FUNDAMENTALS OF PHYSICS

* Concepts like mechanics, electrical, electronics, magnetics, thermodynamics, semiconductors and optics play a role of great importance in the process of innovation & development.
* Everything around us uses energy in one way or other. Search for new tech, to enhance by modifying properties like internal & external parameters like ext force, temp, chem, struct, etc
* Physics – natural science that involves study of matter and its motion and behavior thrgh space and time with related compounds like Energy and force

UNIT - 1

WAVES AND OSCILLATION

Depending on the system, force value changes

$$\boxed{F = ma}$$

$$\boxed{F = m\frac{d^2x}{dt^2}}$$

$$\int m\frac{d^2x}{dt^2} = \int \frac{1}{4\pi\epsilon_0}\cdot\frac{q_1q_2}{r^2} = \int -kx$$

$$= \int \frac{GmM}{R^2} = \int$$

PERIODIC MOTION:

Periodic motion can cause disturbances that move thrgh a medium in the form of a wave

WAVE MOTION:

* Wave is a motion of a disturbance
* Mechanical waves require:
  - some source of disturbance
  - medium that can be disturbed
  - phy connection or mechanism through which adjacent positions of the medium influence each other
  - waves carry energy & momentum.

Waves → Transverse wave

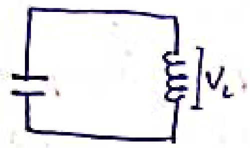
Waves → Logitudinal wave

- Transverse waves – each element ~~in the wave~~ that is disturbed moves in a direction ⊥r to wave motion.

- Logitudinal aka compression waves – the elements of medium undergo displacements parallel to the motion of the wave.

(Particular type of periodic motion)

☆ SIMPLE HARMONIC MOTION:

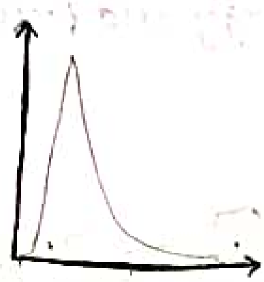


$$\boxed{V_L = -L\frac{di}{dt}}$$

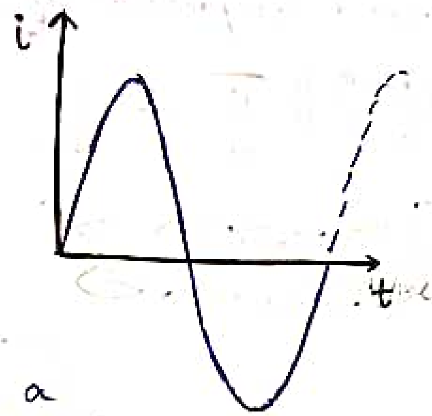
LC oscillator

(discharge)

(RC circuit)



(LC circuit)



→ In a clock when current flows thrgh a quartz crystal which is given a force and vibrates. Vibration rate is controlled by a microchip which is connected to a motor that converts it to circulatory motion.

- Periodic motion is a motion that regularly returns to a given position after a fixed time interval.
- SHM occurs when the net force acting along obeys "Hookes law". (ie) $F = -kx$
- In SHM, force acting on the object is proportional to the position of the object about some equilibrium position.

NOTE: [Force is always directed towards equilibrium position]

Ex: Spring mass system.

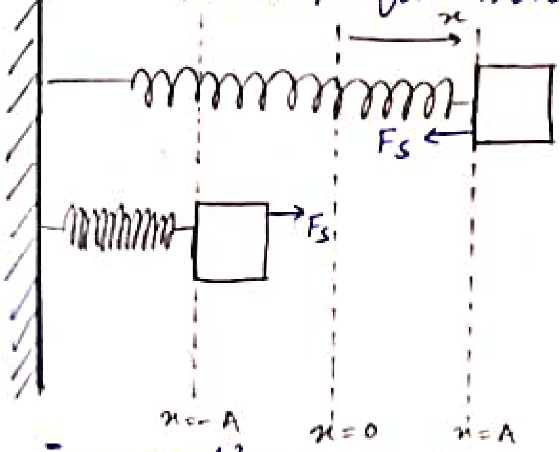
- Clock – phisioelectric principle

(when F is applied – gives rise to V difference)

[voltage → quartz crystal → vibrates → microchip controls the vib
oscillate with same ν ← stepper motor ↲]

(... law) $\boxed{F_s = -kx}$ [k - spring constant defines spring stiffness]

$x=0 \Rightarrow$ equilibrium position



→ K affects the distance it moves given the force F

→ F is always directed opp to the displacement i.e. towards the eq. position aka "Restoring force"

$$\Rightarrow m\frac{d^2x}{dt^2} = F = -kx$$

$$\boxed{\omega^2 = \frac{k}{m}}$$

$$\frac{d^2x}{dt^2} = -\omega^2 x \quad \text{—①}$$

$$\boxed{\frac{d^2x}{dt^2} + \omega^2 x = 0}$$

[Equation of motion for simple harmonic motion]

$$\boxed{x = ce^{\alpha t}} \quad \text{(solution)} \quad \text{—②}$$

$$\left[\begin{array}{l} D^2 = -\omega^2 x \\ D = \pm i\omega \end{array}\right]$$

$$\frac{dx}{dt} = ce^{\alpha t}\cdot\alpha$$

$$\frac{d^2x}{dt^2} = ce^{\alpha t}\cdot\alpha^2 \quad \text{—③}$$

$$ce^{\alpha t}\alpha^2 + \omega^2 ce^{\alpha t} = 0$$

$$ce^{\alpha t}(\alpha^2 + \omega^2) = 0$$

$$\alpha^2 + \omega^2 = 0$$

$$\boxed{\alpha = \pm i\omega}$$

$$\boxed{x = ce^{\pm i\omega t}} \quad \text{(or)} \quad \boxed{x = c_1 e^{i\omega t} + c_2 e^{-i\omega t}}$$

$$x = c_1(\cos\omega t + i\sin\omega t) + c_2(\cos\omega t - i\sin\omega t)$$

$$= (c_1 + c_2)\cos\omega t + i(c_1 - c_2)\sin\omega t$$

$$\boxed{\begin{array}{l} c_1 + c_2 = a\sin\phi \\ c_1 - c_2 = a\cos\phi \end{array}}$$

$$= a\sin\phi\cos\omega t + a\cos\phi\sin\omega t$$

$$\boxed{x = A\sin(\omega t + \phi)}$$

→ Phase const.

→ Frequency

→ Amplitude

$$x = a\sin(\omega t + \phi)$$

$$v = \frac{dx}{dt} = a\omega\cos(\omega t + \phi)$$

$$\boxed{v = A\omega\cos(\omega t + \phi)}$$

$$\begin{cases} \sin(\omega t + \phi) = \frac{x}{a} \\ \cos(\omega t + \phi) = \sqrt{1 - \frac{x^2}{a^2}} \end{cases}$$

$$\left[\cos\theta = \sqrt{1 - \sin^2\theta}\right]$$

$$v = a\omega\sqrt{\frac{a^2 - x^2}{a^2}}$$

$$v = \omega\sqrt{a^2 - x^2}$$

$$\boxed{v = \omega\sqrt{A^2 - x^2}}$$

$$\boxed{a = -\omega^2 A\sin(\omega t + \phi)}$$

(To calculate Time period)

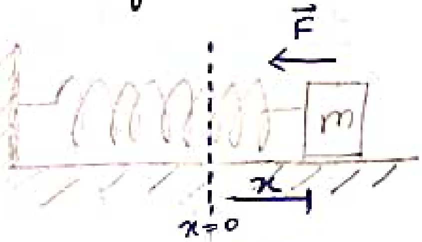
$$T = \frac{1}{\nu} = \frac{2\pi}{\omega}$$

$$\boxed{\omega = \sqrt{\frac{K}{m}}}$$

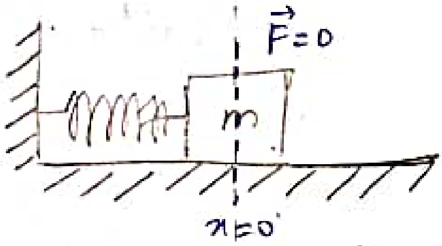
$$T = \frac{2\pi}{\sqrt{K/m}} \Rightarrow \boxed{T = 2\pi\sqrt{\frac{m}{K}}}$$

★ Restoring force and Spring mass system.

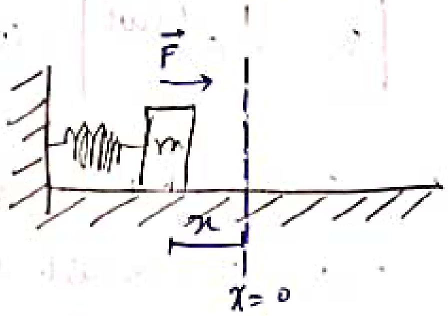
- Here the block is displaced to the right of $x=0$. The restoring force exerted by the spring is directed to the left (negative)



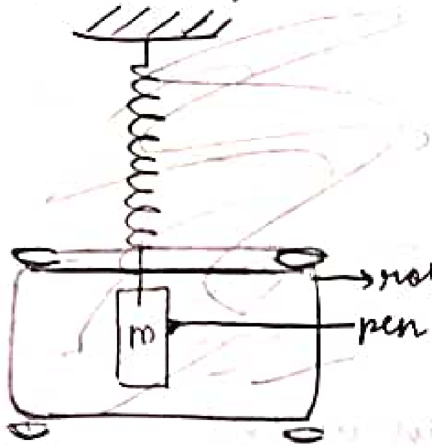
- Block is at eq. position ($x=0$). Thus the spring is neither stretched nor compressed. $\vec{F}_s = 0$



- Block is displaced to the left of $x=0$. (position is −ve) The restoring force is directed to the right (positive)



☆ Verification of Sinusoidal Nature:



BLAH
BLAH

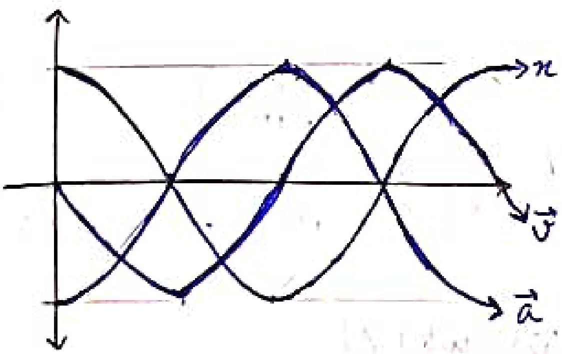
☆ Amplitude:

