PH 301

ENGINEERING OPTICS

Lecture_7

Syllabus

Lens systems: Basics & concepts of lens design, some lens systems.

Optical components: Reflective, refractive & diffractive systems; Mirrors, prisms, gratings, filters, polarizing components.

Interferometric systems: Two beam, multiple beam, shearing, scatter fringe & polarization interferometers.

Vision Optics: Eye & vision, colorimetry basics.

Optical sources: Incandescent, fluorescent, discharge lamps, Light emitting diode.

Optical detectors: Photographic emulsion, thermal detectors, photodiodes, photomultiplier tubes, detector arrays, Charge-coupled device, CMOS.

Optical Systems: Telescopes, microscopes (bright field, dark field, confocal, phase contrast, digital holographic), projection systems, interferometers, spectrometers.

Display devices: Cathode ray tube, Liquid crystal display, Liquid crystals on silicon, Digital light processing, Digital micro-mirror device, Gas plasma, LED display, Organic LED.

Consumer devices: Optical disc drives: CD, DVD; laser printer, photocopier, cameras, image intensifiers.

Texts

1. R. S. Longhurst, *Geometrical & Physical Optics*, 3rd ed., Orient Longman, 1988.
2. R. E. Fischer, B. Tadic-Galeb, & P. R. Yoder, *Optical System Design*, 2nd ed., SPIE, 2008
3. W. J. Smith, *Modern Optical Engineering*, 3rd ed., McGraw Hill, 2000.
4. K. Iizuka, *Engineering Optics*, Springer, 2008.
5. B. H. Walker, *Optical Engineering Fundamentals*, SPIE Press, 1995.

