In the name of GOD

Ansys Zemax OpticStudio

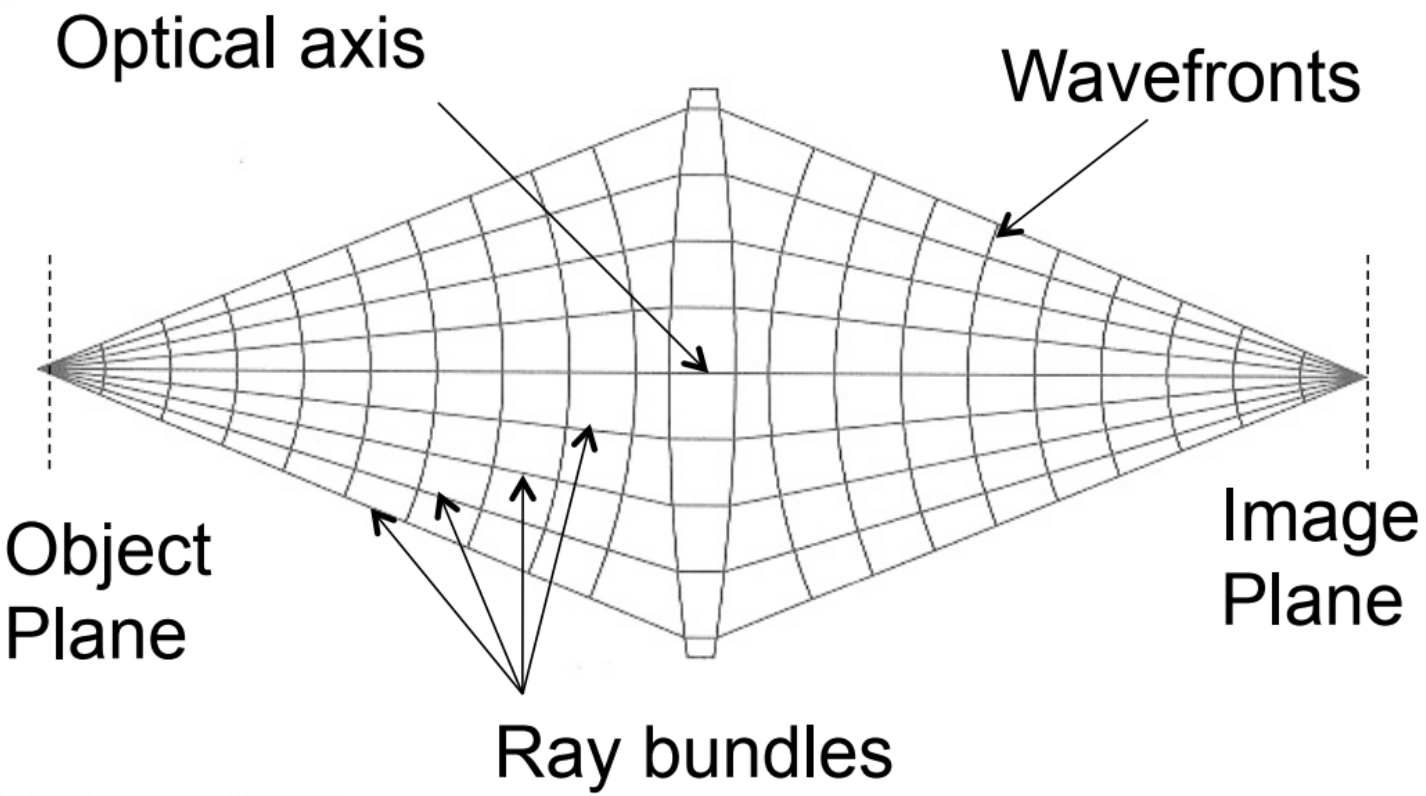
Comprehensive Optical Design Software

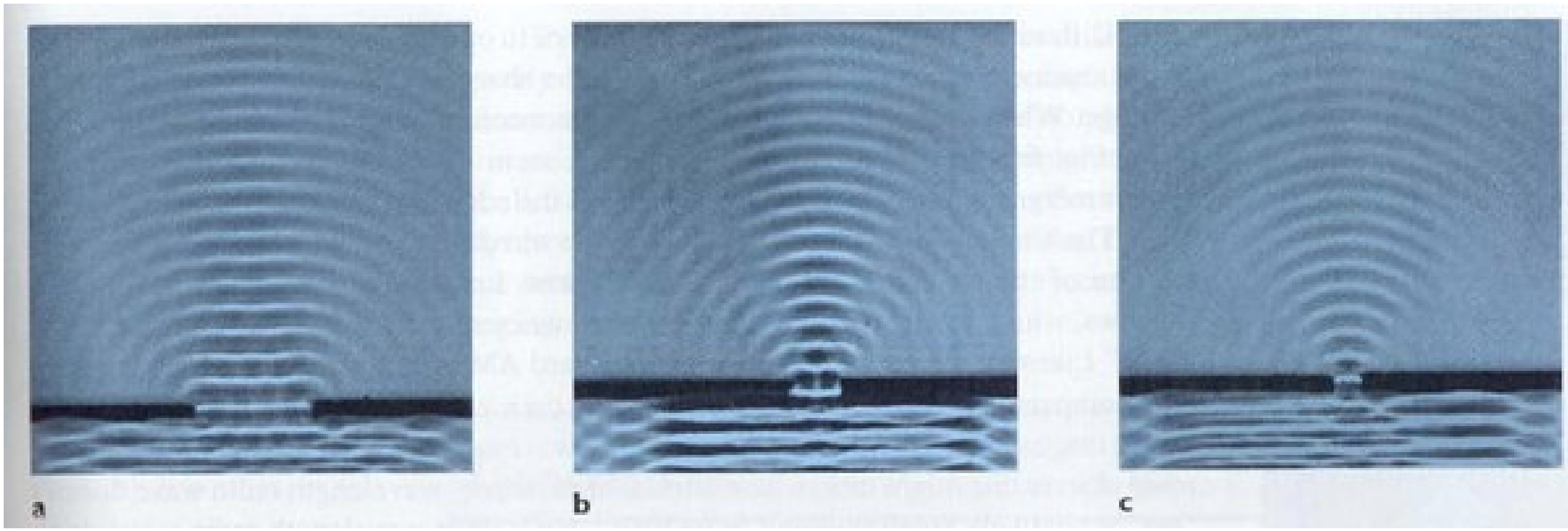
Mojtaba Golshani

March 2025

Optics

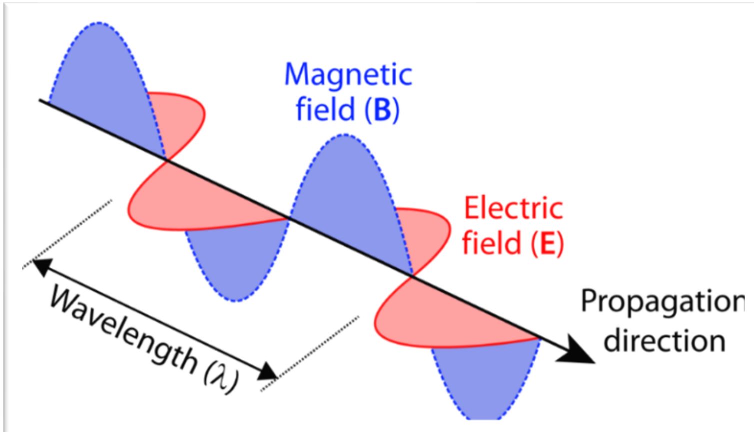
Geometrical Optics / Wave Optics

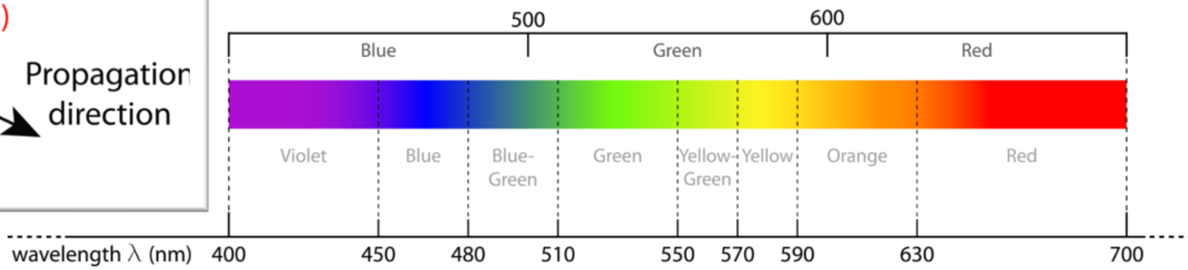




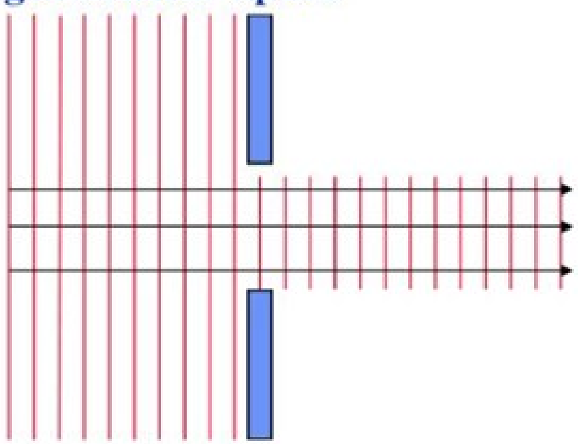
$a \gg \lambda$

$a \sim \lambda$

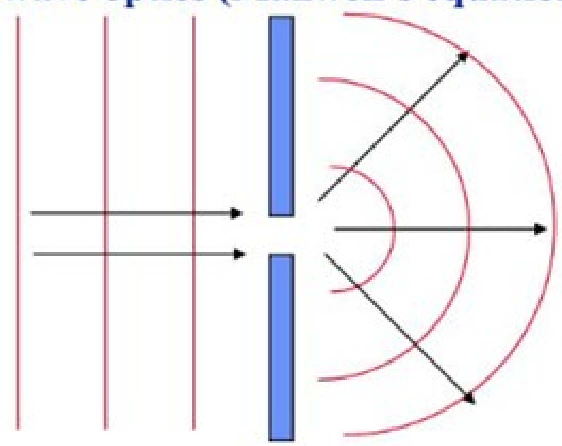




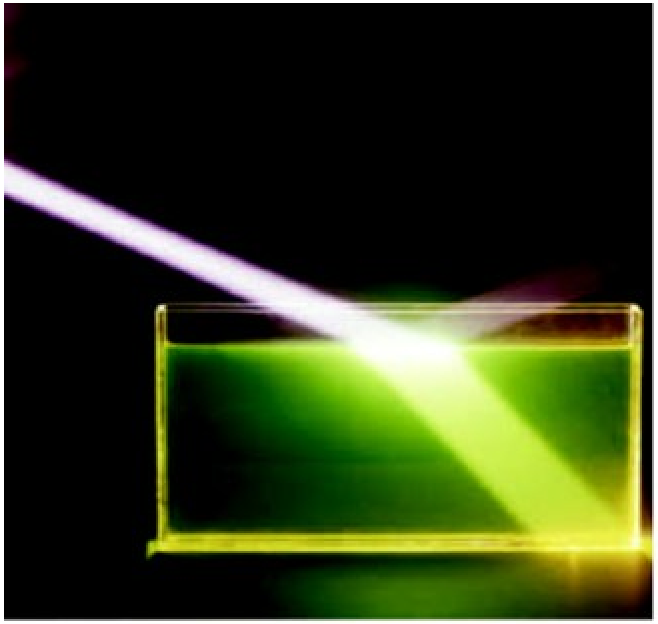
This can be described using geometrical optics

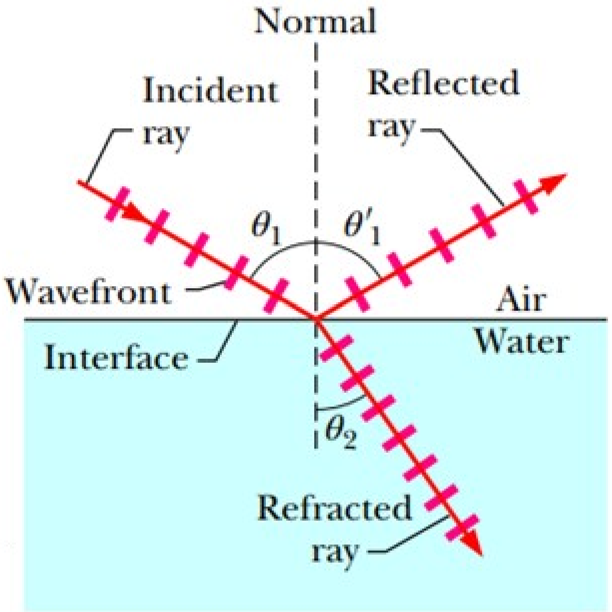


This requires the use of full wave optics (Maxwell's equations)



Geometrical Optics Laws

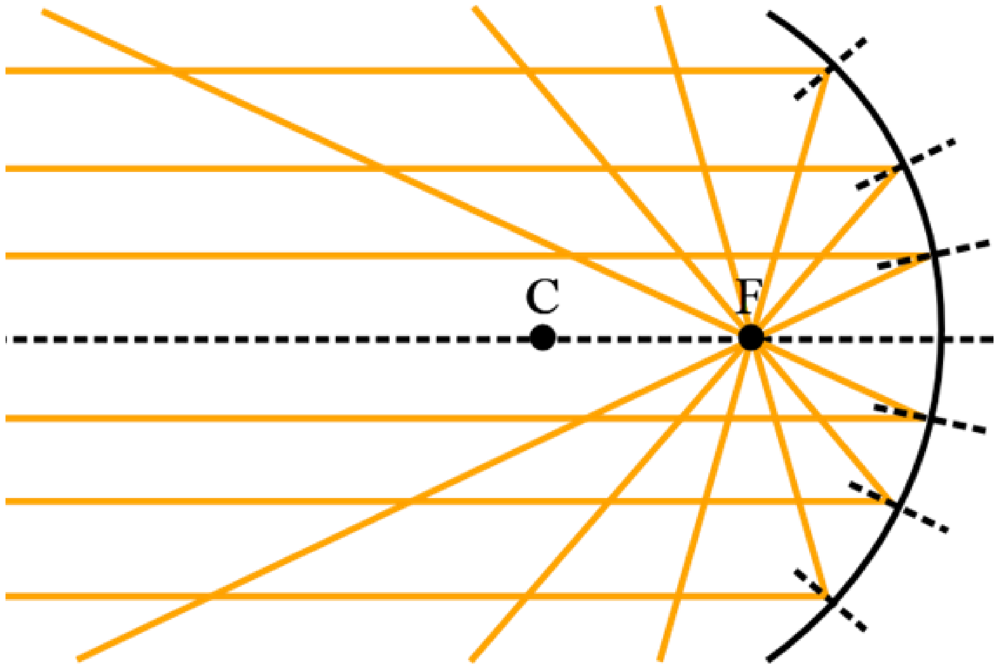




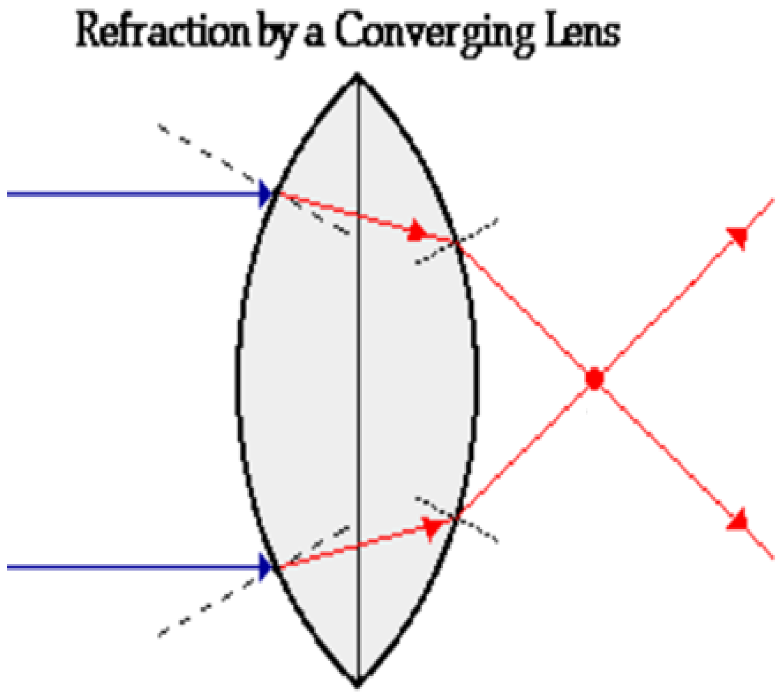
$$\theta_1{}' = \theta_1$$

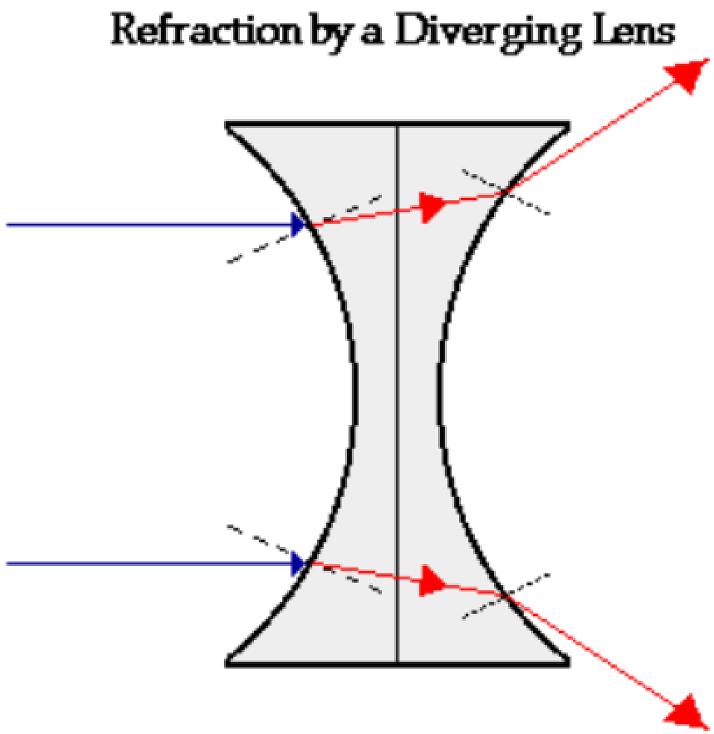
$$\mathrm{n}_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