- Amplitude is the maximum position of the object from its equilibrium position.
- [Ideal SHM involves oscillation of m between $x = \pm A$]

☆ Period:

- The period is the time taken by object to complete one complete cycle of motion. [$x=A$ to $x=-A$ to $x=A$]
- Represented by 'T' (seconds)
- The frequency is the no of complete cycles per unit time

$$\boxed{f = 1/T} \quad \text{(Hertz)}$$



- velocity is 90° out of phase with displacement
- acceleration is 180° out of phase with displacement

$x = AC$

- when $x = max$; $v = zero$
- when $x = 0$; $v = max$ and in negative direction
- when $x = +max$; $a = max$ and in $-ve$ direction

☆ Kinetic and Potential energies w.r.t Force.

$$F = -kx$$

$$F = -\frac{dU}{dx}$$

$$\int \frac{du}{dx} = \int kx$$

$$U = \frac{1}{2}kx^2 + C$$

$$\boxed{U = \frac{1}{2}Kx^2}$$

$$x = A\sin(\omega t + \phi)$$

$$U = \frac{1}{2}KA^2\sin^2(\omega t + \phi)$$

$$\boxed{U = \frac{1}{2}KA^2\sin^2(\omega t+\phi)}$$

$$\boxed{U_{max} = \frac{1}{2}KA^2}$$

$$K.E = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{dx}{dt}\right)^2$$

$$\boxed{K.E = \frac{1}{2}mv^2}$$

$$= \frac{1}{2}m[A\omega\cos(\omega t+\phi)]^2$$

$$\boxed{K.E = \frac{1}{2}m\omega^2A^2\cos^2(\omega t+\phi)}$$

$$KE = \frac{1}{2}m\omega^2A^2\cos^2(\omega t+\phi)$$

$$K.E_{max} = \frac{1}{2}m\omega^2A^2$$

$$\boxed{K.E_{max} = \frac{1}{2}KA^2}$$

$$\left[\begin{array}{l} \omega = \sqrt{\frac{K}{m}} \\ \omega^2 = \frac{K}{m} \end{array}\right]$$

$$T.E = \frac{1}{2}AK\sin^2(\omega t+\phi) + \frac{1}{2}AK\cos^2(\omega t+\phi)$$

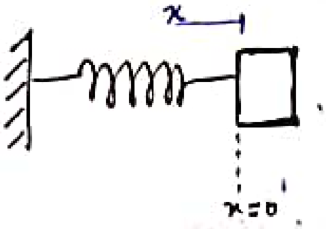
$$= \frac{1}{2}KA^2$$

$$\boxed{T.E = \frac{1}{2}KA^2}$$

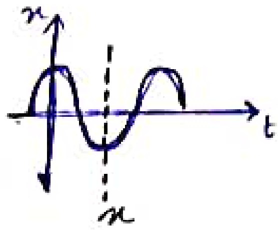
☆ Transfering of Energy of SHM:

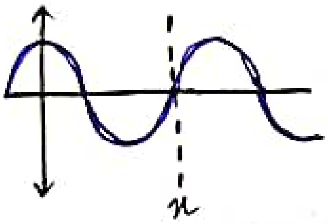
- Total energy is always constant. $E = \frac{1}{2}kA^2$
- Energy is continuously being transfered from P.E in the spring to K.E in the block

QUE:



Velocity is zero
Force is to the left





Velocity is positive
Force is zero

QUE (i) Total distance travelled by m in SHM in T

$\Rightarrow 4A$

(ii) displacement after $T \Rightarrow 0$

(iii) At what point is $v = 0$ and $a = 0$ simultaneously

not possible. [v and a can not be zero at the same time]

QUE: In an SHM, when the m is doubled and A is unchanged, T.E = ?

$T.E \propto A^2$

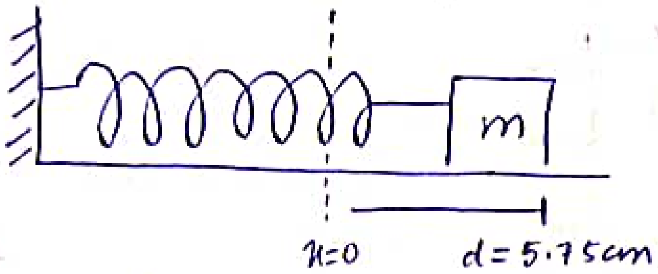
Total energy does not change bcz it does not depend on mass. $\boxed{TE = \frac{1}{2}kA^2}$

QUE: mass oscillating on a vertical spring with T is taken to the moon.

Time period will not change

$\boxed{T = 2\pi\sqrt{\frac{m}{k}}}$ (does not depend on 'g')

Que: 1.55 Kg block sliding on a $\mu = 0$ plane is connected to a horizontal spring of $K = 2.55$ N/cm. Block is pulled to the right by $d = 5.75$cm and released from rest. v after 1.5 s ?



$$x = d = A \sin(\omega t + \phi)$$

$$d = A \sin\phi \quad — ① \qquad (t=0)$$

$$v = \omega_0 A \cos(\omega t + \phi)$$

$$v = \omega_0 A \cos\phi \qquad (t=0)$$

$$[v = 0 \text{ at } t = 0] \text{ (extreme end)}$$

$$\therefore \cos\phi = 0$$

$$\boxed{\phi = \pi/2} \qquad d_{max} = A$$

$$[\cos(\omega t + \pi/2) = -\sin\omega t]$$

$$\Rightarrow \quad \therefore \quad v = -\omega_0 d \sin\omega t$$

$$= -\omega_0 d \sin(\sqrt{K/m}\, t)$$

$$= -\sqrt{\frac{2.55}{1.55}}\,(0.0575) \sin[\omega_0 (1.5)] \qquad \omega = \sqrt{\frac{K}{m}}$$

$$\simeq \ldots$$

Ans: $\boxed{v_{t=1.5s} = 6.92 \text{ cm/s}}$ //

QUE : If displacement of a moving particle at any time is $x = a\cos\omega t + b\sin\omega t$, show that the motion is SHM. If $a = 3$, $b = 4$, $\omega = 2$, find period, v_{max}, a_{max}

$$x = a\cos\omega t + b\sin\omega t$$

$$\frac{dx}{dt} = -a\sin\omega t\,(\omega) + b\omega\cos\omega t$$

$$\frac{d^2x}{dt^2} = -a\omega^2\cos\omega t - b\omega^2\sin\omega t$$

$$= -\omega^2(a\cos\omega t + b\sin\omega t)$$

$$= -\omega^2 x \quad \therefore \text{SHM}$$

$$A_{max} = \sqrt{a^2+b^2} = \sqrt{9+16} = 5\,cm \qquad \boxed{A = 5\,cm}$$

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{2} = \pi \qquad \boxed{T = \pi\,s}$$

$$v_{max} = \omega A = 2\times 5 \qquad \boxed{v_{max} = 10\,cm/s}$$

$$a_{max} = \omega^2 A = 4\times 5 \qquad \boxed{a_{max} = 20\,cm/s}$$

QUE :

$A = 5\,cm \qquad \nu = 1\,Hz$

$x = A\cos(\omega t + \alpha)$

$0 = 5\cos\alpha$

$\cos\alpha = 0$

$\boxed{\alpha = \pi/2}$

$T = \frac{2\pi}{\omega} = 1$

$\boxed{\omega = 2\pi}$

$\Rightarrow x = 5\cos(\omega t + \pi/2)$

(at $t = 8/3\,s$)

$$\frac{dx}{dt} = 5\omega\cos(\omega t + \pi/2)$$

$$v = -5\omega\sin(8\omega/3 + \pi/2)$$

$$v = -10\pi\sin\left(\frac{16\pi}{3} + \frac{\pi}{2}\right)$$

$$= -10\pi\sin\left(\frac{35\pi}{6}\right) = -10\pi\sin\left(6\pi - \frac{\pi}{6}\right)$$

$$= -10\pi\sin(5.83\pi) = -10\pi\sin\left(-\frac{\pi}{6}\right)$$

$$= 10\pi\left[\sin\frac{\pi}{6}\right]$$

$$= 10\pi\left(\frac{1}{2}\right)$$

$$\Rightarrow 5\pi\,cm/s$$

$$\Rightarrow 15.7\,cm/s$$

QUE: $m = 10g$ is placed in a potential field.
$V = (50x^2 + 100)$ ergs/gm. $\vartheta = ?$

$U = mV = 10 \times 10^{-3} \times (50x^2 + 100)$

$\boxed{U = 0.5x^2 + 1}$

$F = -\frac{dU}{dx} = -\frac{d}{dx}(0.5x^2 + 1)$

$U = -F dx$

$F = -(0.5 \times 2)x$

$\boxed{F = -x}$

$F = kx = m\omega^2 x$

$m\omega^2 = 1$

$10^{-2} \times \omega^2 = 1$

$\omega^2 = 100$

$\boxed{\omega = 10}$

$T = \frac{\omega}{2\pi} = \frac{10}{2\pi}$

$\boxed{T = \frac{5}{\pi} s}$

QUE: write eqn of SHM
(i) $\phi_i = 0$ (ii) $\phi_i = \pi/2$ (iii) $A = 5cm$ $T = 8s$.

