Telescope: refractive (dioptric)

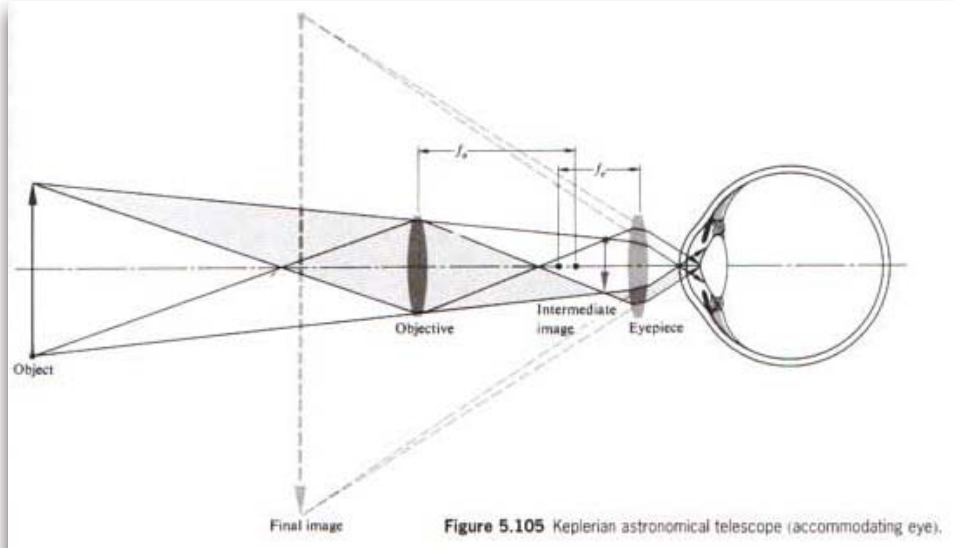
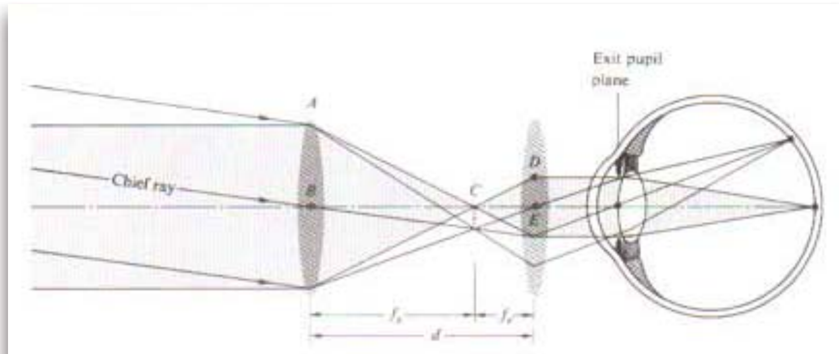


Figure 5.105 Keplerian astronomical telescope (accommodating eye).



- Purpose: to "magnify" thereby providing additional detail on a large, remote object
- Objective lens followed by an eyepiece
  - Objective: forms real, **de**magnified image of the object at the plane where the instrument's field stop is located
  - Eyepiece: its object plane is the objective's image plane and forms a virtual image at infinity
  - Objective's intermediate image location is fixed; eyepiece is moved to focus
- Special case: object at infinity
  - ➡ since the virtual image must be at infinity,* the distance between objective (o) and eyepiece (e) must satisfy

$$d = f_\mathrm{o} + f_\mathrm{e}$$

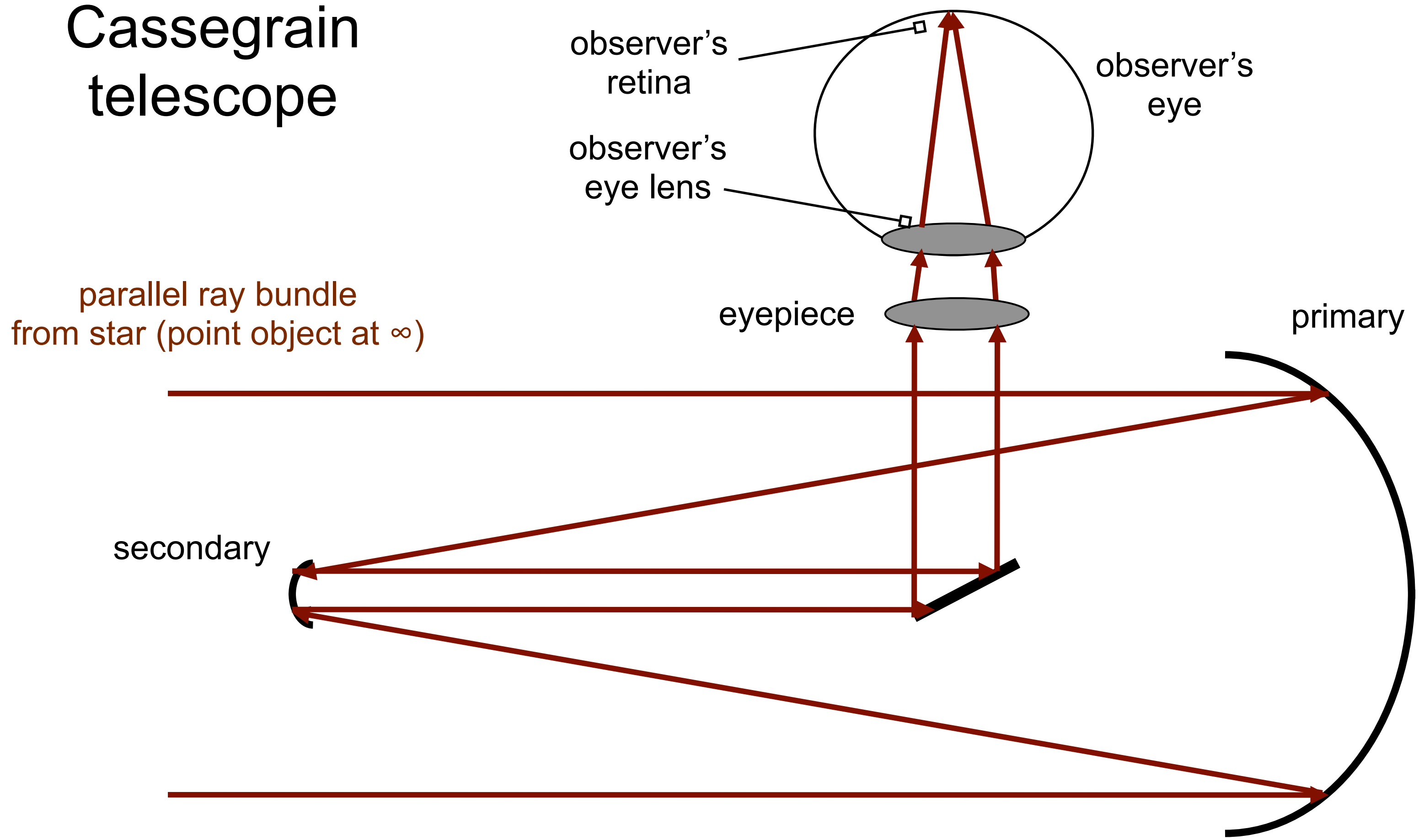
  - ➡ This type of instrument is known as afocal, because its focal length is undefined (the 12 matrix term is 0)

