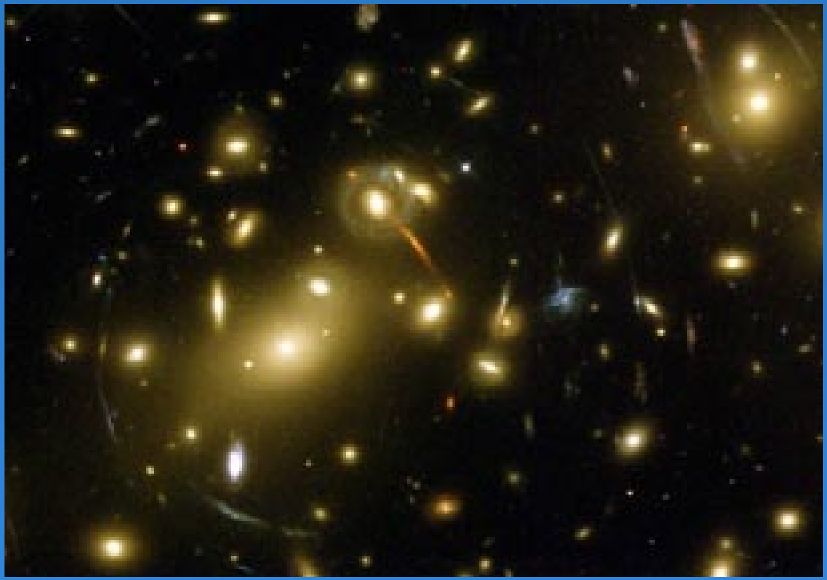


Astronomy 80 B: Light

Lecture 15: vision, instruments

20 May 2003

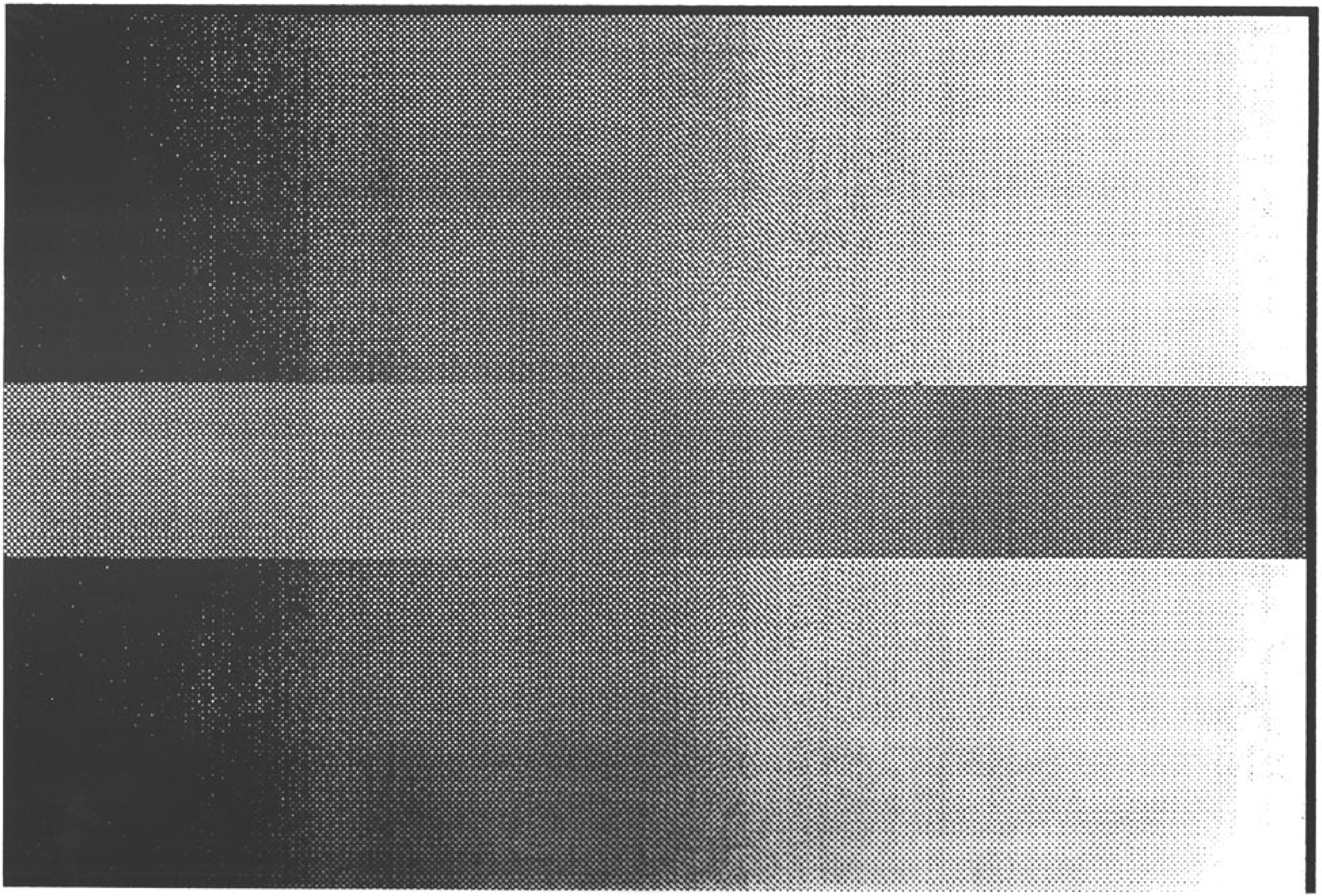
Jerry Nelson

Topics for Today

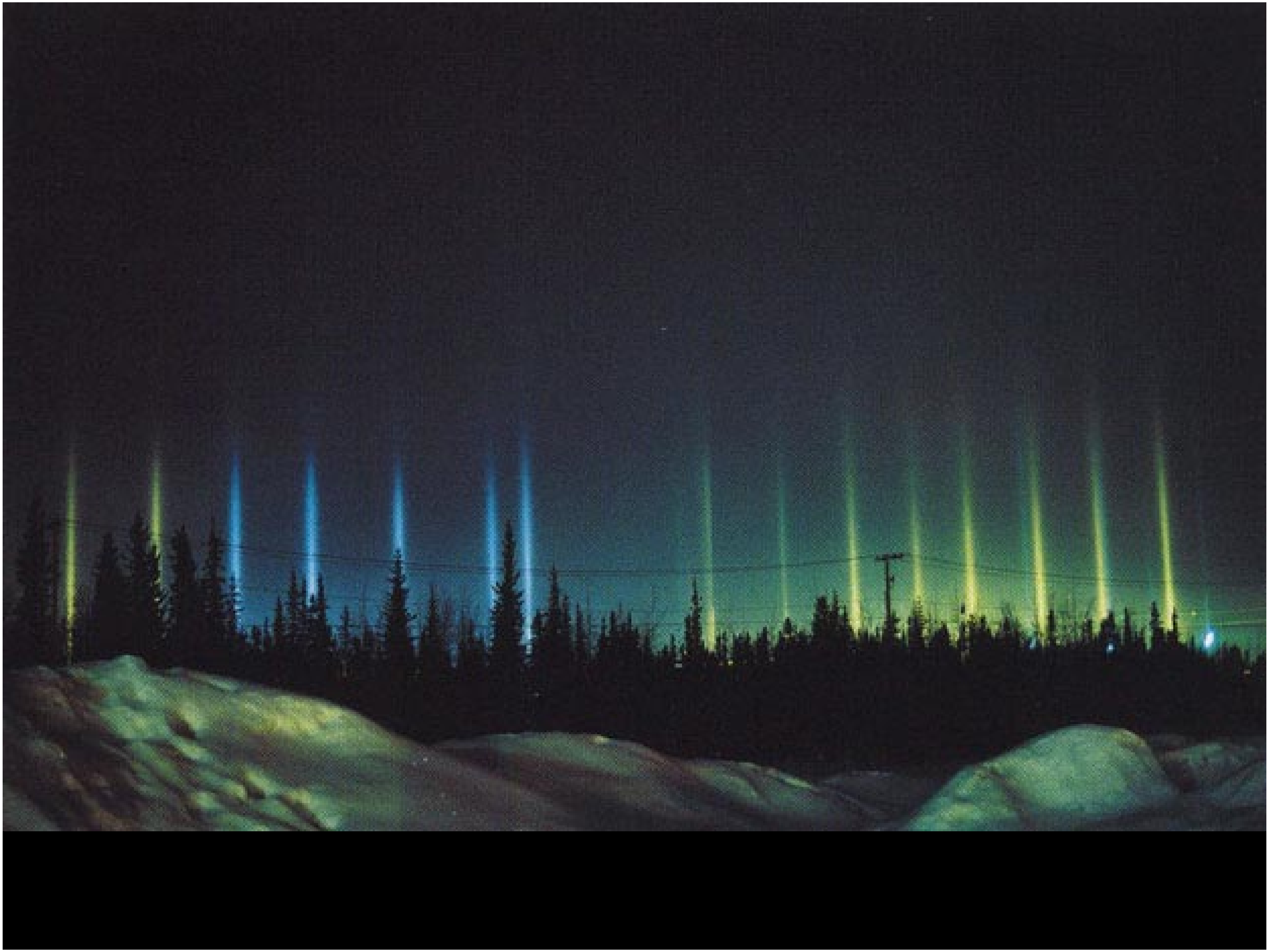
- Quiz #3 on Thursday (Ch 1-6, App A-J)
- Research paper is due on or BEFORE 5 June
- Did you see the eclipse?
- Optical illusion
- Atmospheric picture
- Principles of vision
- Optical instruments

Total eclipse of moon 2003 may 15

Why is bright edge curved?

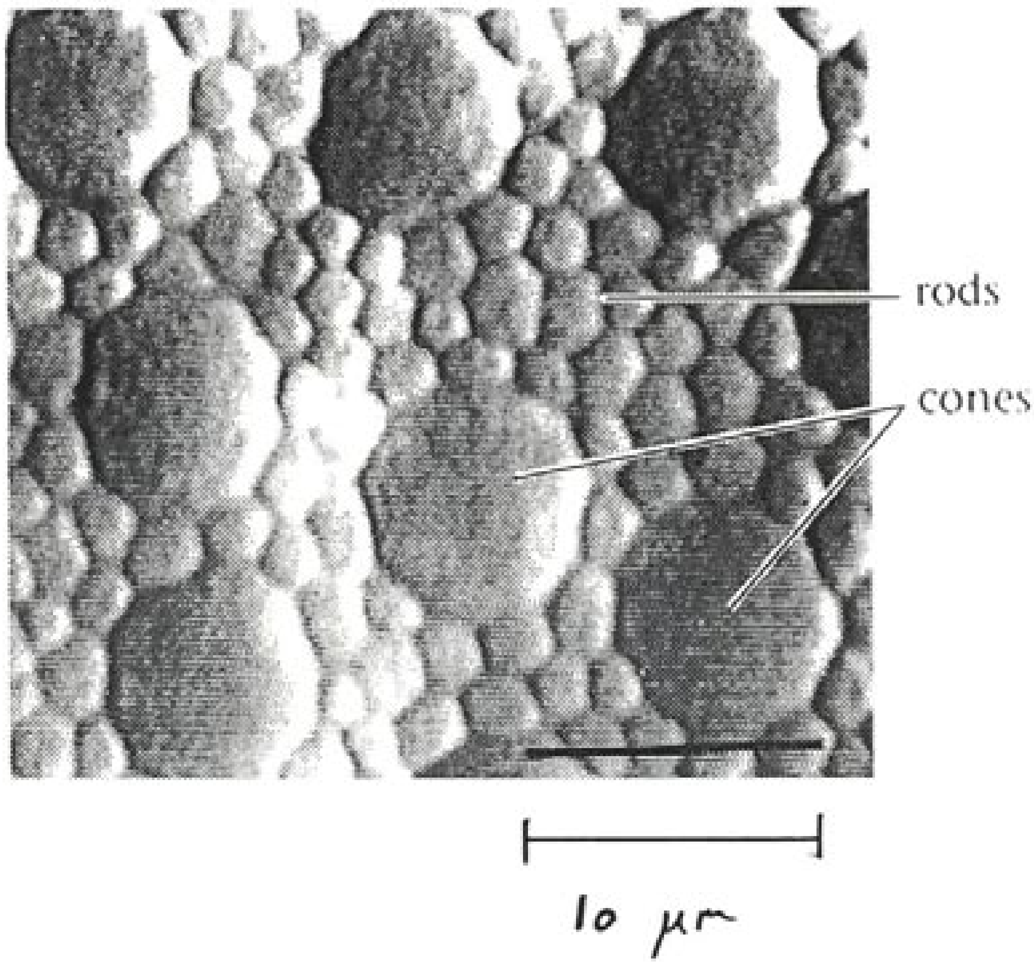


[redacted]



Mosaic in periphery

Rods and cones in the periphery of the retina

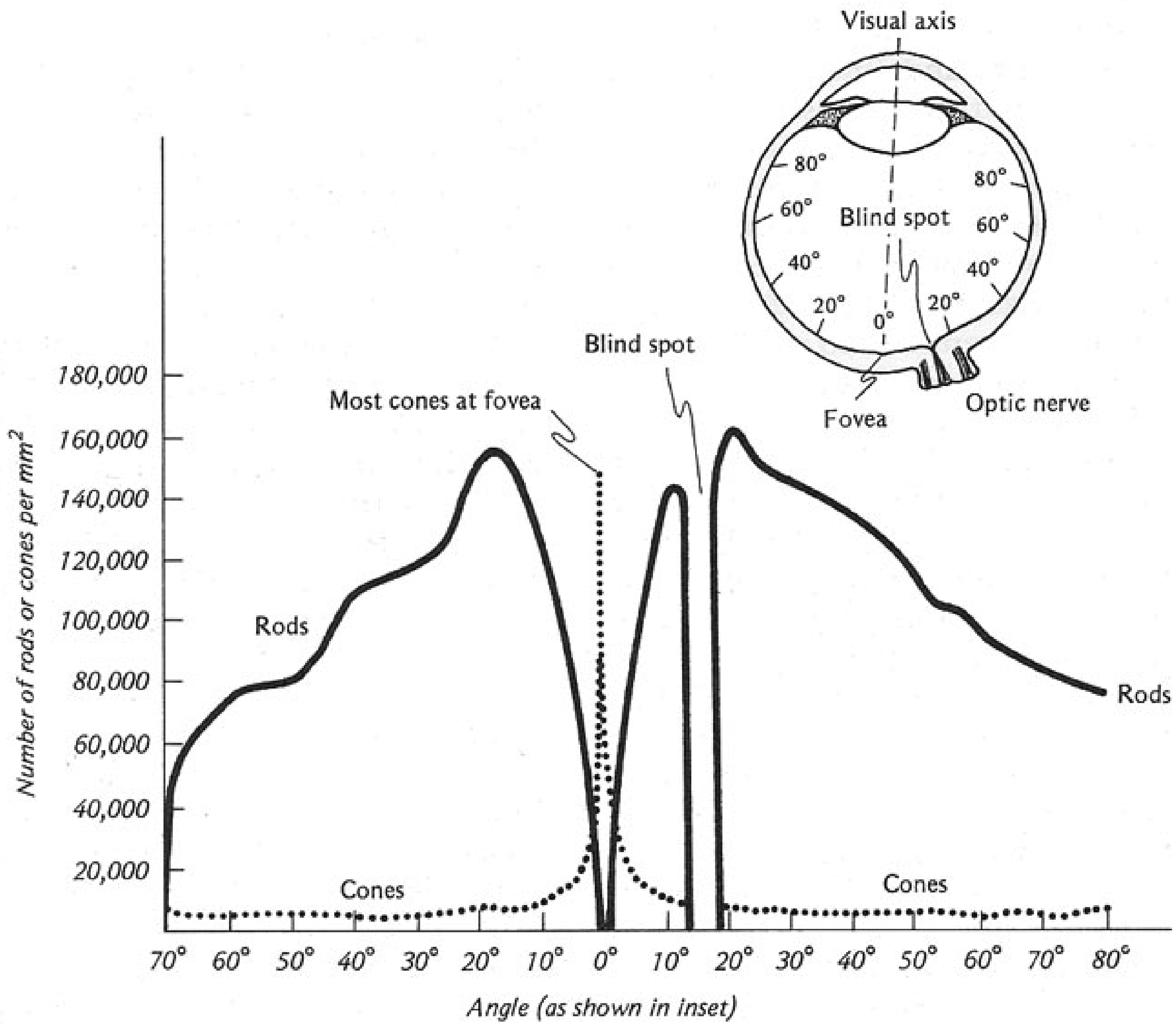


Retina

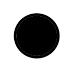
- **100 million rods**
  - Low light level sensitivity
  - Peripheral vision
- **7 million cones**
  - Concentrated in fovea
  - Color vision
- **1 million optic nerves**
  - Preprocessing of rod and cone signals needed

FIGURE 5.12

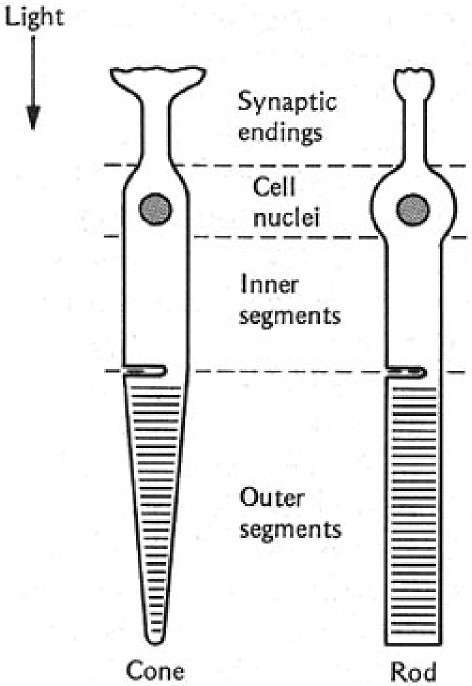
Distribution of rods and cones along the equator of an eyeball. The fovea has no rods but many cones. Rods predominate in the periphery. The blind spot has no photoreceptors. Inset shows left eye viewed from above. (Check your answer to the PONDER of Sec. 5.2.)