Mirror Reflects Light

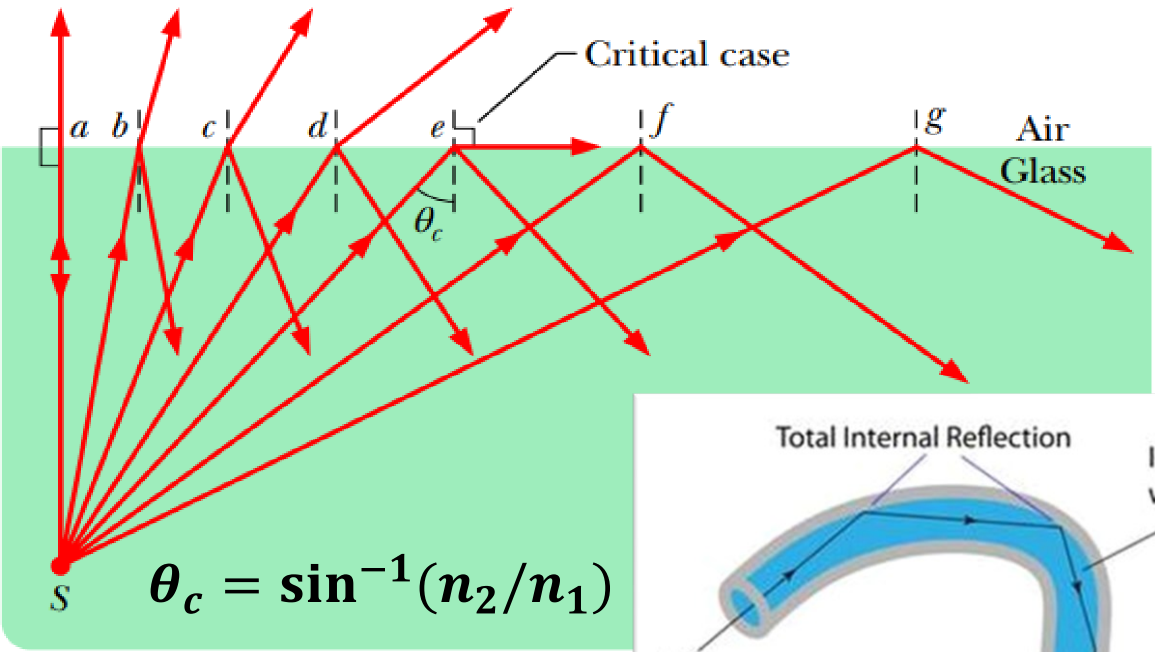


How a Lens Refracts Light

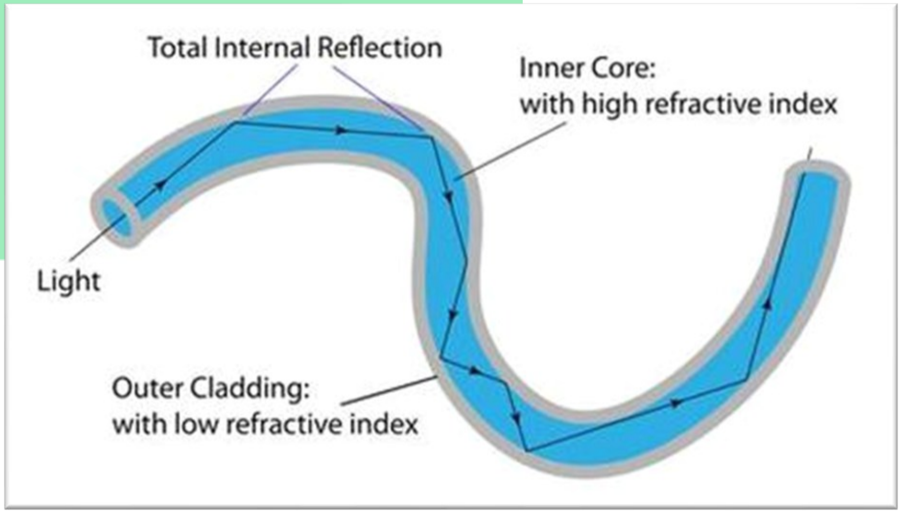


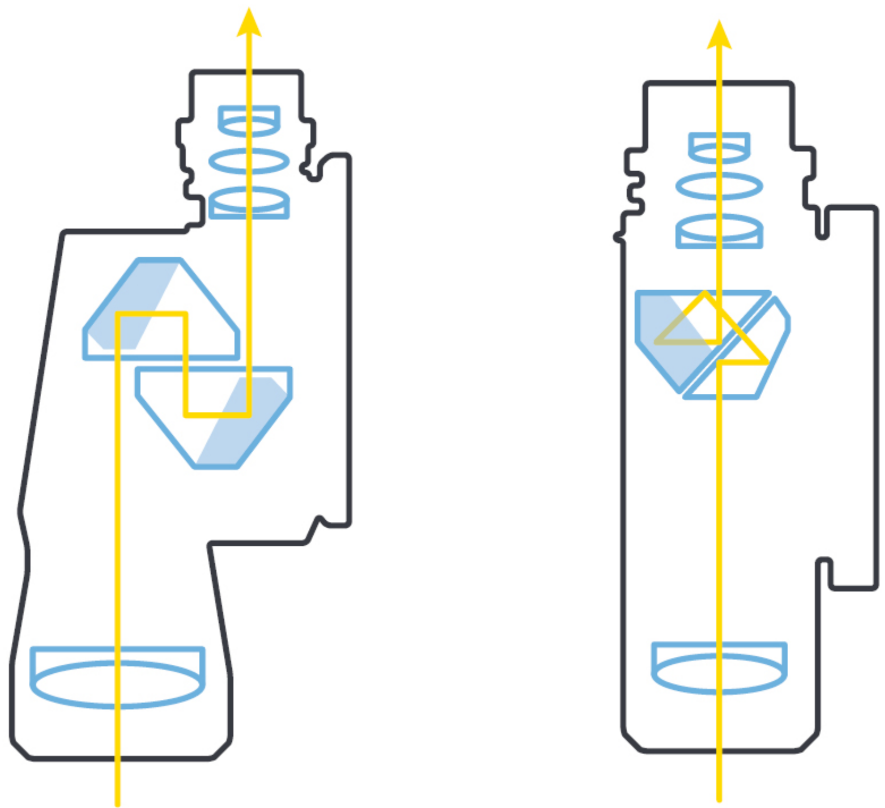


Total Internal Reflection



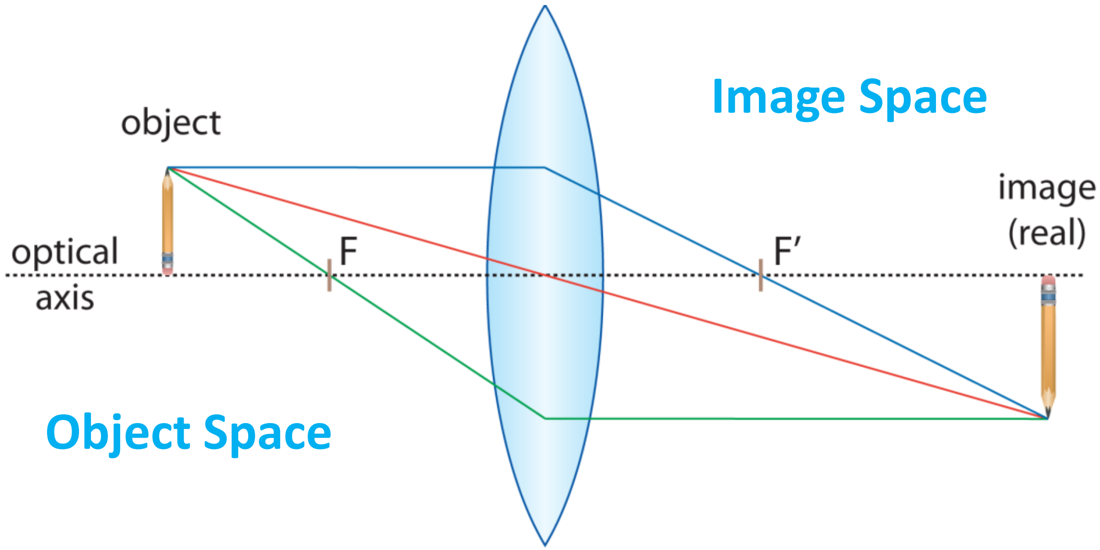
$$\theta_c = \sin^{-1}(n_2/n_1)$$



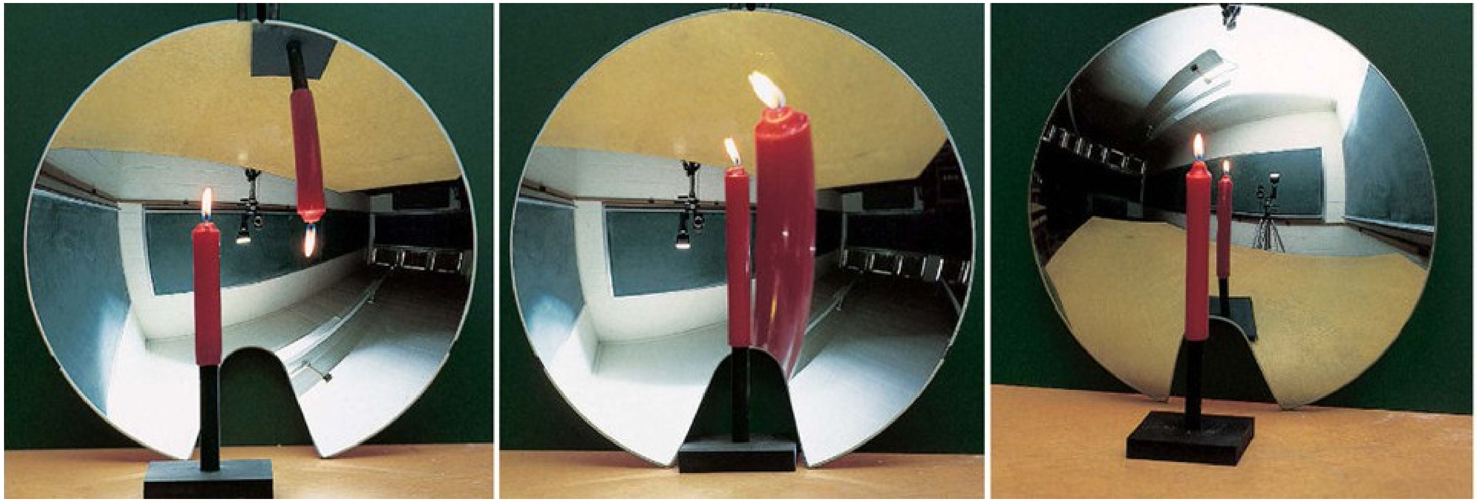


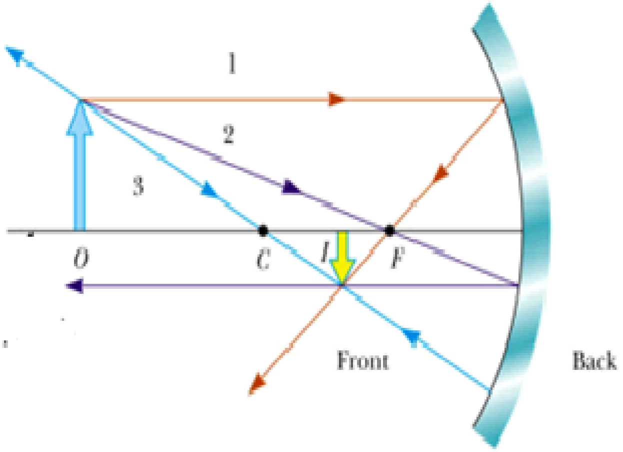
Left: Beam path in a pair of binoculars with Porro prism system.
Right: Beam path in a pair of binoculars with a roof prism system.

Geometric-optical Imaging (Ray Tracing)

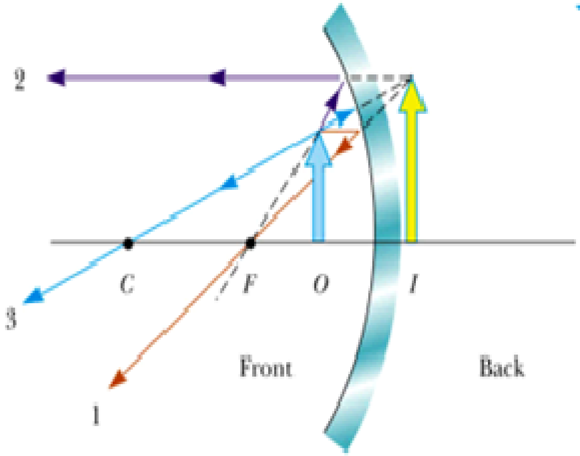


$$Magnification = \frac{image\ height}{object\ height}$$

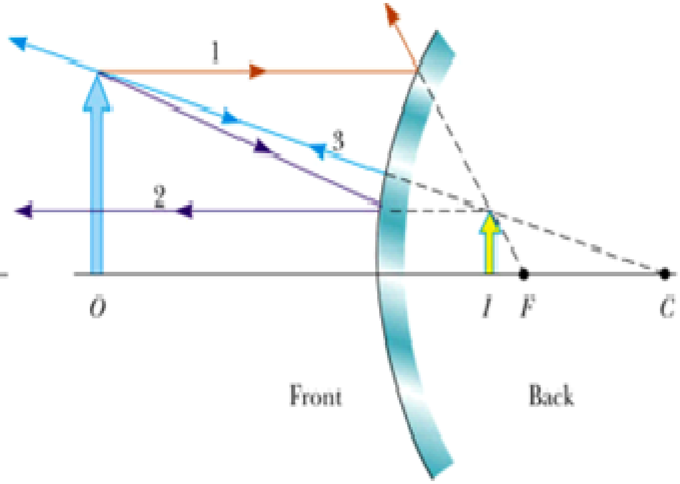




1
2
3
O
C
I
F
Front
Back

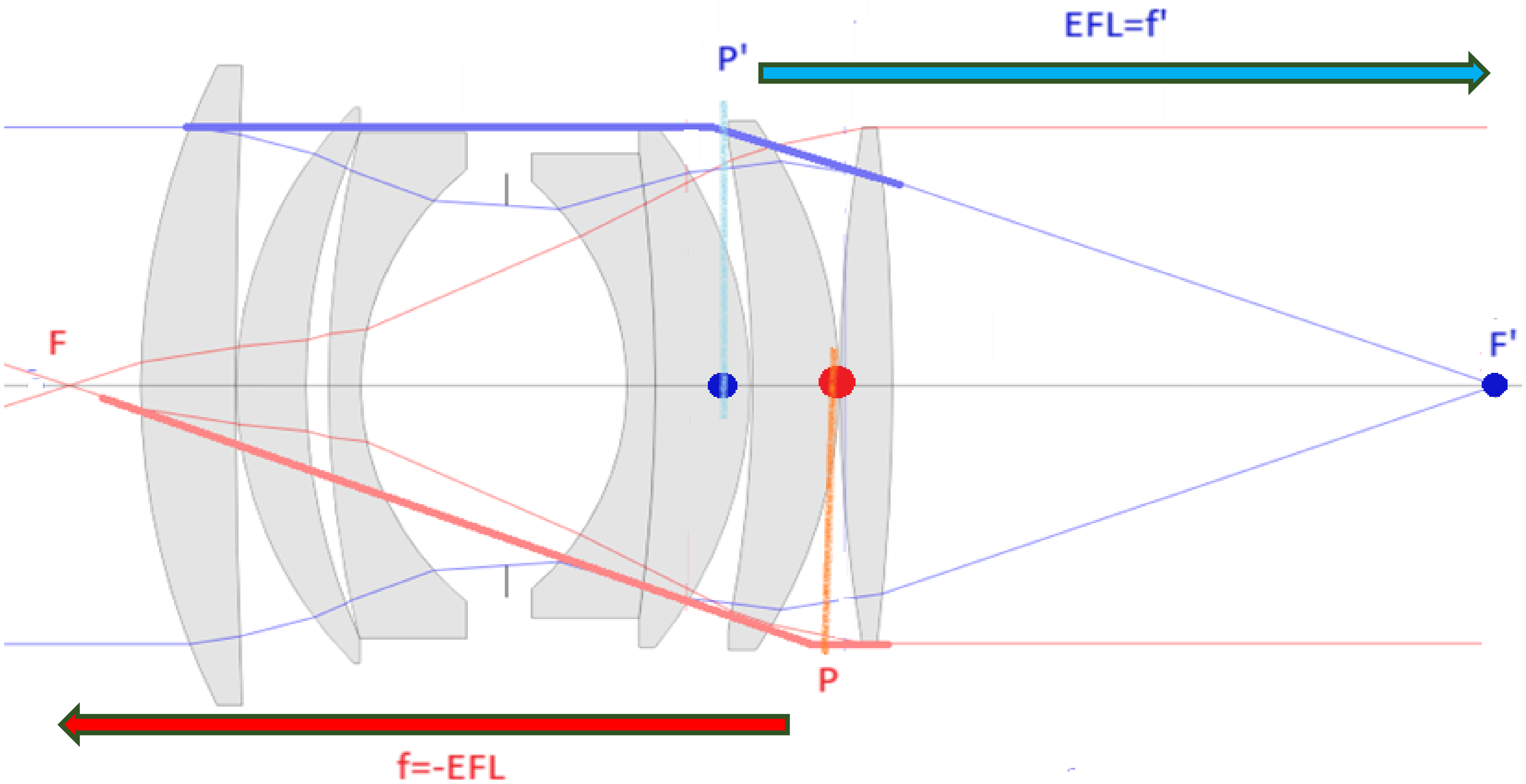


2
3
1
C
F
O
I
Front
Back



1
3
2
O
I
F
C
Front
Back

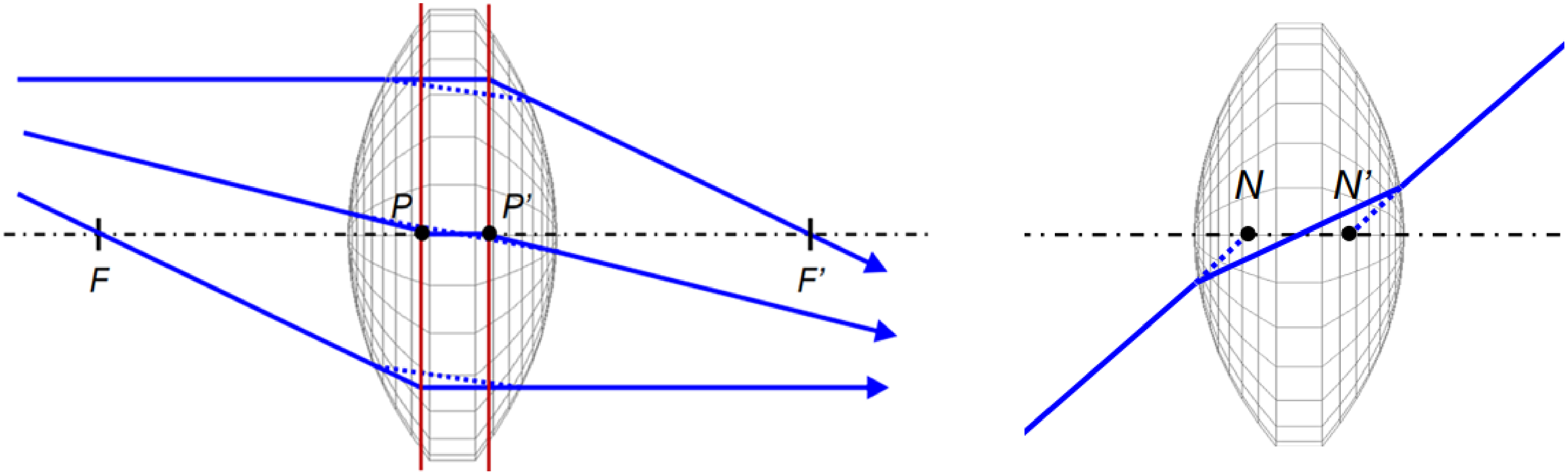
Focal and Principal Points, Focal Lengths



Object Space

Image Space

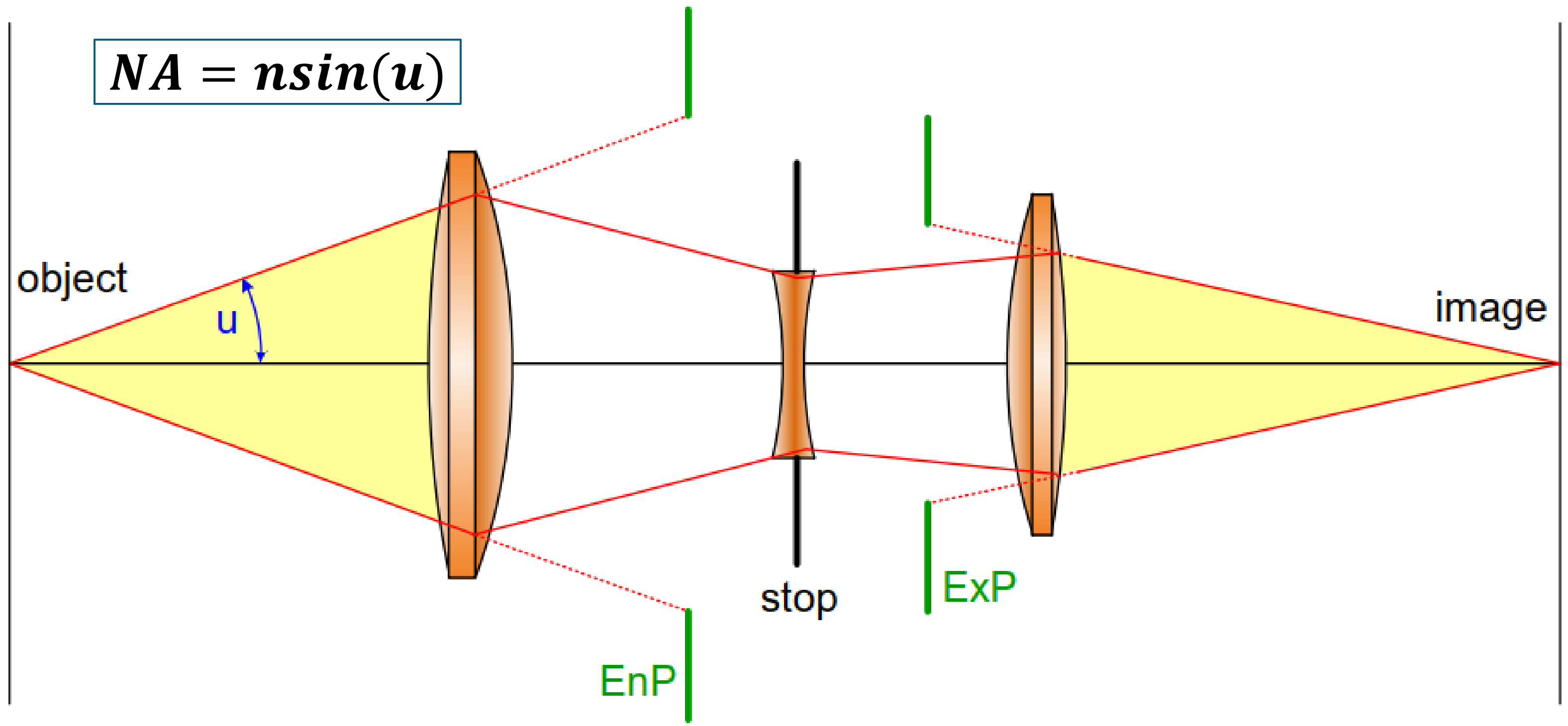
Cardinal Points of a Thick Lens



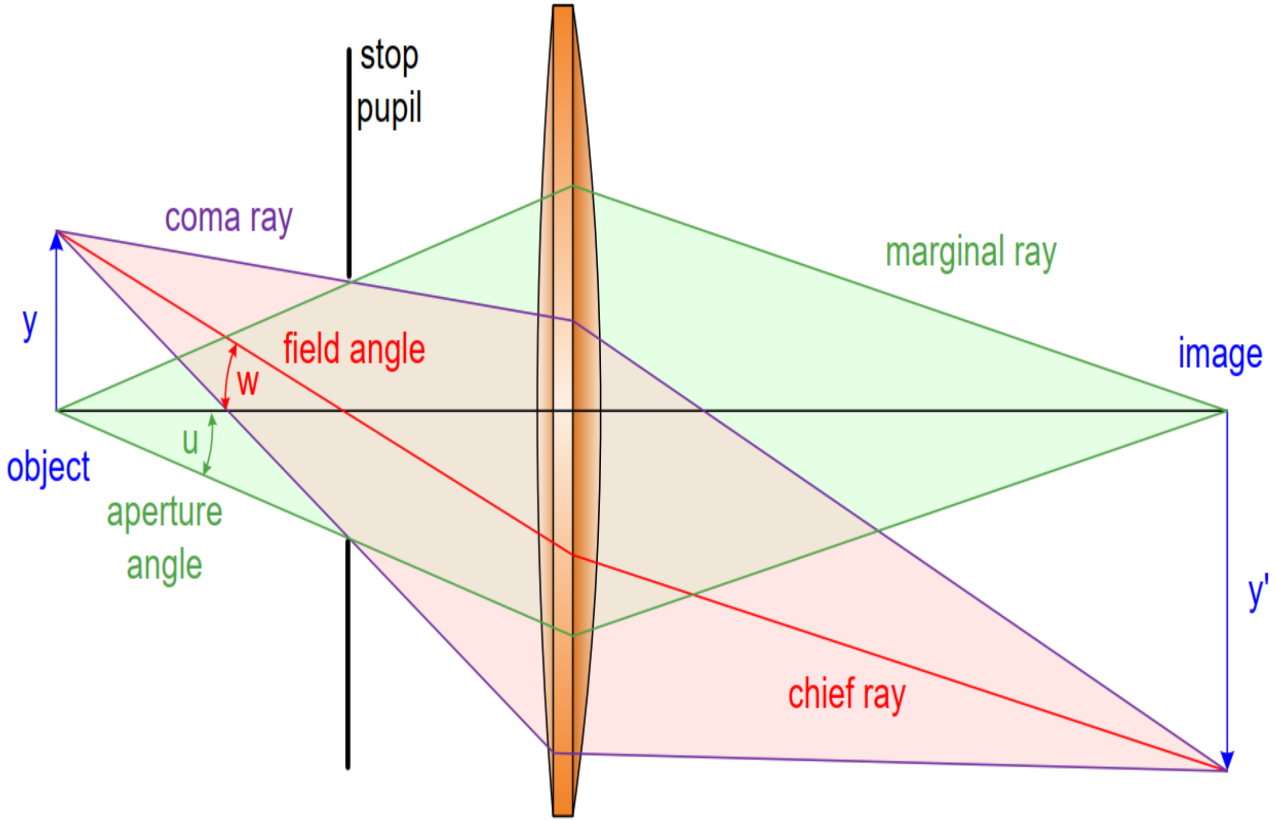
$$K = \frac{1}{\mathrm{EFL}} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)\,t_c}{n\,R_1\,R_2}\right)$$

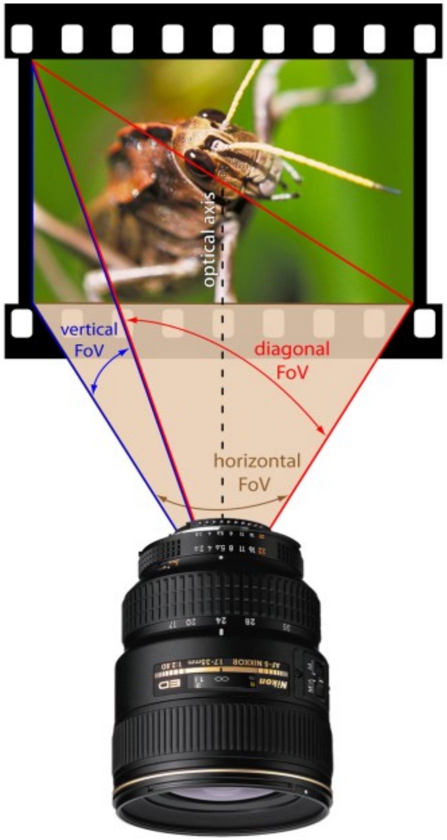
Stops and Pupil

The entrance pupil fixes the acceptance **cone angle** or **numerical aperture** (NA) in the object space.