Magnifying power $\mathrm{MP} \equiv \dfrac{\alpha_a}{\alpha_u} = -\dfrac{f_\mathrm{o}}{f_\mathrm{e}}$

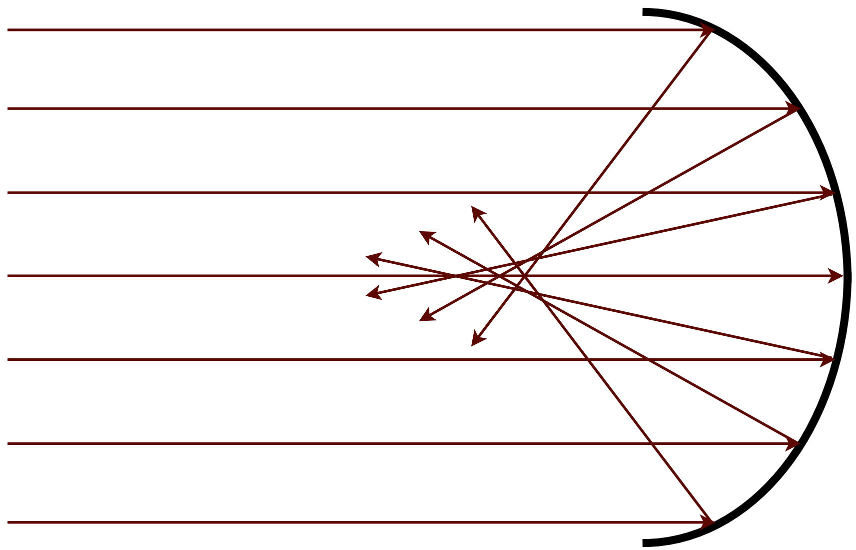
* Recall that the eye lens forms the final real image on the retina

Telescope: reflective (catoptric)

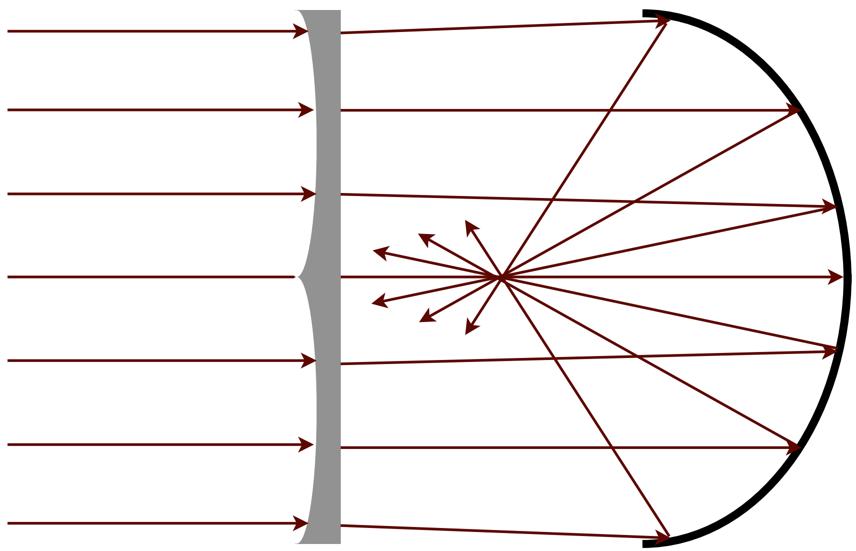
Cassegrain telescope



Telescope: catadioptric



spherical mirror
➡ spherical aberration
(due to the difference from the ideal parabolic shape)



Schmidt's correction
➢ toroidal glass surface deviates the rays so the reflections focus perfectly
(in practice, the design is more complicated because of the presence of aberrations other than spherical)

Aberrations

- Chromatic
  - is due to the fact that the refractive index of lenses, etc. varies with wavelength; therefore, focal lengths, imaging conditions, etc. are wavelength-dependent

- Geometrical
  - are due to the deviation of non-paraxial rays from the approximations we have used so far to derive focal lengths, imaging conditions, etc.; therefore, rays going through imaging systems typically do not focus perfectly but instead scatter around the "paraxial" (or "Gaussian") focus

Chromatic aberration

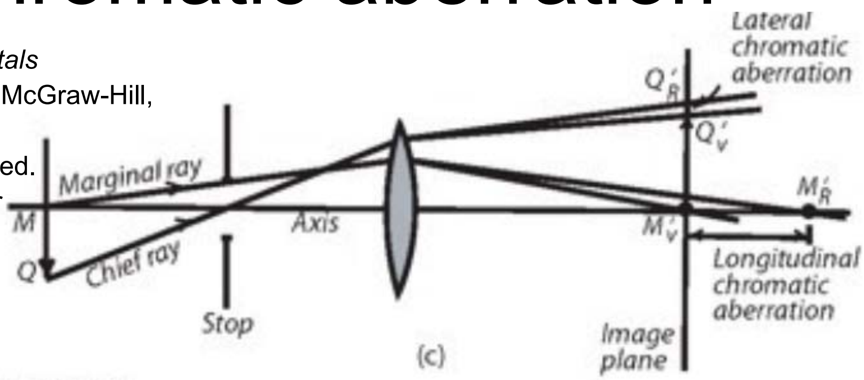


FIGURE 9X
(a) Cromatic aberration of a singel lens. (b) Acemented doublet corrected for chromatic aberration. (c) Illustrating the difference between longitudinal chromatic aberration and lateral chromatic aberration.