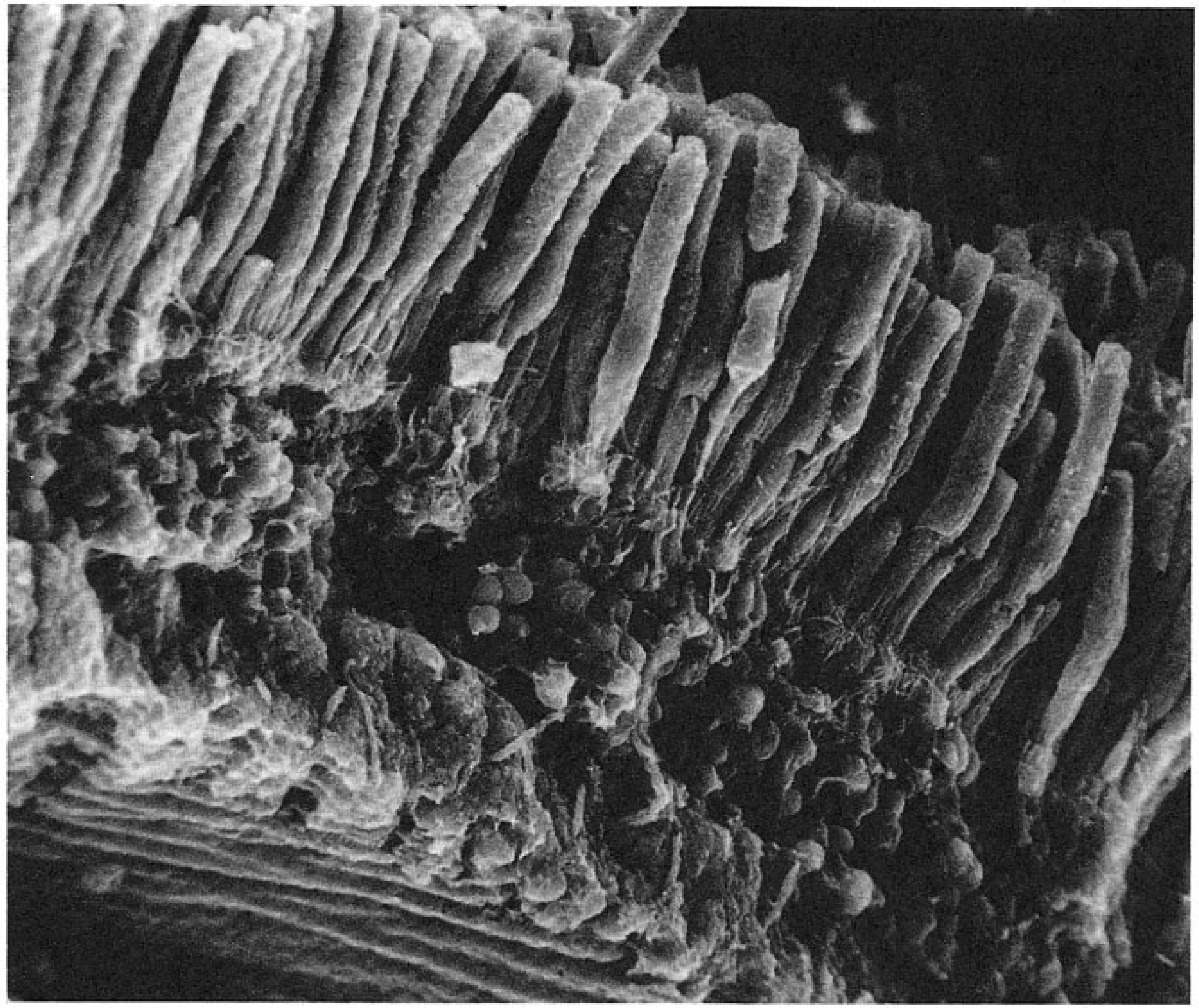
Find your blind spot



Light sensors: cones and rods



(a)

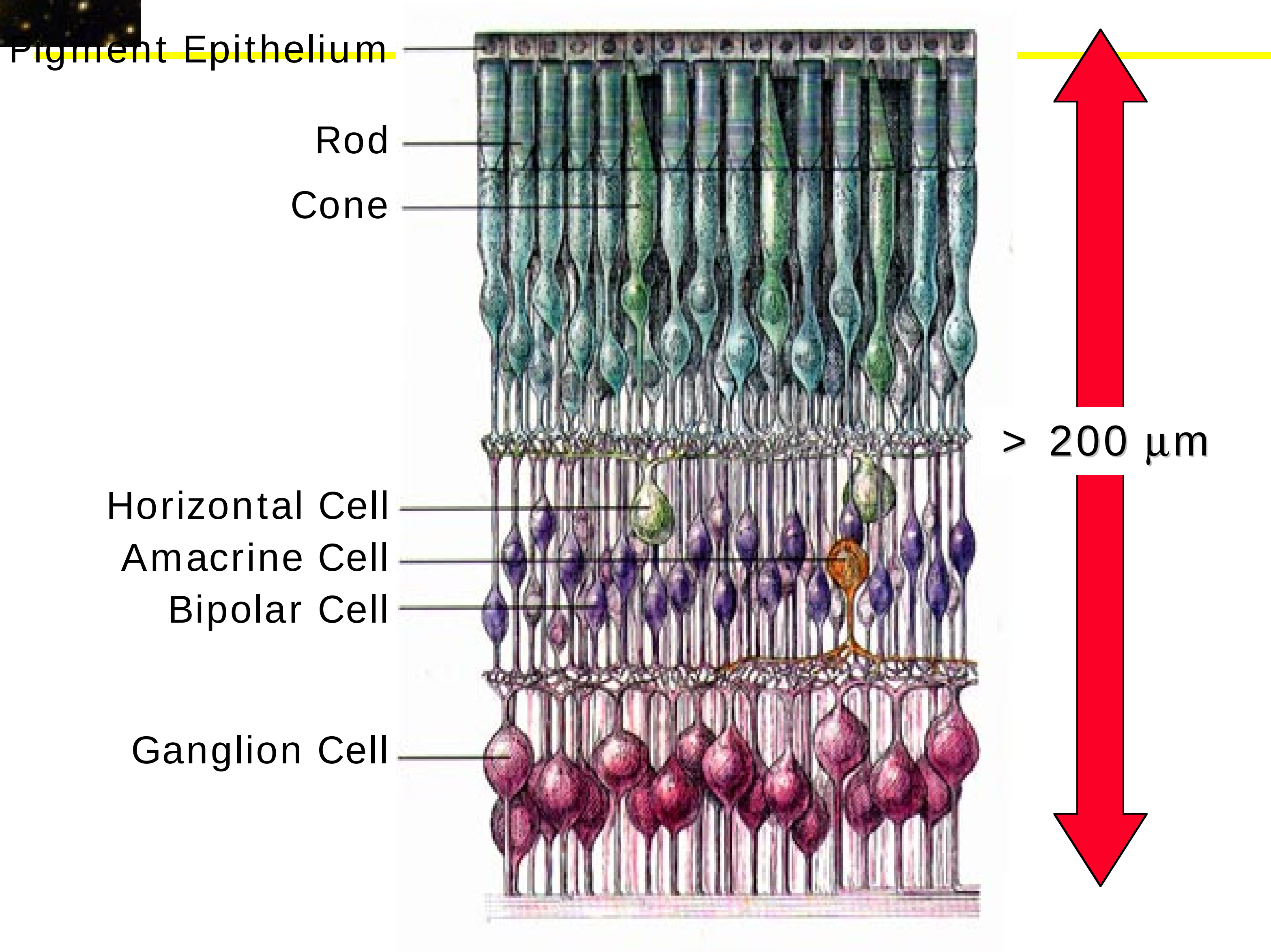


(b)

FIGURE 5.13

Physiology of the photoreceptors: **(a)** schematic, **(b)** actual photograph of rods.

Retina Cross Section



Retinal wiring

- Light sensors are rods and cones
- Rods and cones connect to Bipolar cells
- Rods and cones are interconnected by horizontal cells
- Bipolar cells connected to Ganglion cells through amacrine cells
- 1 million ganglion cells- optic nerve

Light sensing

- **Stacks of disks of light sensitive material containing rhodopsin**
  - Rhodopsin is light sensitive molecule
  - Breaks up, gives off electrical signal
  - Recombined by enzymes
  - Ultimately wears out and is continuously replaced
- **In cones, light is internally reflected**
- **It takes time to respond to light**
  - About 1/25 second low light levels
  - About 1/50 second high light levels

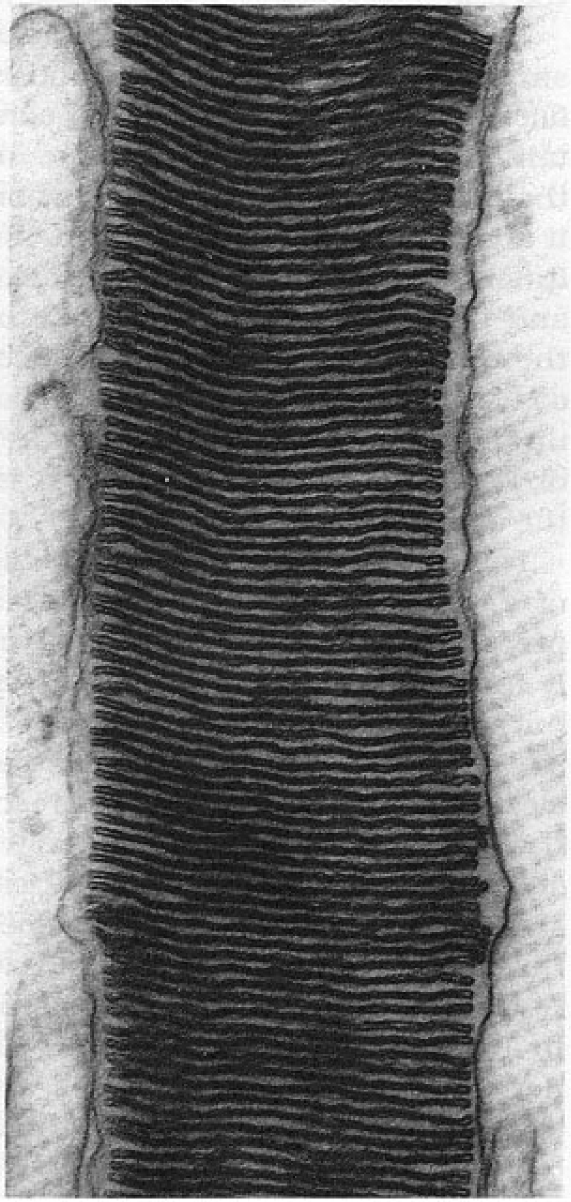


FIGURE 5.14

Electron micrograph of the outer segment of a cone.

Light sensitivity

- **Low light levels**
  - With time ~ 10 minutes) one dark adapts
  - Increased light sensitivity
  - Scotopic vision
  - Rods
  - No color sense
  - More blue sensitivity
- **High light levels**
  - Less sensitive to light
  - Cones
  - Color vision

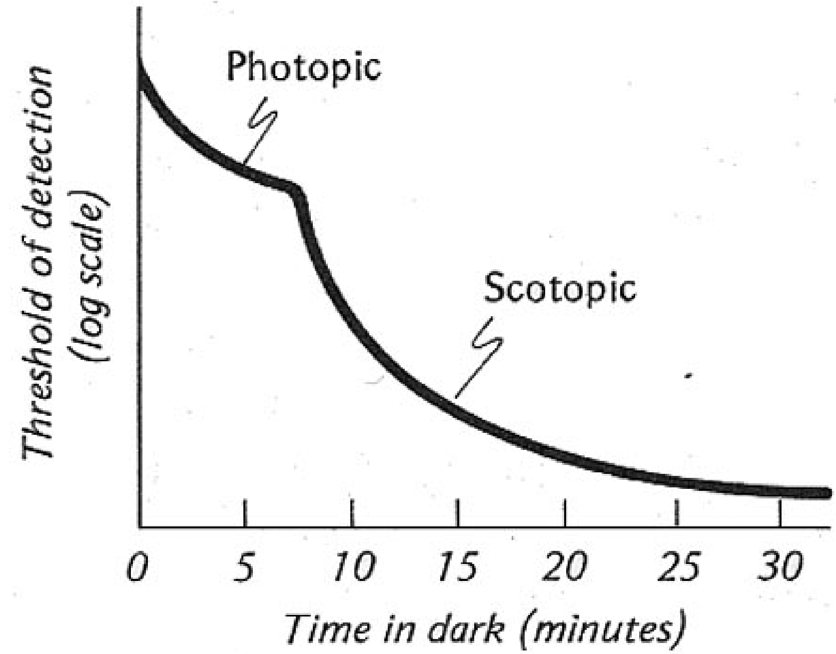


FIGURE 5.16

Dark adaptation. The threshold of detection (log scale) versus time in the dark. The first section (photopic) is due to the cones. You sense color at these thresholds. The second section (scotopic) is due to the rods. You see the world as black, white, and gray at these thresholds. Details of this curve will vary, depending upon the specific conditions and the individual subject.

- **Threshold of light detection**
  - Lower for rods
  - Bluer for rods

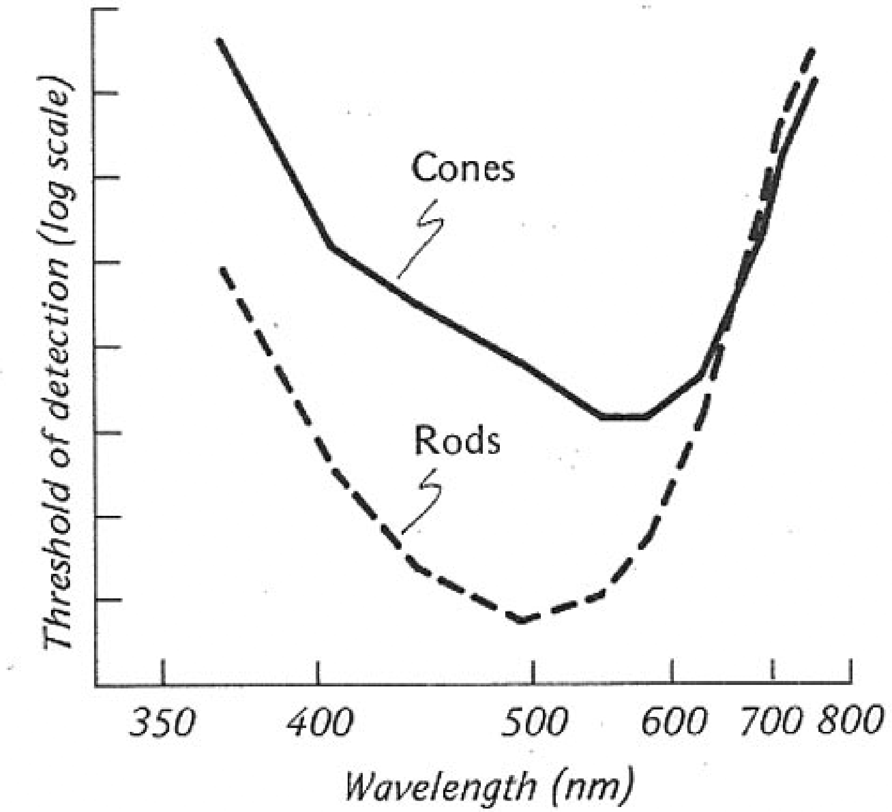
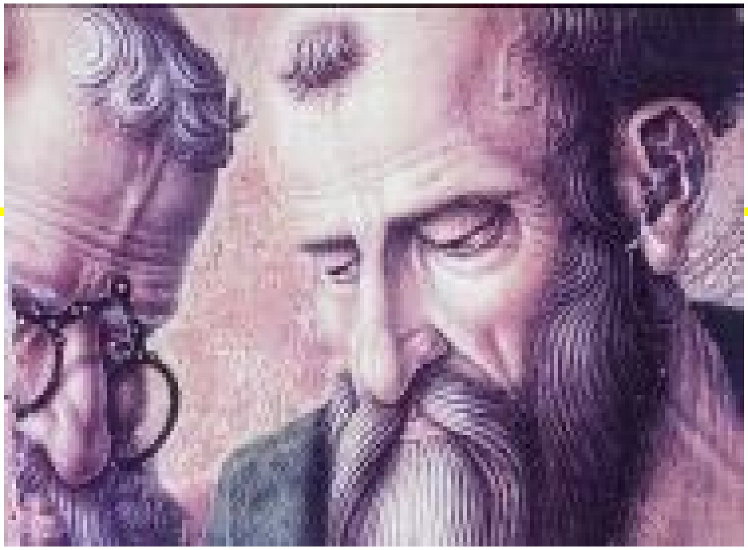


FIGURE 5.17

Relative thresholds of the rod and cone systems versus wavelength of light at some late stage of dark adaptation. The rod system is, overall, more sensitive than the cone system and is most sensitive at about 505 nm. The cone system is most sensitive at about 555 nm.

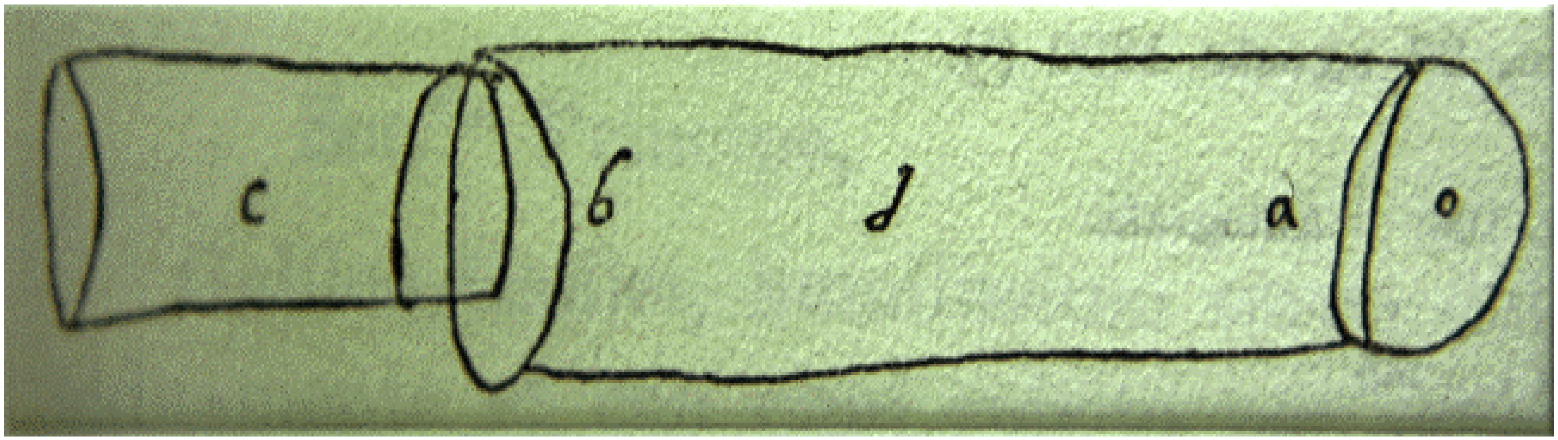
Early eyeglasses



Detail of *Hugh of St. Cher*, painted in 1352 by Crivelli

Detail of *Death of the Virgin* painted between 1400 and 1410 by the Master of Heiligenkreuz

