Interference

Book reference: Ajoy Ghatak (optics)

Gaur and Gupta: (Engineering Physics)

NK Verma: Enginnering Physics

Topics to be covered:

1. Interference due to thin parallel films
2. Interference due to thin wedge shaped films
3. Newton’s ring
4. Application of newton’s ring
5. Non reflecting films

SYLLABUS

UPH004: APPLIED PHYSICS

L	T	P	CREDIT
3	1	2	4.5

Prerequisite(s): None

Course Objectives:

To introduce the student to the basic physical laws of oscillators, acoustics of buildings, ultrasonics, electromagnetic waves, wave optics, lasers, and quantum mechanics and demonstrate their applications in technology. To introduce the student to measurement principles and their application to investigate physical phenomena

Oscillations and Waves: Oscillatory motion and damping, Applications - Electromagnetic damping – eddy current; ***Acoustics:*** Reverberation time, absorption coefficient, Sabine's and Eyring's formulae (Qualitative idea), Applications - Designing of hall for speech, concert, and opera; ***Ultrasonics:*** Production and Detection of Ultrasonic waves, Applications - green energy, sound signaling, dispersion of fog, remote sensing, Car's airbag sensor.

Electromagnetic Waves: Scalar and vector fields; Gradient, divergence, and curl; Stokes' and Green's theorems; Concept of Displacement current; Maxwell's equations; Electromagnetic wave equations in free space and conducting media, Application - skin depth.

Optics: ***Interference:*** Parallel and wedge-shape thin films, Newton rings, Applications as Non-reflecting coatings, Measurement of wavelength and refractive index. ***Diffraction:***Single and Double slit diffraction, and Diffraction grating, Applications - Dispersive and Resolving


THIN FILM
INTERFERENCE

Introduction:

Superposition principle

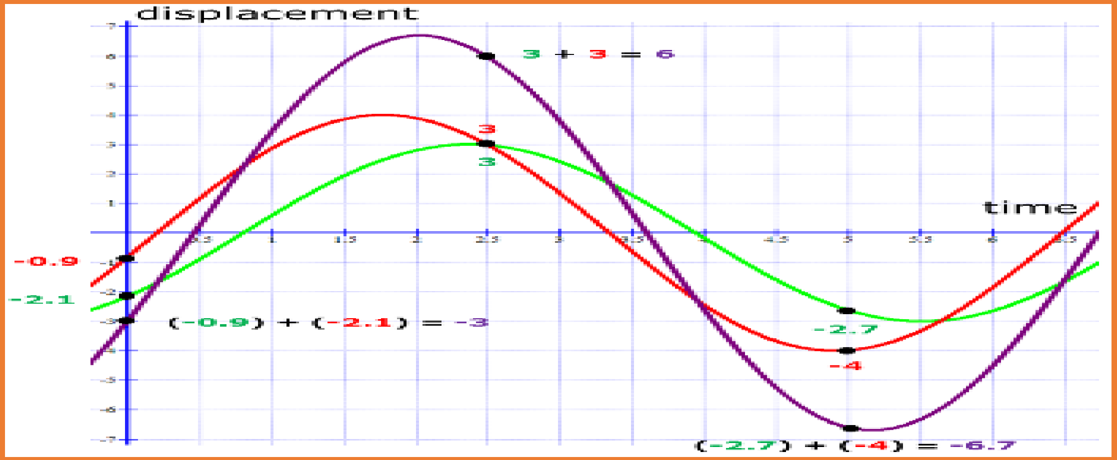
The Principle of Superposition When two or more waves are simultaneously present at a single point in space, the displacement of the medium at that point is he sum of the displacements due to each individual wave.

At any instant of time the resultant amplitude will be the algebraic sum of all individual waves at that instant

R=a1 ± a2 ± a3 ± a4……….

Intensity at any point of time is (when only two waves with a1 and a2 amplitude then the I will be

$$R^2 = a_1^2 + a_1^2 + 2a_1a_2\cos\delta$$



Constructive and destructive interference

δ = 2n π   (max)

or path difference is n λ

δ= (2n+1) π   (min)

or when path difference is (2n+1) λ/2

Conditions for interference

1. condition for sustained interference

2. condition for observation

3. condition for good contrast

1. Sorces shd be coherent
2. Sources emit same wavelength

1. Seperation between 2 sources shd be small
2. Distance between the source and screen shd be large
3. 3. bg shd be dark

1.Sources must be narrow and monochromatic

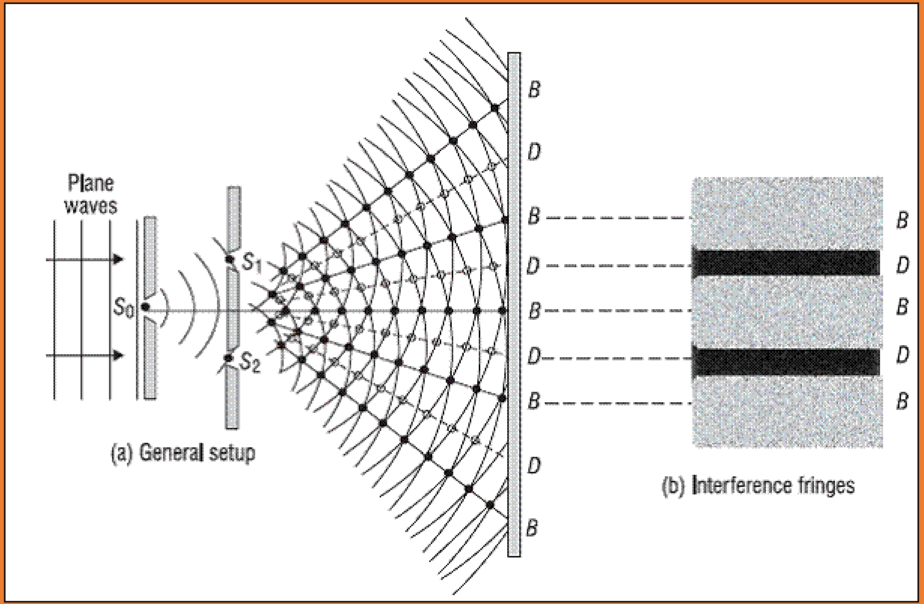
Two types of interference:

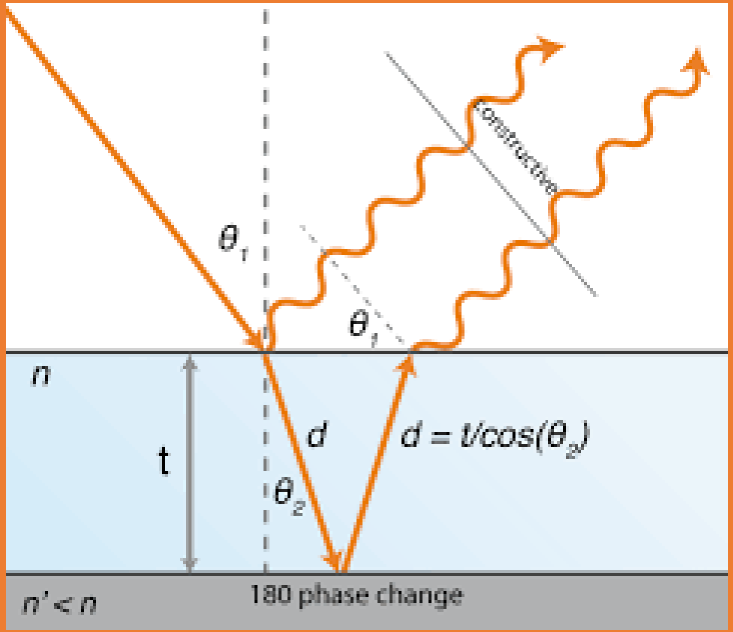
Division of wavefront

(Ex. Young double slit, Fresnel biprism)

