PHYS 434 Optics

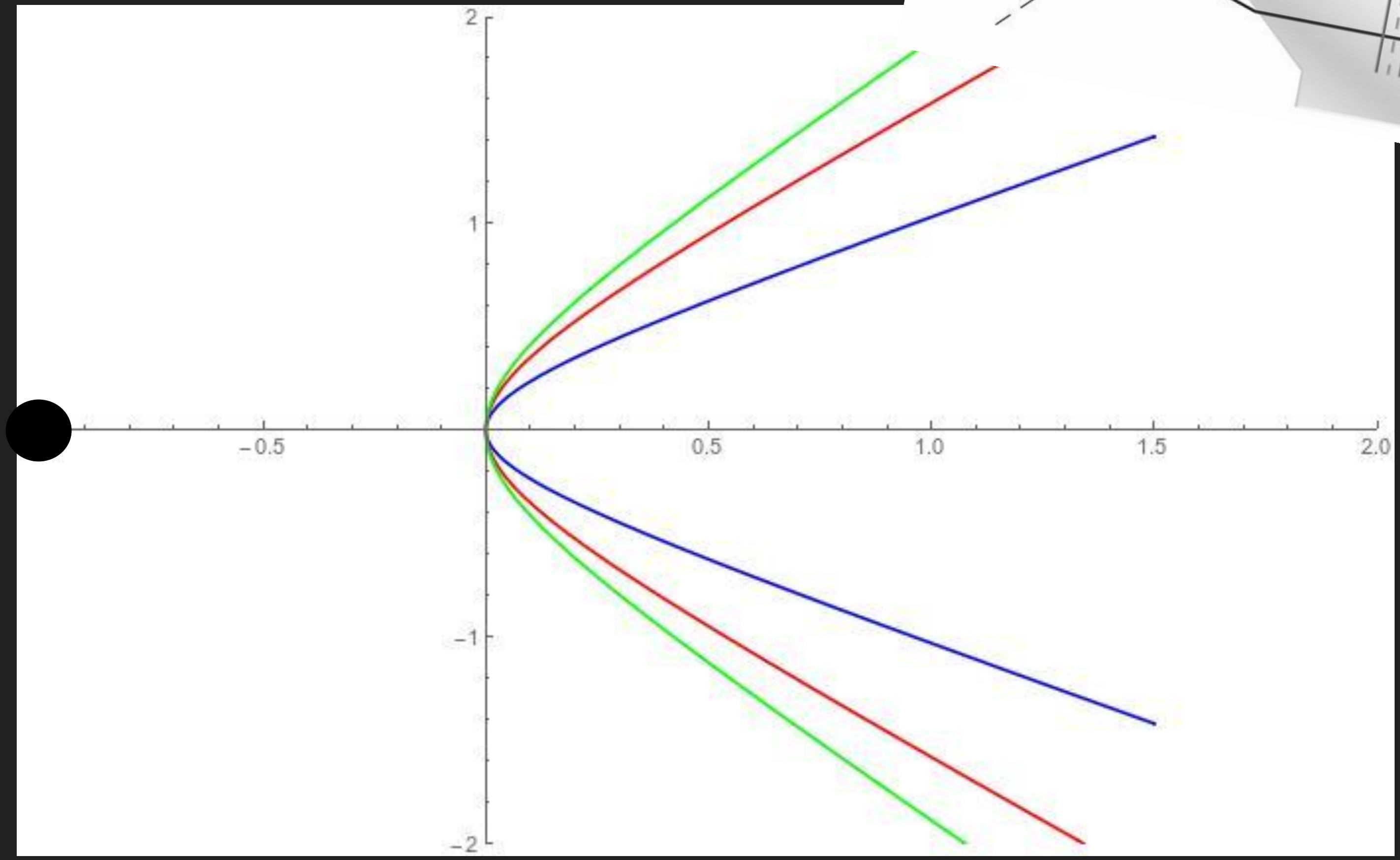
Lecture 5: Introduction to Lenses

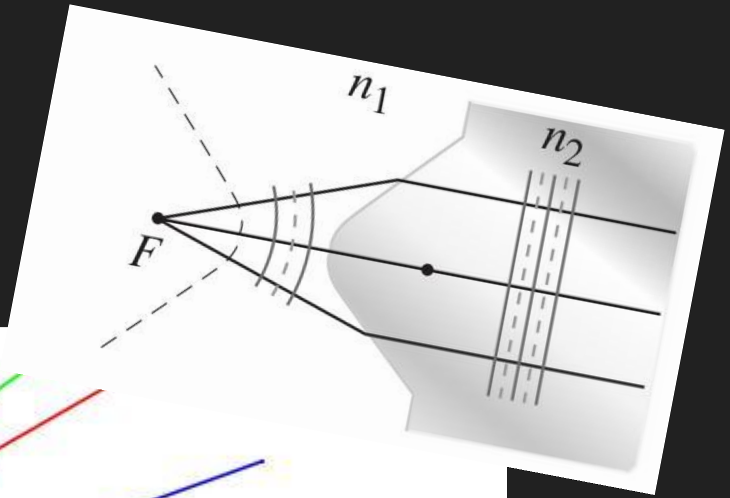
Reading: 5.1, 5.2

Summary Lecture 4

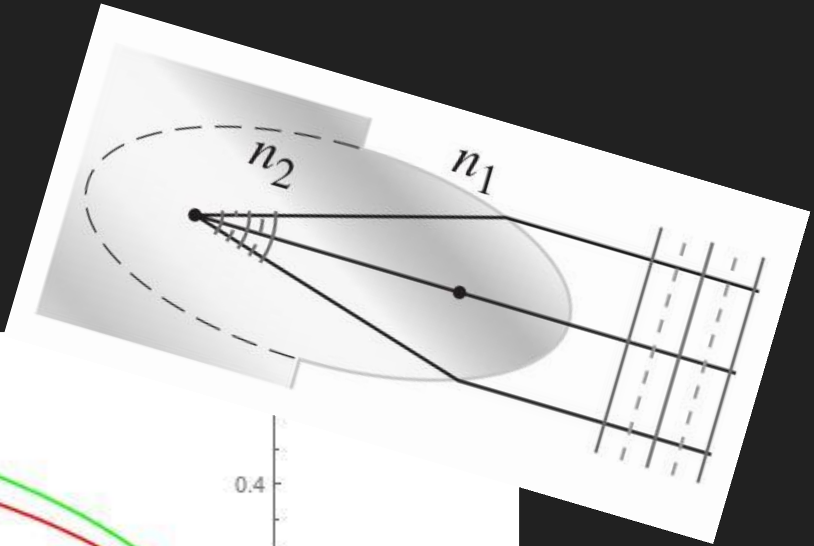
- Based on continuity conditions for the electric and magnetic field components, as well as the laws of reflection and refraction, we can derive ratios of the incident and reflected/transmitted wave amplitude.
- The resulting Fresnel equations provide the means to quantitatively study how an incident EM wave is affected by an interface and 'proof' several of the concepts, we have discussed so far.
- We calculated the power transferred in this process by addressing the reflectance and transmittance.

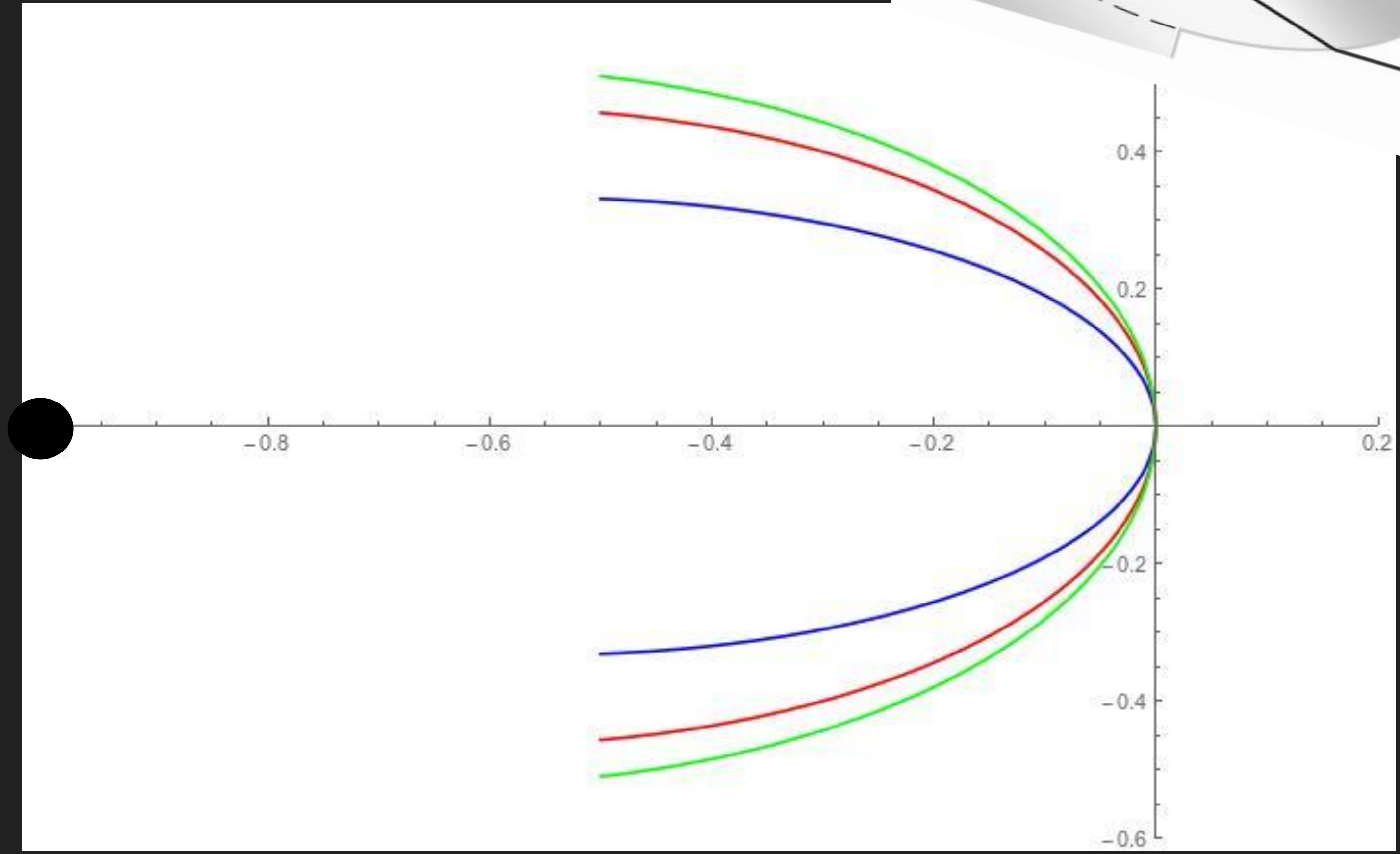
Ideal lenses I



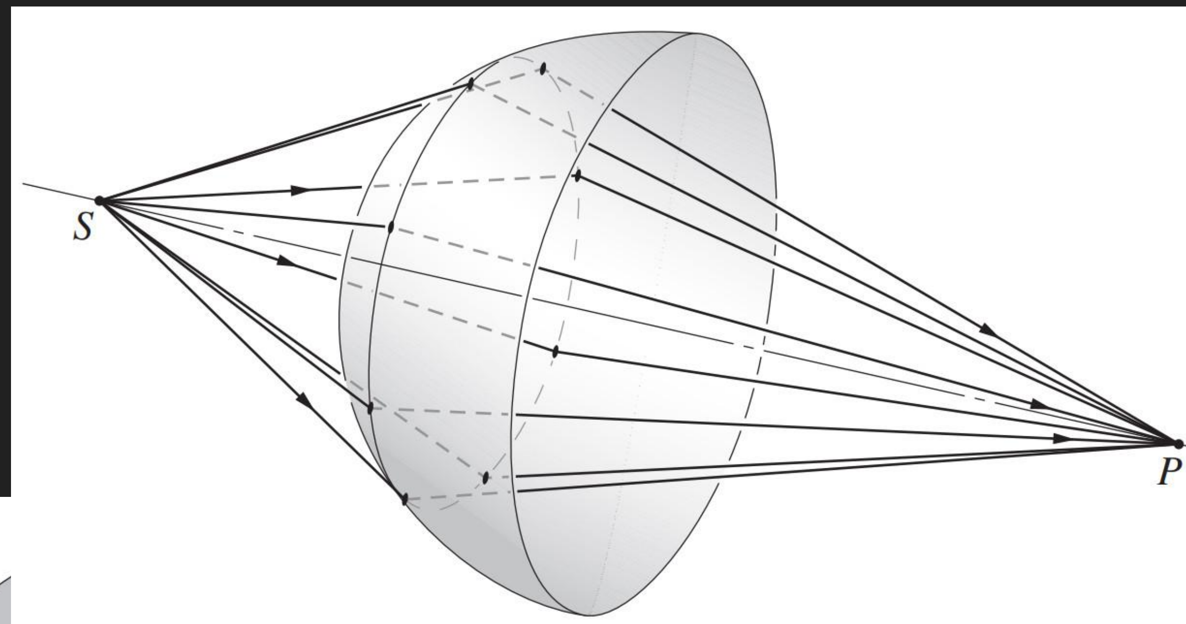


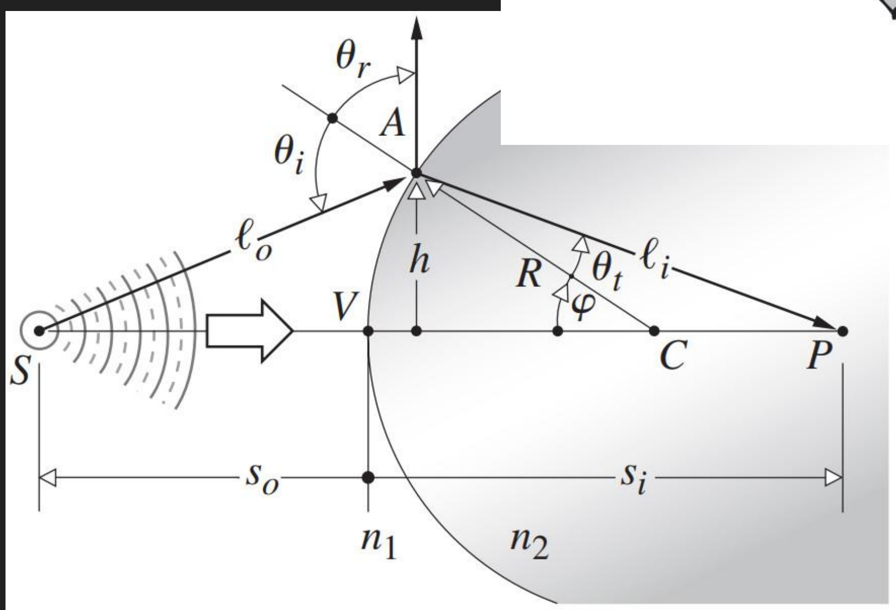
Ideal lenses II



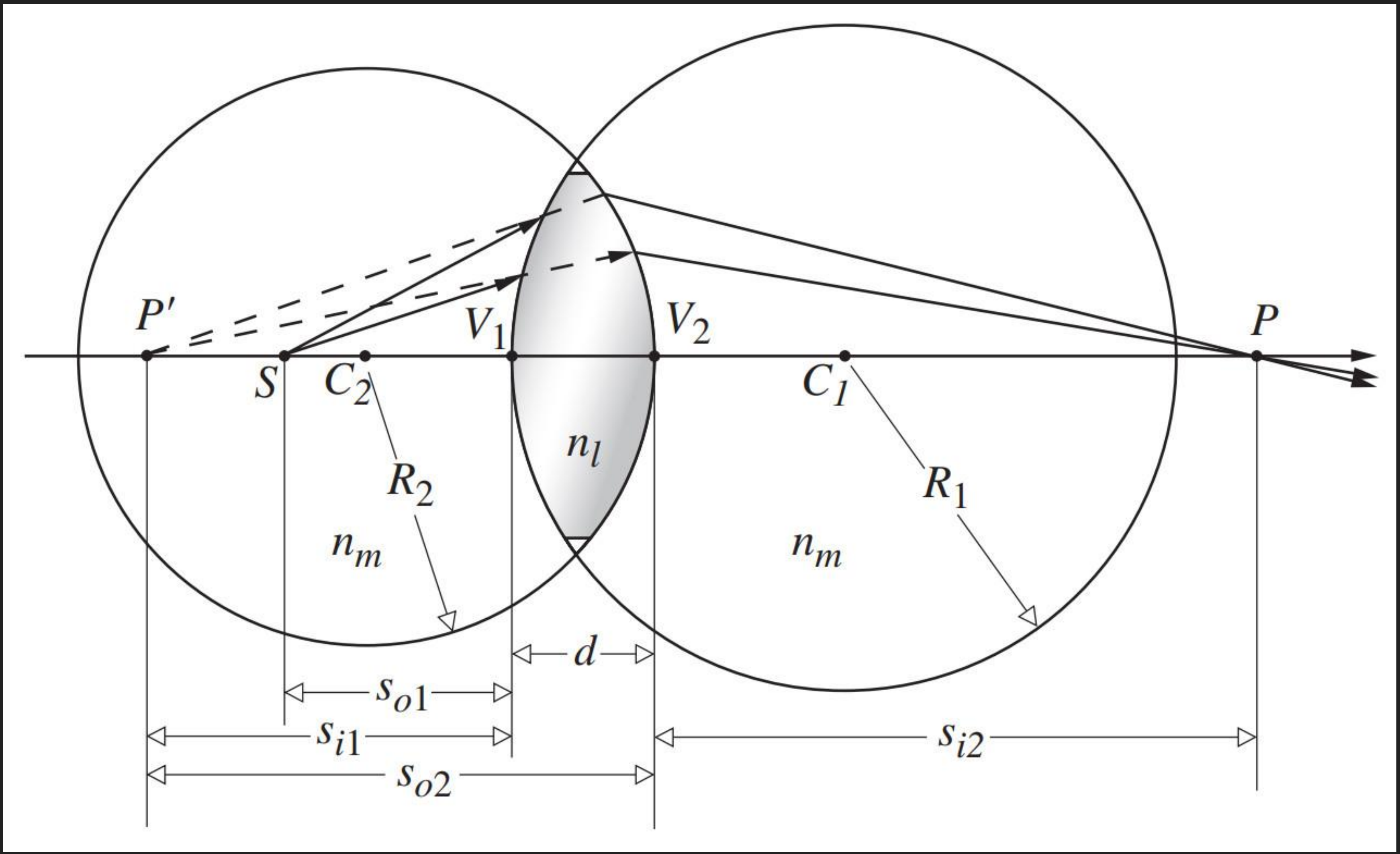


Spherical lenses





Thin lenses I



Summary Lecture 5

- Lenses reconfigure the angular distribution of rays and can be used to collimate and focus light. Convex lenses converge light, concave ones cause divergence.
- While ideal lenses are aspherical (hyperbolic/elliptic), most lenses are segments of spheres. Ray propagation is often simplified by a paraxial approximation.
- Most common lenses can be considered thin. With this approximation, we can derive the lensmaker formula, relating object and image distances, radii of the lense surfaces and refractive indices.

PHYS 434 Optics

Lecture 6: Lenses, Mirrors

Reading: 5.2.3, 5.4

Admin

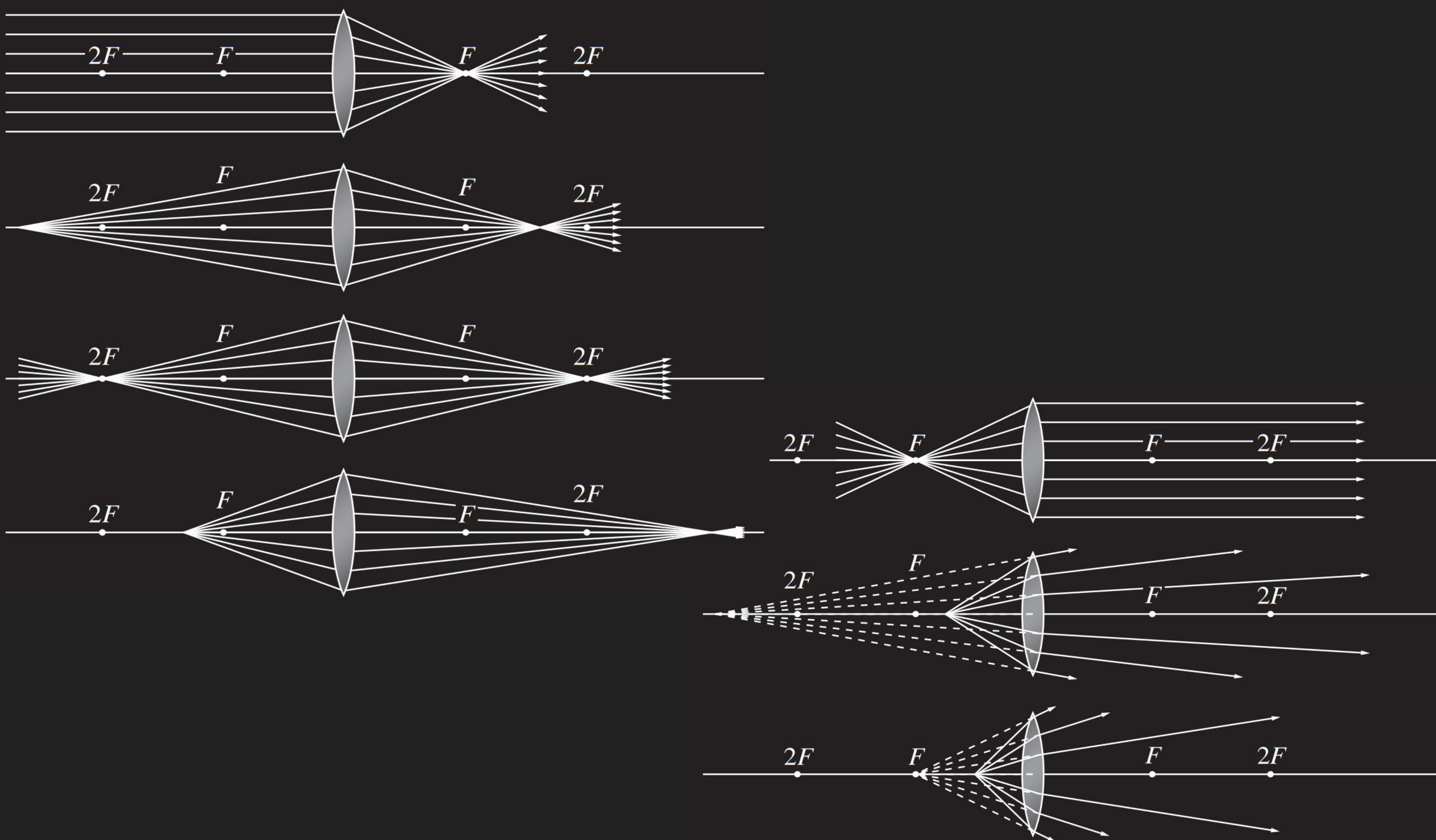
- Second problem set is available on myCourses website:
  - Grader: Ziggy
  - Due date: Wednesday, Jan 30 (beginning of class)

- Bring a laptop to Lecture 7 on Monday, Jan 28.