The earliest known illustration of a telescope



Giovanpattista della Porta, August 1609

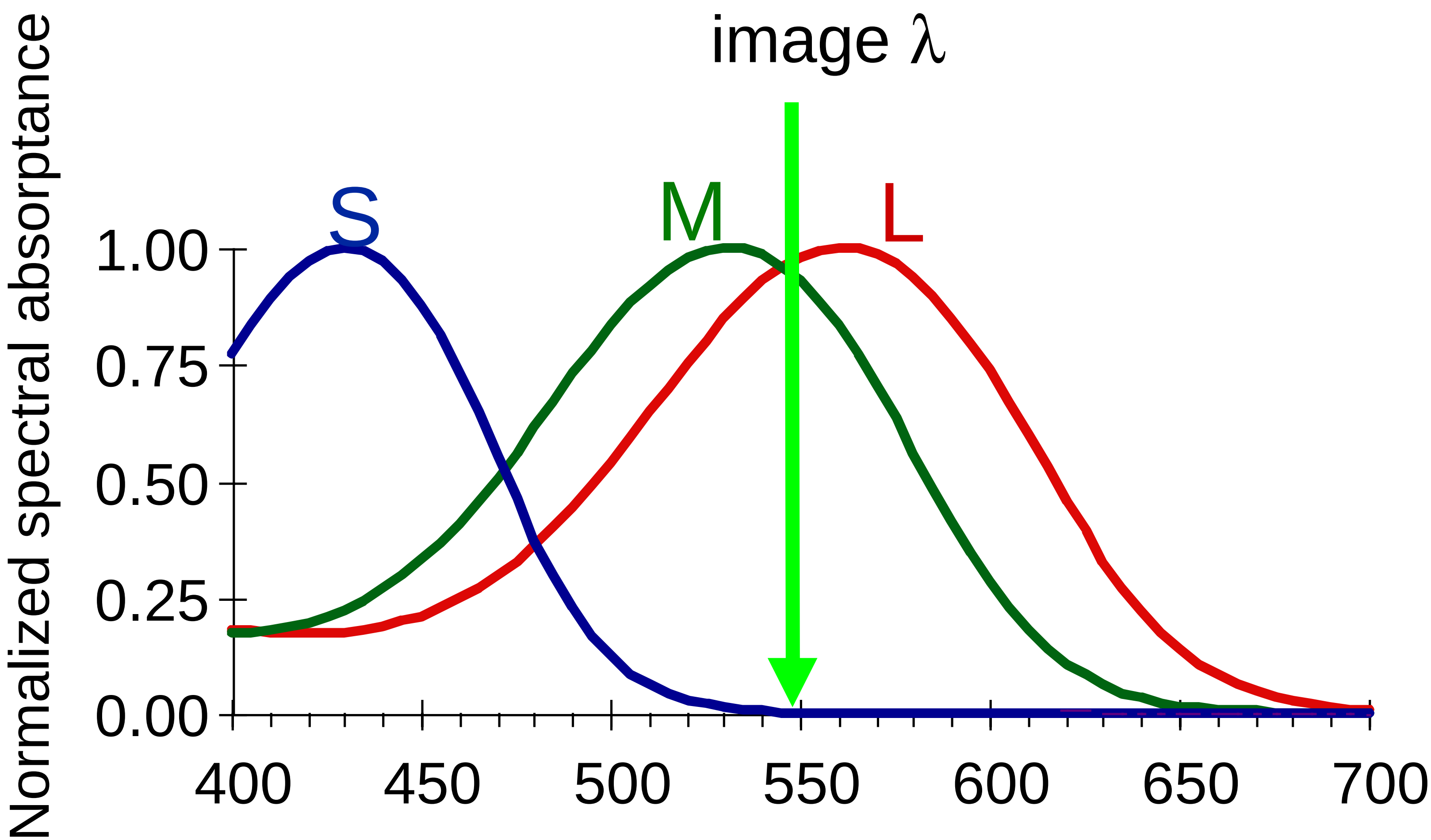
Kepler

1604: Kepler explains optics of near- and far-sightedness

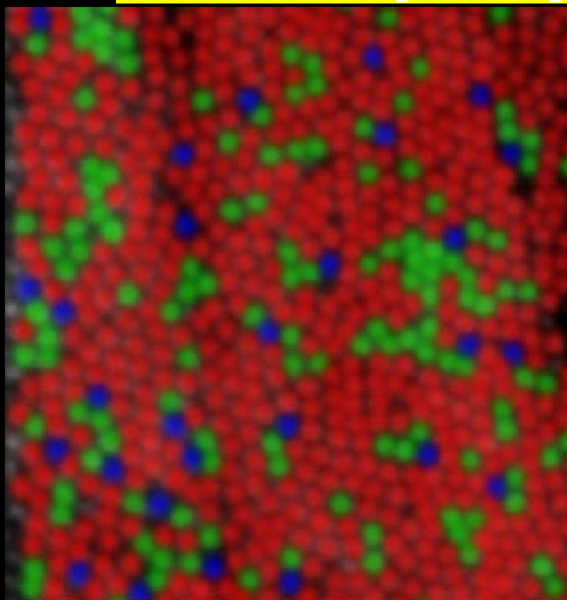
"*Now, it is not too much to say that if an optician wanted to sell me an instrument which had all these defects, I should think myself quite justified in blaming his carelessness in the strongest terms and giving him back his instrument*"

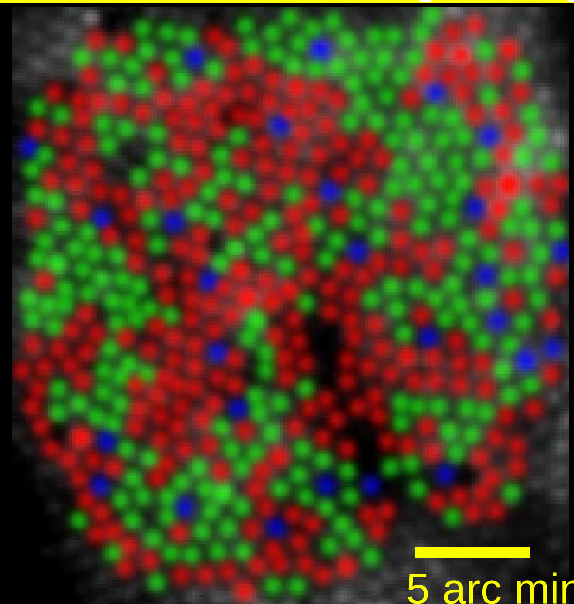
Helmholtz (1881) on the eye's optics.

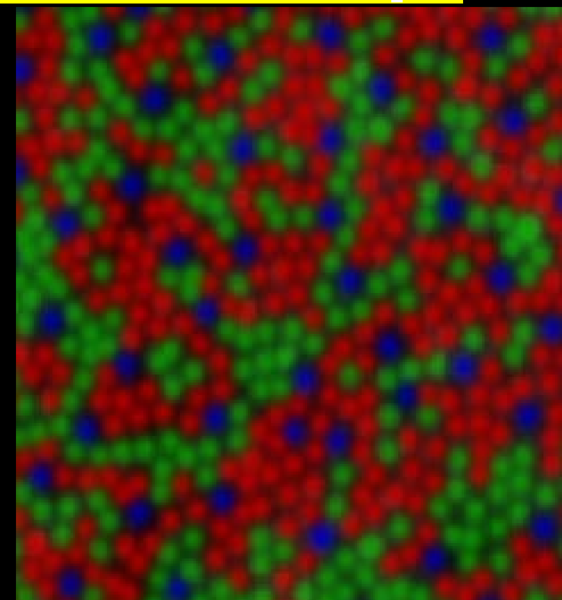
The Trichromatic Cone Mosaic



human (JW) | **human (AN)** | **macaque**







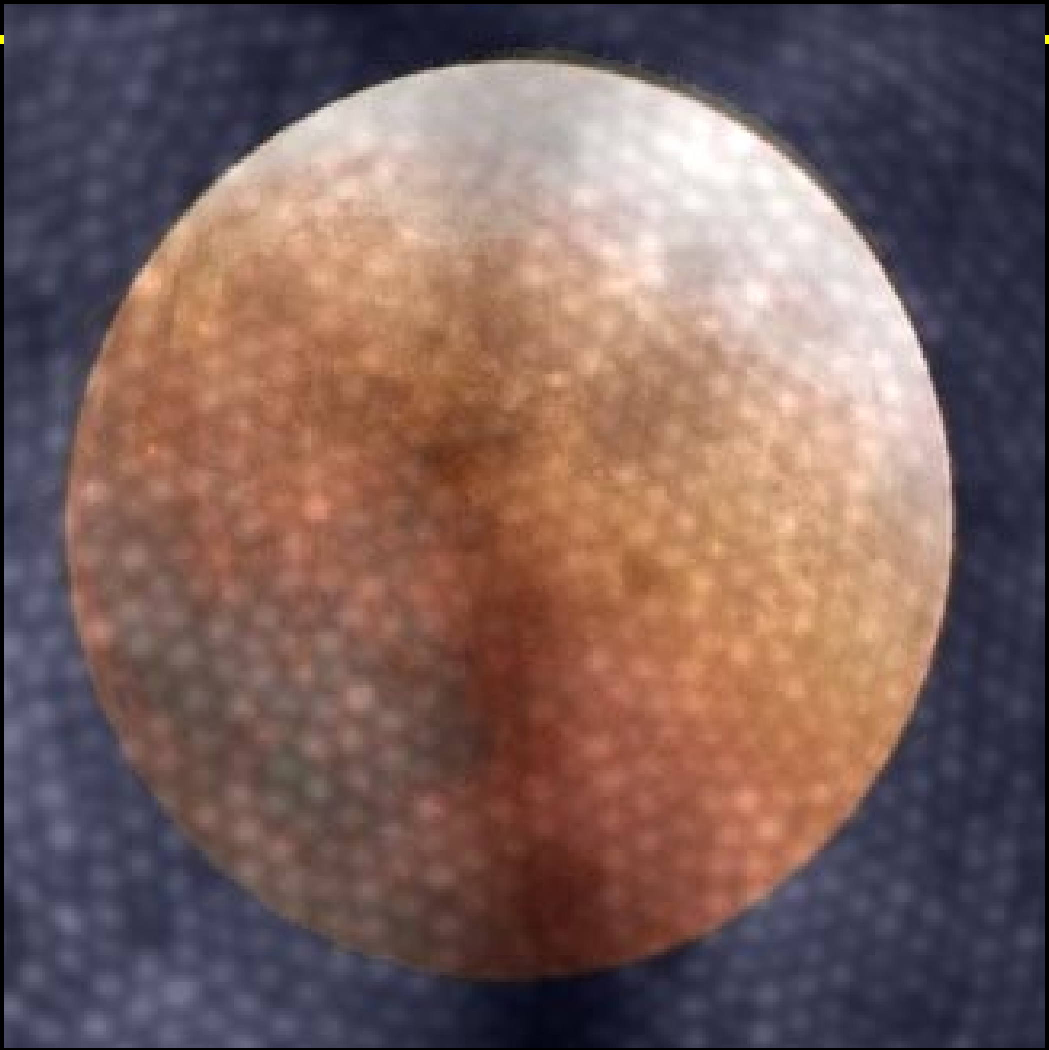
	human (JW)		human (AN)		macaque
L	75.8%	L	50.6%	L	53.4%
M	20%	M	44.2%	M	38%
S	4.2%	S	5.2%	S	8.6%

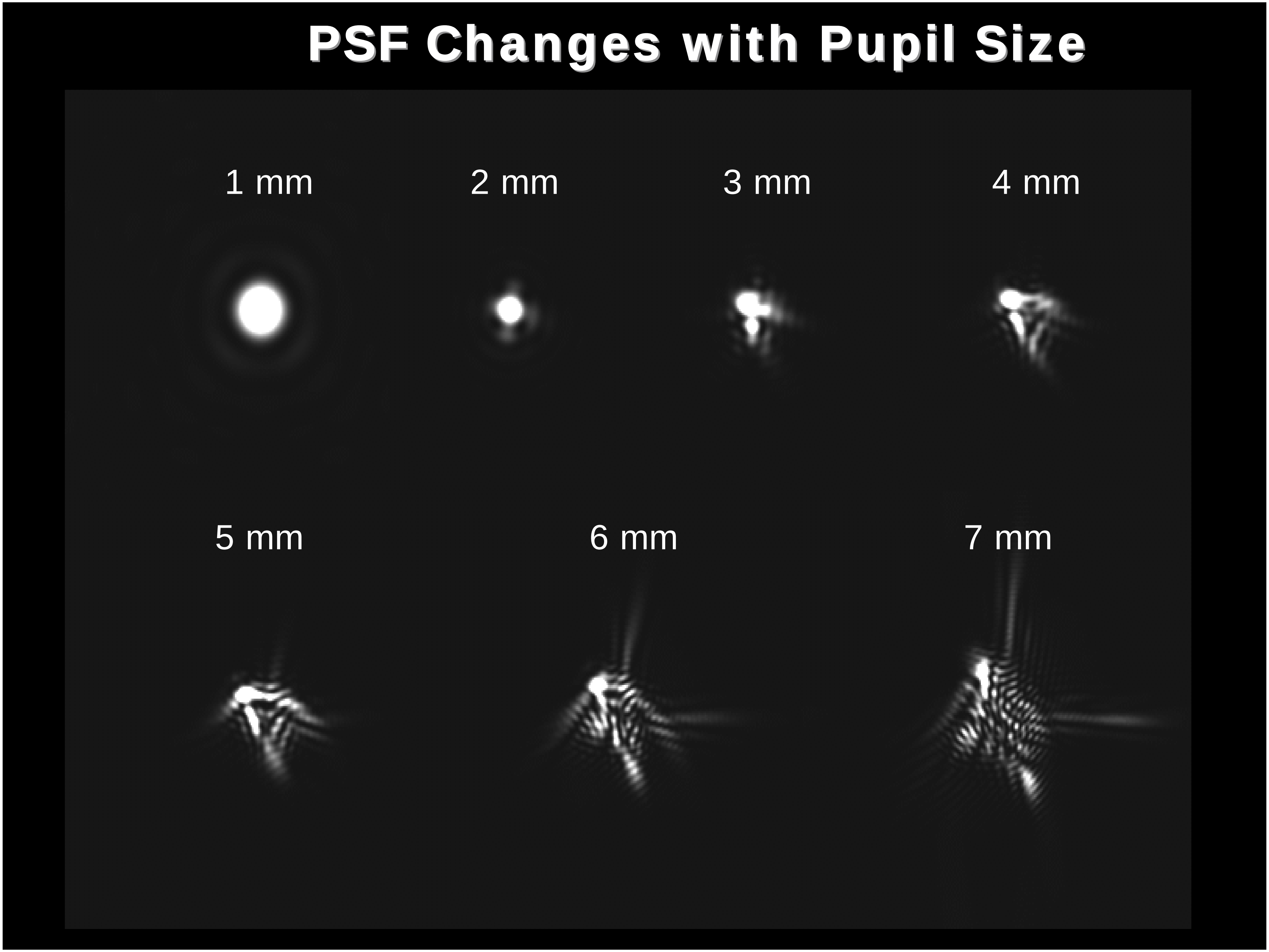
L/M = 3.79

L/M = 1.14

L/M = 1.40

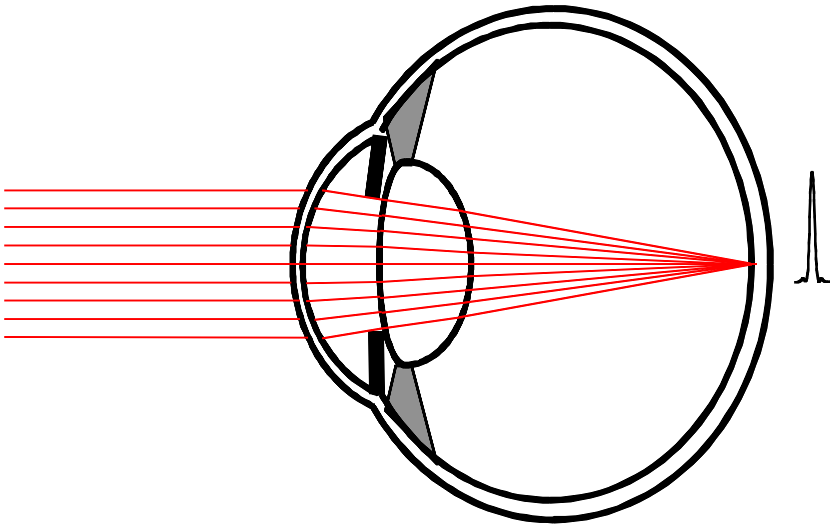
View of Lunar Eclipse



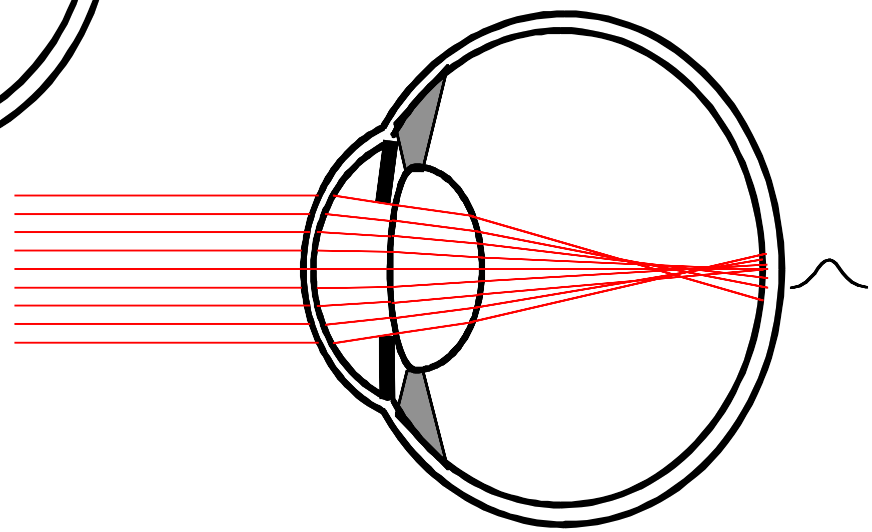

PSF Changes with Pupil Size
1 mm
2 mm
3 mm
4 mm
5 mm
6 mm
7 mm

Why Correct the Eye's Optics?

Perfect Eye

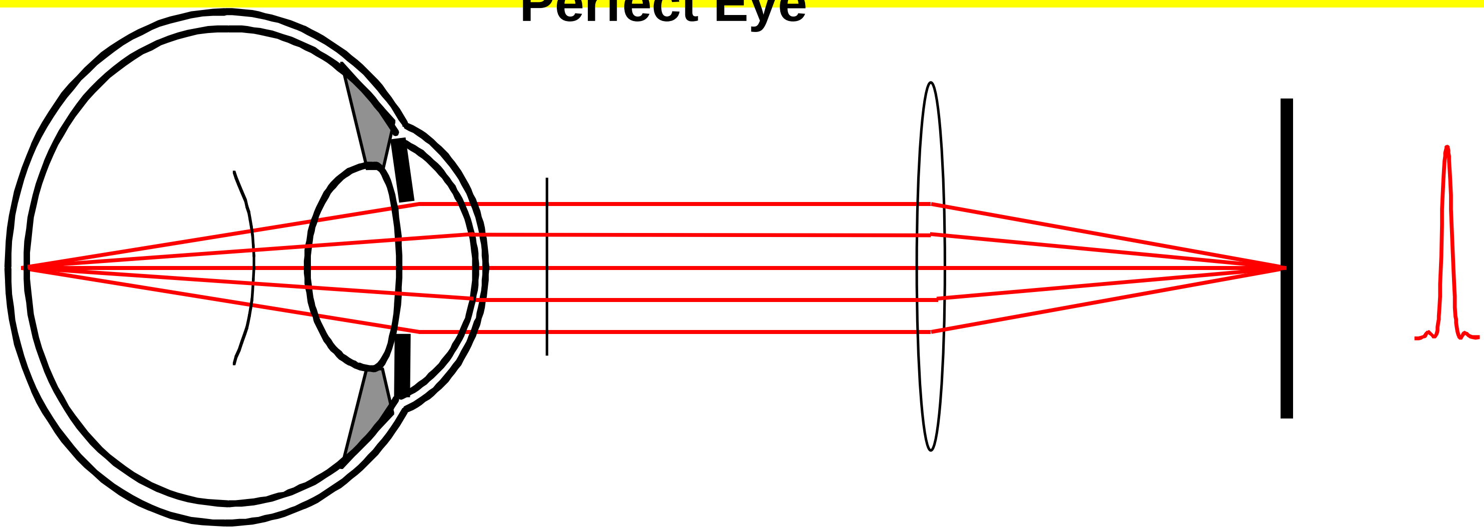


Aberrated Eye

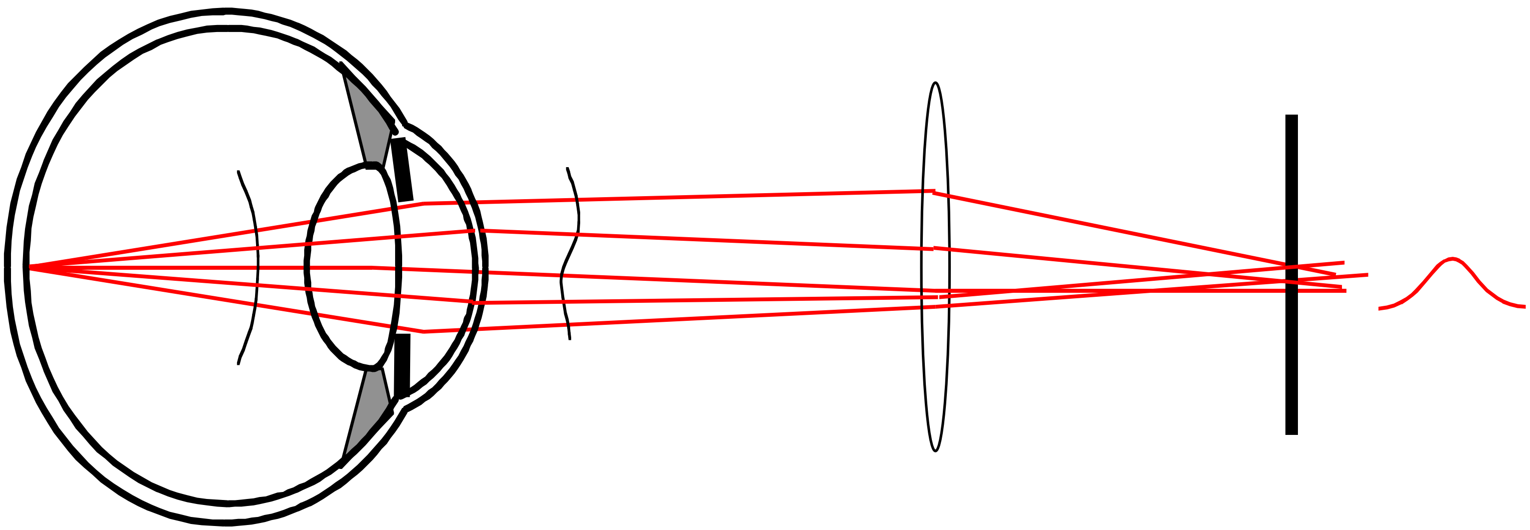


Why Correct the Eye's Optics?

