Module # 2: Measurement by Light wave Interference.

Reference Book: R.K. Jain Ch 6: Sec 6.1 — 6.5

Let us understand few basic concepts first

* Significance of monochromatic light in interference.

Interference: The phenomenon where two ~~or~~ more waves superimpose to form a resultant wave of
a) Greater Amplitude
b) Lower Amplitude
3) Same Amplitude.

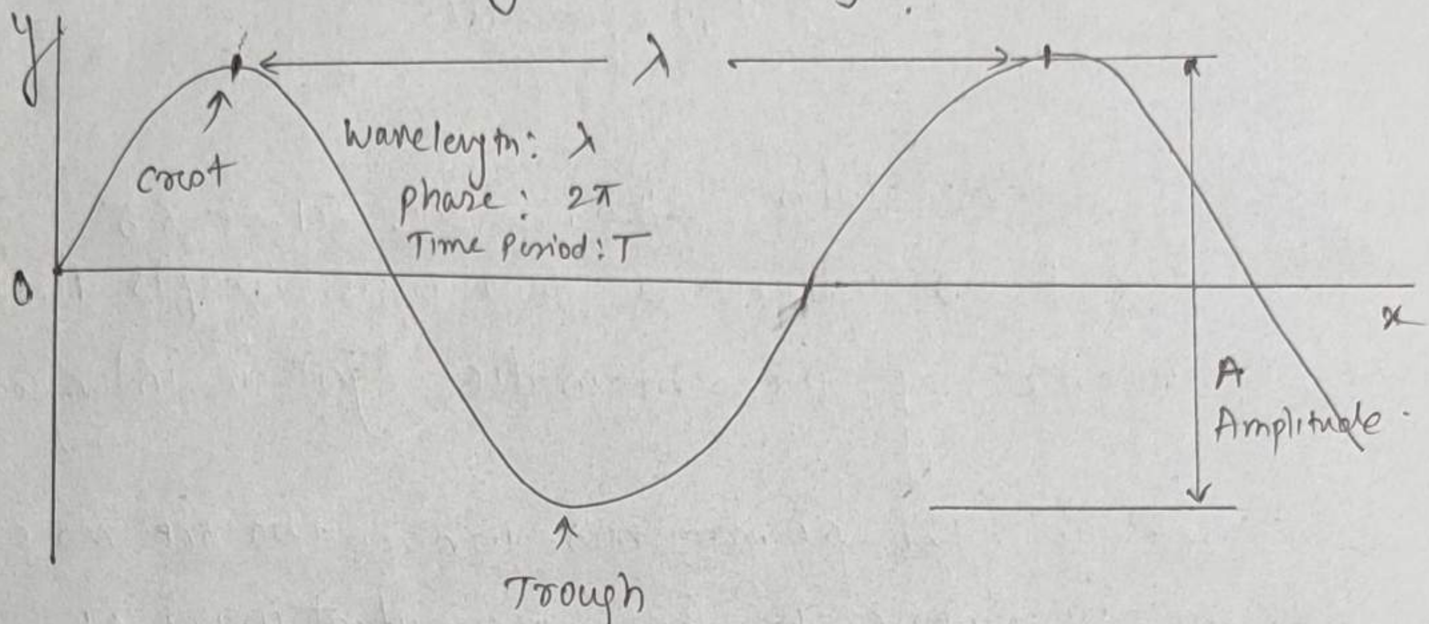
ex: It can occur in light waves, sound waves, waterwaves.

Two types of Interference:

1) Constructive interference: when waves add ups and resultant intensity is increased.
i.e. Crest of one wave falls on Crest of another wave such that the amplitude is maximum.

2) Destructive interference: when waves cancel each other leading to decrease in intensity i.e. crest of one wave falls on the trough of another wave such that amplitude is minimum.