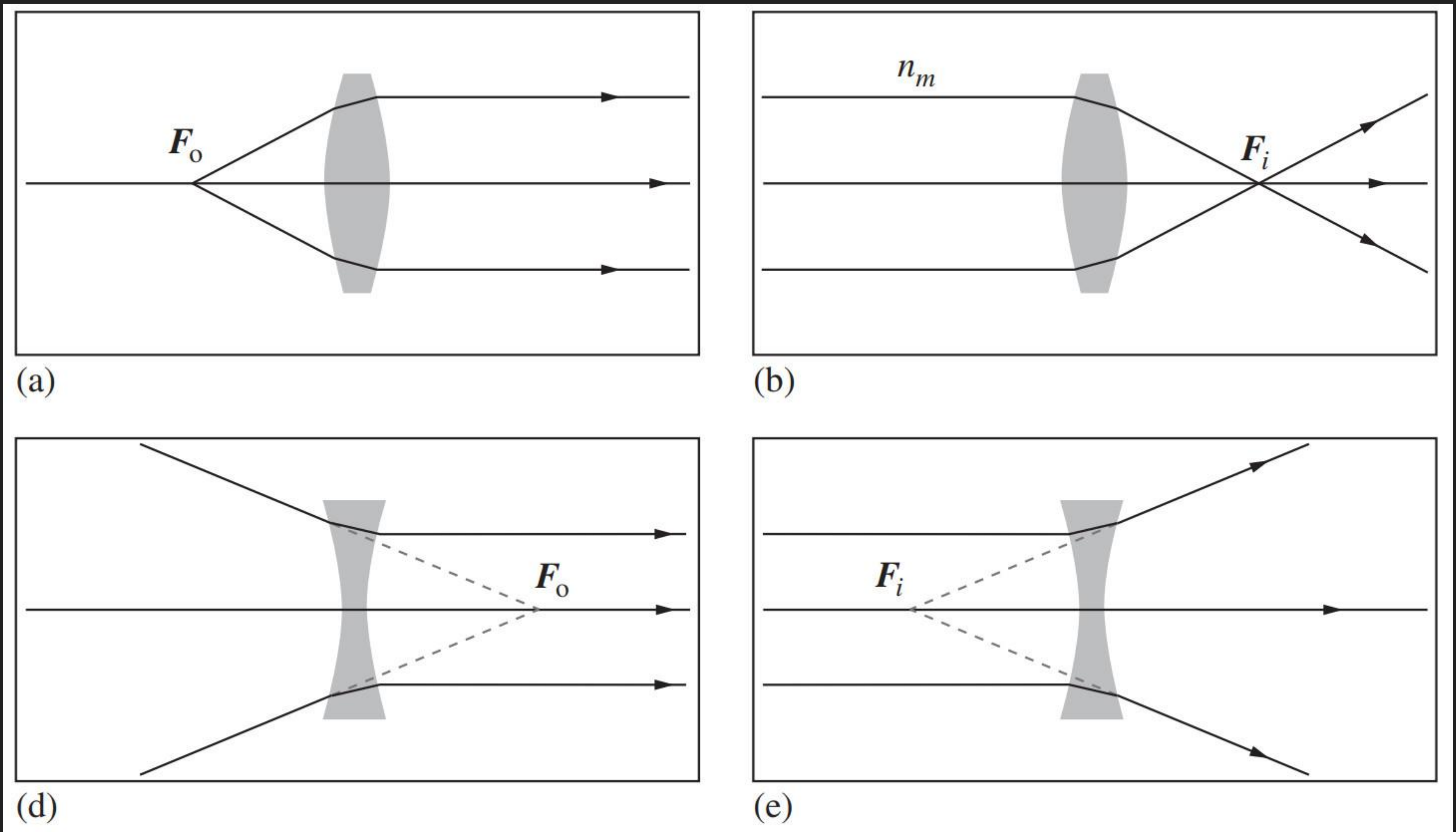
Summary Lecture 5

- Lenses reconfigure the angular distribution of rays and can be used to collimate and focus light. Convex lenses converge light, concave ones cause divergence.
- While ideal lenses are aspherical (hyperbolic/elliptic), most lenses are segments of spheres. Ray propagation is often simplified by a paraxial approximation.
- Most common lenses can be considered thin. With this approximation, we can derive the lensmaker formula, relating object and image distances, radii of the lense surfaces and refractive indices.