Perfect Eye



Aberrated Eye

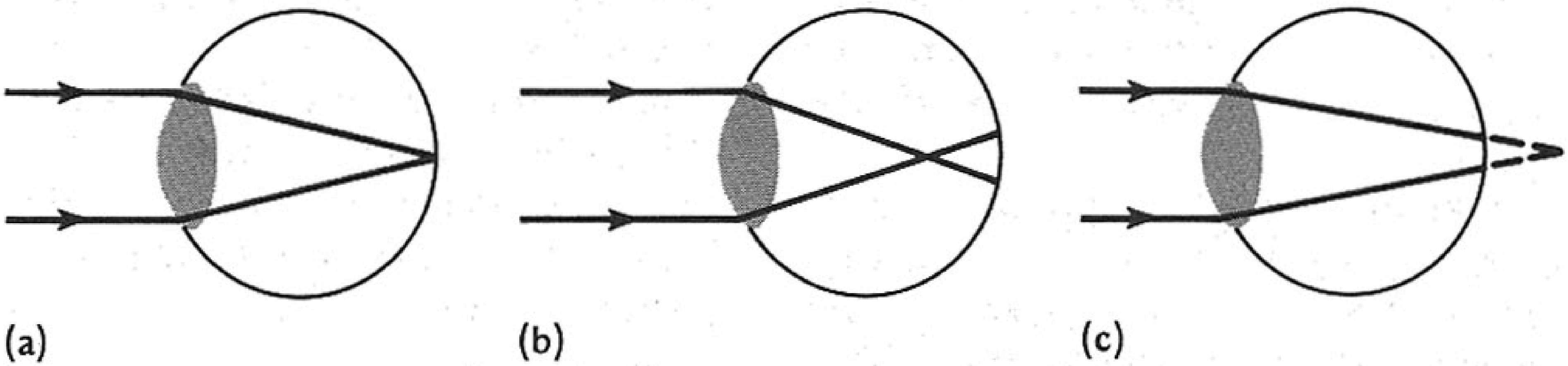


Optical instruments

Focus errors in eyes

FIGURE 6.1

Relaxed eyes viewing a distant object, **(a)** normal, **(b)** myopic, **(c)** hyperopic.



- **Normal eye has about 60 diopters of power**
  - Lens has adjustable power, ranging from 0-10 diopters

Myopic eye

- **Relaxes eye focuses at far point**
  - For normal eye at infinity
  - For myopic eye closer
- **Myopic eye lens is too powerful**
  - Lens focal length is too short
  - Eyeball is too long
- **Diverging lens corrects for overpowered natural lens**

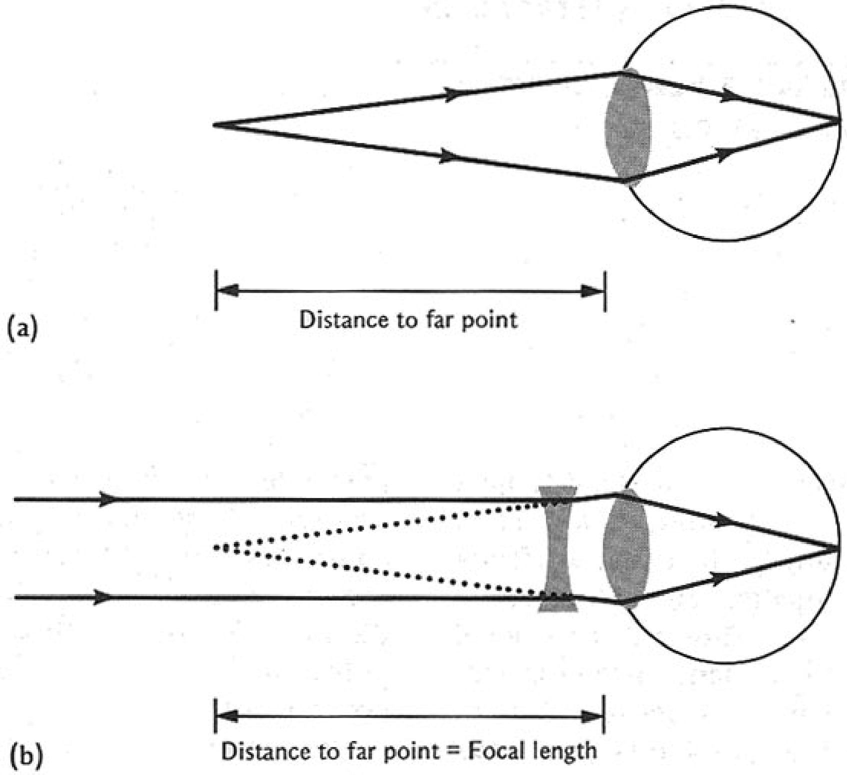


FIGURE 6.2

Relaxed myopic eye, **(a)** without glasses, **(b)** with glasses. The diverging lens is drawn separated from the eye to show that the rays leaving the glasses look as in **(a)**; but there need be no separation; the correction works also for contact lenses.

Accommodation

- **Human eyes have the ability to adjust the focus**
  - Near point is closest distance for good focus
  - Far point is most distant point for good focus
  - Range of focus is amount of accommodation
    - Example: far point is infinity (P_f=0)
    - Near point is 20 cm (P_n= 5 diopters)
    - Accommodation is $P_f - P_n$ = 5 diopters
- **As people age, the amount of accommodation decreases to zero by about age 50**
- **This condition is called presbyopia**
  - People often use reading glasses to compensate for this
  - Positive power glasses, P = 1-2 diopters typically

Hyperopic eye

- Partially accomodated
- Fully accomodated, image blurred
- Fully accomodated, object at near point
- Addition of lens brings near point inwards

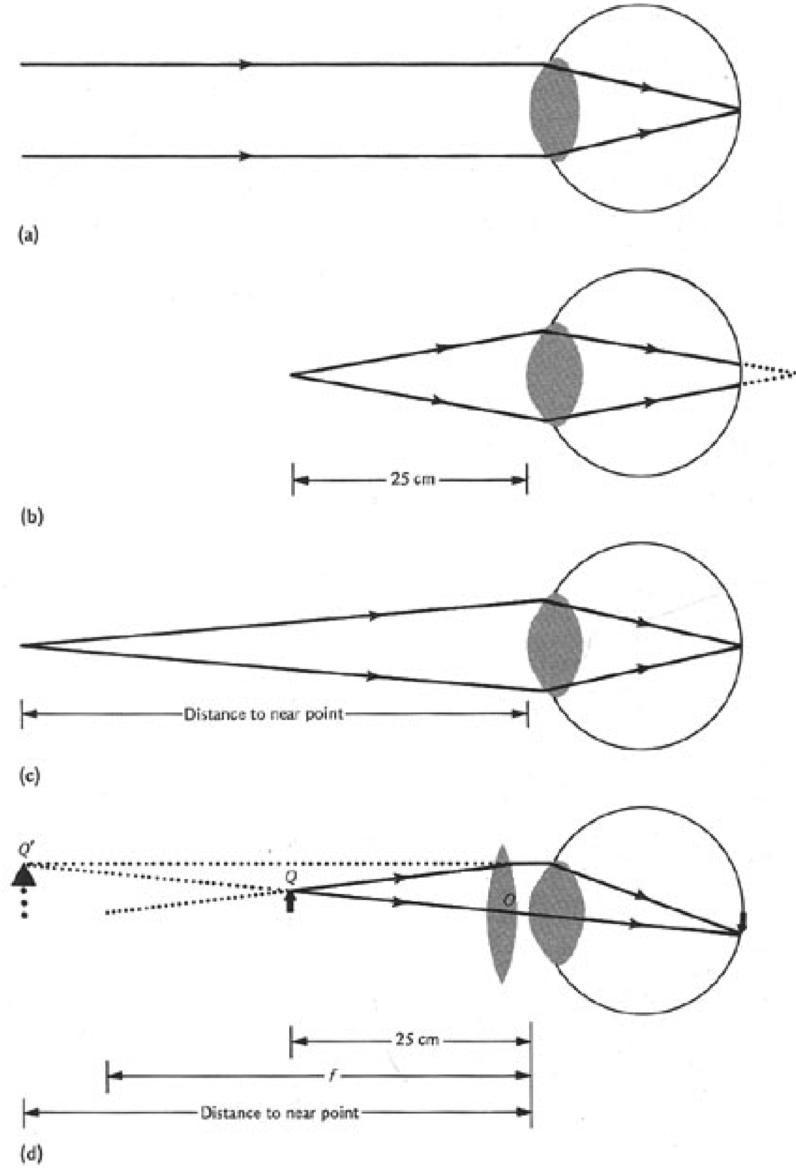


FIGURE 6.3

The hyperopic eye, **(a)** partially accommodated, **(b)** fully accommodated, object at 25 cm, **(c)** fully accommodated, object at near point, **(d)** corrected, fully accommodated, object at 25 cm appears to be at near point.

astigmatism

- **Test for astigmatism**
  - Cant use the image projected here
    - Or at least not so good
  - Use the book image
  - Get image very close to uncorrected eye
    - Images fuzzy
  - Gradually draw book away until one set of lines looks sharp
  - Keep drawing book away until other set of lines (perpendicular) looks sharp

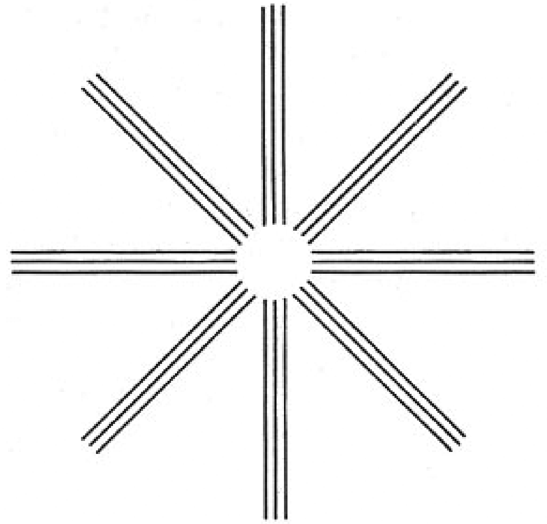


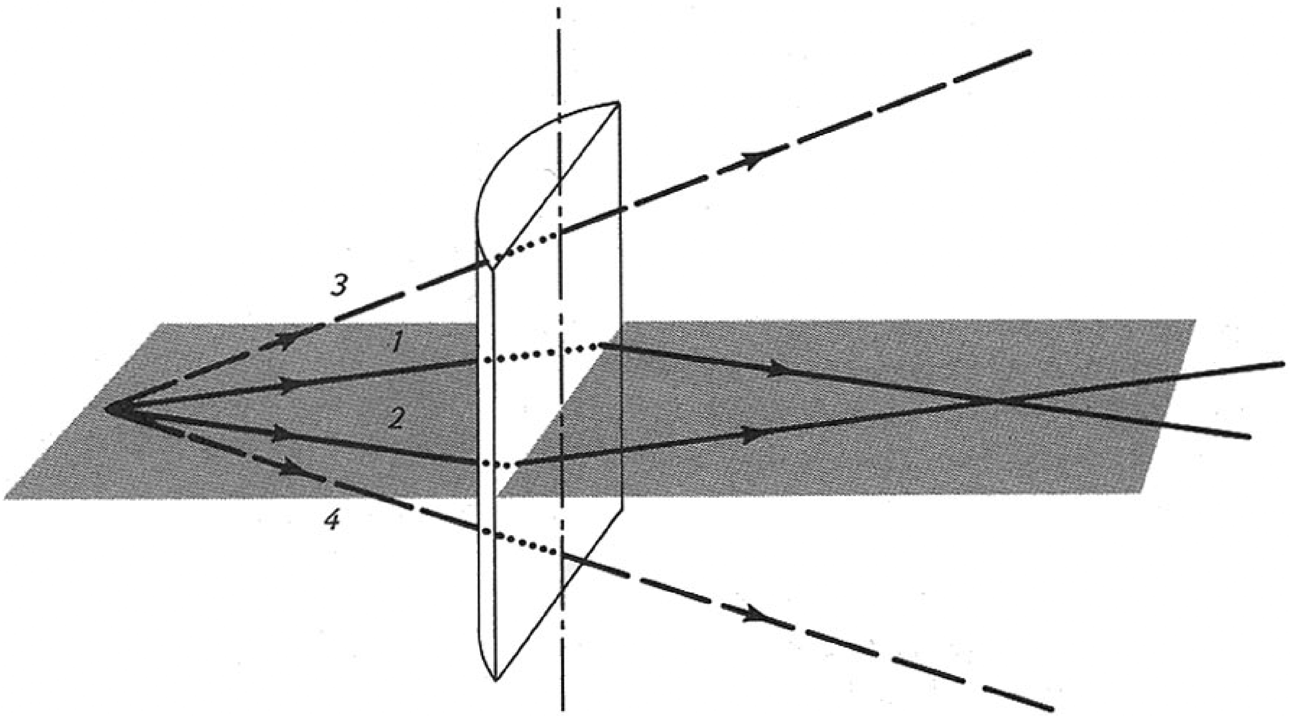
FIGURE 6.4

Test for astigmatism. Close one eye and view this figure through the other eye (without glasses or contact lenses). Hold the figure sufficiently close to the eye so that all lines look blurred. Then gradually move the figure away until one set of lines comes into focus, with the rest blurred. (If two adjacent sets come into focus together, rotate the figure a little until only one is in focus. If all sets come into focus together, you don't have astigmatism.) You have now found the near point for a line in the direction of the lines that are in focus. Move the pattern away further until the lines perpendicular to the first set come into focus. (The first set may or may not remain in focus.) This is the near point for a line perpendicular to the original set. The different near points mean that your eye has a different focal length for lines parallel to and perpendicular to the original set. Try the procedure again with your glasses or contact lenses to see if your astigmatism is corrected.

Cylindrical lens and astigmatism

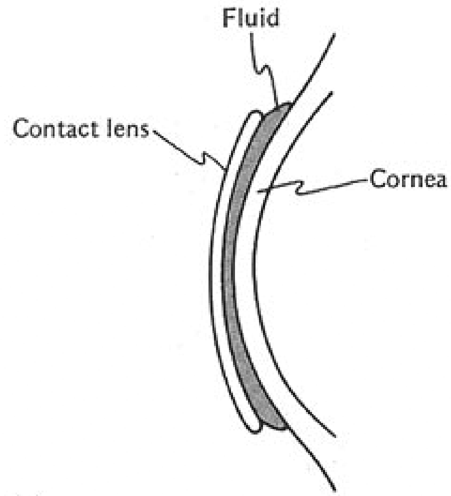
FIGURE 6.5

Cylindrical lens. Rays *1* and *2*, in the horizontal plane, are made to converge. Rays *3* and *4*, in the vertical plane, are essentially unaffected.

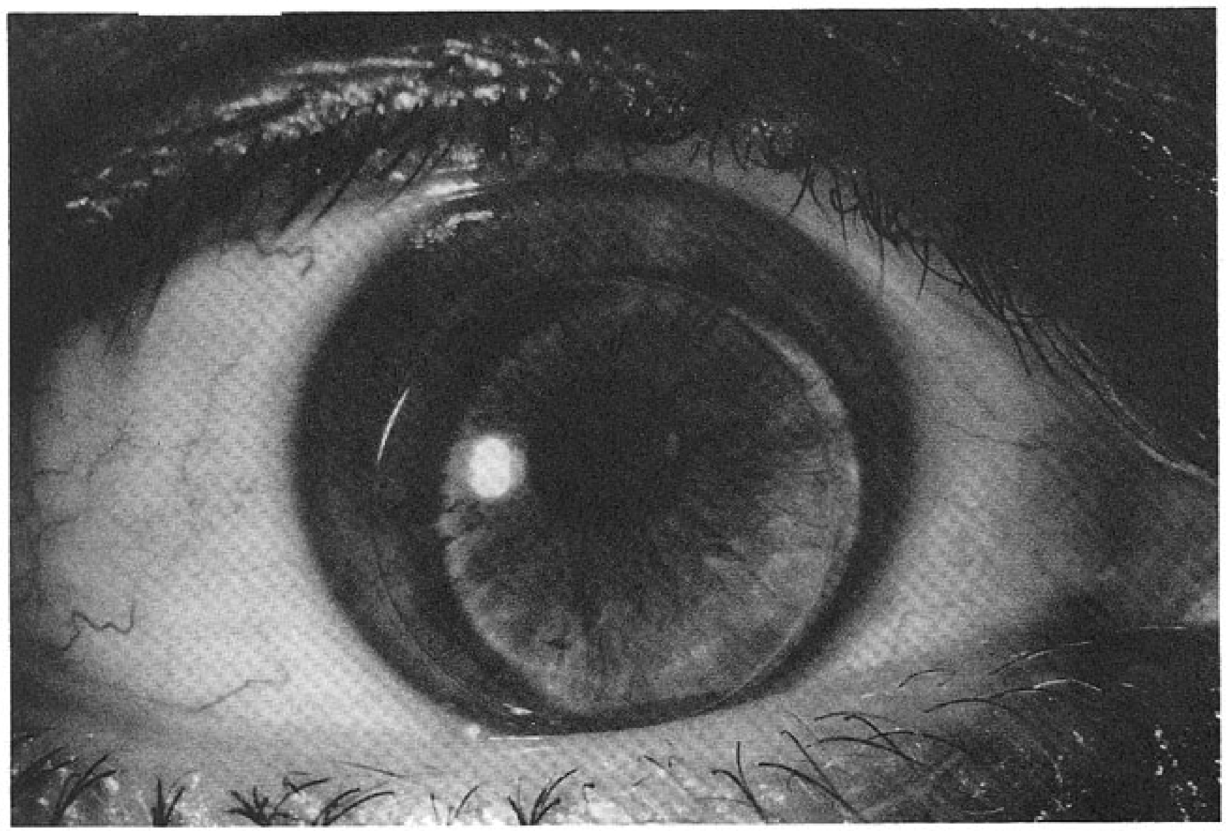


Contact lens

- **Contact lens**
  - Defined by inner curve to match cornea
  - Outer curve to produce desired power
  - Diameter to cover pupil
  - Index of refraction
- **Tear film allows good contact with cornea**



(a)



(b)

FIGURE 6.6

(a) A contact lens on the cornea with tear fluid in between. **(b)** Photograph of a contact lens.