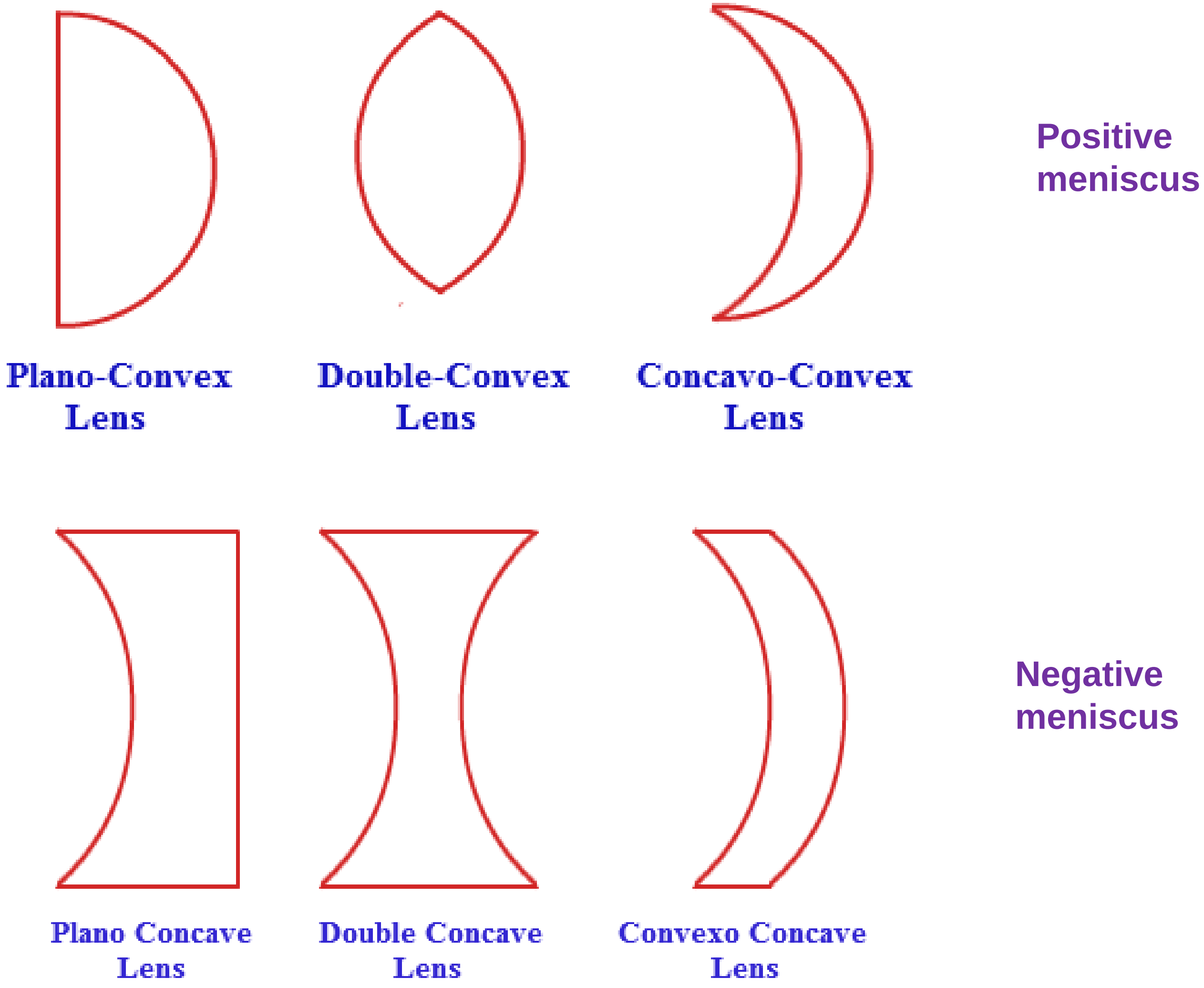
Lens systems

Lenses are among the most used