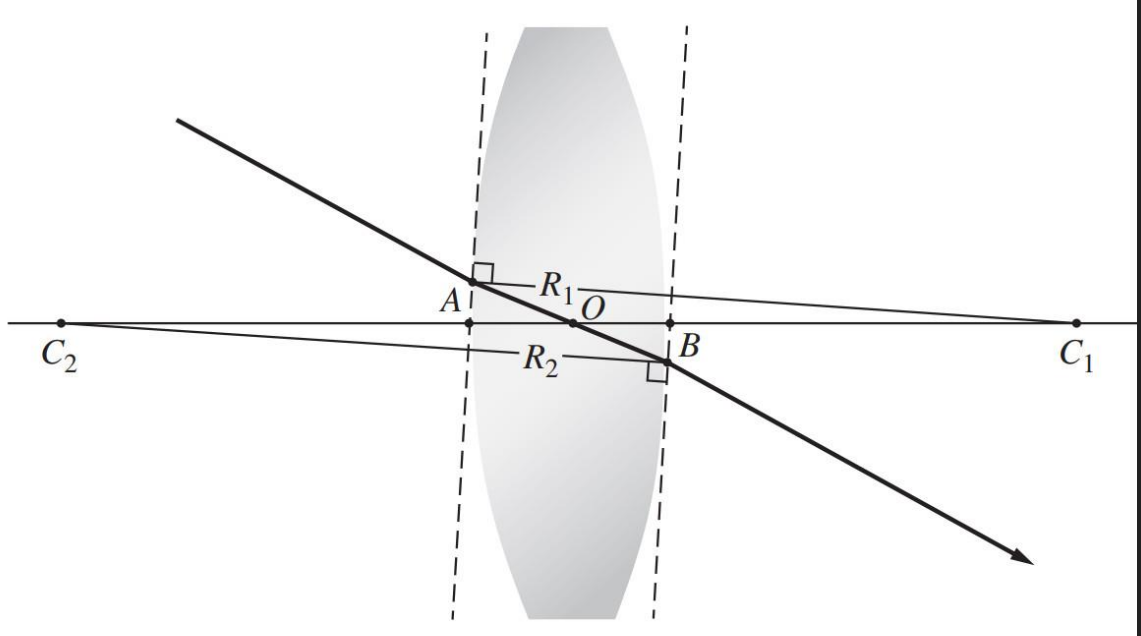
Thin lenses II

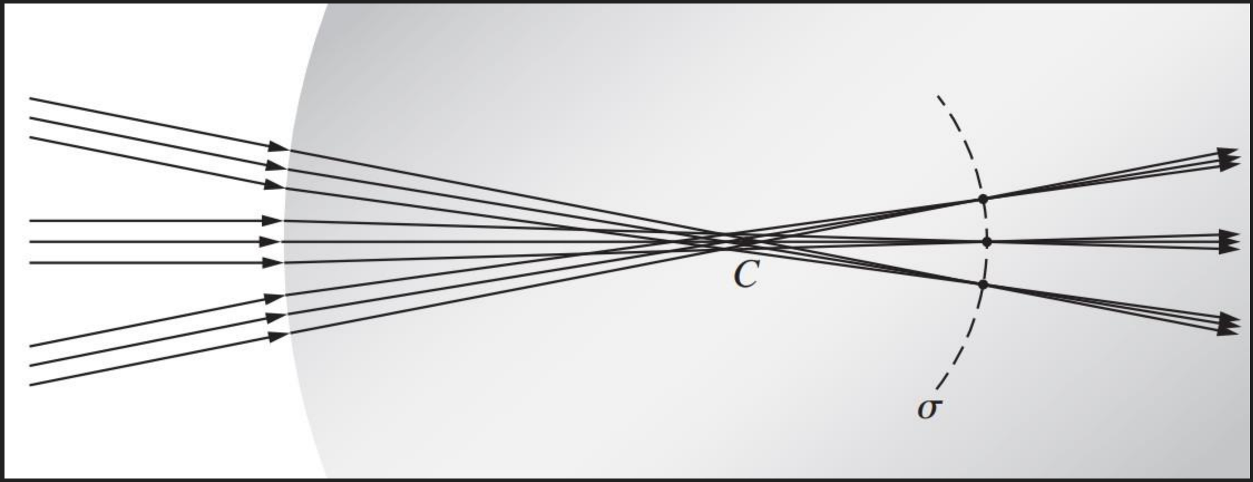


Focal points

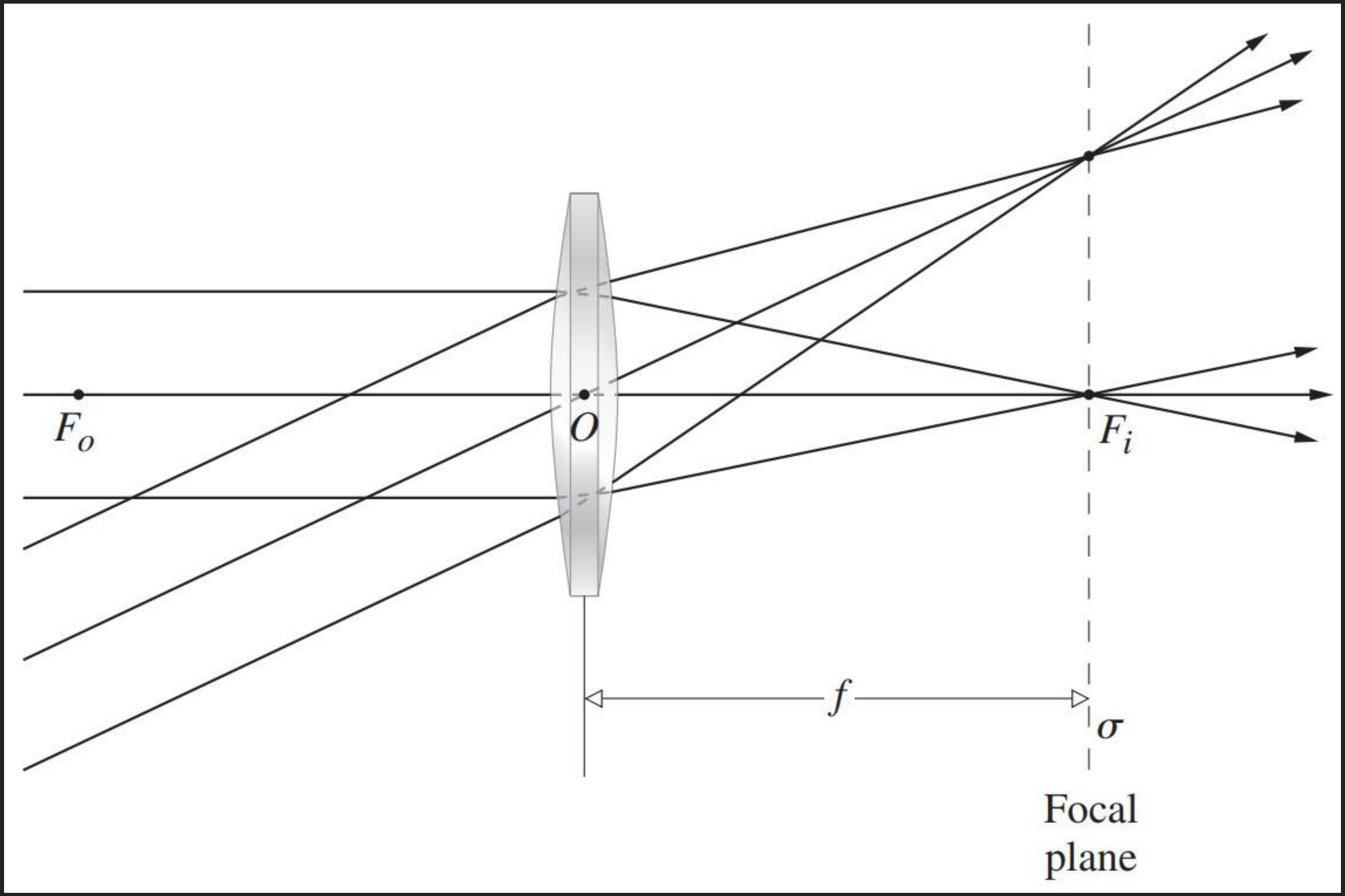


Two useful concepts

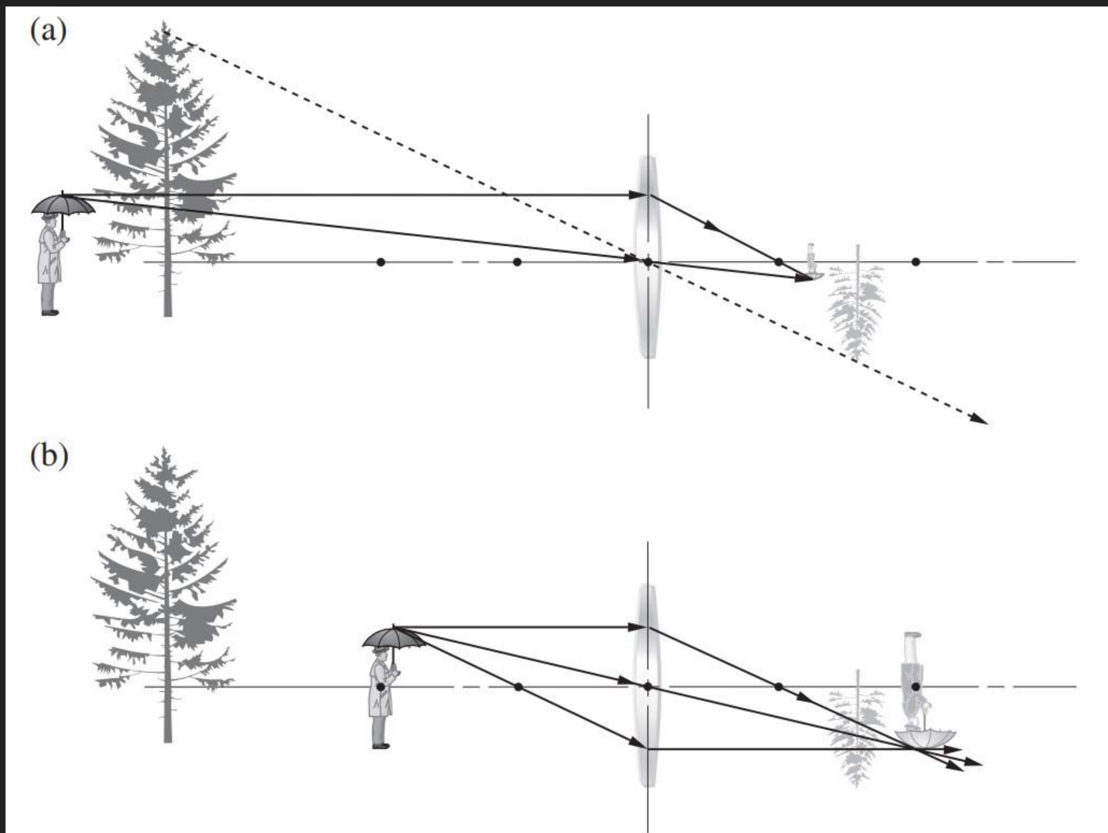


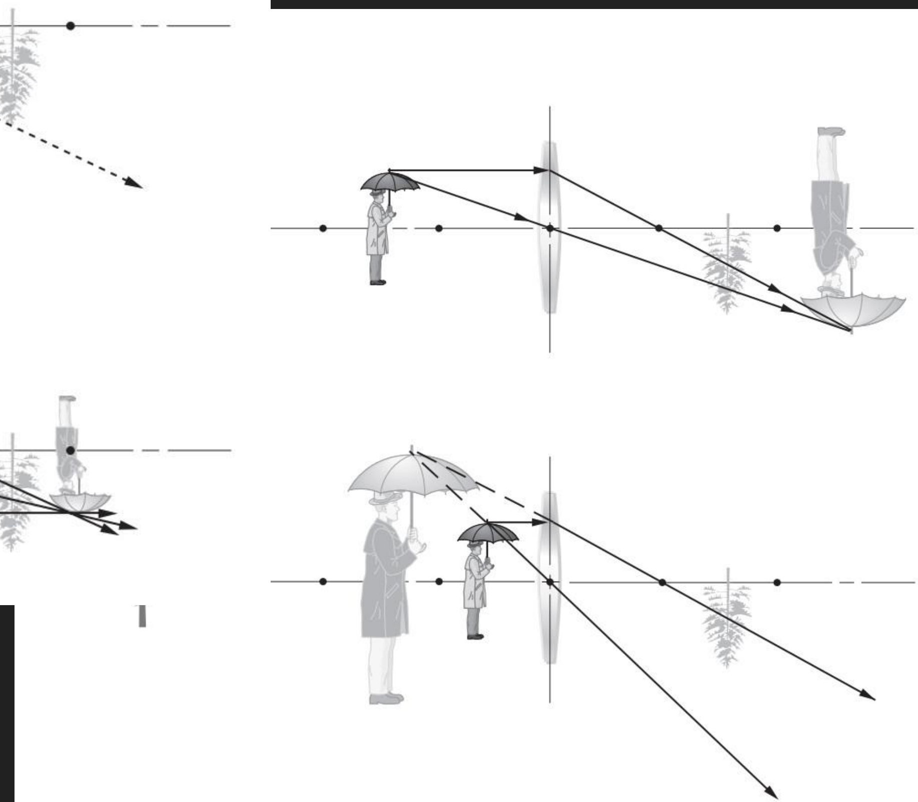


Focal plane

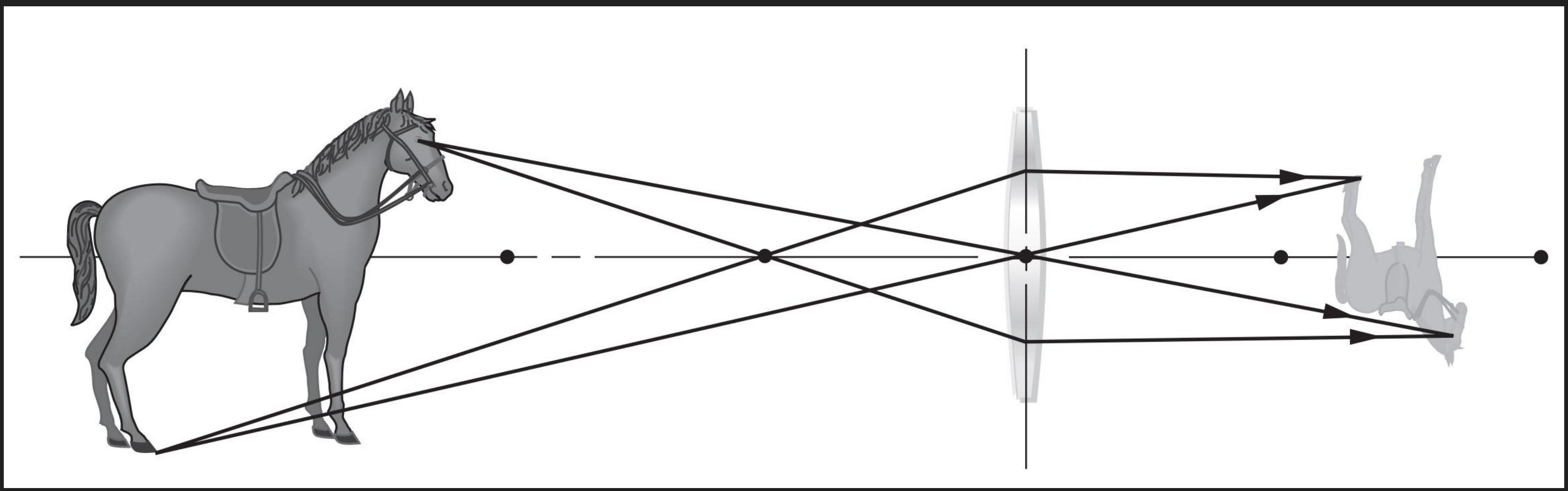


Imaging with lenses

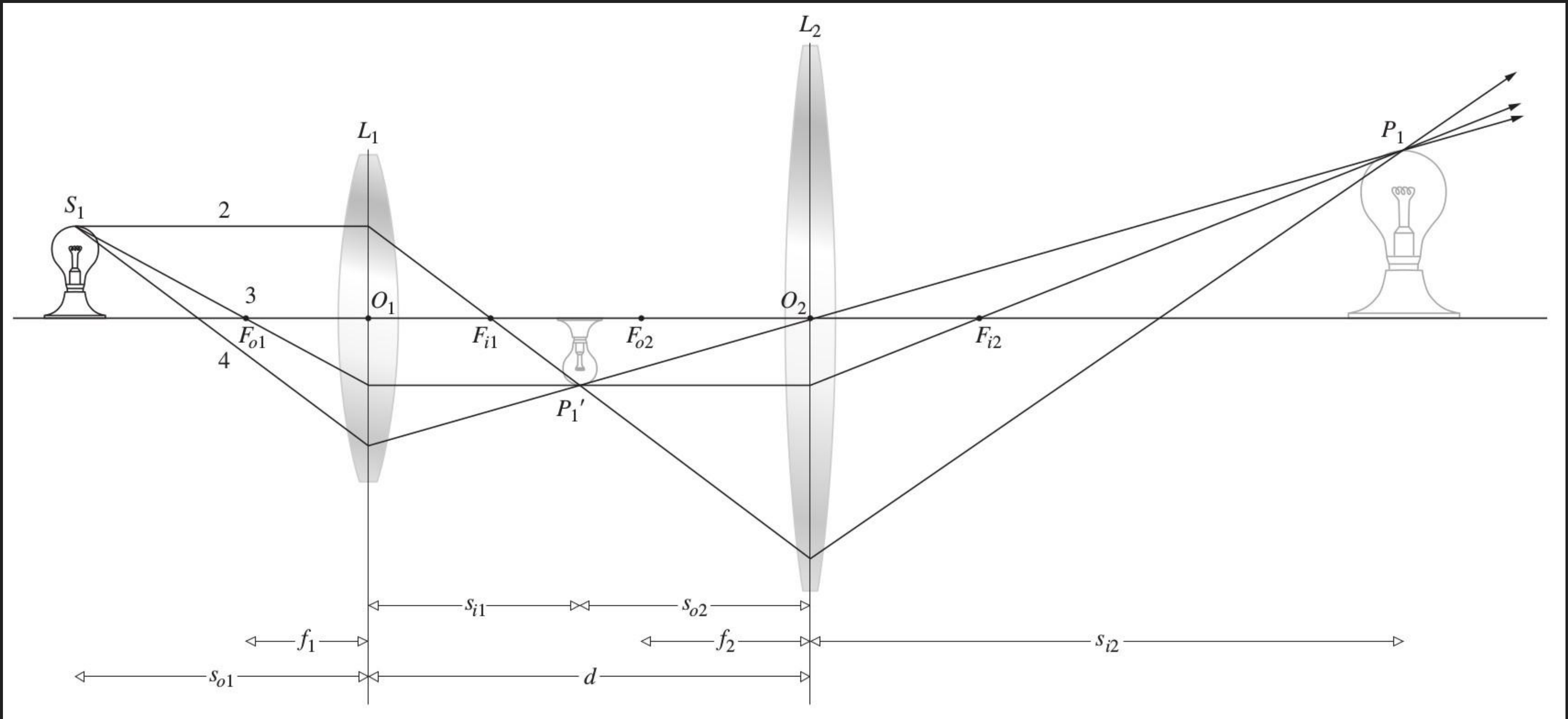




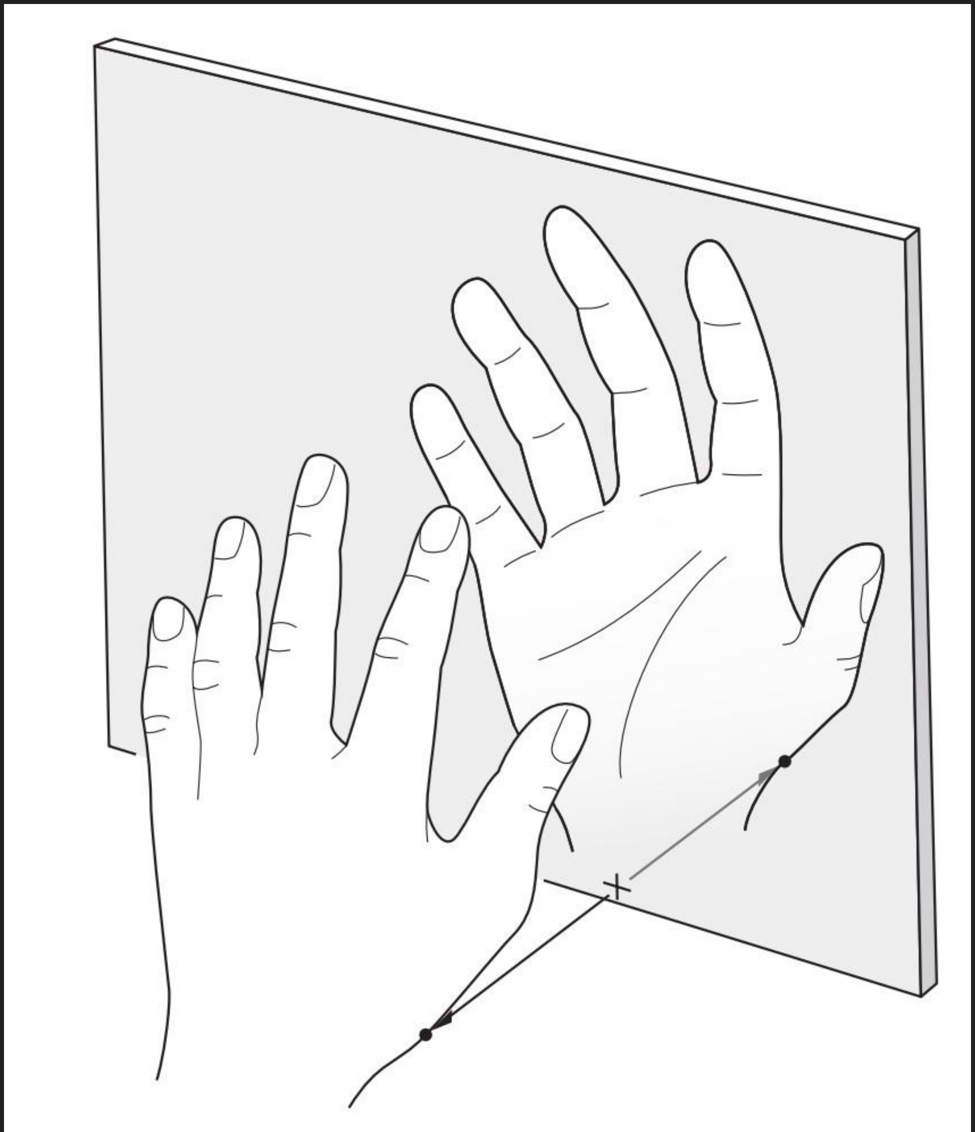
Longitudinal magnification



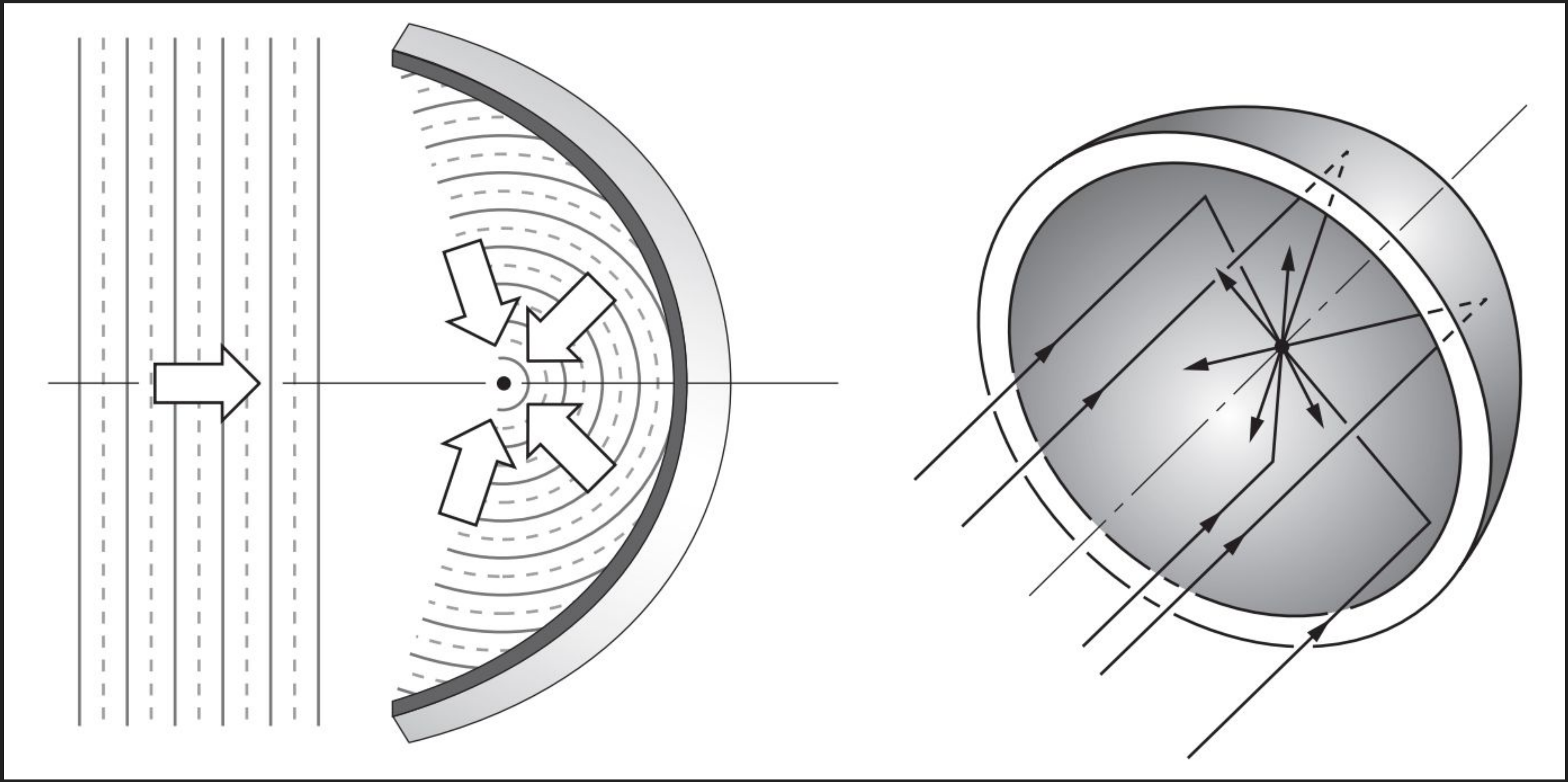
Compound lenses



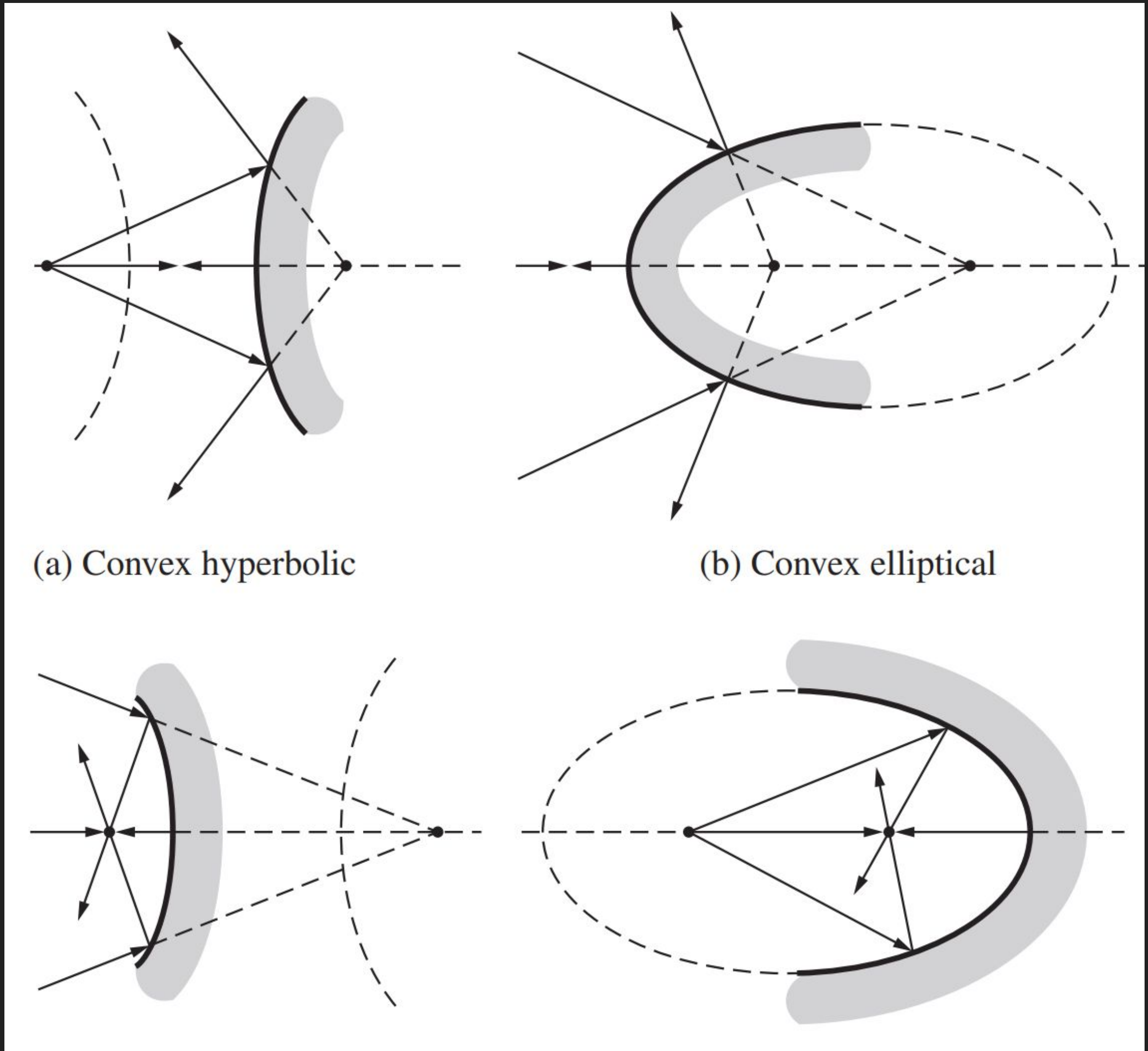
Handedness



Parabolic mirror



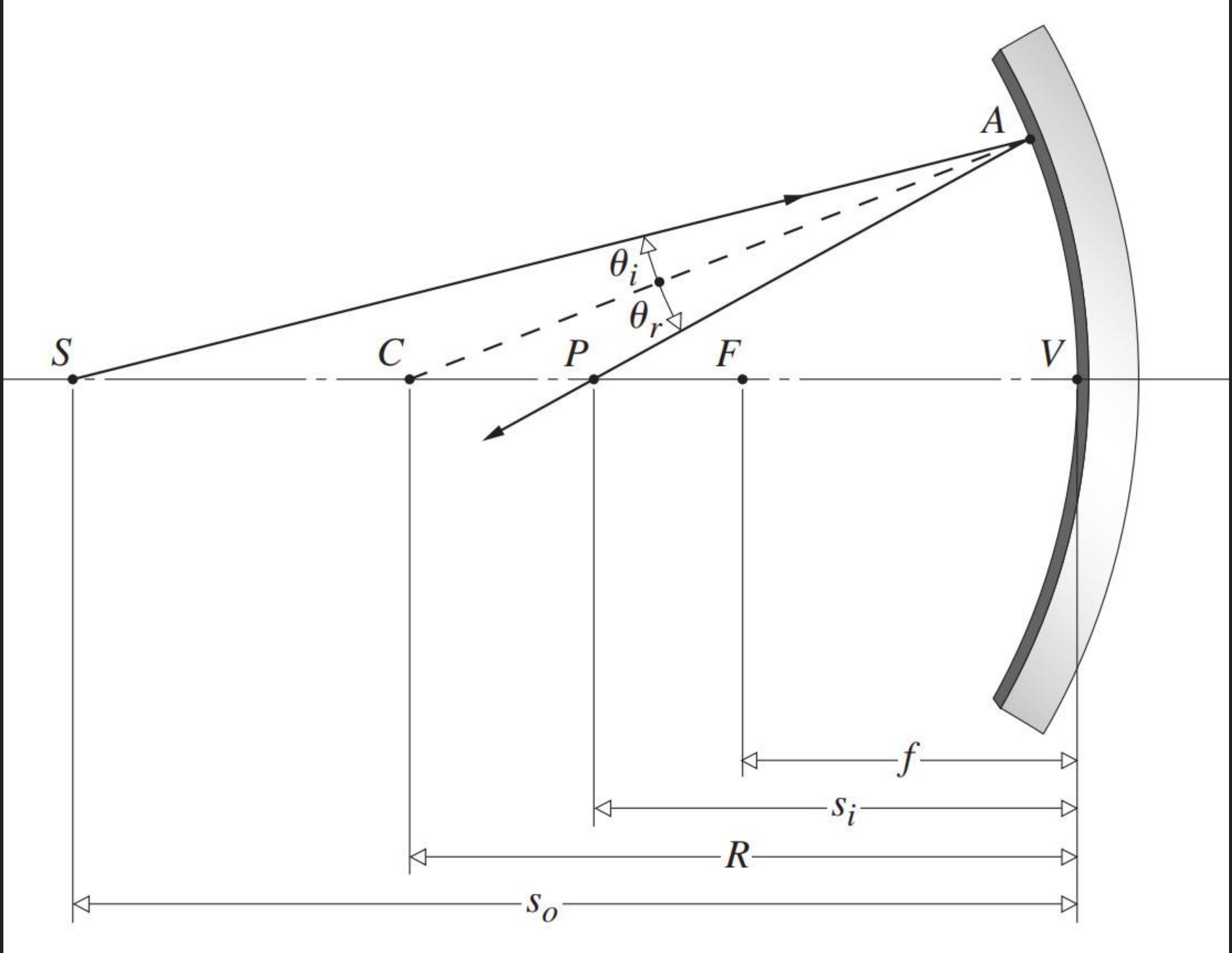
Elliptic/hyperbolic mirrors



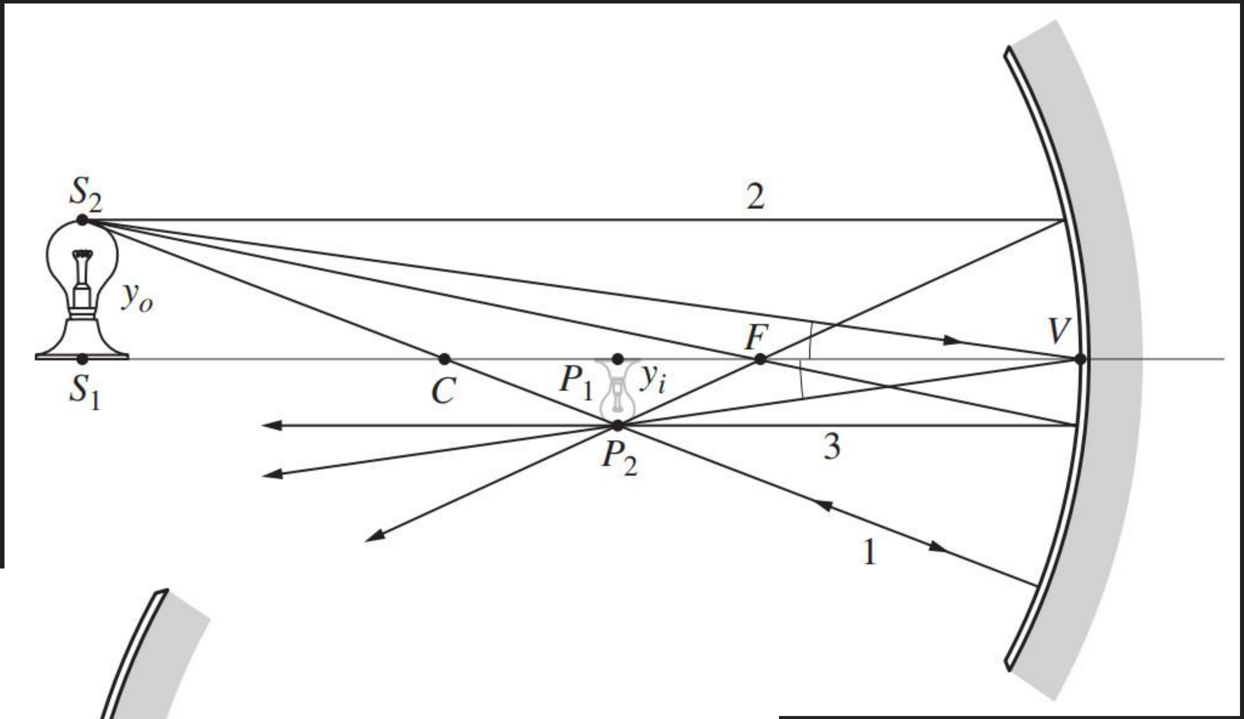
(a) Convex hyperbolic (b) Convex elliptical