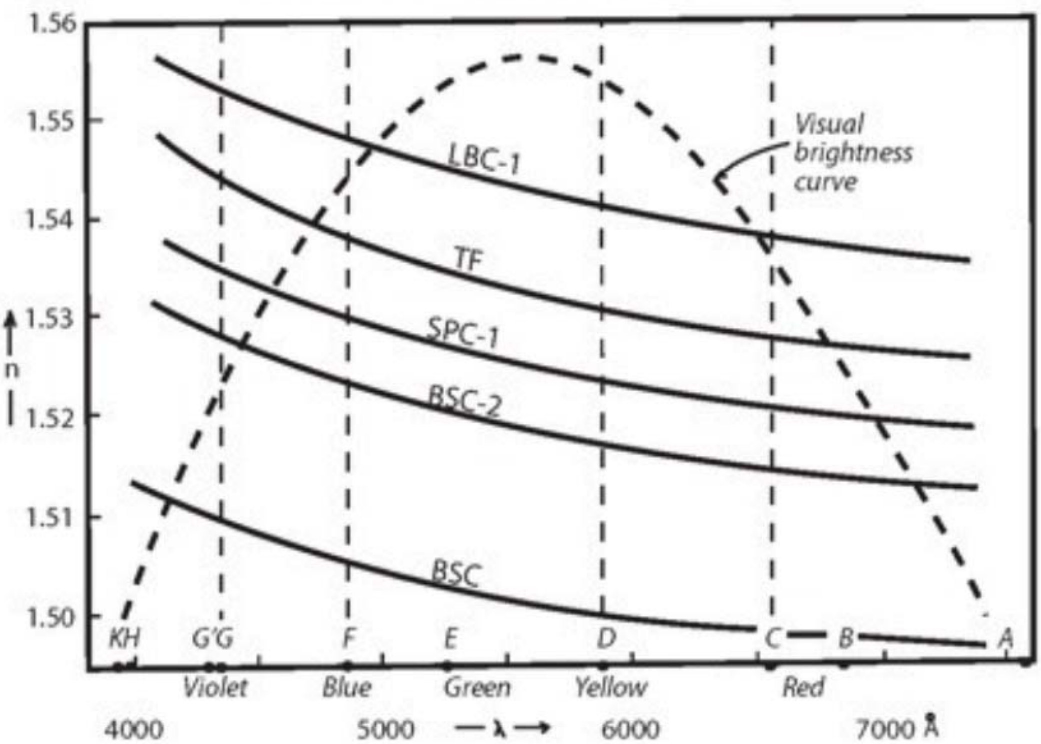
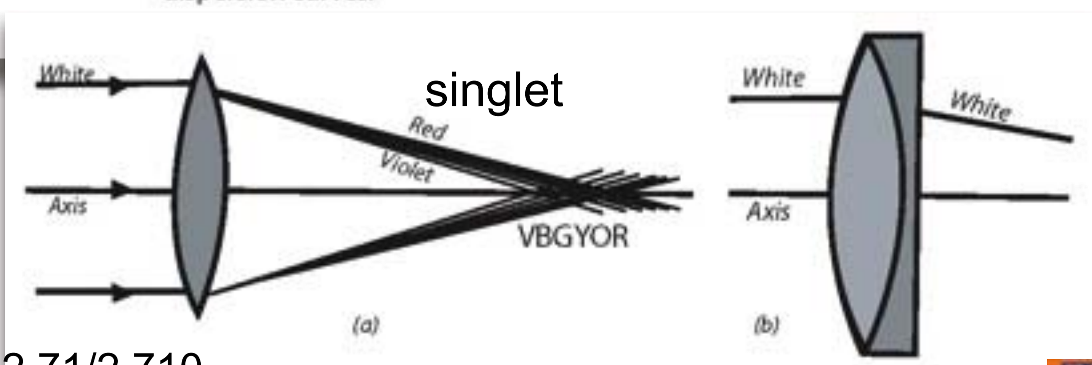
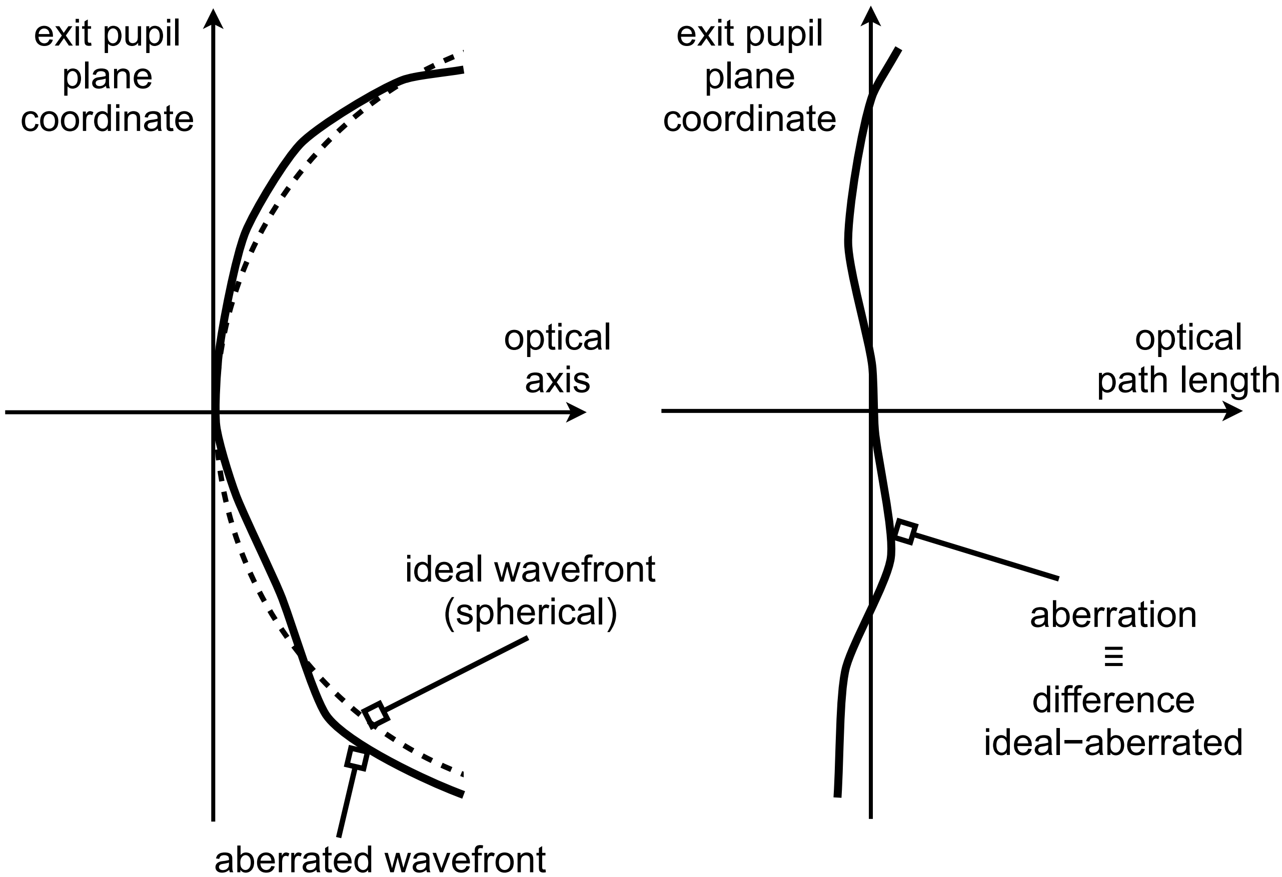


FIGURE 9Y
Graphs of the refractive indices of several kinds of optical glass. Theseare called dispersion curves.



doublet (corrected)

Geometrical aberrations



Geometrical aberration is the deviation of the wavefront produced by an optical system at the exit pupil, with respect to the ideal spherical wavefront that would have produced a point image.