components in optical systems.

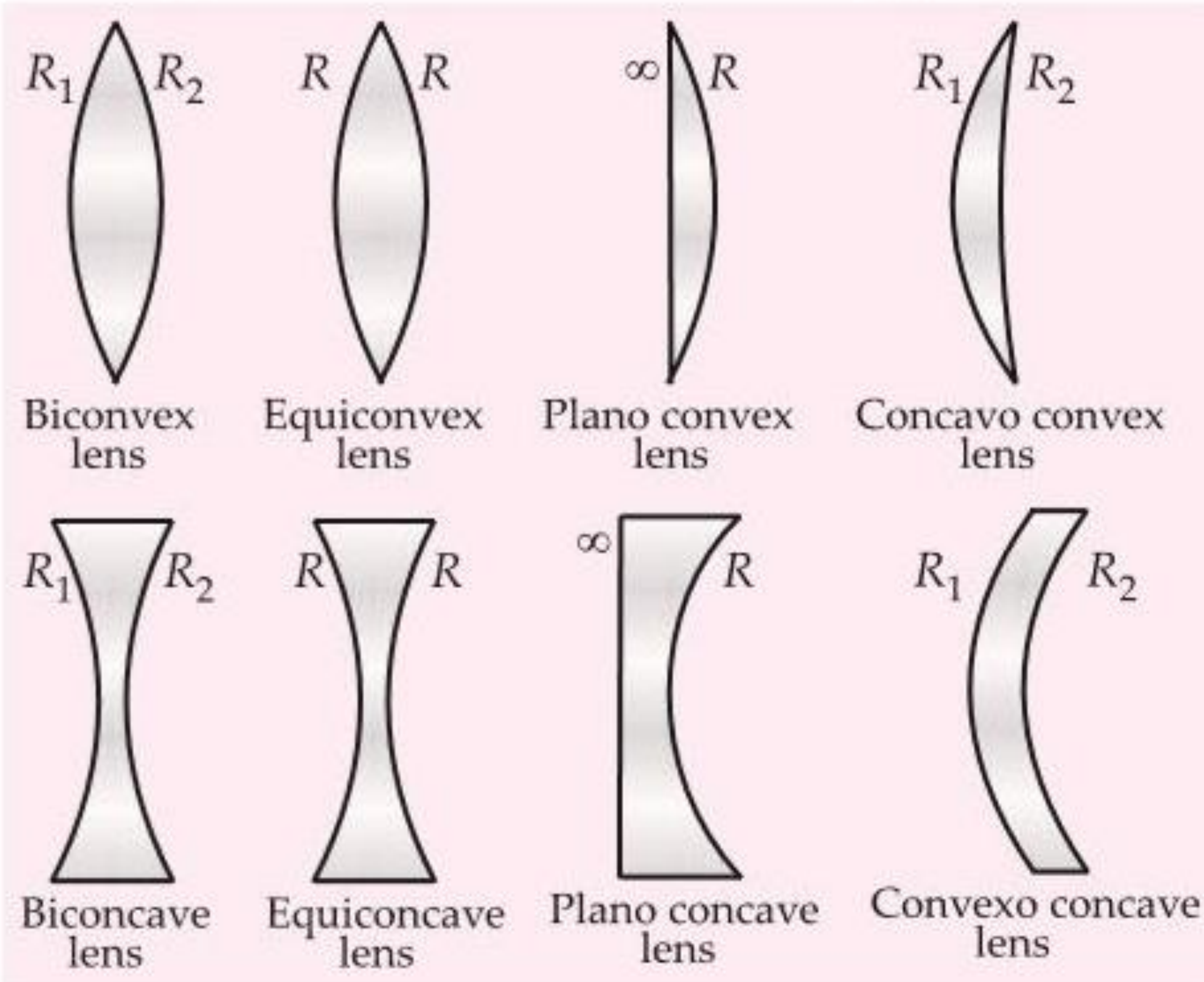
Functions:

