Engineering Physics (FYBTech)

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Interference

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Content:

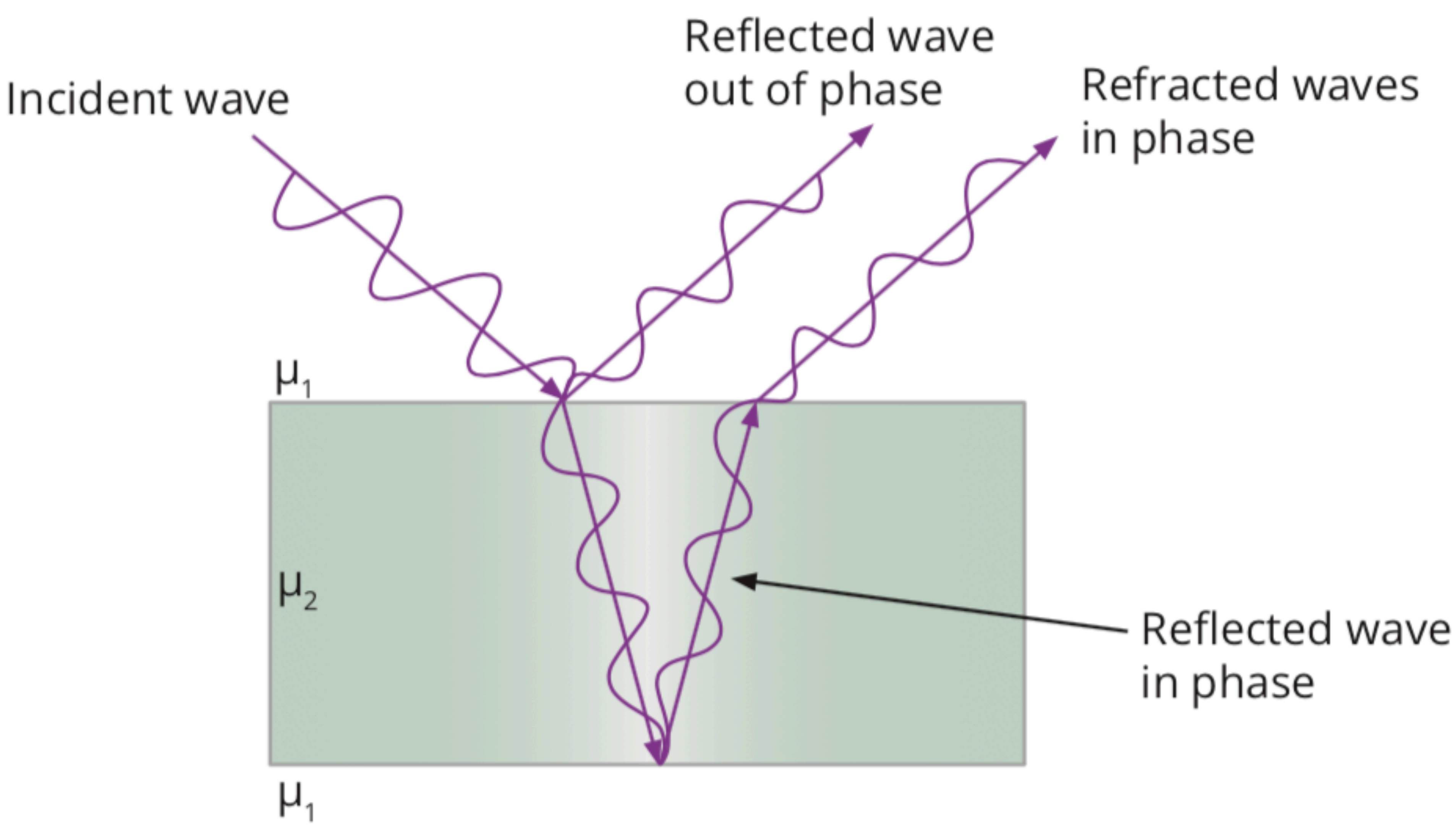
- Stokes Law
- Concept of Thin film
- Concept of Interference
- Thin Parallel film (P D ,conditions maxima, minima, wedge shaped film, and fringe width (without derivations),
- Newton's rings Formation

  Applications of Newton's rings Antireflection (high transmission) coating
- Anti-transmission (high reflection coatings)

Stokes Law

Stokes law states that

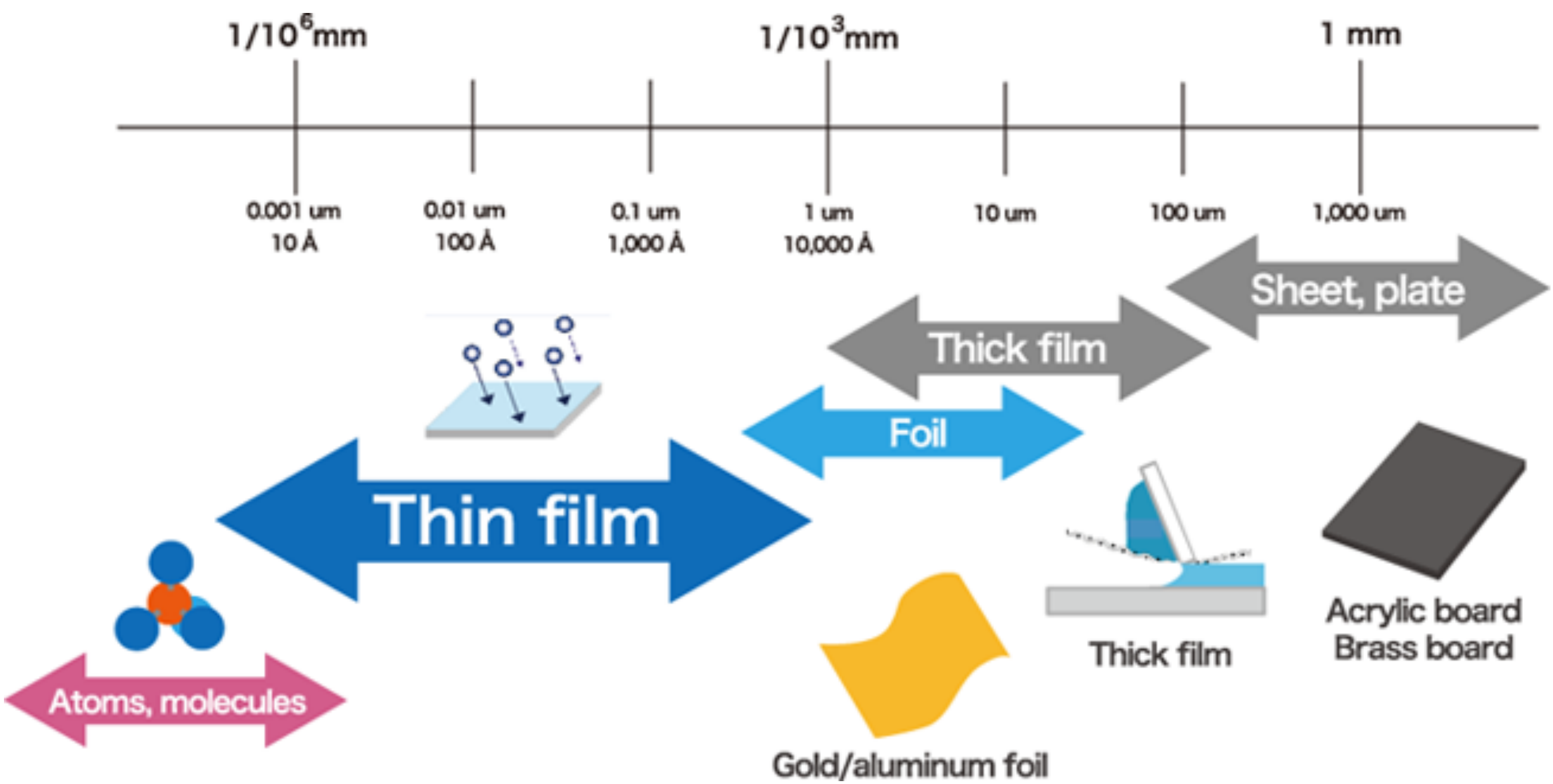
- Phase change of π or path difference (λ/2) occurs when light waves are reflected at the surface of the denser medium.
- No change of phase occurs when light waves are reflected at the surface of a rarer medium.