Generally, computing aberrations is a complicated geometrical/algebraic exercise. Traditionally, and to gain intuition, aberrations have been studied as successive terms in a perturbation (Taylor) expansion of the aberrated wavefronts in the rotationally symmetric case.

Here, we will only consider only 3rd order aberrations.

Primary (Seidel) aberrations

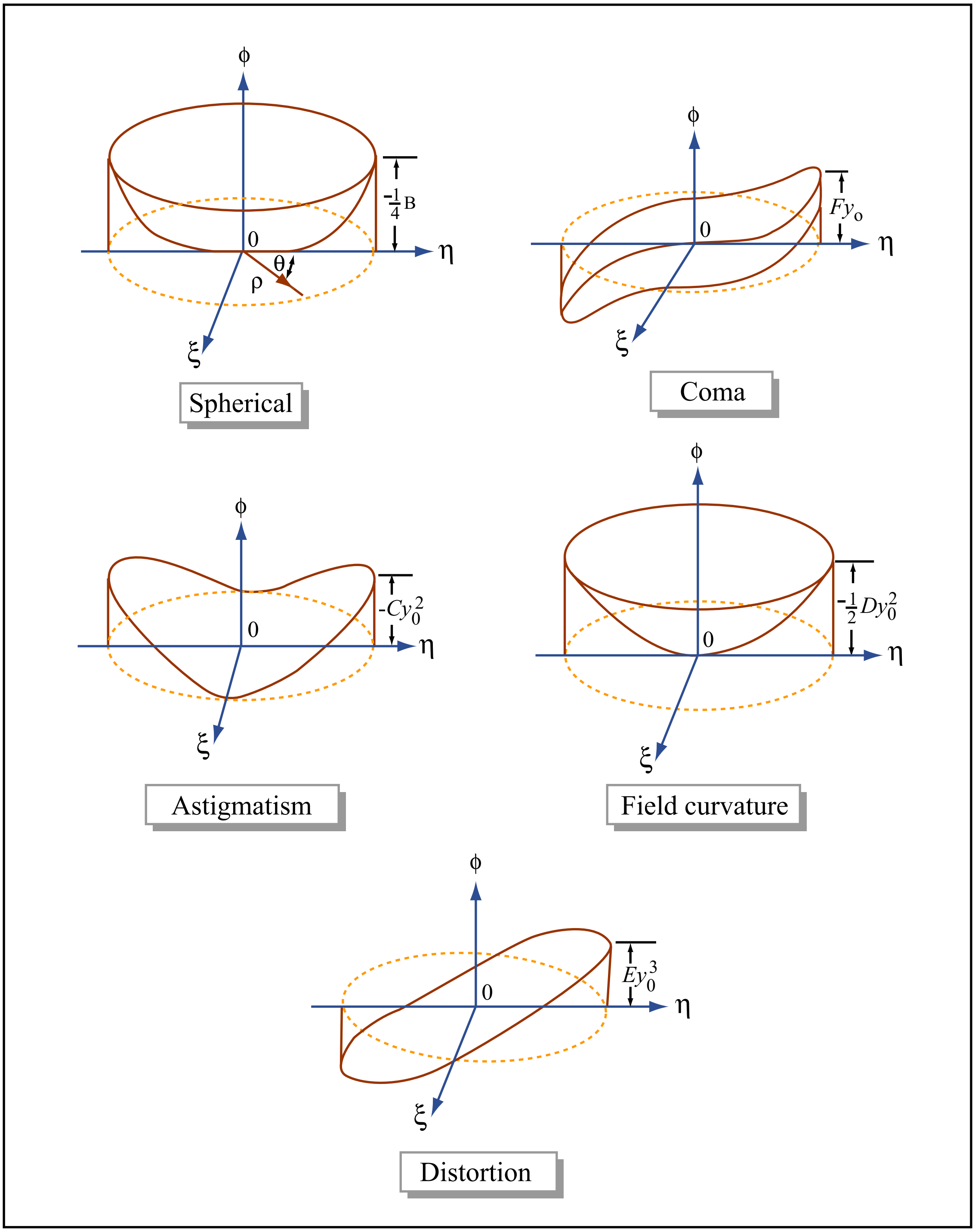
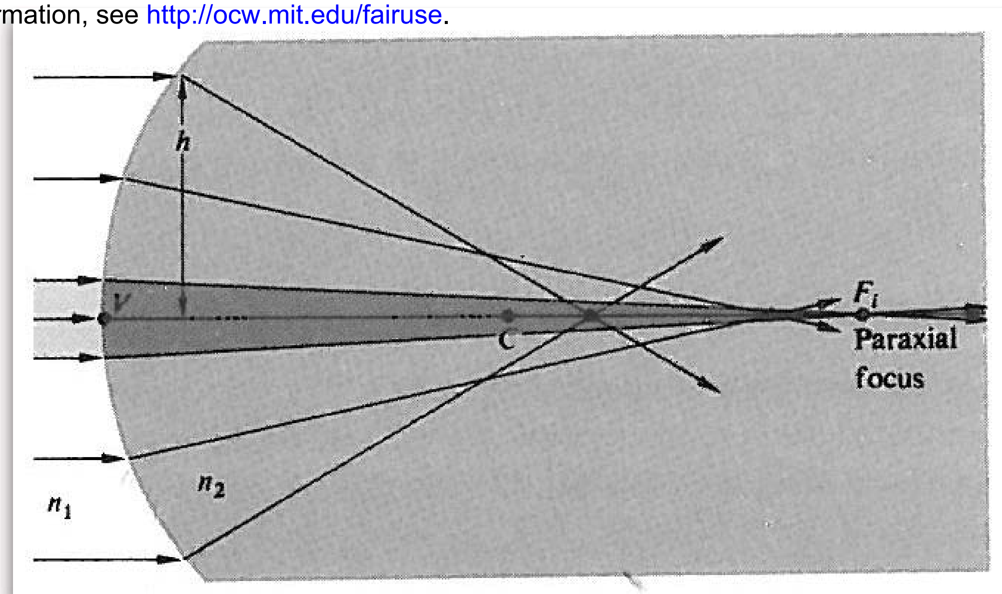
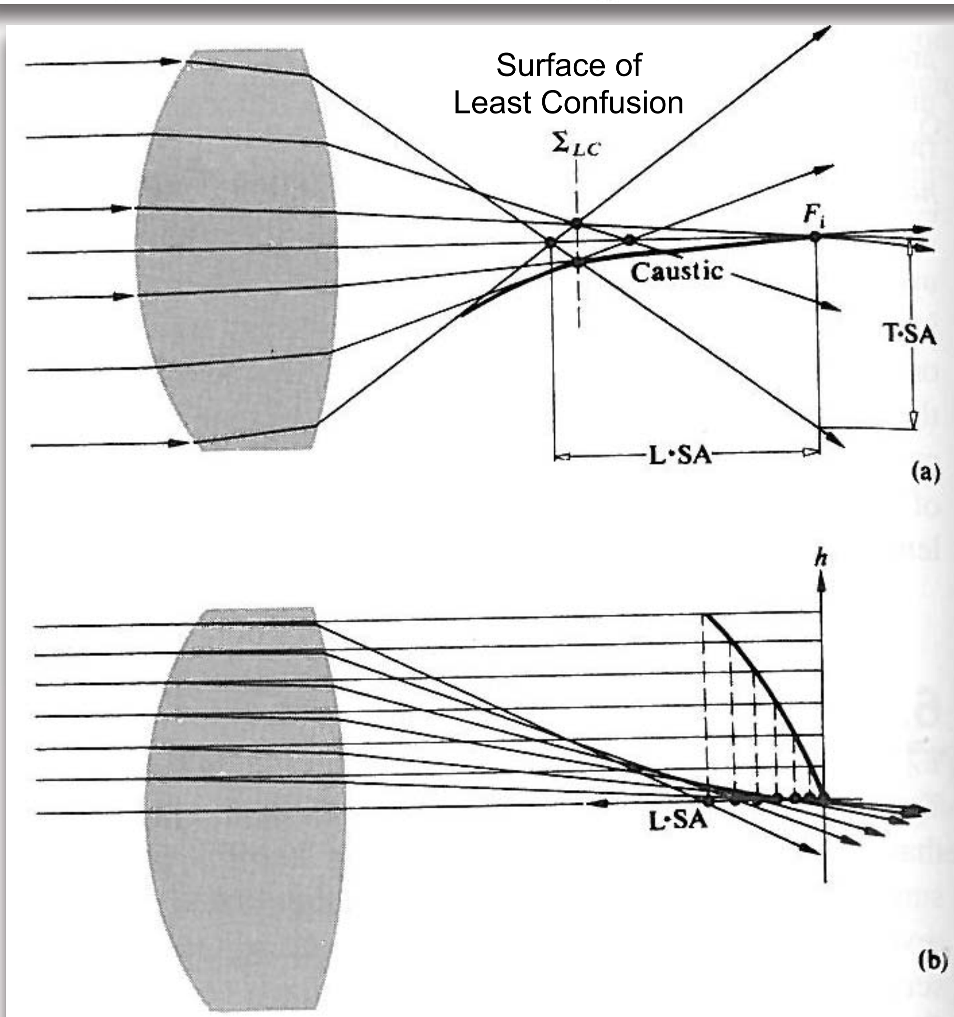