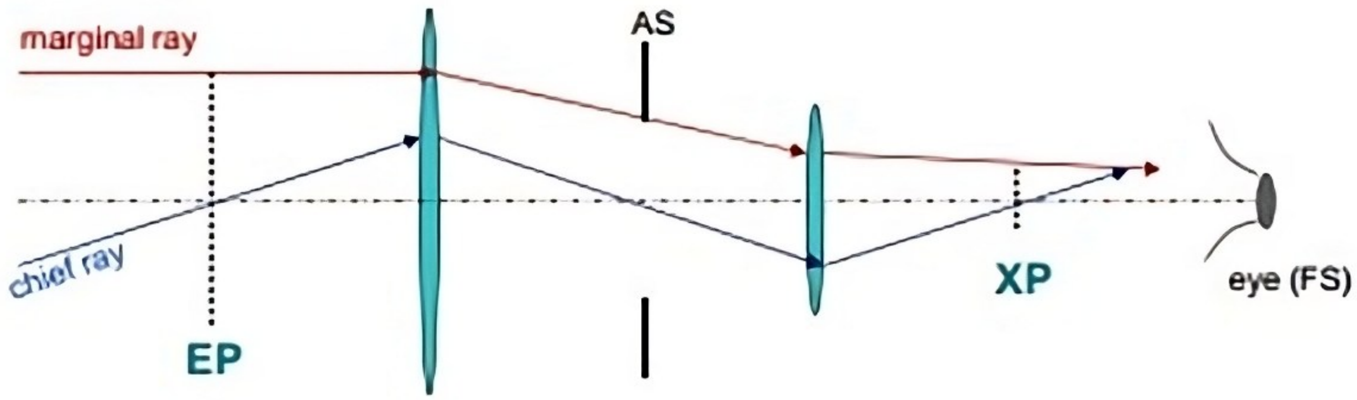


Marginal Ray and Chief Ray

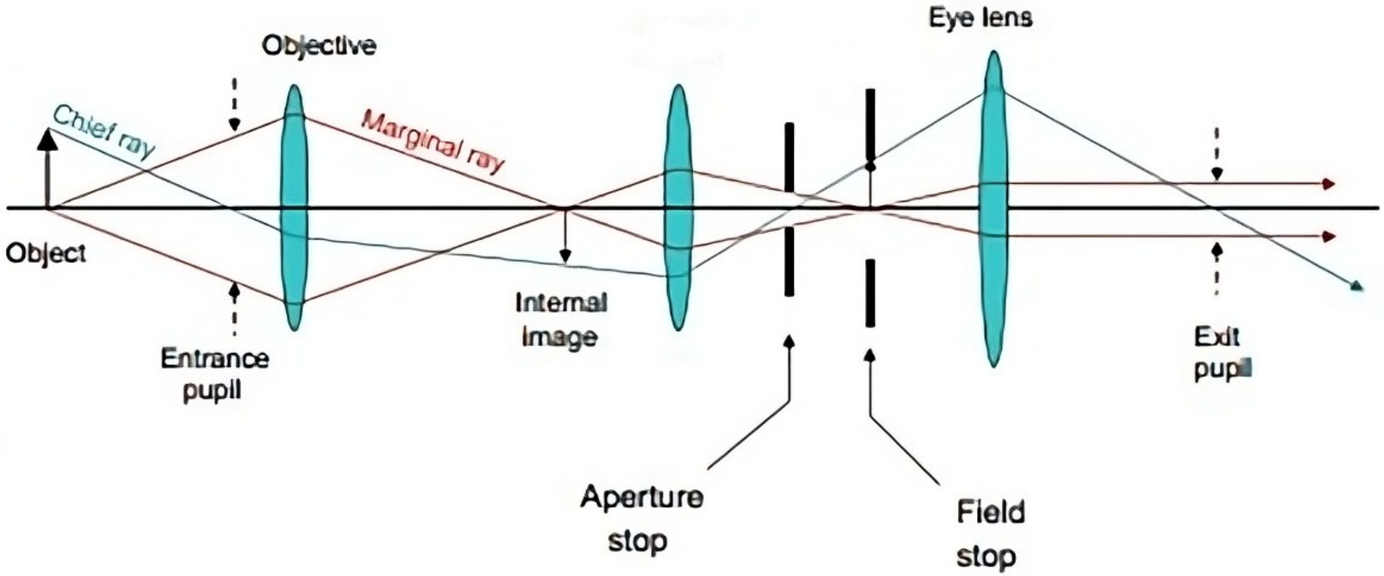




$$\boxed{FOV = 2w}$$

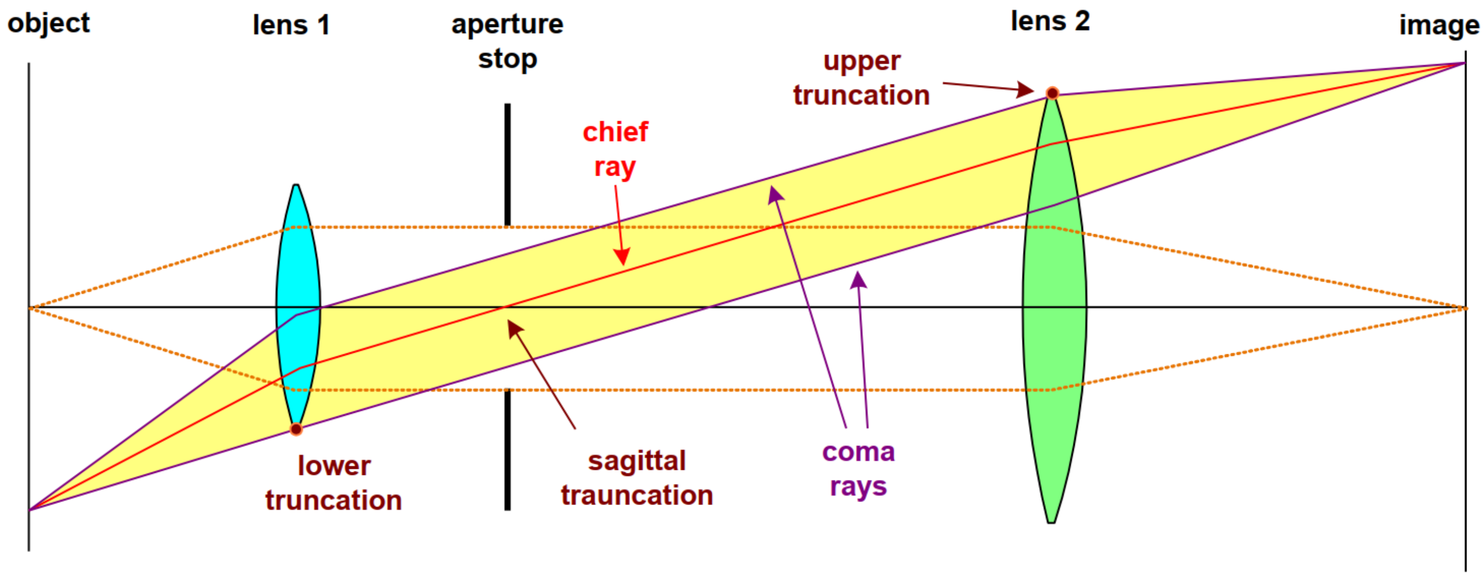


marginal ray
AS
chief ray
EP
XP
eye (FS)



Eye lens
Objective
Chief ray
Marginal ray
Object
Internal image
Entrance pupil
Exit pupil
Aperture stop
Field stop

Vignetting



object
lens 1
aperture stop
lens 2
image
upper truncation
chief ray
lower truncation
sagittal trauncation
coma rays

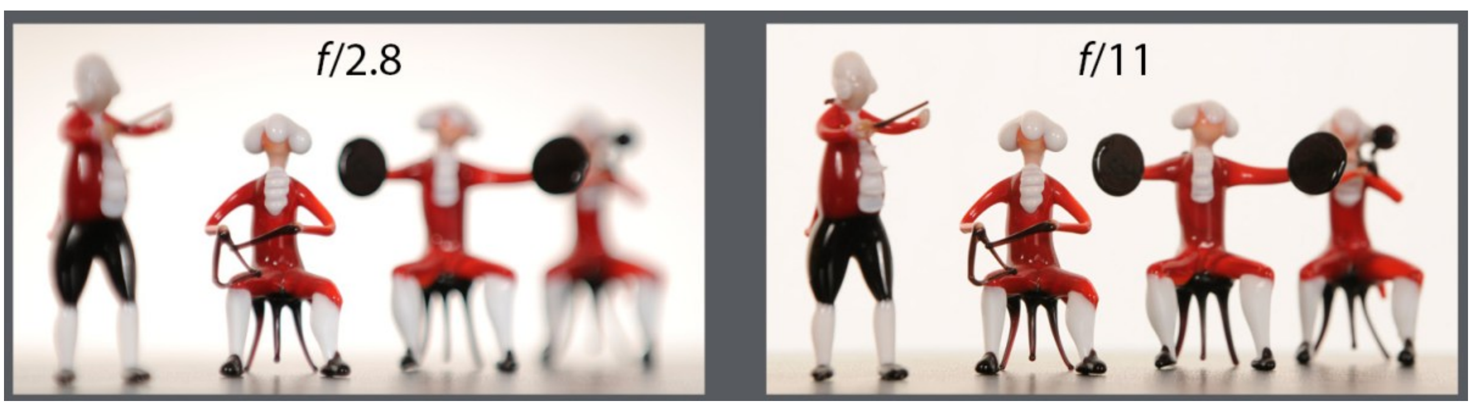
F-Number (F/#)

$$F/\# = \frac{EFL}{EPD}$$

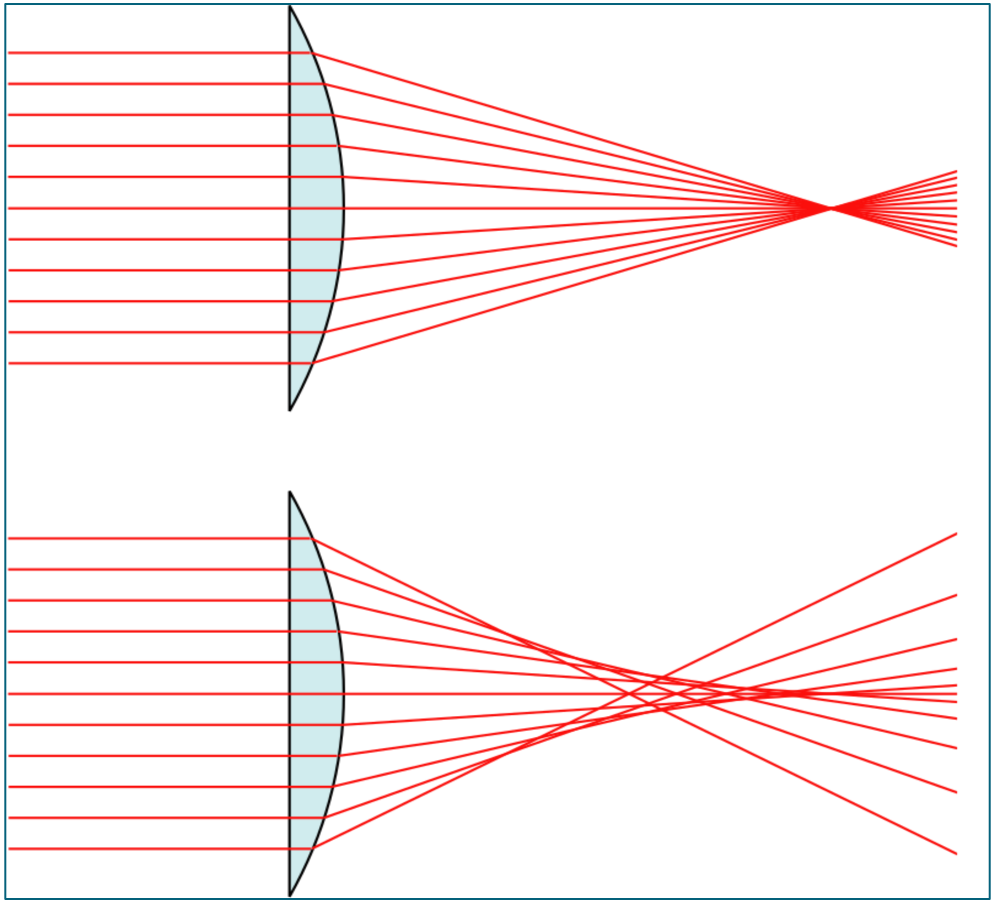
$$Working\ F/\# = \frac{EFL}{EPD}(1 - Magnification) = \frac{1}{2n' \sin(u')}$$

f-number x √2

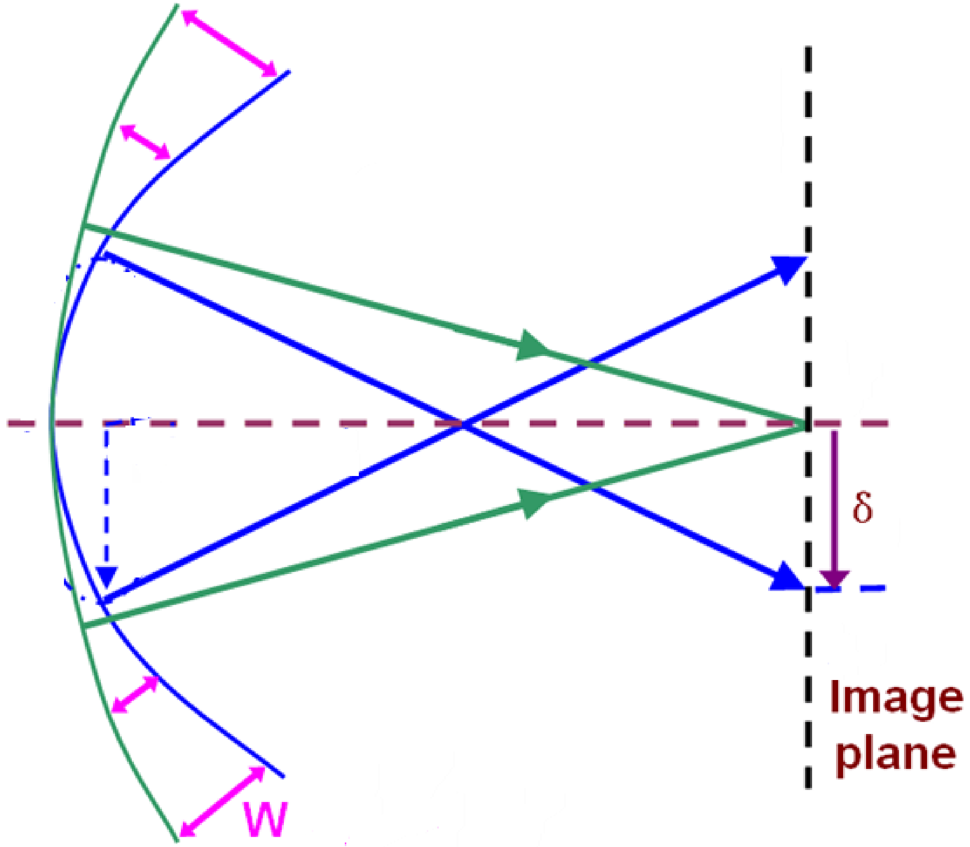
f/1.4	f/2	f/2.8	f/4	f/5.6	f/8	f/11	f-stop
A	A/2	A/4	A/8	A/16	A/32	A/64	Area
100	50	25	12.5	6.25	3.13	1.56	Light