(i) $x = A\sin(\omega t + \phi)$

$\omega = \frac{2\pi}{T} = \frac{\pi}{6}$

$x = 5\sin(0.785t)$ //

$\boxed{\omega = 0.785 \text{ rad/s}}$

(ii) $x = 5\sin(0.785t + \pi/2)$ //

QUE: $x = 2\sin\left(\frac{\pi t}{2} + \frac{\pi}{4}\right)$ cm. $T = ?$ $V_{max} = ?$

$\omega = \frac{\pi}{2} = \frac{2\pi}{T}$

$\boxed{T = 4s}$ //

$\vartheta = \pi\cos(\omega t + \pi/4)$

$\vartheta = \pi\cos(\pi/2\, t + \pi/4)$

$\boxed{\vartheta_{max} = \pi \text{ cm/s}}$ //

$\boxed{\vartheta_{max} = \omega A = \frac{\pi}{2} \times 2 = \pi \text{ cm/s}}$ //

QUE $T = 31.4s$; $A = 5cm$ $v_{max} = ?$

$T = \frac{2\pi}{\omega}$ $\boxed{\omega = 0.2}$

$\boxed{v_{max} = \omega A = 1 \text{ cm/s}}$

$\boxed{a_{max} = -\omega^2 A = 0.2 \text{cm/s}^2}$

$\boxed{\begin{array}{l} v_{max} = \omega A \\ a_{max} = -\omega^2 A \end{array}}$

QUE : $T = 10s$; $A = 0.1m$

Write the equation. What are phase & displacement at $t = 5s$ after a passage of the particle through its extreme positive elongation. $v_{max} = ?$

$[\omega = \pi/5 \text{ rad/s}]$

$\boxed{v_{max} = \omega A = 2\pi \text{ m/s}}$

$x = A\sin(\omega t + \phi)$

$x = 0.1 \sin(\pi/5 \, t + \phi)$

$t=0$ $A = 0.1 \sin\phi$

[starts at extrem]

$0.1 \sin\phi = 0.1$

$\sin\phi = 1$

$\boxed{\phi = \pi/2}$

* SUPER-POSITION OF WAVES

* HUYGEN'S PRINCIPLE :

- A wave is continuously repeating change or oscillation in matter or in a physical field. Light is also a wave
- Huygen's believed that light was made of waves vibrating up & down ⊥r to direction of motion (ie) transverse waves

$$\boxed{\nu = \frac{1}{\lambda}}$$

* Wave characteristics :

Wavelength (λ) :

distance between 2 crests or 2 troughs is λ (lambda)

Frequency (ν)

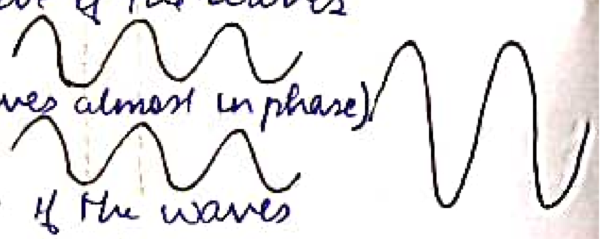
no of waves that pass a ⊥r point in one second.

Amplitude (A)

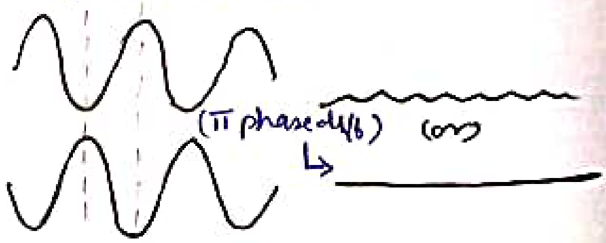
the vertical distance from midline of waves to the top of peak or bottom of troughs.

* Combination of waves :

- Composite wave = 2 waves combined is the algebraic sum of the 2 original waves point by point – (Superposition principle)
  - direction, Amplitude & Phase need to be taken into account while adding
  - phase difference should not be there.
- The interference is constructive if the waves reinforce each other



- The interference is destructive if the waves tend to cancel each other.
- If the phases are exactly opp (ie) π, then the result is nothing since the waves cancel each other completely



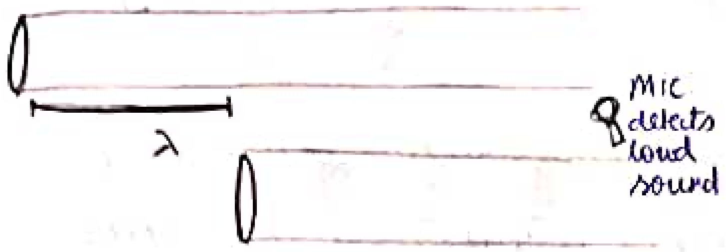
- The resultant Amplitude of the new wave depends on the phase differences of the 2 original waves.

* Coherence :

Coherent sources → same frequency
→ same phase values

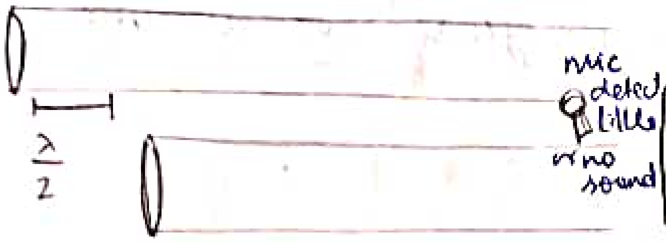
[To keep the phase diff 0 along the length along the dir
of propagation . the frequency

- In phase – peaks line up with peaks, valleys line up with valleys } waves add up and $A_R = A_1 + A_2$
- Ex: sound amplifiers, surround sound



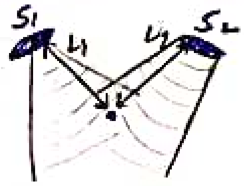
$\boxed{\text{Path diff} = n\lambda \quad \text{constructive interference}}$

(m – odd integer – 2n+1)



$\boxed{\text{Path diff} = \frac{m\lambda}{2} \quad \text{destructive interference}}$

Noise cancellation headphones use destructive interferance.



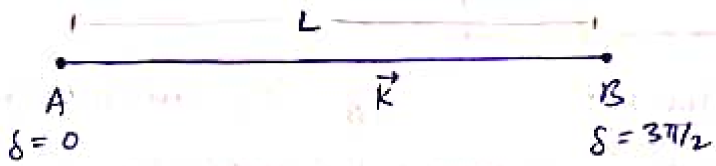
☆ Path difference (ΔL):

- Path difference ΔL is the absolute value of the difference ~~between~~ in the distances from each source to a point being considered.

$$\boxed{\Delta L = |L_1 - L_2|}$$

- We express the path difference in terms of number of wavelengths. Ex: $3\frac{1}{2}\lambda$, 5λ, etc

☆ Theory of Super-position:



- Let light travell from A to B and travells a distance L, its phase changes from 0 to $3\pi/2$.

$$\boxed{\delta = nKL}$$

$$\boxed{\delta = n\frac{2\pi L}{\lambda}}$$

$$\boxed{K = \frac{2\pi}{\lambda}}$$

K – wave vector
λ – wavelength

$\delta \propto n$
$\delta \propto 1/\lambda$
$\delta \propto L$

• Consider a constructive interference situation where Amplitudes of original waves are A & A resp.

$\Rightarrow A_R = A + A = 2A$

$\boxed{A_R = A_1 + A_2}$ $\qquad I \propto |A_R|^2$

$\Rightarrow I_R = (2A)^2 = 4I$

$\boxed{I_R > I_1 + I_2} \rightarrow$ constructive interference

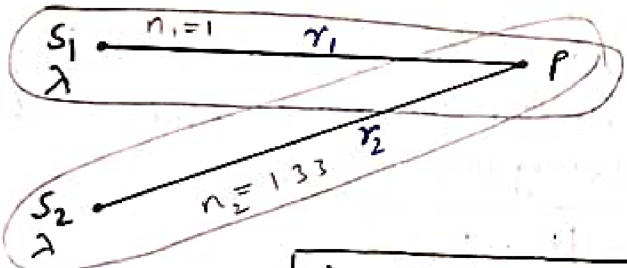
• Consider a destructive interference situation where amplitudes of original waves are A & A resp.

$\Rightarrow A_R = A - A = 0$

$\Rightarrow I_R = (0)^2 = 0$

$\boxed{A_R = A_1 + A_2}$

$\boxed{I_R < I_1 + I_2} \rightarrow$ destructive interference



• Consider 2 coherent sources but in 2 different media of refractive indexes n_1 & n_2 resp.

$\boxed{\Delta = n_2 r_2 - n_1 r_1}$

$\Delta = n\lambda$	$\rightarrow$ constructive
$\Delta = \frac{(2n+1)\lambda}{2}$	$\rightarrow$ Destructive

• $E_A = E_1 \sin \omega t \qquad E_B = E_2 \sin(\omega t + \delta)$

[2 waves of same freq but diff phase]

$E_R = E_1 + E_2 = E_1 \sin\omega t + E_2 \sin(\omega t + \delta)$

$= E_1 \sin\omega t + E_2 (\sin\omega t \cos\delta + \cos\omega t \sin\delta)$

$= \underbrace{(E_1 + E_2\cos\delta)}_{E\cos\phi} \sin\omega t + (E_2 \sin\delta)\cos\omega t$

[Let $E_1 + E_2\cos\delta = E\cos\phi$ — ①
$E_1 \sin\delta = E\sin\phi$ — ②]

$= E\cos\phi \sin\omega t + E\sin\phi\cos\omega t$

$①^2 + ②^2 \Rightarrow (E_1 + E_2\cos\delta)^2 + (E_1 \sin\delta)^2 = E^2\cos^2\phi + E^2\sin^2\phi$

$= E_1^2 + E_2^2\cos^2\delta + 2E_1E_2\cos\delta + E_2^2\sin^2\delta = E^2$

$\Rightarrow E_1^2 + E_2^2 + 2E_1E_2\cos\delta = E^2$

$\boxed{E_R^2 = E_1^2 + E_2^2 + 2E_1E_2\cos\delta}$

$\boxed{I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta}$

- $\boxed{\delta = \frac{2\pi n L}{\lambda}}$ $\boxed{K = \frac{2\pi}{\lambda}}$

- Constructive:

  $\boxed{\Delta = n\lambda}$

  $A_R = A_1 + A_2$

  $I_R > I_1 + I_2$

  Destructive:

  $\boxed{\Delta = \frac{(2n+1)\lambda}{2}}$

  $A_R = A_1 + A_2$

  $I_R < I_1 + I_2$

- $\boxed{E_R^2 = E_1^2 + E_2^2 + 2E_1E_2 \cos\delta}$

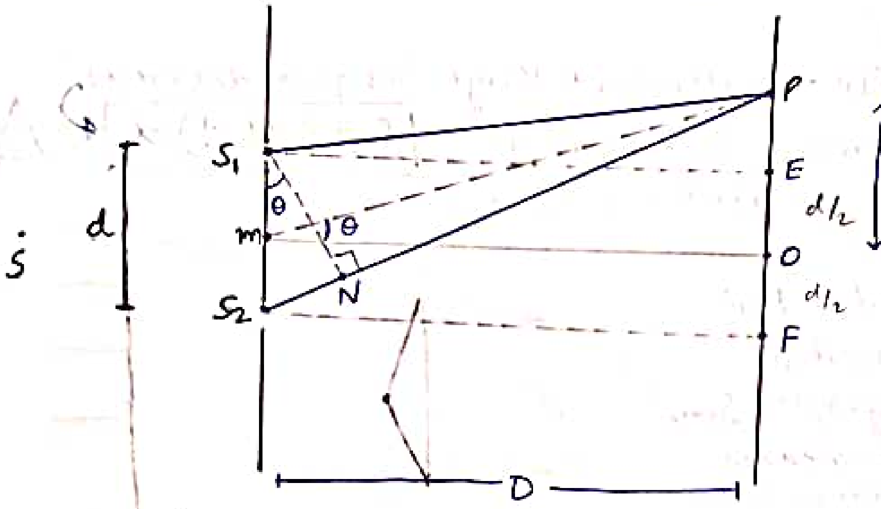
- $\boxed{I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta}$

$\boxed{I_{max} = 4I}$ $\boxed{I_{min} = 0}$

★ YOUNG'S DOUBLE SLIT EXPERIMENT:

Describes the wave nature of light and demonstrates the interference of light.