Division of Amplitude

Thin parallel films, Newton's ring, MI etc

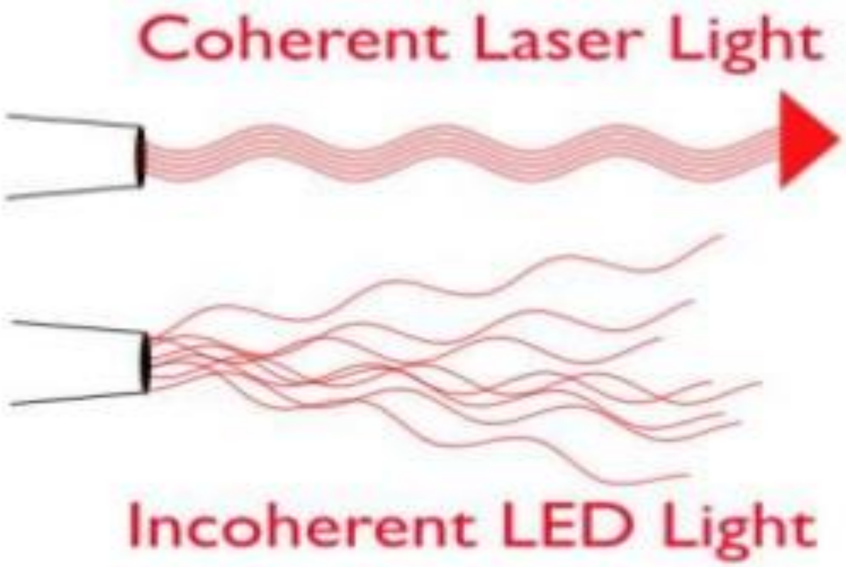


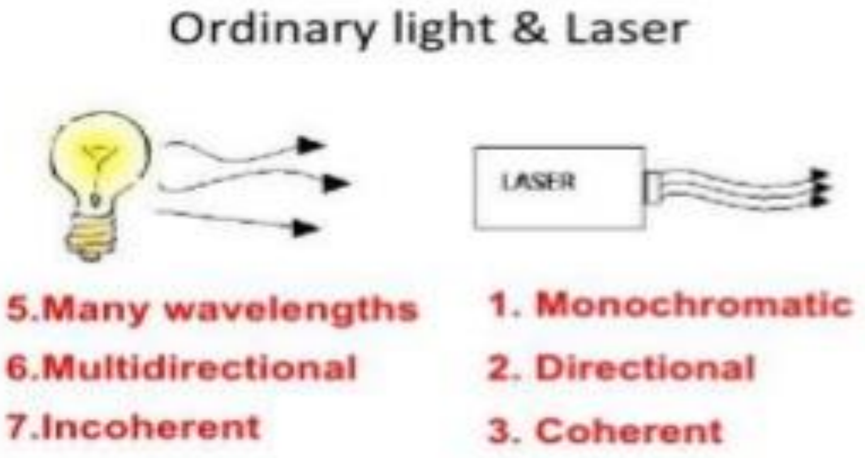


COHERENCE

Two wave sources are perfectly coherent if they have a constant phase difference and the same frequency. Coherence is an ideal property of waves that enables interference.

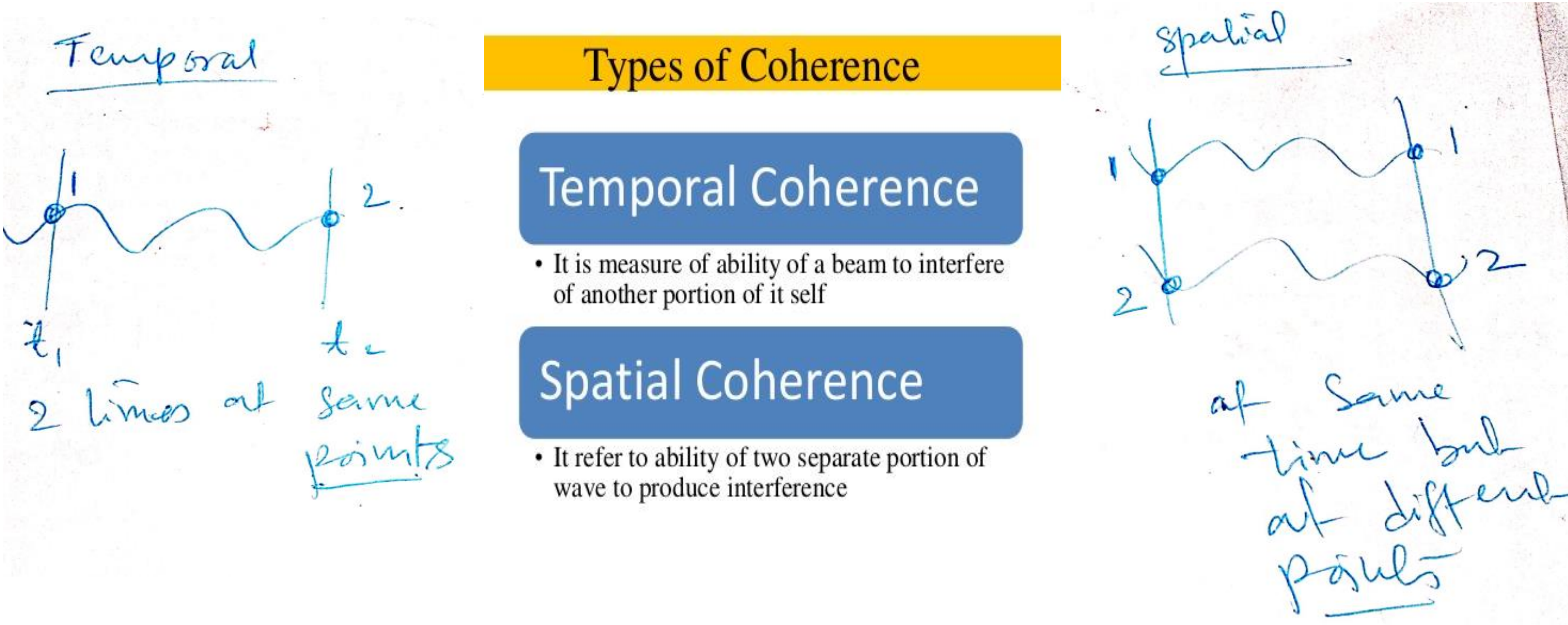
Coherent sources are those which emits light waves of same wave length or frequency and have a constant phase difference.





Temporal coherence tells us how monochromatic a source is. In other words, it characterizes how well a wave can interfere with itself at a different time. It leads to monochromaticity.

Spatial coherence is when waves at different points in space preserve a constant phase difference over a time t. It leads to directionality.



Spatial and Temporal Coherence

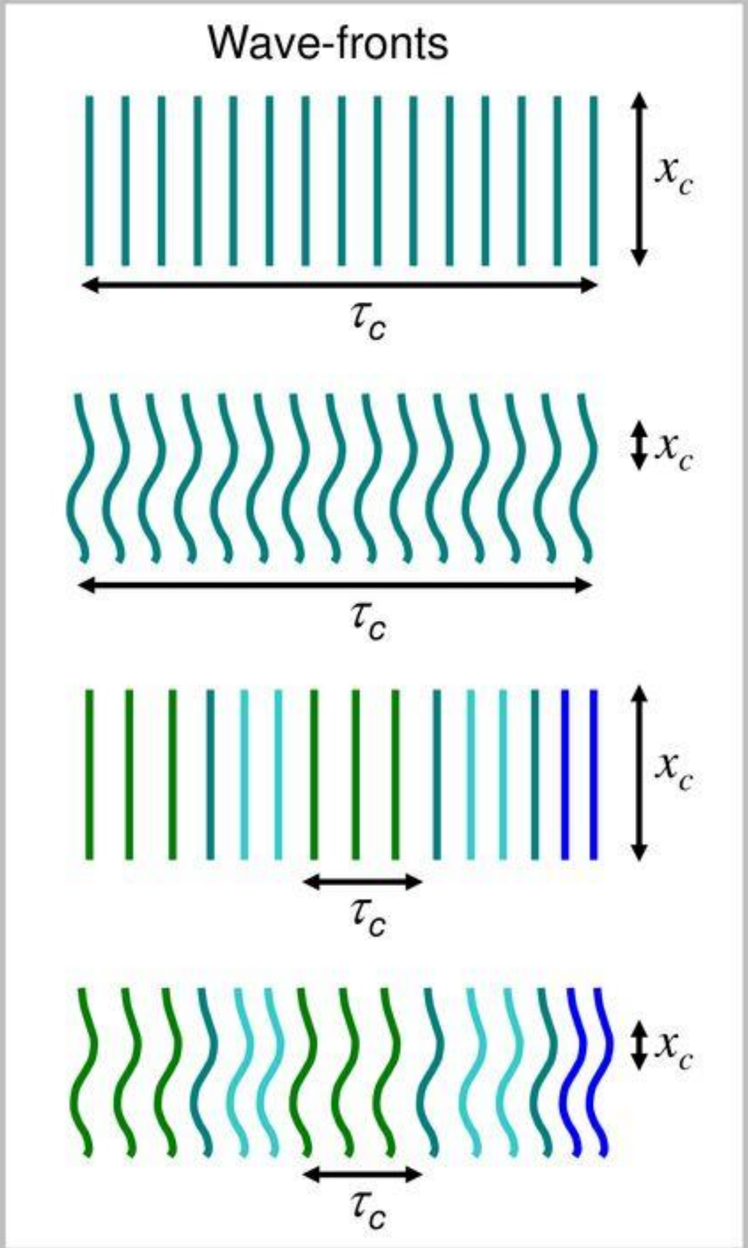
Beams can be coherent or only partially coherent (indeed, even incoherent) in both space and time.