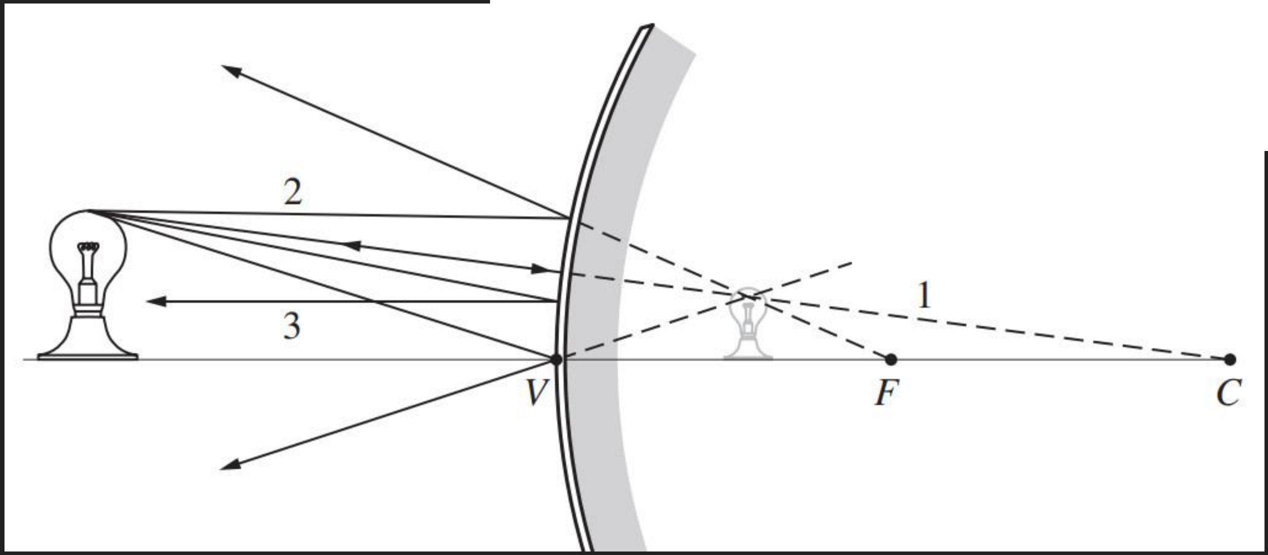
(c) Concave hyperbolic (d) Concave elliptical

Mirror formula



Imaging with mirrors





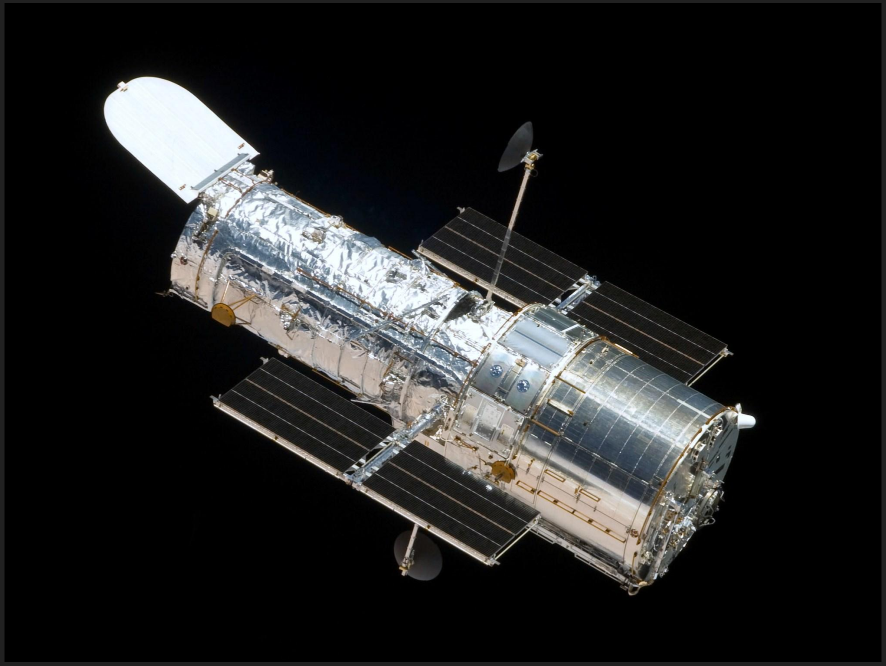
Summary Lecture 6

- We can construct finite images of objects created with lenses, lens systems or mirrors by following different rays emerging from an object.
- The focal points of lenses/mirrors are particularly useful to construct these images, as they will collimate the rays passing through them. Position of object relative to focal length controls image size.
- Rays passing through the optical centre of a lens or the mirror's centre of curvature will not be deflected.

PHYS 434 Optics

Lecture 7: Prisms, Optical Systems, Gravitational Lensing

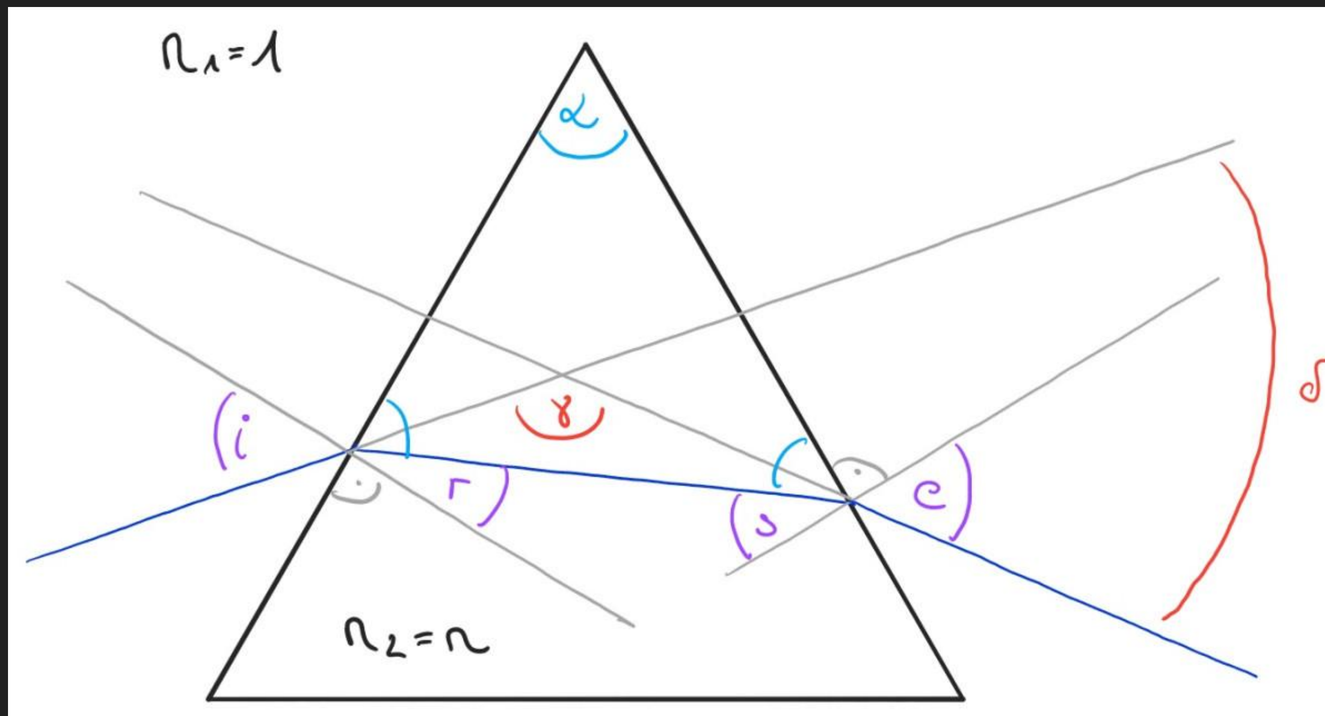
Reading: 5.5, 5.7 - 5.9



Summary Lecture 6

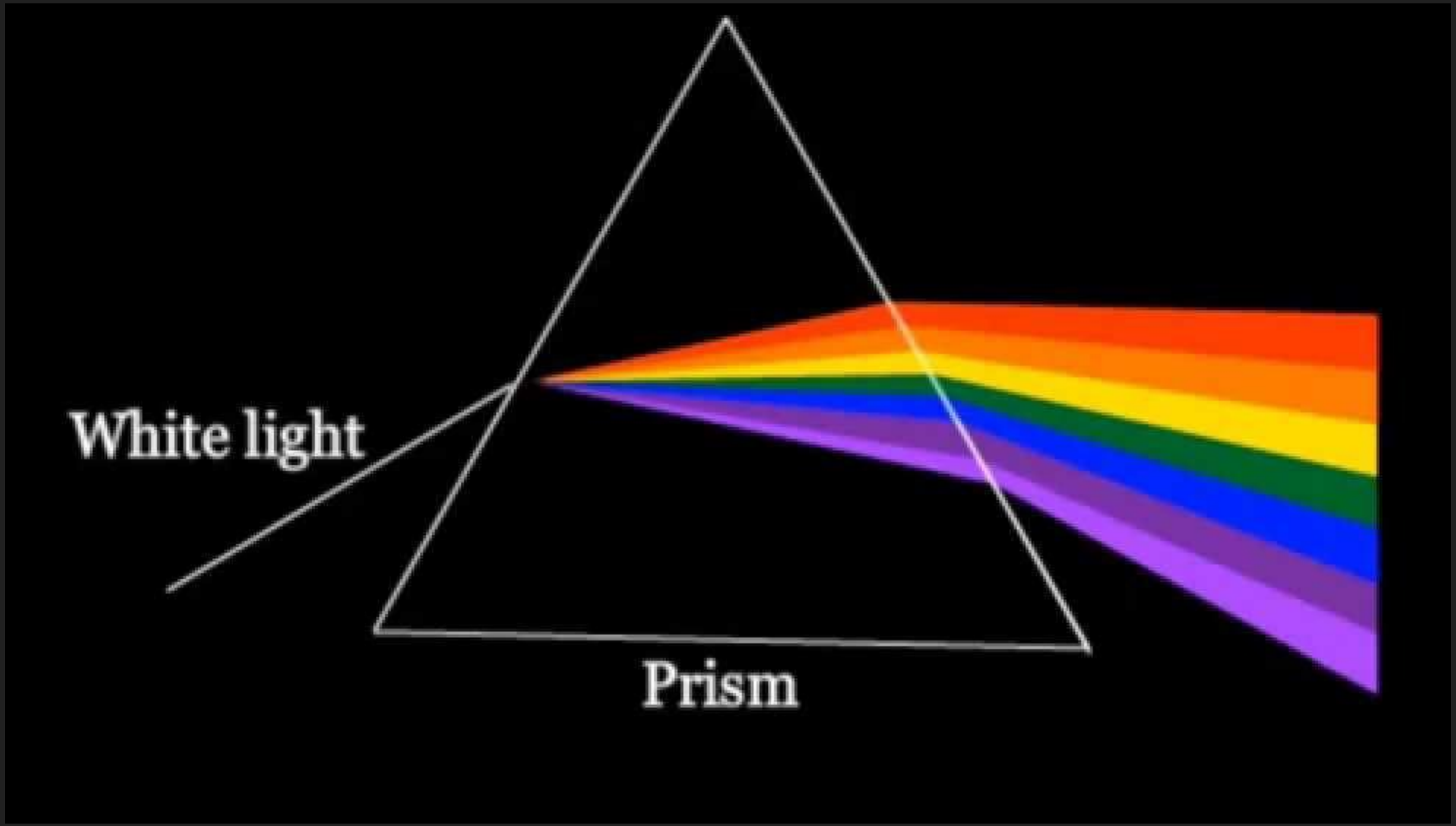
- We can construct finite images of objects created with lenses, lens systems or mirrors by following different rays emerging from an object.
- The focal points of lenses/mirrors are particularly useful to construct these images, as they will collimate the rays passing through them. Position of object relative to focal length controls image size.
- Rays passing through the optical centre of a lens or the mirror's centre of curvature will not be deflected.

Deflection angle

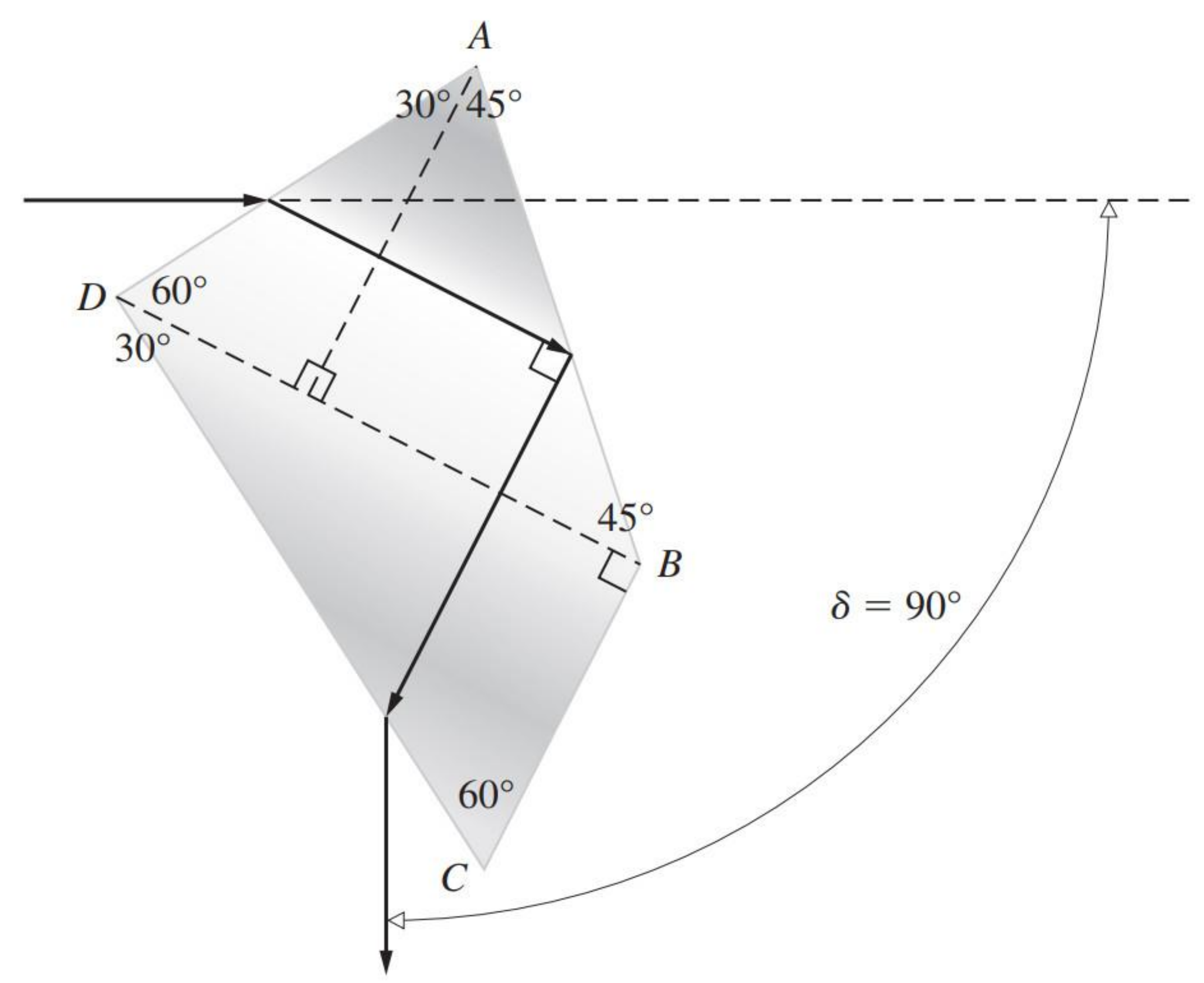


$$\delta = i - \alpha + \mathrm{Arcsin}\left(n \sin\alpha \sqrt{1 - \sin^2 i / n^2} - n \cos\alpha \sin i / n\right)$$