- ❖ Perform convergence of light beams,
- ❖ Perform divergence of light beams,
- ❖ Formation of virtual or real images,
- ❖ Perform 2D Fourier transform.

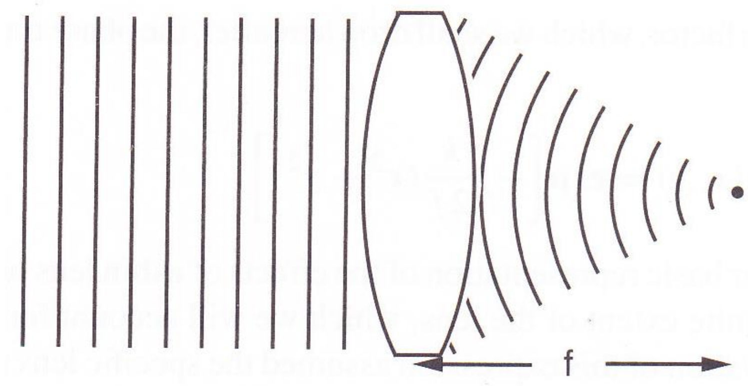
Various types of lenses



Broadly, lenses are of the following types :

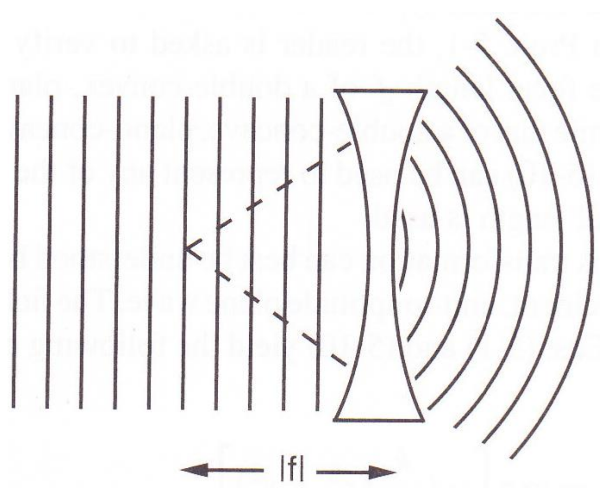


***f* > 0**

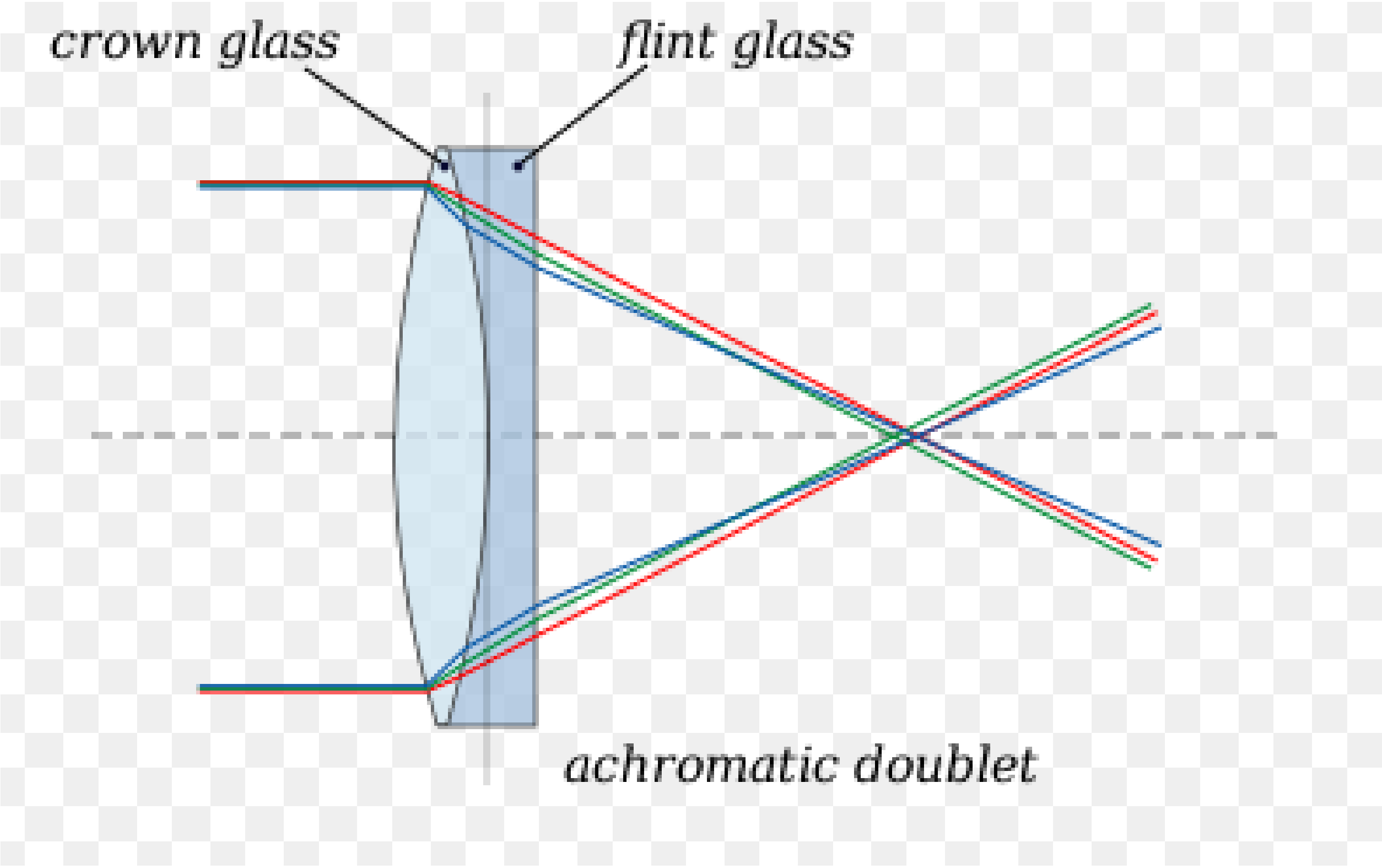


Effect of a converging lens on a normally incident plane wave

***f* < 0**



Effect of a diverging lens on a normally incident plane wave


crown glass
flint glass
achromatic doublet

Lens Kit

Prime Lens

A prime is a fixed-focal-length lens, such as 35mm, 50mm, 85mm & so on. Typically faster (i.e., possessing a wider max. aperture, smaller *f*-number) due to simplified optical construction, primes are frequently smaller & lighter than zoom lenses, & are high quality.