The results can be proved only by taking light as wave.



$S_1P = NP$
(S_2N is path diff)

In ΔS_1PE;

$PE = x - d/2$

$(S_1P)^2 = D^2 + (x - d/2)^2$

In ΔS_2PF;

$PF = x + d/2$

$(S_2P)^2 = D^2 + (x + d/2)^2$

$$(S_2P)^2 - (S_1P)^2 = D^2 - D^2 + x^2 + \left(\frac{d}{2}\right)^2 + xd - x^2 - \left(\frac{d}{2}\right)^2 + xd$$

$$(S_2P)^2 - (S_1P)^2 = 2dx$$

$$(S_2P - S_1P)(S_2P + S_1P) = 2xd$$

$$S_2P - S_1P = \frac{2xd}{S_2P + S_1P}$$

$$S_2P - S_1P = \frac{2xd}{D + D} = \frac{xd}{D}$$

$$S_2P - S_1P = \frac{xd}{D}$$

$$x_m = \frac{m\lambda D}{d} \qquad x_{m+1} = \frac{(m+1)\lambda D}{d}$$

(Fringe width) $\boxed{\beta = \frac{\lambda D}{d}}$

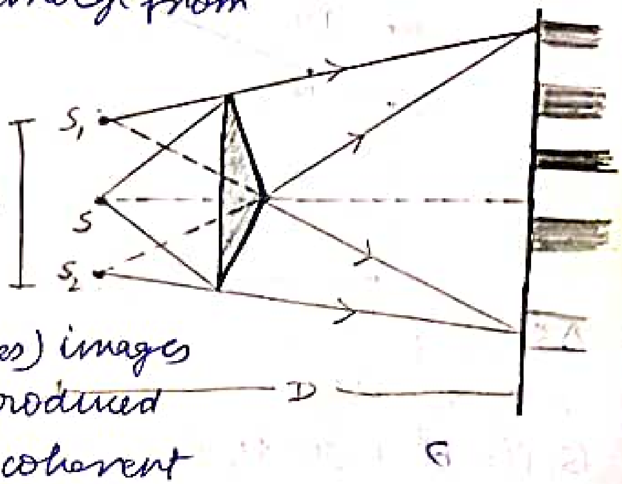
$d\sin\theta = m\lambda$ → constructive (maxima)

$d\sin\theta = \frac{2m+1}{2}\lambda$ → Destructive (minima)

Light can hold coherent only for a limit and thus intensity gradually fades to zero.

✯ FRESNEL'S BIPRISM:

- Biprism consists of 2 prisms of very small refractive angles joined base to base
  - Usually 2 side angles are 30′ (0.5°) and other angle is 179°
  - ordinary prism – ray is bent through 'angle of deviation'. $\boxed{\delta = (\mu - 1)\alpha}$
  - But in a Biprism; the ray coming out of prism, appears to emerge from a source S
  - Then it is said to that prism produced a virtual image of the Source
  - Then biprism creates 2 virtual sources S_1, S_2
  - S_1 & S_2 are (virtual sources) images of the same source S produced by 'Refraction'. They are coherent



$$\boxed{\frac{xd}{D} = m\lambda}$$

(Bright fringe)

$$\boxed{\frac{xd}{D} = (2m+1)\frac{\lambda}{2}}$$

Dark fringe

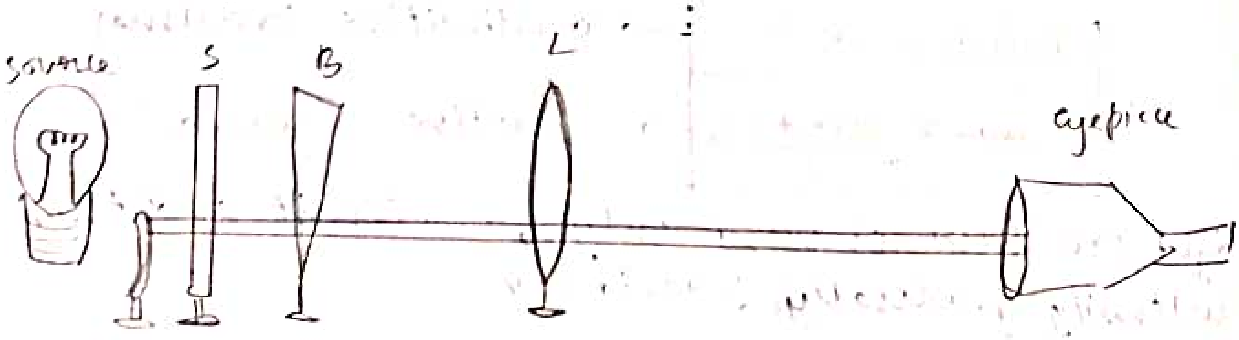
$$x_m = \frac{m\lambda D}{d} \qquad x_{m+1} = \frac{(m+1)\lambda D}{d}$$

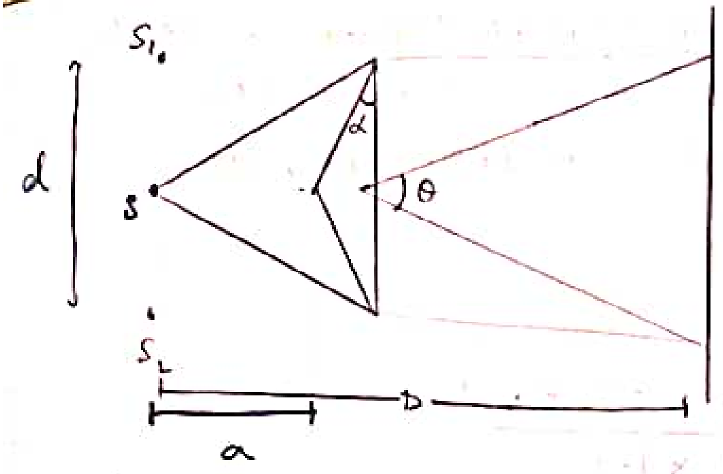
$$\beta = x_m - x_{m+1} = \frac{\lambda D}{d}$$

$$\boxed{\beta = \frac{\lambda D}{d}}$$ ⇒ Fringe width.

~~Expt~~ (Experimental arrangement)

- Biprism mounted on an optical bench – (2 horizontal ∥el rods)
- (Blah)





$\boxed{\delta = \frac{\theta}{2}}$ $\boxed{\theta = \frac{d}{a}}$

$\delta = (\mu - 1)\alpha$

$\theta/_2 = (\mu-1)\alpha = \frac{d}{2a} = (\mu-1)\alpha$

$d = 2a\,(\mu-1)\alpha$

$\boxed{d = 2a(\mu-1)\alpha}$ (a → source to prism)

$\boxed{t = \frac{x d}{D(\mu-1)}}$ (thickness of mica sheet)

$\boxed{d = \sqrt{d_1 d_2} = 2a(\mu-1)\alpha}$

QUE: Viewing screen is ... separated from a double slit by 1.2m. d = 0.030 nm. second order bright fringe (m=2) is 4.5cm from center line.

(a) $\lambda = ?$ (b)

$$x = \frac{m\lambda D}{d}$$

$$\lambda = \frac{xd}{mD} = \frac{0.045 \times 0.030 \times 10^{-9}}{2 \times 1.2}$$

$$= \frac{4.5 \times 3 \times 10^{-13}}{2 \times 1.2}$$

$$= 5.625 \times 10^{-13}$$

$\Rightarrow$

QUE: Screen placed 13.7 m apart. 3rd order fringe is seen 2.50 cm from central. d = 0.960 cm. $\lambda = ?$

$D = 13.7\ m$ $\quad x = 2.50\,cm = 0.025\,m$

$d = 0.0096\ m$

$$x = \frac{3\lambda D}{d} = \frac{3\lambda(13.7)}{96 \times 10^{-4}} = 25 \times 10^{-3}$$

$$\lambda = \frac{25 \times 96 \times 10^{-7}}{13.7 \times 3}$$

$$\lambda = 5.84 \times 10^{-7} m$$

$$\boxed{\lambda = 584\ nm}$$

QUE: How far ~~will~~ from the central fringe the first order violet ($\lambda = 350$ nm) & Red ($\lambda = 700$ nm)

$D = 10\,m$ $\quad d = 0.50\,cm$

$$x_V = \frac{\lambda m D}{d} = \frac{350 \times 10^{-9} \times 1 \times 10}{0.05 \times 10^{-2}} \Rightarrow 0.007\ m$$

$$x_R = \frac{\lambda m D}{d} = \frac{700 \times 10^{-9} \times 1 \times 10}{0.05 \times 10^{-2}} \Rightarrow 0.014\ m$$