Eye and lens aids

- **Normal eye**
- **Eye with converging lens**
  - Note image on retina is larger (because object is closer!)
  - Produces virtual image
- **Magnifying power**
  - Defined to be 0.25/f where f is in meters
  - Note difference with optical power which is measured in diopters (1/f)

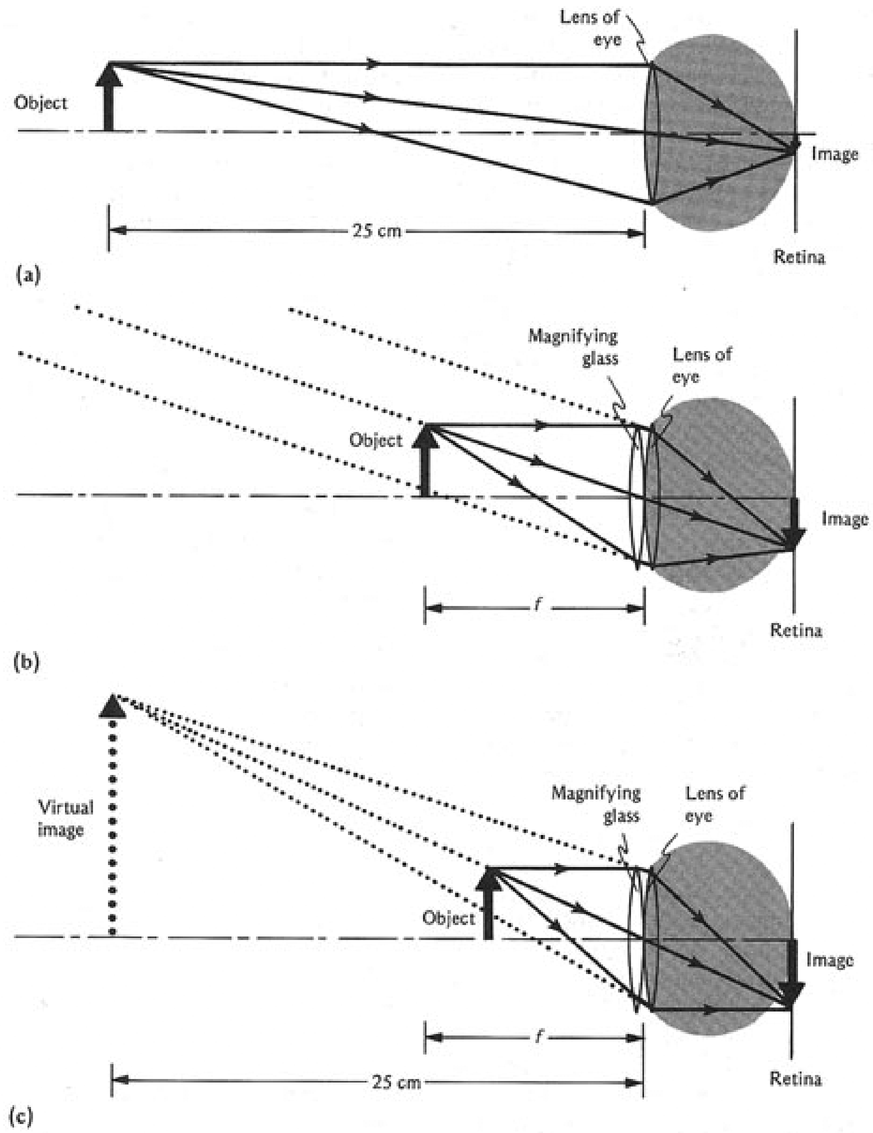


FIGURE 6.7

(a) Unaided normal eye, object at near point. (b) Eye with magnifying glass, image at infinity. (c) Eye with magnifying glass, image at 25 cm. Note the relative sizes of the images on the retinas. The compound lens of the eye is treated as a thin lens in this figure.

Optics for illumination

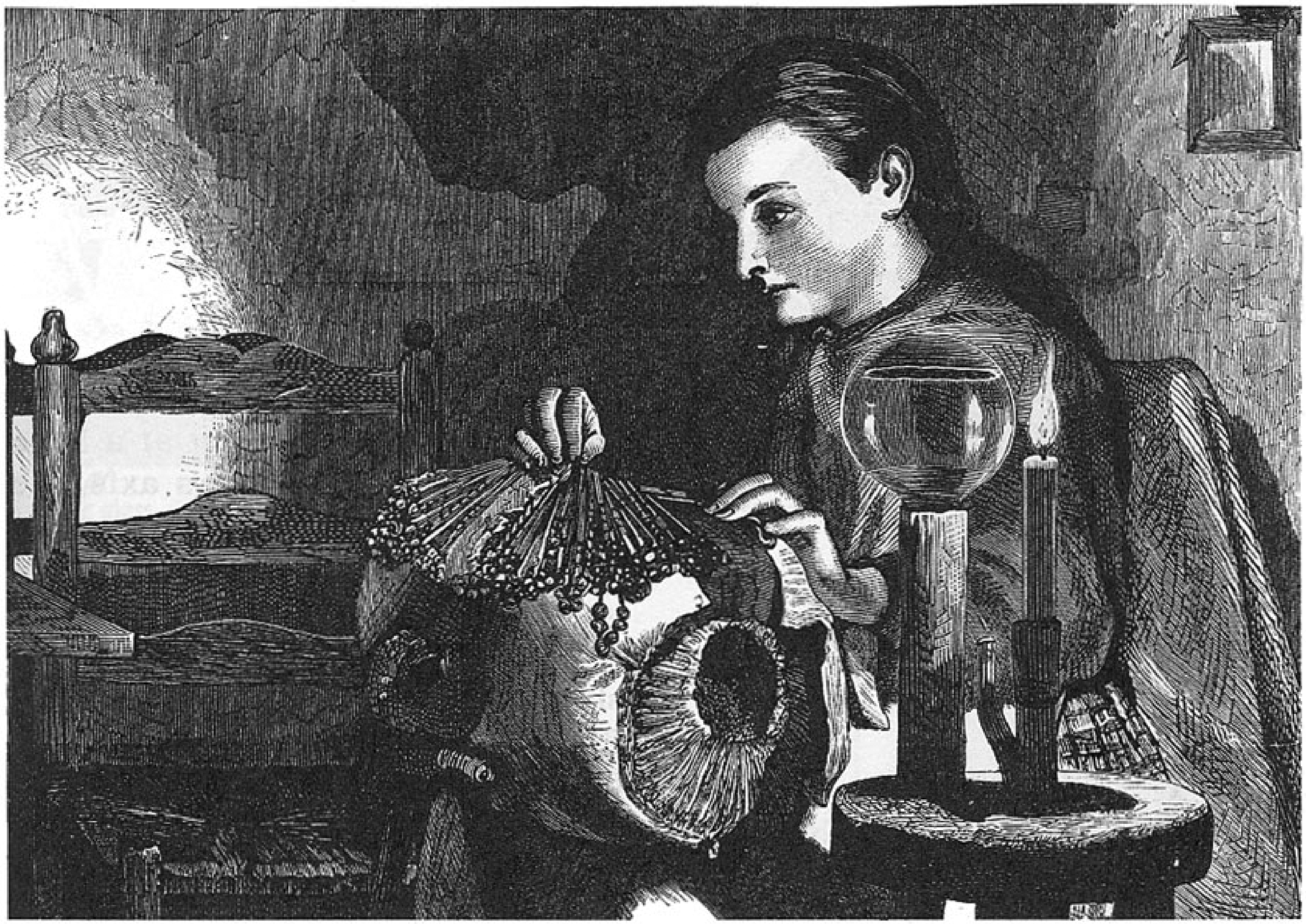


FIGURE 6.8

Lacemakers' condenser, capable of focusing the light of a candle on the work of the lacemaker.

Compound microscope

- **Two lens system**
- **First lens is objective**
  - Objective makes image of object
  - Shorter focal length makes larger image
  - This image is real
  - May need field lens to gather this light
- **Second lens is eyepiece**
  - Generates parallel light to enter eye
  - Should be lens focal length from image
  - Acts as magnifier

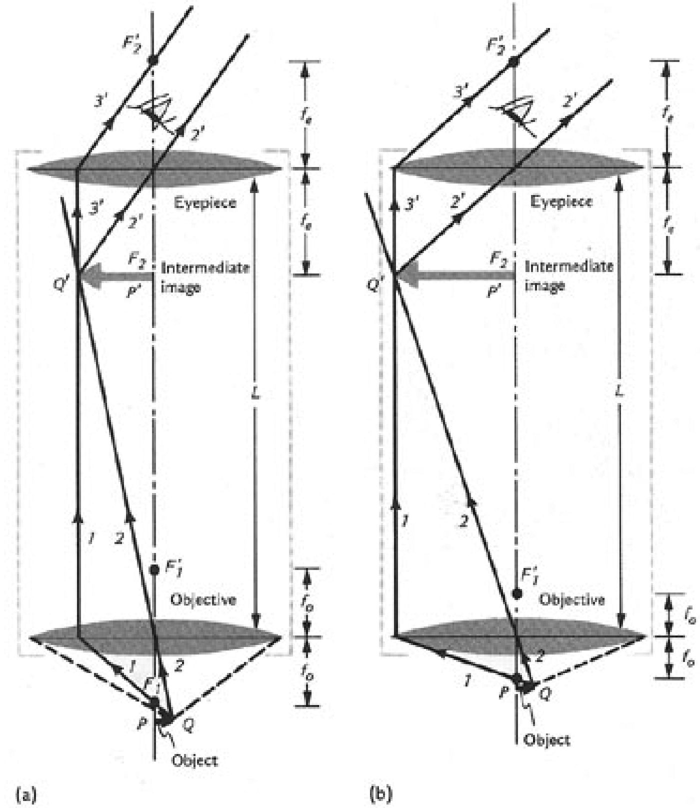


FIGURE 6.9

The compound microscope, **(a)** with larger objective focal length, **(b)** with smaller objective focal length. The magnification is greater in **(b)**. Rays from Q between the dashed lines strike the objective lens. Note: This figure uses our ray tracing convention that the intermediate image serves as a source of new rays, not necessarily extensions of the rays converging to it. Thus, for example, ray $2'$ must actually originate at Q and pass through the objective before reaching Q'. If the objective is sufficiently large, such a ray will, in fact, exist. Since we are only interested in locating images, or, in this case, the *direction* of the beam emerging from the eyepiece, we don't really care whether ray $2'$ actually exists. We simply treat it as originating at Q'—we treat the intermediate image as a new object. (A field lens would cause ray 2 to become ray $2'$—see Sec. 6.6A.)

Oil immersion microscope

- **Oil eliminates spherical aberration**

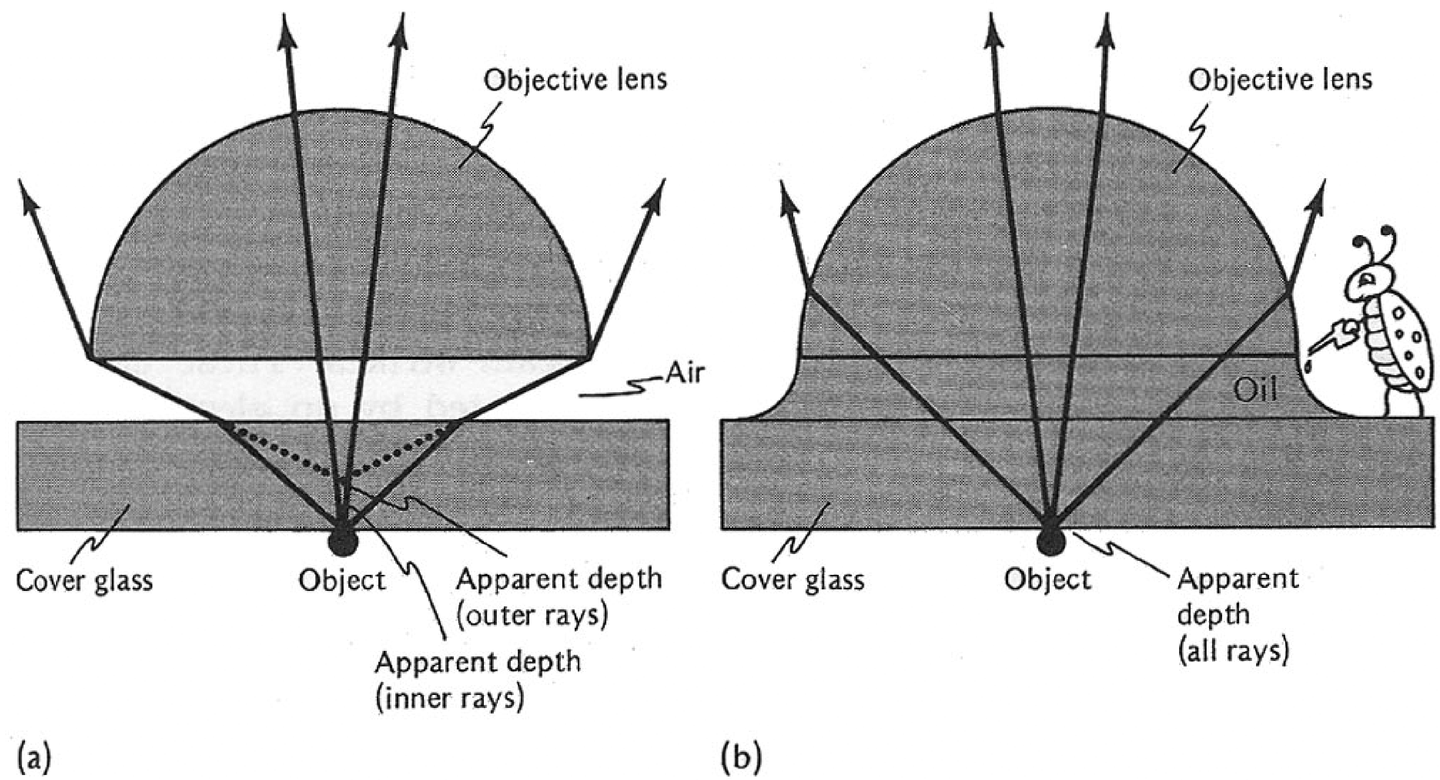


FIGURE 6.10

The oil immersion microscope objective, **(a)** without oil, **(b)** with oil.

- **Flying spot microscope**
  - Uses light
  - Focuses with microscope
  - Illuminates single spot at a time
  - Measure scattered light
  - Illuminate and display with TV tube

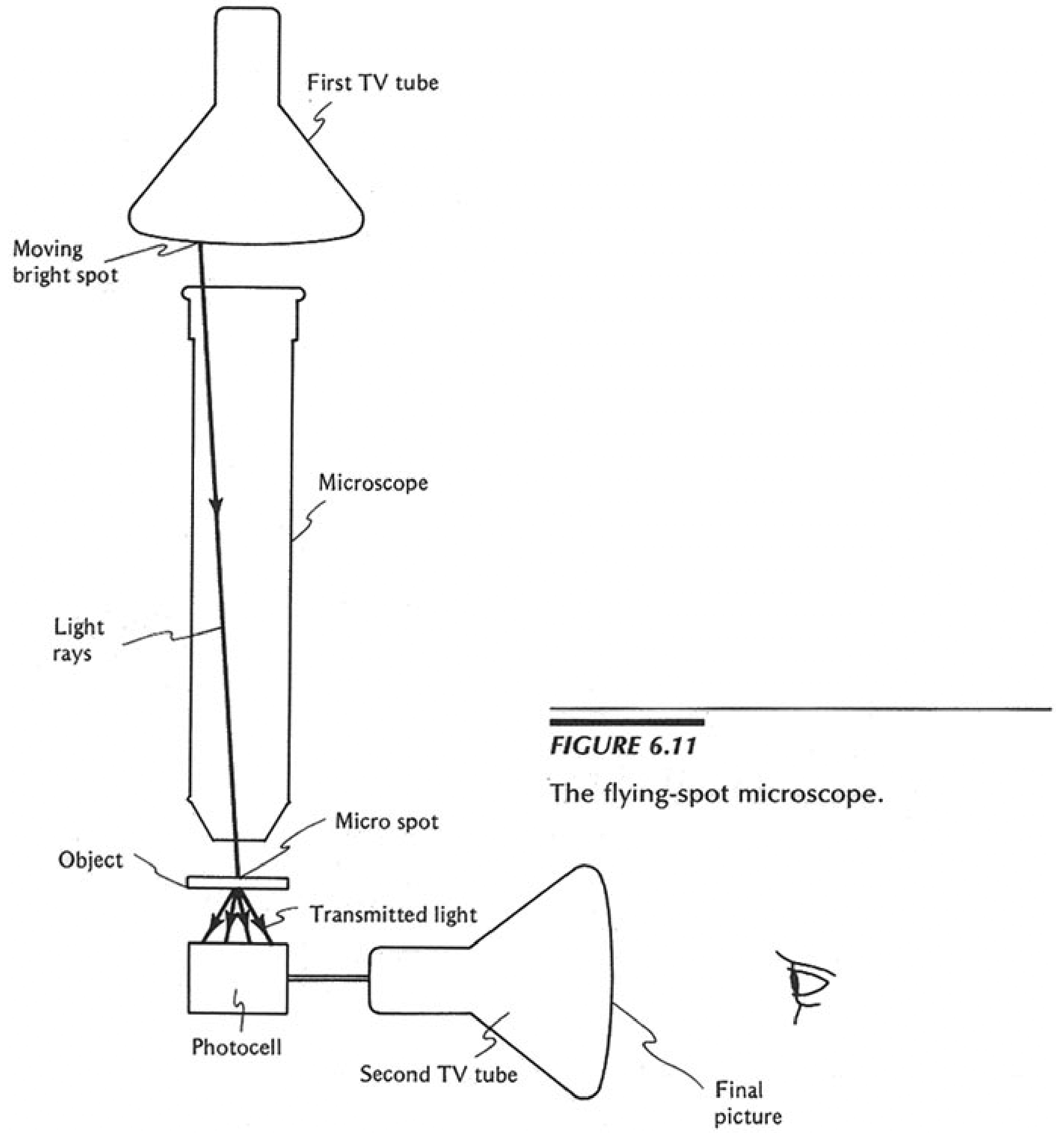
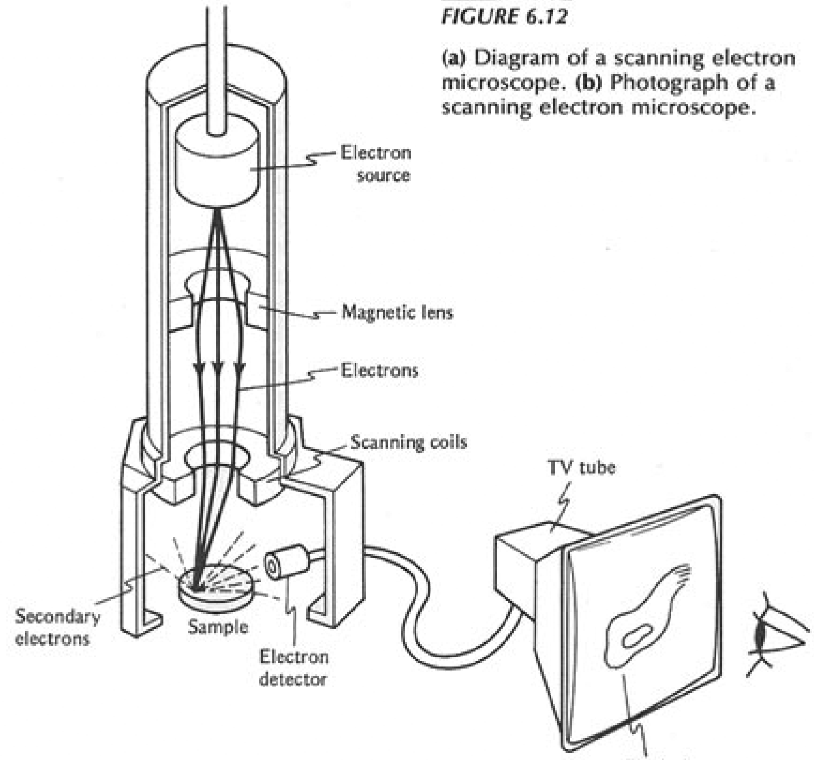


FIGURE 6.11

The flying-spot microscope.

