Optical engineering

- Study of light and its applications: optical instruments (lens, microscope, telescope, optical sensors etc.)

- Interference

- Diffraction

- Polarization

Interference

Introduction

- **Wave theory of light:** Proposed by Huygen in 1679 (Reflection, refraction and total internal reflection)
- Failed: wave nature of light
- **Thomas Young (1801):** **Interference of Light** (wave nature of light)
- **Diffraction** (wave nature) and **Polarization** (oscillation of light wave)
- **Huygen's Wave Theory:**
  each point on wavefront acts as secondary source of light (wavelets)
- **Superposition principle:**
  resultant wave is vector addition of all individual waves

Interference:
Redistribution/modification in the intensity when two or more waves are superimposed

Constructive Interference (Maxima):
superposition of two light waves are in phase (resultant intensity is greater)
Path Difference: $\Delta = n\lambda$
Phase difference: $\Phi = k\Delta$

Destructive Interference (Minima):
out of phase (resultant intensity is less)
Path Difference: $\Delta = (n + \frac{1}{2})\lambda$
Phase difference: $\Phi = k\Delta$

E.g., color due to oil spread on water or road, color in soap bubbles

Conditions to get stable interference pattern:

1. Two sources must be coherent: constant phase difference

2. Should have same amplitude : to get good contrast

3. Two sources should be monochromatic (sharp pattern)

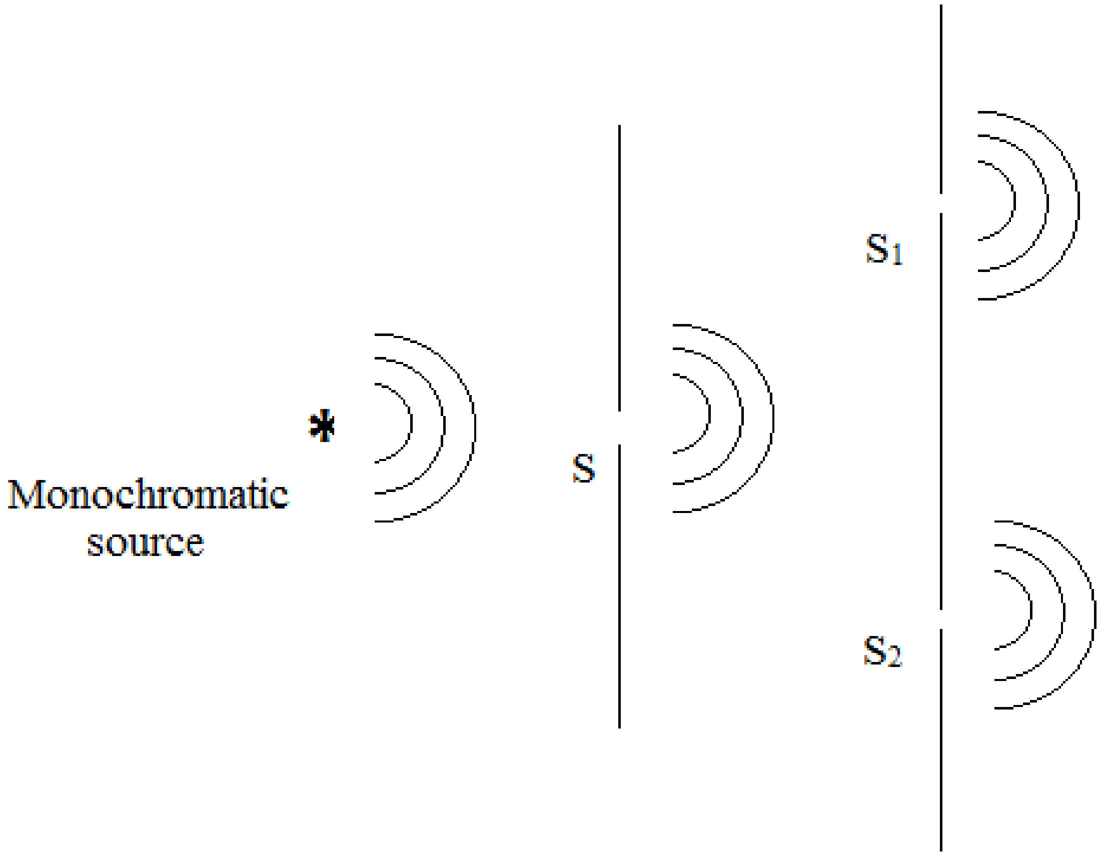
4. Two waves must be propagated along the same direction