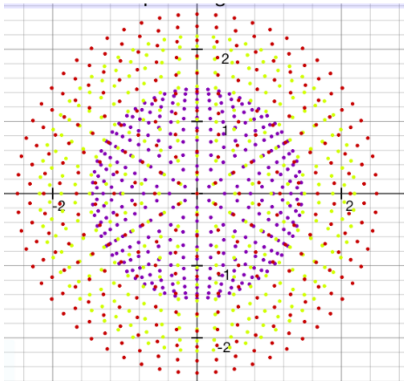
Optical (Seidel) Aberration

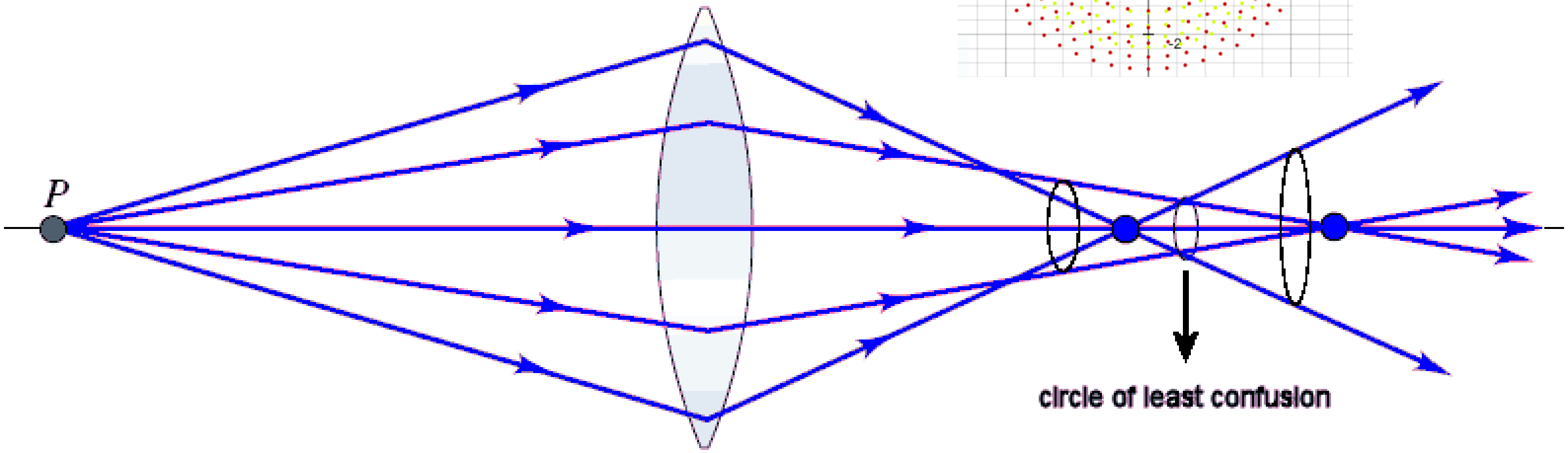


Ray Aberration / Wave Aberration

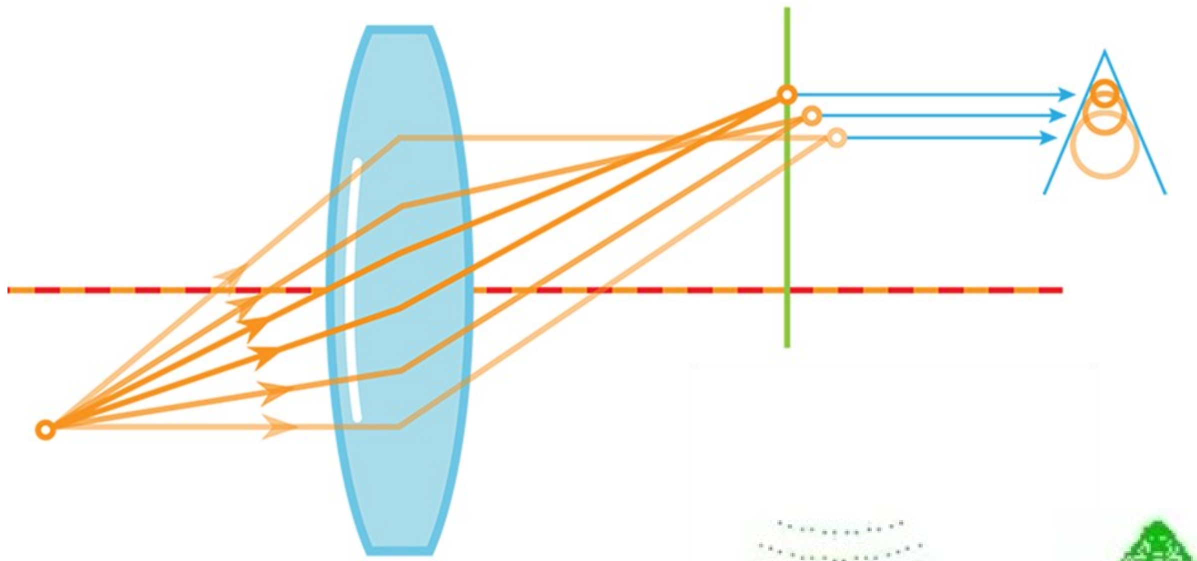


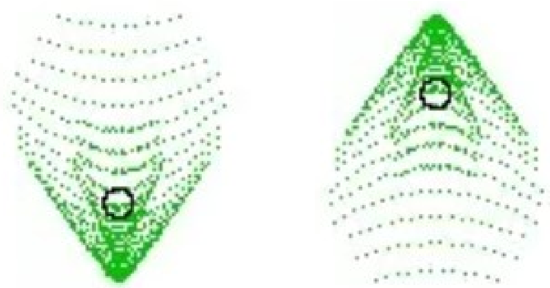
1- Spherical Aberration



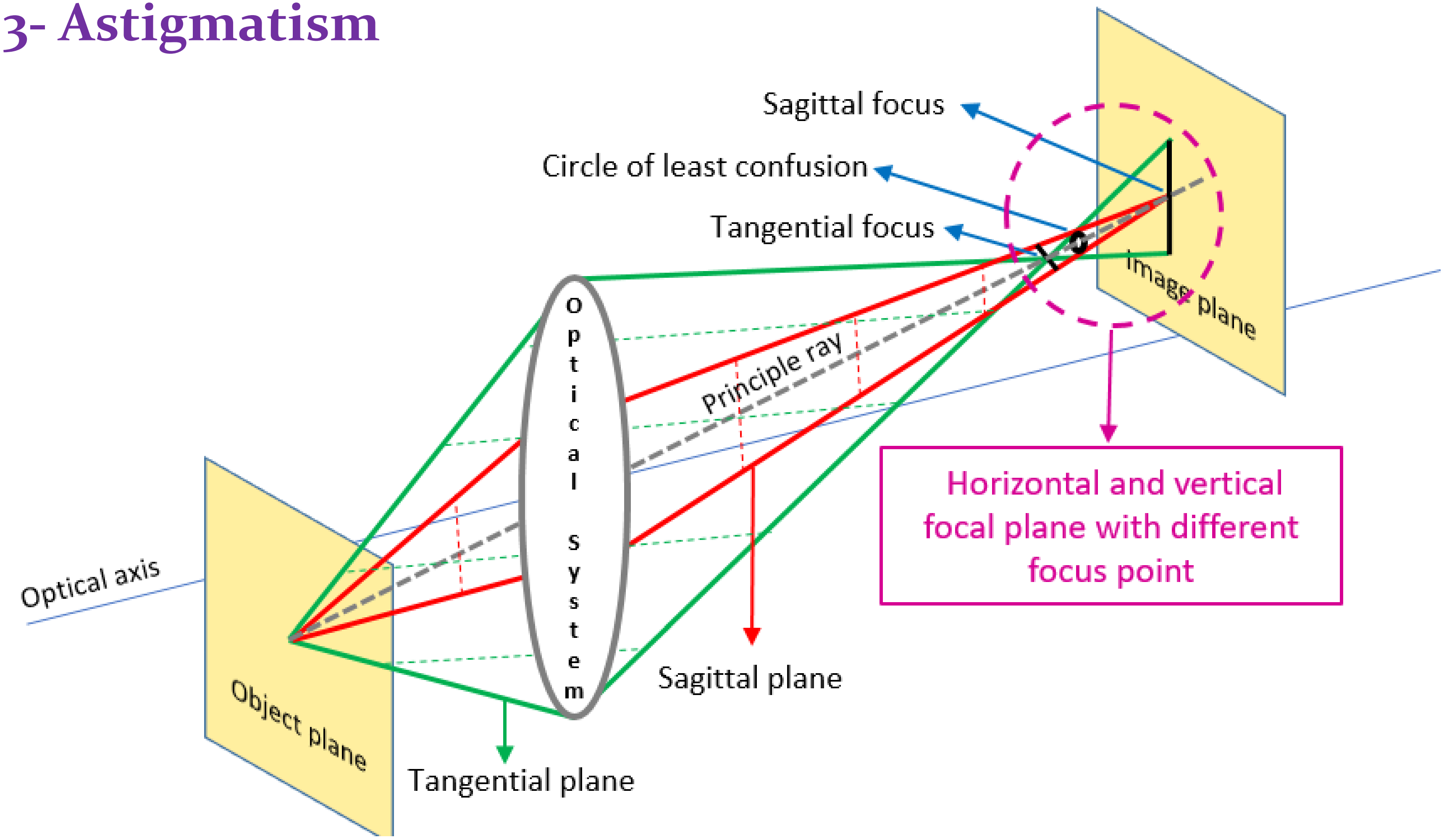


2- Coma

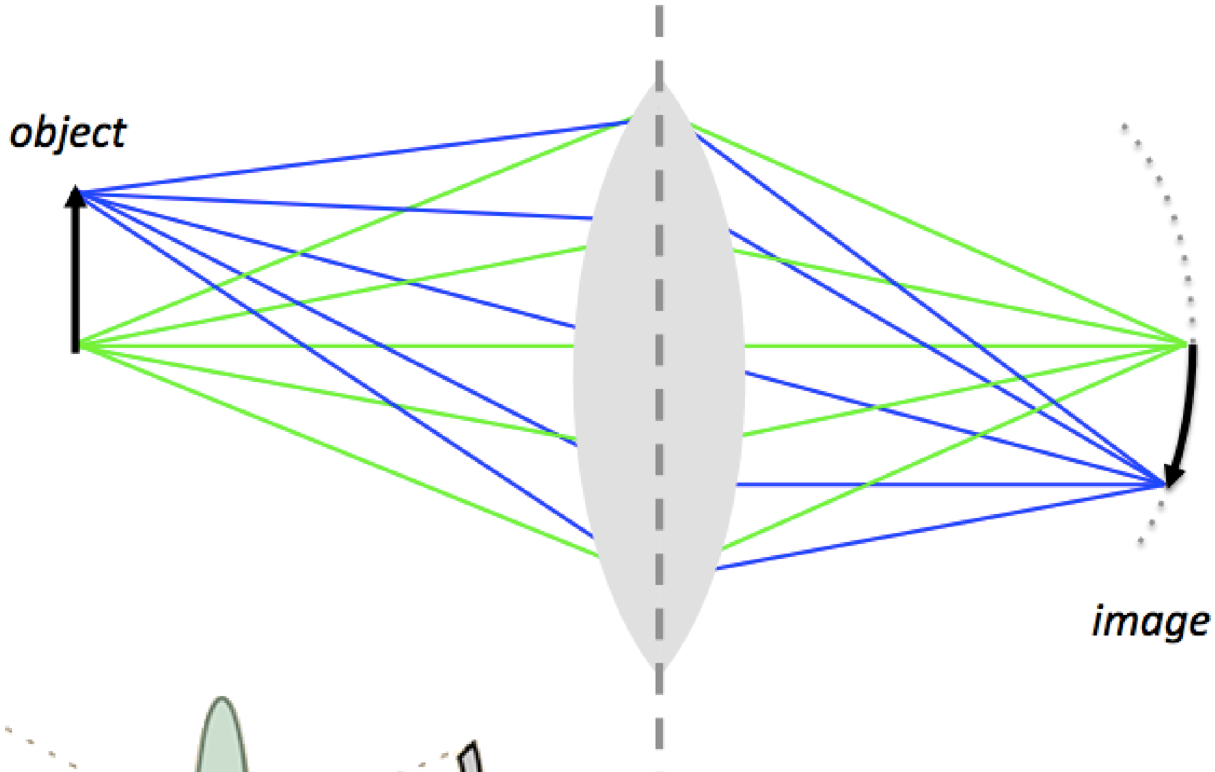


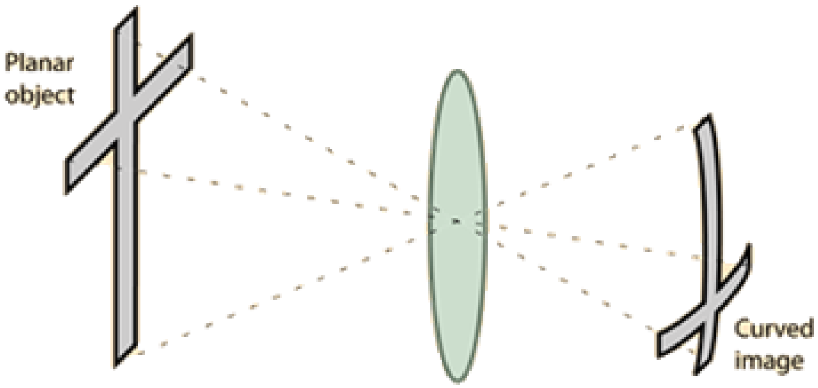


3- Astigmatism

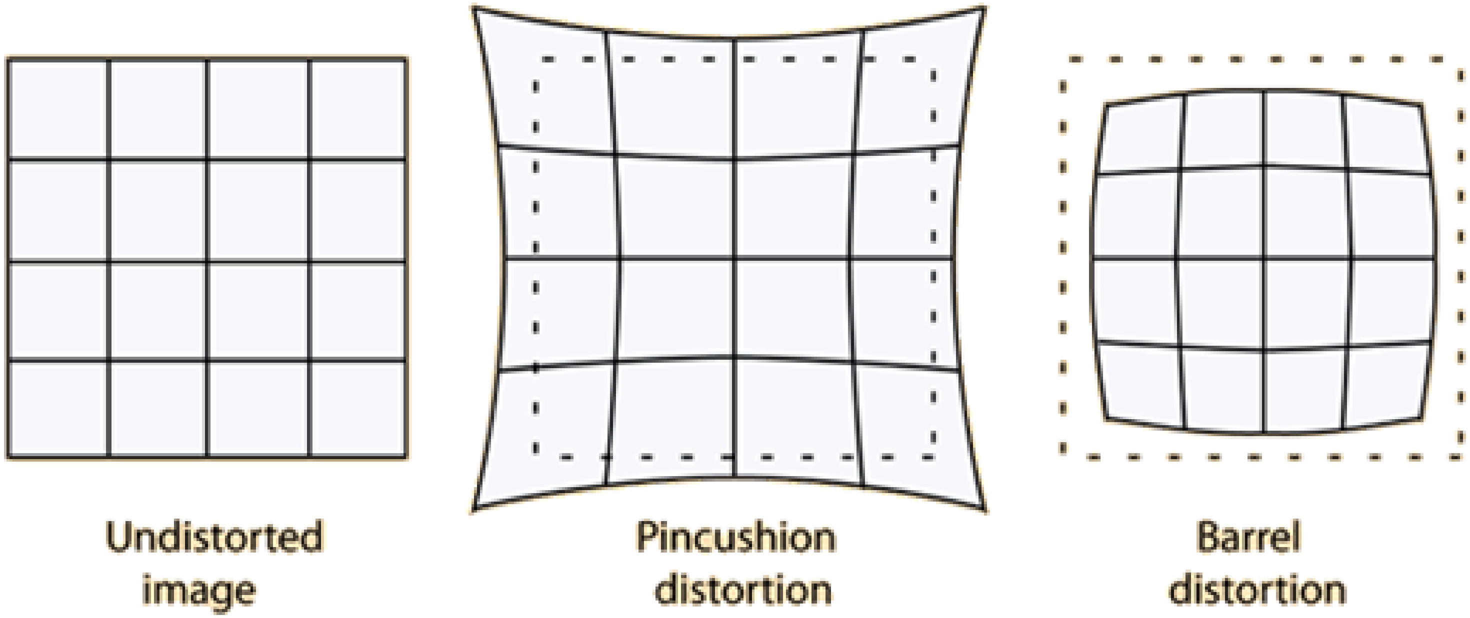


4-Filed Curvature





5-Distortion

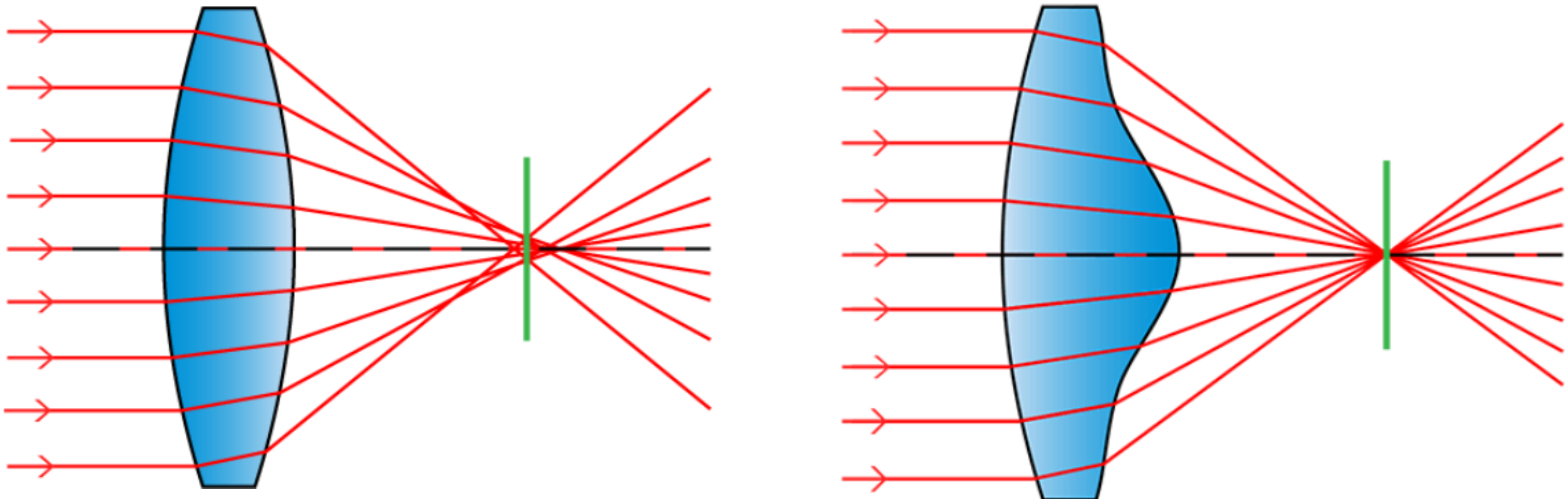


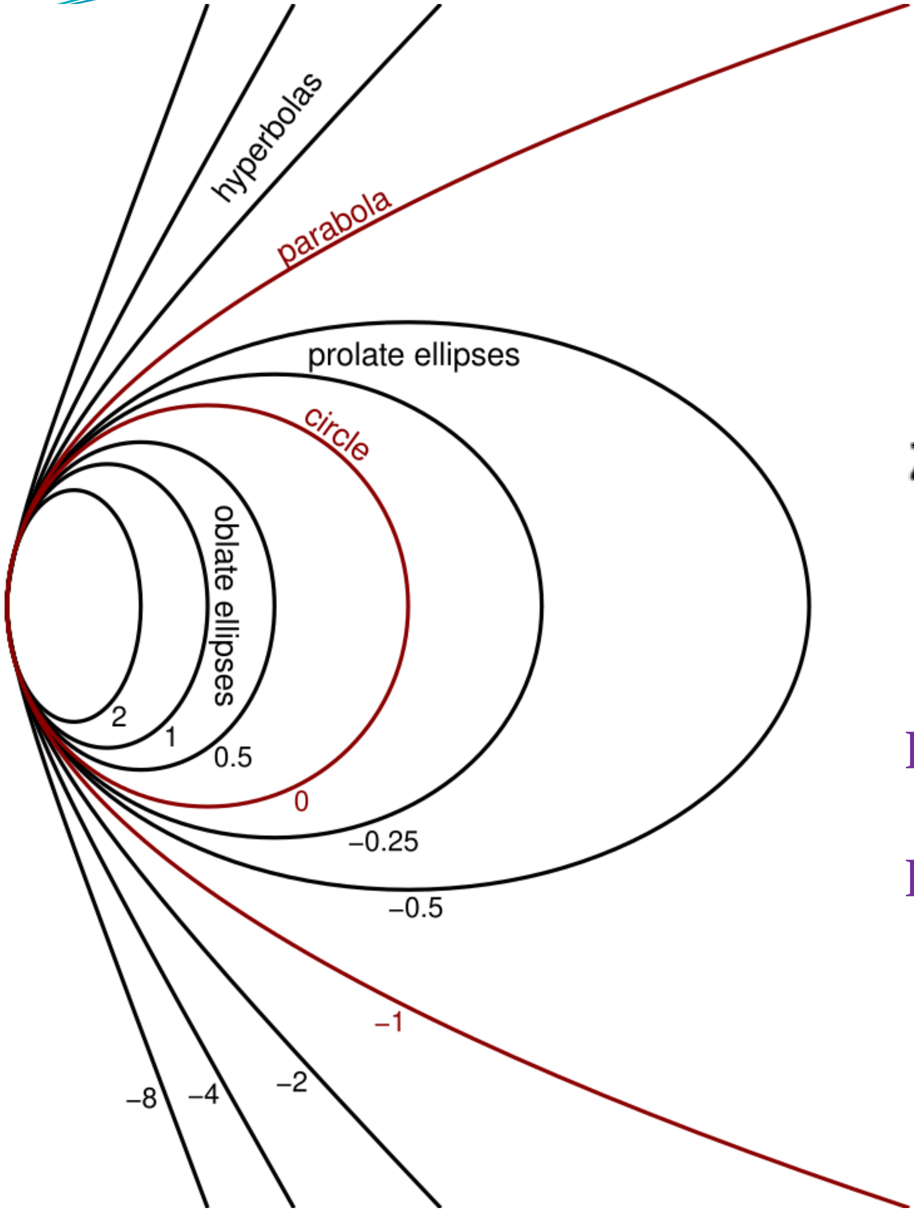
Aberration Dependence on Aperture and Field

	Aperture Exponent	Field Exponent
Longitudinal colour	1	0
Lateral colour	0	1
Spherical aberration	3	0
Coma	2	1
Astigmatism	1	2
Field curvature	1	2
Distortion	0	3

Aspheric Surface

Spherical aberration in a Spherical Lens (left) vs an Aspheric Lens (right)



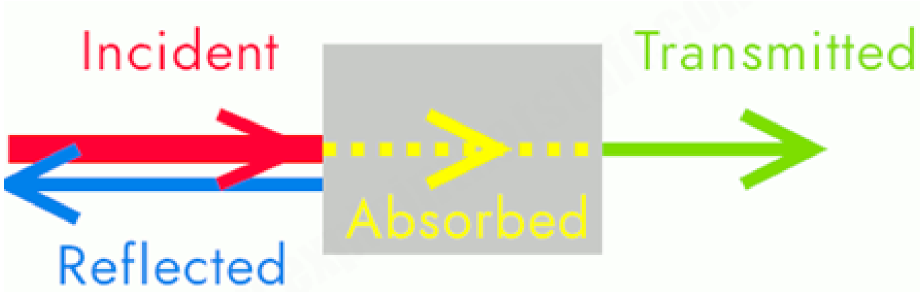


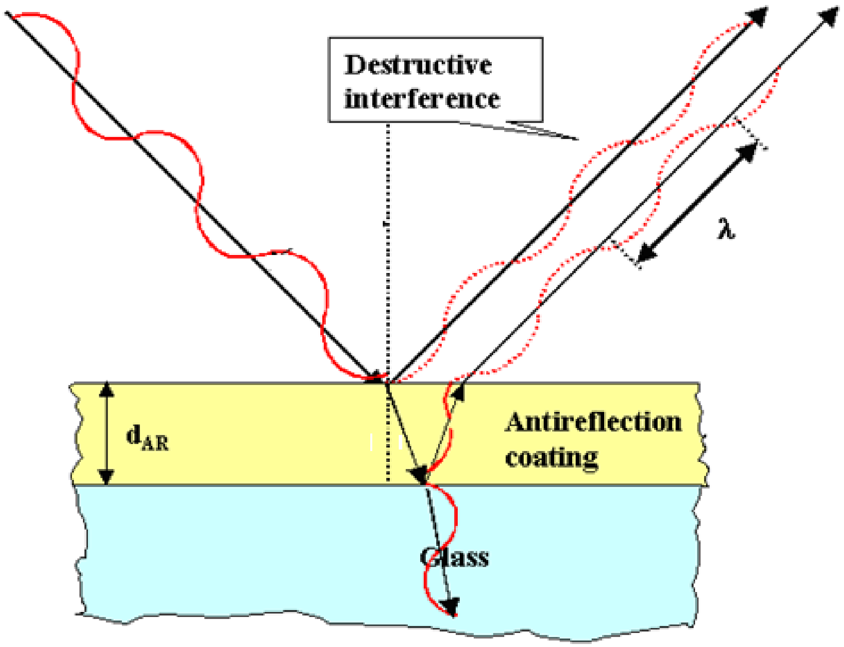
$$z = \frac{y^2}{R + \sqrt{R^2 - (K+1)y^2}}$$

