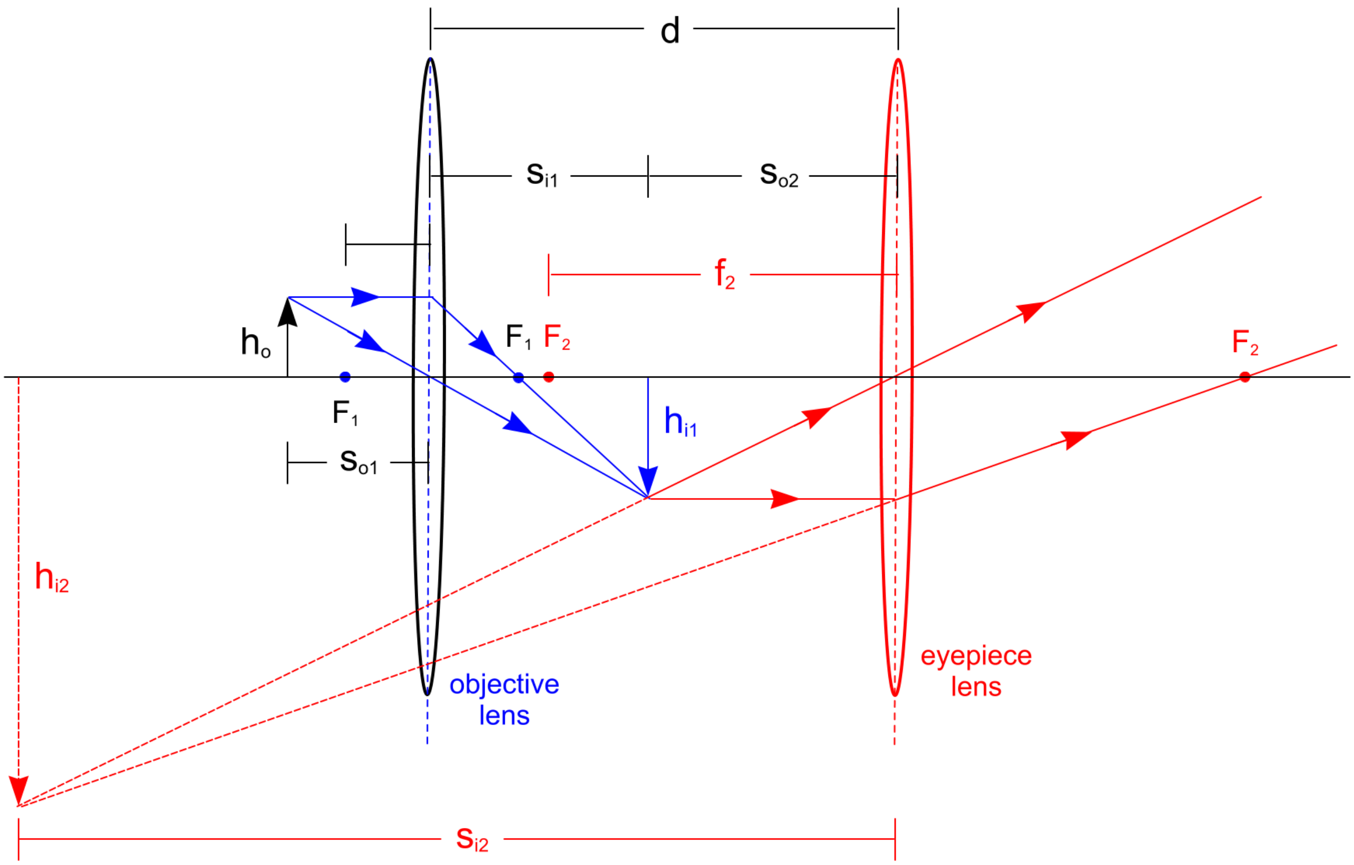
a) the focal length of the Fresnel lens,
b) the focal length of the upper lens.

If the teacher pulls the overhead farther away from the screen, to keep the focus, she must turn the black adjustor to change the distance between the upper lens and Fresnel lens. Which way?

J9. Microscope. The magnifying glass is also called the ***simple microscope***. Two converging lenses can be used to provide greater magnification with a two-step process. Such an instrument is called the ***compound microscope***, which is what we typically mean by the word microscope. The first lens, the ***objective*** collects the light and forms a magnified real image. Where should the object be relative to the focal point of the objective? Then the observer inspects this magnified image with another converging lens, the ***ocular*** or **eyepiece**. The ocular, so named because it is the lens nearest the eye, serves as a magnifying glass.



Below is a detailed drawing. **Important:** Why must $f_1 < s_{o1} < 2f_1$ and $s_{o2} < f_2$?



Microscope. Inspired by Maier A, Steidl S, Christlein V, et al., editors.
Medical Imaging Systems, Cham (CH): Springer; **2018.** Creative Commons License

Time for engineering design.

First off, what is our design constraint on overall instrument size? Well, it has to sit on a lab bench for use. The eyepiece is at the top and objective below but above the glass plates that hold the specimen. Below the plates is a light source to direct light upward towards the specimen. From eyepiece to objective looks like 15 cm = 6 inches. So we start by taking d = 15 cm = 150 mm.

Microscope in Biology Lab. Wikipedia: Acagastya. Creative Commons License

We want $f_1 < s_{o1}$, but $s_{o1} \approx f_1$, like the slide projector!

Let's take $s_{o1} = 1.04 f_1 = \dfrac{104}{100} f_1$, i.e., very close to the focal point F_1 on its left side.

Then, $\dfrac{1}{f_1} = \dfrac{1}{s_{o1}} + \dfrac{1}{s_{i1}}$ => $\dfrac{1}{f_1} = \dfrac{100}{104 f_1} + \dfrac{1}{s_{i1}}$ => $\dfrac{1}{f_1}\left[1 - \dfrac{100}{104}\right] = \dfrac{1}{s_{i1}}$

$\dfrac{1}{f_1}\left[\dfrac{104-100}{104}\right] = \dfrac{1}{s_{i1}}$ => $\dfrac{1}{f_1}\left[\dfrac{4}{104}\right] = \dfrac{1}{s_{i1}}$ => $s_{i1} = \dfrac{104}{4} f_1 = 26 f_1$.

$$s_{i1} = 26 f_1 .$$

We need to pick f_1 to be small so $s_{i1} = 26 f_1 < d = 150 \text{ mm}$.

Choosing $f_1 = 5 \text{ mm}$ leads to $s_{i1} = 26 f_1 = 26 \cdot 5 \text{ mm} = 130 \text{ mm}$, definitely acceptable since our choice for the separation between the two lenses is $d = 150 \text{ mm}$.

Summary: $f_1 = 5 \text{ mm}$, $s_{o1} = 1.04 f_1 = 5.2 \text{ mm}$, $s_{i1} = 26 f_1 = 130 \text{ mm}$

What is our magnification so far?

$$M_1 = -\frac{s_{i1}}{s_{o1}} = -\frac{130}{5.2} = -25$$

Remember that we are looking at very small specimens and we want much magnification.

With $d = 150 \text{ mm}$, $s_{o2} = d - s_{i1} = 150 - 130 = 20 \text{ mm}$.

For the eyepiece to act as a magnifying lens we need $s_{o2} < f_2$.

Take $f_2 = 22 \text{ mm}$. Then, with $s_{o2} = 20 \text{ mm}$,

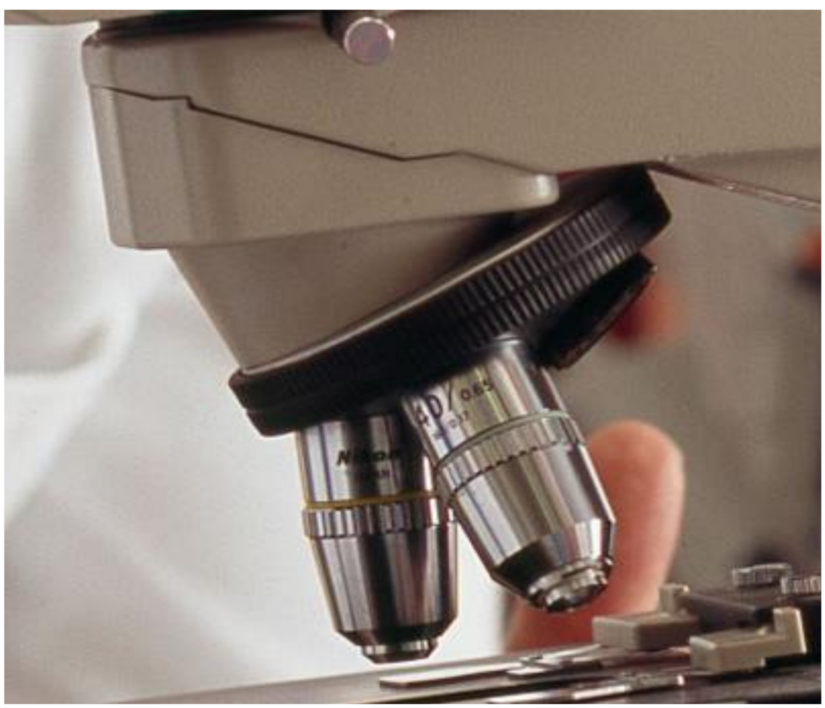
$$\frac{1}{f_2} = \frac{1}{s_{o2}} + \frac{1}{s_{i2}} \quad \Rightarrow \quad \frac{1}{22} = \frac{1}{20} + \frac{1}{s_{i2}} \quad \Rightarrow \quad s_{i2} = -220 \text{ mm}.$$

$$M_2 = -\frac{s_{i2}}{s_{o2}} = -\frac{(-220)}{20} = +11$$

$$M_1 M_2 = (-25)(11) = -275$$

A serious overall magnification!