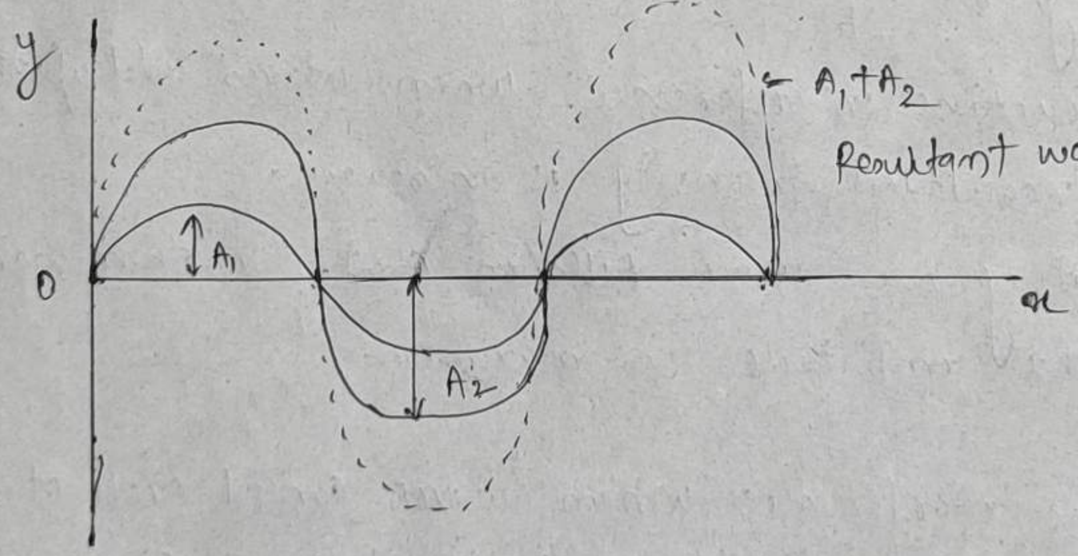
Basics of wave theory



Note: i) Intensity of Light (I) $\propto$ (Amplitude)^2 ie $I \propto A^2$

ii) Resultant intensity of two or more wave depends on the superposition principle and the Resultant amplitude is given by $R = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos(\delta\phi)}$ $\quad \delta\phi = \phi_2 - \phi_1$ phase difference

For Constructive interference



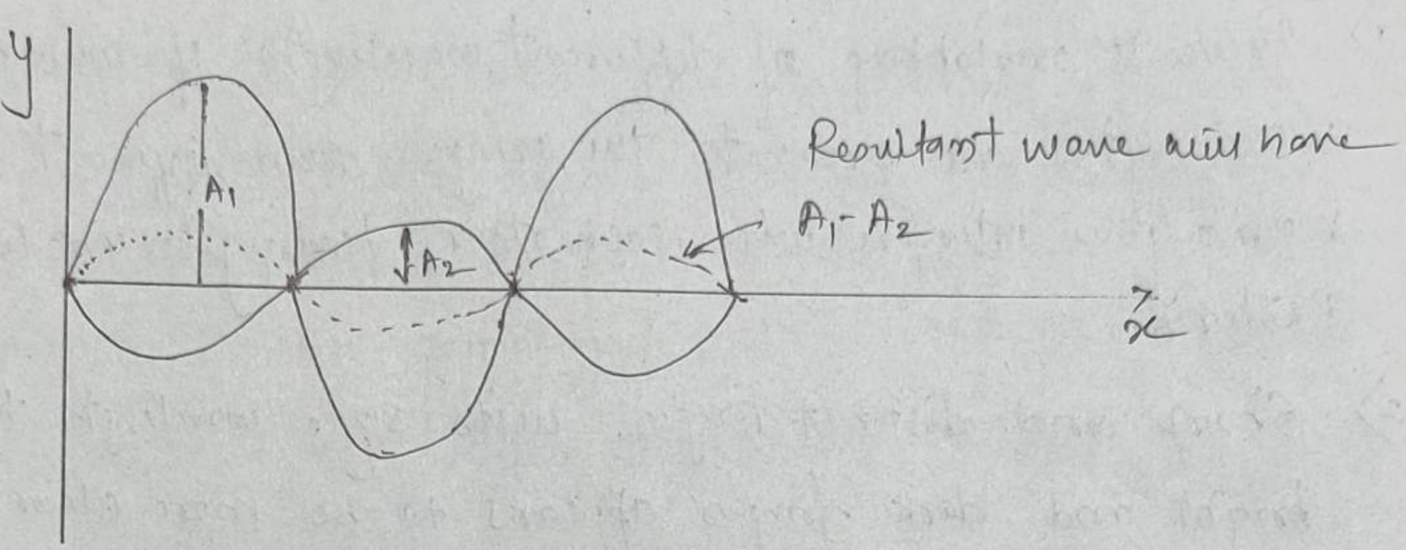
Mathematical Conditions for Constructive interference