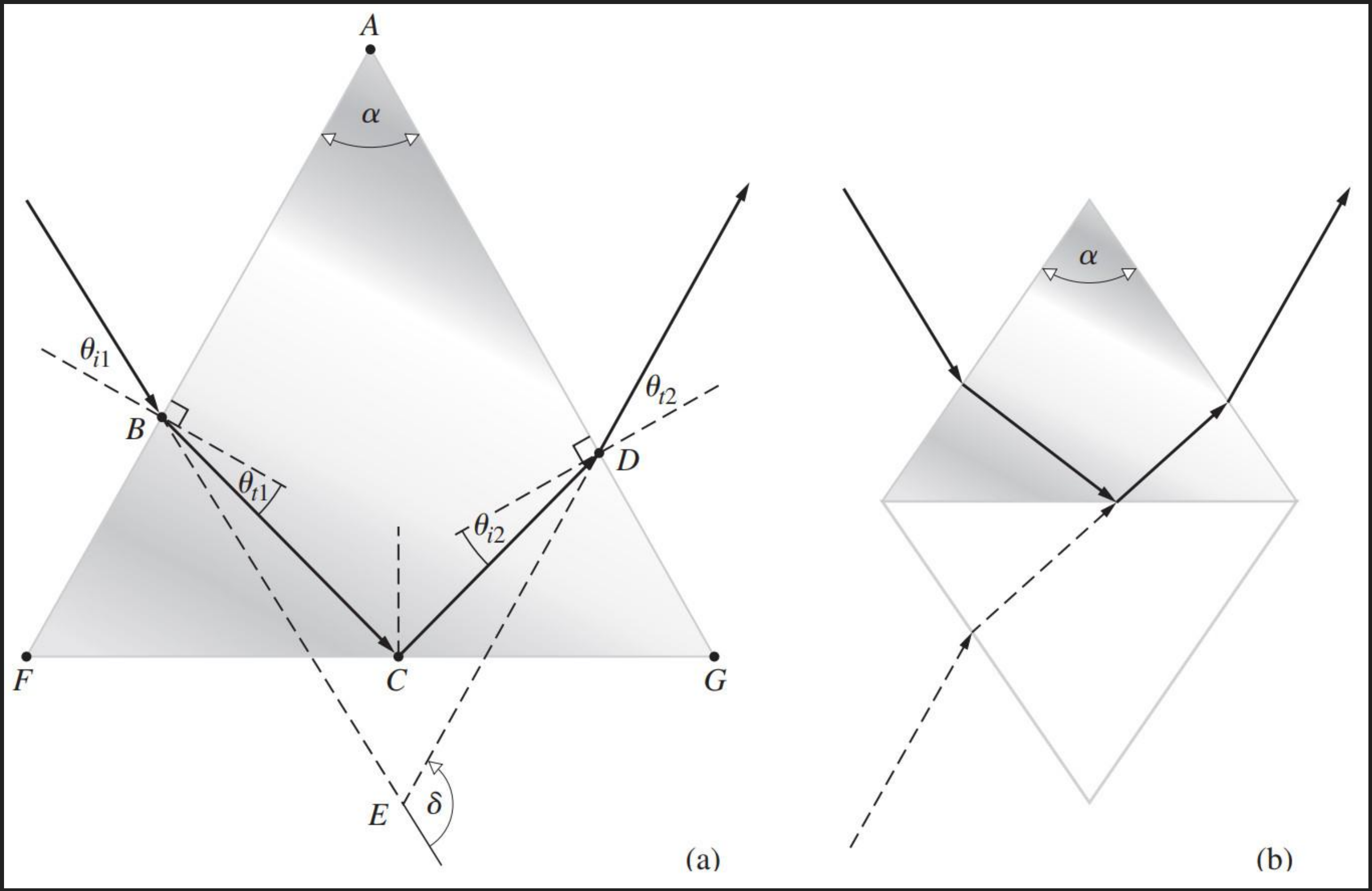
Dispersion



Constant deviation prism



Reflecting prism



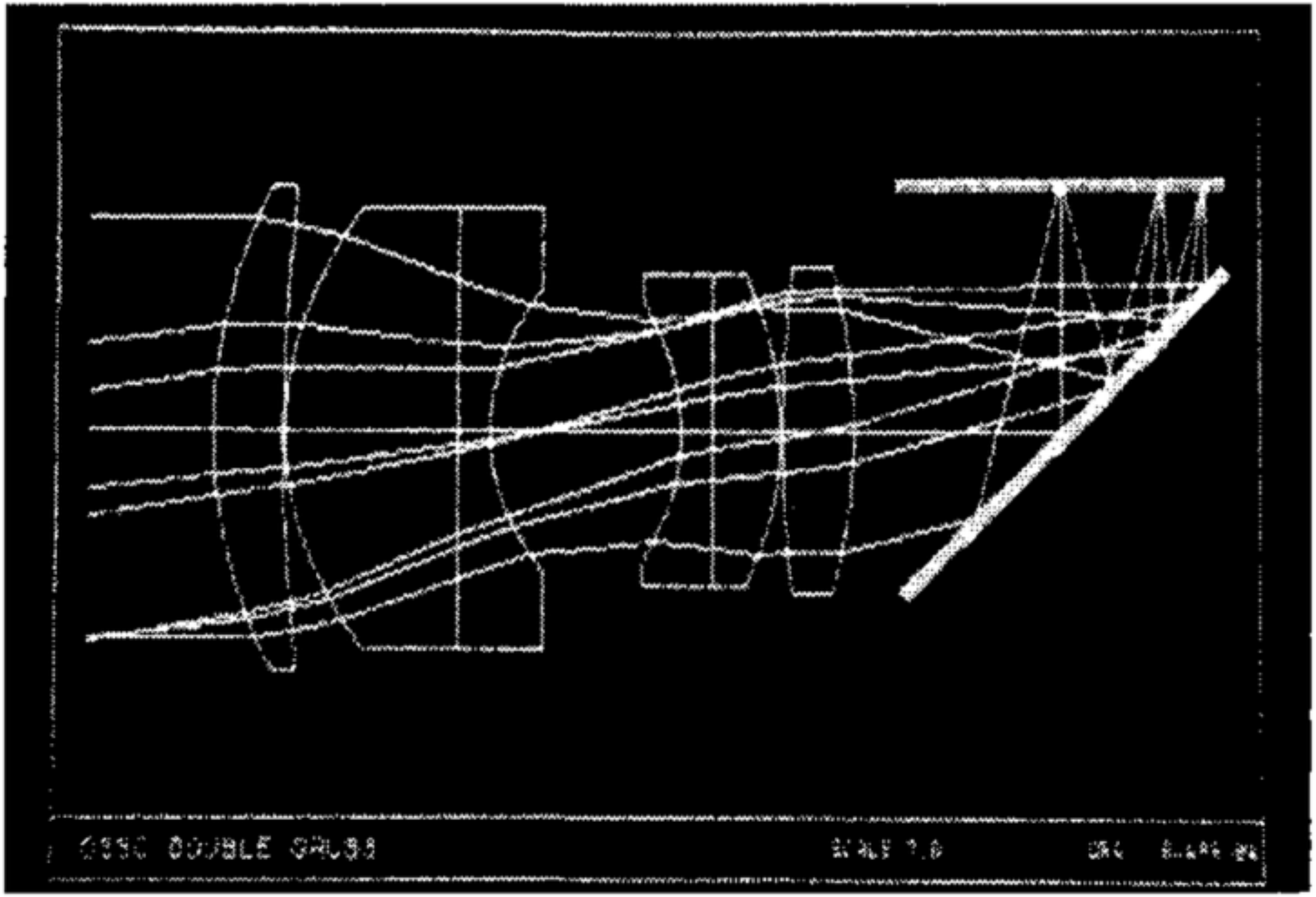
PHYS 434 Optics

Lecture 8: Matrix Methods
Reading: 6.1, 6.2

Summary Lecture 7

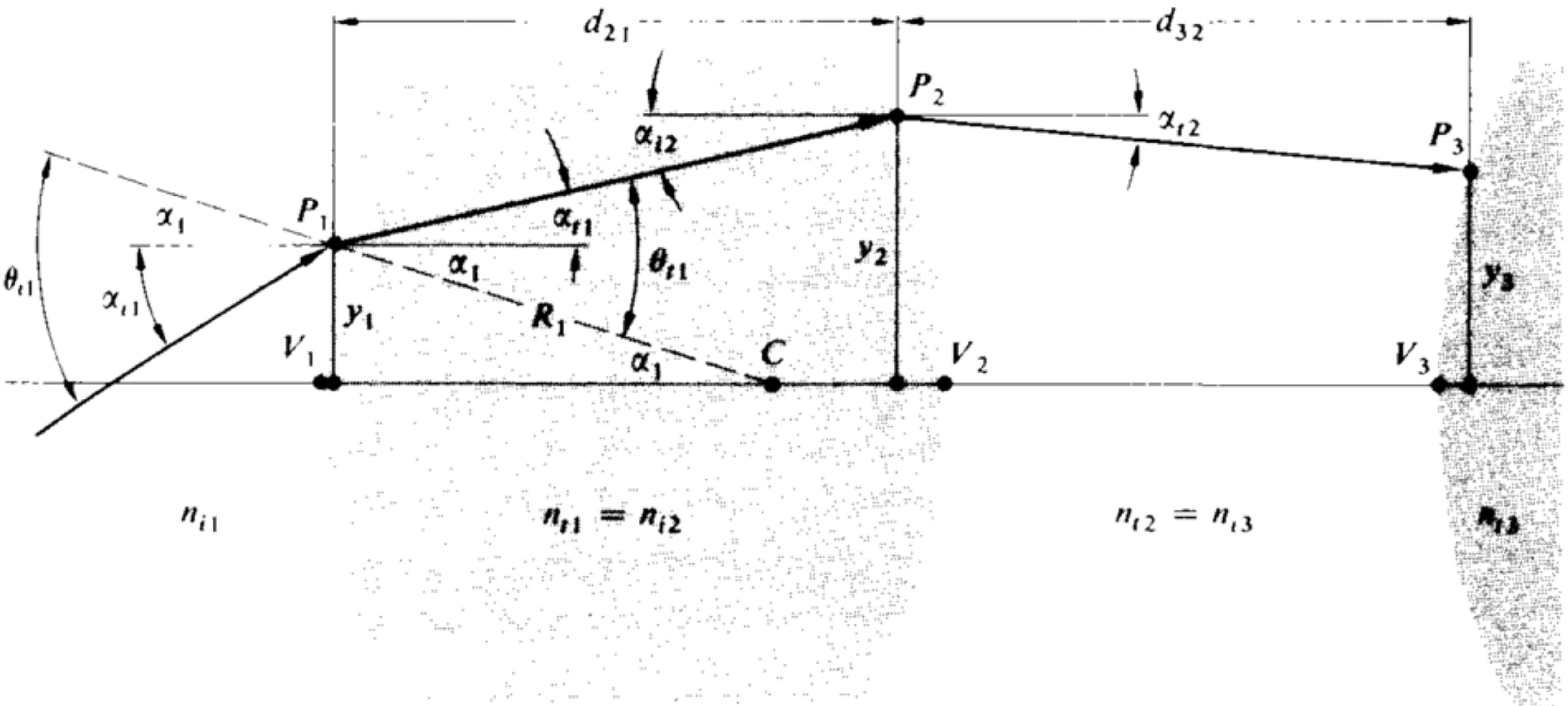
- Prisms are mainly used because they are dispersive and because they can change the direction of a beam or image.
- Other examples of optical systems are the compound microscope, eye glasses, gravitational lenses, magnifying glasses and the telescope.

Beyond the lensmaker's equation



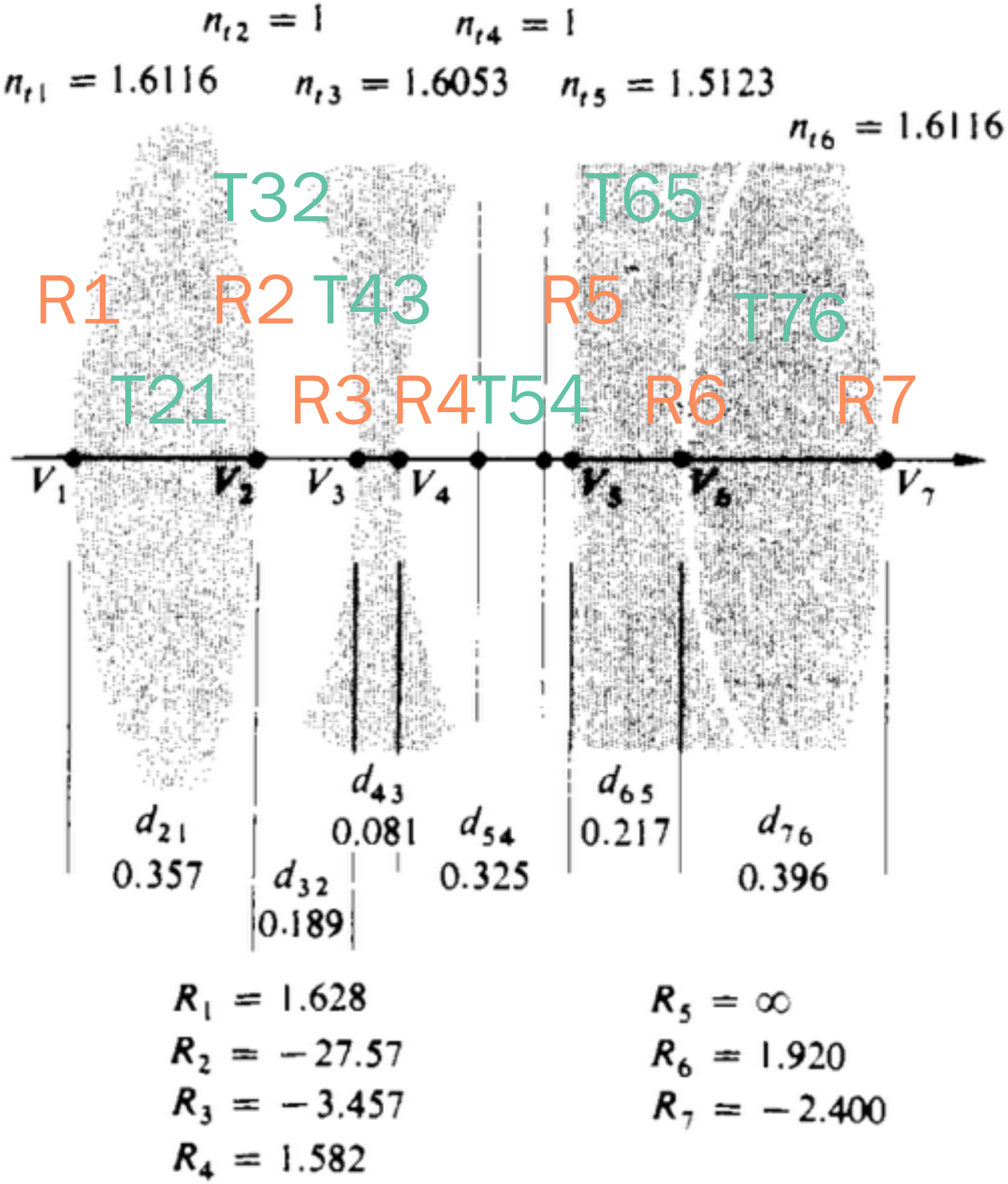
Computer ray tracing. (Photo courtesy of Optical Research Associates, Pasadena, California.)

Ray tracing



d_{21}
d_{32}
P_2
α_{i2}
α_{t2}
P_3
P_1
α_1
α_{t1}
θ_{i1}
α_{i1}
α_1
θ_{t1}
y_2
y_3
y_1
R_1
V_1
C
α_1
V_2
V_3
n_{i1}
$n_{t1} = n_{i2}$
$n_{t2} = n_{i3}$
n_{t3}

Applying the matrix method to a Tessar lens



Applying the matrix method to a Tessar lens

System matrix

$$\mathcal{A}_{71} = \mathcal{R}_7 \mathcal{T}_{76} \mathcal{R}_6 \mathcal{T}_{65} \mathcal{R}_5 \mathcal{T}_{54} \mathcal{R}_4 \mathcal{T}_{43} \mathcal{R}_3 \mathcal{T}_{32} \mathcal{R}_2 \mathcal{T}_{21} \mathcal{R}_1$$

Multiplying out the matrices, in what is obviously a horrendous, though conceptually simple, calculation, one presumably will get

$$\mathcal{A}_{71} = \begin{bmatrix} 0.848 & -0.198 \\ 1.338 & 0.867 \end{bmatrix}$$

and from that, $f = 5.06$, $\overline{V_1H_1} = 0.77$, and $\overline{V_7H_2} = -0.67$.

Summary Lecture 8

- By using ray-tracing techniques the analysis of an optical system can be formulated into matrix multiplication in the paraxial approximation.
- In this approximation, a compound lens can be described by an effective thick lens with the same system matrix.
- A thick lens is usually characterized by two principal planes and by an effective focal length.

PHYS 434 Optics

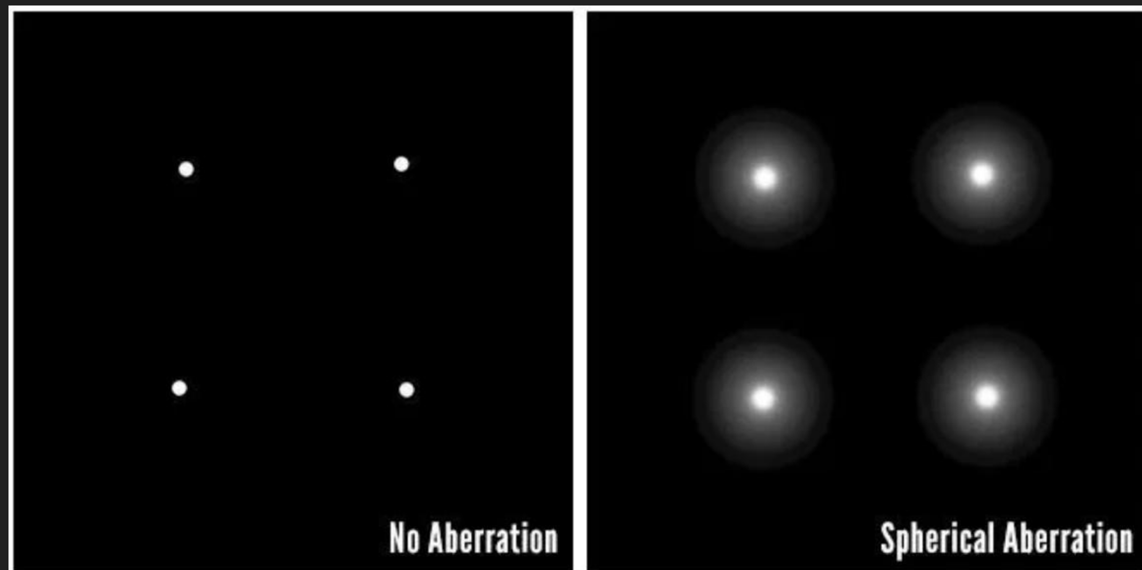
Lecture 9: Aberrations

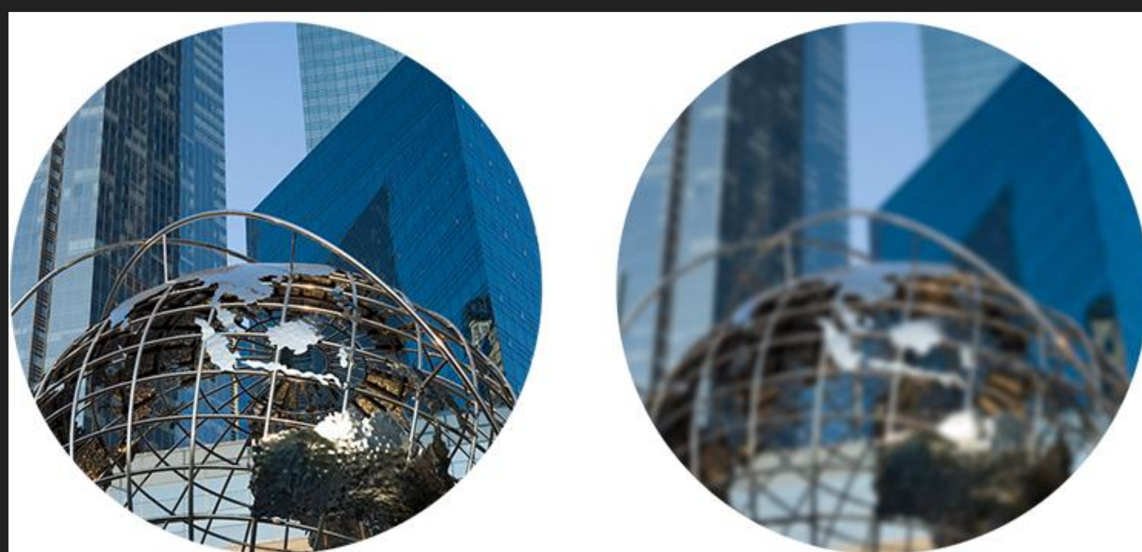
Reading: 6.3

Summary Lecture 8

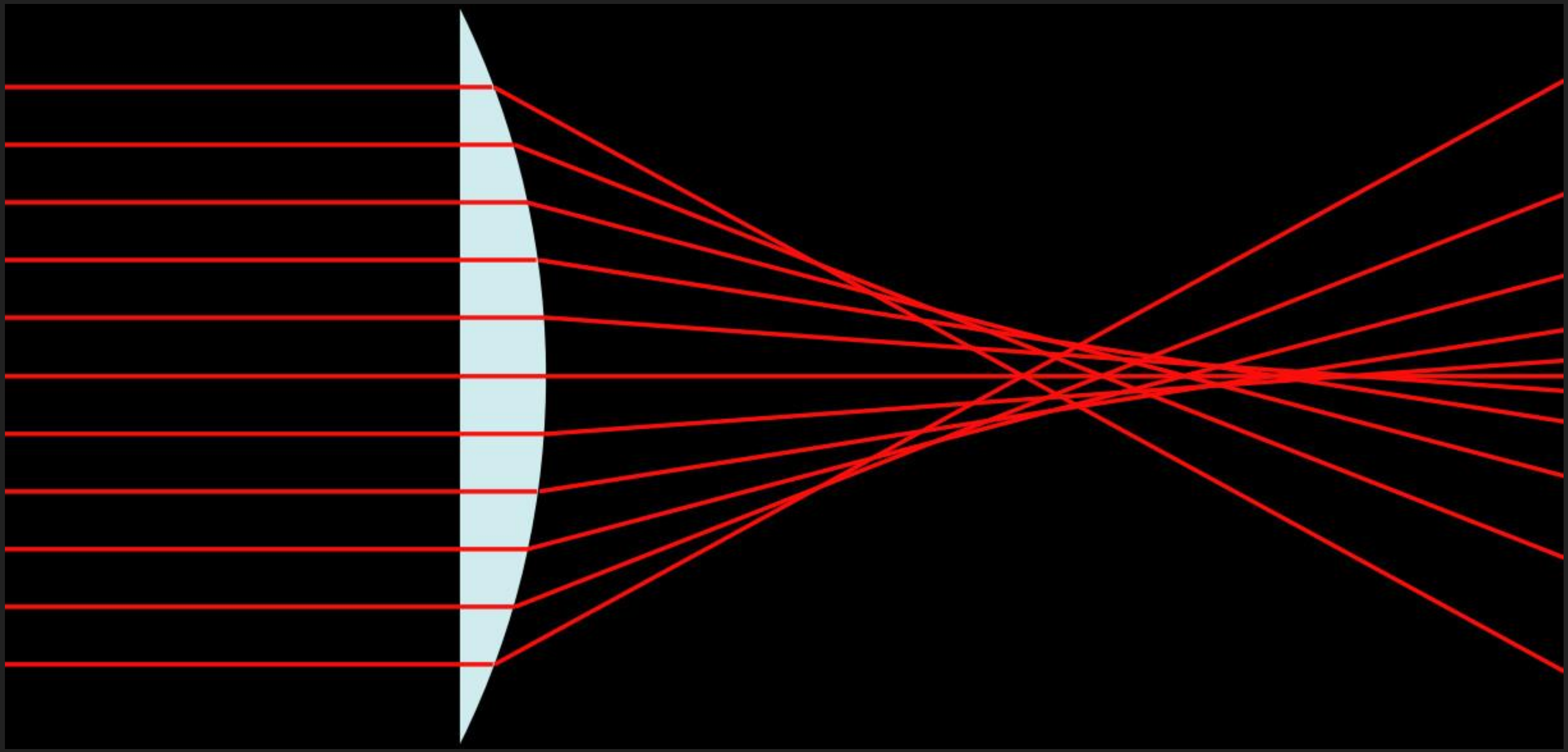
- By using ray-tracing techniques, the analysis of an optical system can be formulated into matrix multiplication in the paraxial approximation.
- In this approximation, a compound lens can be described by an effective thick lens with the same system matrix.
- A thick lens is usually characterized by two principal planes and by an effective focal length.