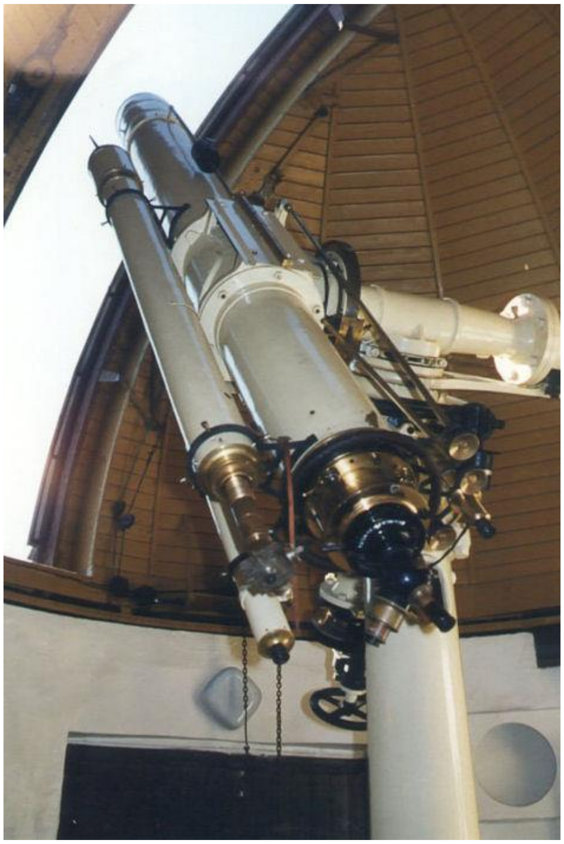
See the microscope on the next page, where the observer can switch objectives.



Courtesy Wikipedia: Rhoda Baer and the National Cancer Institute, NIH

J10. Telescopes.

a) The Refractor or Keplerian Telescope



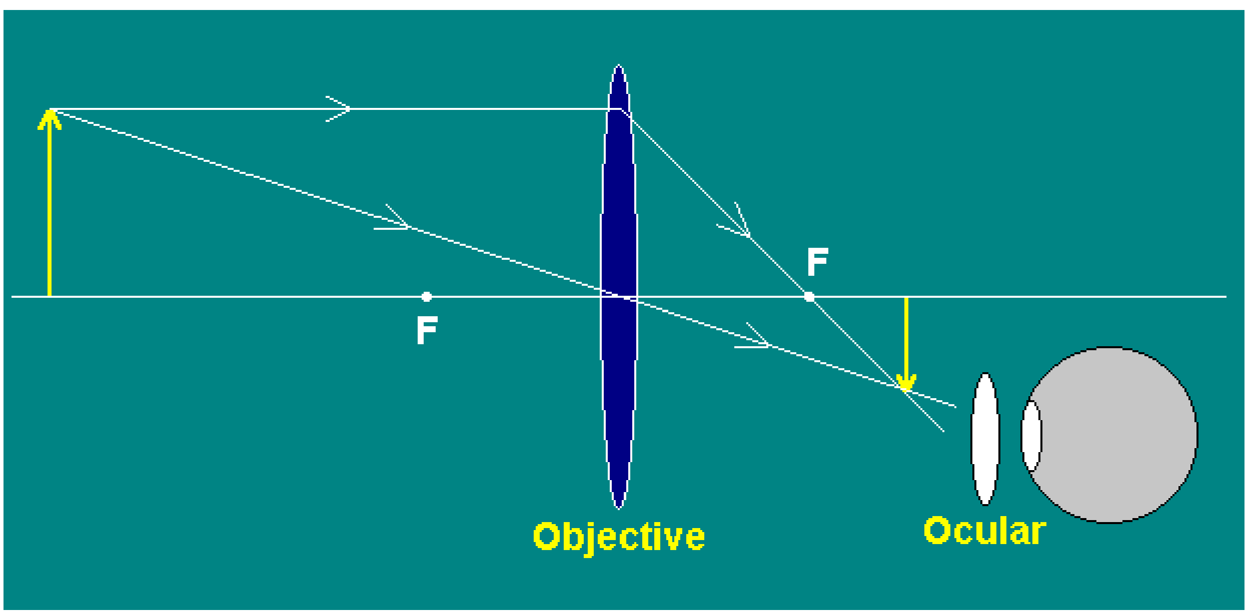
Polski: Zabytkowy refraktor Zeissa 200/3000 mm.
Wikipedia: Bori64.
Creative Commons License

One type of popular telescope is the ***refractor***, where two lenses are employed. The common refractor uses two converging lenses, much like the microscope. However, the objects for telescope viewing are very far from the lens. Therefore, the real images formed by the first lens, the ***objective***, are very small and essentially on the focal plane.

The best we can do is view this small real image with a magnifying glass, referred to again as the ***ocular*** or ***eyepiece***. Surprisingly, inspecting the small real image in this way can result in overall magnification if the focal lengths are chosen properly.

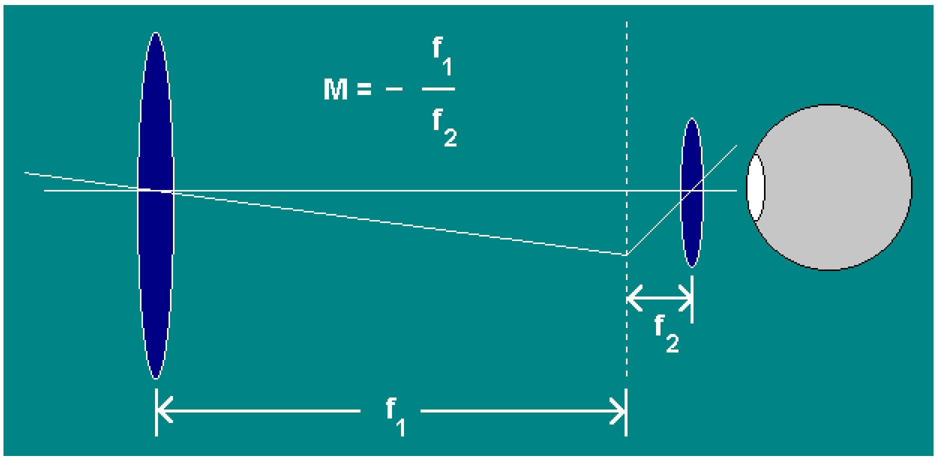
The basic idea is illustrated below with a fairly close object in order to easily make a ray diagram.

Basic Idea of Telescope: Small Intermediate Real Image



The objective must have a longer focal length than the eyepiece and the lenses must be positioned so that their focal planes coincide (as illustrated below). Look at the gentle slant of the incoming light through the objective. Compare the corresponding slant at the ocular. The angle is steeper, implying magnification. The magnification is given by the telescope formula included in the figure. The final image is inverted as the observer needs to look down at this ray from the top of the object. The observer sees the top of the object coming from a point very much below the object itself.

Telescope Formula



Angular Magnification: $M = -\frac{f_2}{f_1}$

The upside-down image is the reason for the minus sign in the formula. The first lens produces an inverted image, while the second lens, acting as a magnifying glass, does not invert the intermediate image. Think of the objective focusing parallel rays on the focal plane. Then, think of rays emanating from the focal plane hitting the ocular and going out parallel - a reverse effect. The eye can relax, focusing on infinity, to view the final outgoing parallel rays.

Magnification (Magnifying Power). The focal length of the objective for a given refractor telescope is 700 mm. An eyepiece typically used with such a telescope is one with a focal length of 20 mm. The magnification is therefore -700/20 = -35. But the convention with manufacture is to report the positive 35 with "x" after it. Therefore, the magnification is 35x in the ads.

Johannes Kepler (1571-1639)

The refractor is named after Kepler. The first telescope was invented in the Netherlands in the early 1600s. The refractor is also known as the Keplerian telescope.