Spatial and Temporal Coherence:

Temporal Coherence; Spatial **In**coherence

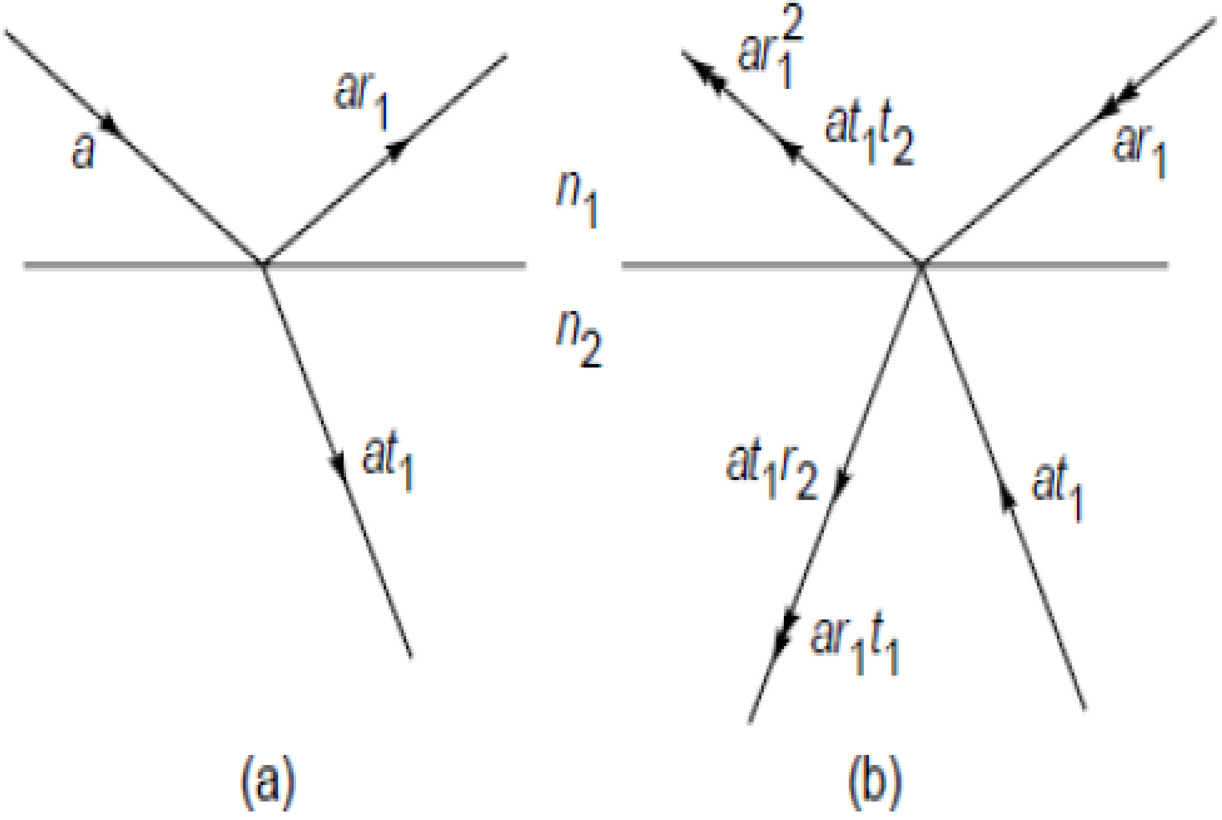
Spatial Coherence; Temporal **In**coherence

Spatial **and** Temporal **In**coherence



Stokes law: Phase change on reflection

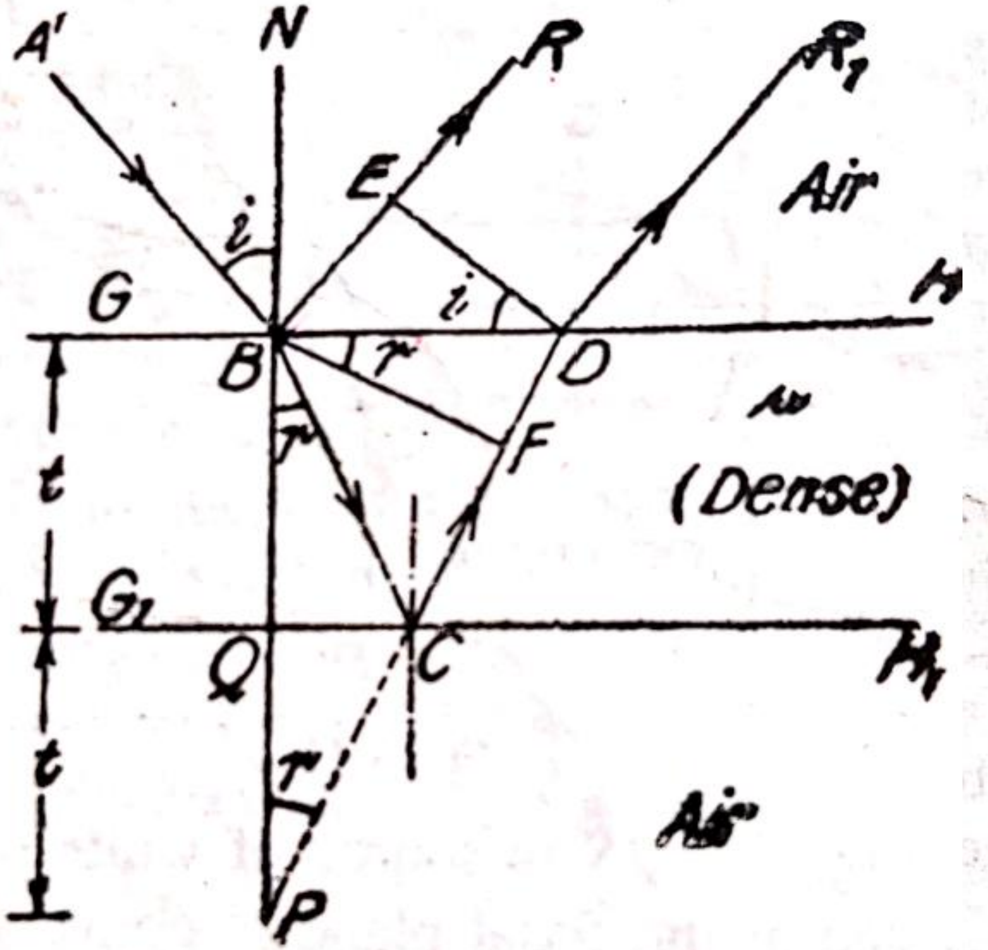
- It says that when a light wave is reflected at the surface of an optically denser medium, it suffers a path change of $\lambda/2$ or phase change of π, but not when when reflected at the surface of a rarer medium. This can be explained on the theoretically on the basis of the principle of reversibility of light.



According to the principle of optical reversibility, the two rays of amplitudes ar_1^2 and at_1t_2 must combine to give the incident ray.

$ar_1^2 + at_1t_2 = a$ Or $t_1t_2 = 1 - r_1^2$

$ar_1t_1 + at_1r_2 = 0$ Or $r_1 = -r_2$



$$\Delta = \text{Path } (BC + CD) \text{ in film—Path } BE \text{ in air}$$
$$= \mu\,(BC + CD) - BE \qquad \ldots(1)$$

We know that

$$\mu = \frac{\sin i}{\sin r} = \frac{BE/BD}{FD/BD} = \frac{BE}{FD}$$

$$\therefore\ BE = \mu\,(FD) \qquad \ldots(2)$$

From equations (1) and (2)

$$\Delta = \mu\,(BC + CD) - \mu\,(FD)$$
$$= \mu\,(BC + CF + FD) - \mu\,(FD)$$
$$= \mu\,(BC + CF)$$
$$= \mu\,(PF) \qquad (\because\ BC = PC) \qquad \ldots(3)$$