Concept of Thin Film

Thin Film:

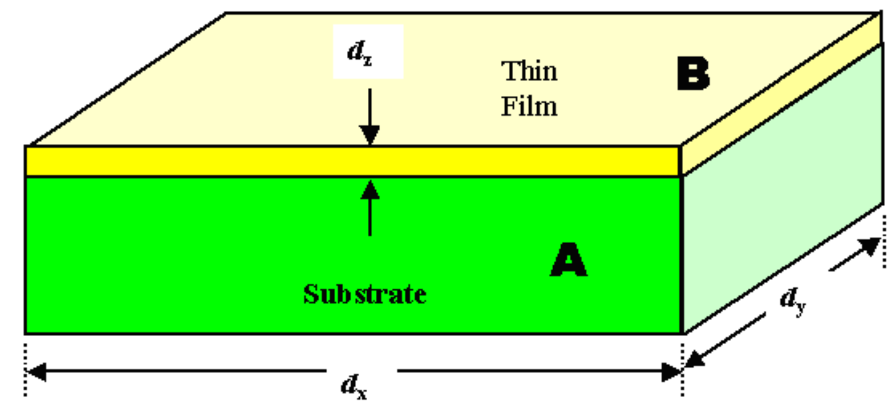
- Film thickness is nearly equal to wavelength of light
- Average wavelength of visible light 5500Å/550 nm (0.55μm)
- When exposed to light, the thin film produces an interference pattern



Concept of Thin Film

Examples:

- Oil films on the road during rainy days
- Soap bubble



Applications:

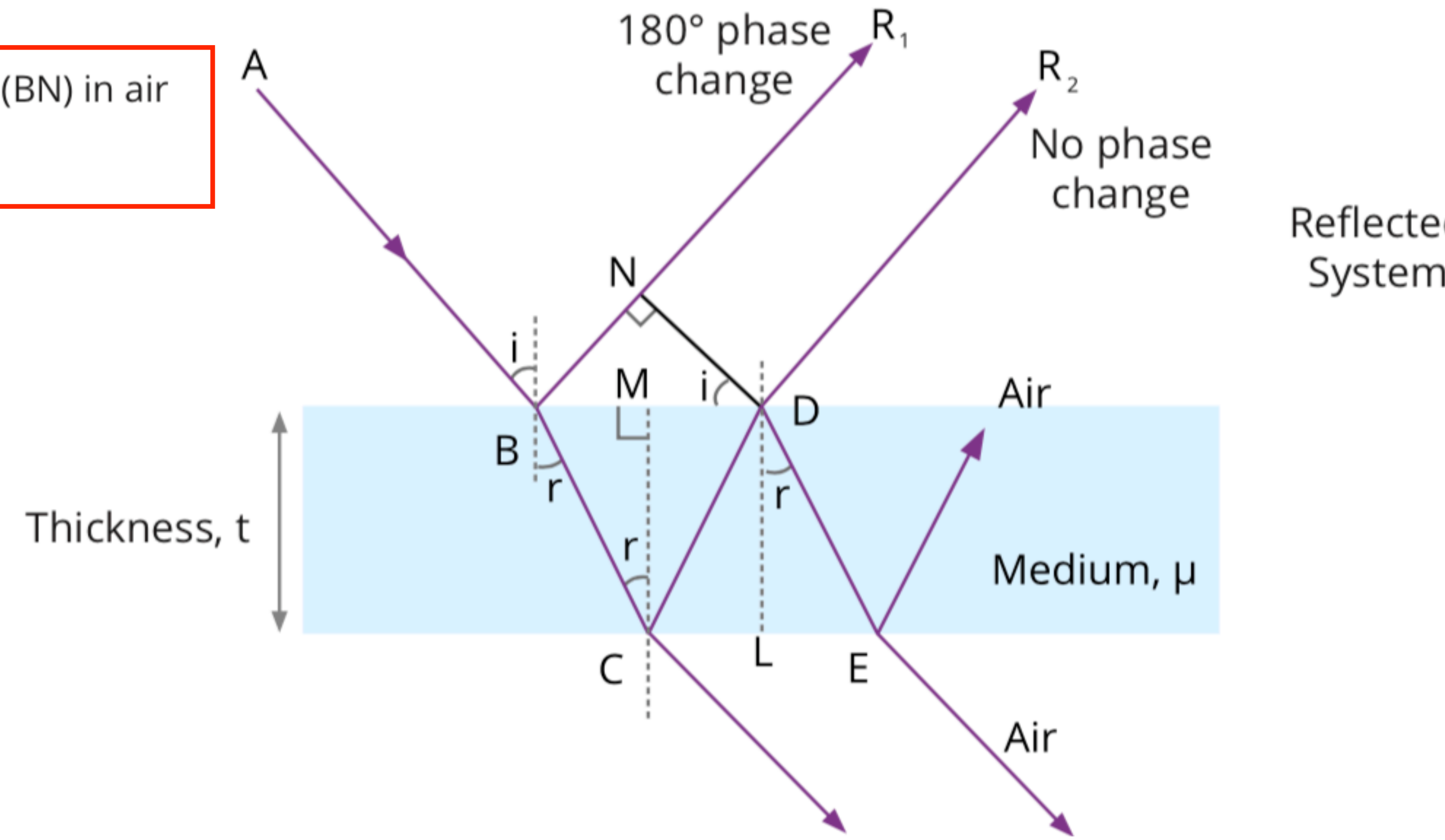
- Anti-reflection coating on camera lens, Solar cell Interference filters
- Anti transmission coating on glass

Interference due to Thin Film

Path difference $= \Delta =$ Path (BC + CD) in film – Path (BN) in air

$$\Delta = \mu(BC + CD) - BN$$

$$\boxed{\Delta = 2\,\mu t \cos r}$$



- Ray BR_1 is reflected from a denser medium to rarer medium, so according to stokes law, additional path difference of $\left(\frac{\lambda}{2}\right)$ or phase difference (π) is introduced.

Total path difference $= 2\,\mu t \cos r \pm \frac{\lambda}{2}$

Interference due to Thin Film

- **Condition for constructive interference or maxima**

For bright point path difference is integral multiple of λ,

$$2\mu t\cos r \pm \frac{\lambda}{2} = n\lambda = 2n\left(\frac{\lambda}{2}\right)$$

$$2\mu t\cos r = (2n-1)\frac{\lambda}{2} \text{ ....} n = 1, 2, 3,$$

$$2\mu t\cos r = (2n+1)\frac{\lambda}{2} \text{ ...... } n = 0, 1, 2, 3,$$

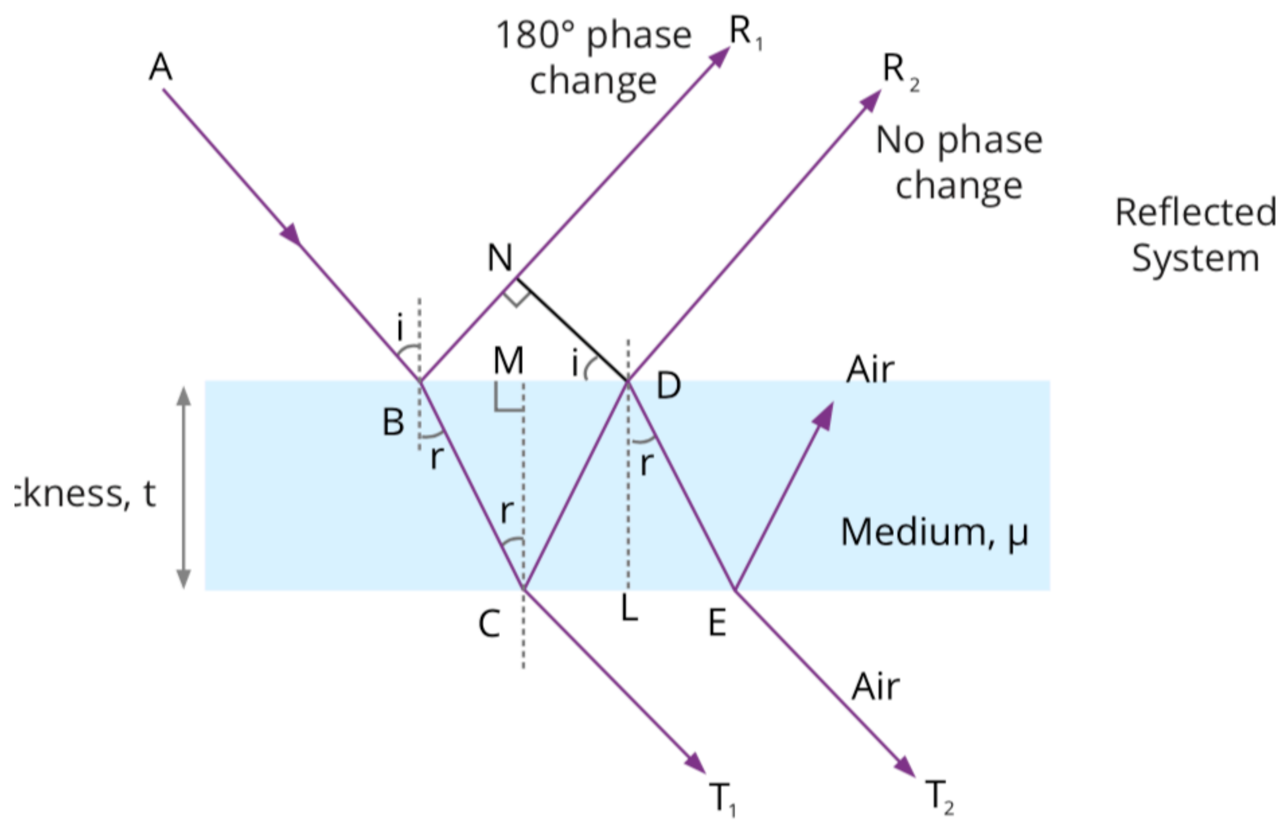
- **Condition for destructive interference or minima**