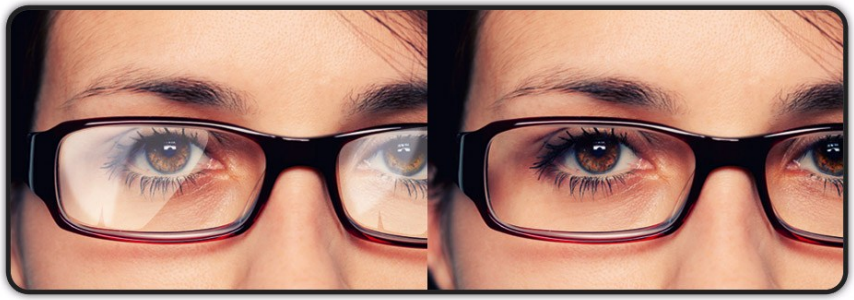
K=-e²: Conic Constant

R: Radius of curvature at z = 0

Coating



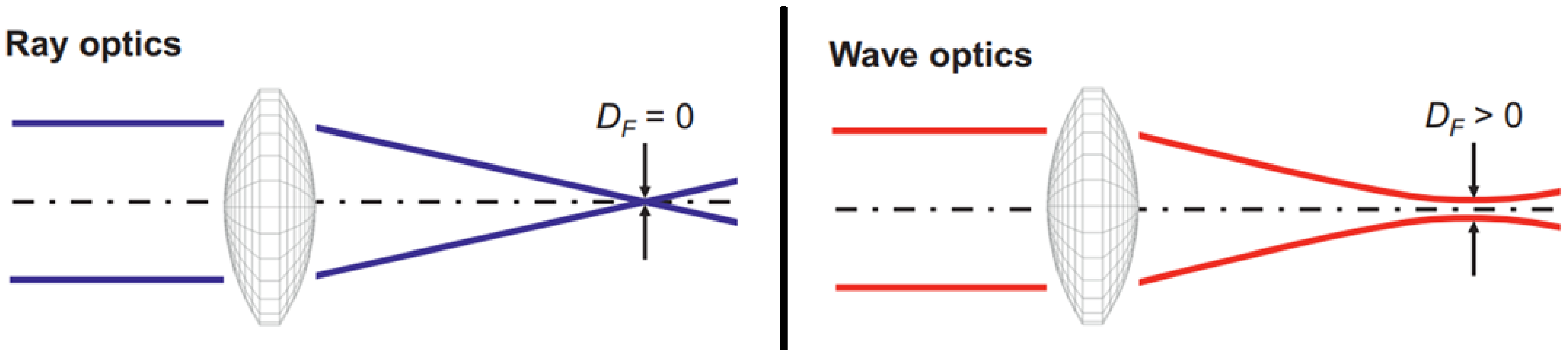


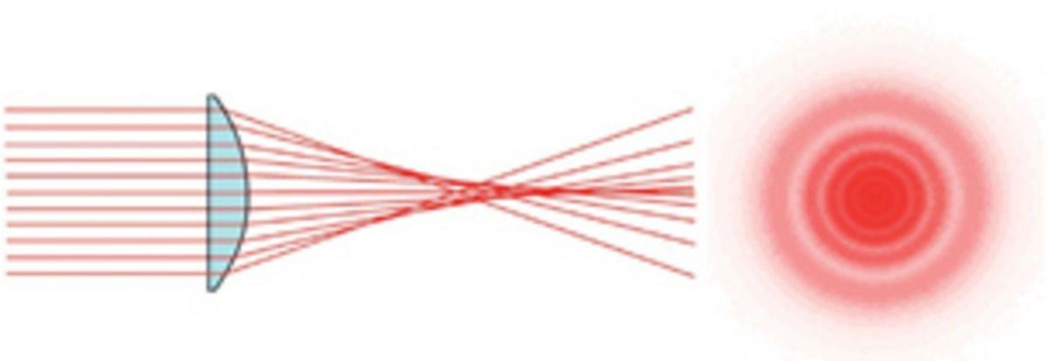


Without anti-reflection

With anti-reflection

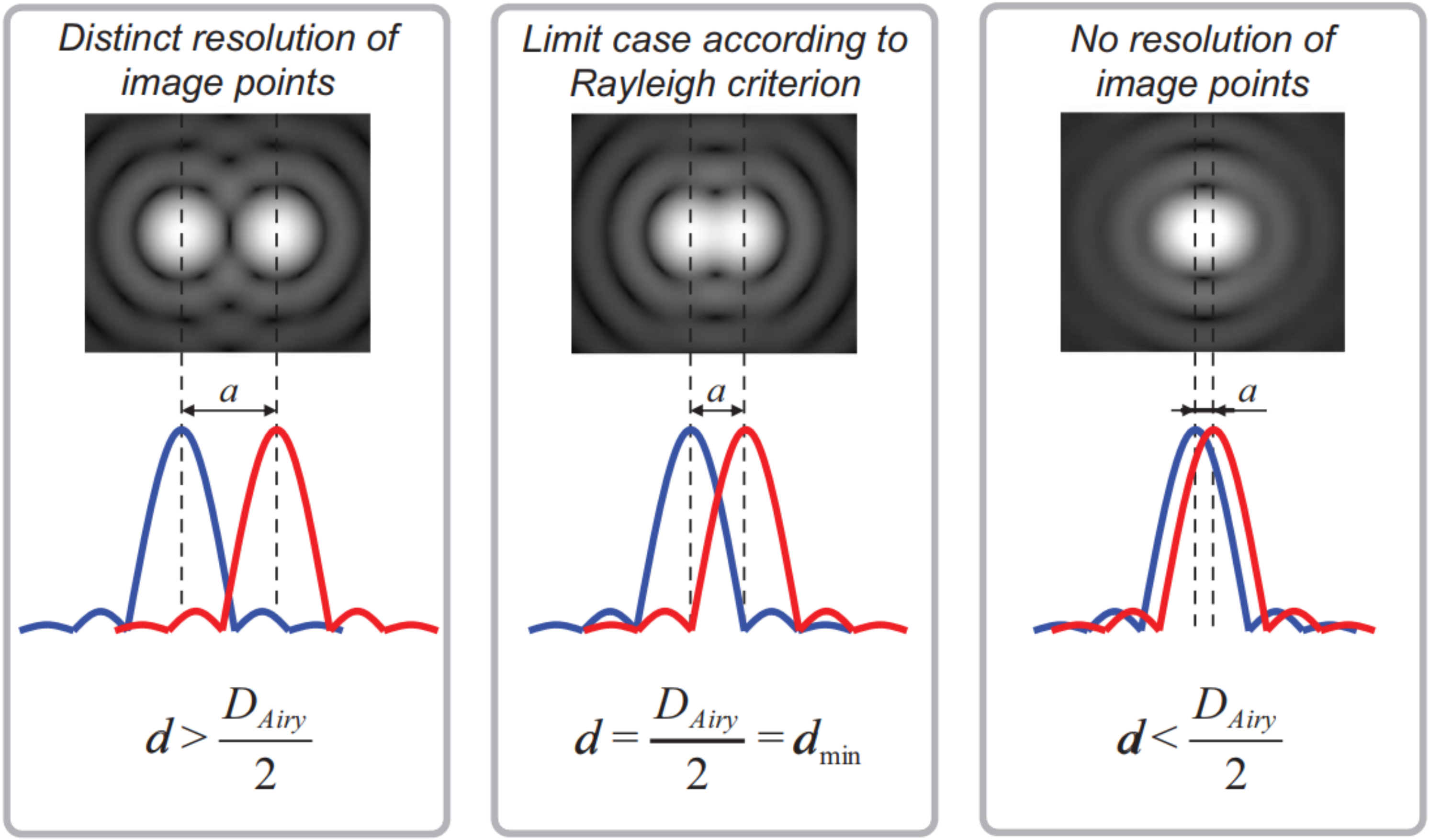
Diffraction





$$D_{\mathrm{Airy}} = 1.22 \cdot \frac{\lambda \cdot f}{D_{\mathrm{stop}}}$$

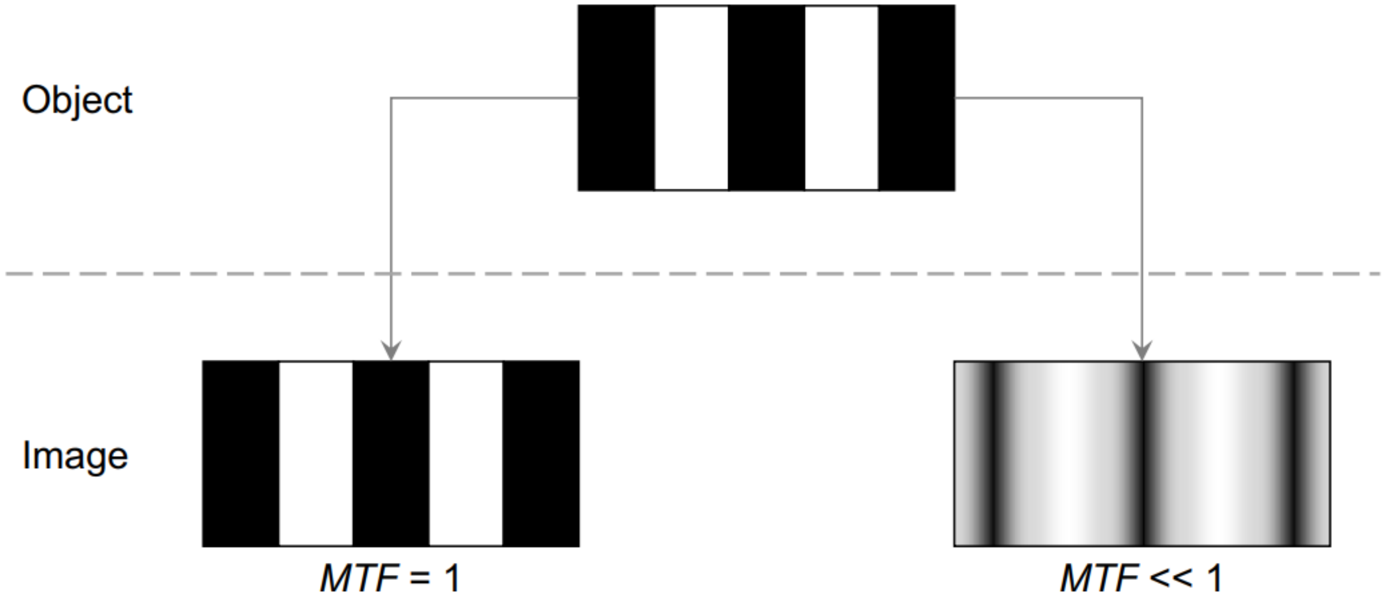
Rayleigh Criterion

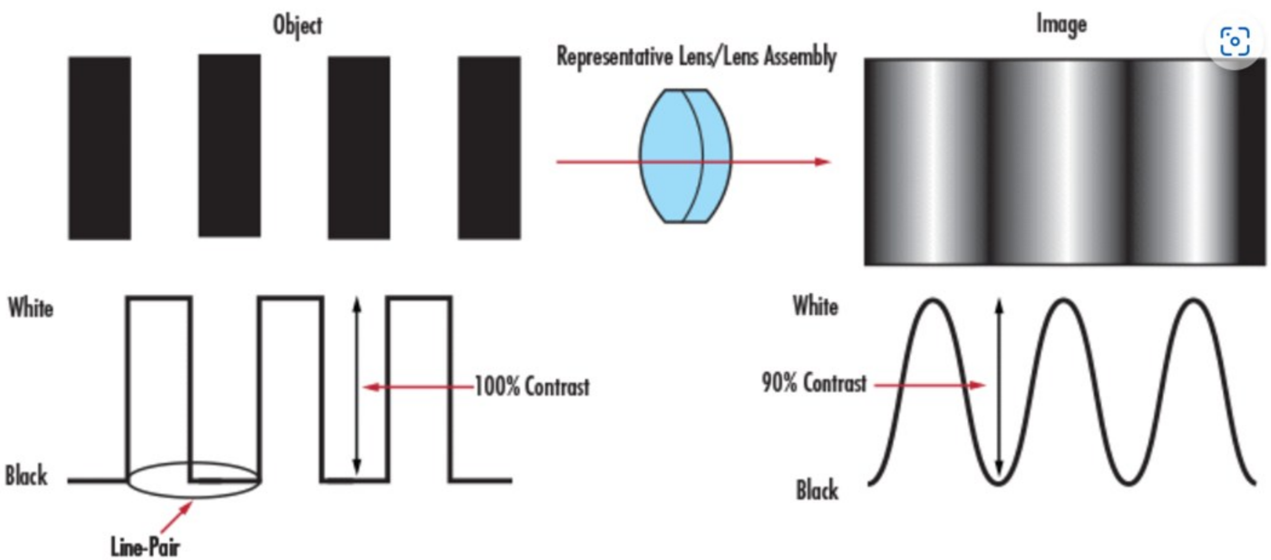


Contrast and Modulation Transfer Function (MTF)

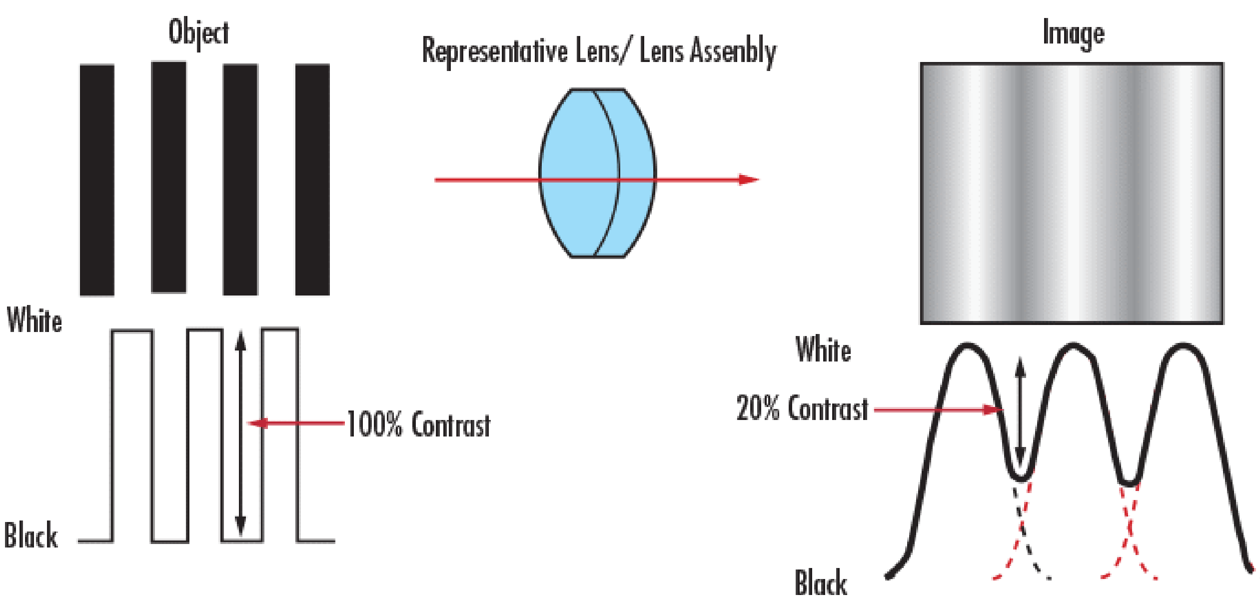
$$M = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

$$\mathrm{MTF} = \frac{M_{\mathrm{image}}}{M_{\mathrm{object}}}$$



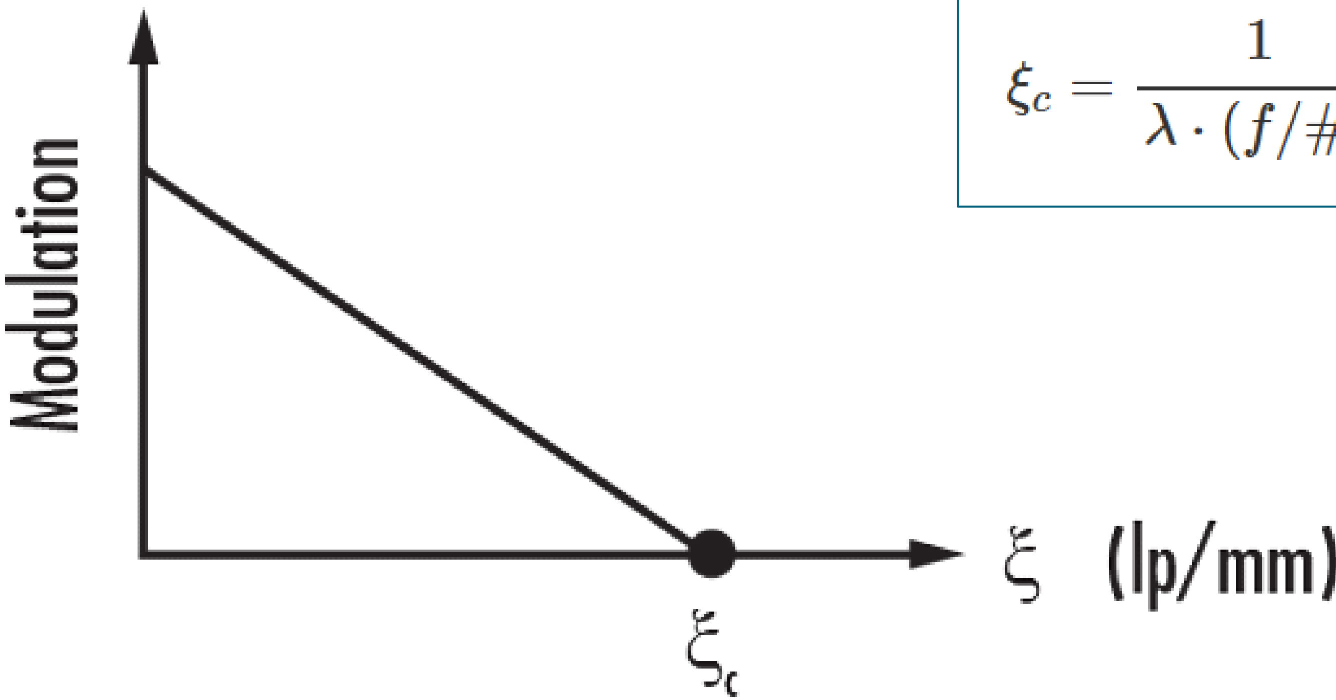


Object
Representative Lens/Lens Assembly
Image
White
100% Contrast
Black
Line-Pair
White
90% Contrast
Black



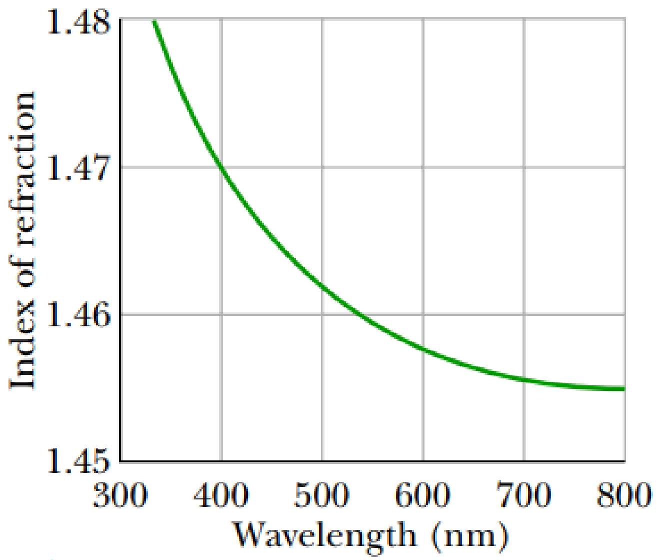
Object
Representative Lens/ Lens Assenbly
Image
White
100% Contrast
Black
White
20% Contrast
Black

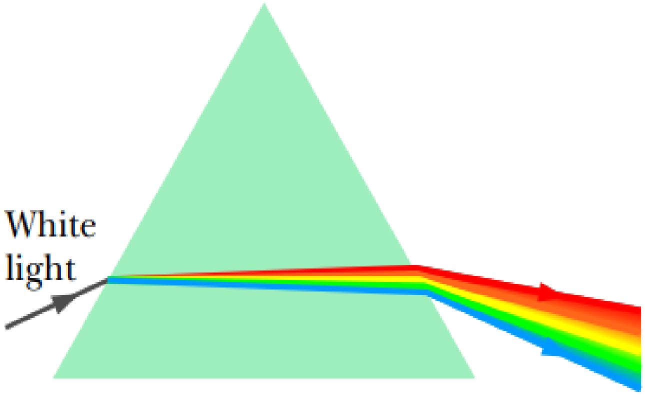
MTF for an Aberration-Free Lens with a Rectangular Aperture

