OPTI 415/515 Introduction

Optical Specification, Fabrication and Testing is designed to unify concepts from ~~geom~~ geometrical optics, aberrations, Fourier optics, interference and diffraction. In the real world, a lens designer may provide ~~an~~ an optical design (maybe even with tolerances). How do you go about turning this into a real system? This class hopes to illustrate some of these processes. Namely

- Creating specifications
    - Drawings that someone at an optics shop can ~~under~~ interpret correctly
    - Specifying tests to verify the part was made correctly or to within some performance metric
- Fabrication techniques - what's possible, costs, limitation

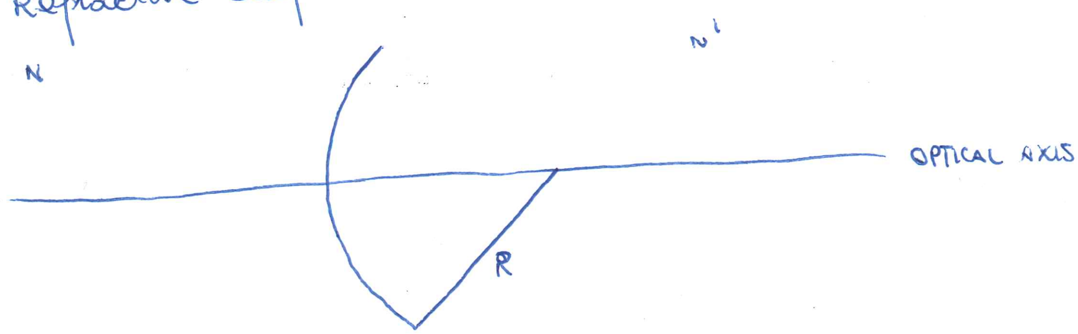
We will look at

- Performance Metrics
- Simple and Complex tests to verify performance
- Standards for creating drawings.

$\boxed{1}$ Properties of Optical Systems (Brief Review)

$\boxed{1.1}$ Optical Properties of a single Spherical Surface

$\boxed{1.1.1}$ Refractive Surface



Spherical Surfaces are Specified by a single value

- R = Radius of Curvature (units mm, m, in.)

Alternatively, we can use Curvature

$$C = 1/R$$ (units mm^{-1}, m^{-1})

- $R = \infty$ means $C = 0$ is a planar or flat surface.

Curvature sometimes more useful in computer code since it remains finite

~~Effective Focal Length (EFL~~

Power of a optical surface ϕ (Ability of the lens to converge/diverge light)

$$\phi = (n' - n)\,C = \frac{n' - n}{R}$$ (units mm^{-1}, m^{-1} = Diopters)

sign convention

$R > 0$ $\qquad$ $R < 0$

Example

$n' = 1.5$

$n = 1.0$

$R = 80$ mm

$$\phi = \frac{(1.5 - 1.0)}{80} = 0.00625 \text{ mm}^{-1}$$

put in water

$$\phi = \frac{1.5 - 1.33}{80} = 0.002125 \text{ mm}^{-1}$$

power is reduced when difference in n's reduced.

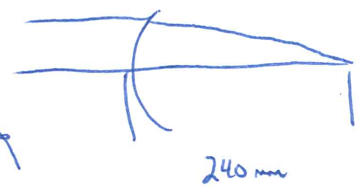
Effective Focal Length (EFL, f_E)

$$f_E = \frac{1}{\phi}$$

For our example

$$f_E = \frac{1}{0.00625} = 160 \text{ mm}$$

$$f_R' = \frac{1.5}{0.00625} = 240 \text{ mm}$$

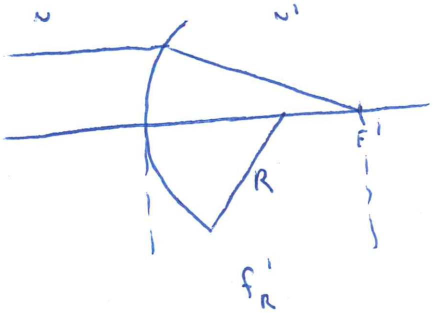


~~Measures~~ Front Focal length (FFL, f_F)

$$f_F = \frac{-N}{\phi} = -N f_E$$

Rear (~~Back~~) Focal length (~~BFL~~, f_R')