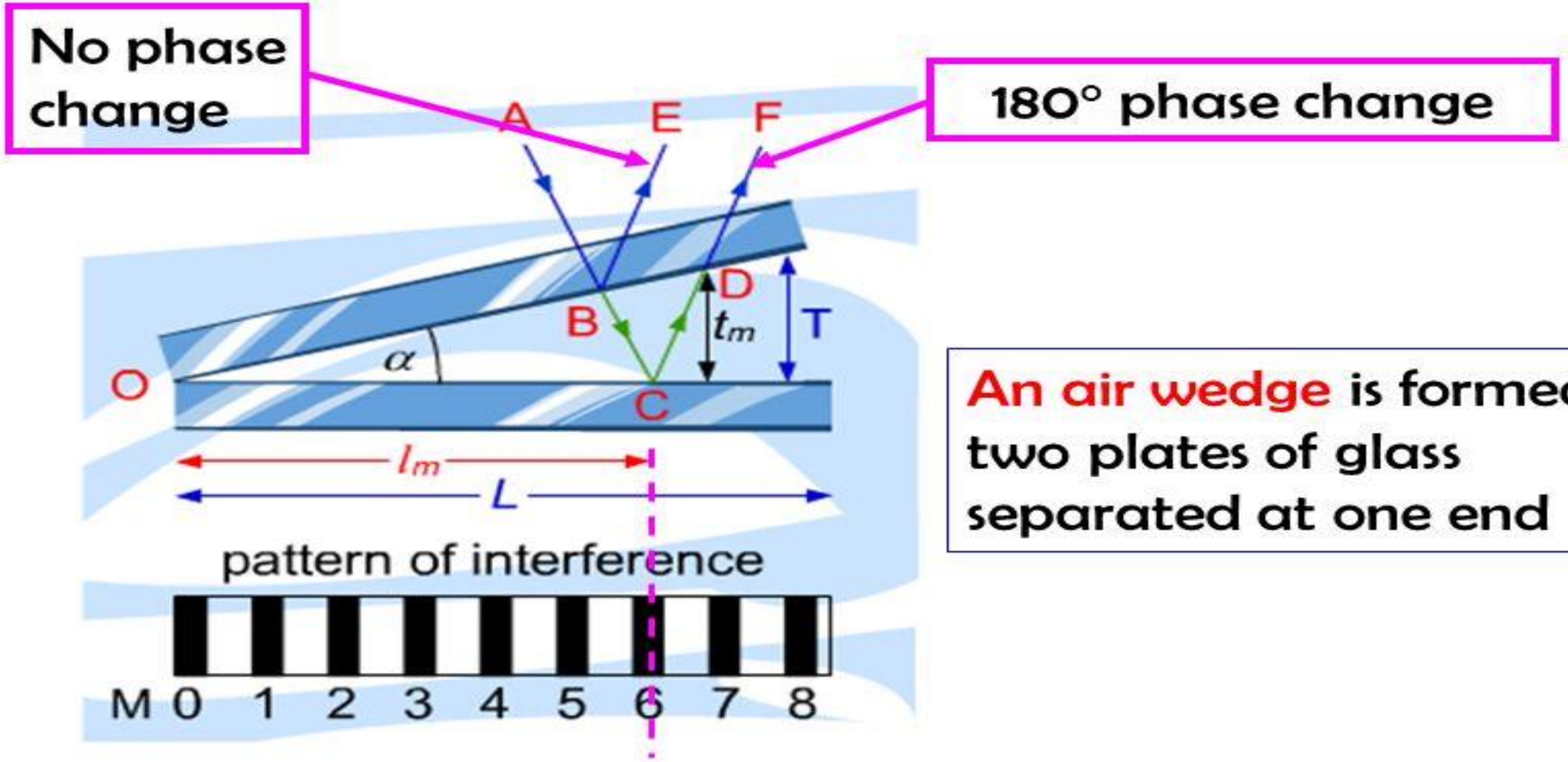
From triangle BPF, $\cos r = PF/BP$

or $\quad PF = BP\cos r = 2t\ \cos r \qquad \ldots(4)$

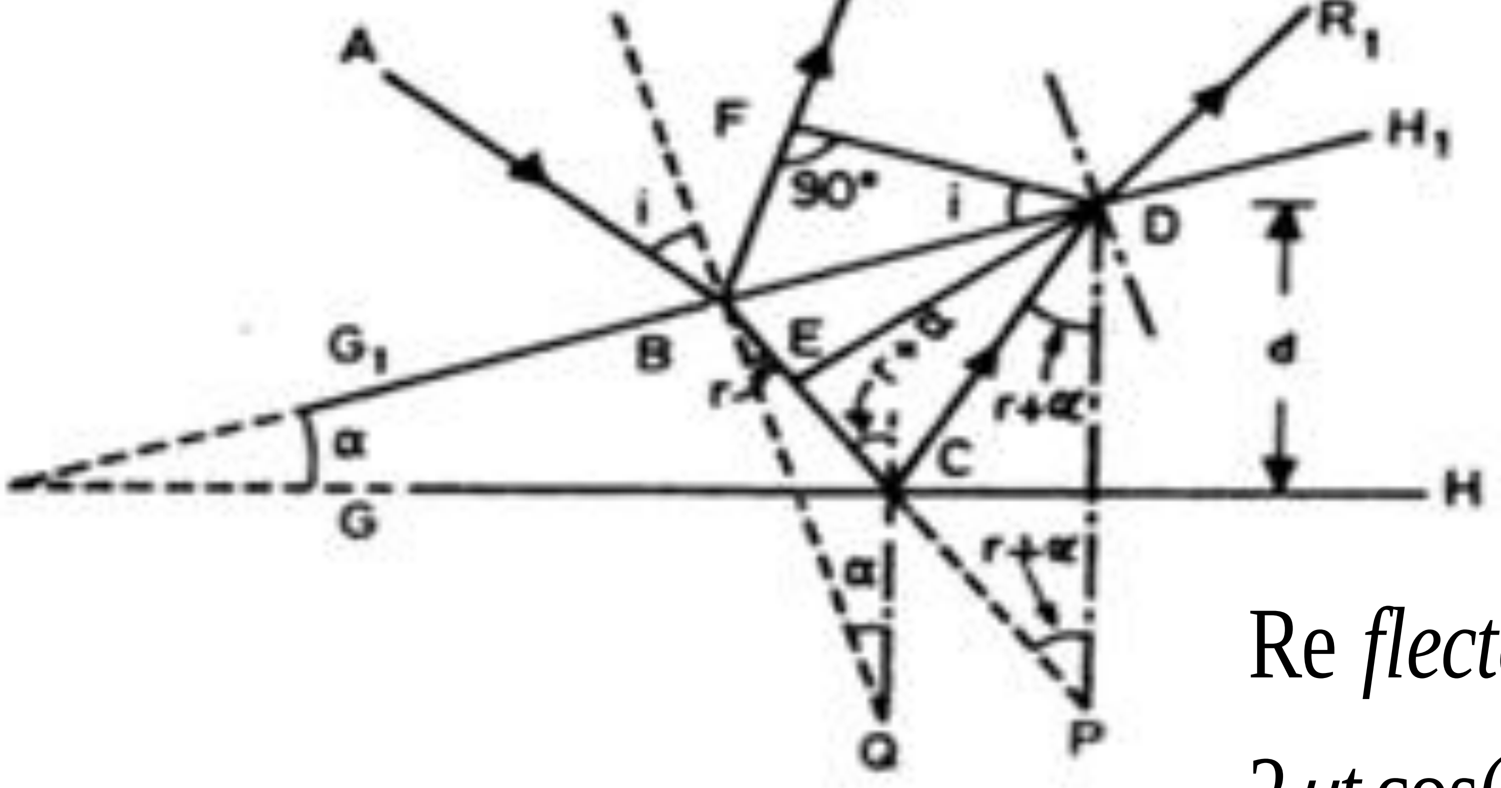
Substituting the value of PF from equation (4) in equation (3), we have

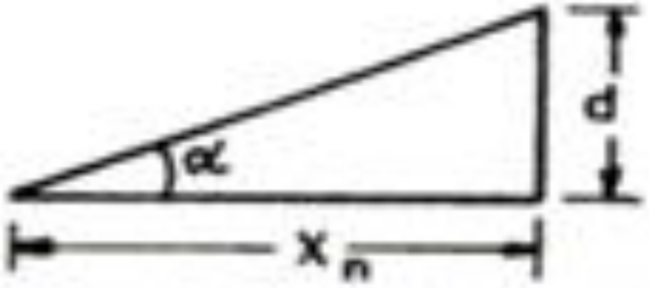
$$\Delta = \mu \times 2t\cos r = 2\,\mu t\cos r \qquad \ldots(5)$$

Interference at a Wedge-Shaped Film



An air wedge is formed by two plates of glass separated at one end



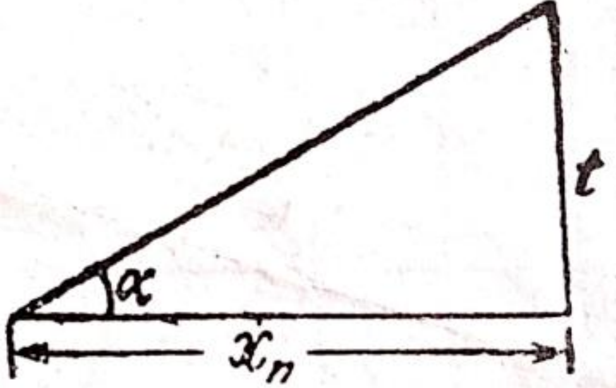


Interference in a wedge shaped film

Reflected case

$$2\mu t\cos(r+\alpha) = n\lambda(\text{min}\,ima)$$

$$2\mu t\cos(r+\alpha) = (2n\pm 1)\lambda/2(\text{max}\,ima)$$



Spacing between two consecutive bright bands. For n^{th} maxima, we have

$$2\mu t \cos(r+\alpha) = (2n+1)\lambda/2$$

For normal incidence and air film

$$r = 0 \text{ and } \mu = 1$$

$$\therefore \quad 2t \cos\alpha = (2n+1)\lambda/2 \qquad \ldots(1)$$

Let this band be obtained at a distance x_n from the thin edge as shown in Fig. 9·15.