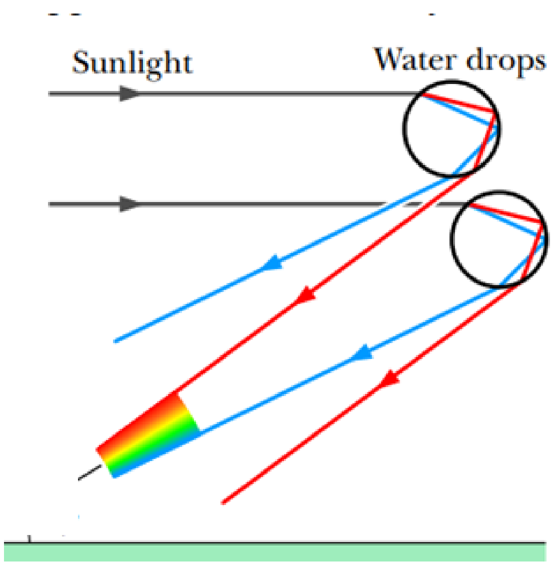


$$\xi_c = \frac{1}{\lambda \cdot (f/\#)}$$

Dispersion





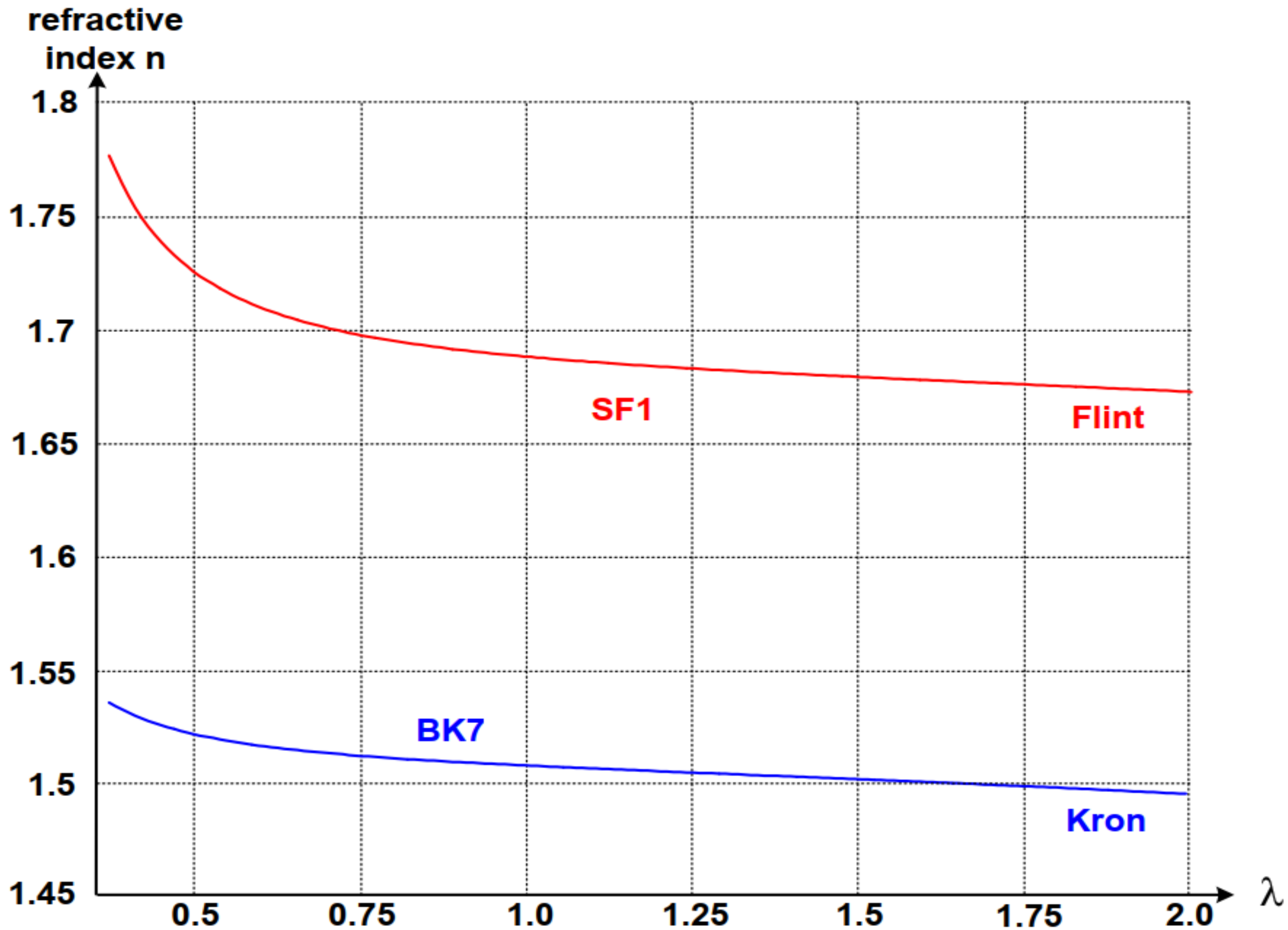


Cauchy equation:

$$n(\lambda) = A + \frac{B}{\lambda^2} + \ldots$$

Sellmeier equation:

$$n(\lambda) = \sqrt{1 + \frac{B_1 \cdot \lambda^2}{\lambda^2 - C_1} + \frac{B_2 \cdot \lambda^2}{\lambda^2 - C_2} + \frac{B_3 \cdot \lambda^2}{\lambda^2 - C_3}}$$

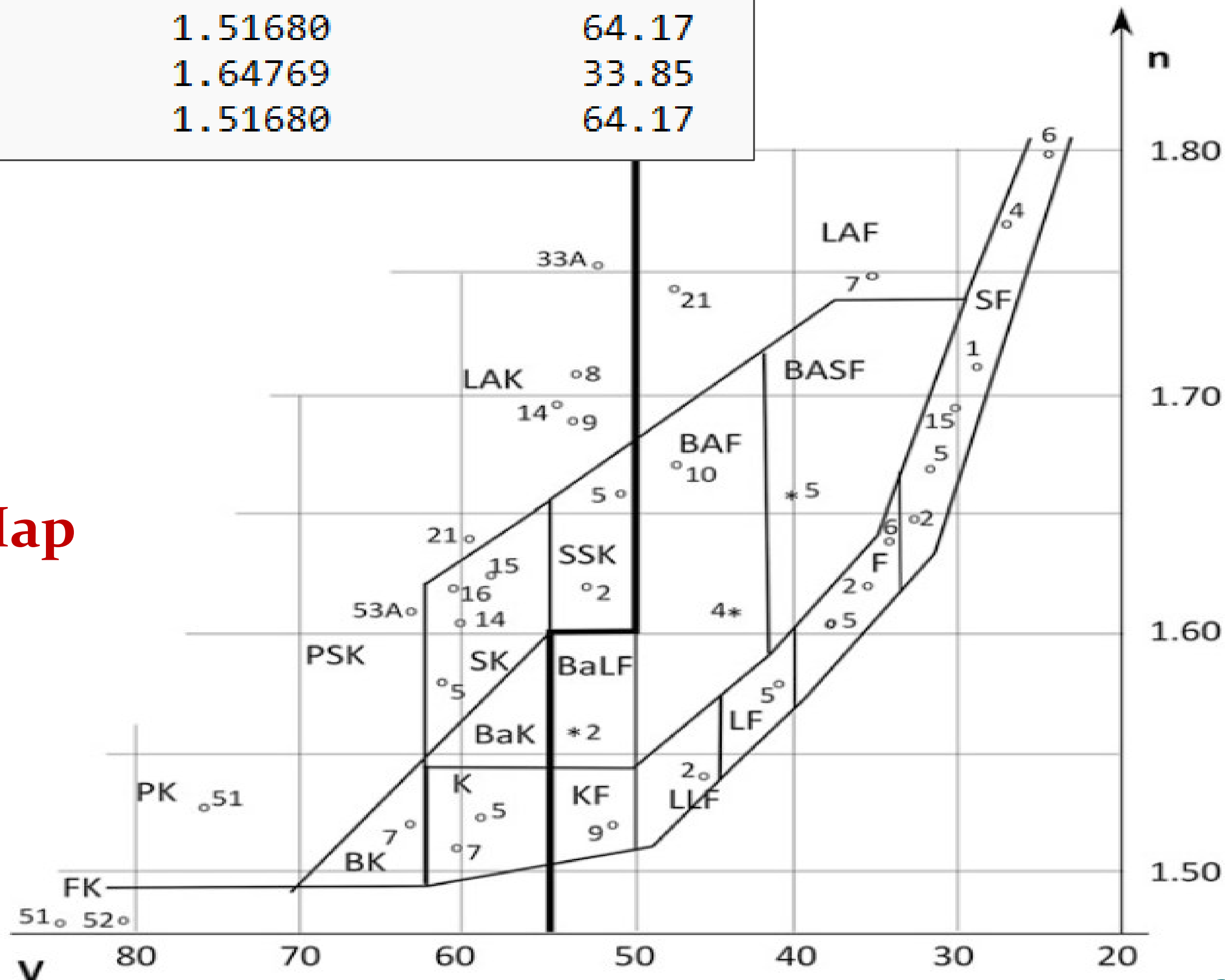


Abbe Number

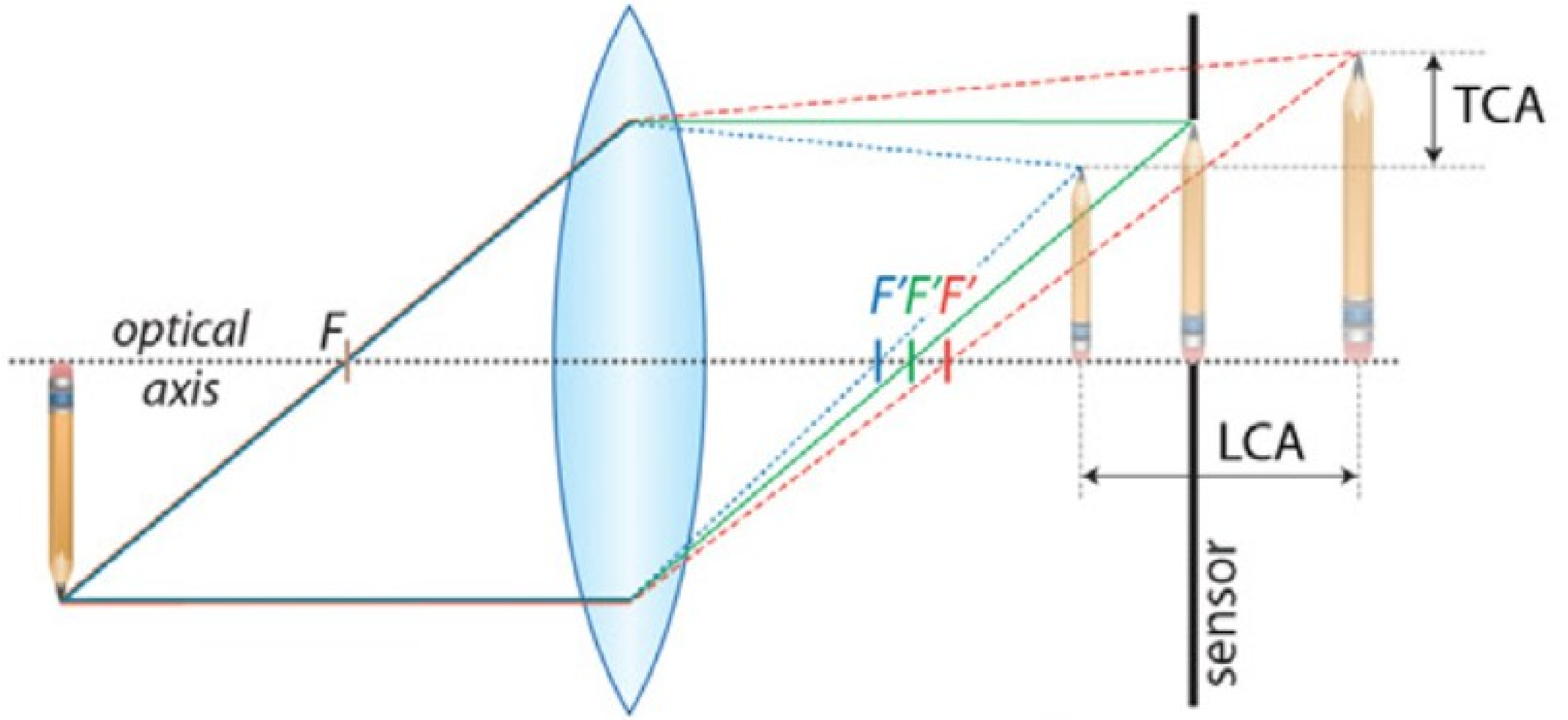
$$V = \frac{n_d - 1}{n_F - n_C}$$

Glass Name	Index	Abbe
N-BK7	1.51680	64.17
SF2	1.64769	33.85
BK7	1.51680	64.17

Glass Map



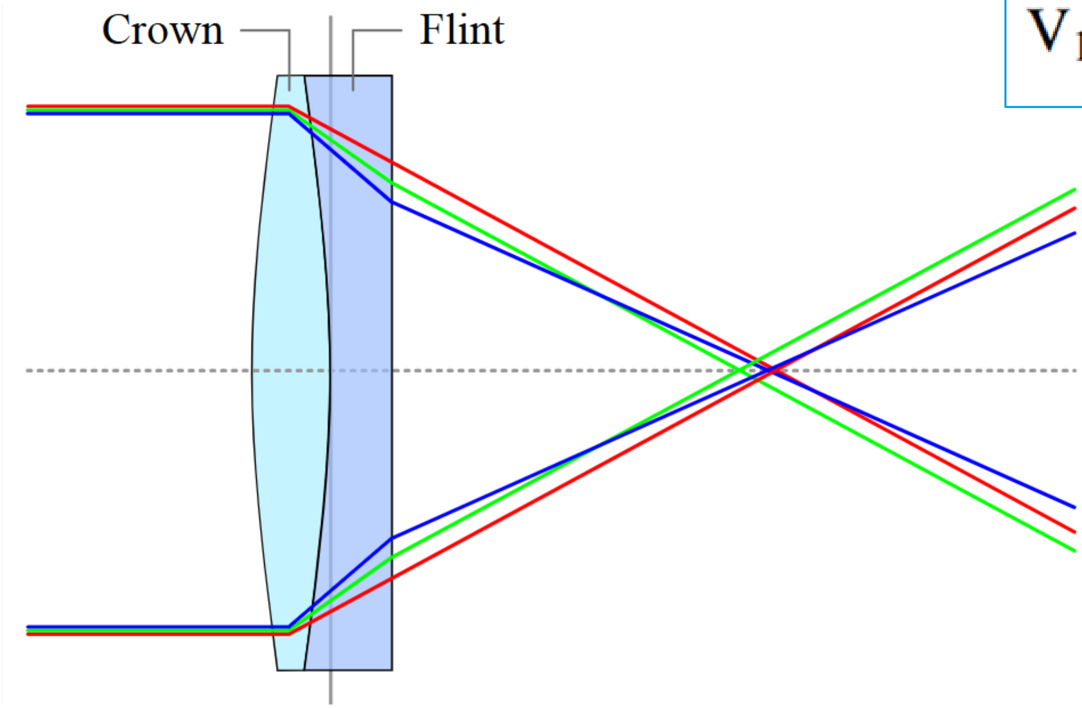
Chromatic Aberration



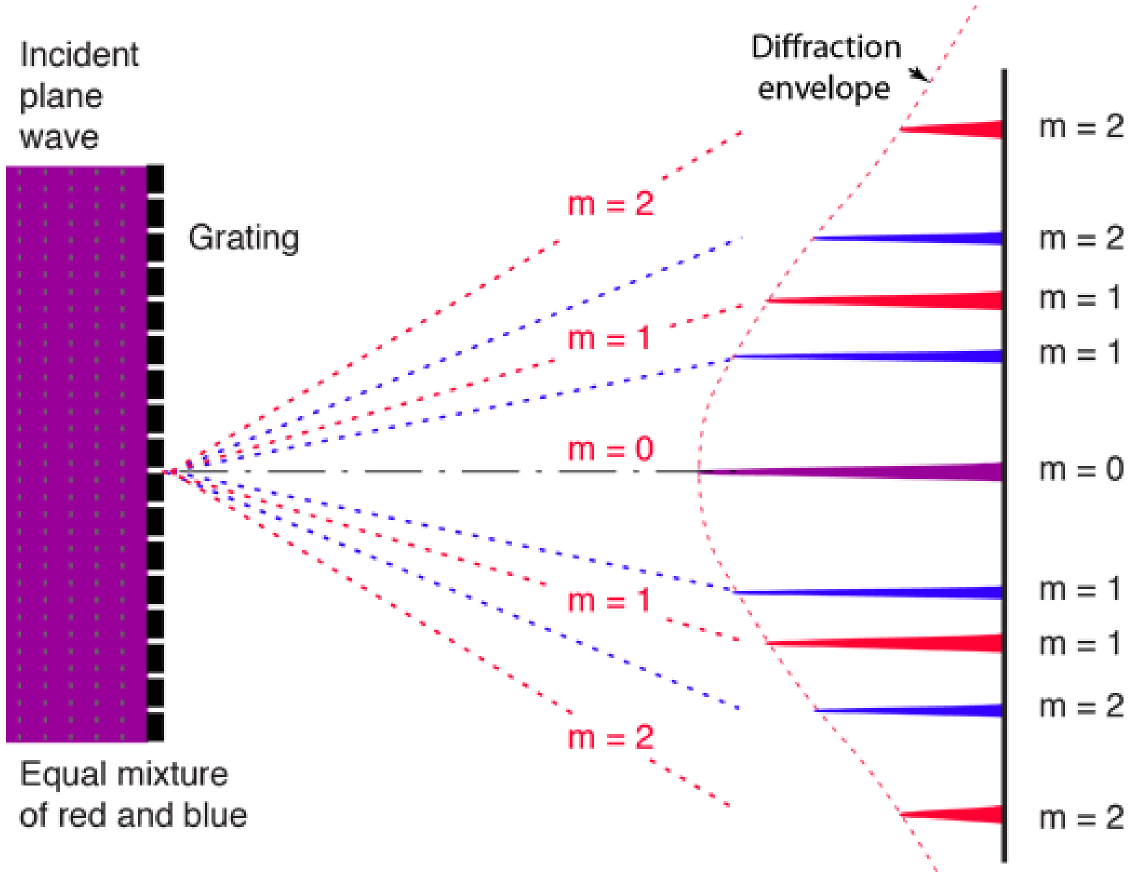
Doublet lens

$$K = K_1 + K_2$$

$$\frac{K_1}{V_1} + \frac{K_2}{V_2} = 0$$



Diffraction Grating



$$d\sin(\theta_m) = m\lambda$$

$$\frac{lines}{\mu m} = \frac{1}{d}$$

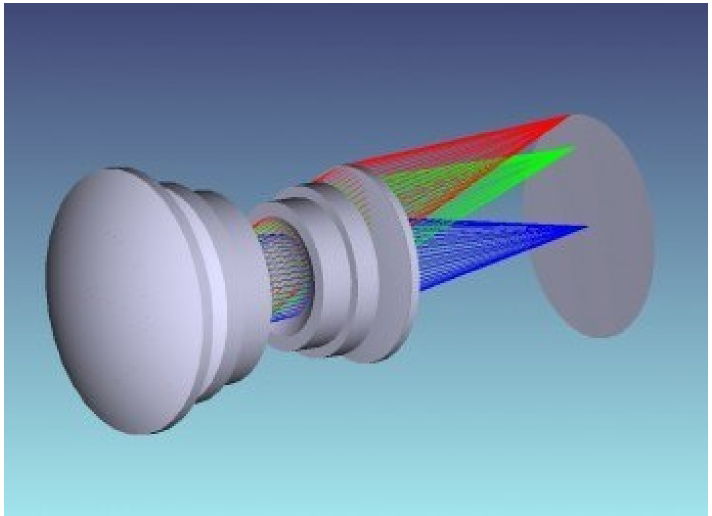
Zemax

Introduction

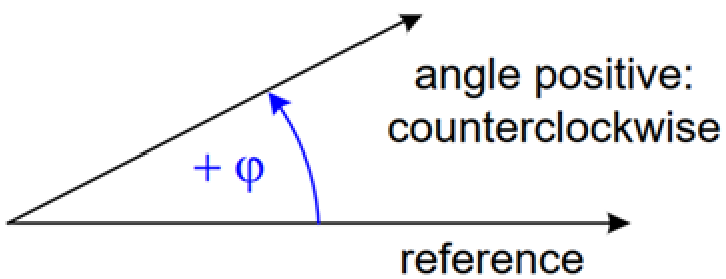
The ZEMAX optical design program is a comprehensive software tool.

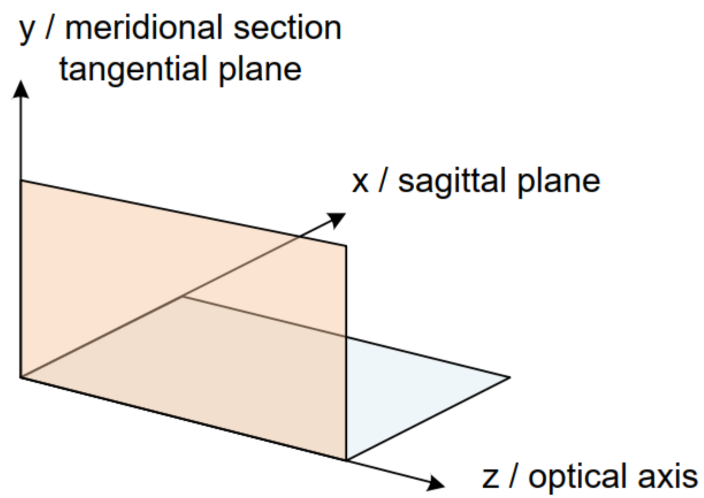
It integrates all the features required to design, optimize, analyse, tolerance and document virtually any optical system.

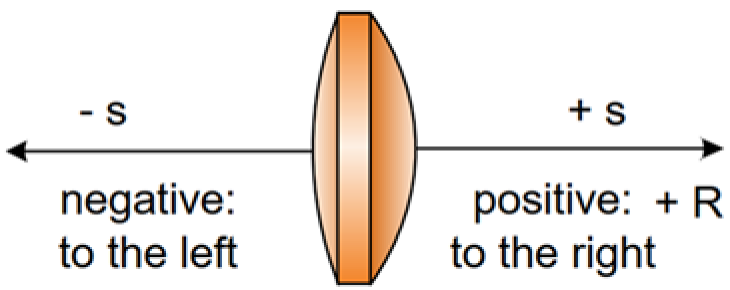
It is widely used in the optics industry as a standard design tool.