Spherical aberration I

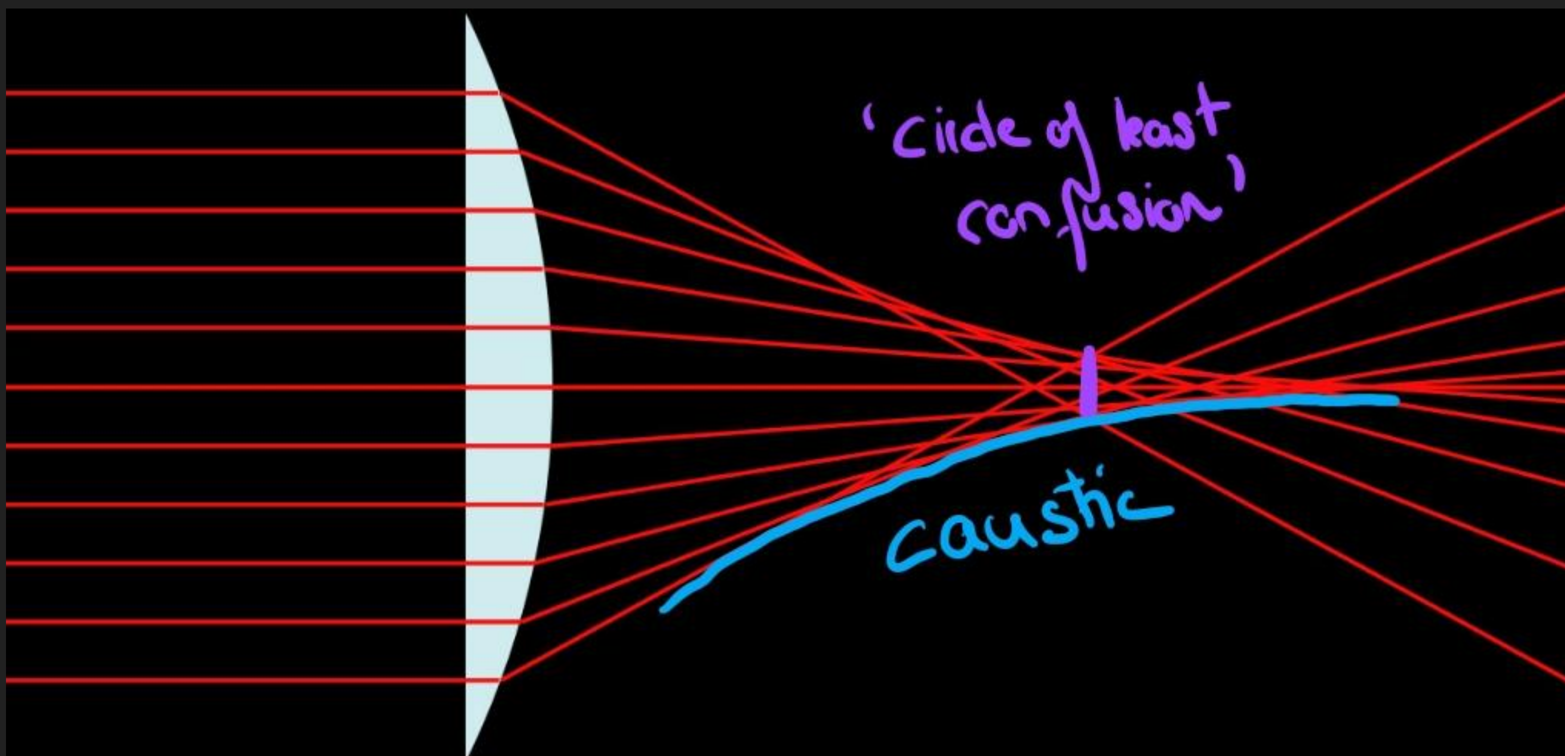




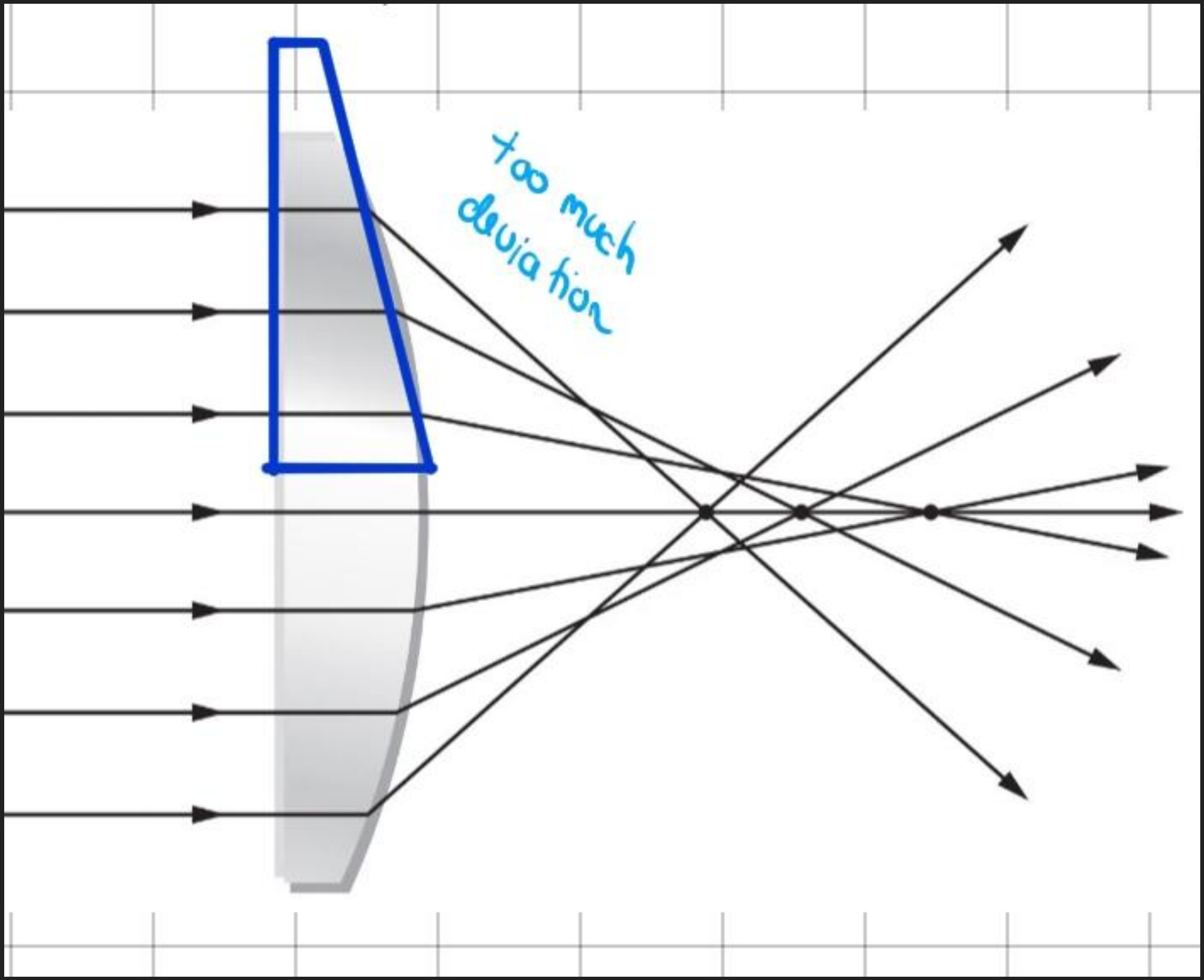
Spherical aberration II



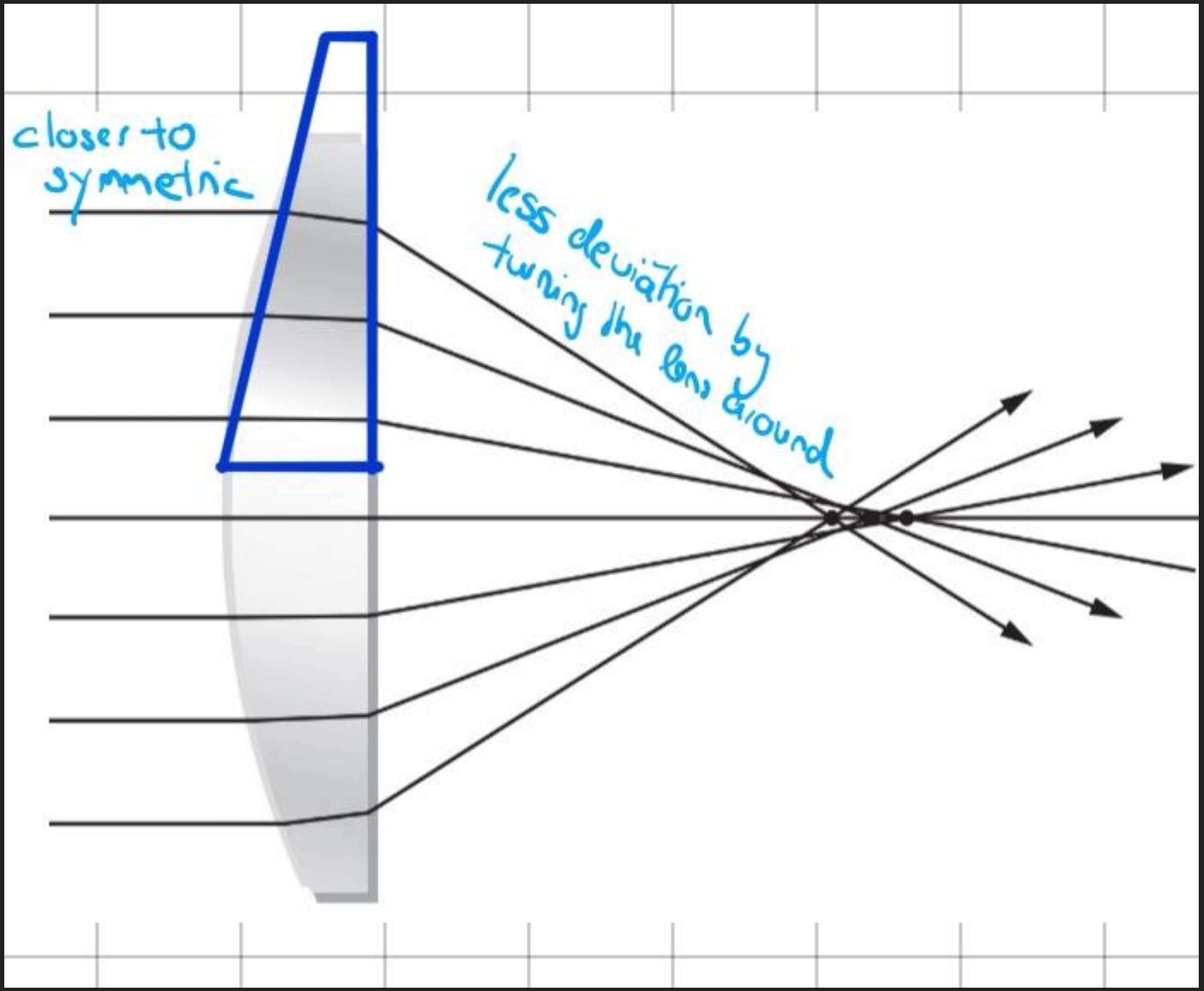
Spherical aberration II



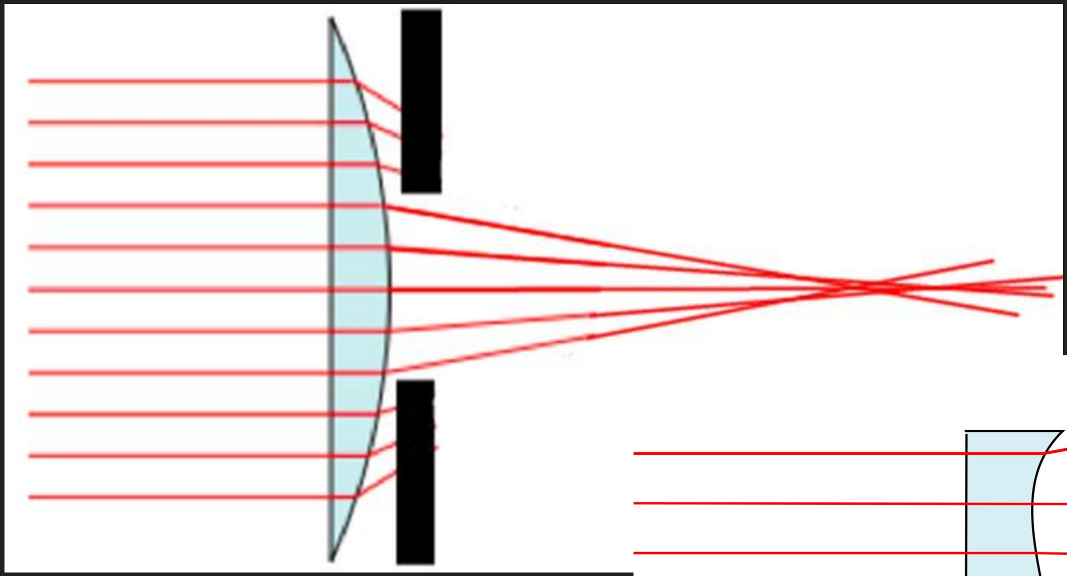
Reducing spherical aberration I

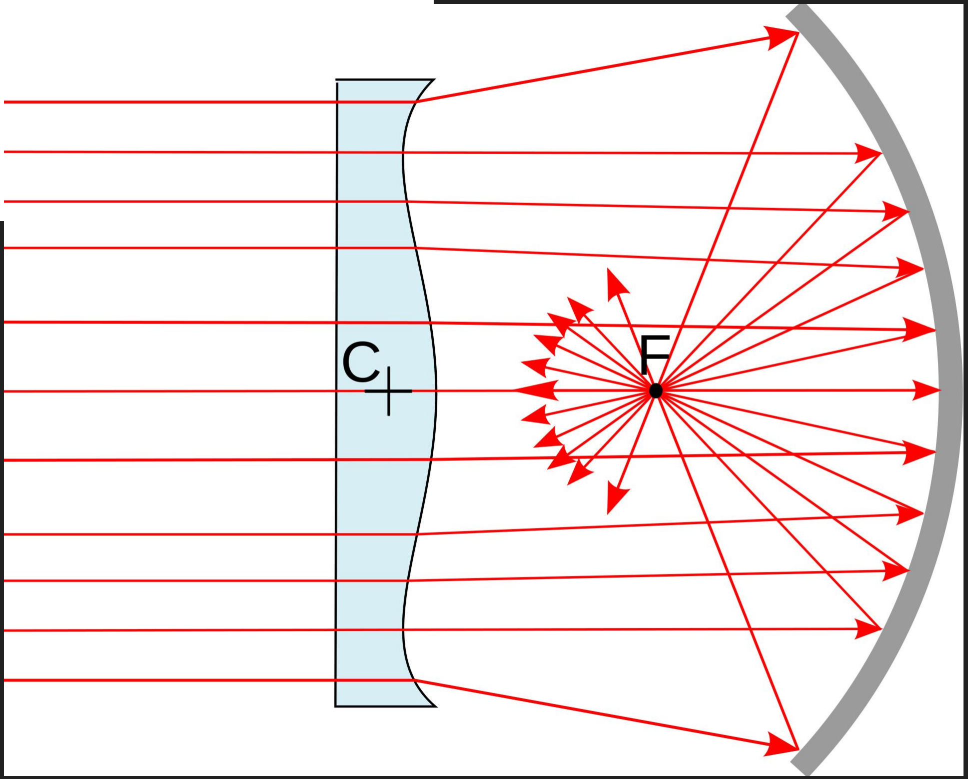


Reducing spherical aberration I

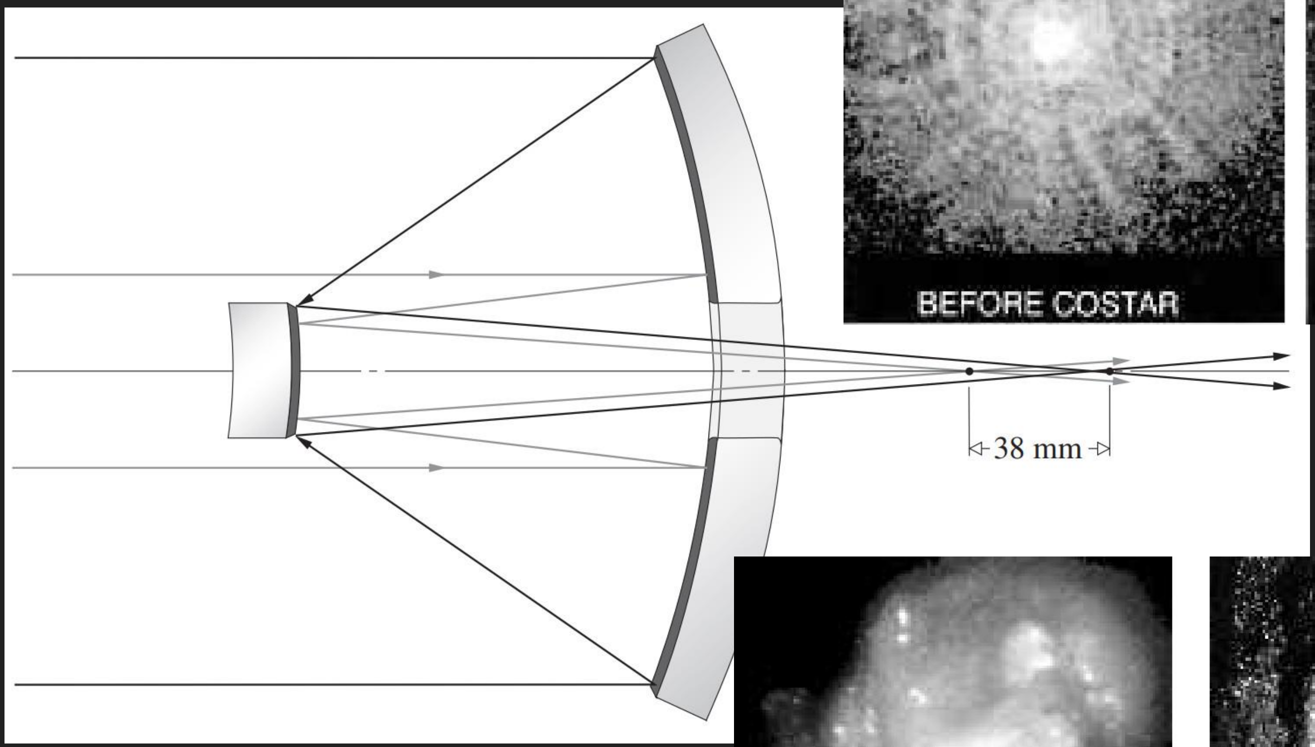


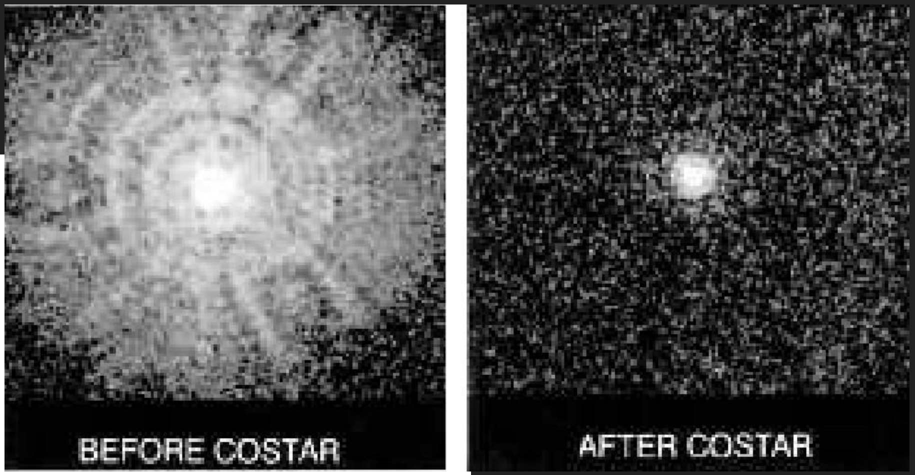
Reducing spherical aberration II

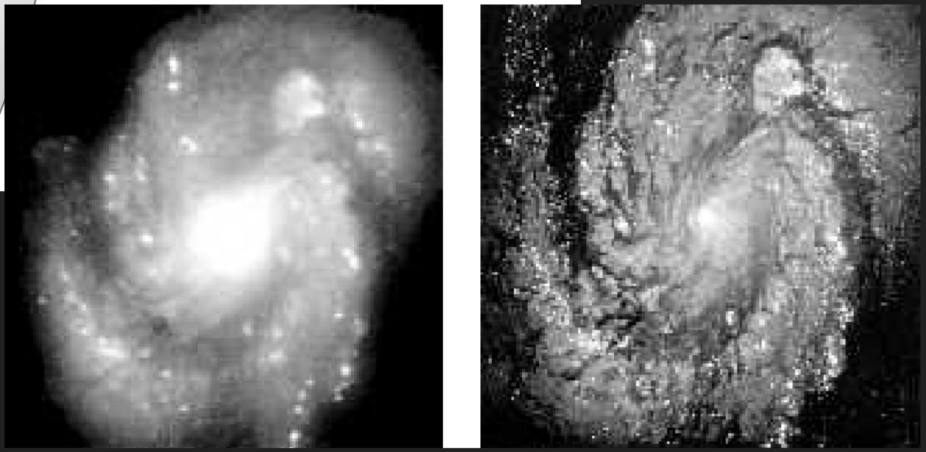




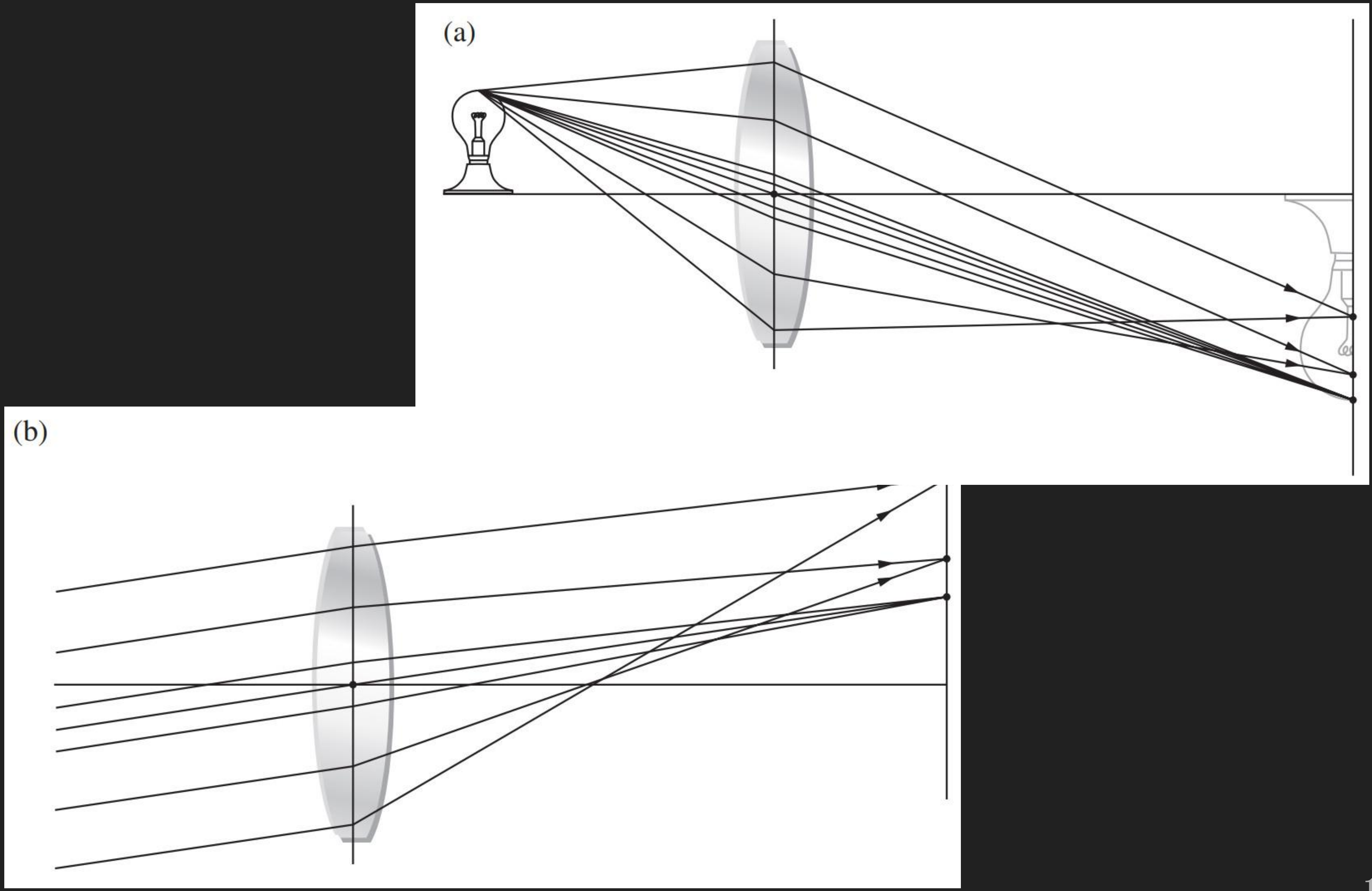
Hubble Space Telescope



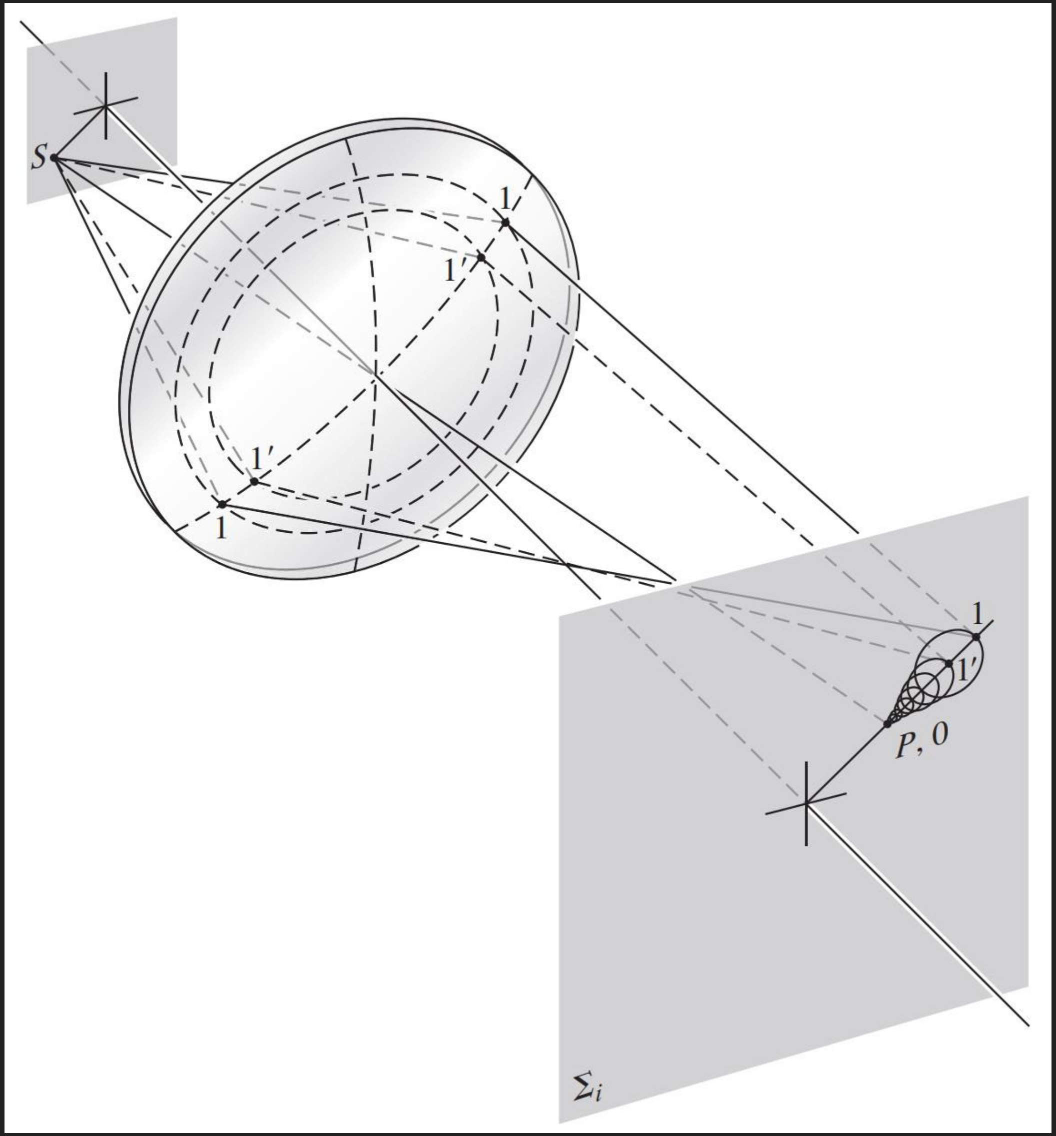