For dark point path difference is odd multiple of $\frac{\lambda}{2}$,

$$2\mu t\cos r \pm \frac{\lambda}{2} = (2n \pm 1)\times\frac{\lambda}{2}$$

$$2\mu t\cos r = 2n\times\frac{\lambda}{2}$$

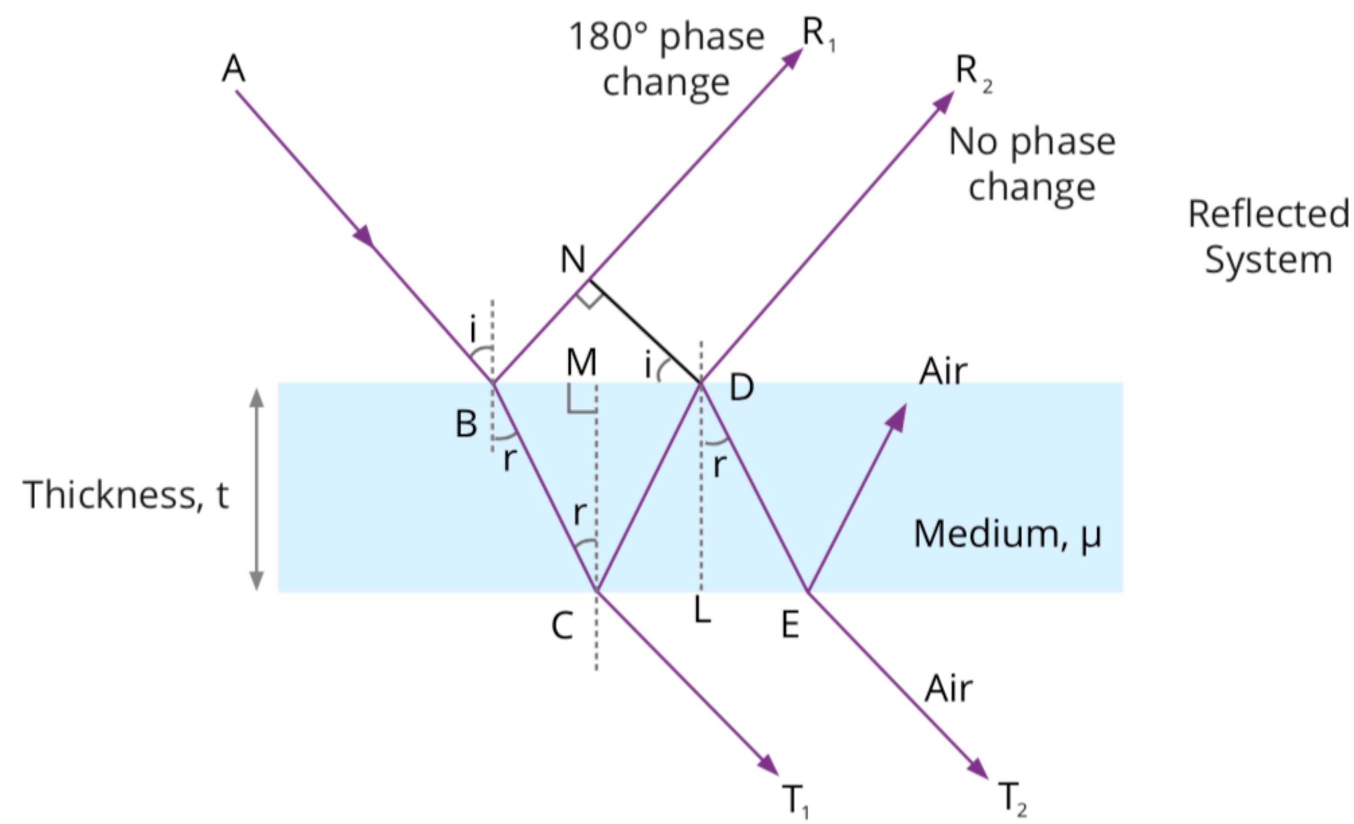
$$= n\lambda \text{......} n = 0,1,2\text{......}$$



If a point appears bright at a given angle in the reflected system, then it appears dark at the same angle in the transmitted system and vice versa

Interference due to Thin Film

- **If t<<λ then tends to 0 (Extreme Thin)**
- All point on the film has same path difference (±λ/2 or 0)
- Thus all points on reflected system appears dark and bright in transmitted system (or vice versa) This is not an interference pattern

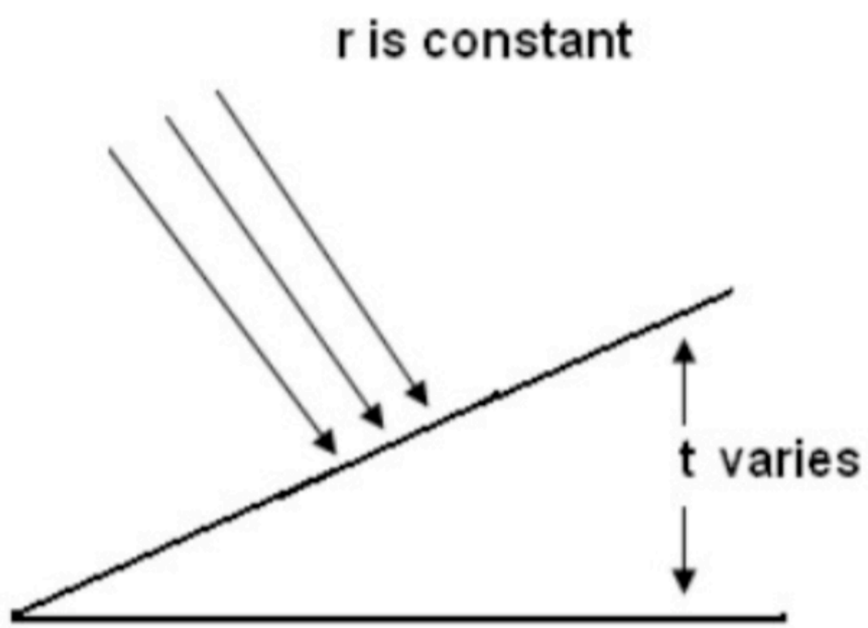


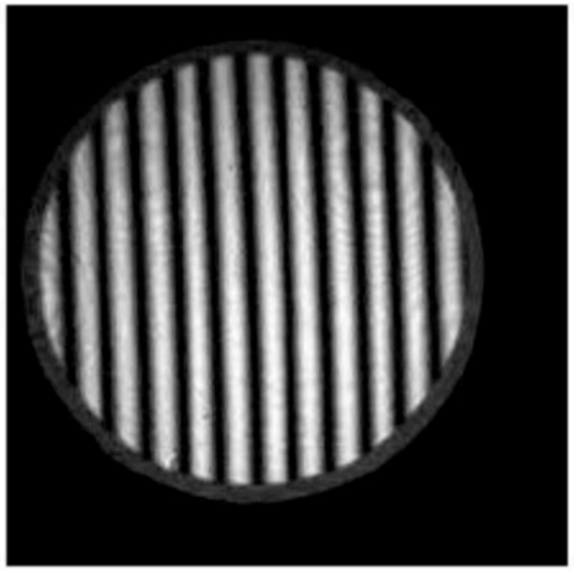
- **If t>>λ then path difference >>λ (Extreme Thick)**
- For every λ, there exist some path difference, which is an even and odd multiple of λ/2. Thus at every point constructive as well as destructive interference is possible Therefor interference pattern will not be observed