From the figure $t = x_n \tan\alpha$ $\qquad \ldots(2)$

From equations (1) and (2),

$$2x_n \tan\alpha \cos\alpha = (2n+1)\lambda/2$$

or

$$2x_n \sin\alpha = (2n+1)\lambda/2 \qquad \ldots(3)$$

If the $(n+1)^{th}$ maximum is obtained at a distance x_{n+1} from the thin edge, then

$$2x_{n+1} \sin\alpha = [2(n+1)+1]\lambda/2$$
$$= (2n+3)\lambda/2 \qquad \ldots(4)$$

$$2(x_{n+1} - x_n)\sin\alpha = \lambda$$

$$\text{spacing } \beta = x_{n+1} - x_n$$

$$= \frac{\lambda}{2\sin\alpha} = \frac{\lambda}{2\alpha}$$

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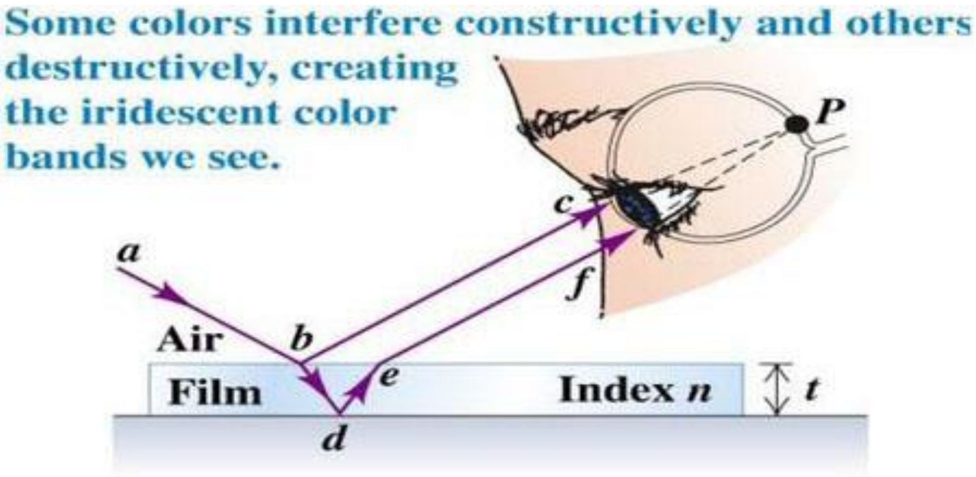
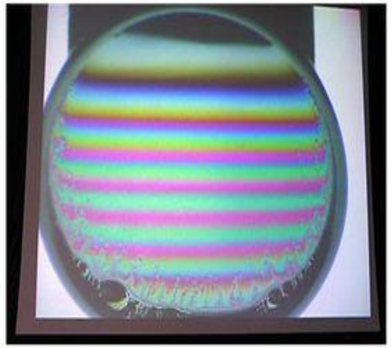
Interference in thin films due to reflection (Division of Amplitude)