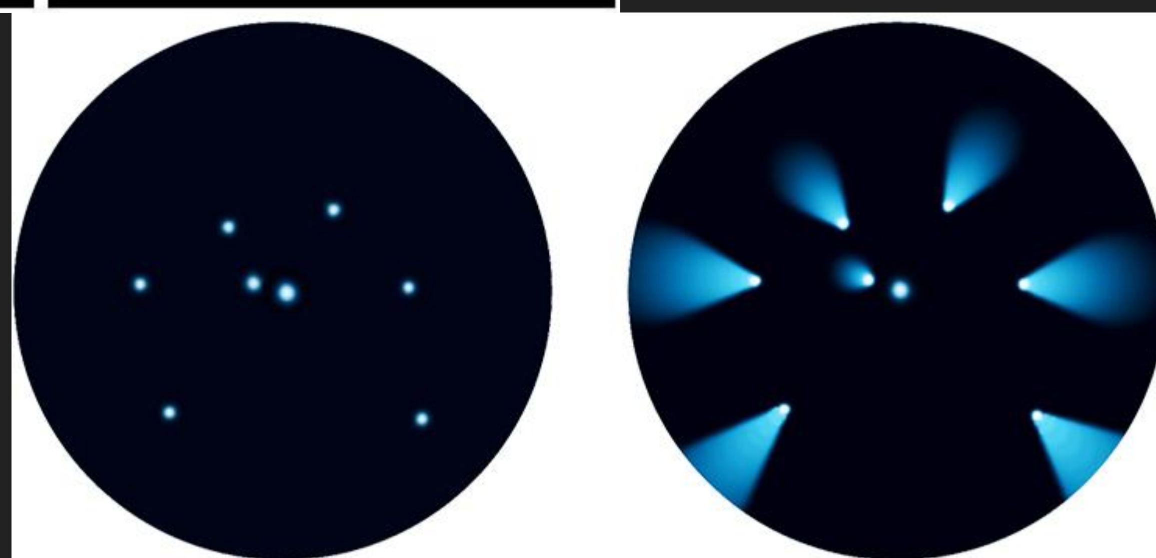
Comatic aberration I



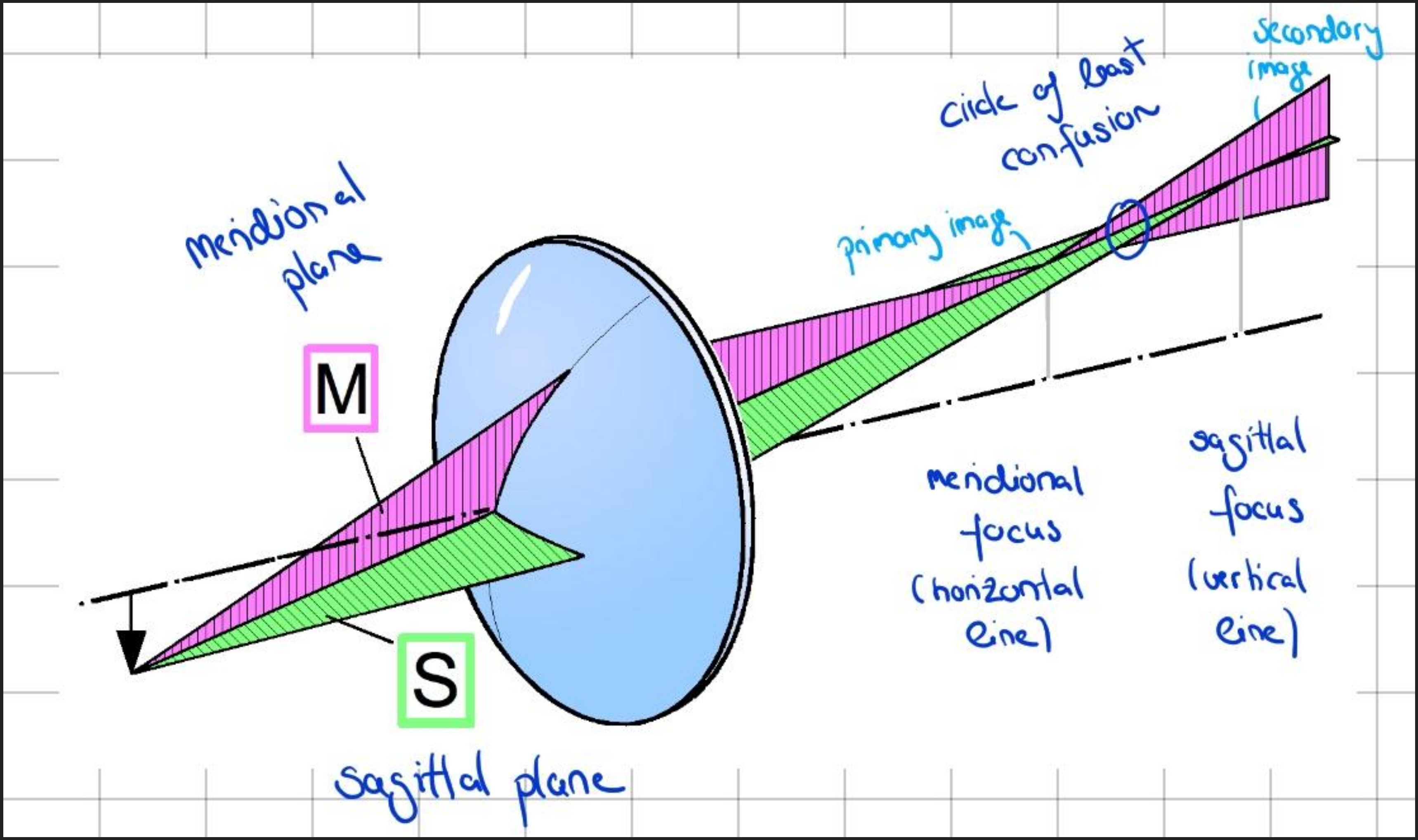
Comatic aberration II



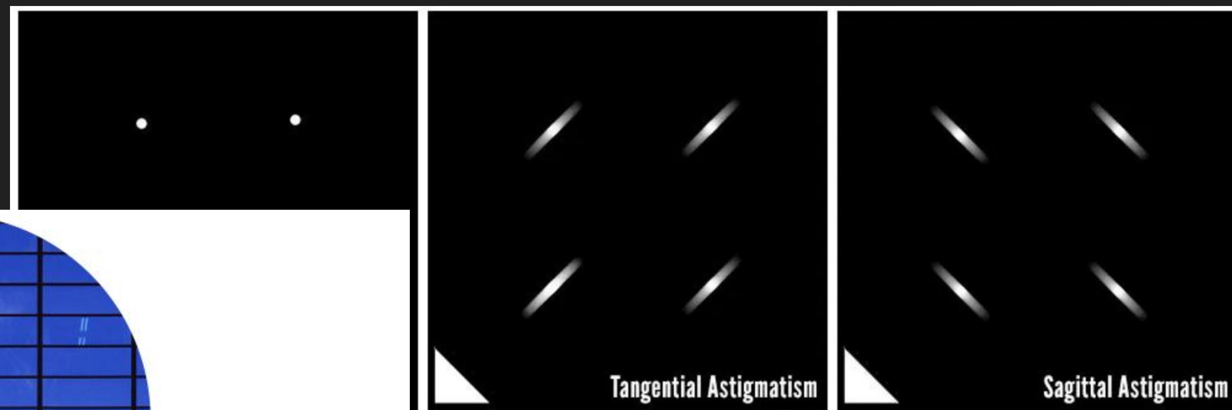
Comatic aberration III

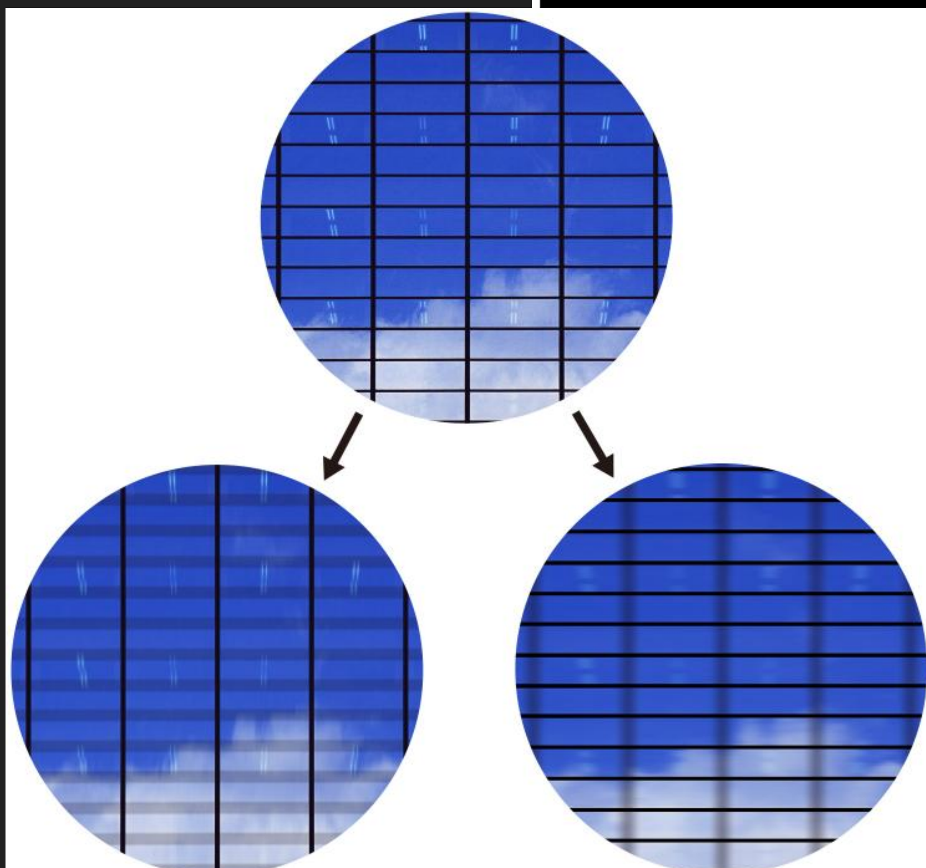


Astigmatism I

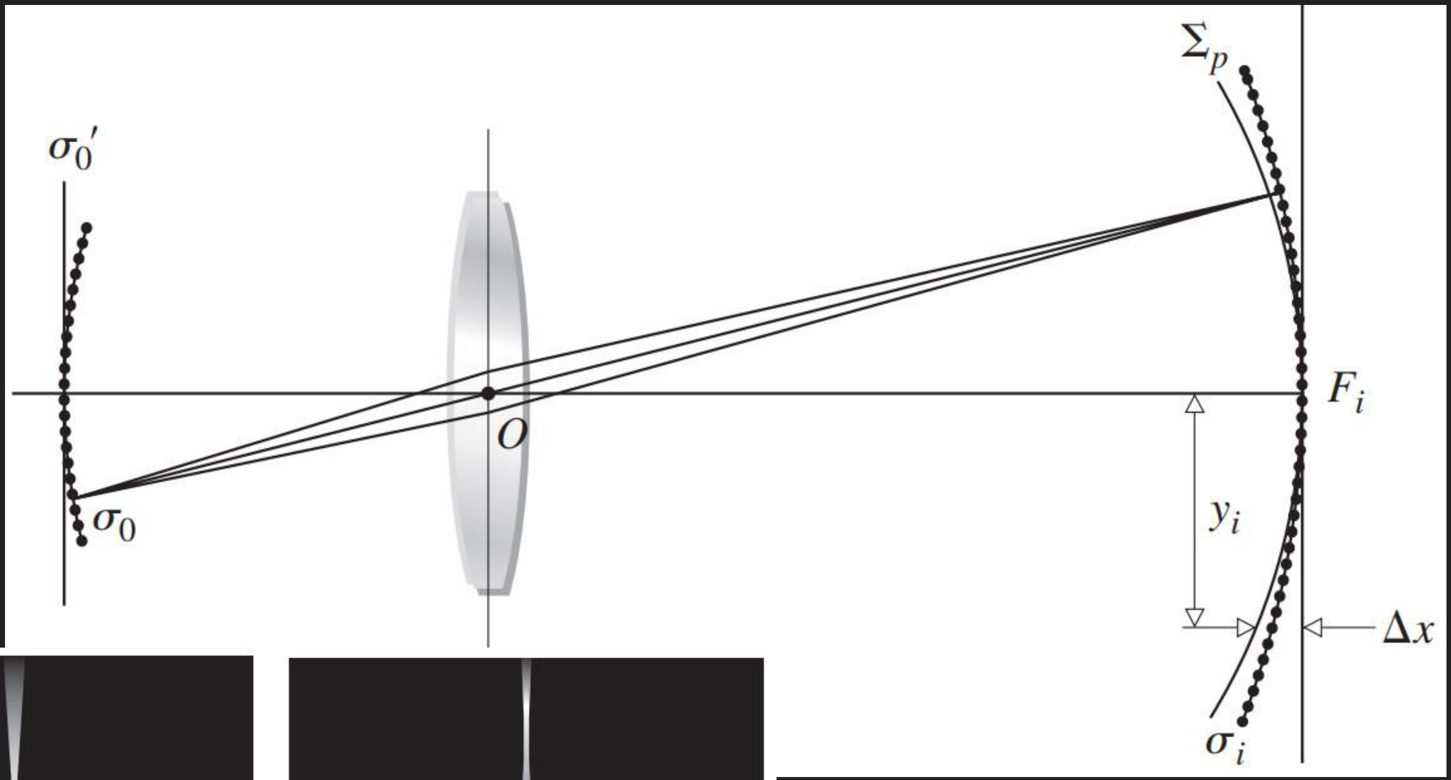


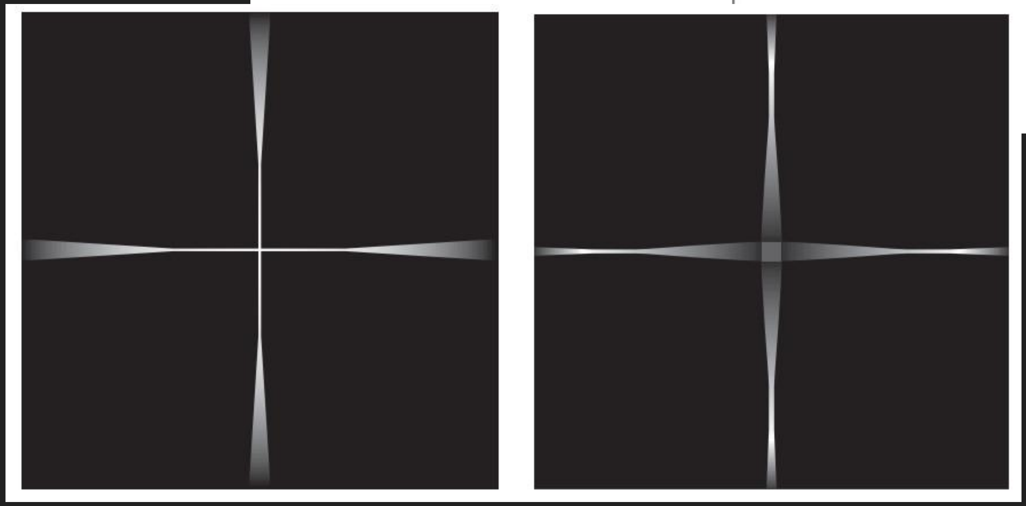
Astigmatism II





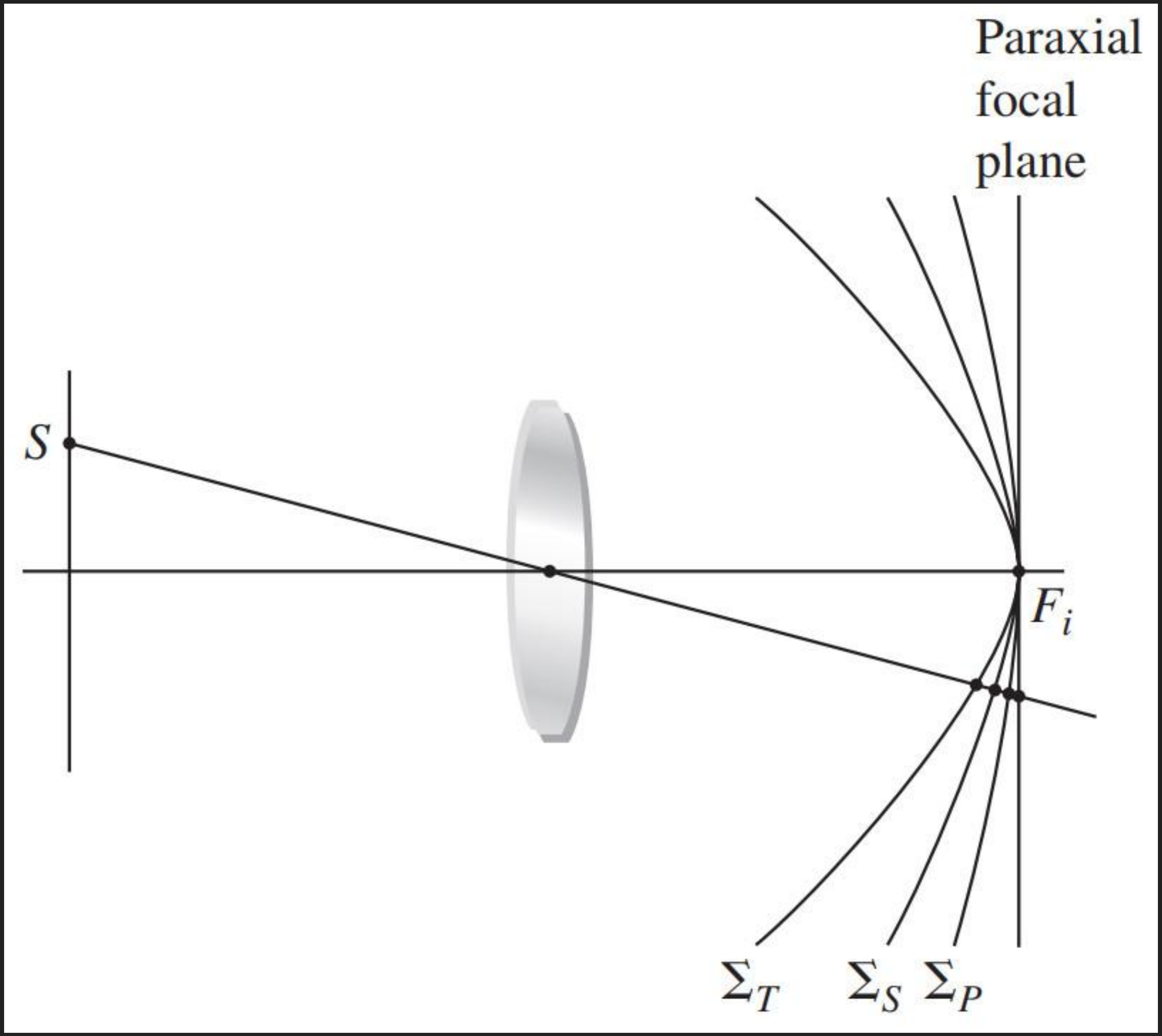
Field curvature I



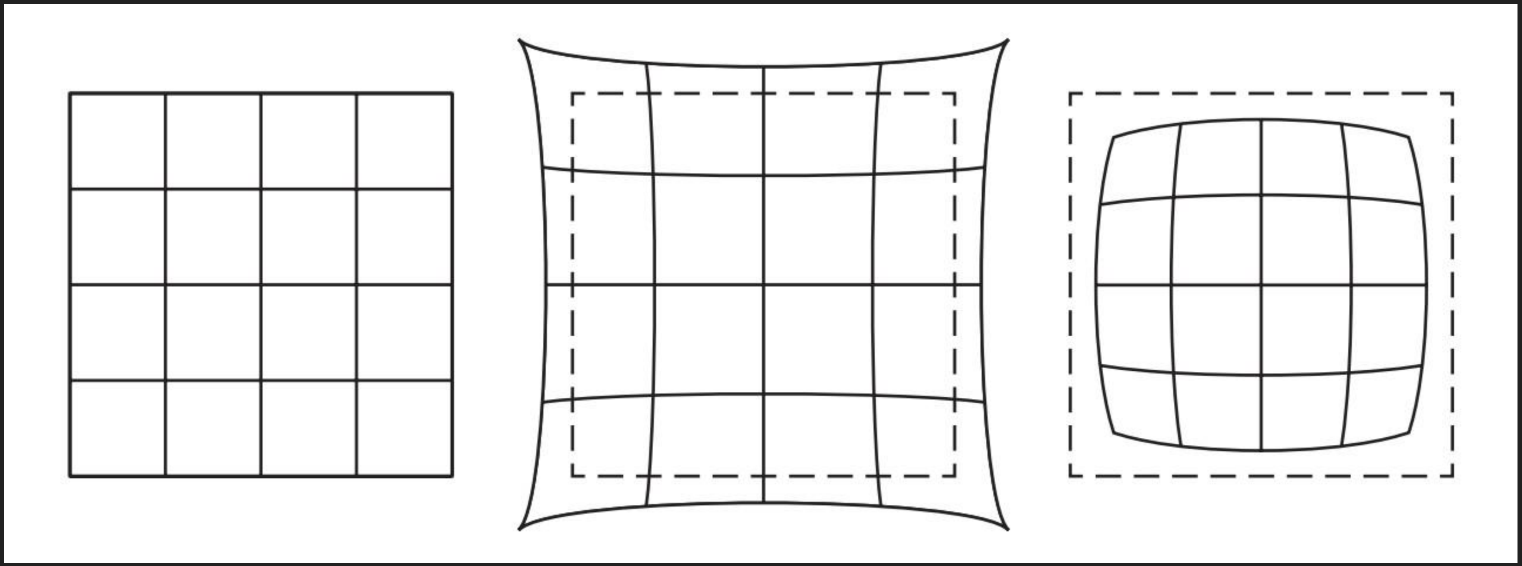


Field curvature II

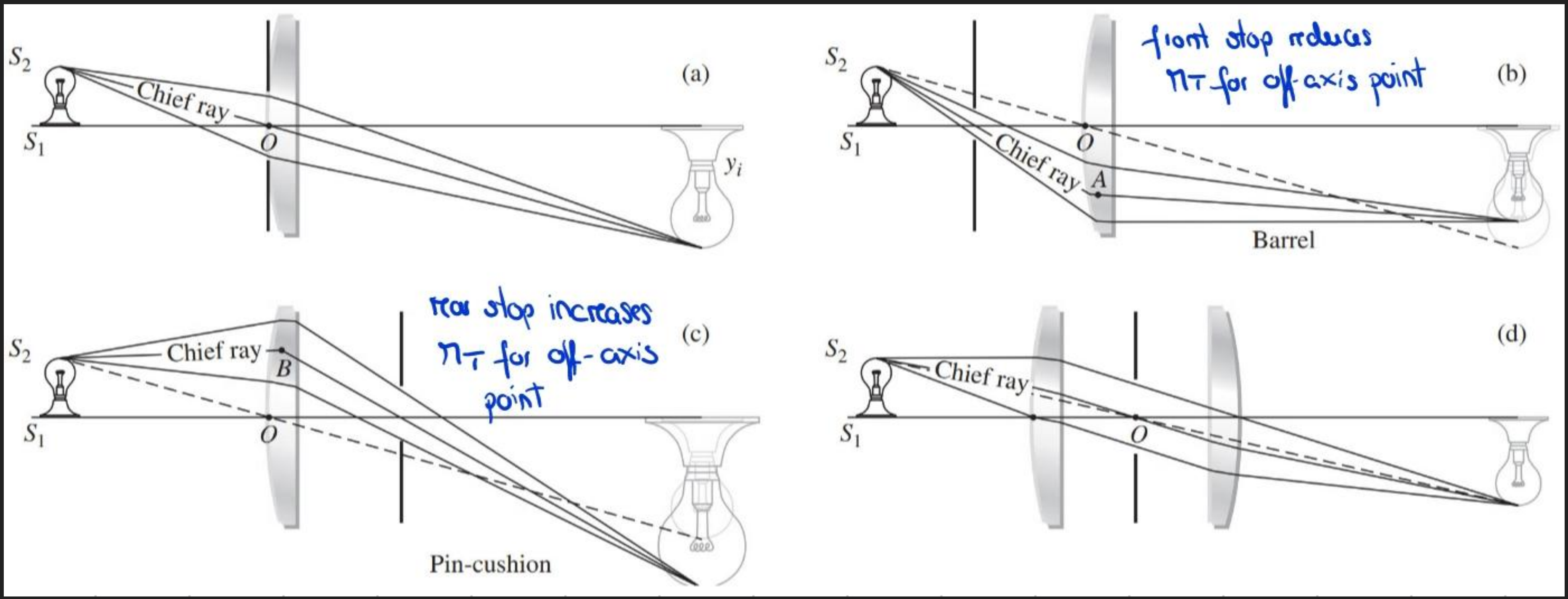
Field curvature + astigmatism



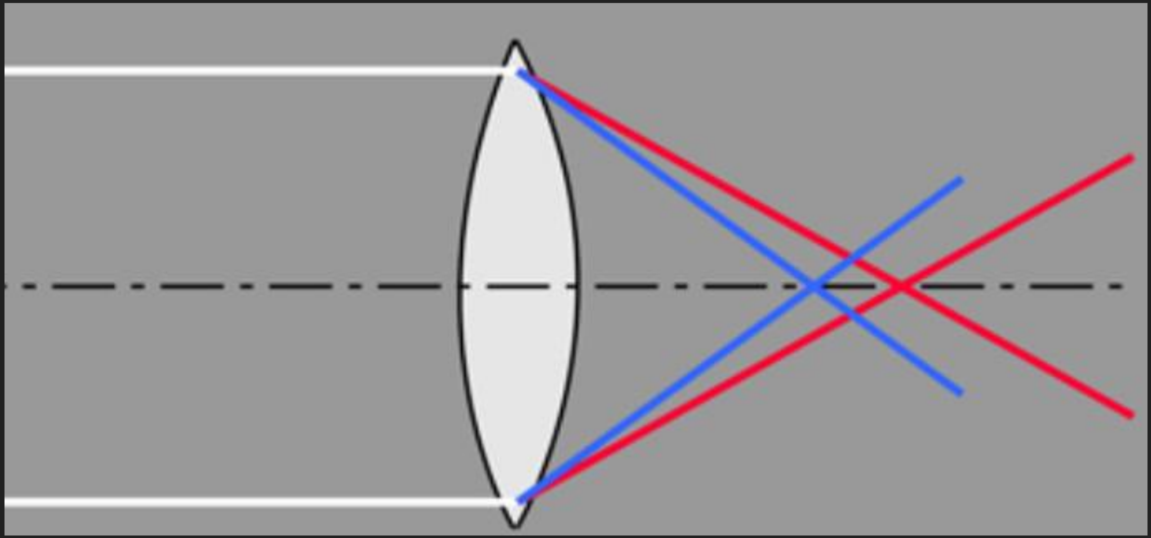
Distortion