$$f_R' = \frac{N'}{\phi} = N' f_E$$



$N' > N$

$\phi > 0$

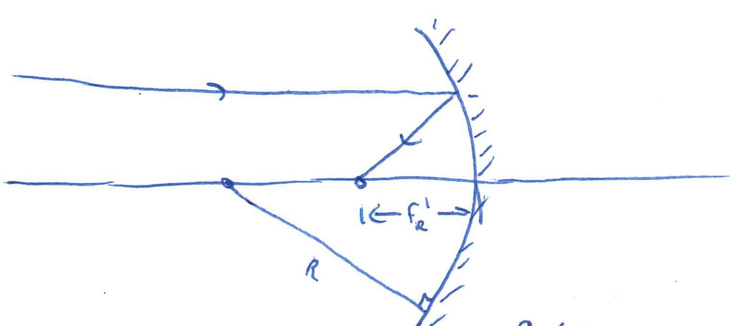
$\boxed{1.1.2}$ Reflective Surfaces

Special case of above with $N' = -N$

$\therefore$

- Power $\phi = -2NC = \frac{-2N}{R}$

$$f_F = f_R' = \frac{-N}{\phi} = -N f_E = \frac{R}{2} = \frac{1}{2C}$$



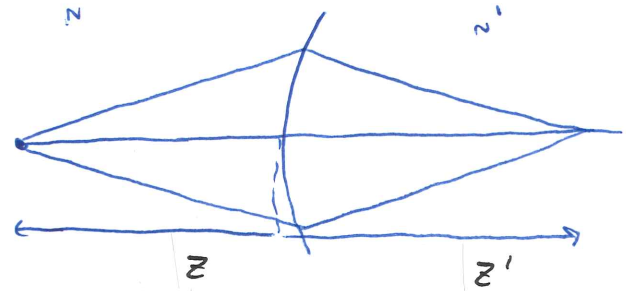
$R < 0$

$N' = -N$

$\phi > 0$

1.1.3 Gaussian Imaging Equation

$$\frac{N'}{z'} - \frac{N}{z} = \phi$$



By convention $z < 0$ and $z' > 0$ in above.

To left of vertex negative

To right of vertex positive

Continuing our example suppose you have object at 500 mm left of surface, where is image formed?

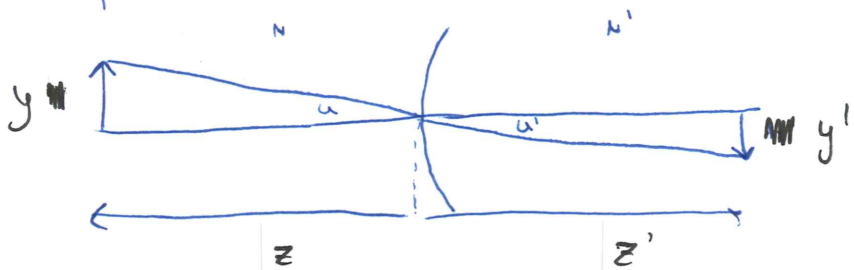
(Recall $N = 1.0$
$N' = 1.5$
$\phi = 0.00625 \text{ mm}^{-1}$ from $R = 80$ mm)

$$\frac{1.5}{z'} - \frac{1}{-500} = 0.00625$$

$$\frac{1.5}{z'} = 0.00425$$

$$z' = +352.94 \text{ mm}$$

We can also look at magnification (transverse or lateral) of the surface for an extended object



Transverse magnification $m = \frac{y'}{y}$

by sign convention up is positive

down is negative

So in this example $m < 0$ meaning ~~object~~ image is upside down.

Again by our sign convention $u < 0 \quad u' < 0$

In paraxial region

$$u = \frac{y}{z} \qquad u' = \frac{y'}{z'}$$

Paraxial version of Snell's Law

$$Nu = N'u'$$

$$\frac{Ny}{z} = \frac{N'y'}{z'} \Rightarrow \frac{y'}{y} = \frac{Nz'}{N'z} = m$$

We can use this to rewrite the gaussian imaging equation

$$\frac{z'}{N'}\left[\frac{N'}{z'} - \frac{N}{z}\right] = \phi \frac{z'}{N'}$$

$$1 - m = \frac{\cancel{N'}}{f'_R} \frac{z'}{\cancel{N'}}$$

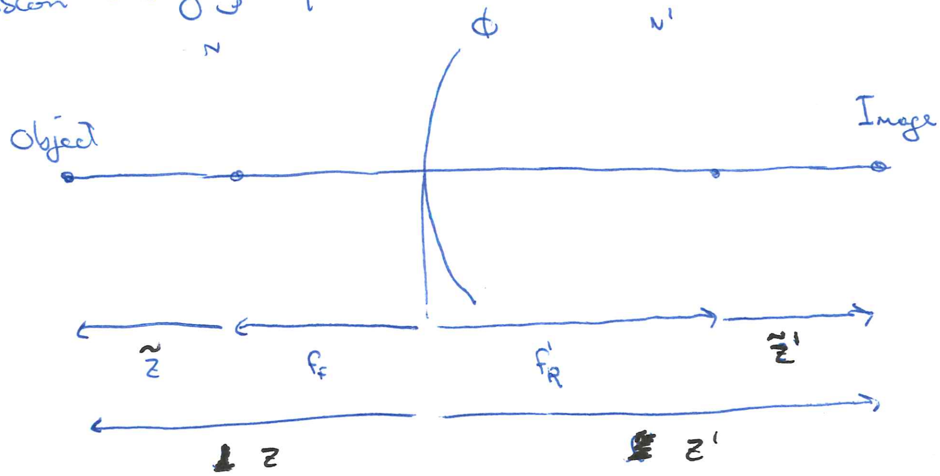
$$\boxed{z' = f'_R(1-m)}$$

Similarly if you multiply gaussian imaging equation by $\frac{z}{N}$ on both sides you get