QUE: If yellow light with $\lambda = 540\,nm$ shines on a double slit; $d = 0.01$ mm $\theta = ?$ $n=2$

$$\boxed{\sin\theta = \frac{x}{D}}$$

$$\left[\sin\theta = \frac{x}{D}\right]$$

$$x = \frac{\lambda m D}{d} = \frac{540 \times 2 \times D \times 10^{-9}}{1 \times 10^{-}}$$

$$\lambda = \frac{d}{m} \times \frac{x}{D} = \frac{d}{m}\sin\theta$$

$$\sin\theta = \frac{2 \times 540 \times 10^{-9}}{10^{-5}} = 1080 \times 10^{-4}$$

$$\sin\theta \approx \frac{1}{10}$$

$$\boxed{\theta = \sin^{-1}(1/10)} \qquad \boxed{\theta \approx 6.20}$$

QUE: Distance between adjacent dark spots from a double slit; $\lambda = 500\,nm$; $d = 1\,mm$; $D = 2\,m$

$\theta = ?$

$$\text{distance} = \frac{2\lambda D}{d} - \frac{\lambda D}{d} = \frac{\lambda D}{d}$$

$$\boxed{\beta = \frac{\lambda D}{d}} \Rightarrow \quad = \frac{500 \times 2 \times 10^{-9}}{10^{-3}}$$

$$= 1000 \times 10^{-6}$$

$$\boxed{y = 10^{-3}\,m}$$

$$\sin\theta_1 = \frac{x}{D} = \frac{\lambda D}{d D} = \frac{\lambda}{d} = \frac{500}{10^{-3}} \times 10^{-9} = 500 \times 10^{-6}$$

$$\sin\theta_1 = 5 \times 10^{-4}$$

Ans: $\boxed{\theta_1 = \sin^{-1}(5 \times 10^{-4}) \Rightarrow 0.0286}$ //

$$m\lambda = d\sin\theta$$

$$\theta = \sin^{-1}\left(\frac{m\lambda}{d}\right)$$

$$\sin\theta = \frac{1 \times 500 \times 10^{-9}}{10^{-3}}$$

$$\sin\theta = 5 \times 10^{-4}$$

$$\boxed{\theta = 0.0286^\circ}$$ //

QUE : Biprism exp ; refracting angles ⇒ 1.5 ; $\mu = 1.5$
with single slit of 5cm from biprism ; $\lambda = 580 nm$;
fringes were formed 1m from the slit. fringe width = ?

$\mu = 1.5$ $a = 5 cm$

$\boxed{d = \sqrt{d_1 d_2}}$

$\alpha = 1.5 \times \frac{\pi}{180}$

$d = 2 \times 5 \times 10^{-2} (1.5 - 1) \left(\frac{1.5 \times \pi}{180}\right)$

$\boxed{d = 0.13 \times 10^{-2} m}$ //

$\boxed{\beta = \frac{\lambda D}{d}}$

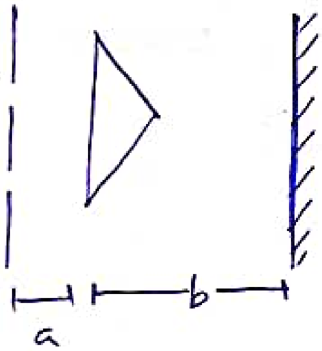
$\beta = \frac{\lambda D}{d} = \frac{580 \times 1}{0.13 \times 10^{-2}}$

$\boxed{d = 2a(\mu - 1)\alpha}$

$\boxed{\beta = 4461.5 \times 10^{-7} m}$ //

QUE : $a = 25 cm$ (biprism to slit) $b = 100 cm$ (slit to screen) $\alpha = 20'$

$\beta = 0.55 mm$



$\boxed{\Delta x = \beta = \frac{D\lambda}{d}}$

→ $\Delta x = \frac{l\lambda}{d}$ $[l = a + b = 125 cm]$

$\Delta x = \frac{125 \times \lambda}{d}$

→ $\boxed{d = 2a(\mu - 1)\alpha}$

$= 2 \times 0.25 (1.5 - 1) \; 20 \times \pi/180$

$= 0.25 \times \pi/9$

→ $\Delta x = \frac{l\lambda}{d} = \frac{1.25 \times \lambda}{0.25 \times \pi/9} = \beta$

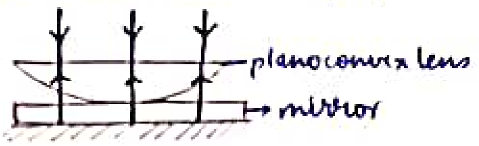
$\lambda = \frac{0.25 \times \frac{\pi}{9} \times \beta}{1.25}$

$\lambda = \frac{25 \times \pi \times 0.55 \times 10^{-3}}{9 \times 125}$

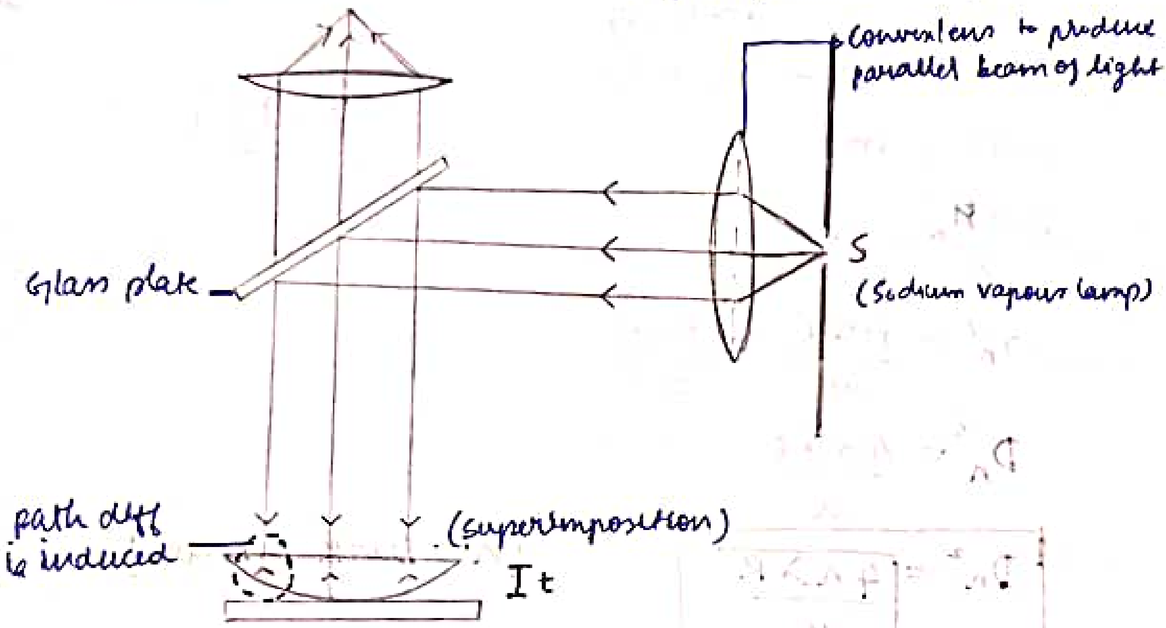
Ans : $\boxed{\lambda = 0.64 \times 10^{-6} m}$ //

* NEWTON'S RING:

- Used to calculate the refractive index of the given material.
- Works based on superposition principle of wave



[partially the light will pass through the lens and partially get reflected back by the mirror]



$$\boxed{\Delta = 2\mu t \cos(r+\theta) - \lambda/2}$$

$$\boxed{\Delta = 2\mu t - \lambda/2}$$

Constructive $\Rightarrow$ $\boxed{2\mu t - \lambda/2 = m\lambda}$

Destructive $\Rightarrow$ $\boxed{2\mu t = (2m+1)\lambda/2}$

Conclusion: The central fringe will be dark for Newton's ring

* For constructive interference;

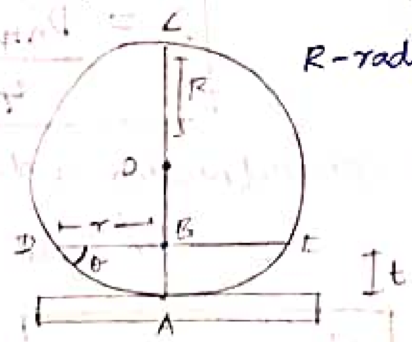
$$r \times r = t(2R - t)$$

$$r^2 = 2Rt - t^2 \qquad t^2 \simeq 0$$

$$r^2 = 2Rt$$

$$\boxed{t = \frac{r^2}{2R}} \quad —(1)$$

R-radius



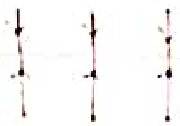
$DB \times BE = AB \times BC$

$$\Delta = \frac{2\mu r_n^2}{2R} = \frac{(2n+1)\lambda}{2}$$

$$r_n^2 = \frac{(2n+1)\lambda R}{2\mu} = \frac{D_n^2}{4}$$

$$D_n^2 = \frac{4(2n+1)\lambda R}{2\mu} = \frac{2(2n+1)\lambda R}{\mu}$$

$$\boxed{D_n = \sqrt{\frac{2(2n+1)\lambda R}{\mu}}} \quad \text{—②} \quad [n^{th} \text{ Bright fringe}]$$



☆ For destructive interference;

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

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

$$2\mu t = n\lambda \qquad \left[t = \frac{r^2}{2R}\right]$$

$$\frac{2\mu r_n^2}{2R} = n\lambda$$

$$r_n^2 = \frac{n\lambda R}{\mu} = \left(\frac{D_n}{2}\right)^2$$

$$D_n^2 = \frac{4n\lambda R}{\mu}$$

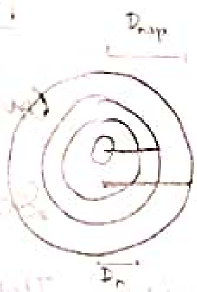
$$\boxed{D_n = \sqrt{\frac{4n\lambda R}{\mu}}} \qquad [n^{th} \text{ Dark fringe}]$$

☆ For wavelength;

$$D_n^2 = \frac{4n\lambda R}{\mu} \quad ; \quad D_{n+p}^2 = \frac{4(n+p)\lambda R}{\mu}$$

$$D_{n+p}^2 - D_n^2 = \frac{4p\lambda R}{\mu}$$

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR} \qquad [\mu = 1]$$



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

☆ For refractive index;

$$(D_n^2)_{med} = \frac{4n\lambda R}{\mu} \quad ; \quad (D_n^2)_{air} = 4n\lambda R$$

$$\boxed{\frac{(D_n^2)_{air}}{(D_n^2)_{med}} = \mu}$$

* DIFFRACTION :
(Bending of light)