5. Systematic and gradual variations of the path difference

- **Two methods for obtaining two coherent waves of same amplitude**

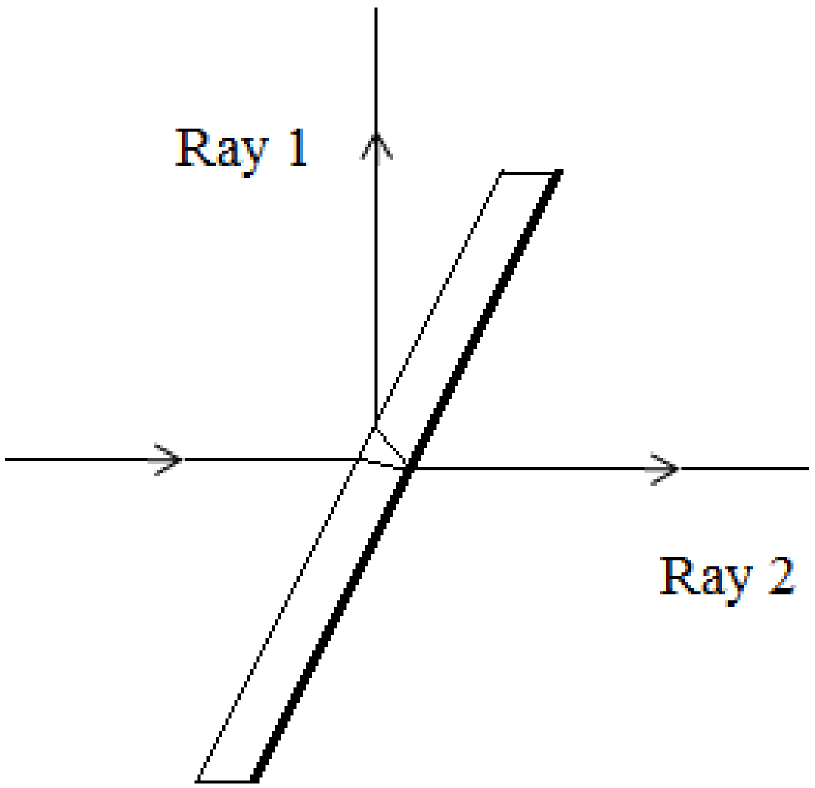
1. **Division of wavefront**
2. **Division of amplitude**

Division of Wavefront



- (Point source)
- E.g. Young’s double slit experiment, Fresnel’s biprism etc.

Division of amplitude (Intensity)



- Extended source
- Incident wave divided into two beams
- Eg. Newton’s ring, thin films interference, Michelson’s interferometer