Zoom Lens

A zoom lens can be adjusted across a range of focal lengths, for instance, a 24-70mm zoom lens. Some zooms are wide-angle, some are telephoto, & some "extreme zooms" cover a range from wide to telephoto. As for benefits, a single lens can cover a wide range, so a single zoom can replace two or three prime lenses.

Fisheye & Ultrawide Zoom Lens

- A normal lens, in 35mm film terms, is a 50mm lens. This lens approximates angle of view of human eye, so it’s considered to produce a normal view. Normal lenses range, generally, from 40mm to 60mm in 35mm equivalent terms.

- A wide-angle lens is generally any lens shorter than 40mm, which provides an angle of view “wider” than a normal lens. Typical wide-angle focal lengths are 17mm, 20mm, 24mm, 28mm & 35mm. Lenses shorter than 17mm are considered “superwide” & provide a huge angle of view up to & beyond 180 degrees. The widest of these lenses are known as fisheyes.

- Portrait Lens: A lens ideal for portraits is a short to medium telephoto with a wide maximum aperture. So, a 100mm *ƒ*/2 lens, for instance, or an 85mm *ƒ*/1.4, are ideal portrait lenses. They allow for compression to simplify backgrounds & minimize facial features, while not requiring you to stand so far from your subject that you can’t easily interact with them.

Supertelephoto Zoom Lens

A telephoto lens has a focal length greater than 70mm in 35mm equivalent terms. Popular telephoto focal lengths are 70-200mm zooms, & 85mm, 100mm, 135mm & 150mm primes. Especially long lenses, above 300mm, are called supertelephotos.

- **Sports/Wildlife Lens**: A sports/wildlife lens is a supertelephoto such as a 400mm prime or a 100-400mm zoom. High-end lenses such as 600mm & 800mm primes were all but mandatory for professional sports & wildlife photographers until resolution advances in the digital era, combined with crop sensors that make focal lengths effectively longer, made extreme telephotos less necessary. Today, a 400mm lens is plenty for most sports & wildlife needs.

- **Landscape Lens**: It refers to wide-angle lens that allows for foreground/background compositions popular in landscape photography. A 35 mm lens is a great landscape lens.

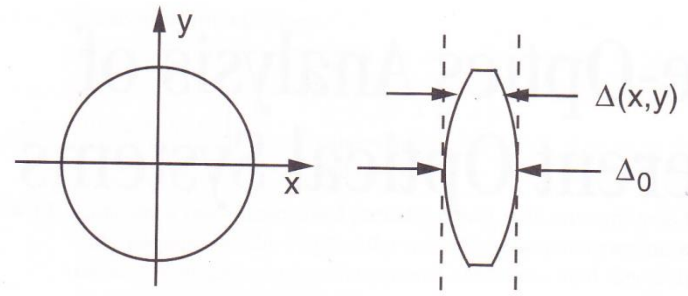
A Thin Lens as a Phase Transformation

- Lenses are the most important components of optical imaging & data processing systems.

- A lens is composed of an optically dense material, usually glass with a r.i. of approx. 1.5, in which propagation velocity of an optical disturbance is less than velocity in air.

- A lens is said to be a thin lens if a ray entering at coordinates (x,y) on one face exits at approx. same coordinates on opposite face, i.e., if there is negligible translation of a ray within lens.

- A thin lens simply delays an incident wavefront by an amount proportional to thickness of lens at each point.