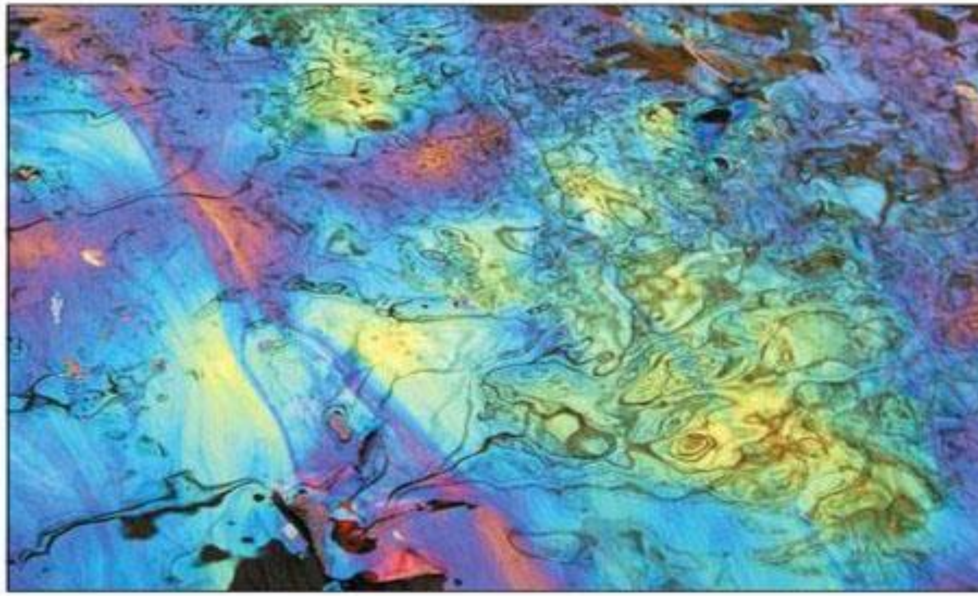


(a) Interference between rays reflected from the two surfaces of a thin film

Colors of oil film on water

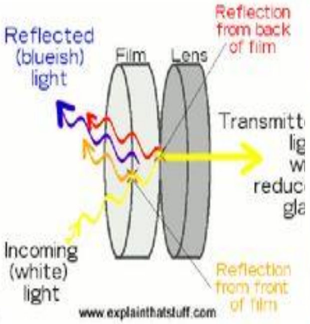


Colors of soap bubble

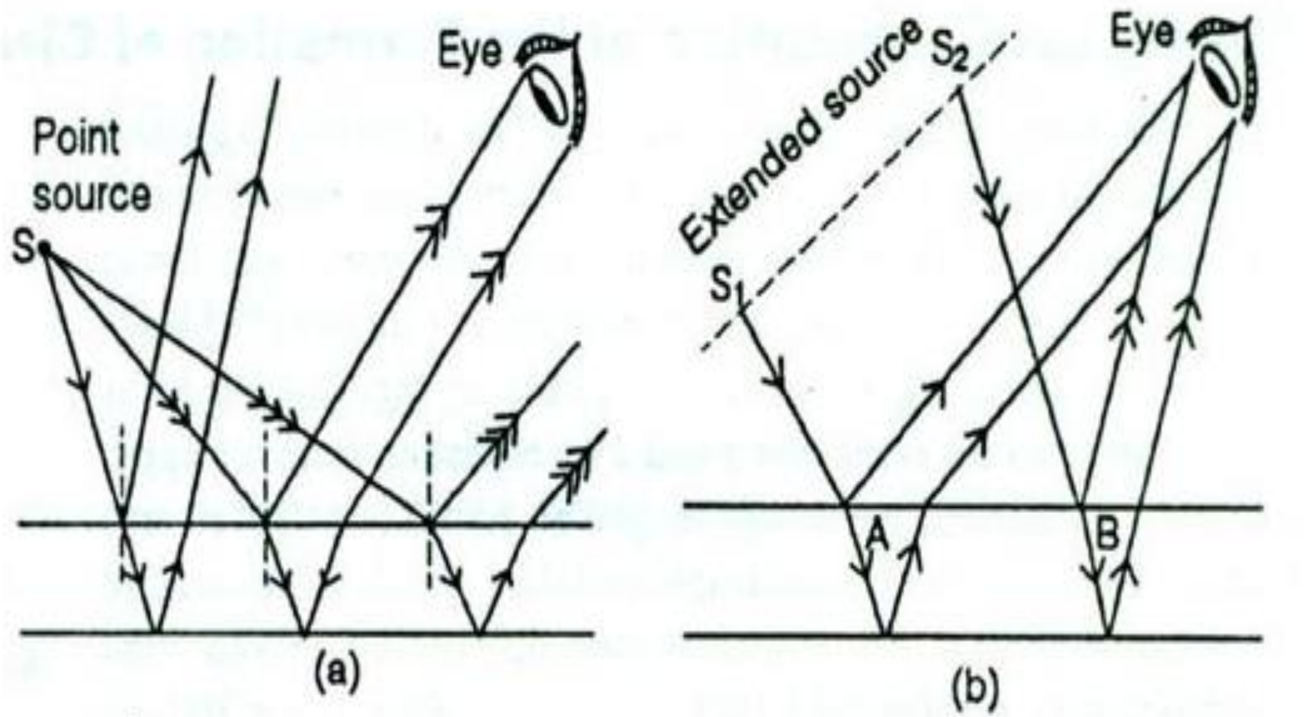


(b) The rainbow fringes of an oil slick on water

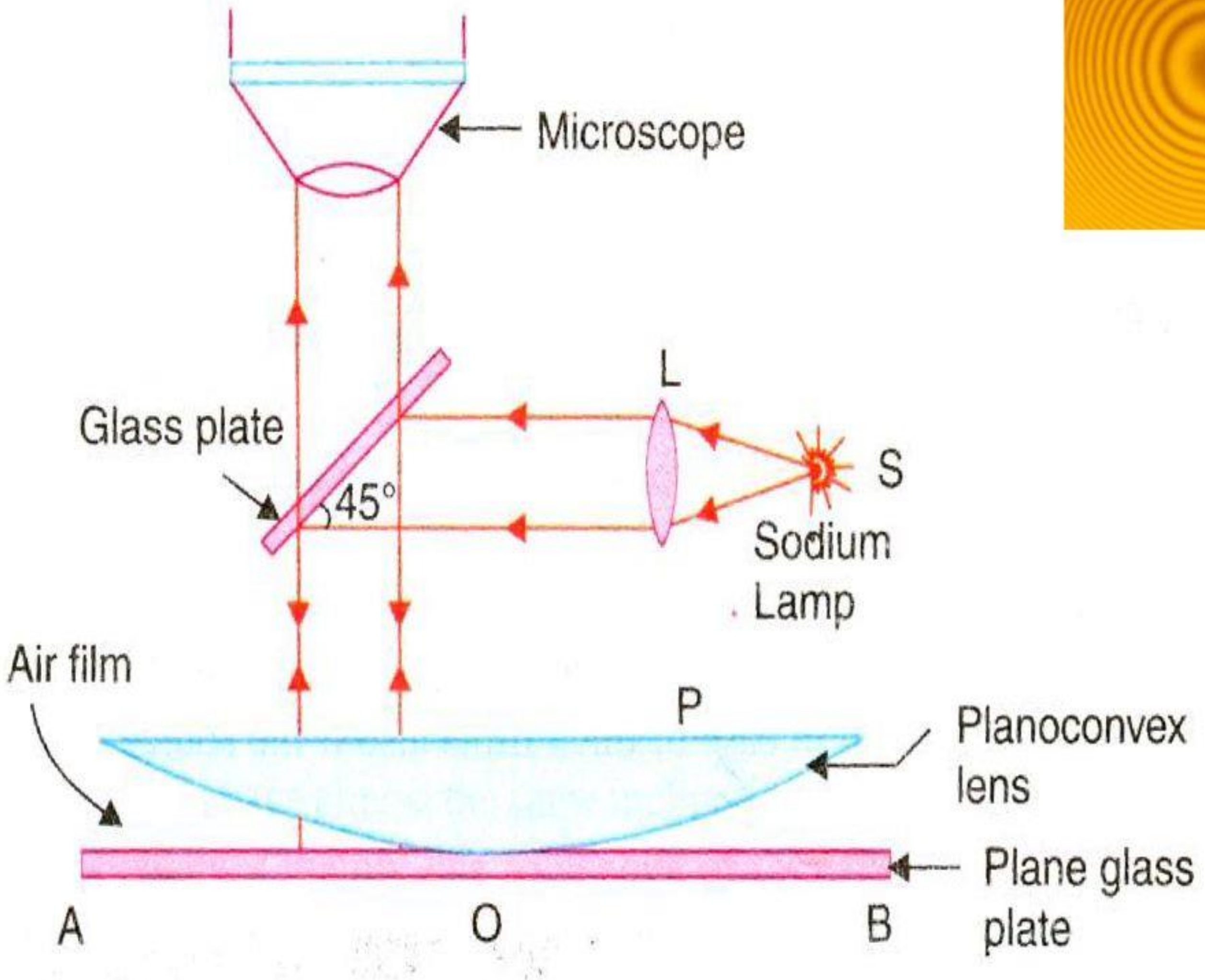
Antireflection thin films

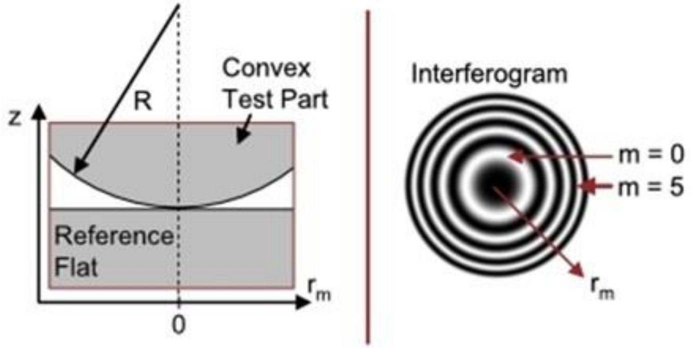


Need of an extended source for viewing the fringes from the same inclination



Newton’ s Ring Interferometer: construction and working with principle





$$R = \frac{r_m^2}{\lambda\left(m + \frac{1}{2}\right)}$$

$$\mathrm{Re}\ flected\ case$$

$$2\mu t\cos(r+\alpha) = n\lambda(\min ima)$$

$$2\mu t\cos(r+\alpha) = (2n\pm1)\lambda/2(\max ima$$

$$if\ \ \alpha = 0(R\ is\ La\,\mathrm{rg}\,e)\ and\ \ \mu = 1(air)$$

$$and\ normal\ incidence\ r = 0$$

$$2t = n\lambda(\min ima)$$

$$2t = (2n\pm1)\lambda/2(\max ima)$$

Theory : (1) Newton's rings by reflected light. Now we shall calculate the diameters of dark and bright rings. Let LOL' be the lens placed on a glass plate AB. The curved surface LOL' is the part of spherical surface (shown dotted in Fig. 9·20) with

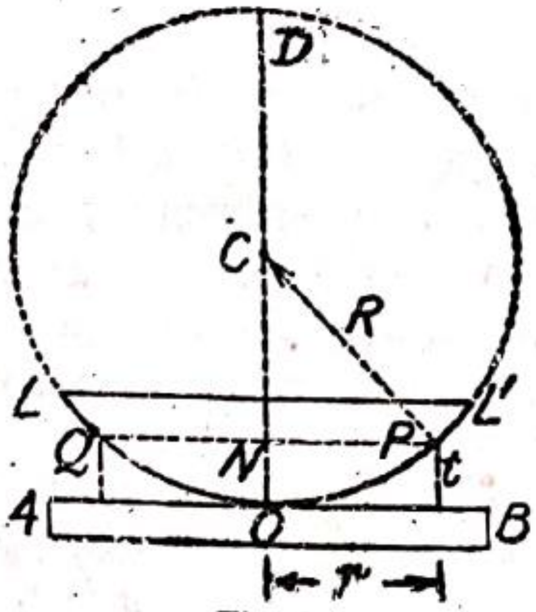


Fig. 9·20.

centre at C. Let R be the radius of curvature and r b the radius of Newton's ring-corresponding to the con stant film thickness t. As discussed above,

$$2t + \lambda/2 = n\lambda$$

or $$2t = (2n-1)\,\lambda/2 \text{ for the bright ring}$$

where $$n = 1, 2, 3, \ldots\ldots \text{etc.}$$

and $$2t = n\lambda \text{ for dark ring}$$ 2t + λ/2

where $n = 0, 1, 2, 3$

From the property of the circle 2t = nλ

$$NP \times NQ = NO \times ND$$

Substituting the values

$$r \times r = t \times (2R - t) = 2Rt - t^2 \approx 2Rt$$

(approximately)

$$\therefore \quad r^2 = 2Rt \quad \text{or} \quad t = r^2/2R.$$

Thus for a bright ring

$$2\,\frac{r^2}{2R} = (2n-1)\,\frac{\lambda}{2}$$

or $$r^2 = \frac{(2n-1)\,\lambda R}{2}$$

Replacing r by $D/2$, we get the diameter of n^{th} bright ring as

$$\frac{D^2}{4} = \frac{(2n-1)\,\lambda R}{2}$$

or $$D = \sqrt{(2\lambda R)}\,\sqrt{(2n-1)}$$

or $$D \propto \sqrt{(2n-1)}$$

Thus the diameters of the bright rings are proportional to the square roots of odd natural numbers as $(2n-1)$ is an odd number.

Similarly for a dark ring

$$2\,\frac{r^2}{2R} = n\,\lambda$$

or $$r^2 = n\,\lambda R$$

or $$D^2 = 4n\,\lambda R$$

or $$D = 2\sqrt{n\,\lambda\,R} \propto \sqrt{n}$$

Thus diameters of dark rings are proportional to the square roots of natural numbers.

Prove that the fringe width decreases with the order of the fringe and fringes get closer with the increase in

It can be shown that fringe width decreases with the order of the fringe and fringes get closer with increase in their order.