Scanning electron microscope

- **Illumination by electrons**
  - Electron source
  - Magnetic lens
  - Scattered electrons are measured
- **Single spot illuminated at a time**



(a)

(b)

FIGURE 6.12

(a) Diagram of a scanning electron microscope. **(b)** Photograph of a scanning electron microscope.

Astronomical Telescope

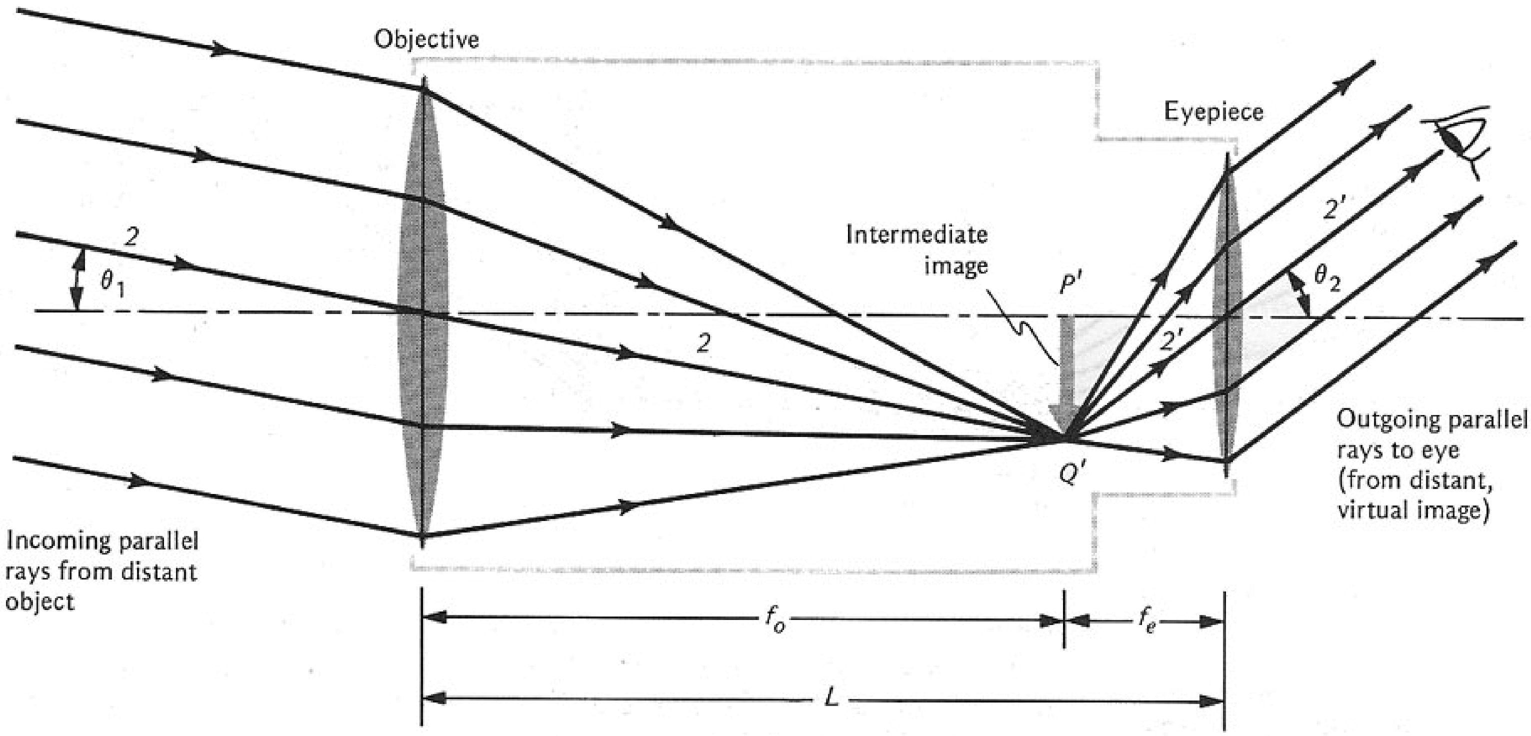


FIGURE 6.13

Principle of an astronomical telescope. This figure uses our ray tracing convention (see caption Fig. 6.9) whereby the intermediate image serves as a source of new rays, not necessarily extensions of the rays converging to it. This is achieved physically by a field lens (Sec. 6.6A).

Terrestrial Telescope

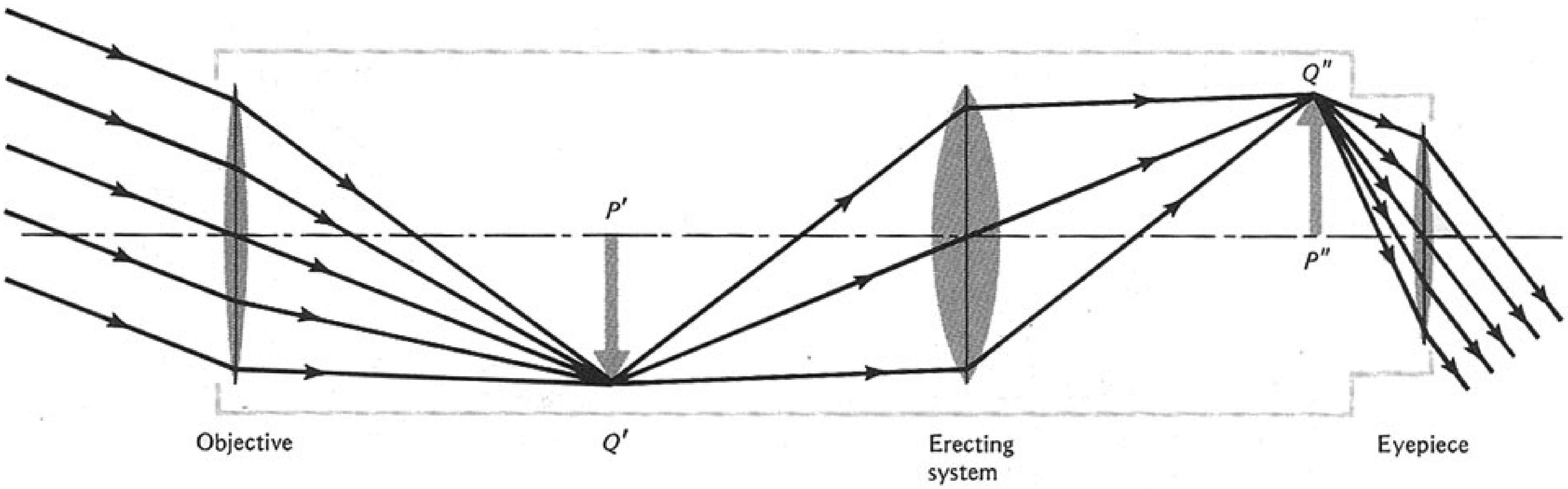


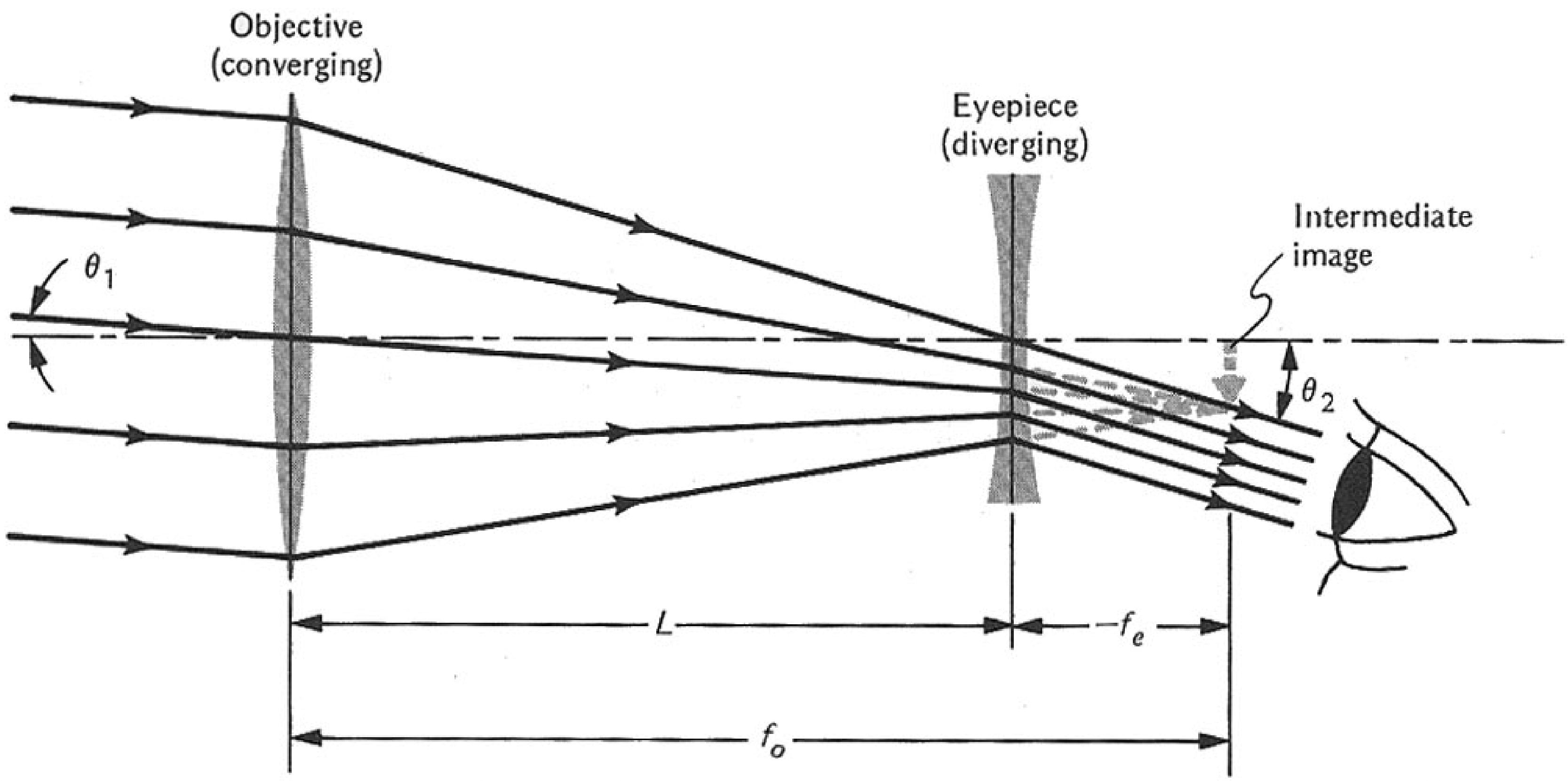
FIGURE 6.14

Principle of a terrestrial telescope, which uses an erecting system. This figure uses our ray tracing convention (see caption Fig. 6.9) whereby the intermediate image serves as a source of new rays, not necessarily extensions of the rays converging to it.

Galilean Telescope

FIGURE 6.15

Galilean telescope.



Reflecting Telescopes

- **Newtonian telescope**
  – Fold flat near the prime focus
- **Cassegrain telescope**
  – Convex secondary
  – Focus behind the primary
- **Gregorian telescope**
  – Concave secondary

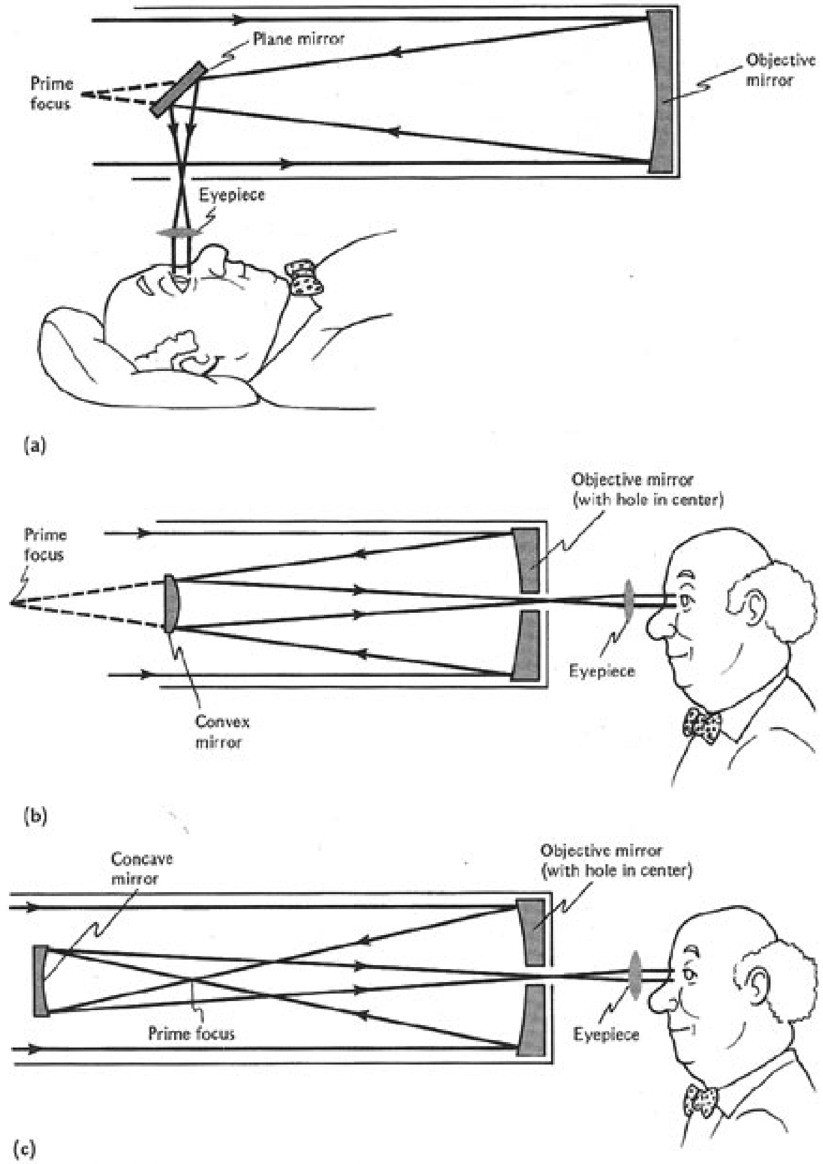


FIGURE 6.16

Reflecting telescopes: **(a)** Newtonian telescope, typically has speeds between f/4 and f/8, **(b)** Cassegrain telescope, the most compact reflecting telescope, with typical speeds between f/7 and f/12, **(c)** Gregorian telescope, longer and less aberration-free than the Cassegrain, but produces an erect image.