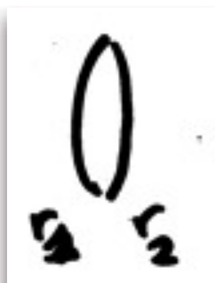
Image by MIT OpenCourseWare.

Spherical


h
V
C
F_i
Paraxial focus
n_2
n_1


Surface of
Least Confusion
Σ_{LC}
F_i
Caustic
T·SA
L·SA
(a)
h
L·SA
(b)

Spherical aberration and lens asymmetry (the *q* factor)



$$q \equiv \frac{r_2 + r_1}{r_2 - r_1}$$

$$p \equiv \frac{s_o + s_i}{s_o - s_i}$$

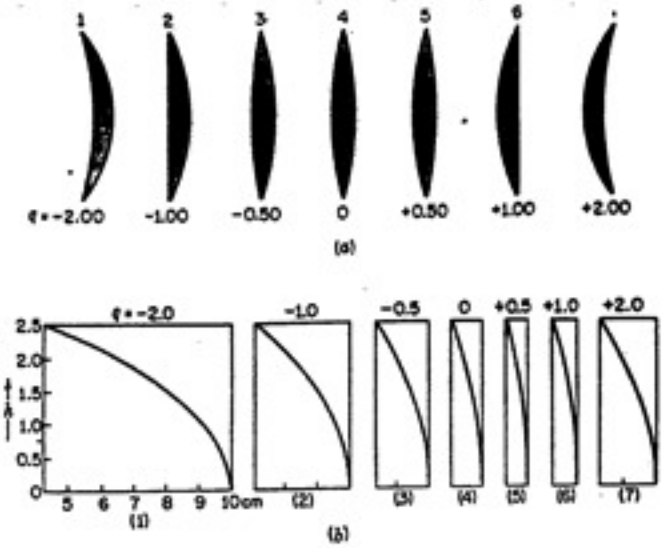
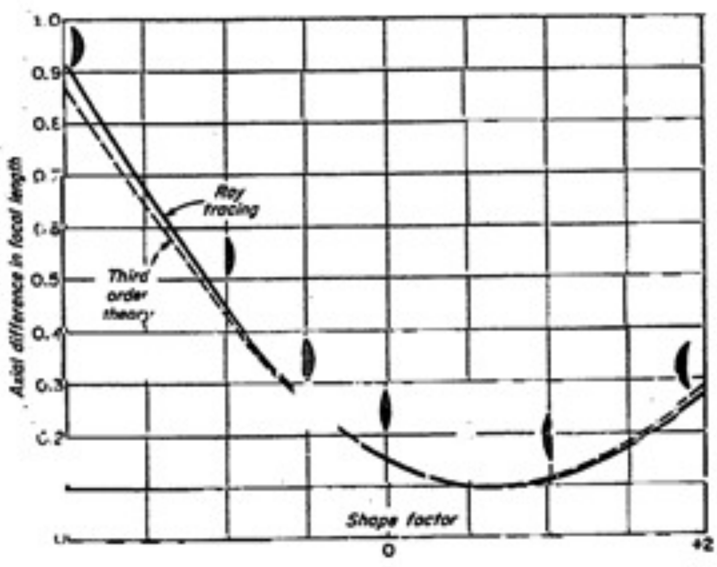
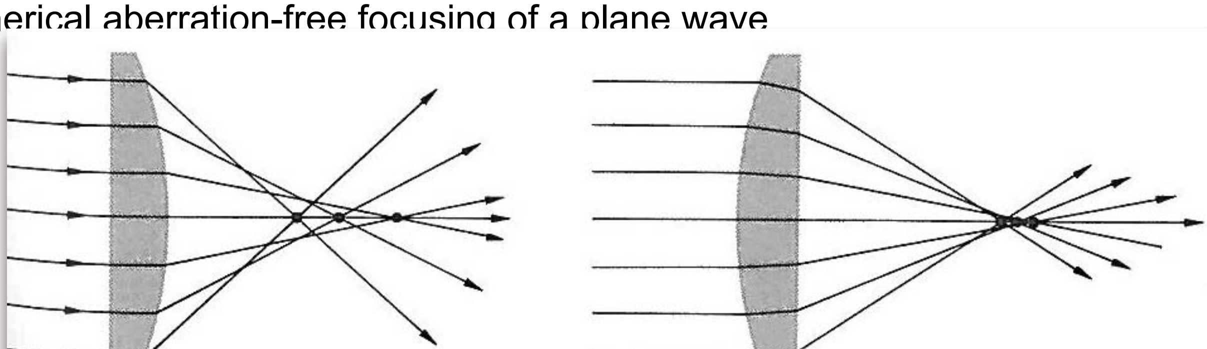