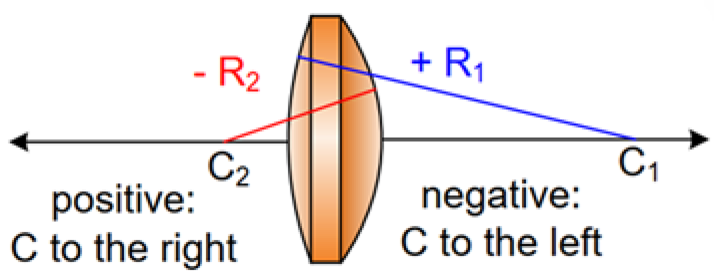


Zemax Sign Convention

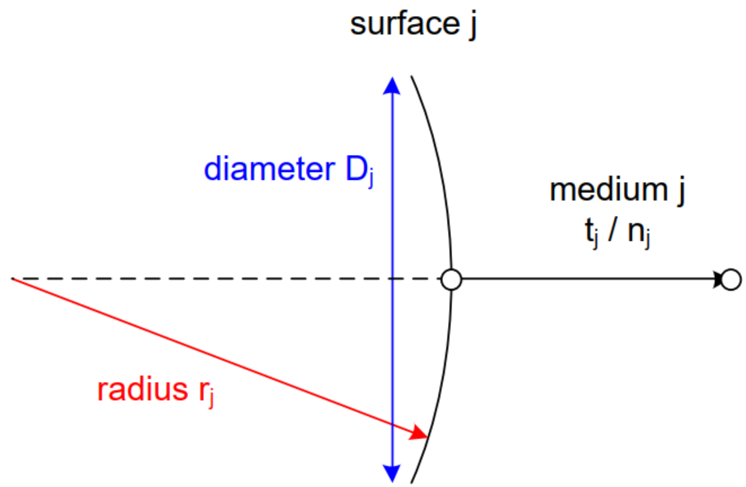




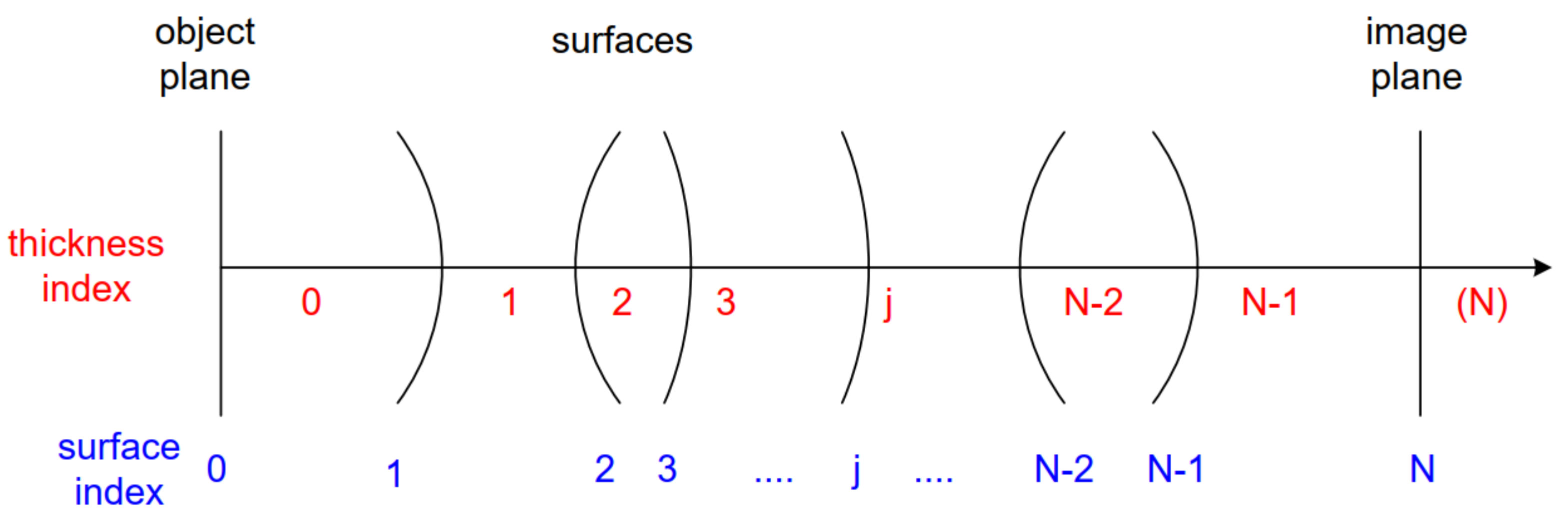




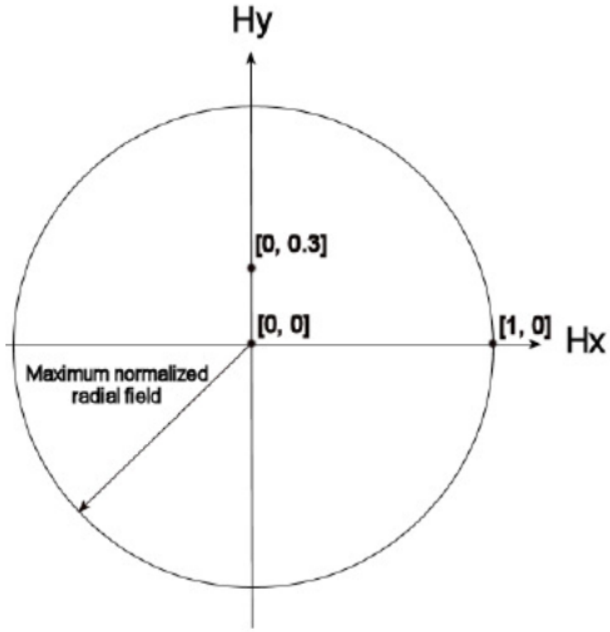
Single Surface

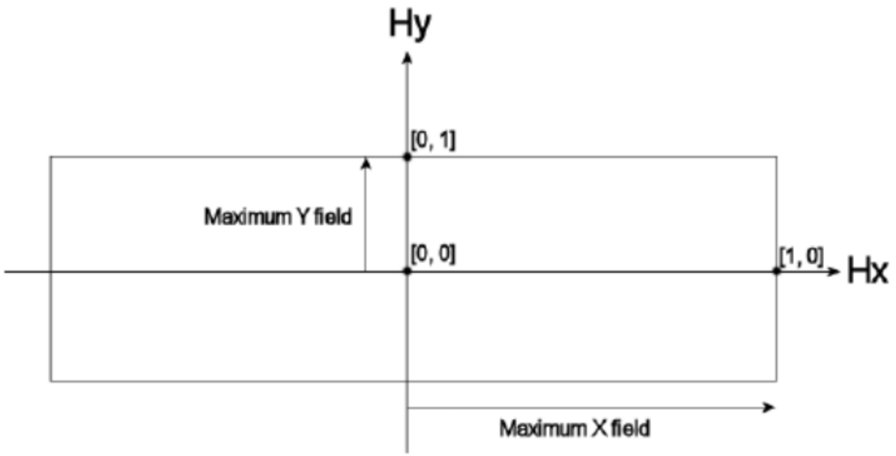


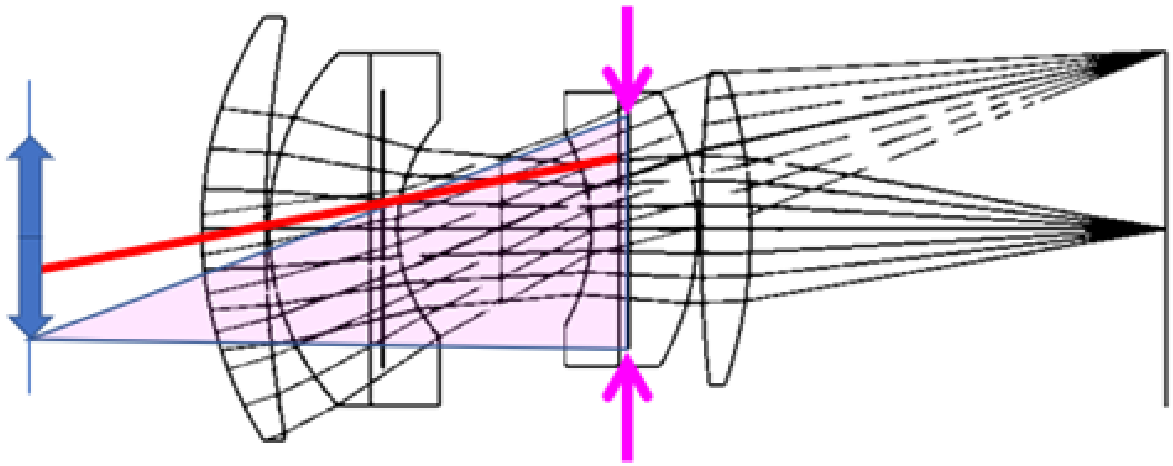
Complete System

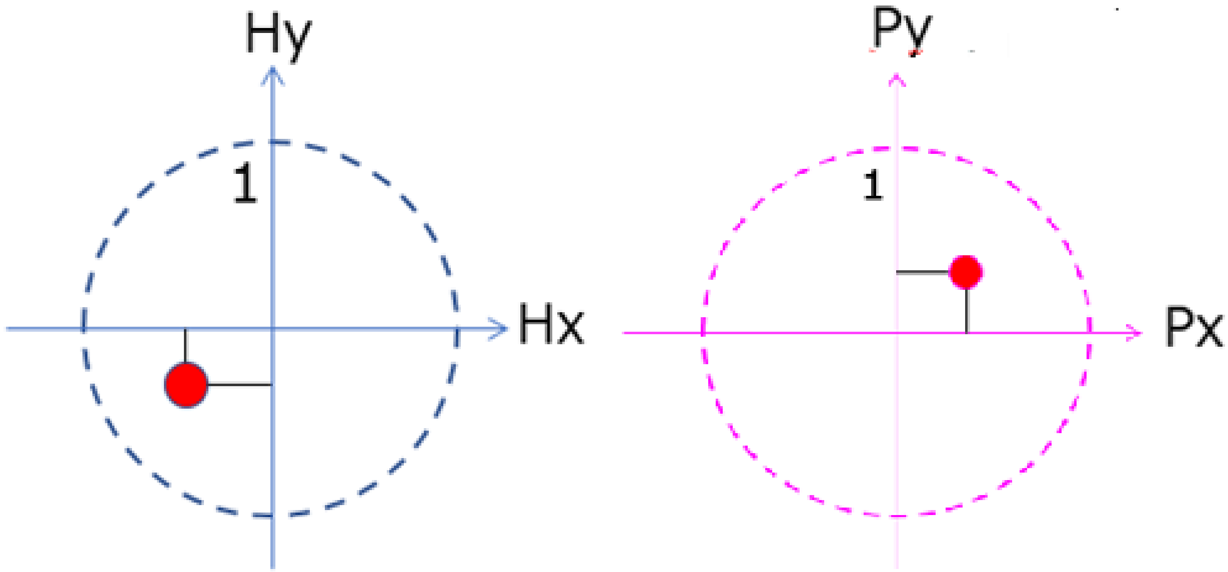


Normalized Field (H) or Pupil (P) Coordinates

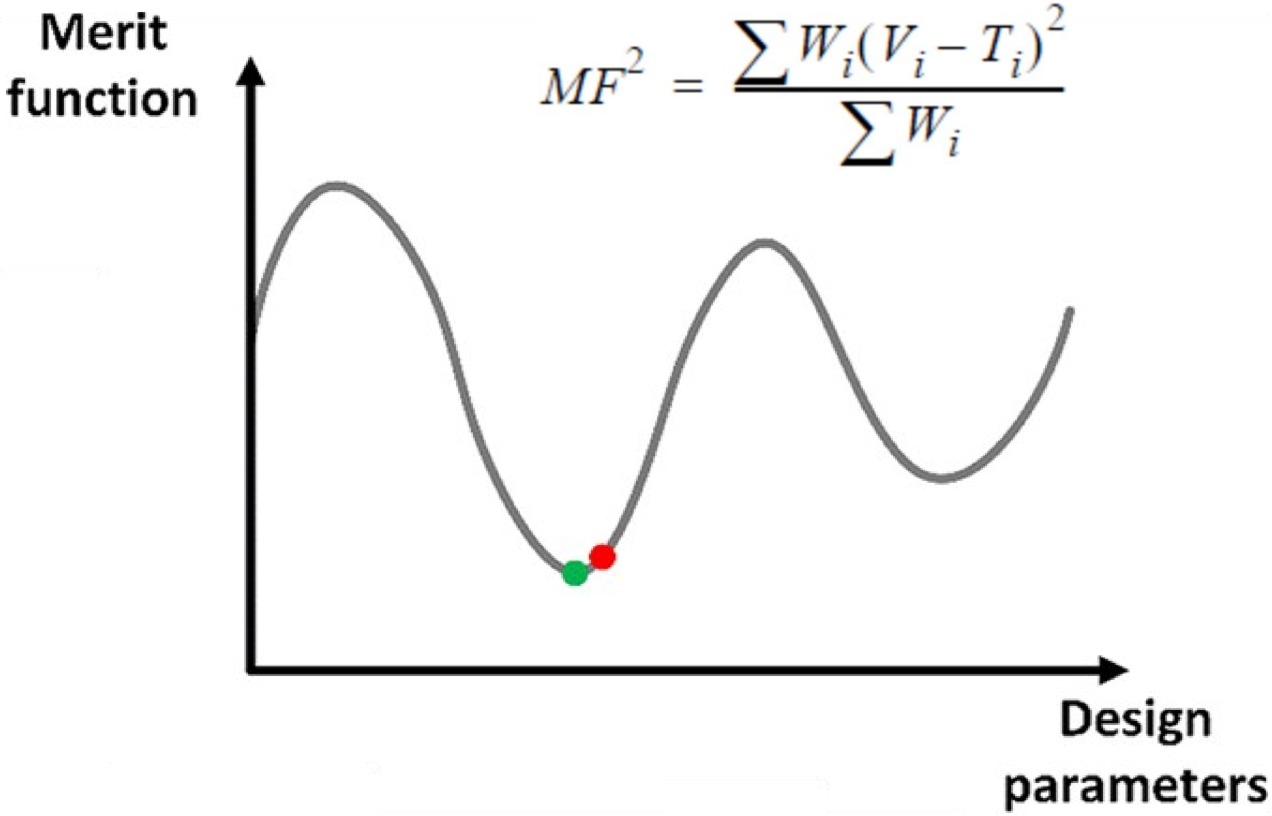







Hy
1
Hx
Py
1
Px

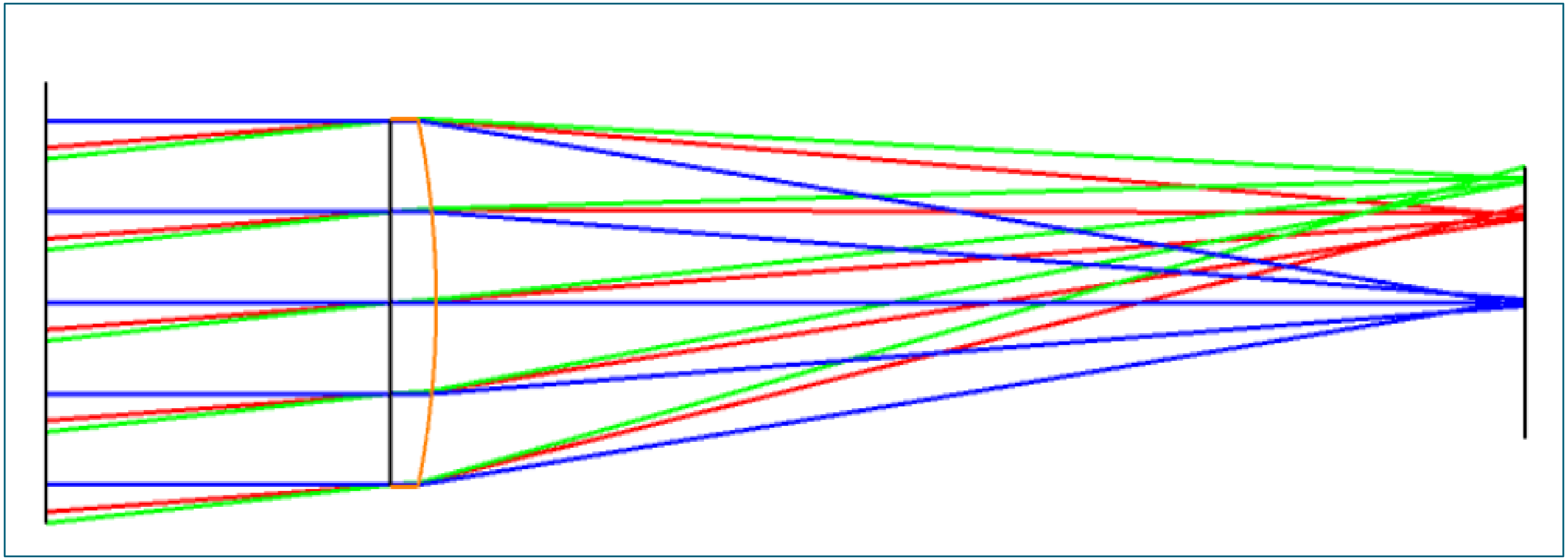
Merit Function, Variables and Constraints



Examples

Example 1

Singlet Lens

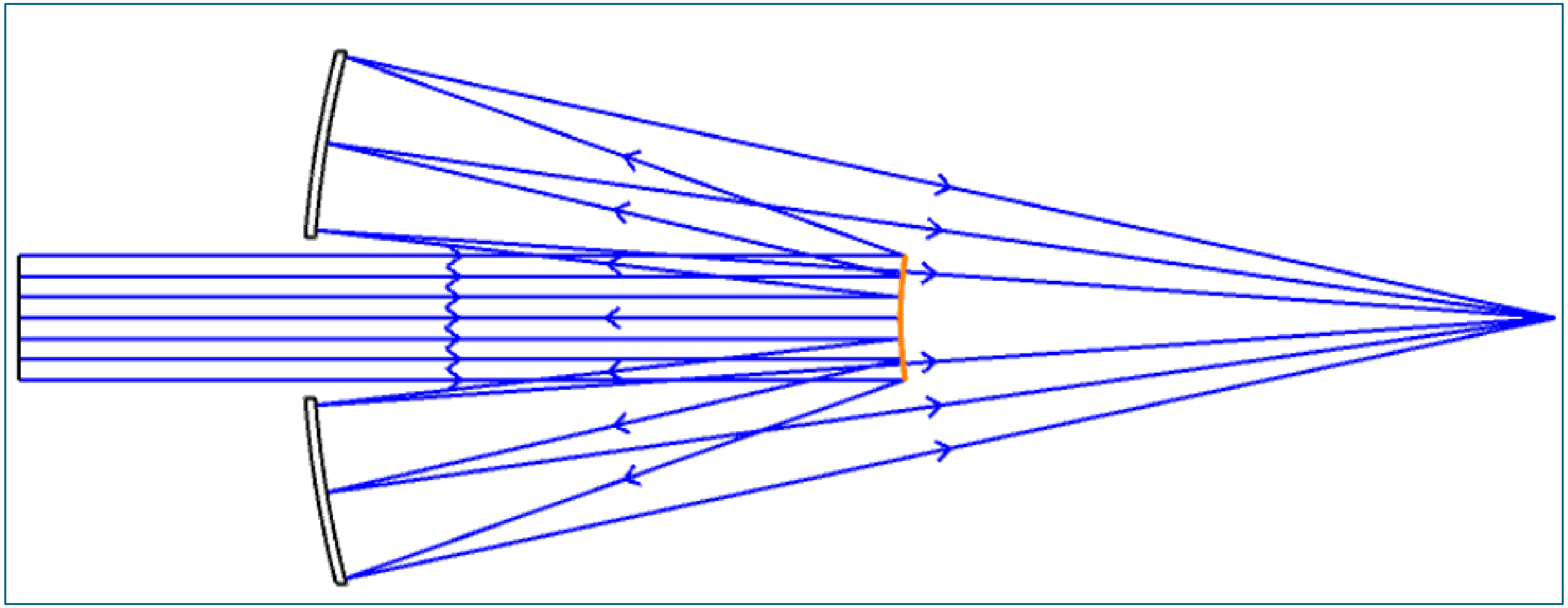


Focal Length	**100 mm**
Semi-Field of View (SFOV)	5 degrees
Wavelength	632.8 nm (HeNe)
Center Thickness of singlet	Between 2 nm and 12 nm
Edge Thickness of singlet	Larger than 2 mm
Object location	At infinity
Material	N-BK7
F-Number	F/4

$$F/\# = \frac{EFL}{EPD} \rightarrow EPD = 25mm$$

Example 2

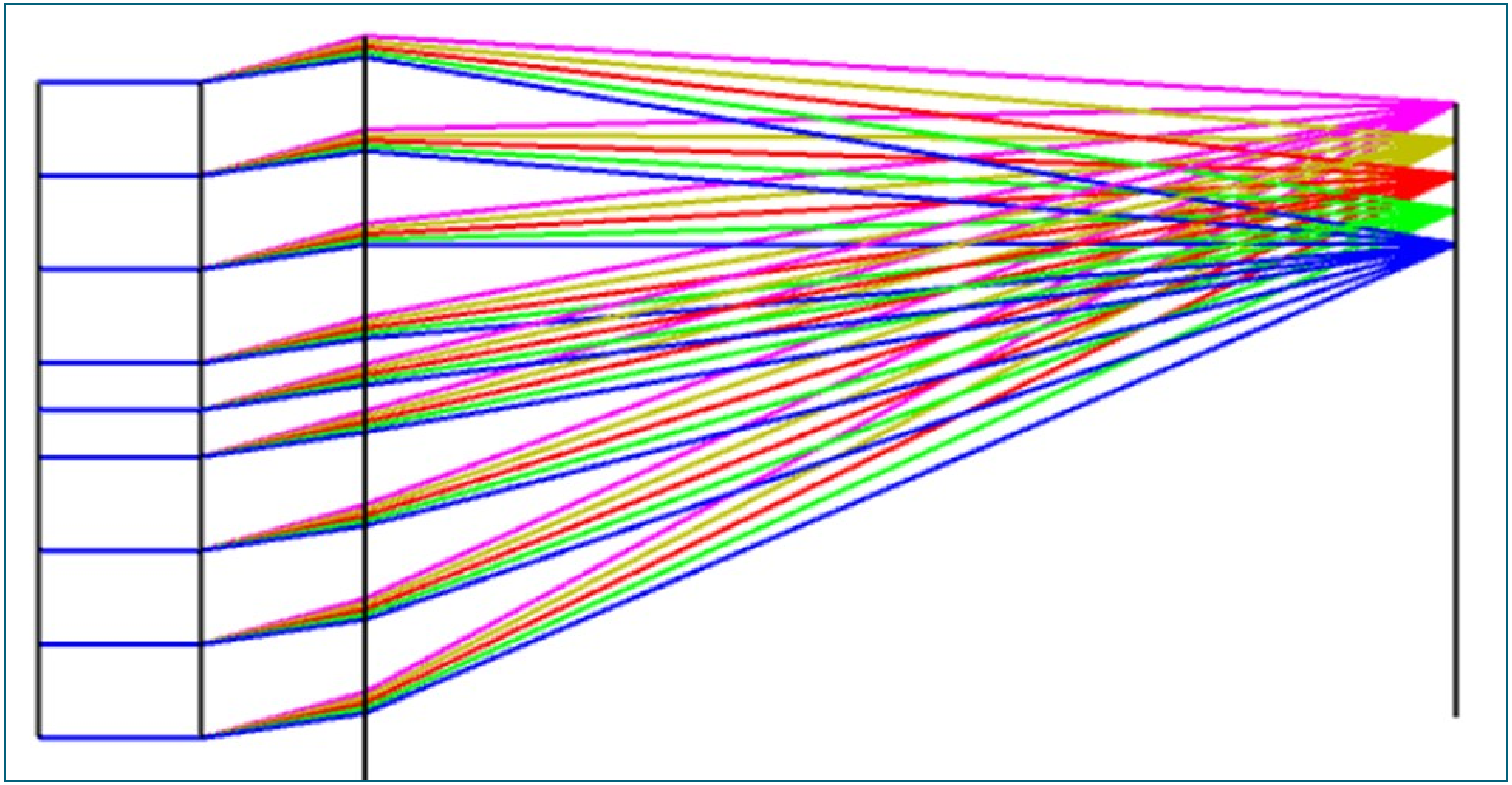
Schwarzschild Mirrors



1st mirror diameter (Stop)	**20 mm**
1st mirror radius	61.803 mm
2nd mirror radius	161.803 mm
Wavelength	F, d, C (Visible)
Distance between two mirrors	100 mm
Object location	At infinity
Material	Mirror