b) The Galilean Telescope

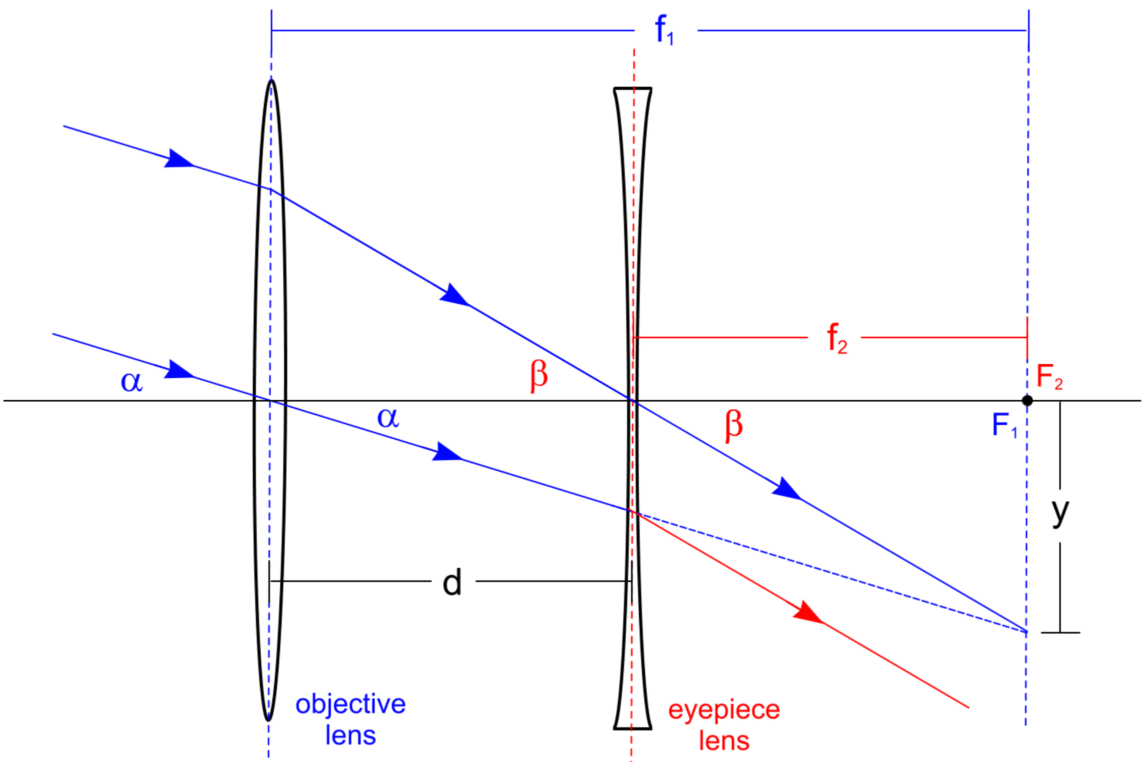
Galileo Galilei (1564 – 1642)

The story goes that when Galileo was told they invented the telescope in the Netherlands, Galileo promptly invented his own. He used a converging lens and a diverging lens. Note that the focal points coincide in the figure below.

So maybe we should tell a super inventor that they invented something crazy like walking through a wall, and then the super inventor will promptly say, oh, I see how they must have done that.

For Galileo's telescope below, note that

$$\tan\alpha = \frac{y}{f_1} \quad \text{and} \quad \tan\beta = \frac{y}{f_2}\,.$$



For the paraxial ray approximation: $\dfrac{\beta}{\alpha} = \dfrac{\tan\beta}{\tan\alpha} = \dfrac{f_1}{f_2}$.

For the Keplerian telescope we wrote $M = -\dfrac{f_2}{f_1}$. Should we include the minus sign for the Galilean telescope? If we do, since the second lens is diverging, it will have a negative focal length. The result will be a final image not inverted. And that is correct. The observer looks upward to see the rays leaving the diverging lens eyepiece. Refer back to the Keplerian diagram and you will see the opposite, i.e., the observer looking down to see the top of the moon. Therefore, we write for both telescopes

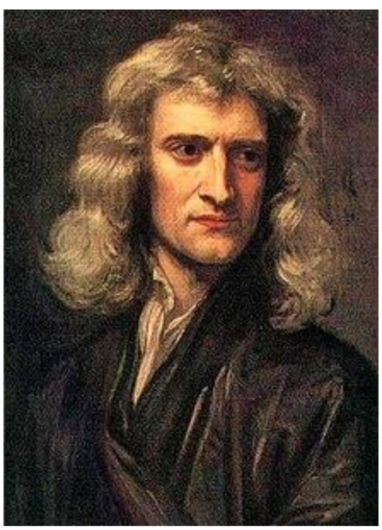
$$M = -\frac{f_2}{f_1} = -\frac{f_{objective}}{f_{eyepiece}} = -\frac{f_o}{f_e},$$

and in both cases we want $f_{objective} > |f_{eyepiece}|$ and $d = f_{objective} + f_{eyepiece}$.

For the Keplerian telescope $d > f_{objective}$ and for the Galilean $d < f_{objective}$.

The Galilean telescope is a terrestrial telescope, meaning that the images are not inverted and the telescope can be used on land to view distance mountains and apartments.

c) The Newtonian Telescope or Reflector

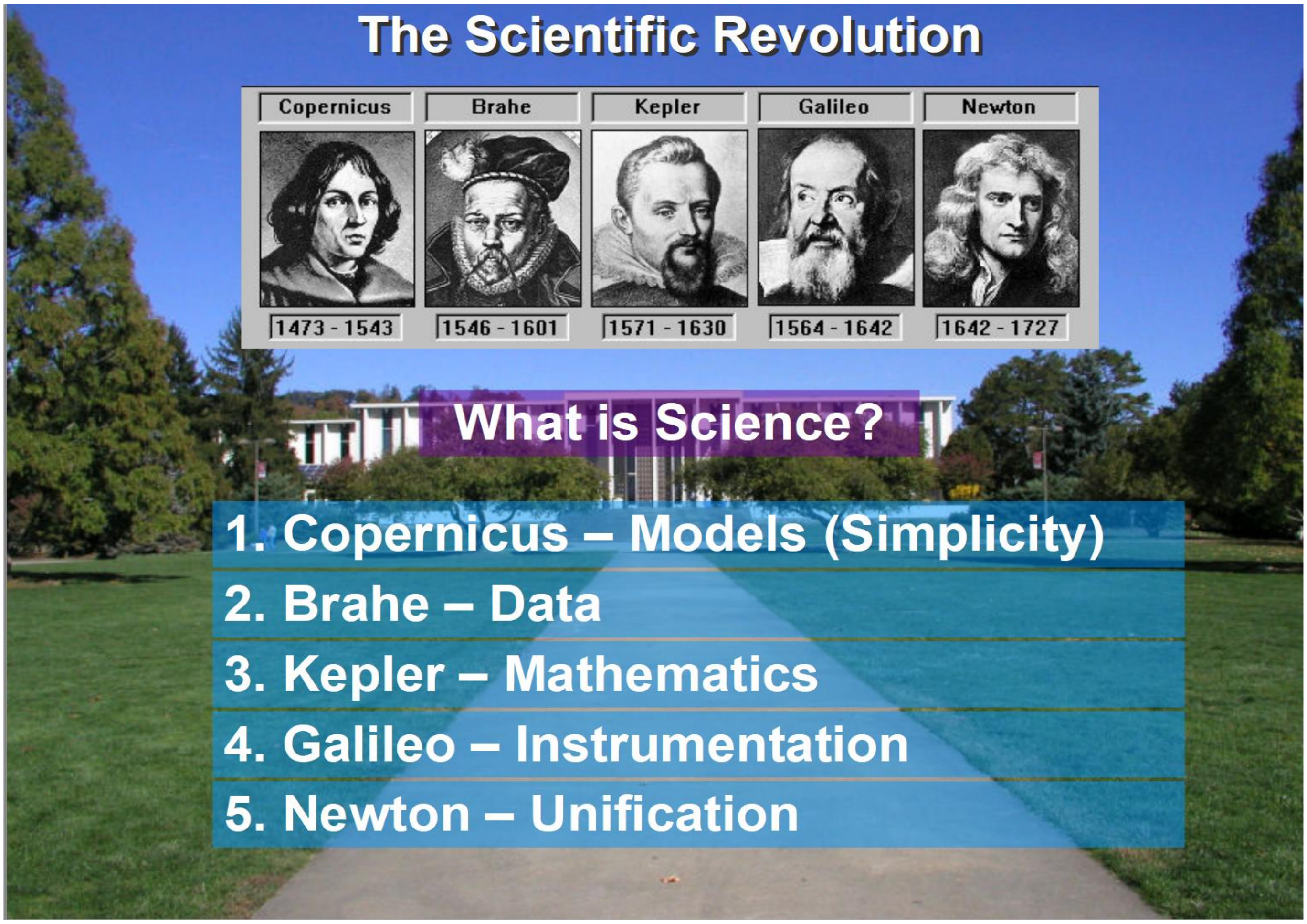


Isaac Newton (1642 - 1726)

Are you amazed to see the high-powered physicist-astronomers in this section as inventors? They were. The big three: Kepler, Galileo, and Newton. These three are known for discovering laws of physics and astrophysics. They are also among the big 5 of the Scientific Revolution in Europe in the 1500s and 1600s.

The five are Copernicus, Brahe, Kepler, Galileo, and Newton. These five great scientists teach me directly the meaning of science. You know how you learn in grade school about hypothesis and control variables. While that is part of science, it is a very small part.

See the next page for what these five architects of a scientific revolution teach us about science before we proceed to the Newtonian telescope. The image for the figure below has our UNCA Ramsey Library as the backdrop.



Now is a time to pause and reflect on your physics genealogy.
You can trace your education back to Galileo since you are studying with me.

http://www.mjtruiz.com/courses/physics_genealogy.pdf

Start with Galileo at the top and work your way down to Newton.

Continue down to Lord Rayleigh (John William Strutt).

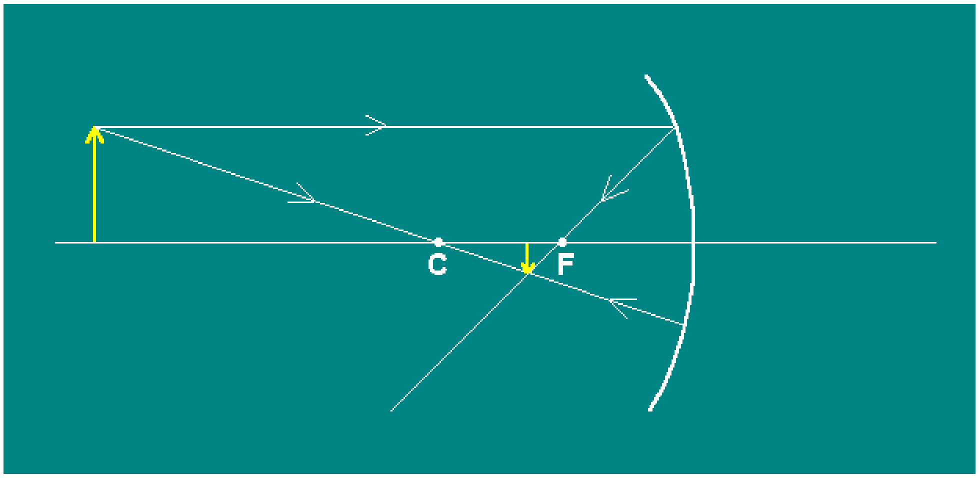
Then head over from England to the United States and find Karl Taylor Compton at MIT.
He was also President of MIT and is the older brother of the very famous Arthur Compton.
His brother Arthur Compton won the Nobel Prize for discovering the "Compton Effect."