Thickness function, front view & side view

Let max thickness of lens (on its axis) = Δ_0

Thickness at coordinates (x,y) = $\Delta(x,y)$

Total phase delay suffered by wave at coordinates (x,y) in passing through lens,

$$\begin{aligned}\phi(x,y) &= kn\Delta(x,y) + k[\Delta_0 - \Delta(x,y)] \\ &= kn\Delta(x,y) + k\Delta_0 - k\Delta(x,y) \\ &= k\Delta_0 + k\Delta(x,y)[n-1]\end{aligned}$$

n = r.i. of lens material

$kn\Delta(x,y)$ = phase delay introduced by lens

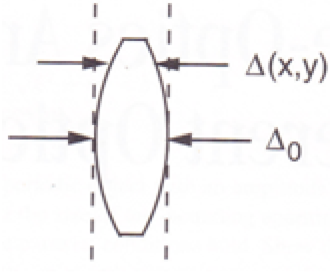
$k[\Delta_0 - \Delta(x,y)]$ = phase delay introduced by remaining region of free space between two planes

Equivalently lens may be represented by a multiplicative phase transformation, $t_l(x,y) = \exp[jk\Delta_0]\exp[jk(n-1)\Delta(x,y)]$

Complex field $U_l'(x,y)$ across a plane immediately behind lens is then related to complex field $U_l(x,y)$ incident on a plane immediately in front of lens,

$$U_l'(x,y) = t_l(x,y)U_l(x,y)$$

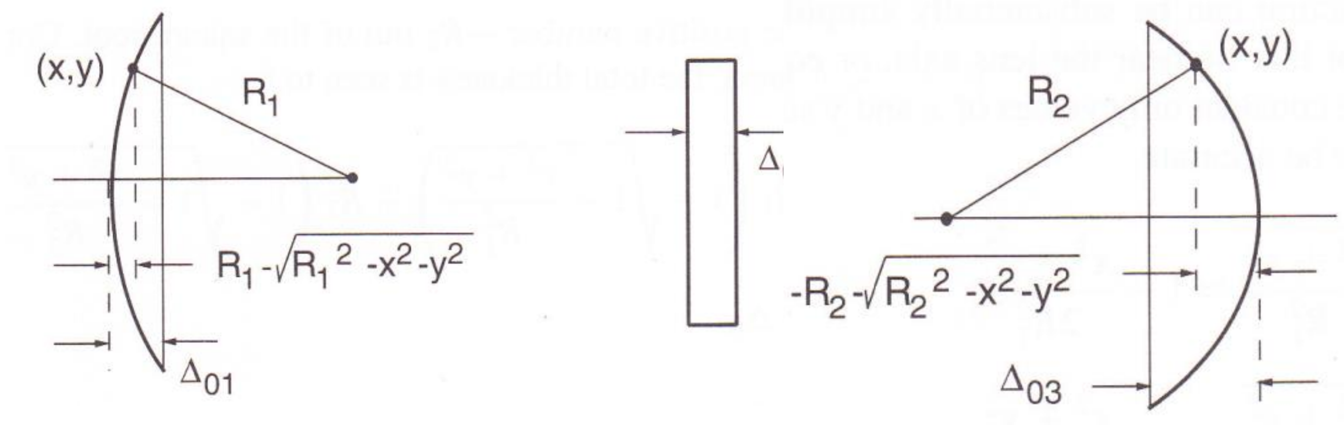
Problem; thickness function, $\Delta(x,y)$



Thickness function

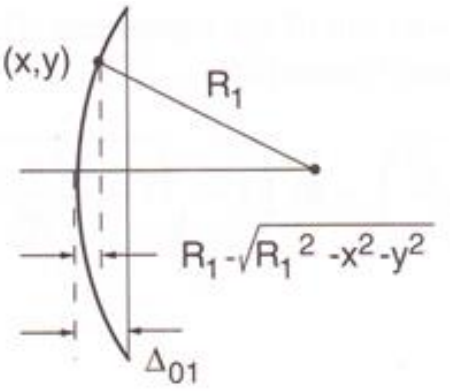
Sign convention:

- As rays travel from left to right, each *convex* surface encountered is taken to have a *positive* radius of curvature, while each *concave* surface is taken to have a *negative* radius of curvature.

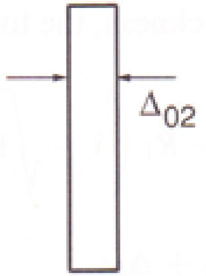


- Radius of curvature of left-hand surface of lens is a positive number R_1, while radius of curvature of right-hand surface is a negative number R_2.