The diameters of 16th and 9th dark rings are given as

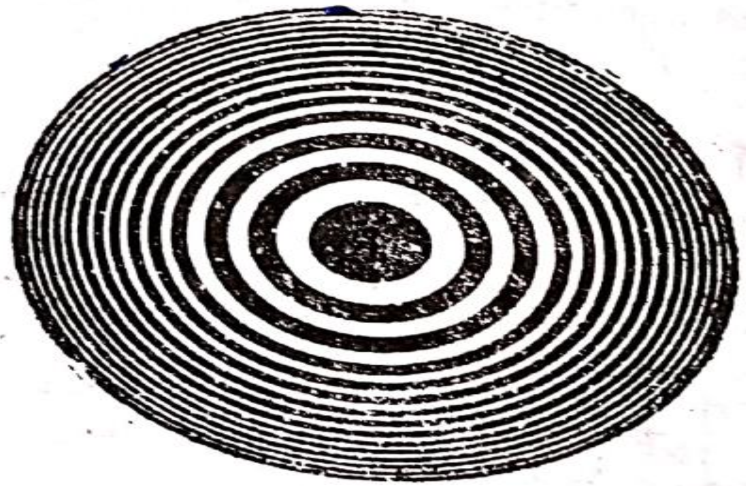
$$D_{16} = 2\sqrt{16\lambda R} = 8\sqrt{\lambda R}$$

$$D_9 = 2\sqrt{9\lambda R} = 6\sqrt{\lambda R}$$

$$\therefore \quad D_{16} - D_9 = 8\sqrt{\lambda R} - 6\sqrt{\lambda R} = 2\sqrt{\lambda R}$$

Similarly $D_4 - D_1 = 4\sqrt{\lambda R} = 2\sqrt{\lambda R}$

This is shown in Fig. 9·21.



Newton's ring by transmitted light

(*ii*) **Newton's rings by transmitted light.** In case of transmitted light

$$2t = n\lambda \text{ for bright rings}$$

and

$$2t = (2n - 1)\,\lambda/2 \text{ for dark rings.}$$

For bright rings

$$\therefore\ 2 \times \frac{r^2}{2R} = n\lambda \quad \text{or} \quad r^2 = n\lambda R$$

or

$$D = 2\sqrt{n\lambda R} \propto \sqrt{n}$$

For dark rings

$$\therefore\ 2 \times \frac{r^2}{2R} = (2n-1)\frac{\lambda}{2} \quad \text{or} \quad r^2 = \frac{(2n-1)\lambda R}{2}$$

$$\therefore\ D = \sqrt{2\lambda R} \times \sqrt{(2n-1)} \propto \sqrt{(2n-1)}$$

Thus in case of transmitted light, the central ring
right (Fig. 9·22). The rings are just opposite to the
;s in reflected light.

Newton's Ring Applications

1. Calculation of wavelength
2. Calculation of refractive index

18. DETERMINATION OF WAVE-LENGTH OF SODIUM LIGHT USING NEWTON'S RINGS

Experimental arrangement. The experimental ngement is shown in Fig. 9·18. [see article 9·17, perimental arrangement].

Theory. Let R be the radius of curvature of the face in contact with the plate, λ the wavelength of ht used and D_n and D_{n+p} the diameters of n^{th} and $+ p)^{th}$ dark rings respectively, then

$$D_n^2 = 4n\lambda R$$

$$D_{n+p}^2 = 4(n+p)R\lambda$$

$$\therefore \quad D_{n+p}^2 - D_n^2 = 4pR\lambda$$

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR} \qquad \ldots(1)$$

Using this formula λ can be determined.

refractive index

$$D_n^2 = 4n\lambda R \quad \text{and} \quad D_{n+p}^2 = 4(n+p)\lambda R$$

$$\therefore \quad D_{n+p}^2 - D_n^2 = 4p\lambda R \qquad \ldots(1)$$

Now the liquid whose refractive index is to be termined is poured in the container without disturb- g the whole arrangement. Again the diameters of n^{th} ng and $(n+p)^{th}$ ring are determined. So, when there a liquid film between glass plate and plano-convex ns, we have

$$D'^2_n = \frac{4n\lambda R}{\mu} \quad \text{and} \quad D'^2_{n+p} = \frac{4(n+p)\lambda R}{\mu}$$

$$\therefore \quad D'^2_{n+p} - D'^2_n = \frac{4p\lambda R}{\mu} \qquad \ldots(2)$$

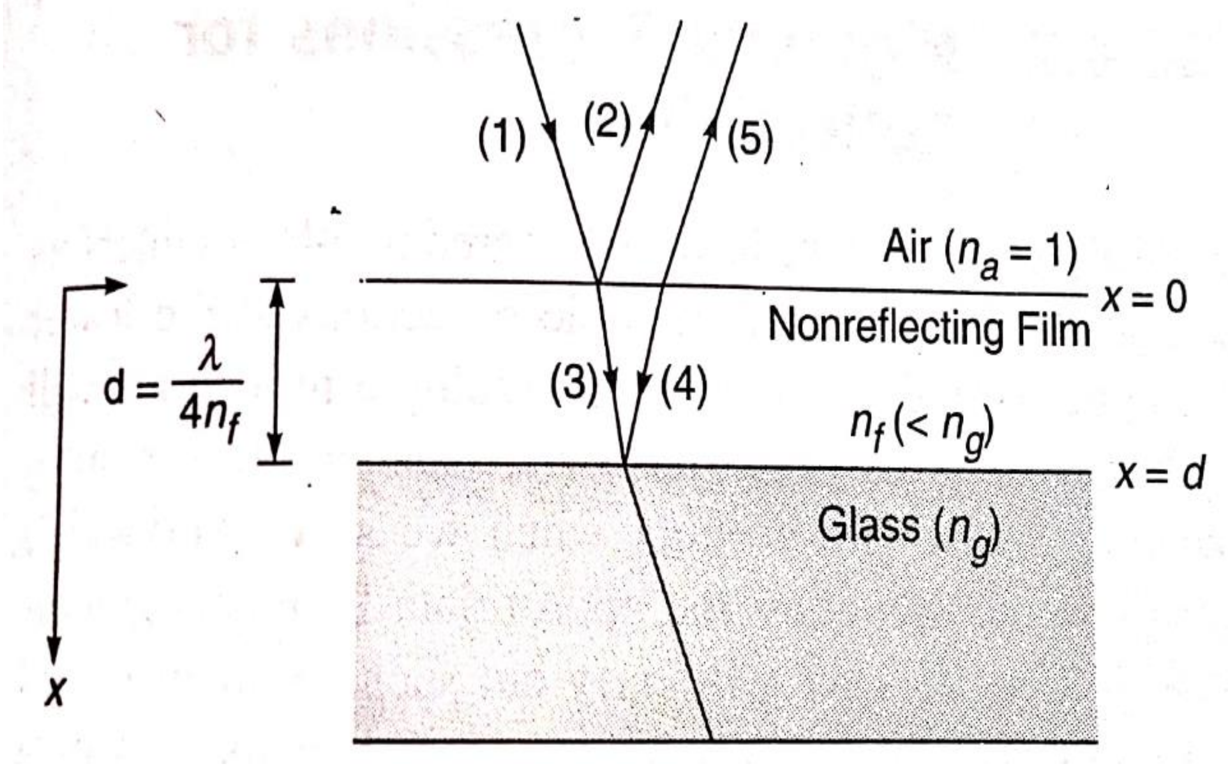
From equations (1) and (2)

$$\mu = \frac{D_{n+p}^2 - D_n^2}{D'^2_{n+p} - D'^2_n} \qquad \ldots(3)$$

Using this formula μ can be calculated.