Then continue to Sam Treiman, elementary particle physicist, at Princeton.
His student was my research advisor Y. S. Kim, theoretical particle physicist.

Then me and finally you, in the line of passing on physics from generation to generation.

In place of the converging objective lens, a concave mirror can serve as the collector of light, producing an inverted real image. Such a telescope is called a ***reflector***.

Concave Mirror Replacing Objective Lens



But now there is a problem if you try to put your head in the way with a magnifying glass to inspect the real image. Newton invented a telescope with a concave mirror. He solved the problem described above by using a small plane mirror to deflect the light to the side. The little flat mirror does block some light heading toward the concave mirror, but not much.

Since this light is blocked before the image is formed, you don't even see the plane mirror. It is similar to putting small piece of tape on a camera lens. The photo still comes out. Another example is this: break a lens or concave mirror in half and you still get an image - just one with less brightness.

The eyepiece is attached to the side of the telescope tube. This design is illustrated with your instructor's $10 reflector telescope, purchased in 1964. With the 2.5-inch mirror in this telescope, an observer can see craters on the Moon, the moons of Jupiter, the rings of Saturn, and phases of Venus.

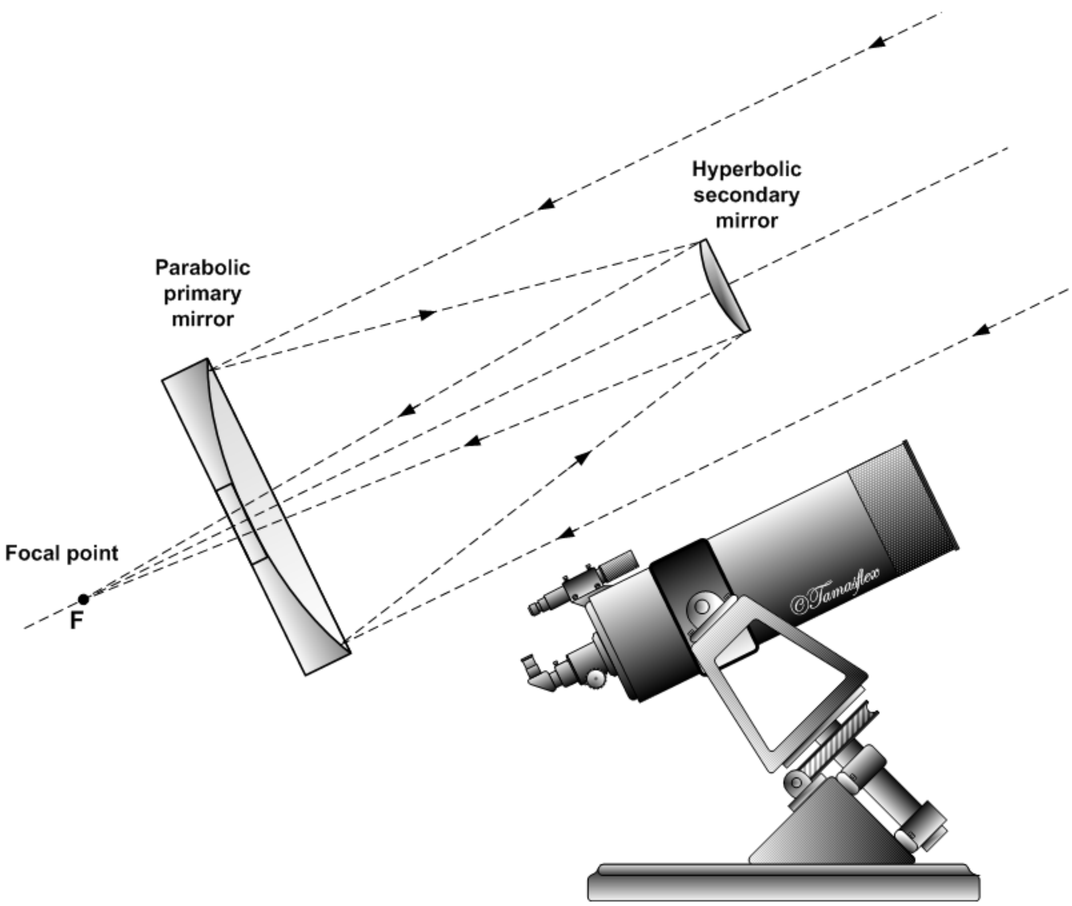
The power is roughly 40x, comparable to the telescope Galileo designed in 1610, using a converging lens (objective) and a diverging lens for the eyepiece. The observer is one of your instructor's daughters (Christa), at about the age when her dad obtained the telescope.

The same magnification formula applies where now the focal length of the objective is the focal length of the concave mirror.

$$M = -\frac{f_2}{f_1} = -\frac{f_{objective}}{f_{eyepiece}} = -\frac{f_o}{f_e}$$

d) The Cassegrain Reflector

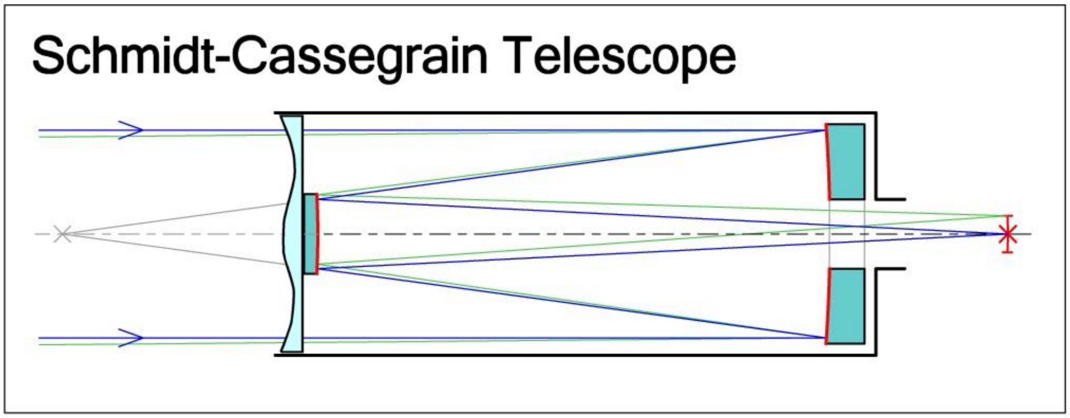
The variation on the Newtonian reflector below uses a little convex mirror to reflect the light through a hole in the large concave mirror. The advantage of the convex mirror trick is that the telescope can be smaller. Such a design is called ***Cassegrain*** or Cassegrainian. For better optics looking at far objects if you want the expensive version, the primary mirror is parabolic and the secondary mirror hyperbolic. These shapes are derived from conic sections: circle, ellipse, parabola, hyperbola.



Cassegrain Telescope. Wikipedia: Szőcs Tamás Tamasflex. Creative Commons License

The Cassegrain telescope dates back to 1972 and Laurent Cassegrain (c. 1629 – 1693), inventor and Catholic priest. He was also a teacher and taught science.

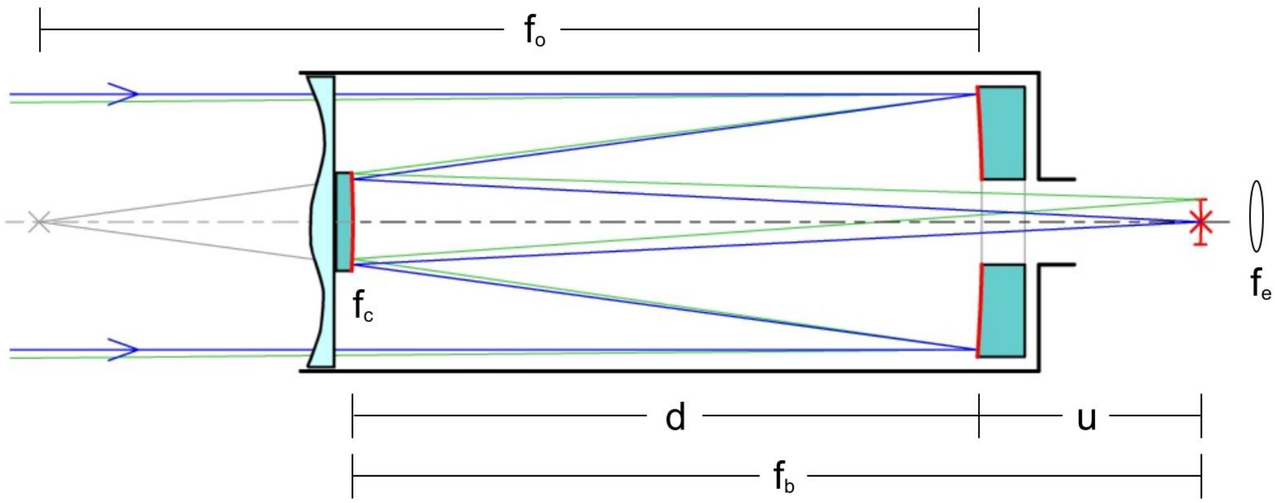
Remember that it is cheaper to make spherical mirrors and lenses than aspherical optical elements. But for a telescope, the spherical shape is not the idea (we would rather have a parabola). So a corrector plate (Schmidt corrector) is used to minimize aberrations of the spherical mirror for incoming parallel light. The result is a sharper image. This variation of the reflecting telescope is called a ***Schmidt-Cassegrain***, the type we most frequently use at UNCA.