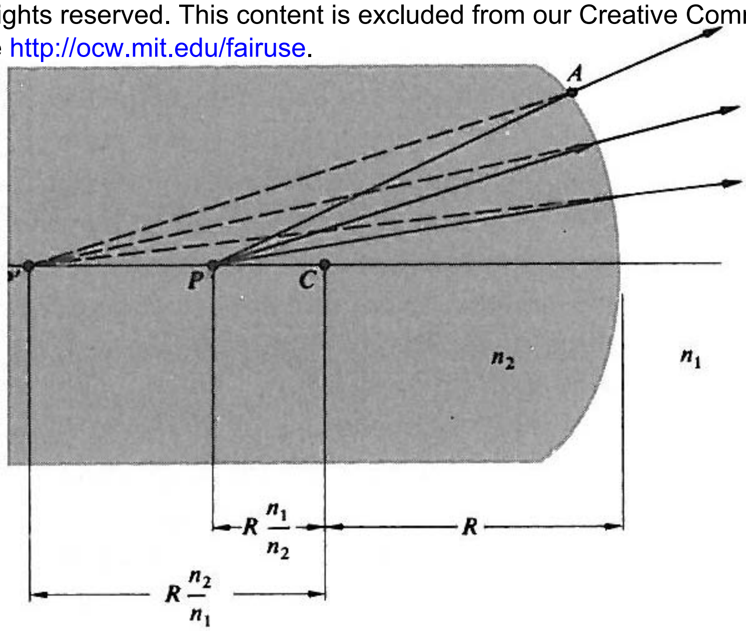
FIGURE 9F
(*a*) Lenses of different shapes but with the same power or focal length. The difference is one of bending. (*b*) Focal length versus ray height *h* for these lenses.



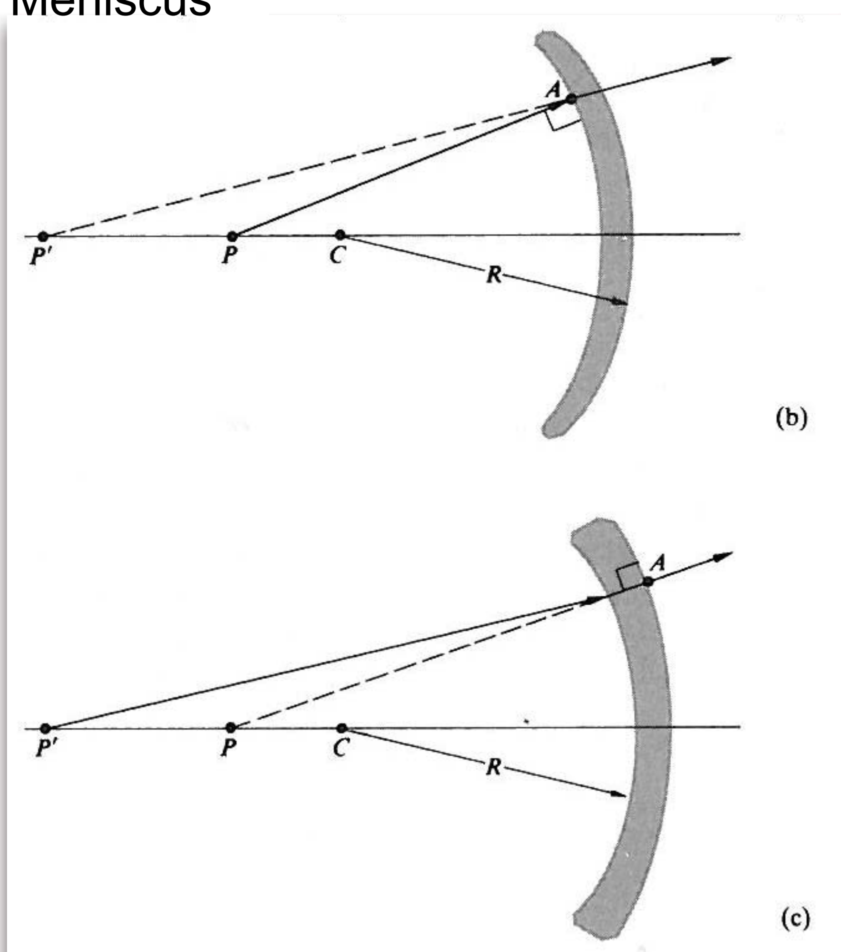
How to orient an asymmetric (plano-convex lens) for spherical aberration-free focusing of a plane wave