Non Reflecting Films

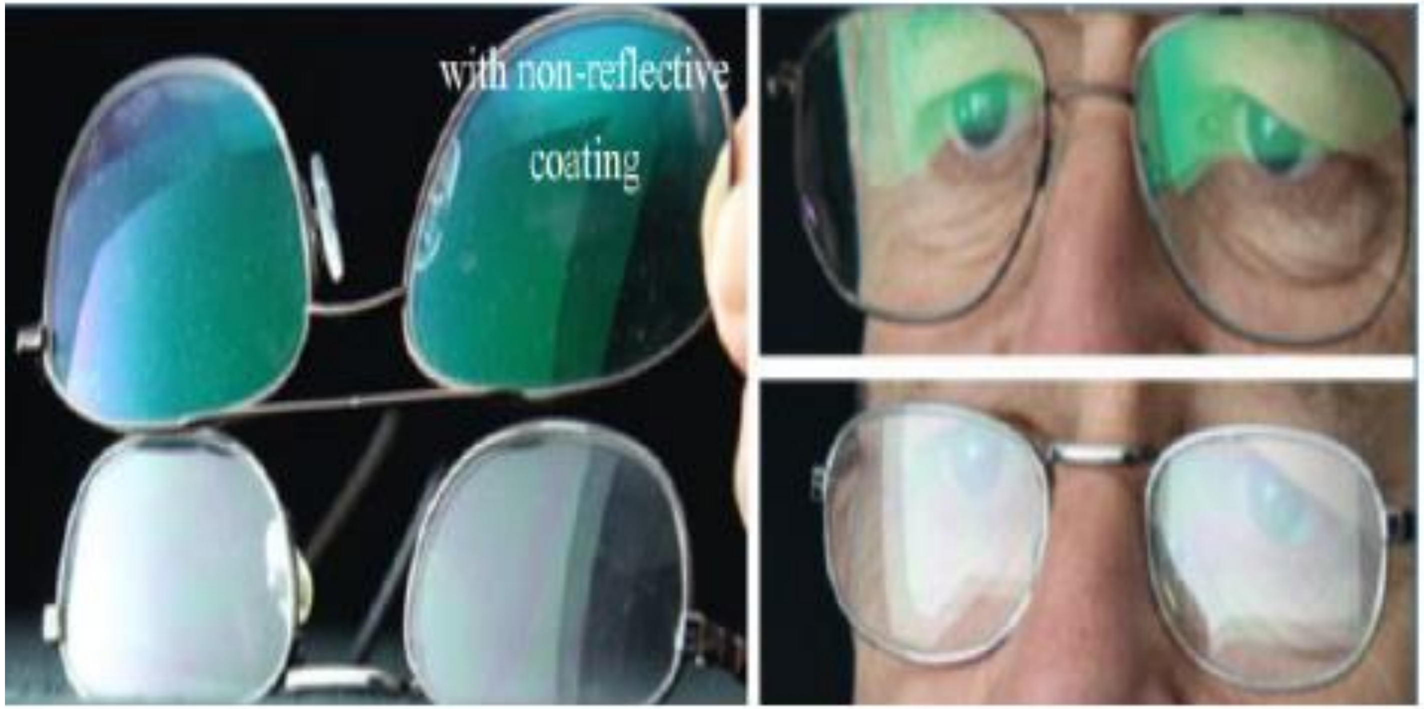
- **Non reflective films** are such **films** when light incident on it (for a selective range of wavelength) light does not get **reflected**. **Non reflecting** coating are made such a way that the **reflected** light form the surface interfere destructively



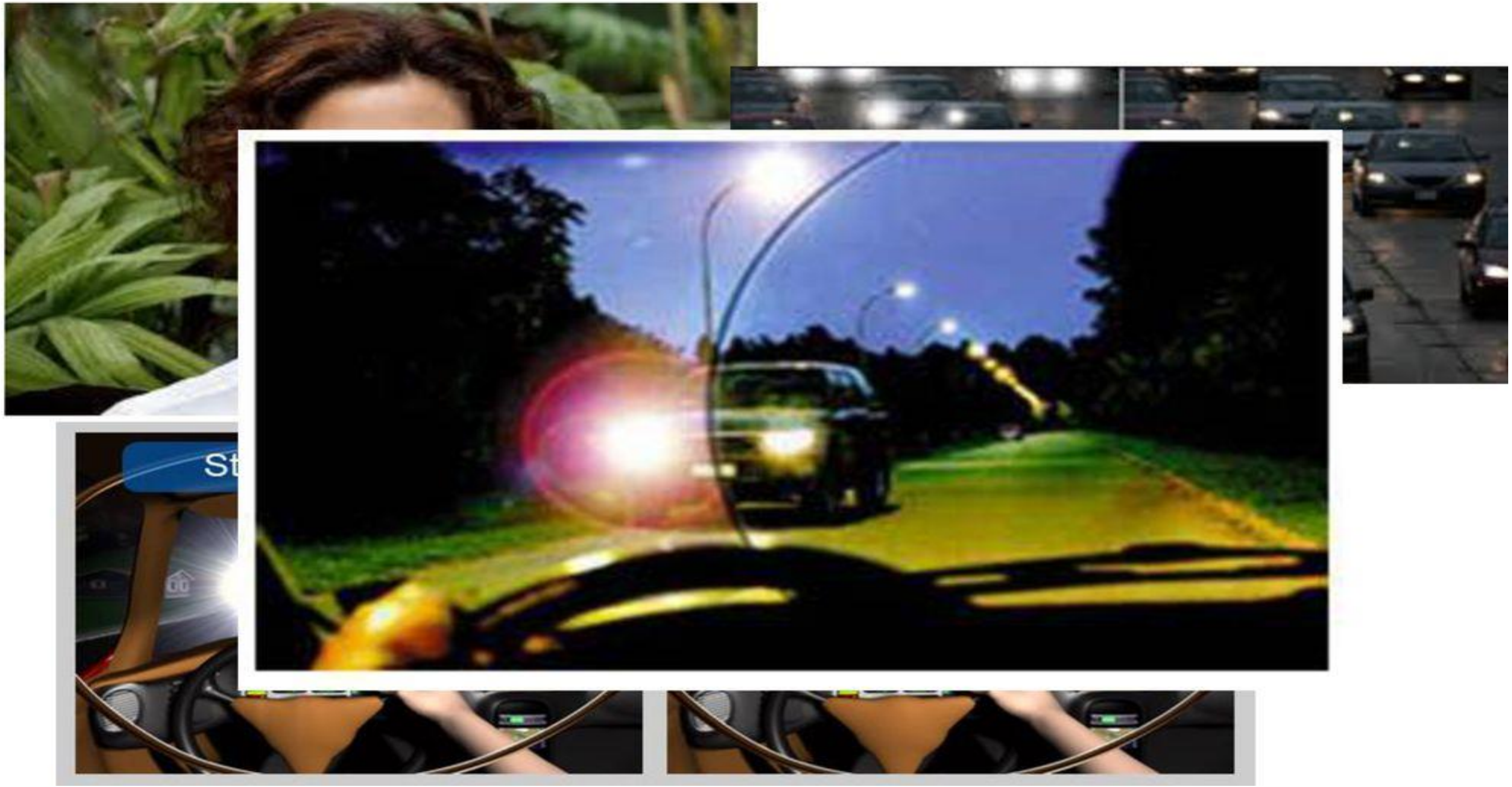
If a film (having a thickness of $\lambda/4n_f$ and having refractive index less than that of the glass) is coated on the glass, then waves reflected from the upper surface of the film destructively interfere with the waves reflected from the lower surface of the film. Such a film is known as a non-reflecting film.

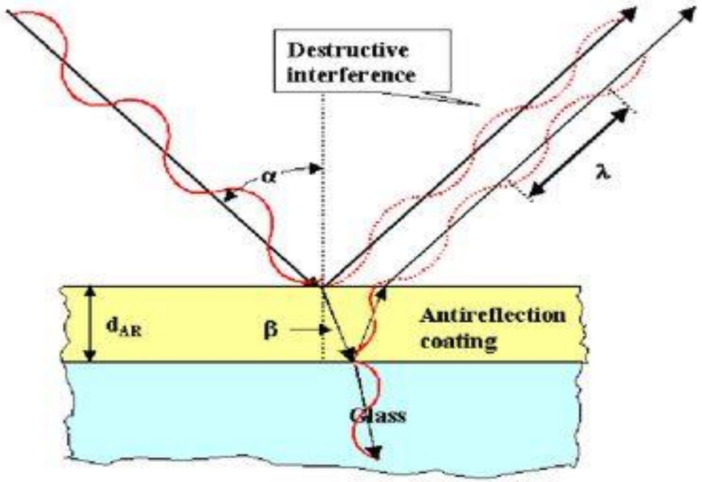
Non-reflecting/Anti-reflecting Coatings:

Non-reflective coatings admit more light into cameras and other optical instruments.



Anti reflection films
[Anti reflection coatings (AR)]





Δ between 1 and 2 = (2n-1)λ/2 ;
where n=1,2,3...

$$\Delta = 2\mu_f t \cos r - \frac{\lambda}{2} - \frac{\lambda}{2}$$

Assuming normal incidence of light i.e. *cos r* = 1

$$\Delta = 2\mu_f t - \lambda = 2\mu_f t$$

$$2\mu_f t = (2n-1)\frac{\lambda}{2}$$

For the film to be transparent, the thickness of the film should be minimum which is possible for *n* = 1.

$$\boxed{t_{\min} = \frac{\lambda}{4\mu_f}}$$

$$\boxed{\text{where} \quad \mu_f = \sqrt{\mu_a \mu_g}}$$

Non reflecting films

- *When films are coated on lens or prism surface the reflectivity of these surfaces is appreciably reduced.*

- *No light is destroyed by non reflecting film, but there is redistribution means decrease in reflection results increase in transmission.*

Thickness 't' and refractive index 'μ' are important parameters for the fabrication of non-reflecting films.