1) optical path difference = integral multiple of wavelength

$$\Delta x = (2n+1)\lambda \qquad n = 0, 1, 2 \ldots$$

2) Phase difference = integral multiple of 2π

For destructive interference.



- Mathematical conditions:

1) Optical path difference = Odd integral multiple of half wavelength

$$\Delta x = (2n+1)\frac{\lambda}{2} \qquad n = 0, 1, 2 \ldots$$

2) Phase difference = integral multiple of π

Note: Intensity of light wave $\propto$ (Amplitude)^2

- $\therefore$ Resultant intensity $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta\phi$

$\delta\phi = 0, \pm 2\pi, \pm 4\pi \ldots$ Maximum Intensity

$\delta\phi = \pm\pi, \pm 3\pi, \ldots$ minimum Intensity

Now let us understand why monochromatic light is important for interference.

(Monochromatic light: Light of single wavelength or single frequency.)

Importance / Significance of Monochromatic light

1) Prevents overlapping of different wavelength: If multiple wavelengths are present, the fringes from different wavelengths interfere with each other, leading to unclear pattern.

2) Sharp and distinct fringes: with single wavelength the bright and dark fringes appears to be more clear and distinct.

3) Avoiding phase shift: polychromatic light can cause variation in phase shifts, leading to washed out pattern.

Conclusion: Interference pattern are more clear and stable when produced using monochromatic light as compared to polychromatic light.

Example of few monochromatic light sources:

A variety of monochromatic light sources are available for interferometry, and their selection depends on application requirements, cost and convinence

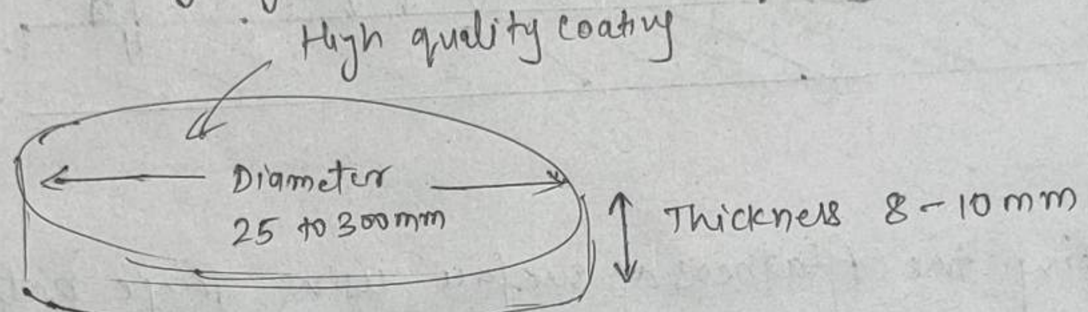
1) For simple applications: A tungsten lamp with narrow band filter is enough.

2) Sophisticated applications require specific sources: Mercury, Cadmium, Krypton, thallium, Sodium vapour lamp, He-Ne Laser

H.W To find wavelength of each source!

Interferometry Applied to flatness testing.

Optical flats: (i) A circular piece of optical glass or fused quartz with highly finished flat surfaces.
(ii) The cylindrical surface of the optical flats are finished by grinding / lapping and polishing process.