$$\boxed{z = -\left(\frac{1-m}{m}\right) f_F} \Rightarrow z = \left[\frac{m-1}{m}\right] f_F$$

The point here is that if we know the front and/or rear focal lengths and the magnification, we can predict where the object/image is located.

1.1.4 Newton's Equation is an alternative form of the Gaussian Imaging equation



$z = f_F + \tilde{z}$ $\qquad$ $z' = f_R' + \tilde{z}'$

Gaussian Imaging Eq.

$$\frac{N'}{f_R' + \tilde{z}'} - \frac{N}{f_F + \tilde{z}} = \frac{N'}{f_R'}$$

$$\frac{N'}{f_R' + \tilde{z}'} - \frac{N'}{f_R'} = \frac{N}{f_F + \tilde{z}}$$

$$\frac{\cancel{N'f_R'} - \cancel{N'f_R'} - N'\tilde{z}'}{f_R'(f_R' + \tilde{z}')} = \frac{N}{f_F + \tilde{z}}$$

$$-\frac{\tilde{z}'}{f_R'}\left[\frac{N'}{f_R' + \tilde{z}'}\right] = \frac{N}{f_F + \tilde{z}}$$

$$\frac{+\cancel{N}\tilde{z}\tilde{z}'}{f_R' f_F \cancel{(f_F + \tilde{z})}} = \frac{\cancel{N}}{\cancel{f_F + \tilde{z}}}$$

$$\boxed{\tilde{z}\tilde{z}' = f_F f_R'}$$

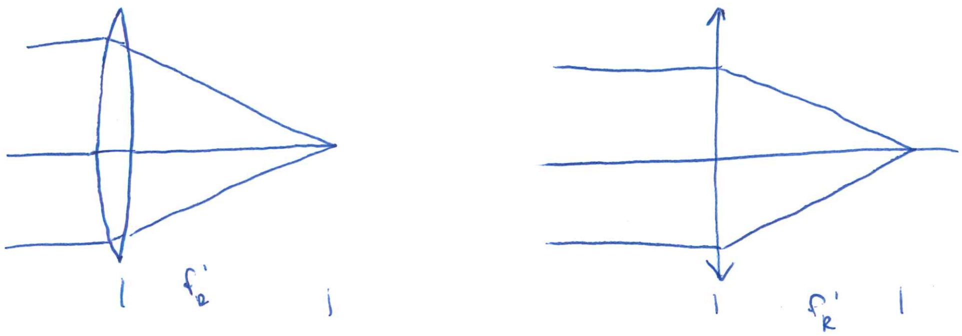
Gaussian Imaging Eq.

$$\frac{N'}{f_R' + \tilde{z}'} - \frac{N}{f_F + \tilde{z}} = \frac{-N}{f_F}$$

$$\frac{N}{f_F + \tilde{z}} - \frac{N}{f_F} = \frac{N'}{f_R' + \tilde{z}'}$$

$$\frac{\cancel{Nf_F} - \cancel{Nf_F} - N\tilde{z}}{f_F(f_F + \tilde{z})} = \frac{N'}{f_R' + \tilde{z}'}$$

The thin Lens

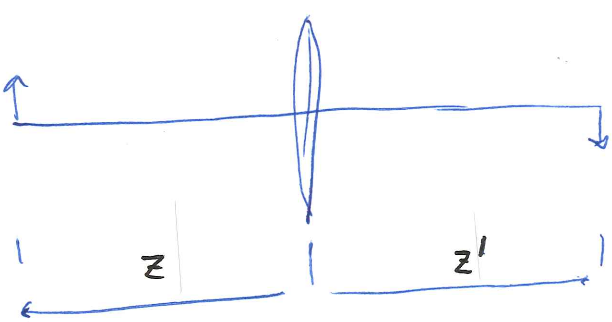


A lens whose thickness is much smaller than its Radii and Diameter can be approximated as an idealize thin lens that is a plane.

Power of a thin lens in air

$$\phi = (N-1)(C_1 - C_2)$$

where C_1 and C_2 are the curvatures of front and back surface. N is index of lens.



z and z' in gaussian imaging equation measured from the plane of the thin lens.