Palomar 5-m telescope

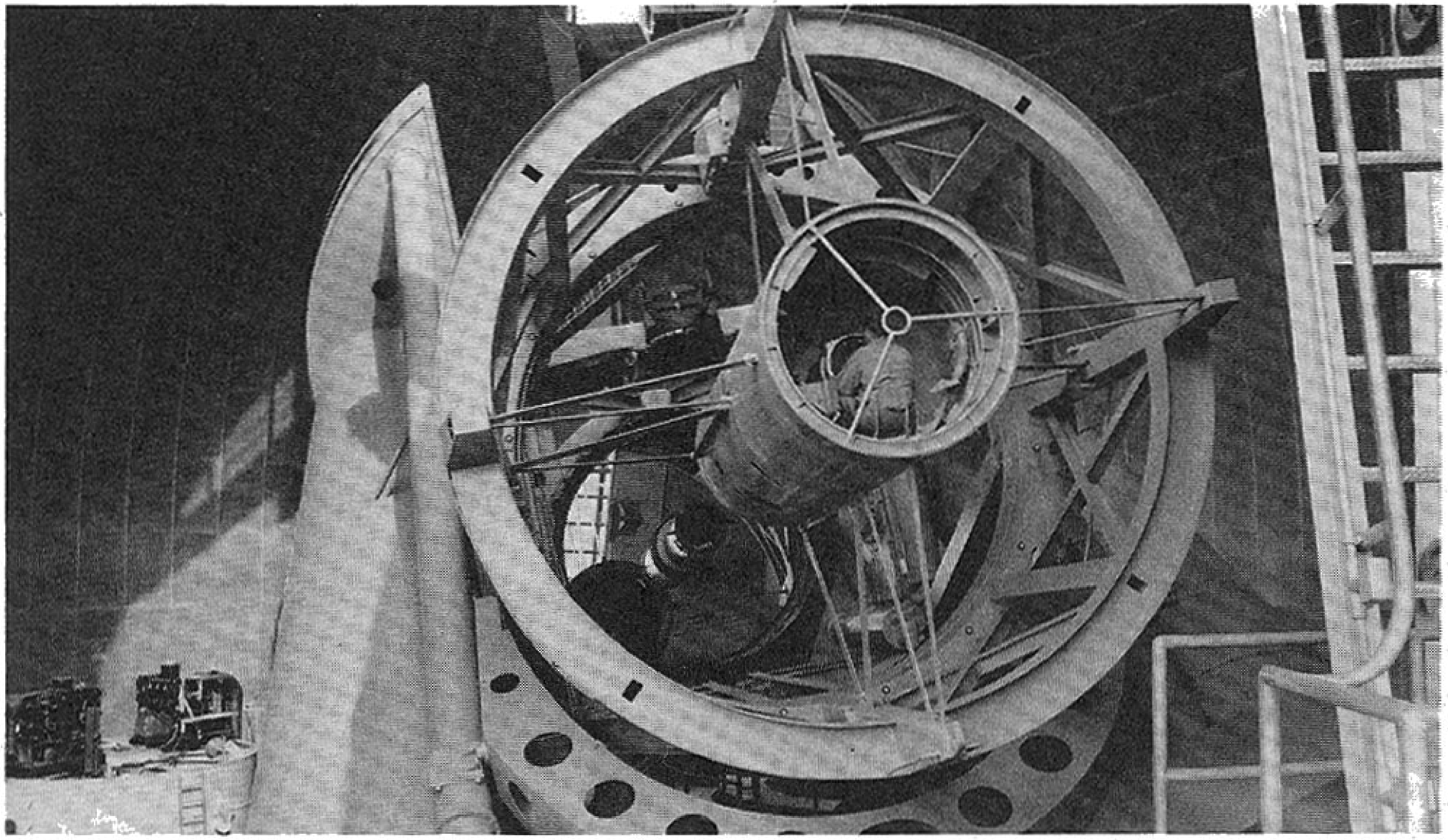
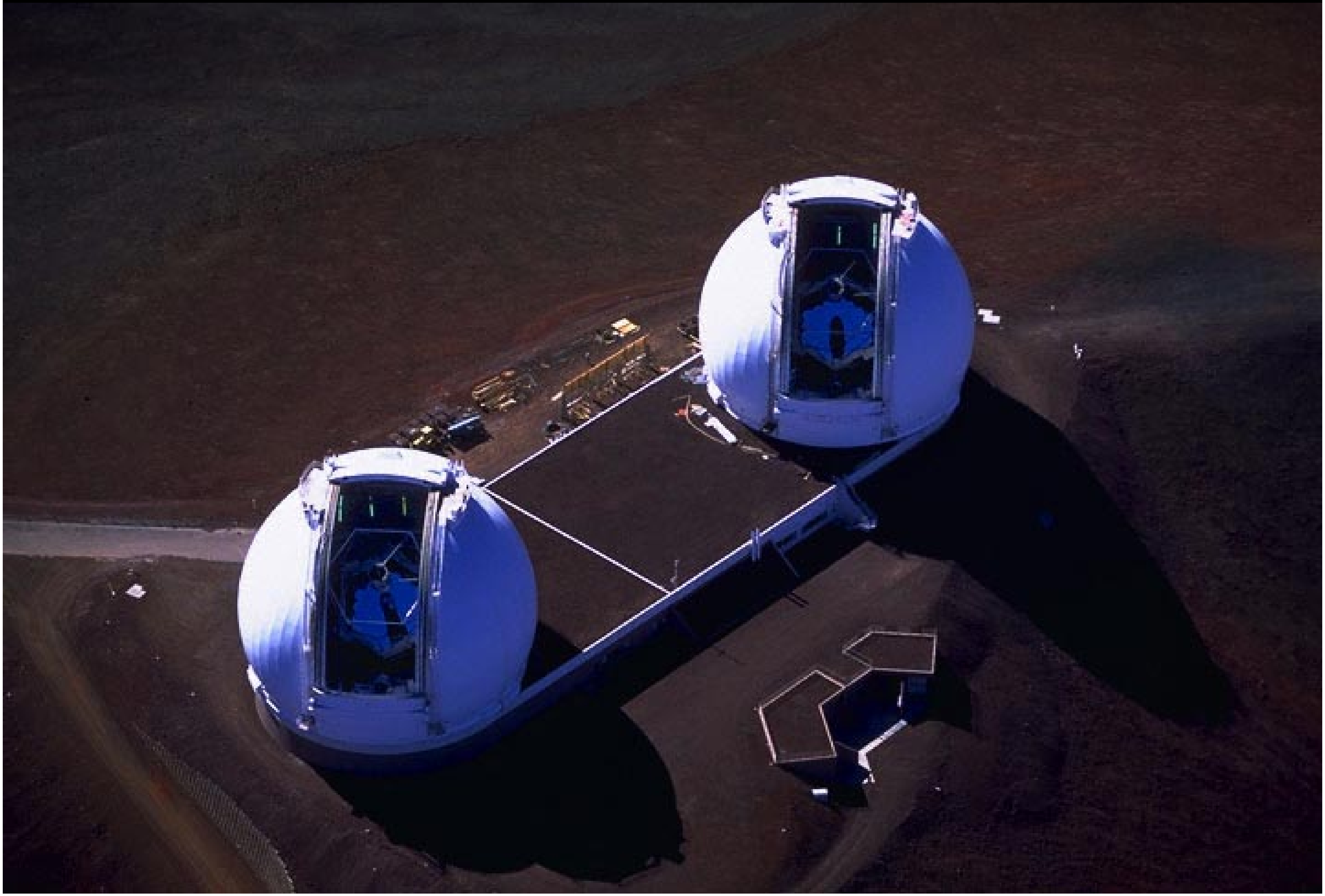


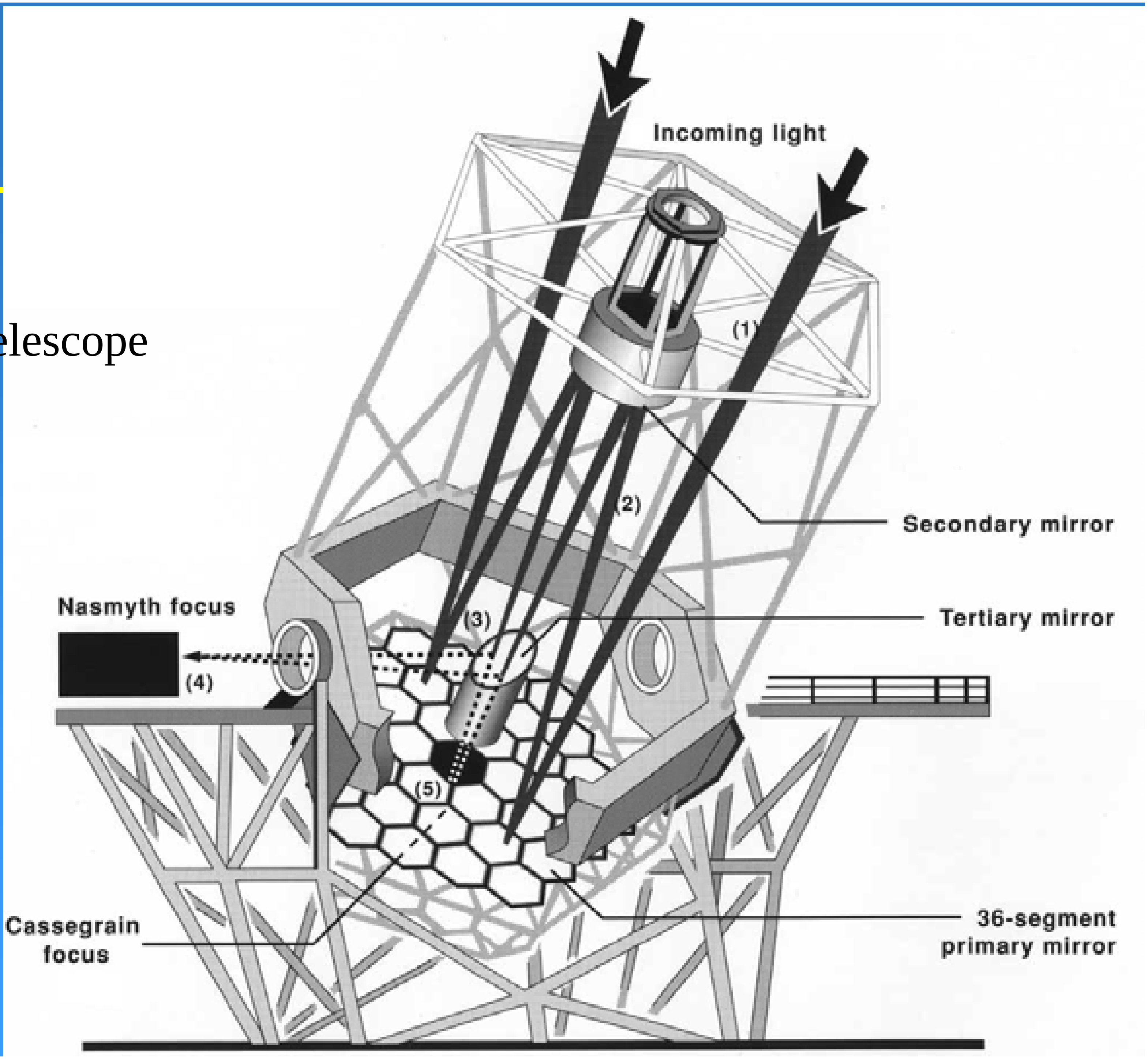
FIGURE 6.17

Photograph of the cage at the primary focus of the Mt. Palomar telescope.

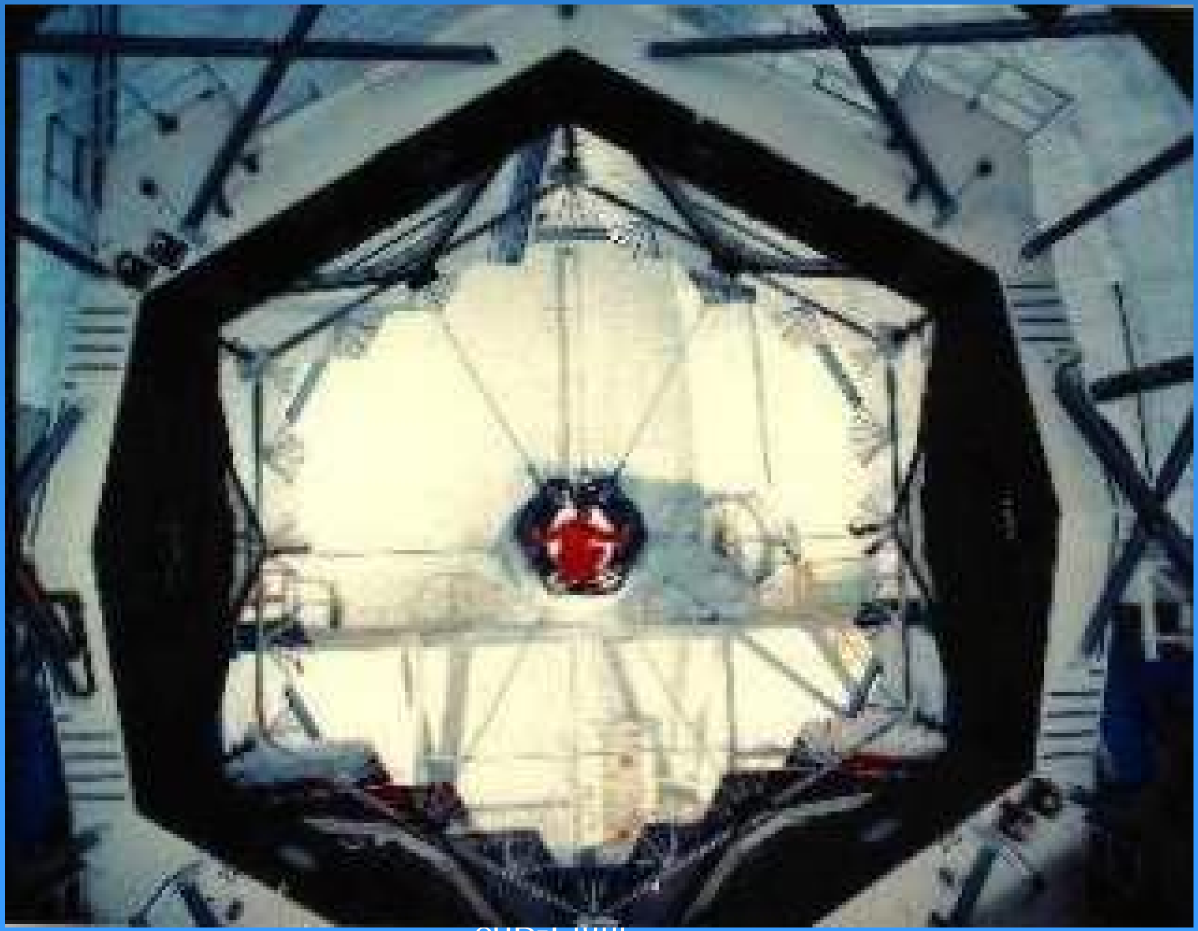
The Keck Telescopes



Keck Telescope

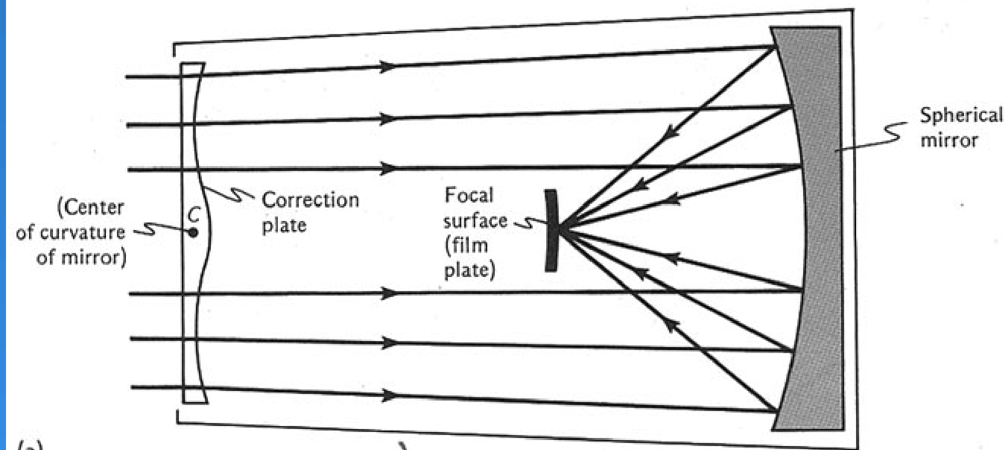


Keck 10-m telescope

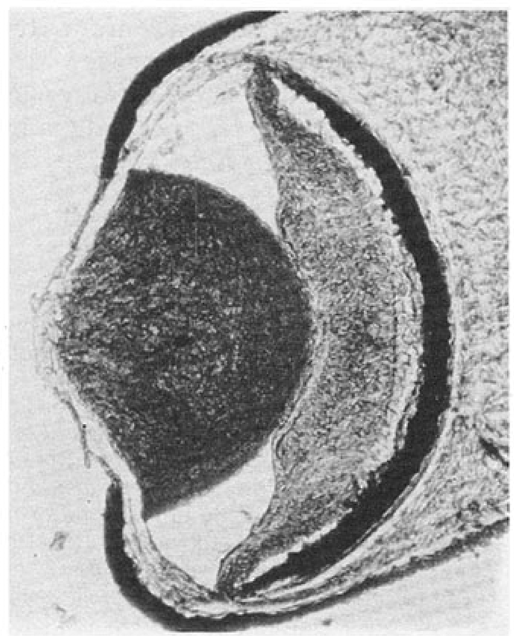


Schmidt telescope

- **Wide field telescope**
  - Lens
    - Correction plate
    - No power
    - Located at center of curvature
  - Spherical mirror
  - Curved focal surface



(a)



(b)

FIGURE 6.18

(a) The Schmidt telescope, and **(b)** a scallop's eye.

Schlieren photograph

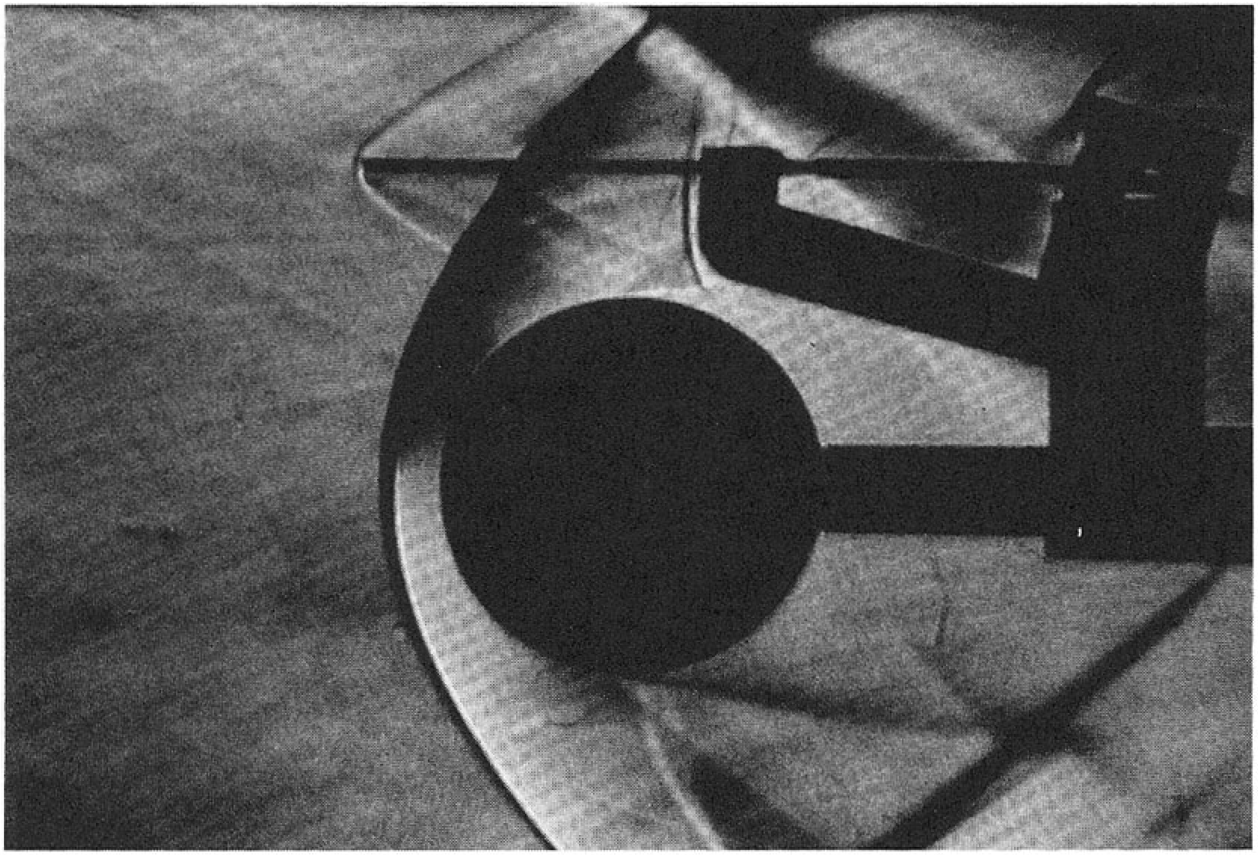


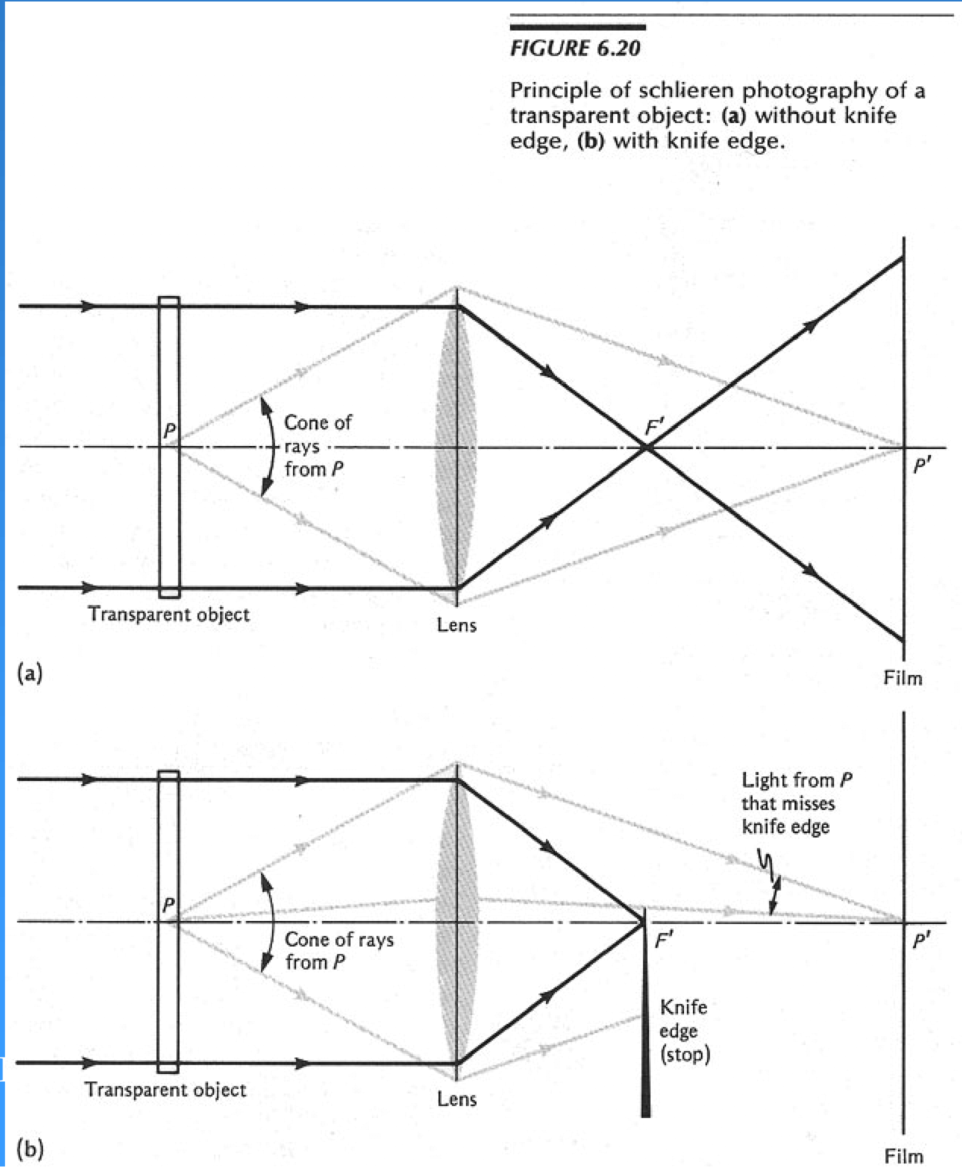
FIGURE 6.19

Schlieren photograph of shock waves in air that moves at supersonic speed past a sphere. The horizontal rod above the sphere measures the pressure.