Phase change due to reflection

1. **Light reflected from denser medium to rarer**

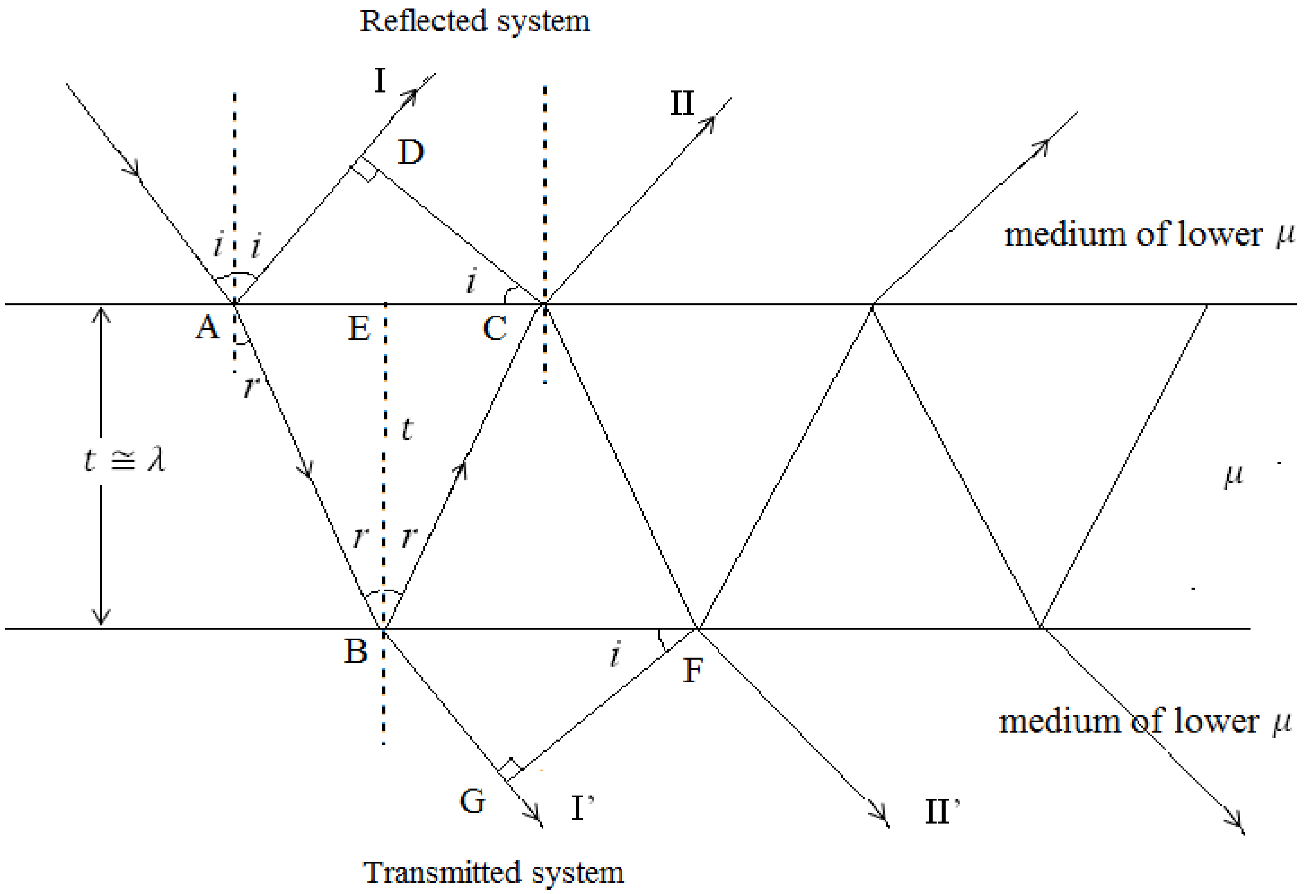
- Phase change (π) and path difference ($\lambda/2$) ; reflected light
- No phase change for transmitted light

2. **Light reflected from rarer medium to denser**

- No phase change for transmitted and reflected light

Thin Film Interference (natural interferometers)

- Thin film: thickness $\approx$ wavelength of visible light (550 nm or 0.55 μm)
- Oil film on road, soap bubble, coating on camera lens, solar cells



$$\Delta = 2\mu t \cos r$$

$$\Delta = 2\mu t \cos r \pm \lambda/2 \text{ (phase change)}$$

Derivation (optional)

Reflected System

- Condition for Maxima (constructive)

  $2\mu t \cos r = (n \pm ½)\,\lambda$

- Condition for Minima (destructive)

  $2\mu t \cos r = n\,\lambda$

Transmitted System

- Condition for Maxima (constructive)

  $2\mu t \cos r = n\lambda$

- Condition for Minima (destructive)

  $2\mu t \cos r = (n \pm ½)\,\lambda$

Reflected and Transmitted systems are complementary

Interference from very thin film

$t << \lambda$ or $t = 0$

$\Delta = \pm\,\lambda/2$

No interference pattern (dark film)

If R.I. of film is less than that of the surface below, the 'Stoke's phase reversal occurs for both the rays, and the factor $\lambda/2$ disappears from the P.D.

$$\Delta = 2\mu t \cos r$$

Condition for Maxima (constructive)

$$2\mu t \cos r = n\lambda$$

Condition for Minima (destructive)

$$2\mu t \cos r = (n \pm ½)\,\lambda$$

A thin film of CCl_4 having refractive index 1.46 and thickness .1068 μm is spread on water having refractive index 1.33. If viewed at 45^o which colour will be seen enhanced?