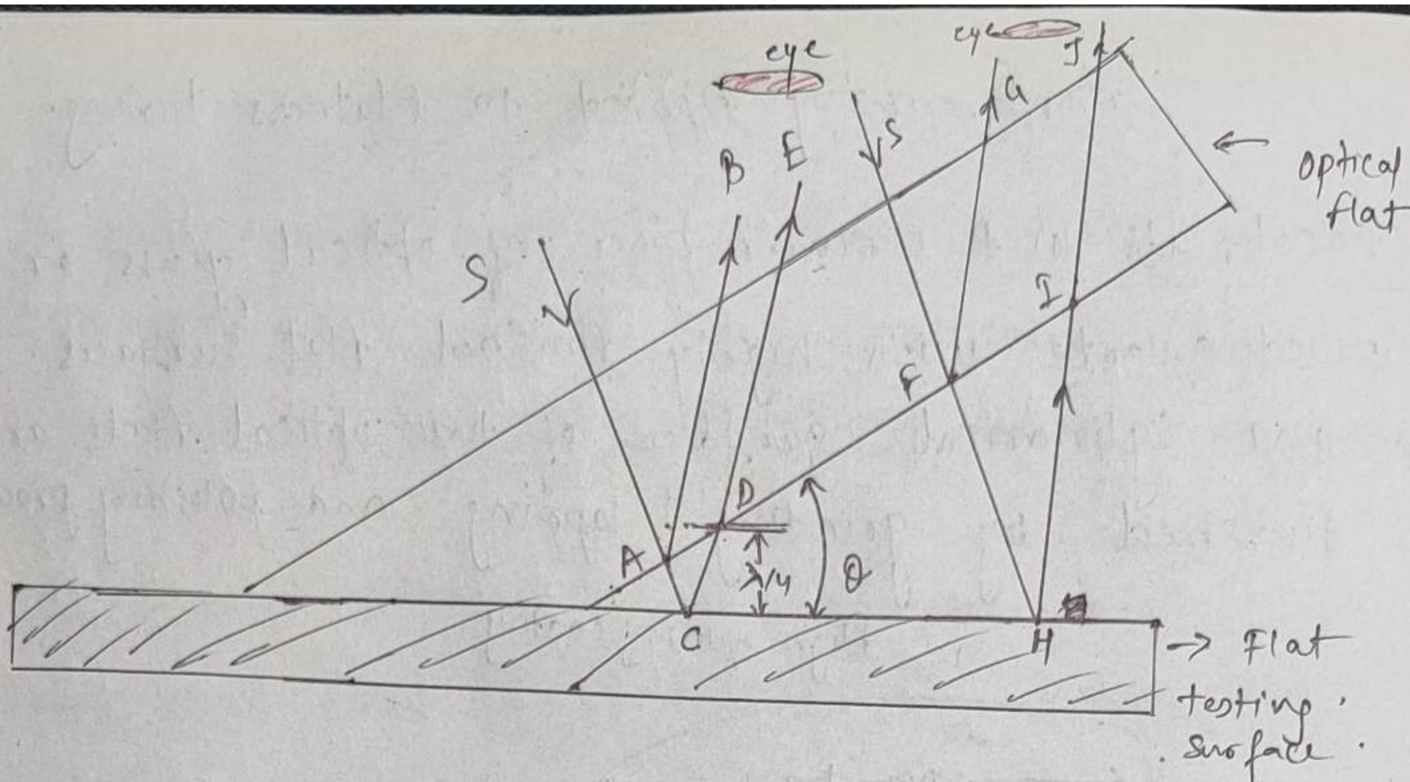
(iii) Optical flats are used to inspect surface flatness by analysing interference patterns created by reflected light (Similar interference what we learned in thin film)

Principle of operation:

i) when an optical flat is placed over a surface with a small air gap, monochromatic light creates an interference pattern due to reflection from the top and bottom surfaces of the air gap.

ii) The interference depends on the path difference of the reflected ray

(iii) If the surface is perfectly flat, straight line fringes are observed; Any deviation from the flatness result in curved or irregular fringes



Checking the flatness of surface using fringe pattern.

i) Consider an optical flat placed upon another flat reflecting surface (whose flatness is to be tested) without applying any pressure. making an inclined plane with small angle 'θ'

ii) If the monochromatic light is illuminated as discussed before we can observe number of bands produced due to interfernce ~~form~~ due to partially reflected light along 'AB' and partially transmitted across the gap 'AC'