- For a single slit diffraction, when the slit width decreases the number of observable fringes
  Lesser width of slit → more fast drop on intensities

[single slit] ⇒ $\boxed{I = I_0\left(\frac{\sin\alpha}{\alpha}\right)^2}$ $\left[\alpha = \pi\frac{a\sin\theta}{\lambda}\right]$

mth minima when ⇒ $\boxed{\sin\theta = \frac{m\lambda}{a}}$ [d – dist btw 2 slits]

[multi slit] $\boxed{I = I_0\left(\frac{\sin\beta}{\beta}\right)^2\cos^2\gamma}$ $\left[\beta = \frac{\pi}{\lambda}b\sin\theta\right]$

$\left[\gamma = \frac{\pi}{\lambda}d\sin\theta\right]$ $(N>1)$ ↓ no. slit

$\boxed{\text{phase diff } \Delta\phi = 2\pi\frac{\text{path diff}}{\lambda}}$

- When no. of slits is increased, the θ – diffraction angle also increases.

$$\boxed{\frac{\Delta\theta}{\Delta\lambda} = \frac{m}{d\cos\theta}}$$

- Diffraction is a wave effect. (explained interms of Huygen's principle
- "Diffraction" is the bending of waves around obstacles or the edges of an opening. (spreading of wavefronts as they pass the edge of an object.
- Single slit fringe pattern – alternate B & D fringes and fringes fade away from 'centre bright'. (series of narrower less intense secondary bands – 'secondary maxima')
- In terms of Heygen's principle, each point on a wavefront can be considered as a source of a new wave. (wavelets)
- For single slit diffraction;

$\boxed{a\sin\theta = m\lambda}$ [dark fringes – minima]

$\boxed{I(\theta) = I_m\left(\frac{\sin(\phi/2)}{\phi/2}\right)^2}$ $\boxed{\frac{\phi}{2} = \frac{\pi}{\lambda}a\sin\theta} \Rightarrow m\lambda$

maxima ⇒ $\boxed{a \sin\theta = \frac{(2m+1)\lambda}{2}}$: $m \in N$

minima ⇒ $\boxed{a \sin\theta = m\lambda}$ $m \in N$

QUE: Single slit; width 1.50 µm ; $\lambda = 500$ nm
Find angular width of central maxima

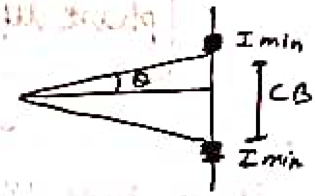
Spread of the maximum is from 1st order minima from either sides.

$$\sin\theta = \frac{\lambda}{b} = \frac{500 \times 10^{-9}}{1.5 \times 10^{-6}} = 0.333$$

$$\theta = \sin^{-1}(0.333)$$

$\boxed{\theta = 19.5^\circ}$ (or (0.34 rad)).//

$b \sin\theta = m\lambda$ (for one minima)



∴ Angle difference $= \theta + \theta = 2\theta$

Ans : Angular width ⇒ 39° //

QUE: 580 nm light incident on slit 0.30 mm
D = 2m . Position of first minima

$b \sin\theta = (1)\lambda$

$$\sin\theta = \lambda / b = \frac{580 \times 10^{-9}}{0.3 \times 10^{-3}} = 1.9 \times 10^{-3}$$

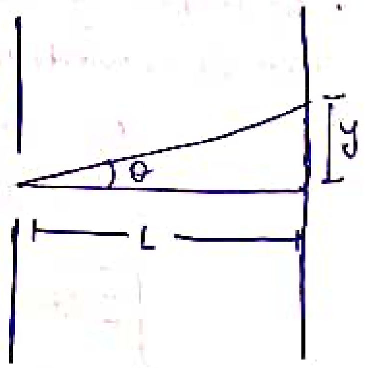
$\sin\theta \approx \theta \Rightarrow 1.9 \times 10^{-3}$

For small angles; $\sin\theta \approx \tan\theta$

$\therefore \tan\theta = \frac{y}{L}$; $[L = D = 2m]$

$y = L\tan\theta = 2 \times 1.9 \times 10^{-3}$

Ans: $\boxed{y = 3.8 \times 10^{-3}\, m}$ //



★ Diffraction and Interference by a double slit:

$$I = I(\text{double slit interference}) \times I(\text{diffraction})$$

$$\boxed{I(\theta) = I_m \cos^2(\beta) \times \frac{\sin^2\alpha}{\alpha^2}}$$

$\boxed{\beta = \frac{\pi d \sin\theta}{\lambda}}$ $\boxed{d\sin\theta = m\lambda}$ $m = 0, 1, 2 \ldots$ [constructive] [maxima]

$\boxed{\alpha = \frac{\pi a \sin\theta}{\lambda}}$ $\boxed{a\sin\theta = m\lambda}$ $m = 1, 2, 3, \ldots$ [destructive] [minima]

[a - slit width
d - distance between the 2 slits]

QUE: Screen is sep from a double slit source by 1.2 m
$d = 0.030$ mm. 2nd order maxima is 4.5 cm from C.B.
$\lambda = ?$ $L = 1.2\,m$; $d = 3\times10^{-5}\,m$; $y = 0.045\,m$

$\tan\theta = y/L$

$\theta = \tan^{-1}\left(\frac{y}{L}\right) = \tan^{-1}\left(\frac{0.045}{1.2}\right) = 2.15°$ //

$d\sin\theta = m\lambda$

$3\times10^{-5} \times \sin(2.15°) = 2\lambda$

Ans: $\boxed{\lambda = 5.62\times10^{-7}\,m}$ //

NOTE:
As the number of slits grow, the peaks become narrower & more intense.

QUE: A grating consists of 4000 slits per cm. Produces 2nd order bright line at 30° $\lambda = ?$

No. slits per cm = 4000

d = dist between slits = —— $= 0.00025\,cm = 2.5\times10^{-6}\,m$

order (n) = 2

$$d\sin\theta = n\lambda$$

$$2.5\times10^{-6} \times \sin(30°) = 2\lambda$$

$$\lambda = 2.5 \times \frac{1}{2} \times \frac{1}{2} \times 10^{-6} = 0.625\times10^{-6}$$

Ans: $\boxed{\lambda = 6250\,\text{Å}}$ //

QUE: $\lambda = 2.5 \times 10^{-7} m$; 10,000 slits / cm ; 2nd bright Q.?

$d = \frac{1}{10k} = 0.0001 cm = 10^{-6} m$ } $n\lambda = d\sin\theta$; $2\lambda = 10^{-6}\sin\theta$

$\sin\theta = \frac{2 \times 2.5 \times 10^{-7}}{10^{-6}} = 0.5 = \frac{1}{2}$ Ans $\boxed{\theta = 30^\circ}$ //

QUE: $\lambda = 5 \times 10^{-7} m$; $L = 2m$; $y_3 = 1.5m$; $d = ?$

$\sin\theta \simeq \tan\theta = \frac{y}{L} = \frac{1.5}{2} = 0.75 = 75 \times 10^{-2}$

$d\sin\theta = n\lambda$

$d = \frac{3 \times 5 \times 10^{-7}}{75 \times 10^{-2}}$ } $d = 2 \times 10^{-6} m$

$\boxed{d = 2 \mu m}$ //

QUE: $\lambda = 500 nm$; $\theta_{4B} = 30^\circ$; no. slits per cm = ?

(i) $d\sin\theta = n\lambda$

$d \times \frac{1}{2} = 4 \times 500 \times 10^{-9} = 40 \times 100 \times 10^{-9} \Rightarrow \boxed{d = 4 \times 10^{-6} m}$

$\boxed{d = 4 \times 10^{-4} cm}$ no. slits per cm $\Rightarrow \frac{1}{d} = \frac{1}{4 \times 10^{-4}}$

Ans: No. slits per cm ⇒ 2500 //

(ii) $\theta_2 = 30^\circ$ $\frac{d}{2} = 2 \times 500 \times 10^{-9}$ } $2000 \times 10^{-9} =$

$\boxed{d = 2 \times 10^{-4} m}$ ⇒ no. slits per cm ⇒ 5000. //

QUE.: $\lambda = 450 nm$; $L = 1.8m$; Dist between dark fringes on either side of C.B = 4.2mm.

(i) $d = ?$ (ii) no. slits / m = ?

$\theta = \tan^{-1}(y/L) = \left(\frac{4.2}{2} \times 10^{-3}\right) \times \frac{1}{1.8}$

$\Rightarrow \tan^{-1}\left(\frac{0.0021}{1.8}\right) = 0.067^\circ$ //

$d\sin\theta = \left(\frac{2m+1}{2}\right)\lambda$

$d = \frac{1}{2} \times 450 \times 10^{-9} \times \sin(0.067^\circ)$

$d = 0.0001924 m$

$\Rightarrow \boxed{d = 1.924 \times 10^{-4} m}$ //

$d = \frac{metres}{line}$

$\frac{lines}{metre} = d^{-1} = \frac{1}{0.0001924}$

$\boxed{\text{no. lines/m} \Rightarrow 5197.2}$ //

d

plates)

lled

d the corners

ter shadow region.

superimposed, form an interference pattern.

• 2 independant coherent waves superimpose.

• Fringes are of uniform I. All bright fringes equally bright

• Good contrast between the maxima & minima

• Constructive ⇒ $\boxed{n\lambda = d\sin\theta}$ 0, 1, 2, 3.

Destructive ⇒ $\boxed{\frac{(2n+1)\lambda}{2} = d\sin\theta}$

• Wavelets result in diffraction

• C.B is max width and subsequent maximas have diminishing I.

• comparitively poor contrast between maxima & minima.

• Constructive ⇒ $\boxed{(2n+1)\frac{\lambda}{2} = d\sin\theta}$ (n = 1, 2, 3...)

Destructive ⇒ $\boxed{n\lambda = d\sin\theta}$ (1, 2, 3...)

QUE: $\lambda = 2.5 \times 10^{-7} m$; 10,000 slits / cm ; 2nd bright θ ?