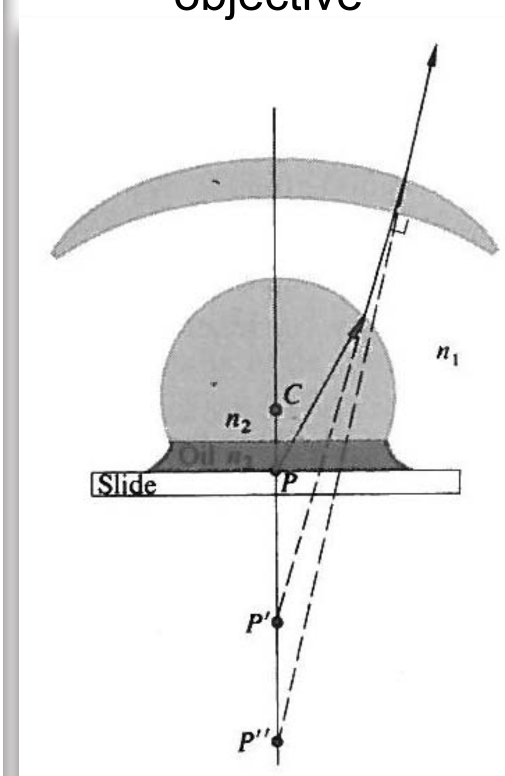
Aplanatic surfaces and conjugate points



Meniscus



Oil immersion microscope objective



Coma

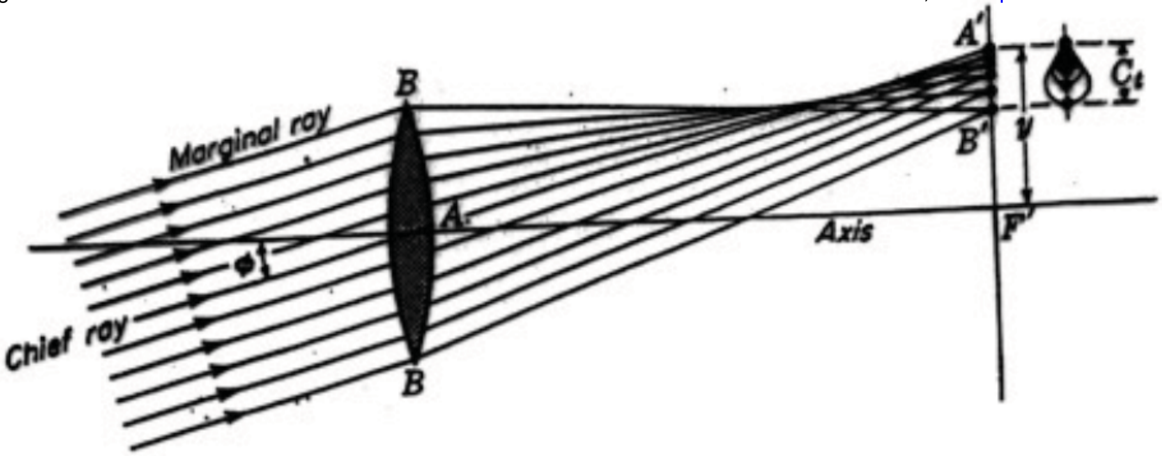
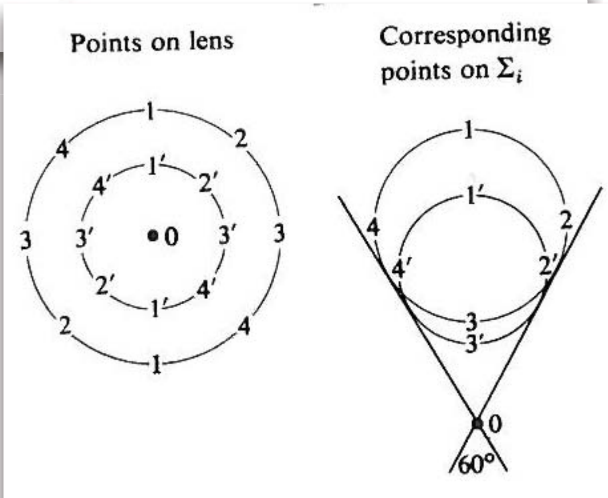
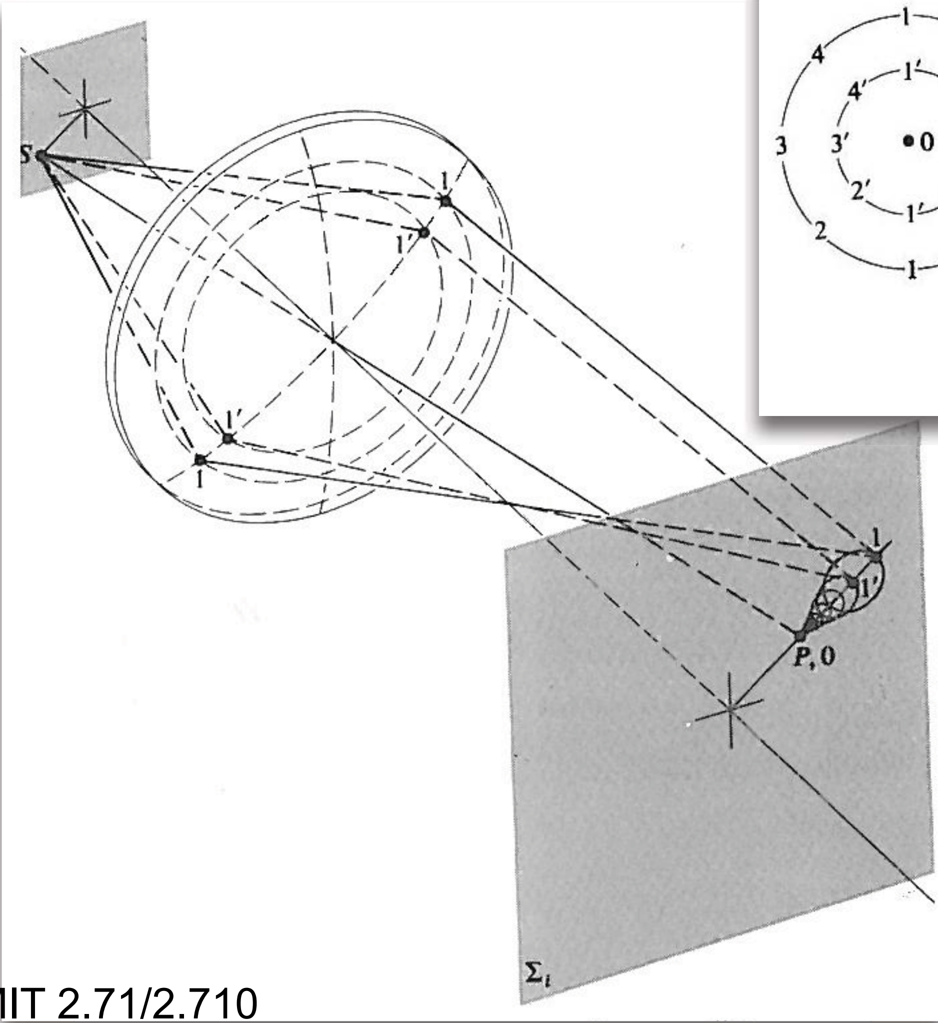


FIGURE 9I
Coma, the second of the five monochromatic aberrations of a lens. Only the tangential fan of rays is shown.