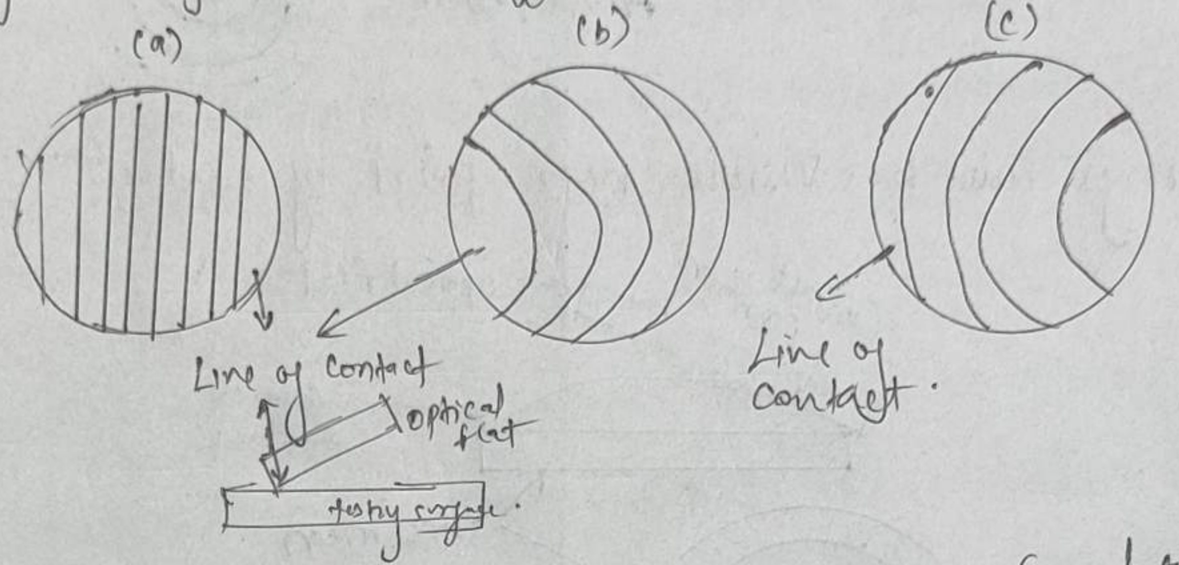
At point 'C' again the ray is reflected along 'CD'

The two reflected components at point 'A' and 'C' combine and we observe interference pattern due to the path difference by amount 'ACD'.

iii) We know that if $ACD =$ odd multiple of $\frac{\lambda}{2}$ then we observe a dark band. (Let say $ACD = \frac{\lambda}{2}$)

Similarly, if $FHI = \frac{3\lambda}{2}$ then again we see a dark band.

Interference fringes: Based on the level of flatness of the test surfaces, the orientation of these dark and bright fringes will differ.



The above figure shows different fringes for different test surface. When the test surface is

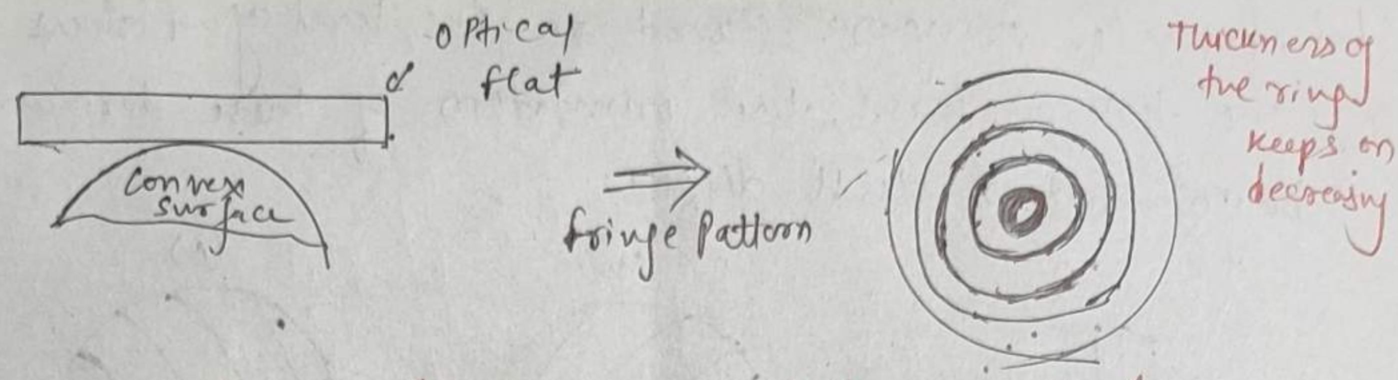
(a) Perfectly flat: A regular fringes are form as shown in fig (a)