Principle of Schlieren photography

- **Basic idea is to block the unscattered light, allowing only scattered light to get to final image of the scattering object**

- **Done by putting an opaque object in the light source image plane (a knife edge)**



Principle of field lens

- **Location of field lens is at the image of the field**

- **Purpose is to increase and make more uniform the illumination (reduce vignettng)**

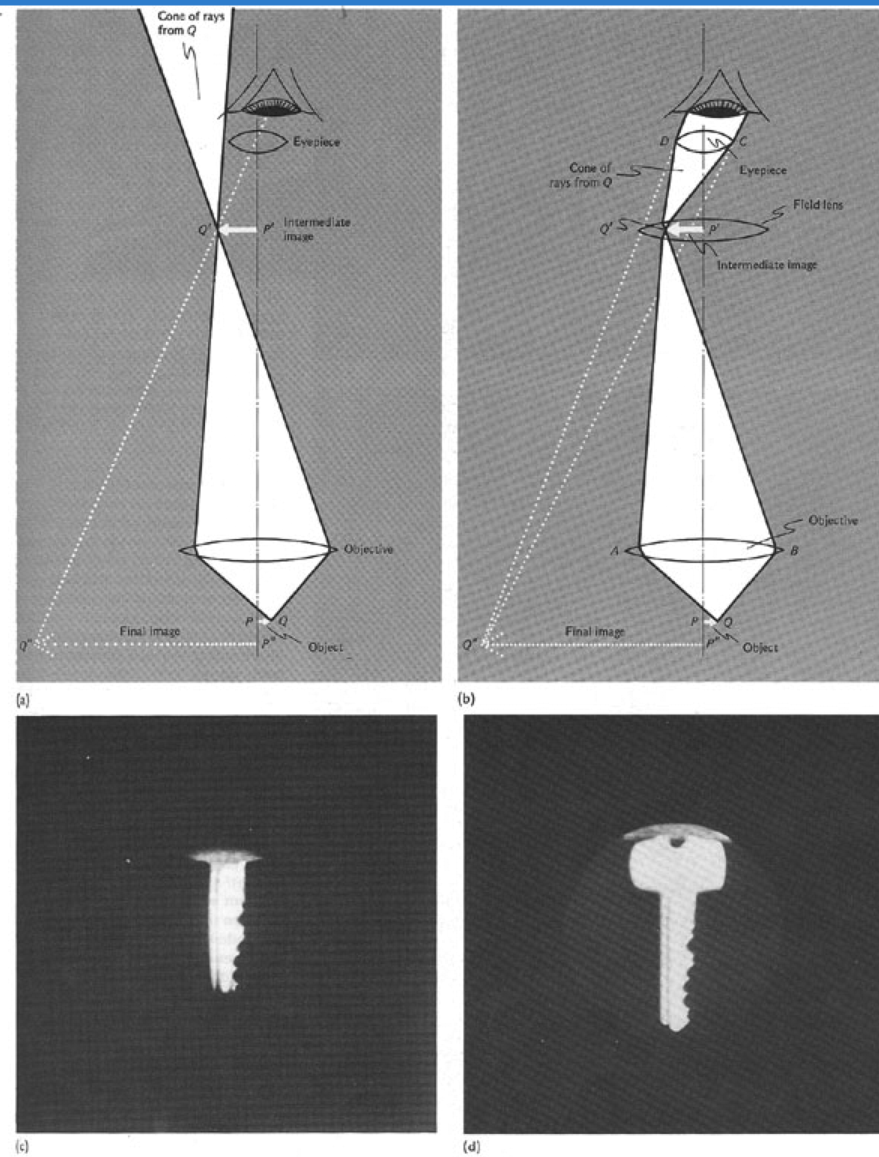


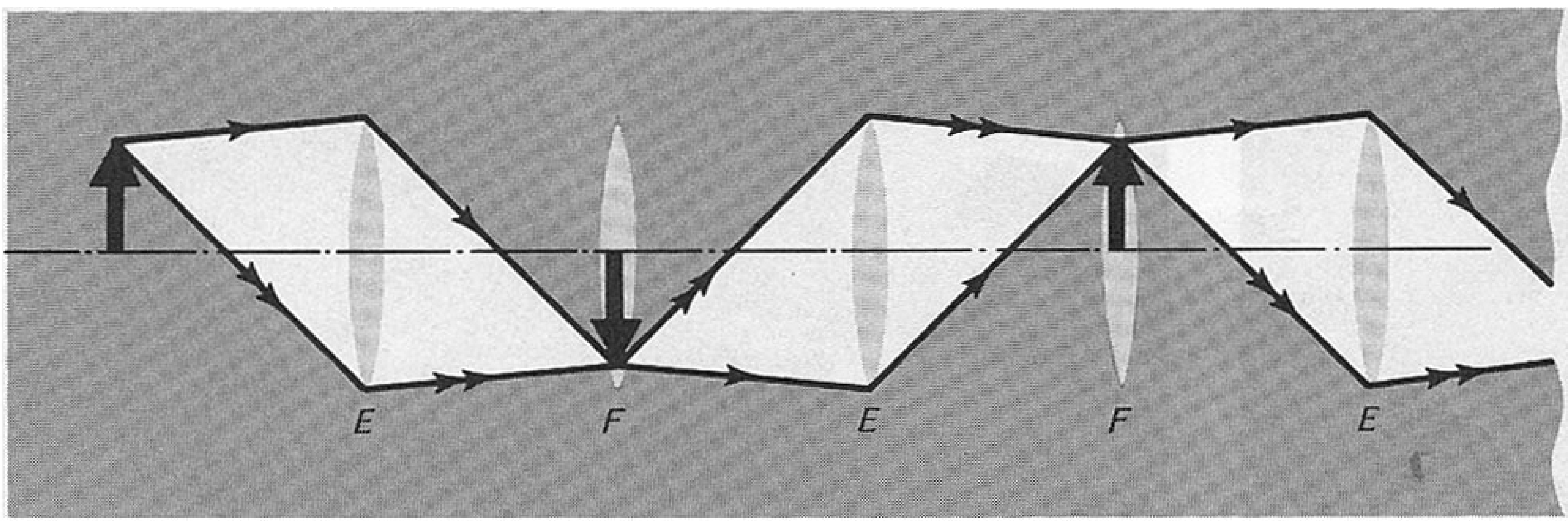
FIGURE 6.21

Principle of the field lens. **(a)** Without field lens the final image is vignetted, only the heavy part of the arrow *P"Q"* is significantly illuminated, the intensity falling to zero at *Q"*. (See this effect in Fig. 4.5c). **(b)** With a field lens the entire field is well illuminated, because the field lens bends the entire cone of rays *AQ'B* into *CQ'D*, so they can reach the eyepiece and the eye. **(c)** and **(d)** Photographs of the eye's view in the two cases, respectively.

Erectng lenses and field lenses

FIGURE 6.22

Erecting lenses *(E)* and field lenses *(F)* that may be part of a long string of lenses in a cystoscope or a periscope. Note that the full cone of rays striking the first lens emerges from the system.



Projector lens

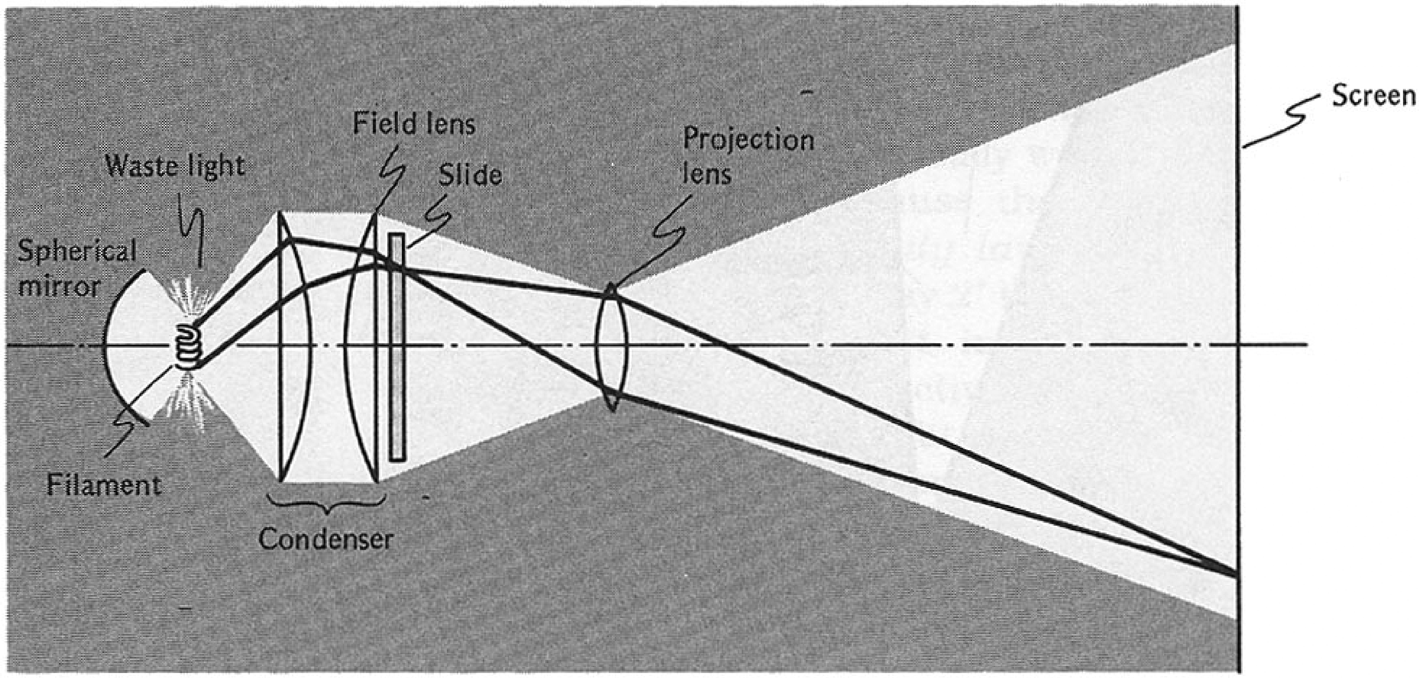


FIGURE 6.23

Projector with illuminating system. Solid outline shows a cone of rays from one point on the slide, defined by the imaging system. White region shows the cone of rays defined by the illuminating system.

Projector lens

- Image made by projector
- Image without field lens
- Image without condenser

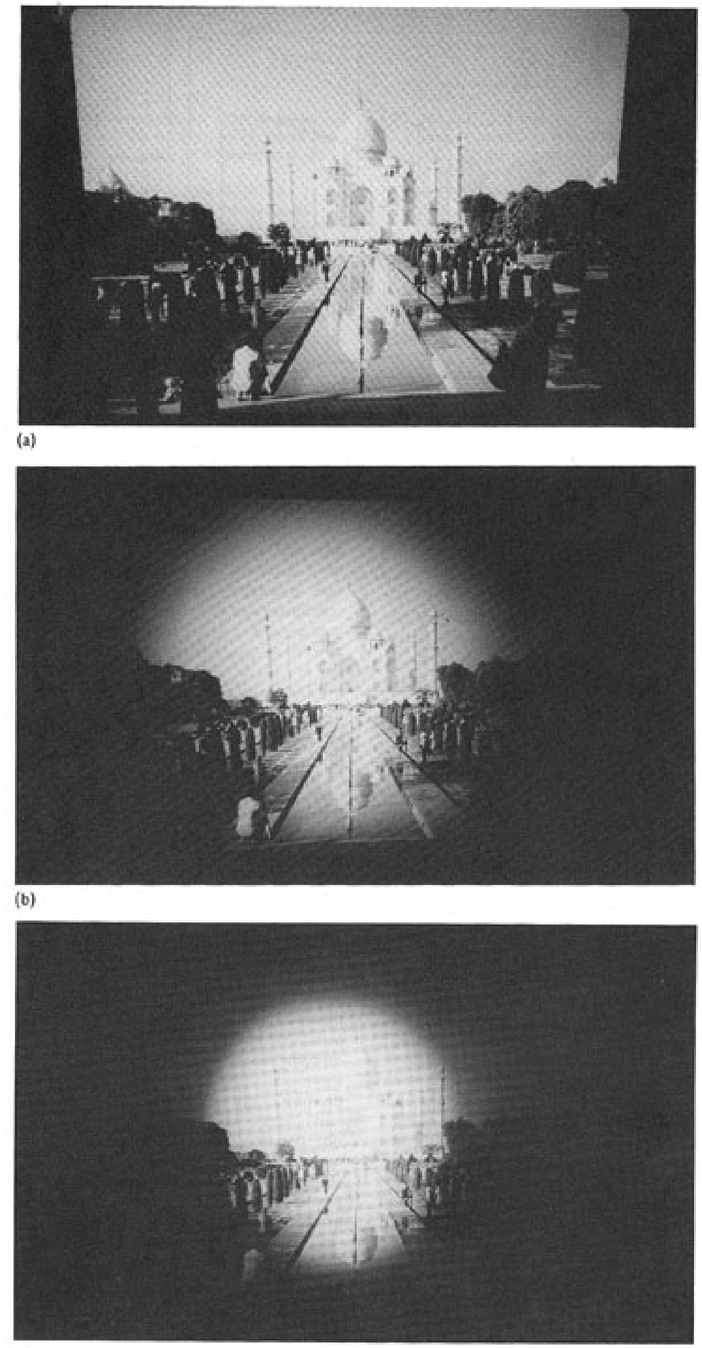


FIGURE 6.24

Image thrown by projector (a) with all lenses in place, (b) with the field lens removed, and (c) with the entire condenser removed. Note the "keystoning" of the image.

Geometry of zoom projection lens

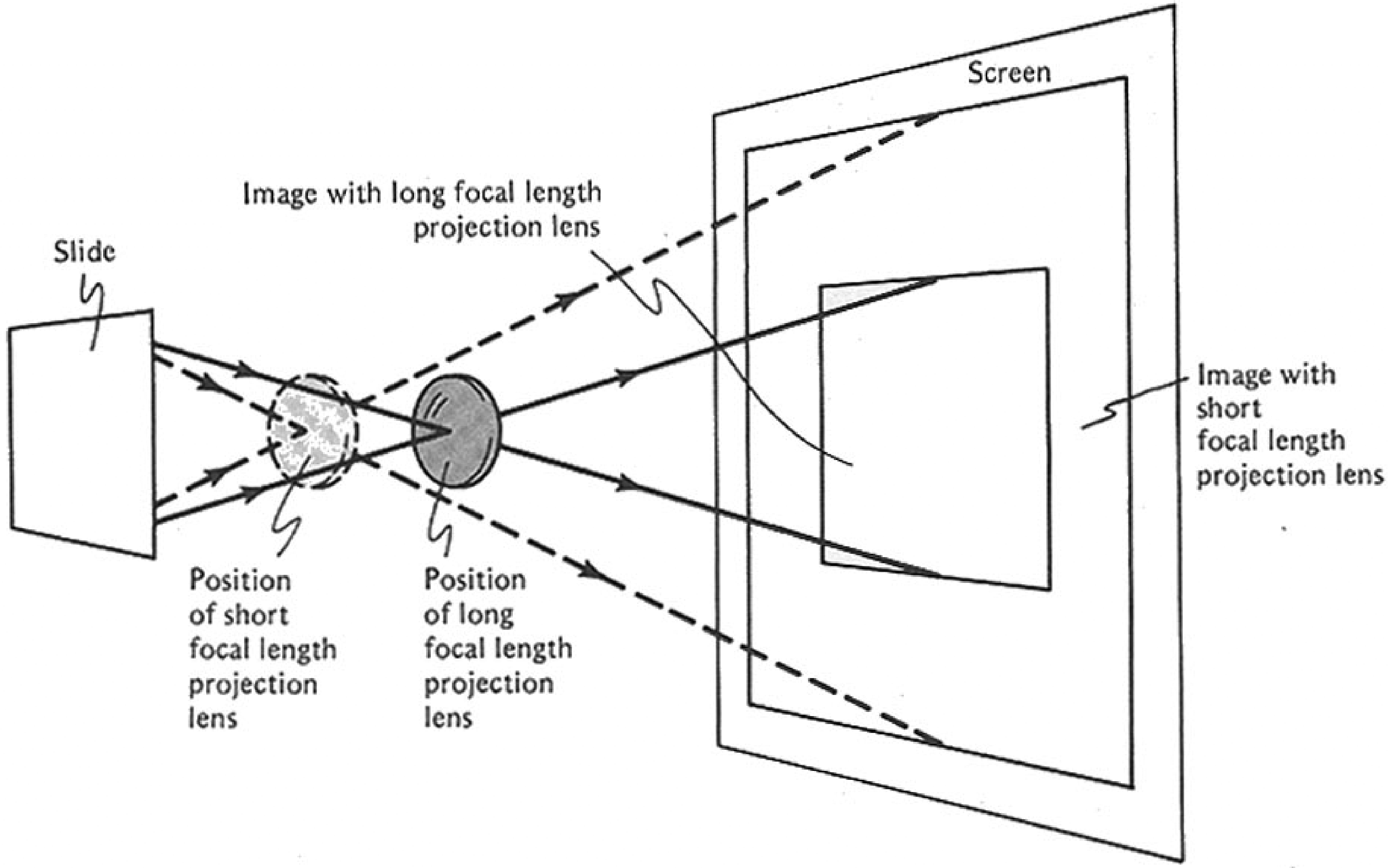


FIGURE 6.25

Zoom projection lens.