Schmidt-Cassegrain Telescope. Wikipedia: Jim Spinner. Creative Commons License

One of UNCA's Cassegrain telescopes is pictured here. Note the clear plate on the front. As mentioned above, this plate is designed in conjunction with the curvature of the two curved mirrors in order to produce a sharp image. The student is alumnus Patrick Ragsdale, a physics graduate.

Photo by Doc



Schmidt-Cassegrain Telescope adapted from Wikipedia: Jim Spinner.

$$\frac{1}{f_o} = \frac{1}{s_{o1}} + \frac{1}{s_{i1}} \qquad \frac{1}{f_c} = \frac{1}{s_{o2}} + \frac{1}{s_{i2}} \qquad s_{o2} = d - s_{i1}$$

For the back focal length, we take $s_{o1} \to \infty$, Then $s_{i1} = f_1$ and $s_{o2} = d - s_{i1} = d - f_1$.

Substituting this $s_{o2} = d - f_1$ into $\frac{1}{f_c} = \frac{1}{s_{o2}} + \frac{1}{s_{i2}}$ gives

$\frac{1}{f_c} = \frac{1}{d - f_o} + \frac{1}{s_{i2}}$ with s_{i2} now being the back focal length $s_{i2} = f_b$.

We want to solve $\frac{1}{f_c} = \frac{1}{d - f_o} + \frac{1}{f_b}$ for f_b.

$$\frac{1}{f_c} = \frac{1}{d - f_o} + \frac{1}{f_b} \quad => \quad \frac{1}{f_c} - \frac{1}{d - f_o} = \frac{1}{f_b} \quad => \quad \frac{1}{f_b} = \frac{1}{f_c} - \frac{1}{d - f_o}$$

$$\frac{1}{f_b} = \frac{(d - f_o) - f_c}{f_c(d - f_o)} \quad => \quad f_b = \frac{f_c(d - f_o)}{(d - f_o) - f_c} \quad => \quad f_b = \frac{f_c(f_o - d)}{f_o + f_c - d}$$

But $f_b = d + u$ from the design figure. Therefore,

$$d + u = \frac{f_c(f_o - d)}{f_o + f_c - d},$$

a nice formula relating design parameters.

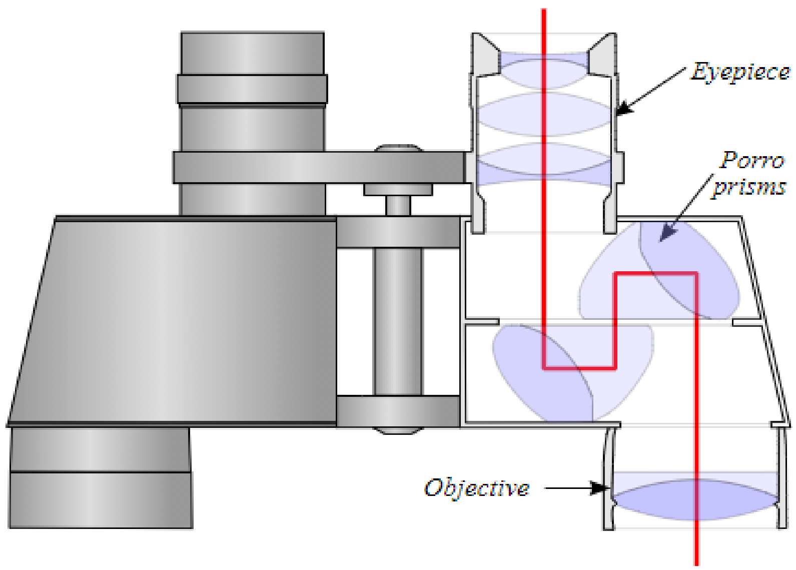
Light-Gathering Power. Collecting light is the most important factor in a telescope. Magnification means nothing if the image is so dark that you can't see it. Light-gathering power implies large objectives, whether they be lenses or mirrors, in order to collect light in the first place. The amount of light a telescope can gather depends on the area of the objective. Think of an analogy with floor space. If you have a square that is 1 meter by 1 meter, you have 1 square meter of area. Now if you double your lengths, you have a new square that is 2 meters by 2 meters. The area is now 2 x 2 = 4 square meters. The area is four times greater. You need 4 times the amount of rug to cover this area.

Telescope objectives are circular rather than square. But the same reasoning with proportions applies. If you double the diameter of the lens or mirror, you quadruple the light-gathering power. As an example, let's compare the telescope Doc Ruiz obtained when he was a boy to the Cassegrain telescope made by Celestron, both pictured here.

Doc's reflector telescope has a mirror with a 2.5-inch diameter, while the Celestron has a mirror with an 8-inch diameter. For our estimation, let's use 2 inches instead of 2.5 inches for the smaller mirror diameter. We find the ratio first: 8/2 = 4. The Celestron has a diameter that is four times the diameter of a small telescope with a 2-inch mirror.

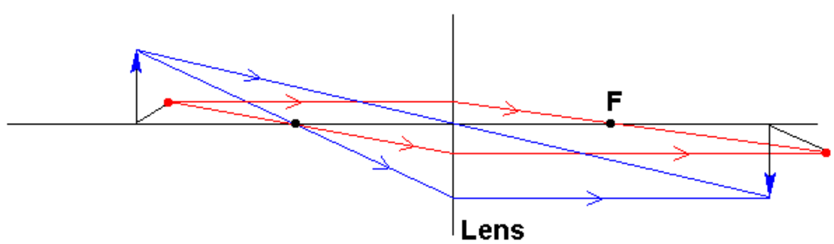
Therefore, the Celestron has 4 x 4 = 16 times the light gathering power when compared to the smaller telescope. With the actual 2.5 value for the smaller telescope, the ratio is closer to 10.

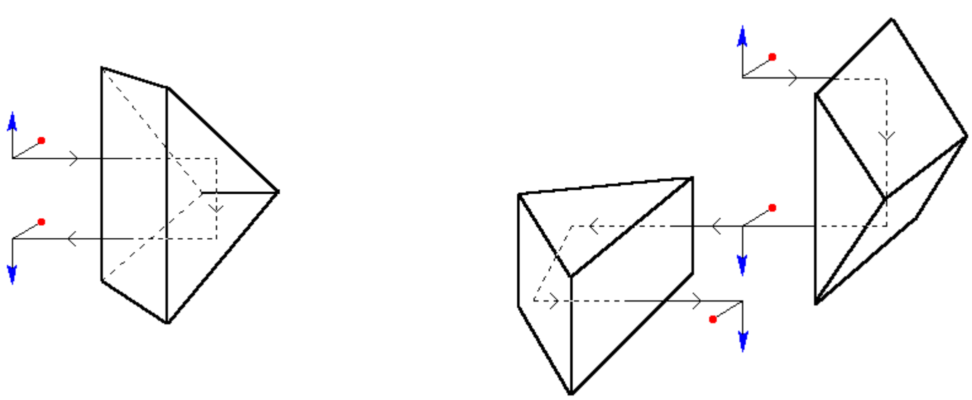
J11. Binoculars. Don't Underestimate Binoculars. Remember our discussion of binoculars? They were a telephoto lens system with prisms to reorient the images so they were not upside down and left-to-right flipped. Telescopes blow things up so much that you cannot enjoy the larger angle of view that comes with less power. The standard 7 x 50 binoculars are great. The 7 means 7x magnification, compared to what you see with the naked eye. The 50 stands for 50 mm, the diameter of the objective. Think of the binoculars as two Keplerian telescopes.