(b) Convex and high at centre: fringes are curved and away from line of contact as shown in fig (b)

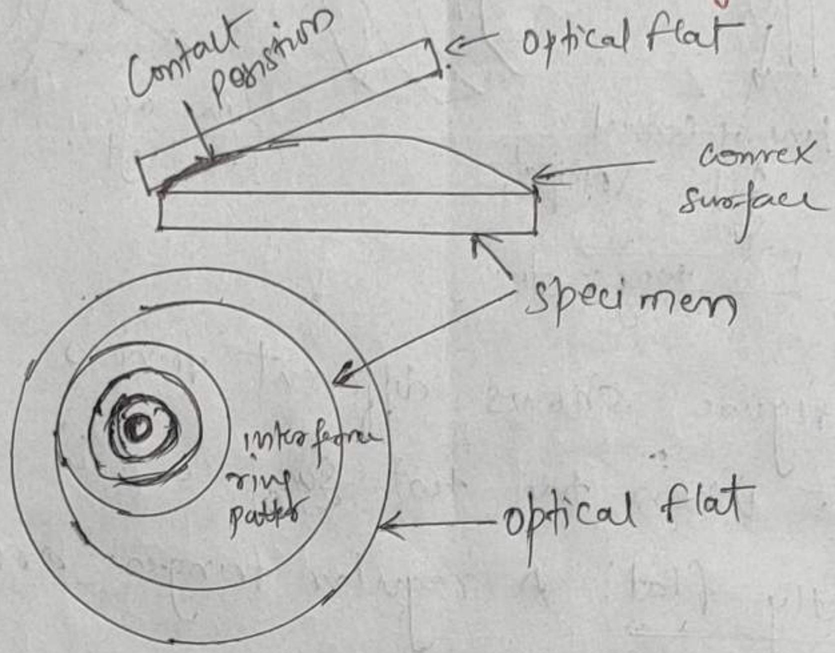
(c) Concave and low in the centre: fringes are curved and towards the line of contact as shown in fig (c)

*Imp: If the optical flat is resting on curved surface a concentric bright and dark fringe appears (similar what you see in Newton's ring experiment)

Note: Ideally the line of sight should be perpendicular to the optical flat.



The rings will be visible near point of contact



Identifying Convex and Concave surface using optical flats.

<u>Convex surface</u>: Light pressure on the edge moves the fringes closer → Convex (hill like) surface

<u>Concave surface</u>: Light pressure at the center reduces fringe count and spreads them apart → Concave (valley like) surface.

<u>Note</u>: Real surfaces may not be perfectly convex or concave and therefore contact is made at multiple points rather than single point and fringe pattern analysis should be done.

Surface Contour Test:

The surface contour test is used to study the surface irregularities of a material by analyzing the interference fringes produced when an optical flat is placed at an inclined angle over the surface.