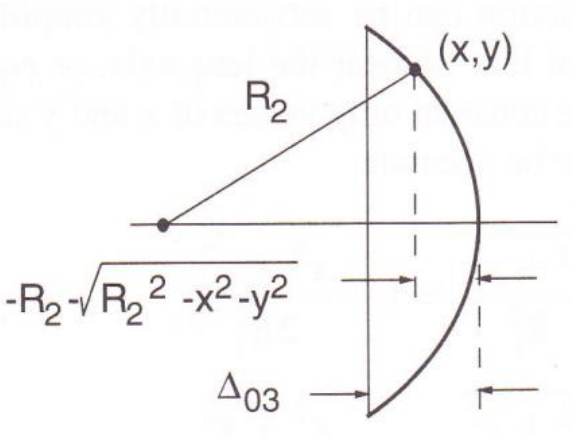
$$\Delta(x,y)=\Delta_1(x,y)+\Delta_2(x,y)+\Delta_3(x,y)$$



$$\Delta_1(x,y) = \Delta_{01} - \left(R_1 - \sqrt{R_1^2 - x^2 - y^2}\right)$$
$$= \Delta_{01} - R_1\left(1 - \sqrt{1 - \frac{x^2 + y^2}{R_1^2}}\right)$$



2nd component of thickness function comes from a region of glass of constant thickness Δ_{02}.



$$\Delta_3(x,y) = \Delta_{03} - \left(-R_2 - \sqrt{R_2^2 - x^2 - y^2}\right)$$

$$= \Delta_{03} + R_2\left(1 - \sqrt{1 - \frac{x^2 + y^2}{R_2^2}}\right)$$

Combining all three thickness components, total thickness is,

$$\Delta(x,y) = \Delta_{01} - R_1\left(1 - \sqrt{1 - \frac{x^2 + y^2}{R_1^2}}\right) + \Delta_{02} + \Delta_{03} + R_2\left(1 - \sqrt{1 - \frac{x^2 + y^2}{R_2^2}}\right)$$

$$= \Delta_0 - R_1\left(1 - \sqrt{1 - \frac{x^2 + y^2}{R_1^2}}\right) + R_2\left(1 - \sqrt{1 - \frac{x^2 + y^2}{R_2^2}}\right)$$

Paraxial Approximation:

$$\sqrt{1-\frac{x^2+y^2}{R_1^2}} \approx 1-\frac{x^2+y^2}{2R_1^2}$$

$$\sqrt{1-\frac{x^2+y^2}{R_2^2}} \approx 1-\frac{x^2+y^2}{2R_2^2}$$

With the help of these approximations, thickness function becomes,

$$\begin{aligned}\Delta(x,y) &= \Delta_{01} - R_1\left(1-\sqrt{1-\frac{x^2+y^2}{R_1^2}}\right) + \Delta_{02} + \Delta_{03} + R_2\left(1-\sqrt{1-\frac{x^2+y^2}{R_2^2}}\right) \\ &= \Delta_0 - R_1\left(1-\sqrt{1-\frac{x^2+y^2}{R_1^2}}\right) + R_2\left(1-\sqrt{1-\frac{x^2+y^2}{R_2^2}}\right)\end{aligned}$$

$$\Delta(x,y) = \Delta_0 - \frac{x^2+y^2}{2}\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$t_l(x,y) = \exp[jk\Delta_0]\exp[jk(n-1)\Delta(x,y)]$$

$$\Delta(x,y) = \Delta_0 - \frac{x^2+y^2}{2}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$t_l(x,y) = \exp[jkn\Delta_0]\exp\left[-jk(n-1)\frac{x^2+y^2}{2}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)\right]$$

Physical properties of lens (*n*, R_1, & R_2) can be combined in a single number *f* called *focal length*,

$$\frac{1}{f} \equiv (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Neglecting constant phase factor, phase transformation may be rewritten,

$$\boxed{t_l(x,y) = \exp\left[-j\frac{k}{2f}(x^2+y^2)\right]}$$