Fizau’s Fringes

Fizau’s Fringes

Here thickness varies gradually, wavefronts parallel and angle refraction r is same





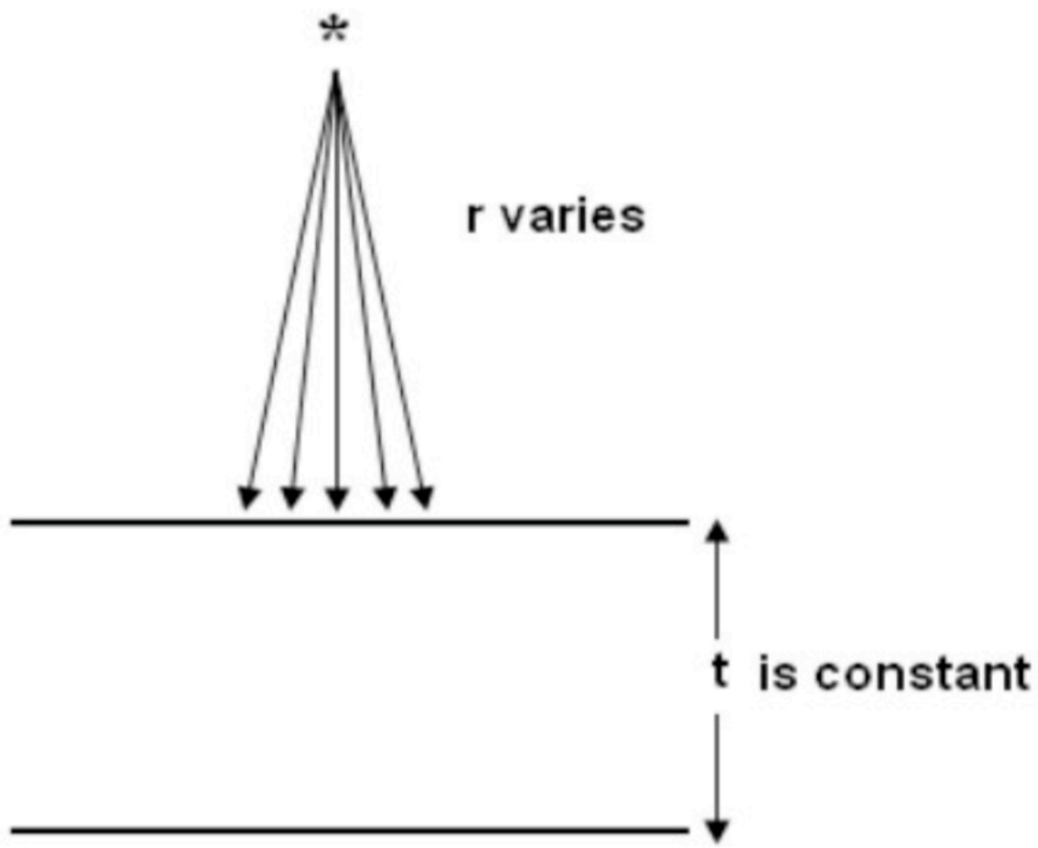
As the variation of the t occurs in horizontal (X)direction, the P.D. and the change in the intensity of the fringe occurs in horizontal (X) direction.

As the thickness gradually increases, the p.d. gradually acquires the values starting from $\lambda/2$, $2\lambda/2$, $3\lambda/2$, $4\lambda/2$....
Correspondingly dark and bright fringes occurs alternatively.

These fringes, which are parallel to the edge of the film, equidistant, and in the horizontal plane, are referred as Fizau’s fringes.

Haidinger's Fringes

r varies, t constant



Consider point source, it emits a spherical wavefront and thus the rays are incident on the film along various cones.
Thus, for each cone, r remains constant over a circle.

Thus PD remains constant over a circle.

Owing to this circular symmetry, if observed from the top, the fringes will appear concentric and circular.
This are referred as Haidenger's

Interference in Wedge Shaped Films

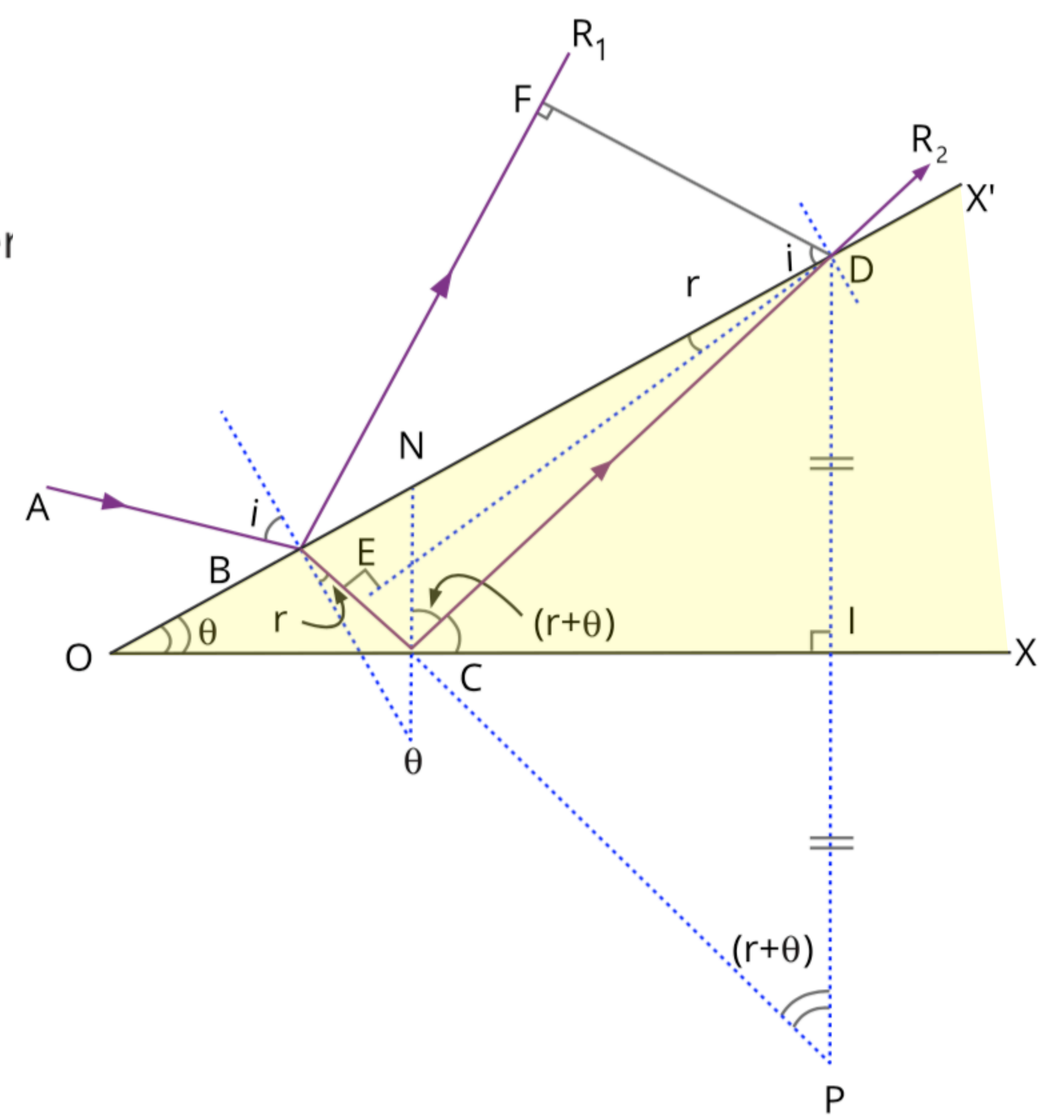
- An arrangement of two surfaces in contact with each other at one point and gradually increasing the thickness of air film at other is known as wedge shaped thin film as shown in figure.