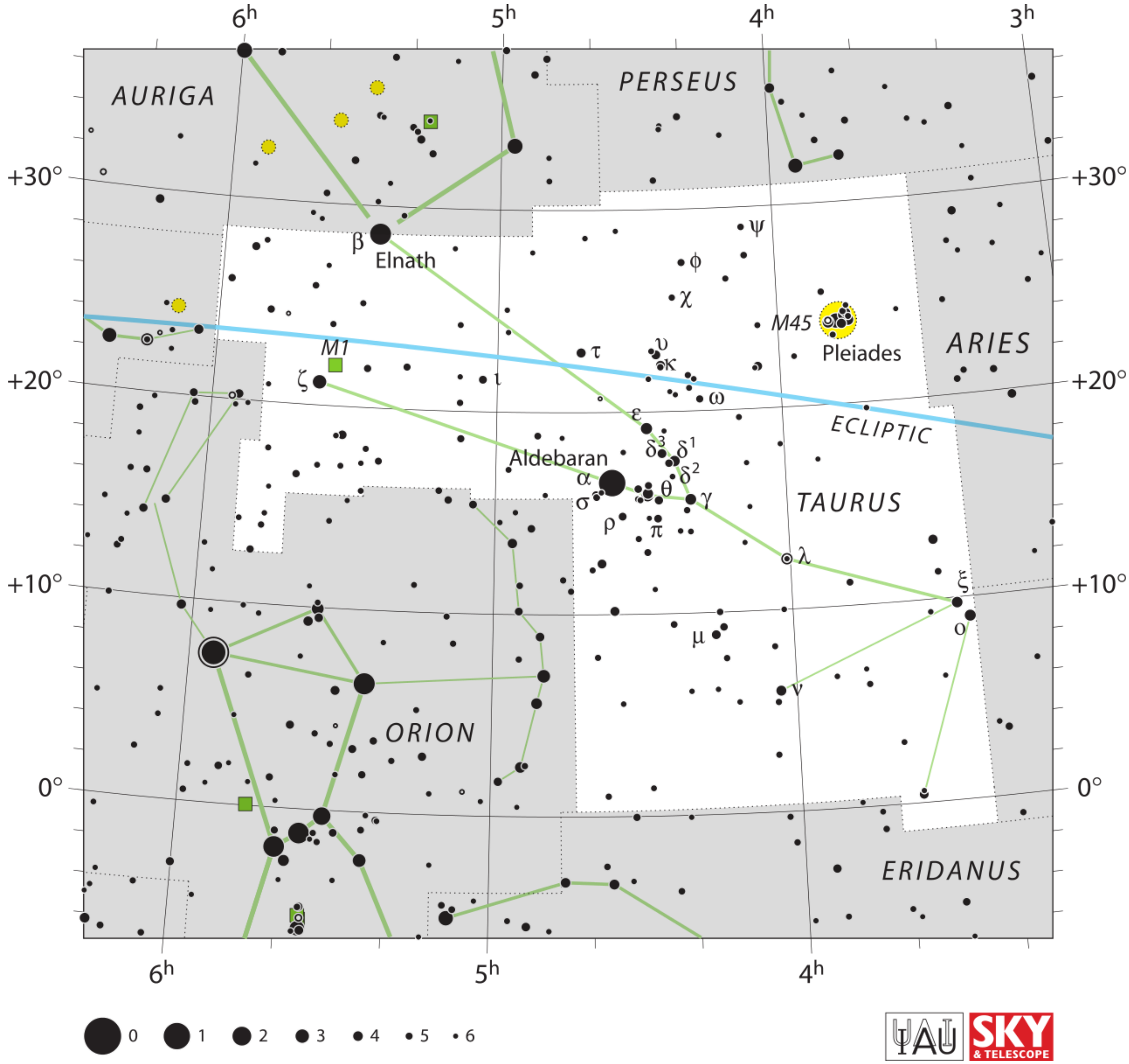


Binoculars. Wikipedia: Antilived. Creative Commons License

But the porro prisms are needed to flip the image. You need one to flip North and South and another to flip East and West. Note that the prism pair is inserted between the two lenses.

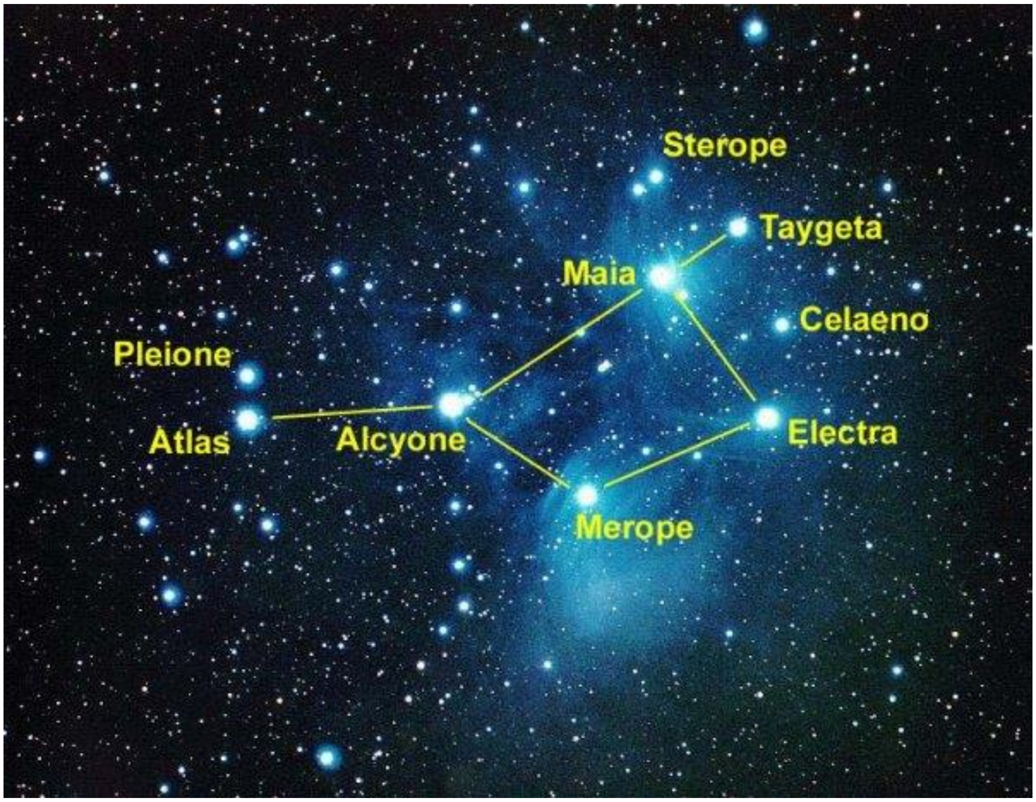




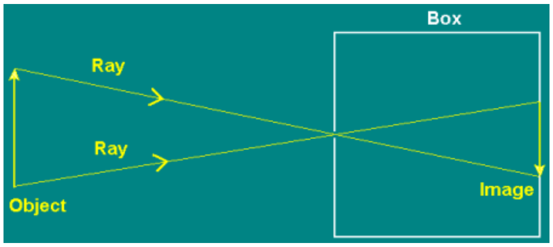


The Pleiades appear very nice in binoculars. On the next page is a nice photo by Jason Wares of the Pleiades. The stars are named after dad Atlas and mom Pleione with their daughters, also known as the seven sisters. With good naked-eye vision one can see Atlas, Alcyone, Maia, Tayegeta, Merope, and Electra. In fact, seeing these 6 stars is a good test for visual acuity. Sailors could tell the weather might get bad if they could not see all 6 stars due to faint clouds moving in.

Courtesy Jason Wares



J12. Eclipses. We started this chapter with the pinhole camera, i.e., camera obscura. Here are images of the sun during a partial solar eclipse in Asheville, NC.



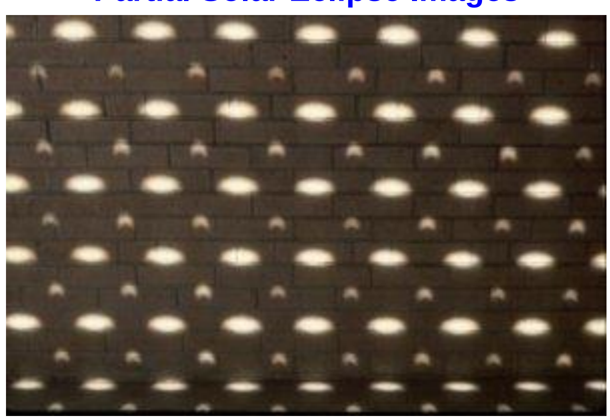
As we

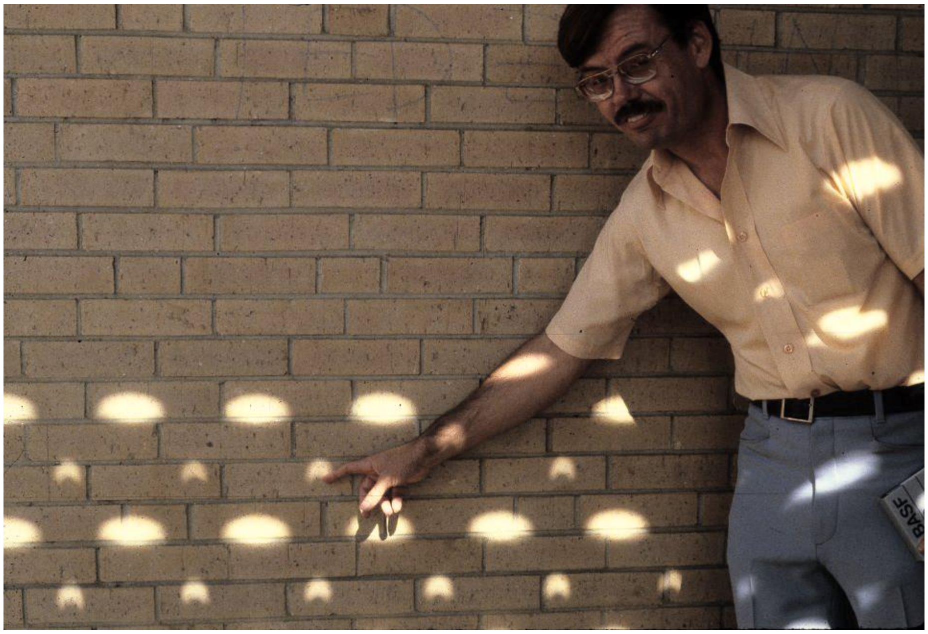
Mentioned in an earlier chapter, four individuals played important roles in the discovery and analysis of the camera obscura. The first was the Chinese philosopher Mozi or Motzu c. 400 BCE), who observed the effect in a room and referred to it as a "locked treasure room." Not long afterward (c. 350), the Greek philosopher Aristotle observed a solar eclipse as sunlight passed through openings in foliage, showing multiple small-hole effects. See an example of partially-eclipsed sun images on the ground near Rhoades Hall during a 1970 partial eclipse. Can you see that the moon has taken a "bite" out of the sun? During the marvelous eclipse day of 1979, Prof. Comer, then Chair of Biology at UNCA, was excited when he saw little eclipse images on the ground due to small openings in leaves. How many images of the Moon taking a cookie-bite out of the Sun can you see on the ground below?