$d = \frac{1}{10k} = 0.0001 cm = 10^{-6} m$ $\Big\}$ $n\lambda = d\sin\theta$
$2\lambda = 10^{-6} \sin\theta$

$\sin\theta = \frac{2 \times 2.5 \times 10^{-7}}{10^{-6}} = 0.5 = \frac{1}{2}$ Ans $\boxed{\theta = 30^\circ}$ //

QUE: $\lambda = 5 \times 10^{-7} m$; $L = 2m$; $y_3 = 1.5m$; $d = ?$

$\sin\theta \simeq \tan\theta = \frac{y}{L} = \frac{1.5}{2} = 0.75 = 75 \times 10^{-2}$

$d\sin\theta = n\lambda$

$d = \frac{3 \times 5 \times 10^{-7}}{75 \times 10^{-2}}$ $\Big\}$ $d = 2 \times 10^{-6} m$

$\boxed{d = 2 \mu m}$ //

QUE: $\lambda = 500 nm$; $\theta_{4B} = 30^\circ$; no. slits per cm = ?

(i) $d\sin\theta = n\lambda$

$d \times \frac{1}{2} = 4 \times 500 \times 10^{-9} = 40 \times 100 \times 10^{-9} \Rightarrow \boxed{d = 4 \times 10^{-6} m}$

$\frac{1}{4 \times 10^{-4}}$

//

- Diffraction observed at small distances is called "near field diffraction" or "Fresnel diffraction". (Zone plates)
Diffraction observed at larger distances are called "far-field diffractions" or "Fraunhofer diffraction".

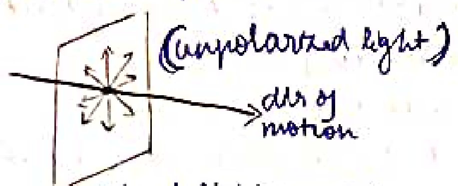
☆

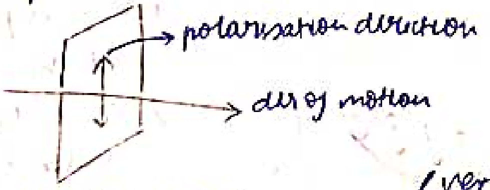
Interference	Diffraction
• Two or more waves travelling in forward direction when superimposed, form an interference pattern.	• Light bends around the corners of sharp edge and enter shadow region.
• 2 independent coherent waves superimpose.	• Wavelets result in diffraction
• Fringes are of uniform I. All bright fringes equally bright	• C.B is max width and subsequent maximas have diminishing I.
• Good contrast between the maxima & minima	• comparatively poor contrast between maxima & minima.
• Constructive $\Rightarrow$ $\boxed{n\lambda = d\sin\theta}$ 0,1,2,3...	• Constructive $\Rightarrow$ $\boxed{(2n+1)\frac{\lambda}{2} = d\sin\theta}$ ($n = 1,2,3...$)
Destructive $\Rightarrow$ $\boxed{(2n+1)\frac{\lambda}{2} = d\sin\theta}$	Destructive $\Rightarrow$ $\boxed{n\lambda = d\sin\theta}$ (1,2,3....)

UNIT - II

BASIC IDEA OF ELECTROMAGNETISM

- Electromagnetic waves have both electric and magnetic fields that oscillate perpendicularly. (Transverse wave)
- Light should be considered as an electromagnetic wave
- What happens when unpolarised light encounteres a filter?





(vertical polarized light)

Unpolarised light means the waves have polarisations in all directions.

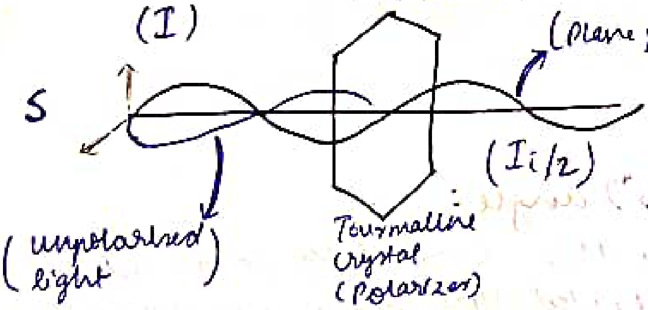
Polarization is indicated with a double headed arrow

- Direction of propagation $\Rightarrow \vec{c}$

$$\vec{E} \perp \vec{B} \perp \vec{c}$$

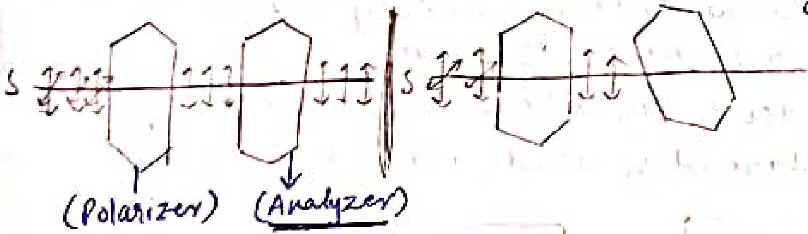
- Controlling a light wave or any em wave to vibrate in one specific dir by making it pass though a filter made out of polaroid material is called "Polarization"

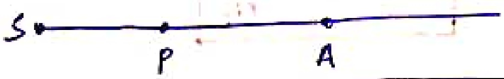
↳ polarizer.

- 

- The direction of $\vec{E}$ in the em wave is called the polarization direction.
- Polaroid filter absorbs light polarised along one axis & transmits light polarized along the other.

- How to check if polarized?



- 

I_i $\quad\quad$ $\frac{I_i}{2}$ $\quad\quad$ $\boxed{I_f = \frac{1}{2} I_i \cos^2\theta}$

$$\boxed{I = I_o \cos^2\theta}$$

(Law of Malus)

[Applicable only of Analyser]

★ Polarization by reflection:

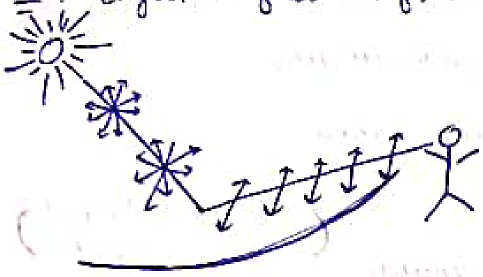
- When unpolarized light beam is reflected from a surface, the reflected light can be completely polarized or partially polarized or Unpolarized
- Depends on angle of incidence θ:

If $\theta = 0°$; reflected beam is unpolarised.

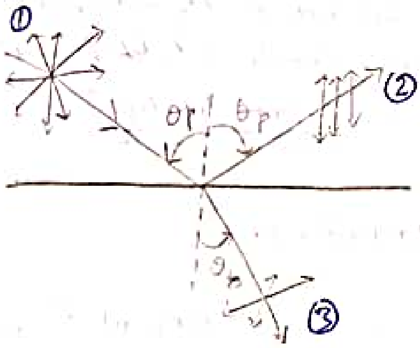
$0 < \theta < 90°$; partially polarized.

one particular angle; completely polarized [polarizing angle]

Ex: Light reflected from a lake is partially horizontally polarized



1. If unpolarized light is incident at the polarizing angle
2. Then the reflected light is 100% polarized $\perp$r to plane of incidence
3. The transmitted light is partly polarized $\parallel$el to plane of incidence
4. Alternatively if unpolarized light is incident on the reflecting surface at an angle other than θ_p, the reflected light is partly polarized.



★ Polarizing ("Brewster's") angle:

- Light in a reflection will be completely polarized if the reflected and refracted rays make a 90° angle
- The incident angle required to achieve this is called the polarizing or Brewster angle, and depends on the ref indices of refraction of the media.
- The angle of incidence for which the reflected ray is completely polarized is called polarizing angle (θ_p)

$$\boxed{\frac{\sin\theta_p}{\sin\theta_2} = \frac{n_2}{n_1}} \qquad \boxed{\tan\theta_p = \frac{n_2}{n_1}}$$

$[\theta_2 = 90° - \theta_p]$

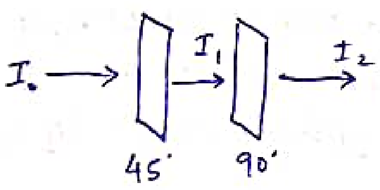
☆ Selective absorption:

- A material that polarizes light through selective absorption is called a "Polaroid".
- The molecules readily absorb light whose $\vec{E}$ is parallel to their lengths and transmit light whose $\vec{E}$ is $\perp r$ to their lengths.

- When unpolarised light passes through polaroid filter;
  - → half the intensity is absorbed by the filter
  - → The transmitted light becomes linearly polarized in the same direction as the filter's polarising axis.
- When linearly polarized light passes through the filter;
  - → The intensity is reduced depending on ϕ, the angle between the polarization direction and polarizing axis. $\boxed{I = I_0 \cos^2\phi}$
  - → The transmitted light becomes linearly polarised in the dir of the filter's polarizing axis.

- If light (any) is passed through 2 ideal polaroid filters with $\perp r$ polarization axes, it will be completely absorbed. (Principle behind sunglasses)

<u>QUE</u>: 3 polarizing filters are stacked with p'ing axis of 2nd and 3rd filters at 45° & 90° resp.



$$\cancel{I_1 = I_0 \cos^2 45° = I_0/2}$$
$$\cancel{I_2 = I_1 \cos^2 90° = I_1 \times 0 = 0 \ //}$$
$$\cancel{\therefore \boxed{I_2 = 0} \ //}$$

$$I_1 = I_0 \cos^2 45 = I_0/2$$
$$I_2 = I_1 \cos^2 45 = I_0/2 \times 1/2 = I_0/4$$
$$I_0 = I/2$$
$$\therefore \boxed{I_2 = I/8} \ //$$

$$\boxed{E_x = E_0 \sin(kz - \omega t)}$$
$$\boxed{B_y = B_0 \sin(kz - \omega t)}$$

$$\boxed{\omega = Kc}$$

$$\boxed{c = \frac{E_0}{B_0}}$$

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}}$$

$\vec{E}$ determines the polarization

$$E = \hat{e}\, E_0 \sin(kz - \omega t + \phi)$$
$$E_x = E_0 \cos\theta \sin(kz - \omega t + \phi)$$
$$E_y = E_0 \sin\theta \sin(kz - \omega t + \phi)$$

- $\boxed{\omega = KC}$ $\quad \boxed{C = \frac{E_0}{B_0} = \frac{1}{\sqrt{\mu_0 E_0}}}$

★ Polarization → Linear polarization / Circular polarization / Elliptical polarization

- For linearly polarized light the $\vec{E}$ and $\vec{B}$ are in phase and the resultant vector oscillates linearly.
- When we shift one of the component by quarter cycle; (ie) [phase difference = $\pi/2 = 90°$]
  Here, the resultant vector appears to be rotating either in clockwise or anti-clockwise direction. This light is called "circular polarised light."
- In circularly polarized light, if the amplitude of the waves $\vec{E}$ and $\vec{B}$ are different, then the resultant vector moves (or rotates like an ellipse and this is called "elliptically polarized light" [phase diff = $\pi/2 = 90°$]

★ Wave plate:

- Optical device - bifringent crystal with chosen thickness
- Light polarized along the extraordinary / fast axis propagates faster than the ordinary / slow axis.