- From figure path difference between BR_1 and DR_2 is

$$\Delta = \mu_{film}(BC + CD) - BF \ldots\ldots (\mu_{air} = 1)$$

Total path difference is given by

$$\Delta = 2\,\mu t \cos(r+\theta) \pm \frac{\lambda}{2}$$, Angle BCN = (r + θ) due to exterior angle proper



- **Condition for constructive interference or maxima**

$$2\,\mu t \cos(r+\theta) \pm \frac{\lambda}{2} = 2n \times \frac{\lambda}{2} = n\lambda \qquad n = 0, 1, 2, 3\ldots\ldots$$

$$2\,\mu t \cos(r+\theta) = (2n \pm 1)\frac{\lambda}{2}$$

- **Condition for destructive interference or minima**

$$2\,\mu t \cos(r+\theta) \pm \frac{\lambda}{2} = (2n \pm 1) \times \frac{\lambda}{2}$$

$$2\,\mu t \cos(r+\theta) = 2n \times \frac{\lambda}{2} = n\lambda \quad n = 0,1, 2, 3\ldots\ldots$$

Interference in Wedge Shaped Films

- **Fringe width**
- Fringe width is defined as "The separation between two successive bright or dark fringes".

$$\omega = \frac{\lambda}{2\mu \sin\theta}$$

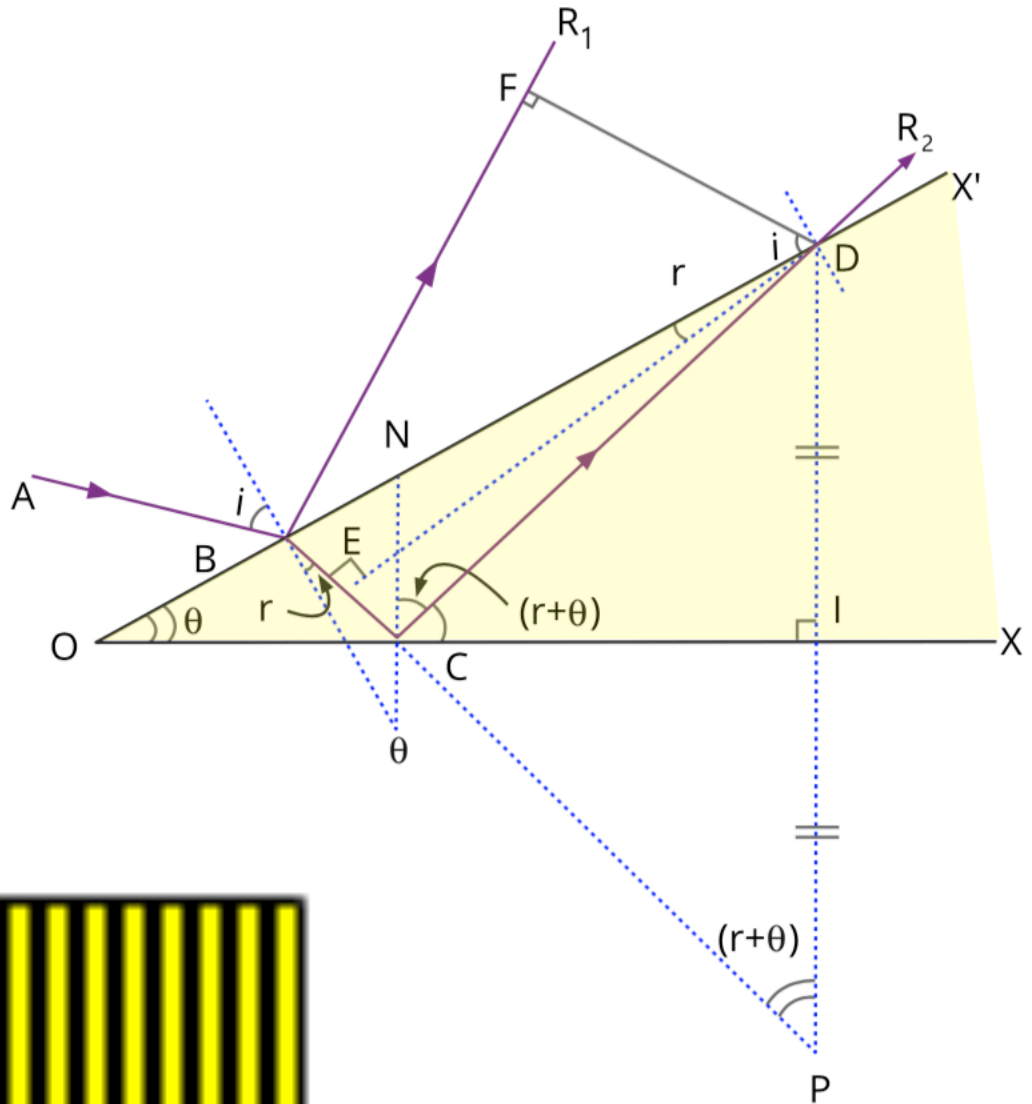
- For very small angle $\sin\theta \approx \theta$,

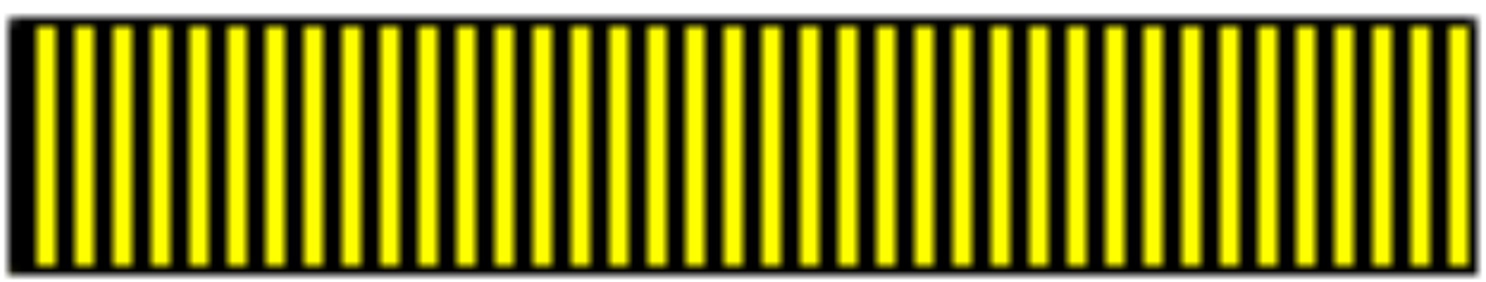
$$\omega = \frac{\lambda}{2\mu\theta},$$

This is the expression for fringe width for any medium.

- For air, $\mu = 1$

$$\omega = \frac{\lambda}{2\theta}$$





Fringe pattern

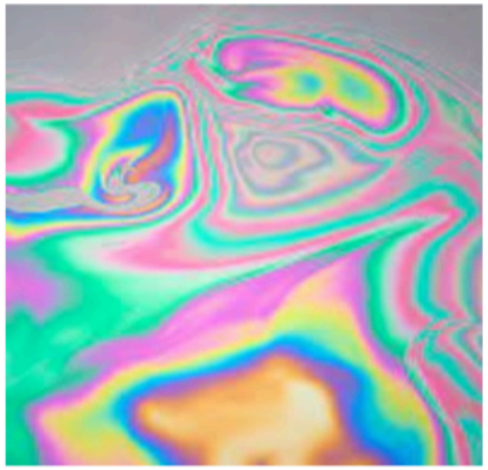
The wedge shaped film produces straight fringes which are parallel to the edge of the film.

Formation of Fringes in Thin Film

Flat Surface and Its Fringes

Formation of Colours in Thin Film

Soap Bubble



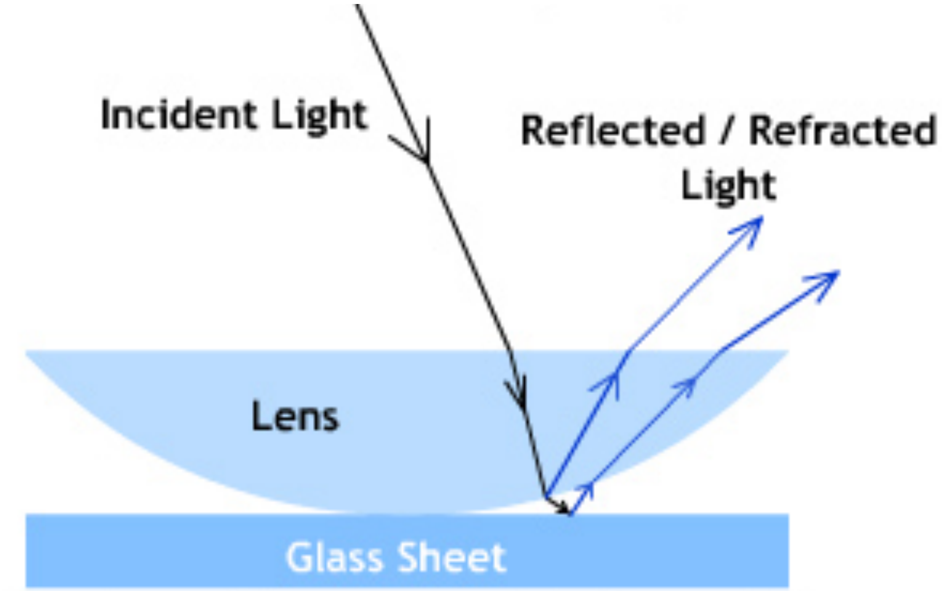
Oil Film

- When white light interacts with film, light reflected from top and bottom surfaces of the film, then these rays interfere with each other and produce interference pattern of colored fringes.
- The path difference between these rays depends upon thickness(t) of film and angle of refraction(r) of the film.
- Due to constructive interference, some colors satisfied the condition of maxima $2\mu t \cos r = (2n \pm 1)\frac{\lambda}{2}$ and will be visible with maximum intensity.
- While other colors satisfy condition of minima i.e $2\mu t \cos r = n\lambda$, will be absent from the reflected system.
- Similarly, if a point is observed at a different angle by keeping the same thickness or different points at different thickness, a different set of colors is observed at each time.