A safe way to view a solar eclipse is to let the light pass through a pinhole in an index card onto the ground. You then look at the ground and see the image of the eclipse. The February 26, 1979 total solar eclipse was a partial solar eclipse from Asheville, NC. Atmospheric Sciences students, in the then new UNCA Atmospheric Sciences Program, were gathered by the entrance to Rhoades Hall closest to the Administration Building. They yelled to your instructor to come over and see eclipse images on the bricks. Below you see these nice images through the small holes in the architecture at that entrance. The holes are not pinholes. But since everything is scaled up, the holes are effectively small enough. Notice that the larger holes do not work. There are alternating rows of fuzzy light ovals and eclipse images with the Moon "taking a cookie bite out of the Sun." If you get a chance, inspect this wall on campus at close range.

Holes in Architecture

Partial Solar Eclipse Images





Ed Brotak (Dr. Ed) Pointing to One of the Eclipse Images (1979)

The Department of Physics gave birth to our Atmospheric Sciences Department.

Closer View of the Wall: Larger and Smaller Openings

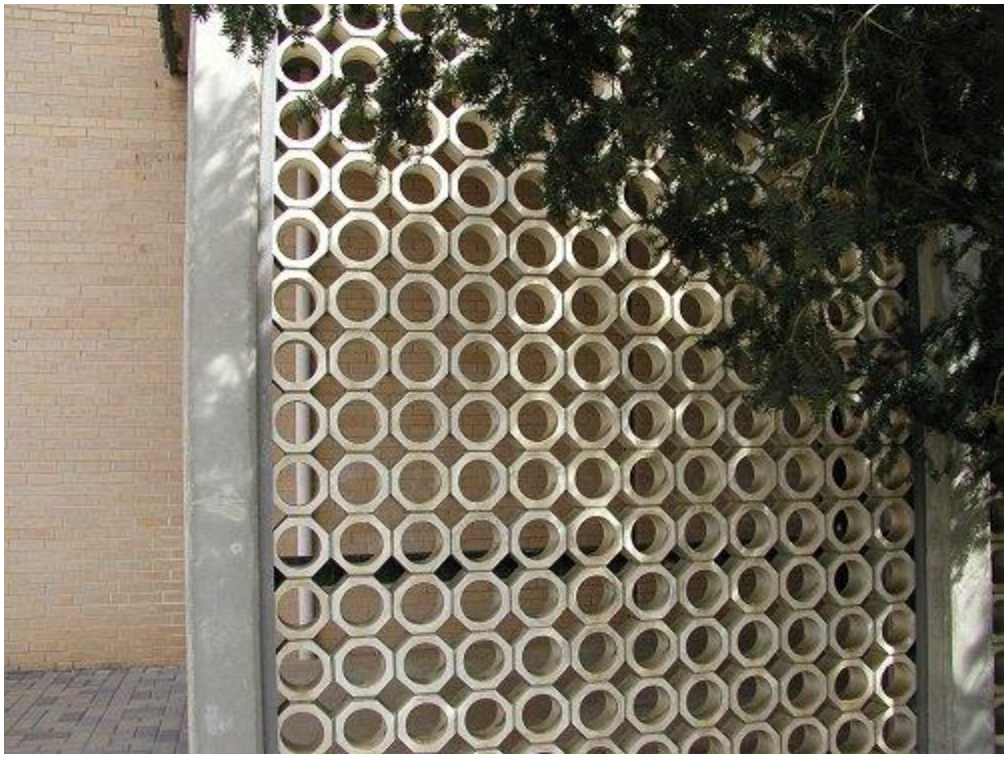
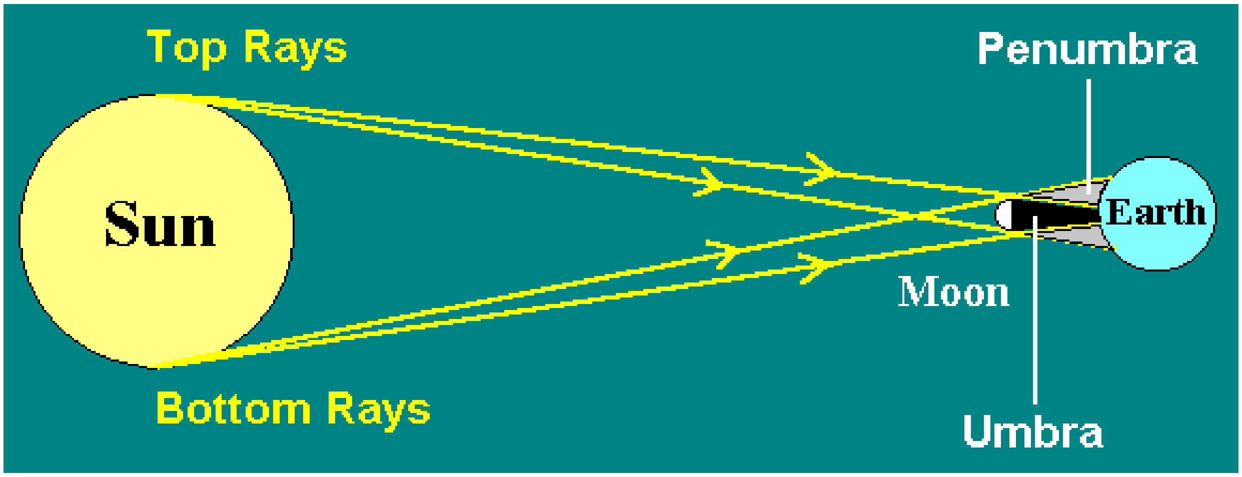
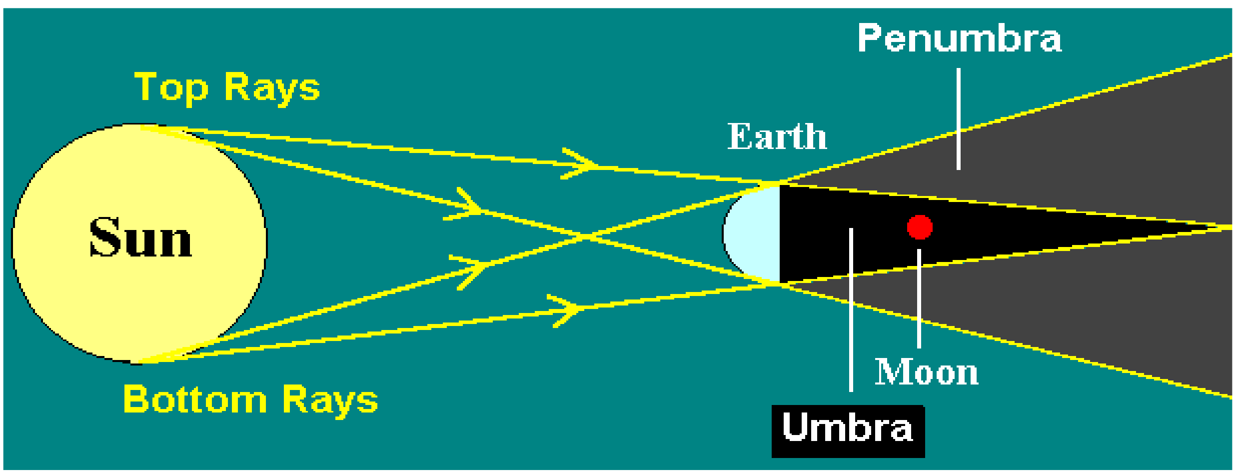


Photo of Left Side of Rhoades Wall by Doc, Tuesday Noon, February 19, 2002

Solar Eclipse (Not Drawn to Scale)



Lunar Eclipse (Not Drawn to Scale)

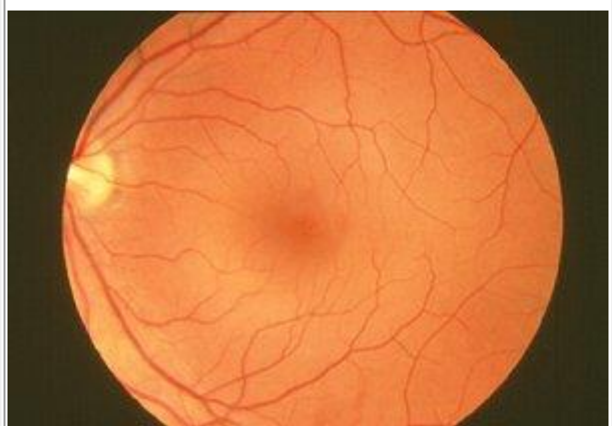


Theoretically, no light from any point on the Sun can reach into the umbra. However, some does during a lunar eclipse due to another effect. The atmosphere refracts some light into the umbra. Light going from the vacuum of space to the Earth's atmosphere "bends toward the normal" and thus into the umbra. We do not show such refraction in eclipse diagrams.