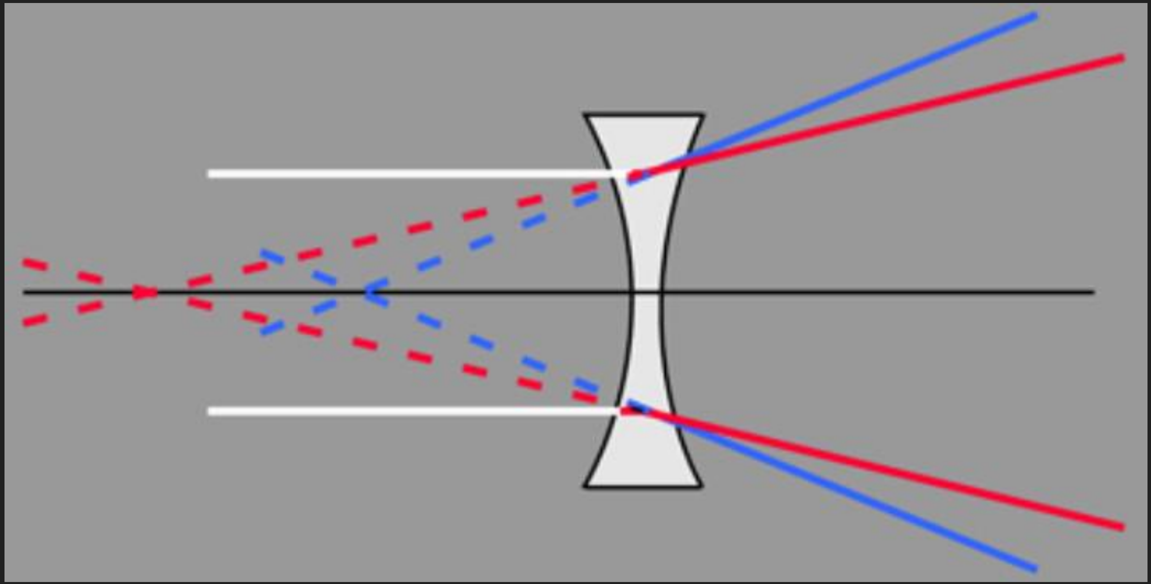


Distortion and stops

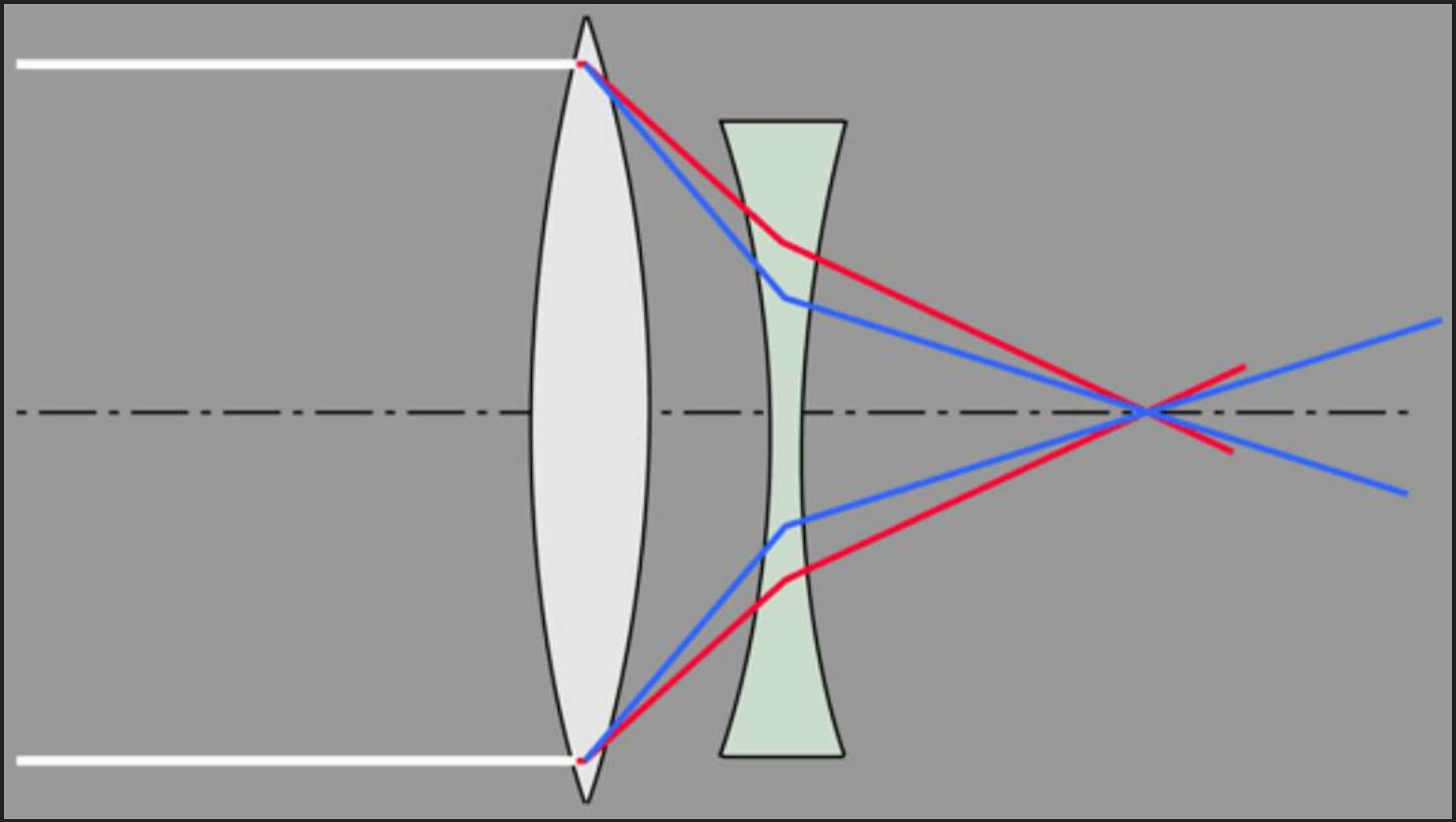


Chromatic aberration I

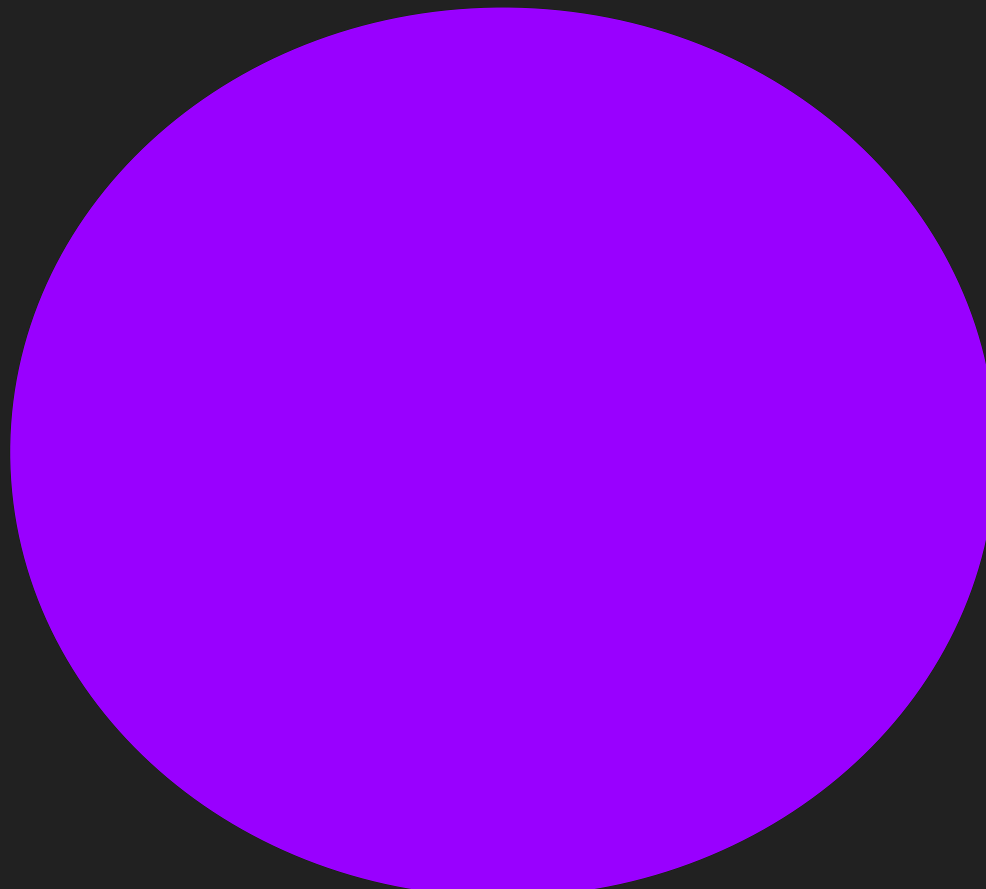




Chromatic aberration II



Chromatic aberration III



Summary Lecture 9

- So far, we have considered the ideal conditions of Gaussian optics. The first-order theory was based on the paraxial approximation.

- Real system diverge from this and show aberrations. Monochromatic/Seidel aberrations: spherical aber-Ration, coma, astigmatism, field curvature, distortion.

- Additionally, chromatic aberrations are present that originate from the density dependence of n and f.