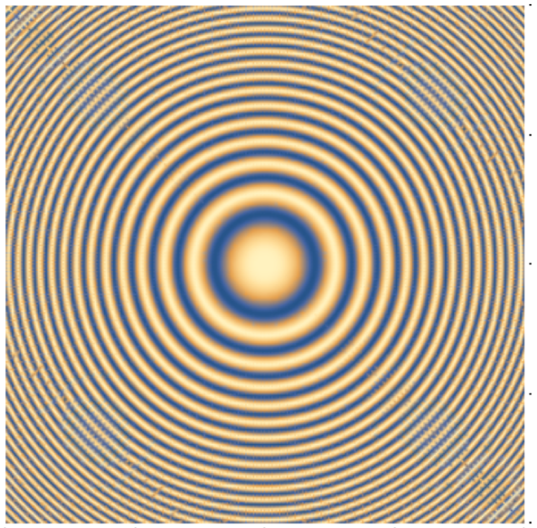
Newton's Ring

When a parallel beam of monochromatic light is incident normally on a combination of a plano-convex lens and a glass plate, a part of each incident ray is reflected from the lower surface of the lens, and a part, after refraction through the air film between the lens and the plate, is reflected back from the plate surface. These two reflected rays are coherent, hence they will interfere and produce a system of alternate dark and bright rings with the point of contact between the lens and the plate as the center. These rings are known as Newton's ring.

- The thin film may be treated as a 'natural interferometer' as it produces an interference pattern.
- It can be understood that, in this case the contours of constant thicknesses i.e. constant path difference form circles.
- Thus the Fizeau's fringes in this case are circular and concentric. The film involved here is a special case of wedge shaped films. Thus, we can proceed ahead with the same eqn for path difference

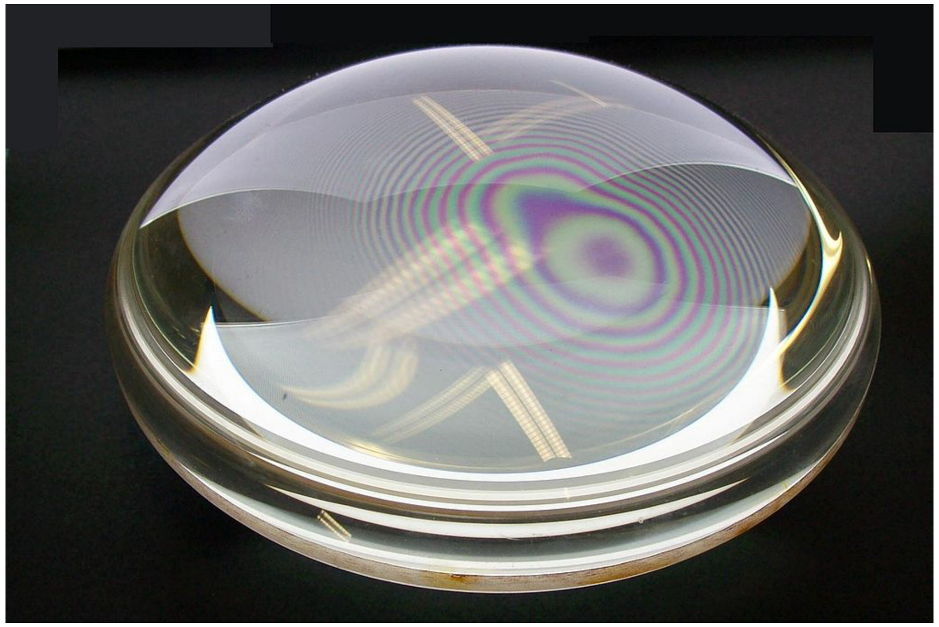


Experimental Arrangement for Newton's Rings



$$\boxed{P.D._{I,II} = 2\mu t\cos(r+\alpha) \pm \frac{\lambda}{2}}$$

Examples of Newton's Ring



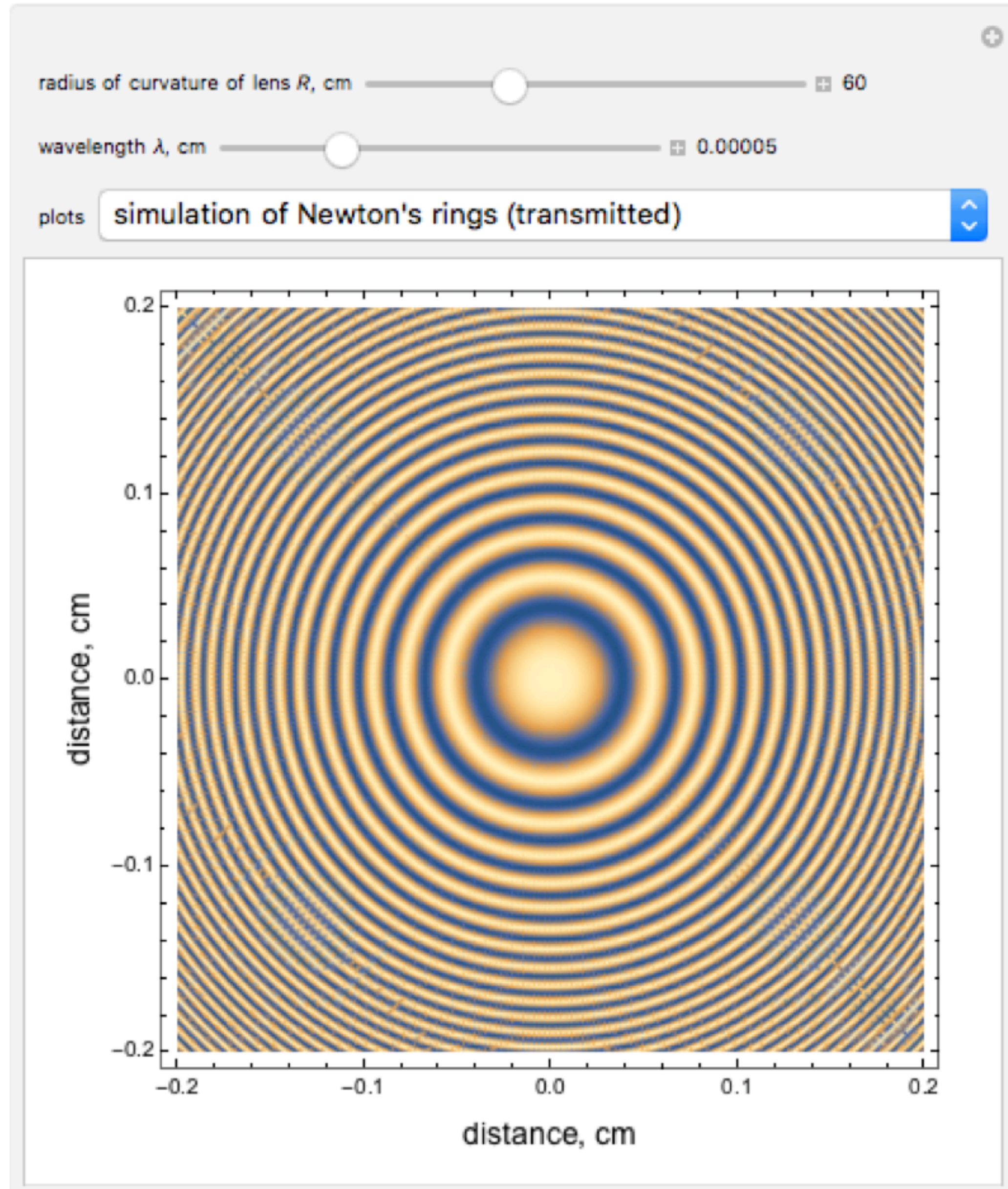
Newton's Ring

Diameter of n^{th} dark ring

$$\boxed{D_n^2 = \frac{4Rn\lambda}{\mu}}$$

$$\boxed{D_n = \sqrt{\frac{4Rn\lambda}{\mu}} = \sqrt{\frac{2R\lambda}{\mu}}\sqrt{2n}}$$