This light is rich in red since the Earth's atmosphere scatters the shorter wavelengths over the sky. This is why our sky is blue. When light passes through lots of atmosphere, much of the short-wavelength end of the spectrum is removed from the light. White minus violets, blues and some cyans leaves us with a red orange, the color characteristic of sunsets. This light makes the Moon appear reddish during totality. We take license to sketch the entire Moon red in the above diagram in order to emphasize this point. Later we will discuss why the sky is blue.

NEVER LOOK AT THE SUN. Here is why.

Now it's time for you to examine two eyes. These appear below. The one on the left is normal. The eye on the right has been damaged due to looking at the sun. The medical term ***solar retinopathy*** or ***retinitis solaris*** means inflammation of the retina due to looking at the Sun, in this case, a partial solar eclipse. Enough light can enter your eyes and cause damage even though the Sun is partially obscured during an eclipse. Look carefully at the dark region in the photo on the right and identify the damaged retina as a small light region in the midst of the surrounding darker tissue.

Normal Retina	**Retinitis Solaris**
	
Courtesy National Eye Institute, National Institutes of Health	***Courtesy Dr. Mark Clark, Anderson, SC***

The individual with retinitis solaris looked at a partial eclipse in 1979 from Anderson, SC. Afterwards, he saw darkness in his central field of view -- a "black hole" that would not go away. After the ophthalmologist told him he was in trouble, he desperately sought out his family physician, Dr. Mark Clark. Dr. Clark, who obtained the above photo for your instructor from the ophthalmologist, reaffirmed what the ophthalmologist had said - basically permanent damage in the fovea. However, to everyone's surprise, after a few months the retina cleared up to some extent and the patient was left with 20/40 uncorrectable vision. The permanent damage was not as severe as the experts had originally thought. Fortunate for the eclipse viewer. Remember, don't look at the Sun.

Many doctors consider the eye damage from looking at the Sun to be caused by a thermal burn, much like a magnifying glass burning a hole in a piece of paper. However, the guest editorial by Johannes J. Vos and Dirk van Norren, appearing in the journal ***Ophthalmic and Physiological Optics***, Vol. 21, No. 6, pp. 427-429 (2000) says this is not the way the damage occurs. They point out that studies have shown that the temperature does not get hot enough for a thermal burn. Heat is dissipated too quickly by the blood and surrounding tissue. Rather, the damage is photochemical. The eye needs time to recover when exposed to light. We all know the effects when a flash goes off and blinds our eyes for s split second. We then see a negative afterimage until the photochemical rhodopsin is replenished. Well, if time is not given for full recovery, temporary damage and permanent damage can occur.

Therefore, glancing at the Sun, looking away and then glancing again are actions that accumulative. Unless one waits long enough for full natural recovery after sudden exposure to bright light, one can suffer permanent damage. Studies have shown that chemical recovery after intense brightness can take hours and even days for complete recovery if some temporary damage occurs. Repeated exposure to light after temporary damage, can quickly result in permanent photochemical destruction of the retina. When this happens, the visual receptors cease to work ever again.

It is always best to never look at the Sun due to the uncertainty in the recovery time needed after exposure to a sudden bright light - especially if the exposure is repeated after relatively short time intervals.

> M. J. Ruiz, "Don't Look at the Sun," *Physics Education* **40**, 411 (No. 5, September 2005). **pdf**. High resolution **jpg file** (710 kB jpg) of figure 1, showing a retina damaged by viewing the Sun, courtesy Dr. Mark Clark, photo by Dr. Charles Hunter, Anderson, SC, USA.

> Michael J. Ruiz, "Video of Scenery During a Total Eclipse: Luminance and Effects of Solar Limb Darkening," *Physics Education* **54**, 035001 (May 2019). **pdf** and **Video Abstract**

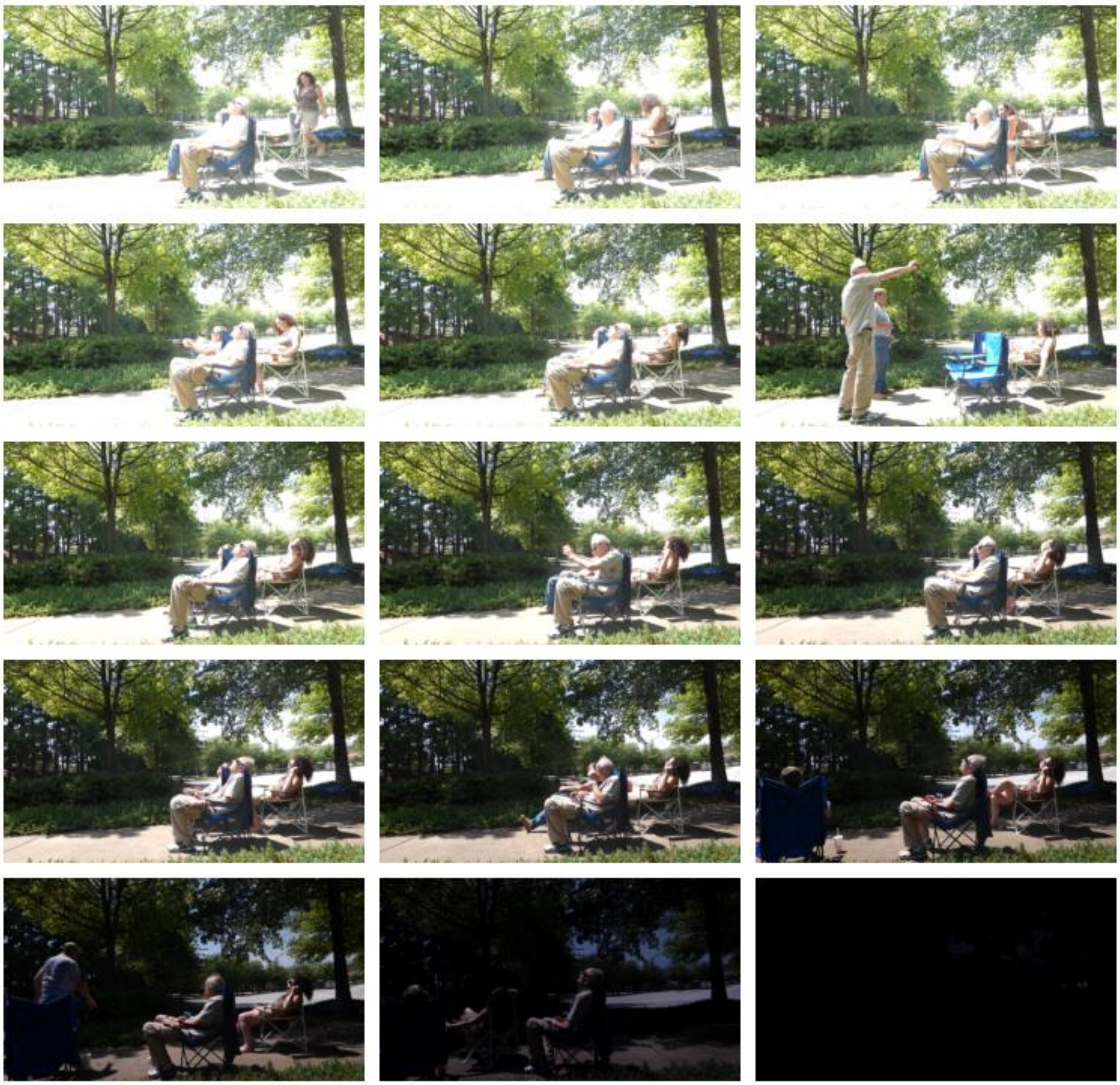
Excerpt Below.

The total solar eclipse is one of nature's most spectacular shows in the sky. Mark Twain includes a climactic scene in his novel A *Connecticut Yankee in King Arthur's Court*. In the story a 19th-century Yankee from Hartford, Connecticut suddenly finds himself in England at the time of King Arthur. Knowing about an eclipse, he escapes being burned at the stake by threatening the court.

> 'Go back and tell the King that at that hour I will smother the whole world in the dead blackness of midnight; I will blot out the sun, and he shall never shine again; the fruits of the earth shall rot for lack of light and warmth, and the peoples of the earth shall famish and die, to the last man!'

Historically, there was no actual eclipse on 21 June, 528 as stated in the novel. Three total eclipses over England in the 5th and 6th centuries occurred [2] respectively in the years 413, 458, and 594.

To capture the awe of the darkening world described by Mark Twain, I shot a video of the local scenery for the 15 minutes just before the onset of totality during the 21 August 2017 total solar eclipse. I set my digital video camera on a tripod and selected manual mode so that the camera would not automatically adjust for the decreasing available light. My pilot friend Bruce Greene flew his girl friend April and me ninety miles from our hometown in Asheville, North Carolina, USA to Greenville, South Carolina, to be in the path of totality.



A series of stills from a video of the surroundings during a total solar eclipse. The time between each still is 1 minute. The last image is at the onset of totality. The author is closest to the camera.

See the above figure for a series of 15 stills from the video spaced one minute apart, arranged from right to left and in rows. Since the video frame rate was 30 frames per second, each still has an exposure of 1/30 second. For one with no understanding of an eclipse, this series of images would be quite alarming. Temperature drops accompany the darkening surroundings and animals get confused as to the time of day. In the Mark Twain story, King Arthur readily orders the Yankee to be released and to name the terms in order to bring the sunlight back. The negotiations need to take place in minutes since the duration of totality is typically 2 or 3 minutes with the longest possible eclipsed Sun being 7.5 minutes. In the next section luminance measurements are obtained from the stills and plotted as a function of time.

Total Solar Eclipse still from my video (August 21, 2017).