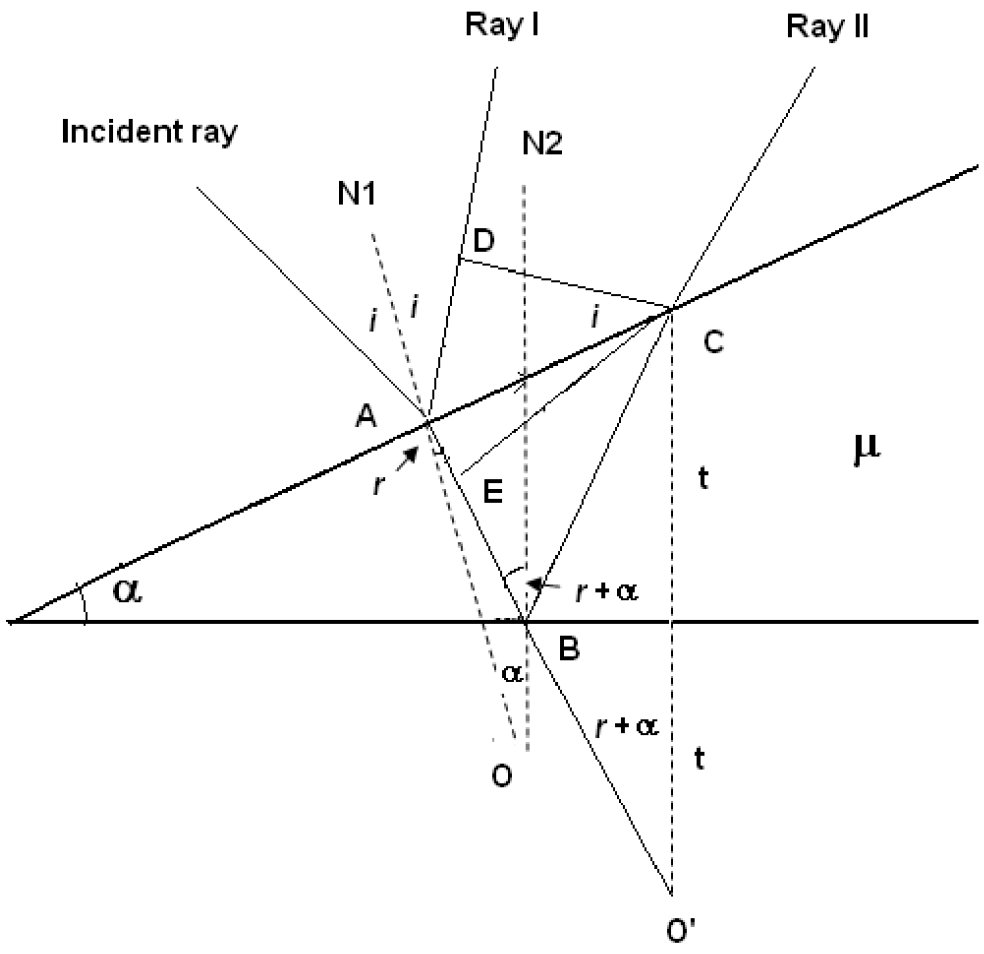
$i = 45^0$, r = ?

$\mu = 1.46$, $t = .1068 \times 10^{-6}$ m

$2\mu t \cos r = (n \pm ½)\lambda$

$\lambda = 5456$ Å

Interference in Wedge Shaped Film



Two plane surfaces inclined at angle ‘α’

Thickness varies from 0 to maximum

$$\Delta = 2\mu t \cos(r + \alpha) \pm \lambda/2$$

Condition for Maxima (constructive)

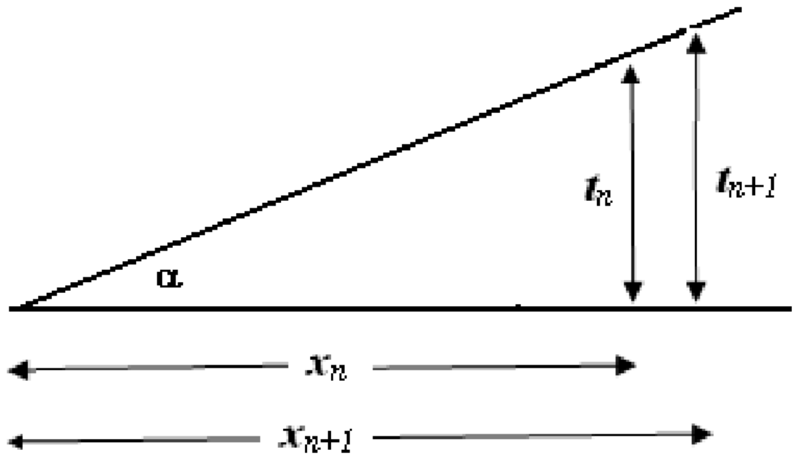
$$2\mu t \cos(r + \alpha) = (n \pm \tfrac{1}{2})\lambda$$

Condition for Minima (destructive)

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

Nature of Interference Pattern ?