$$\Rightarrow D_n \propto \sqrt{2n}$$



Diameter of m^{th} bright ring

$$\boxed{D_m = \sqrt{\frac{2R\lambda}{\mu}}\sqrt{(2m \pm 1)}}$$

$$\Rightarrow D_m \propto \sqrt{(2m \pm 1)}$$

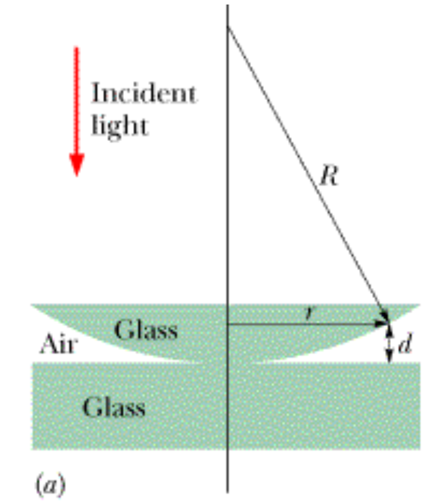
The diameters of Newton's rings are proportional to the square root of the natural numbers.

is case increases gradually, and thus the width of Newton's rings decreases with the sequence

Newton's Ring: Calculation of R and μ

- Consider the formula now for m[th] dark ring and n[th] dark ring,

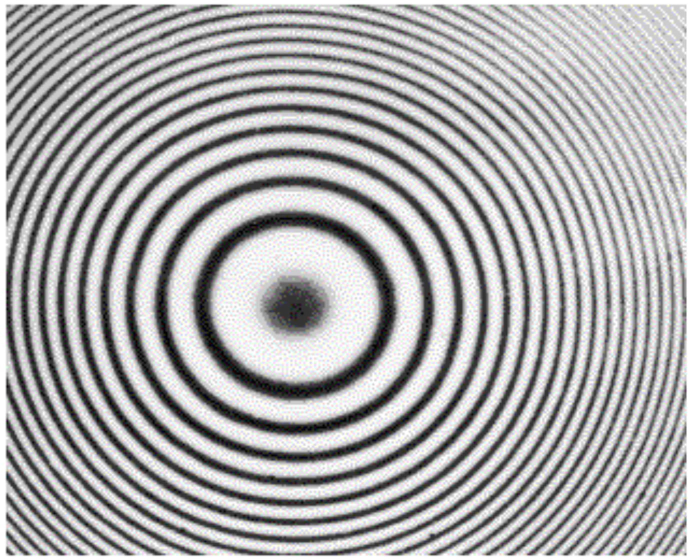
$$\boxed{D_m^2 = \frac{4Rm\lambda}{\mu}} \qquad \boxed{D_n^2 = \frac{4Rn\lambda}{\mu}}$$



(a)

- Taking difference and rearranging,

$$\boxed{R = \frac{\mu\left(D_m^2 - D_n^2\right)}{4(m-n)\lambda}}$$


(b)

$$D_n^{2'} = \frac{4Rn\lambda}{\mu} \text{ and } D_n^2 = 4Rn\lambda \rightarrow \boxed{\mu = \frac{D_n^2}{D_n^{2'}}}$$

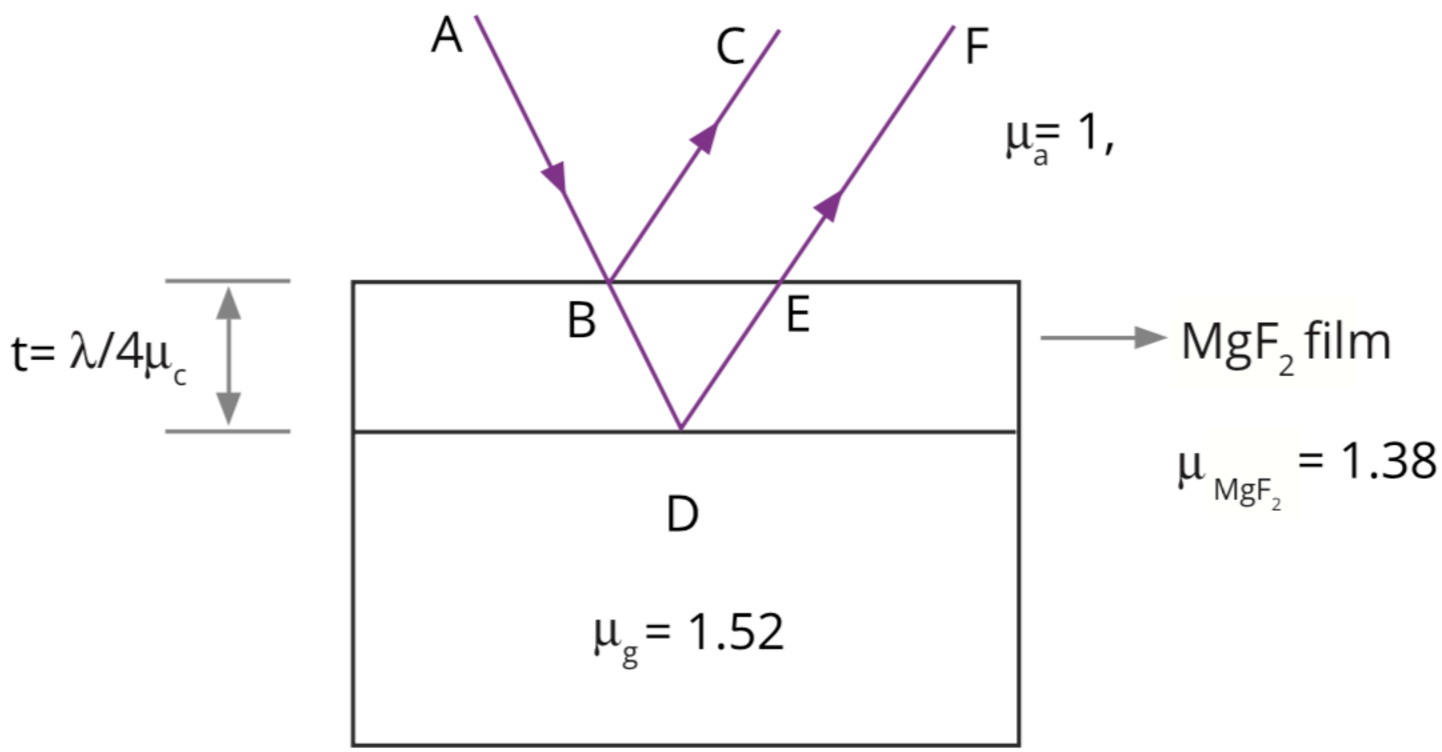
WEDGE OF REFRACTIVE INDEX μ

AIR WEDGE

Characteristics of Newton's rings

- Newton's rings on reflected side are complementary to those on transmitted side.
- If the glass plate in the Newton's ring set up is replaced by the Mirror, then Newton's rings fade out and a uniform illumination is observed.
- If the Newton's ring set up is illuminated by white light then a few coloured rings near the center are observed.
- When there is air gap at the center, the ring at the center may appear bright.If the lens is gradually lifted up, then the Newton's rings are shifted outwards
- If the monochromatic source in the setup is replaced by a source of higher wavelength, then the diameters of Newton's rings are increased.
- If the planoconvex lens in the setup is replaced by the planoconcave lens of higher radius of curvature then the diameters of the rings will increase
- If the lens or a glass slab used in the set up is imperfect then the Newton's rings are irregular.