$$C_T = 3C_s$$



Simultaneous compensation of spherical and coma, using the lens form factor

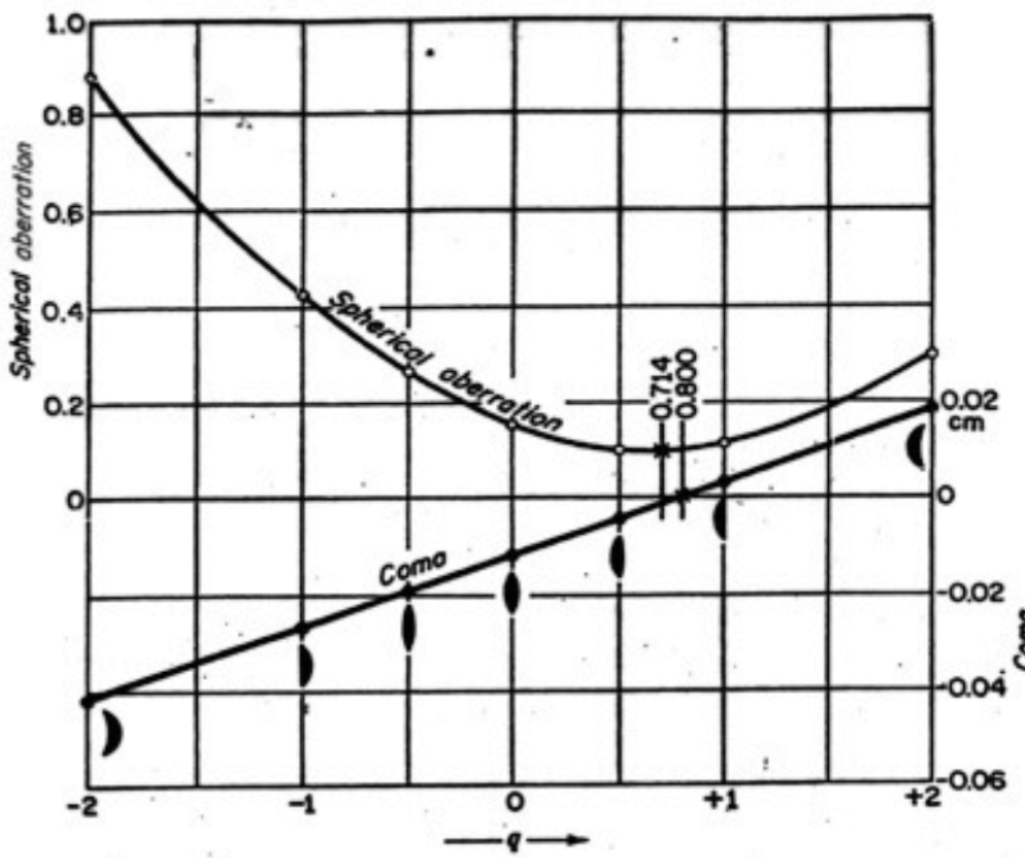


FIGURE 9L
Graphs comparing coma with longitudinal spherical aberration for a series of lenses having different shapes.

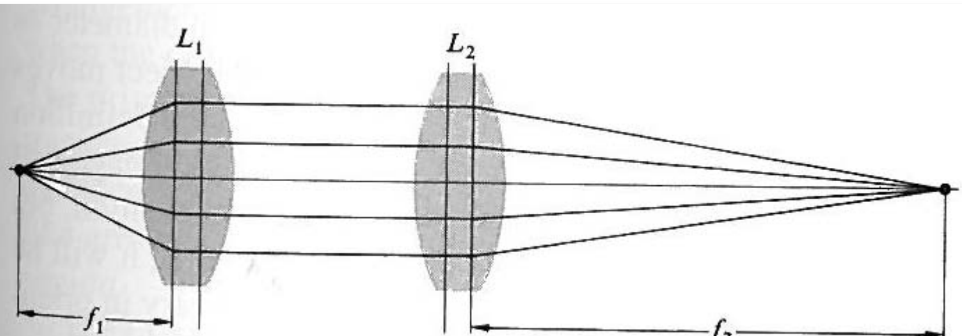


Figure 6.24 A combination of two infinite conjugate lenses yielding a system operating at finite conjugates.

The sine theorem and the sine condition

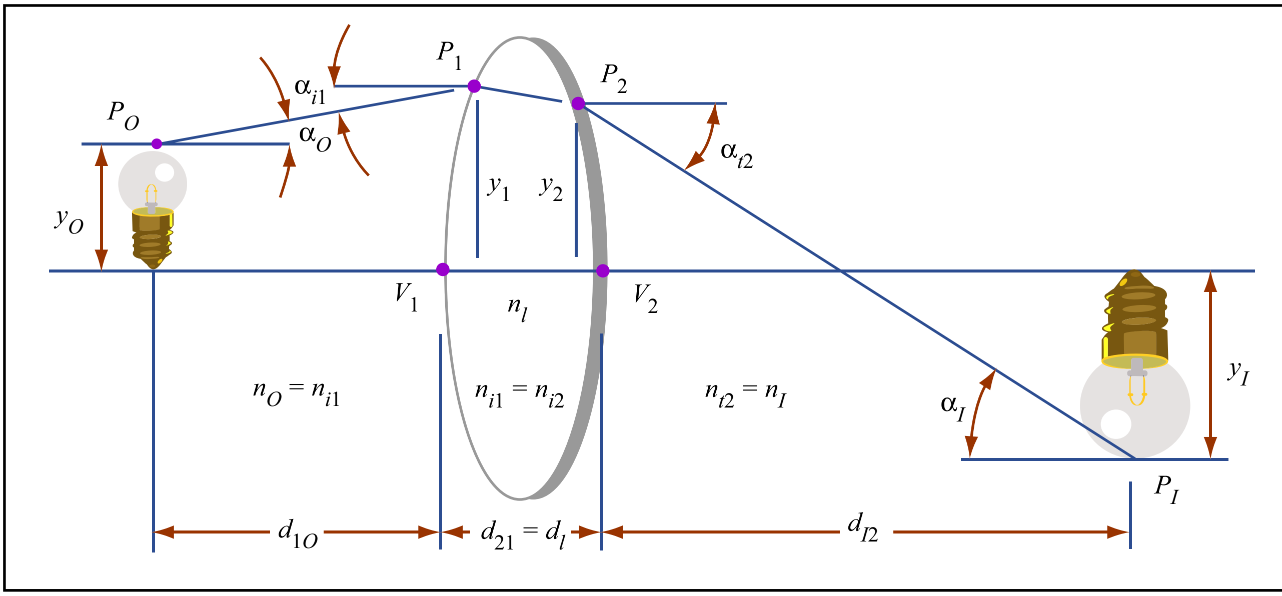


Figure by MIT OpenCourseWare.

Optical sine theorem (Clausius, 1863; Abbe, 1873; Helmholtz, 1873)

$$n_o y_o \sin\alpha_o = n_i y_i \sin\alpha_i.$$

From this we deduce that there is no coma if

$$M_T \equiv \frac{y_i}{y_o}$$

is the same for all rays. For the paraxial rays,

$$n_{o,\mathrm{p}} y_{o,\mathrm{p}} \alpha_{o,\mathrm{p}} = n_{i,\mathrm{p}} y_{i,\mathrm{p}} \alpha_{i,\mathrm{p}},$$

so the constant magnification condition is satisfied.
To satisfy the same condition for non–paraxial rays, we require

$$\frac{\sin\alpha_o}{\sin\alpha_i} = \frac{\alpha_{o,\mathrm{p}}}{\alpha_{i,\mathrm{p}}} = \text{const.} \qquad \textbf{:sine condition}$$

2.71 / 2.710 Optics
Spring 2009