Fringe Width: **Distance between two consecutive bright or dark rings**



$$x_{n+1} - x_n = \frac{\lambda}{2\mu \tan\alpha \cos\alpha} = \frac{\lambda}{2\mu \sin\alpha} \approx \frac{\lambda}{2\alpha}(air)$$

A parallel beam of sodium light strikes a film of oil floating on water. When viewed at an angle of 30^0 from the normal, 8^{th} dark band is seen. Determine the thickness of the film. R.I. of oil is 1.46. Wavelength is 5890 A^0.

For dark band,

$2\mu t \cos r = n\lambda$

Use Snell's law, $\sin r = 0.3424$

$\cos r = 0.9395$

$t = 1.717 \text{ X } 10^{-4}$ cm.

A wedge shaped air film having an angle of 40 seconds is illuminated by monochromatic light and fringes are observed vertically through a microscope. The distance measured between consecutive bright fringes is 0.12 cm. Calculate the wavelength of light used.

θ = 40 Sec = 40/3600 deg = 40/3600 X π/180 radians

Fringe width (β) = λ /2θ

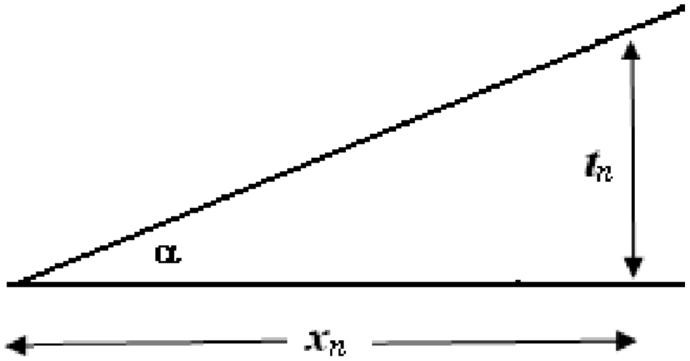
λ = 4652 Å

Two optically plane glass strips of length 10 cm are placed one over the other. A thin foil of thickness 0.010 mm is introduced between the plates at one end to form an air film. If the light used has wavelength 5900 Å, find the separation between consecutive bright fringes.

$\beta = \lambda / 2\theta$

$\theta = t / x = 10^{-4}$ rad

$\beta = 0.295$ cm



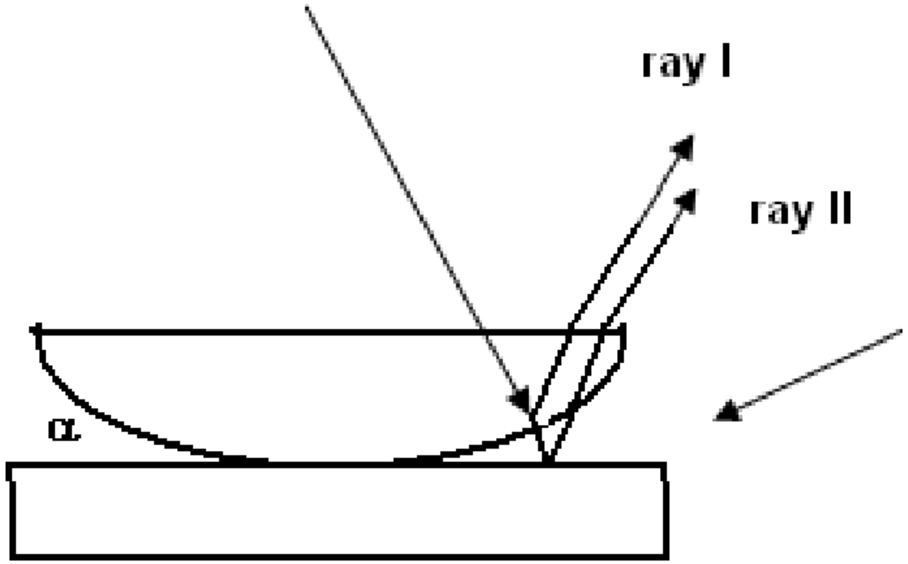
A soap film of R. I. 4/3 and thickness 1.5 X 10^{-4} cm is illuminated by white light incident at an angle of 45^0. the light reflected by it is examined by a spectroscope in which it is found a dark band corresponding to a wavelength of 5 X 10^{-5}cm. Calculate the order of interference band.