Anti-Reflection Coating

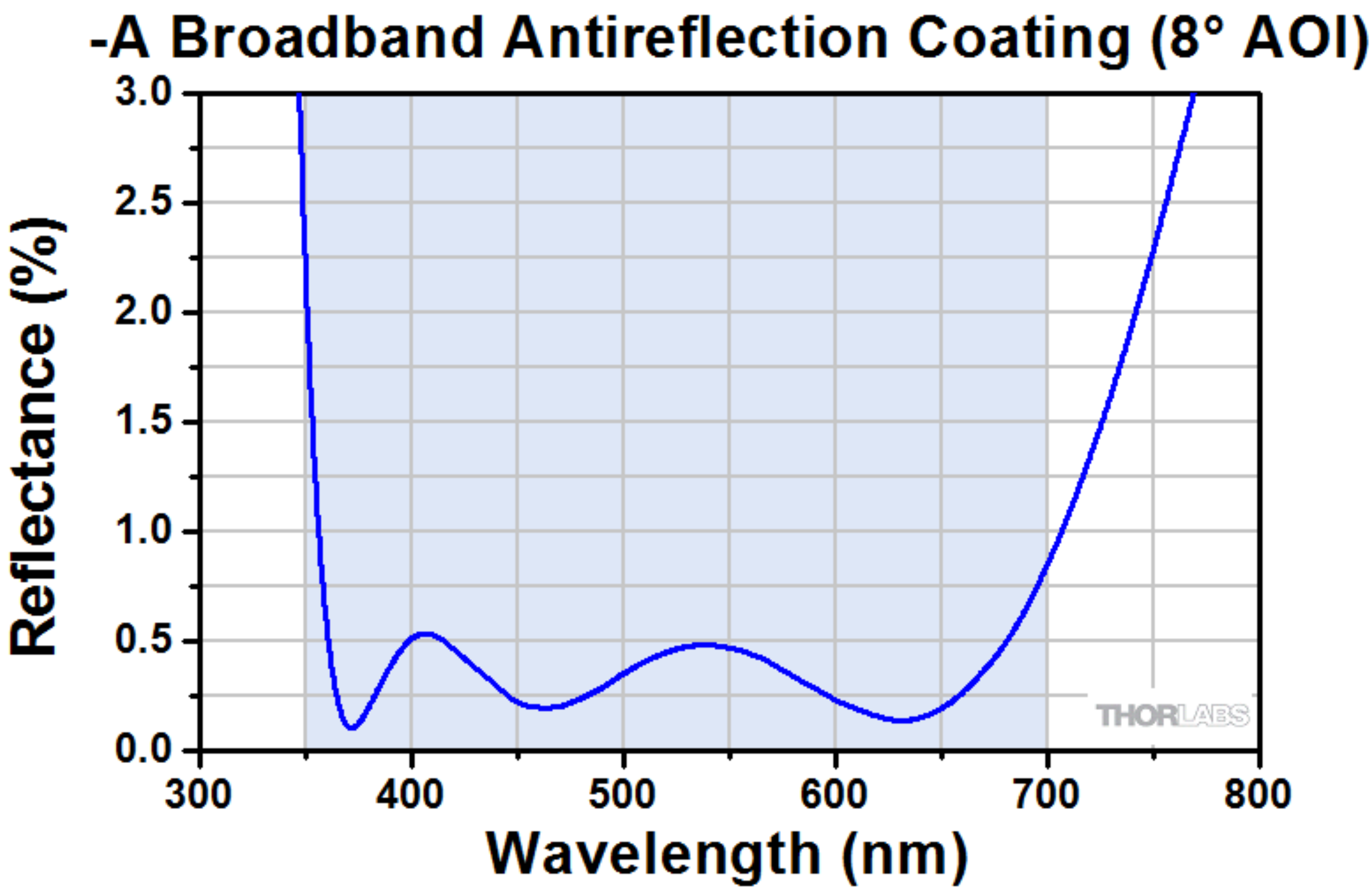


- When light falls on camera then some light gets reflected back it decreases the quality of image.
- Thus, it is necessary to reduce the reflection to improve quality of an image.
- The anti-reflection coating is used in cameras, projector lens, telescopes etc, to reduce loss of light by reflection.

$$\boxed{t_{ARC} = \frac{\lambda}{4\mu}}$$

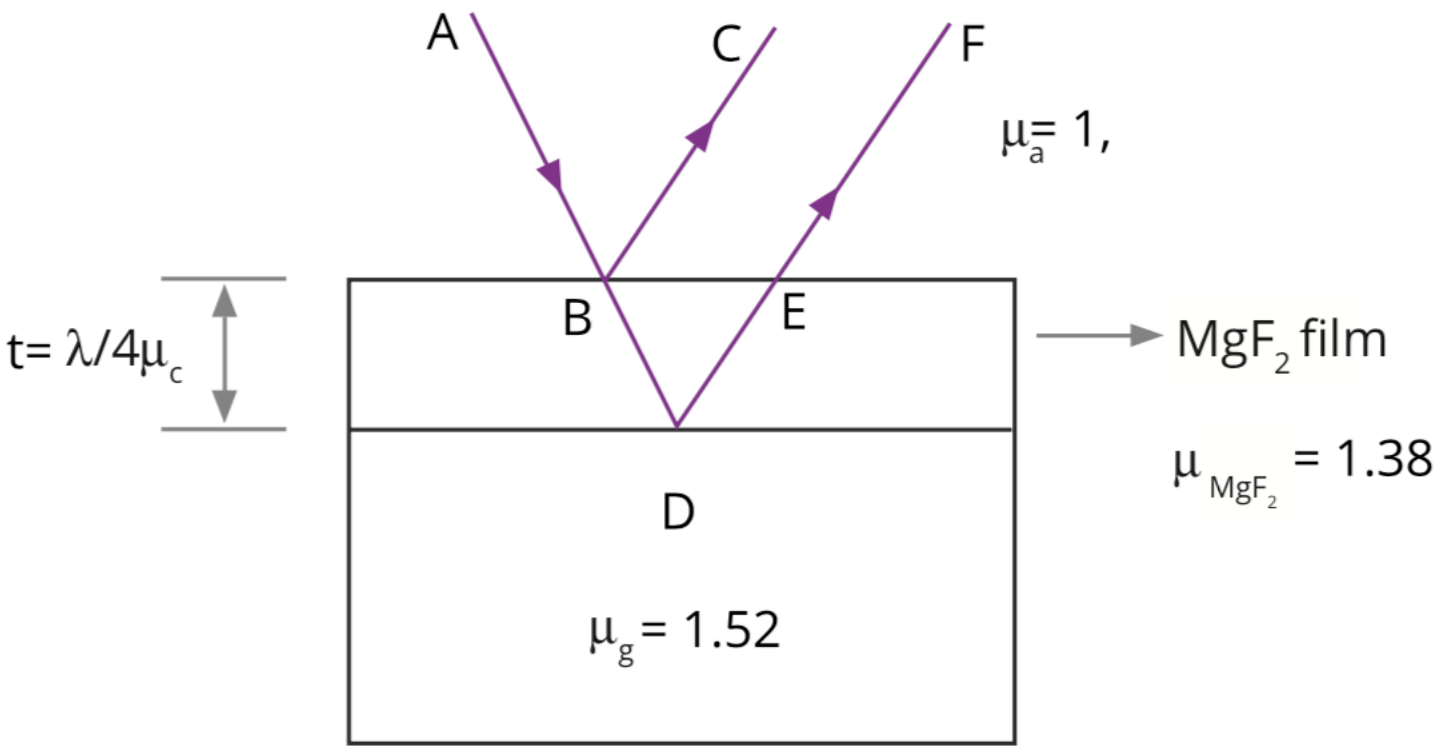
- Thus, the thickness of anti-reflecting coating can be determined by the above formula.

Anti-Reflection Coating



Anti-Reflection Coating

Anti-transmission/High-Reflection Coating



- Reflecting thin film coated on the substrate
- Thin film should be denser than substrate
- Constructive interference between the reflected rays will make the film more reflective
- Thickness of anti transmission coating

$$\boxed{t_{ATC/HRC} = \frac{\lambda}{4\mu}}$$

Reference Books

1. Fundamentals of Physics Extended, David Halliday, Robert Resnick, Jearl Walker,, John Wiley & Sons
2. The Feynman Lectures on Physics (3 Volume Set), by Richard Phillips Feynman (Author), Robert B. Leighton (Contributor), Matthew Sands (Contributor), The New Millennium Edition, Pearson Education India
   - Excellent websites on this book
     1. www.feynmanlectures.caltech.edu/
     2. www.feynmanlectures.info/
3. A Textbook of Engineering Physics, M N Avadhanulu & P G Kshirsagar, 1oth Edition, S. Chand and Company
4. Fundamentals of Optics, by Francis Jenkins, Harvey White , Tata Mcgraw Hill Publishing Co Ltd
5. Optics, Ajoy K. Ghatak, 5th Edition, McGraw Hill Education,
6. Optics, Eugene Hecht, 4th edition, Addison-Wesley
7. M. Born and E. Wolf, Principles of Optics, Cambridge University Press
8. A Text Book Of Optics, Brijlal, Dr. N. Subrahmanyam, Dr. M. N. Avadhanalu, 25th Edition, S. Chand and Company

Thank You