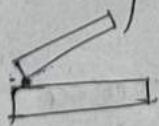
Procedure:

i) For studying various surface contours, an optical flat is inclined over the surface to be tested

ii) Day light with wavelength ≃ 500 nm is commonly used and the each fringe interval corresponds to an elevation change of 2.5 μm (high precision)

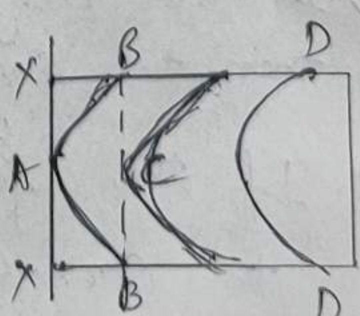
iii) Fringes represent contours of equal height relative to the optical flat, allowing surface mapping

iv) It is important to know where is the optical flat is in contact with surface being tested (The point / Line of contact) under day light the point of contact can be identified by colour changes in the surface being tested.



Here XX: Line of contact

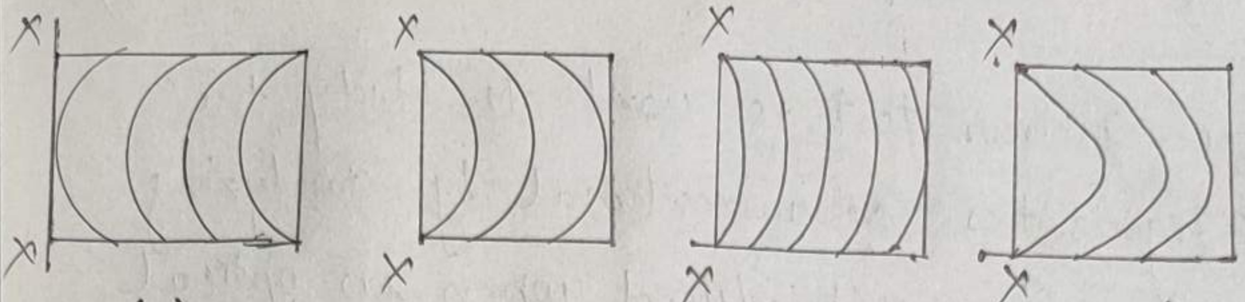
Contour BAB: points at equal height



A Similar phenomenon also observed for Newton's ring experiment

Note: Please do not get confused with fringe pattern shown in reference. R.K. Jain

Concave Surface



(a) Concave surface

(b) Convex surface

(c) less Convex

(d) more Convex

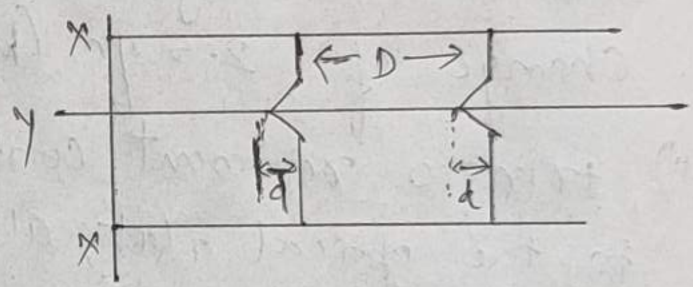
* Depth of Scratch:

i) Let us consider any surface having a scratch as shown in the figure

ii) Let 'D' be the distance between two fringes and 'd' be the distance due to scratch.

iii) The depth of the scratch

$$= \frac{d}{D} \times \frac{\lambda}{2}$$



iv) useful to determine the depth of scratch by this method.

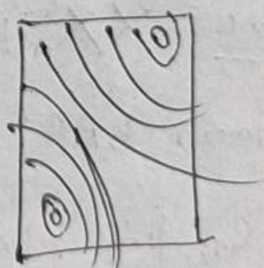
XX: Line of contact

YY: Scratch along the Line

* Detection of High and Low spots using the Pressure test

i) If the fringes move closer together, then the surface is valley

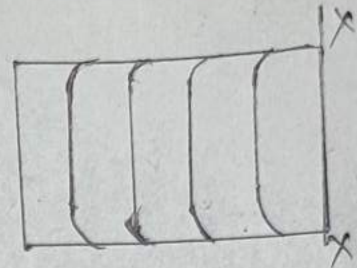
ii) If the fringes move apart, the surface is hill



Surface with two high/Low spots.

* Worn-out Edges in workshop

The middle remains flat, while edges become worn and convex due to lapping wear as shown in diagram.



Surface worn at edges due to lapping in workshop