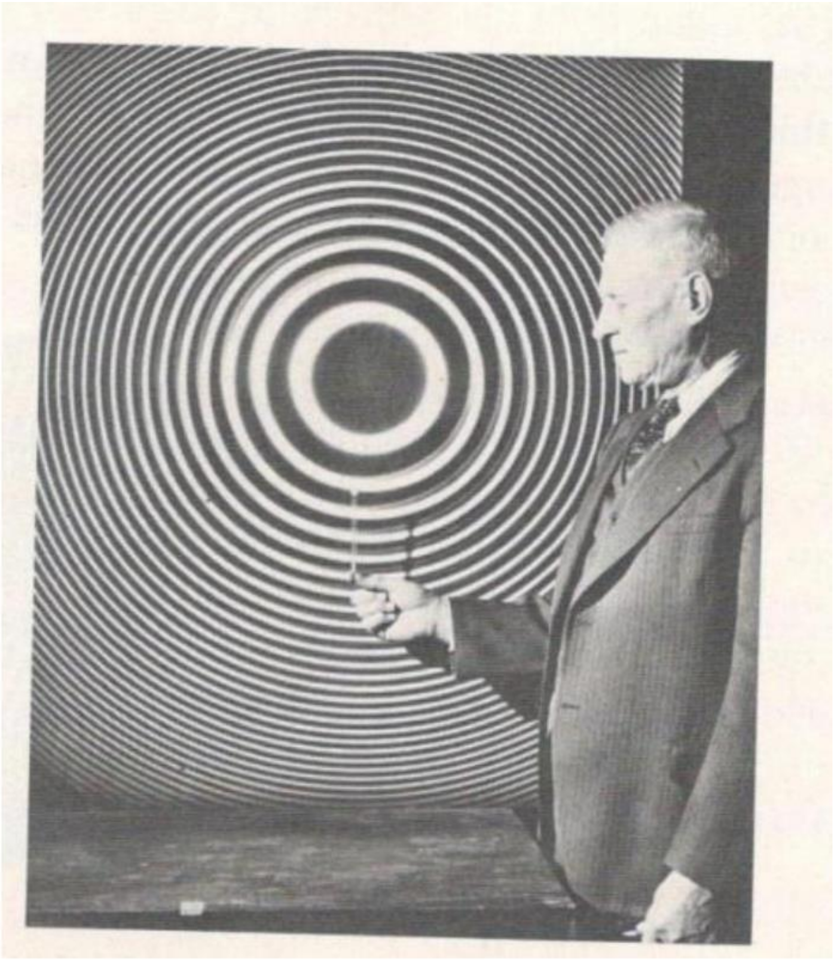
For dark band, $2\mu t \cos r = n\lambda$

$r = 32.02^0$

$n = 6.7 \;\; = 6^{th}$ band

Newton's Ring Experiment





Why the rings are Circular?

Dark Ring

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

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

Bright Ring

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

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

Characteristics of Newton's rings

i. Newton's rings on reflected side are complementary to the Newton's rings on transmitted side

ii. 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.

iii. If the Newton's ring set up is illuminated by white light then a few coloured rings near the center are observed

iv. If the monochromatic source in the setup is replaced by a source of higher wavelength, then the diameters of Newton's rings are increased.

v. If the planoconvex lens in the setup is replaced by the planoconvex lens of higher radius of curvature then the diameters of the rings will increase

vi. If bioconvex lens is used instead of planoconvex: converging power is doubled and area of ring formation is reduced to half, but number of rings are same. Width of rings reduces to half

vii. Change in width of rings w.r.t wavelength and refractive index (fringe width formula)

Newton's ring are formed by light reflected normally from a plano-convex lens and plane glass plate with a liquid between them. The diameter of nth ring is 2.18 mm and that of (n+10)th ring is 4.51 mm. Calculate the R. I. of the liquid. Given: R = 90 cm and wavelength is 5893 Å

$$\mu = (4pR\lambda)/ (D_{n+p}^2 - D_n^2)$$

$$\mu = 1.36$$

Newton's rings are formed with monochromatic light source between flat glass plate and convex lens viewed normally. What will be the order of dark ring which will have double the diameter of that 20^{th} dark ring?