Example 3

Diffraction Grating



Grating	300 lines/mm
Field of View (FOV)	0 degrees
Glass	N-BK7
Wavelength	0.5- 0.9 μm
Paraxial Lens Focal Length	100 mm
Object location	At infinity
Entrance Pupil Diameter	60 mm

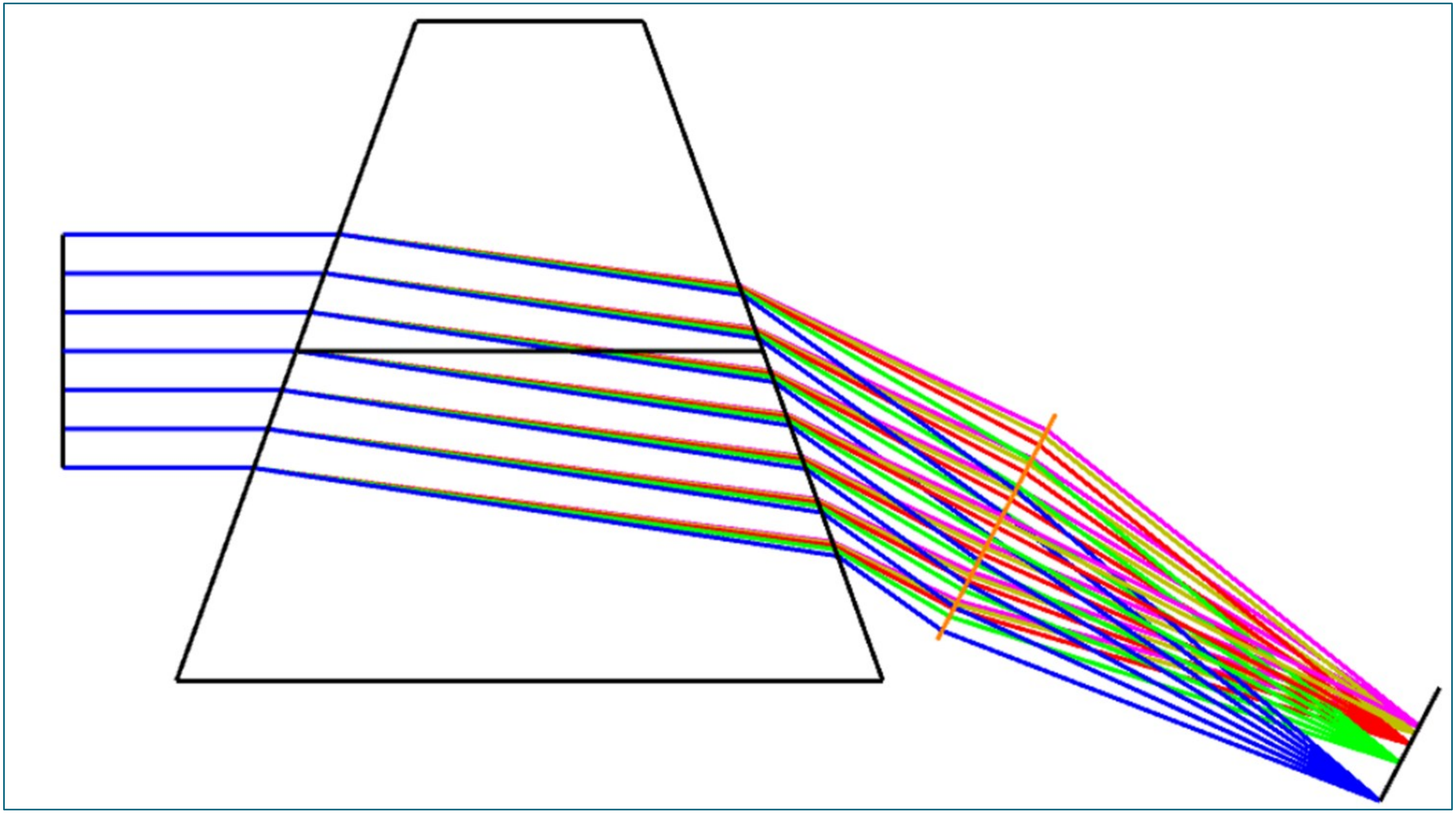
$$d\sin(\theta_m) = m\lambda$$

$$d = \frac{1mm}{300} = 3.3\mu m$$

$$m \leq \left[\frac{d}{\lambda}\right] = \left[\frac{3.3}{0.5}\right] = 6$$

Example 4

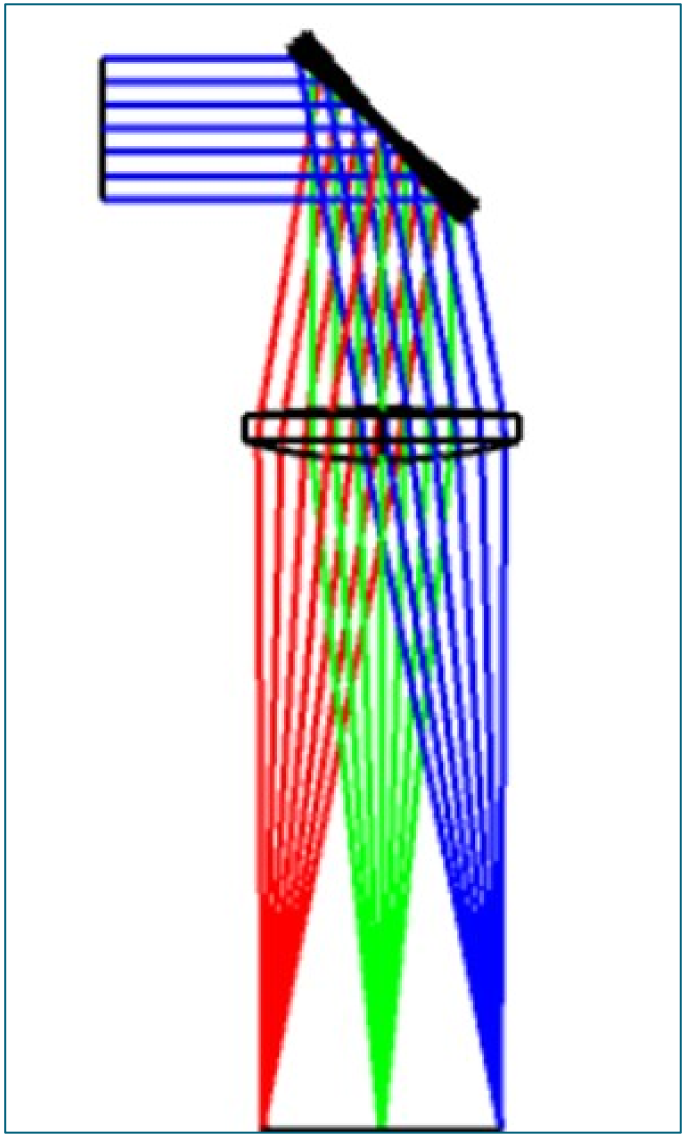
Prism



Field of View (FOV)	**0 degrees**
Glass	N-BK7 – SF2 – Model (V=20,10,5)
Wavelength	0.5- 0.9 μm
Paraxial Lens Focal Length	20 mm
Thickness of prism	20 mm
Prism angle	40 degrees
Object location	At infinity
Entrance Pupil Diameter	10 mm

Example 5

Scanning Mirror

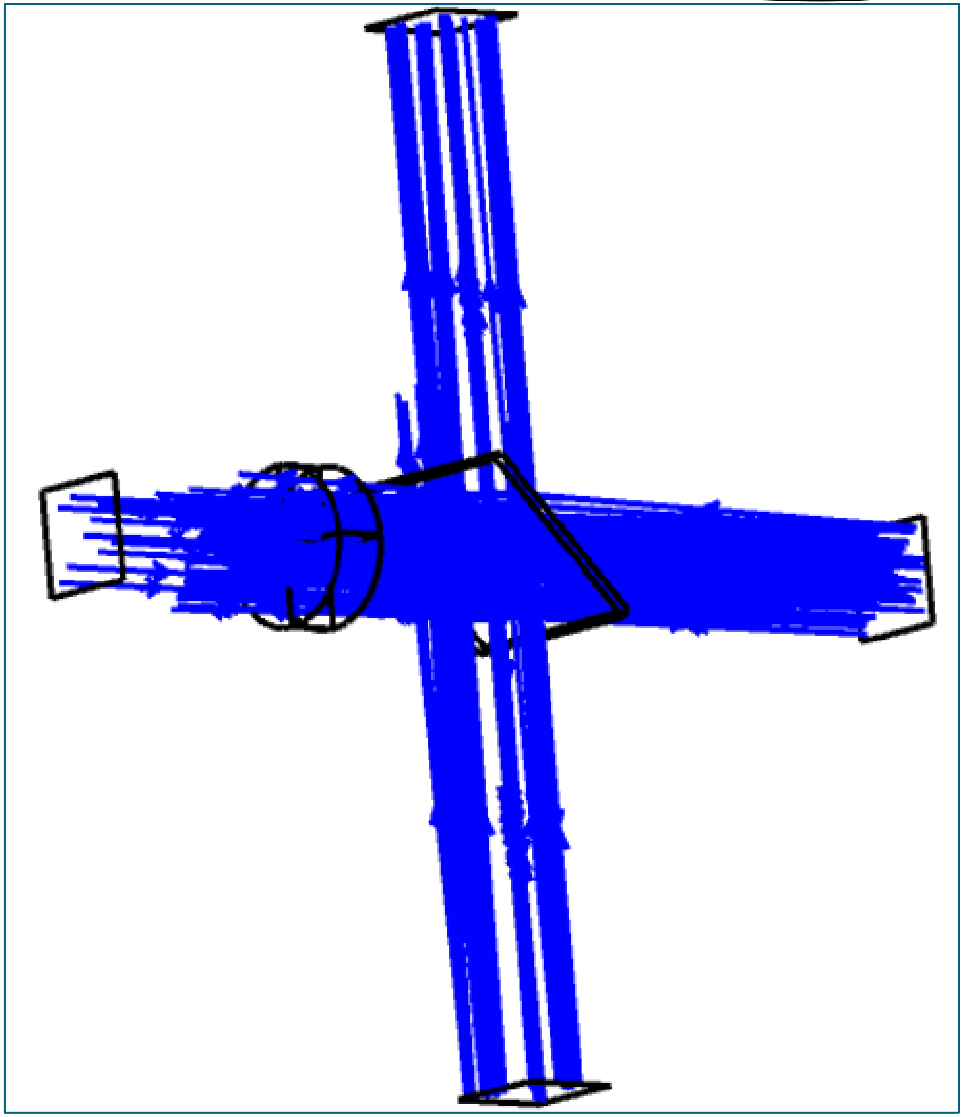


Lens Focal Length	**100 mm**
Field of View (FOV)	10 degrees
Glass	N-BK7
Wavelength	F, d, C (Visible)
Thickness of lens	5mm
Object location	At infinity
F-Number	F/5
Mirror Angle	45 degrees

$$\boldsymbol{F/\# = \frac{EFL}{EPD} \rightarrow EPD = 20mm}$$

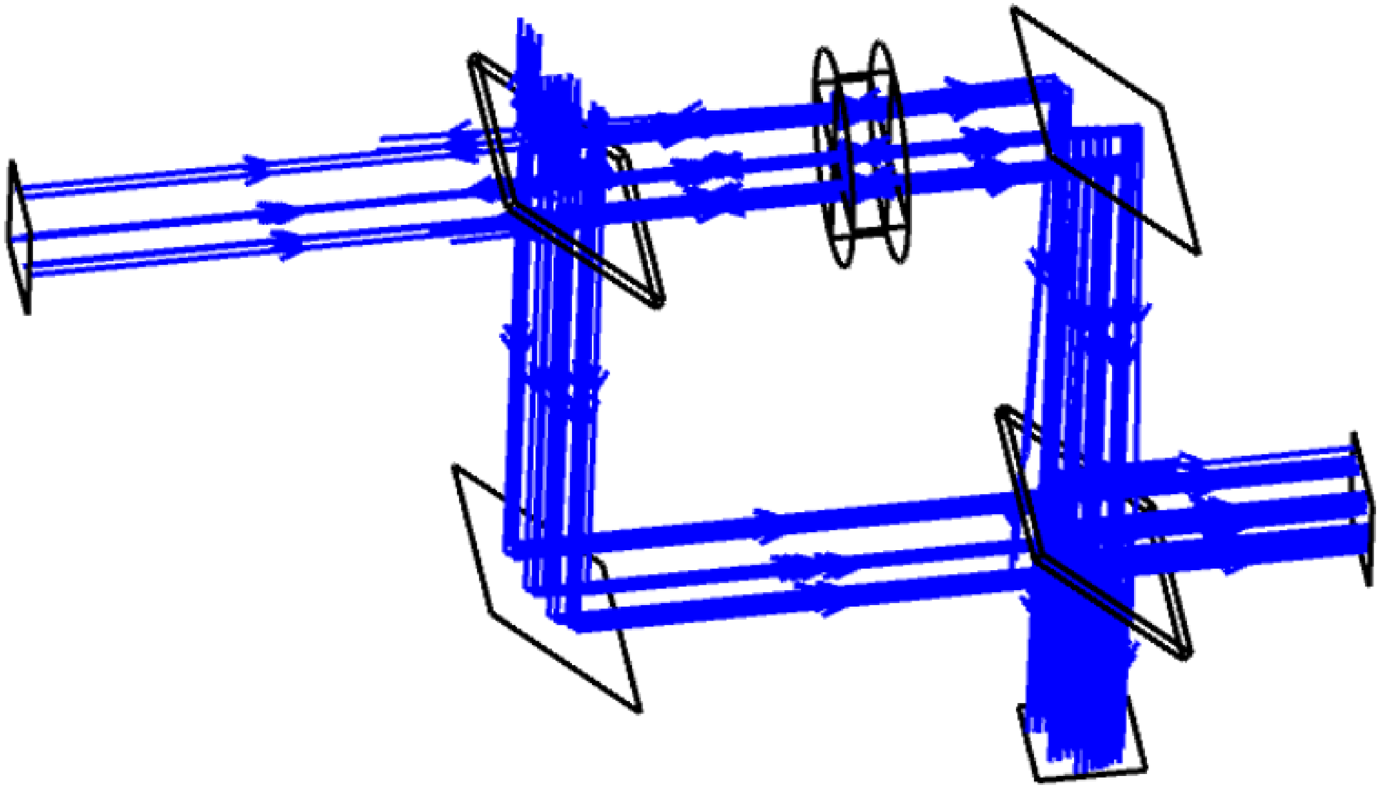
Example 6

Michelson Interferometer (Non-Sequential)



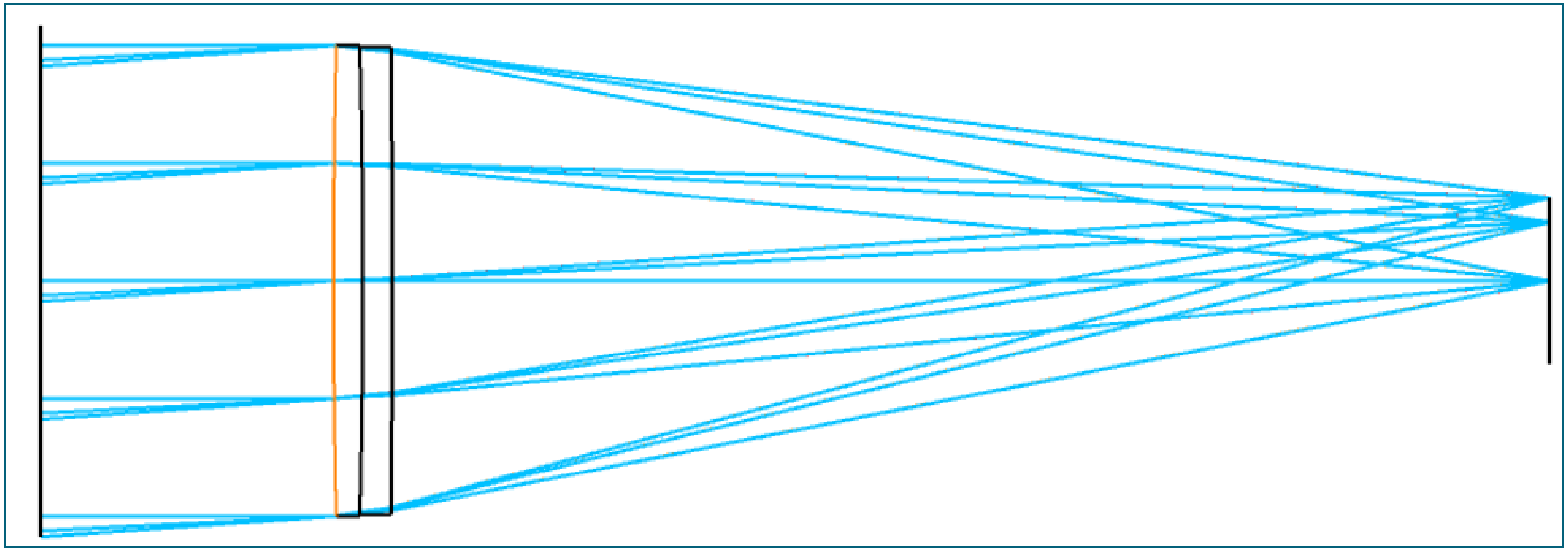
Example 7

Mach-Zehnder Interferometer (Non-Sequential)



Example 8

Achromatic Doublet Lens



Effective Focal Length	**400 mm**
Field of View (FOV)	2 degrees
Glass	BK7 for a @ SF2 for b
Wavelength	F, d, C (Visible)
Center Thickness of lens	5mm for a @ 2mm for b
Object location	At infinity
Entrance Pupil Diameter	40 mm

$$n_1 = 1.5168, \quad V_1 = 64.167$$

$$n_2 = 1.6477, \quad V_2 = 33.848$$

$$K = \frac{1}{EFL} = \frac{1}{400}\, mm^{-1} = 0.0025\, mm^{-1} = 2.5\, D$$

$$\boxed{\begin{aligned} &K = K_1 + K_2 \\ &\frac{K_1}{V_1} + \frac{K_2}{V_2} = 0 \end{aligned}}$$

$$K_1 = 0.005291\, mm^{-1}$$

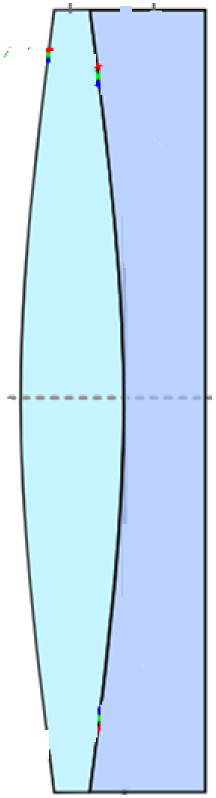
$$K_2 = -0.002791\, mm^{-1}$$

$$K = \frac{1}{\mathrm{EFL}} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)\,t_c}{n\,R_1\,R_2}\right)$$

$$K_1 = (n_1 - 1)\left(\frac{1}{R_{11}} - \frac{1}{R_{21}}\right)$$

$$K_2 = (n_2 - 1)\left(\frac{1}{R_{12}} - \frac{1}{R_{22}}\right)$$

$$R_{12} = R_{21} \quad , \quad R_{11} = -R_{21}$$



$$R_{11} = 195.351$$

$$R_{21} = -195.351$$

$$R_{12} = -195.351$$

$$R_{22} = -1234.7$$

Thank you for Your Attention