$n = 80$

In Newton's ring experiment the diameter of 4th and 12th dark rings are 0.4 cm and 0.7 cm respectively. Deduce the diameter of 20th dark ring.

$D_n^2 = 4Rn\lambda$

$D_4 = 0.4$ cm and $D_{12} = 0.7$ cm

$n = 4$ and $n+p = 12$, hence $p = 8$

$R = (D_{12}^2 - D_4^2)/ 4p\lambda$

$R\lambda = 0.0103\ cm^2$

$D_{20}^2 = 0.9$ cm

In Newton's ring experiment, the diameter of 15th dark ring was found to be 0.590 cm and that of 5th dark ring was 0.336 cm. If the radius of curvature of plano convex lens is 100 cm, calculate the wavelength of light used.

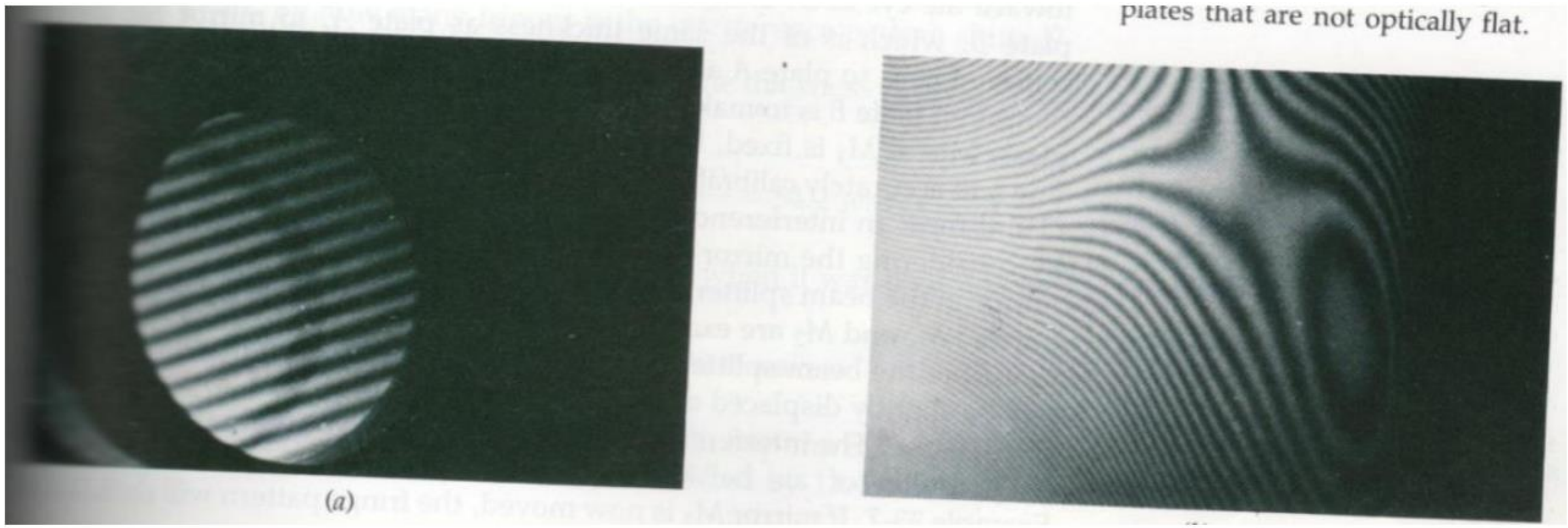
$\lambda = 5880$ Å

Applications of Newton's Ring Experiment

- Determination of wavelength of monochromatic source
- Determination of radius of curvature of planoconvex lens
- Determination of refractive index of liquid

Applications of Interference

- **Testing of optical flatness of glass plate or lens**



- **Measurement of thickness of thin film : t = d/2**

- **Anti reflection coating:** use in camera, projectors, binoculars, telescopes

  - Image is not clear if reflection is more
  - Thin film coating (MgF_2) on surface (lens, glass plate etc.)
  - MgF_2 : R.I = 1.38 between air and glass plate
  - Thickness (λ'/4) : should provide destructive interference (λ/2)


HELIOS-44
HELIOS-44-2

A glass of refractive index 1.5 is to be coated with a transparent material of refractive index 1.2 so that the reflection of light of wavelength 6000 A^0 is eliminated by interference. What is the required thickness of the coating?

$\lambda' = \lambda/\mu = 6000/1.2 = 5000\ A^0$

$t = \lambda'/4 = 1250\ A^0$