Phase shift $\boxed{\phi = \frac{2\pi \Delta n L}{\lambda}}$ $\quad \boxed{\phi = nKL}$

color of light

ref index

thickness of crystal

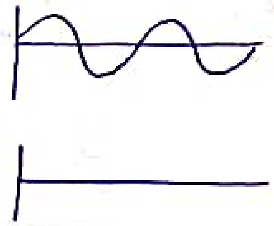
Making ϕ_x diff from ϕ causes circular polarization

31 28

Ex: $\phi_x - \phi_y = \pi/2$ $\quad \boxed{\theta = 45°}$

$$\boxed{E_x = \frac{E_0}{\sqrt{2}} \cos(Kz - \omega t)} \quad \boxed{E_y = \frac{E_0}{\sqrt{2}} \sin(Kz - \omega t)}$$

$$y = a_1 \sin(\omega t - \alpha_1)$$
$$z = a_2 \sin(\omega t - \alpha_2) \qquad [\alpha_1 - \alpha_2 = \phi]$$



$$\Rightarrow \frac{y}{a_1} = \sin\omega t \cos\alpha_1 - \cos\omega t \sin\alpha_1 \quad \text{—(1)}$$

$$\Rightarrow \frac{z}{a_2} = \sin\omega t \cos\alpha_2 - \cos\omega t \sin\alpha_2 \quad \text{—(2)}$$

$$\frac{y}{a_1}\sin\alpha_2 = (\sin\alpha_2)(\,''\,) \quad \text{—(3)}$$

$$= \frac{z}{a_2}\sin\alpha_1 = (\sin\alpha_1)(\,''\,) \quad \text{—(4)}$$

(4) − (3)

$$\frac{z}{a_2}\sin\alpha_1 - \frac{y}{a_1}\sin\alpha_2 = \sin\omega t\,(\cos\alpha_2 \sin\alpha_1 - \sin\alpha_2\cos\alpha_1) \quad \text{—(5)}$$

$$= \frac{y}{a_1}\cos\alpha_2 = (\cos\alpha_2)(\,''\,) \quad \text{—(6)}$$

$$= \frac{z}{a_2}\cos\alpha_1 = (\cos\alpha_1)(\,''\,) \quad \text{—(7)}$$

(6) − (7)

$$\frac{y}{a_1}\cos\alpha_2 - \frac{z}{a_2}\cos\alpha_1 = -\cos\omega t\,(\cos\alpha_2 \sin\alpha_1 - \cos\alpha_1 \sin\alpha_2) \quad \text{—(8)}$$

$(6)^2 + (8)^2$

$$\left[\frac{y}{a_1}\cos\alpha_2 - \frac{z}{a_2}\cos\alpha_1\right]^2 = \cos^2\omega t\,(\cos\alpha_2\sin\alpha_1 - \cos\alpha_1\sin\alpha_2)^2$$

$$\left[\frac{z}{a_2}\sin\alpha_2 - \frac{y}{a_1}\sin\alpha_1\right]^2 = \sin^2\omega t\,(\cos\alpha_2 \sin 2 - \sin\alpha_2\cos\alpha_1)^2$$

$$\left.\begin{aligned}&\frac{y^2}{a_1^2}\cos^2\alpha_2 + \frac{z^2}{a_2^2}\cos^2\alpha_1 + \frac{z^2}{a_2^2}\sin\alpha_2 + \frac{y^2}{a_1^2}\sin^2\alpha_2 \\ &- \frac{2yz}{a_1a_2}\cos\alpha_1\cos\alpha_2 - \frac{2yz}{a_1a_2}\sin\alpha_1\sin\alpha_2\end{aligned}\right\} = 1$$

$$= \frac{y^2}{a_1^2} + \frac{z^2}{a_2^2} - \frac{2yz}{a_1a_2}(\cos\alpha_1\cos\alpha_2 + \sin\alpha_1\sin\alpha_2) = 1$$

$$\Rightarrow \boxed{\frac{y^2}{a_1^2} + \frac{z^2}{a_2^2} - \frac{2yz}{a_1a_2}\cos(\alpha_1 - \alpha_2) = 1}$$

Relation when the 2 waves are superimposed

NOTE: when $\alpha_1 - \alpha_2 = \delta = \pi/2$;

$$\Rightarrow \boxed{\frac{y^2}{a_1^2} + \frac{z^2}{a_2^2} = 1}$$

[Equation of ellipse]

NOTE: When $a_1 = a_2$ & $\delta = \pi/2$;

$$\Rightarrow \boxed{y^2 + z^2 = a^2}$$

[Equation of circle]

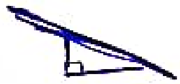
when $\delta = \alpha_1 - \alpha_2 = 0$;

NOTE: $\frac{y^2}{a_1^2} + \frac{z^2}{a_2^2} - \frac{2yz}{a_1 a_2} = 1 = \left(\frac{y}{a_1} - \frac{z}{a_2}\right)^2$

$\frac{y}{a_1} - \frac{z}{a_2} = 1$ $\qquad\qquad \frac{y}{a_1} = \frac{z}{a_2}$

$\Rightarrow \boxed{y = z\left(\frac{a_1}{a_2}\right) m}$ $\qquad y = mx + c$ [Equation of straight line] (positive slope)

NOTE $\delta = \alpha_1 - \alpha_2 = \pi$; $\qquad (\cos\pi = -1)$



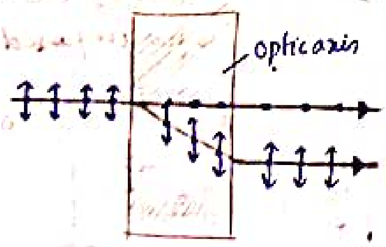
$\therefore \left(\frac{y}{a_1} + \frac{z}{a_2}\right)^2 = 1 = \left(\frac{y}{a_1} + \frac{z}{a_2}\right)$ (negative slope)

$\Rightarrow \boxed{y = -z\left(\frac{a_1}{a_2}\right) m}$ [Equation of straight line]

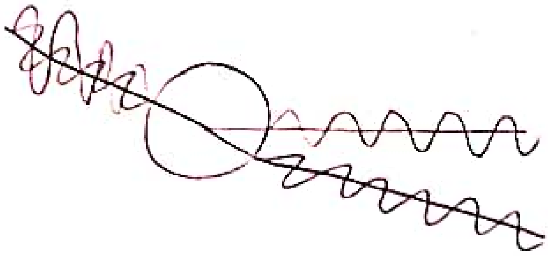
- If the phase difference can be induced 180°, half wave plate is used to retard 180° and rotates polarization direction of linear polarized light
- Quarter-wave plate - retards 90°, changed linearly polarized light to circular. Intensity due to quarter wave plate does not change. I - constant.

☆ DOUBLE REFRACTION:

A light ray incident on a bifringent material is split into two beams namely ordinary ray and extraordinary ray that have mutually ⊥r polarizations. Example for a bifringent material ⇒ Calcite, Iceland spar, etc



This splitting of a ray into two and two refractions is called double refraction.



optical path travelled = $n \cdot d$
" travelled by o ray = $n_o \cdot d$
" travelled by e ray = $n_e \cdot d$

since optical path travelled by o & e are different, the refractive indexes for o and e are different

Ordinary ray	Extra-ordinary ray.
• This ray obeys the laws of refraction	• This ray does not obey the law of refraction.
• Plane of vibration lies ⊥r to the direction of propagation	• plane of vibration is parallel to direction of propagation.
• The vibration of particles are perpendicular to the direction of ray.	• The vibration of particle is parallel to the direction of the ray.
• plane of polarization lies in the principal plane	• plan of polarization lies perpendicular to the principal axis.
• Refractive index is constant along optics axis.	• Refractive index varies along optic axis.
• It travells in constant speed in all directions.	• It travells with different speed in different directions but travel with equal speed along optic axis

☆ Polarization by double refraction :

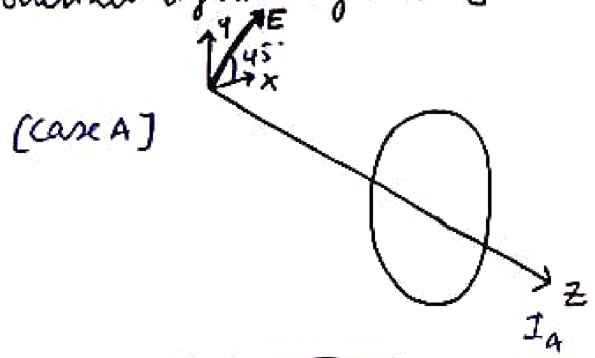
QUE: What happens when circularly polarized light is put through a polarizer along x or y axis?

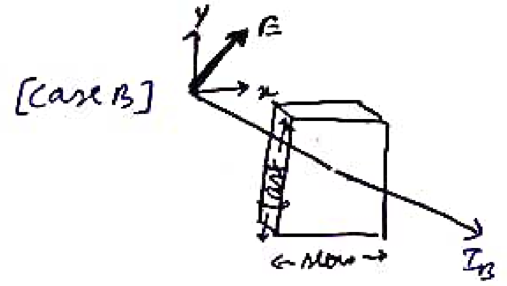
$E_x = E_0 \cos(kz)$ $\quad E_y = E_0 \sin(kz)$ $\Big\} \therefore \boxed{I = \frac{1}{2} I_0}$ //

Intensity is reduced by half

QUE: Linearly polarized light from the y axis is passed through A - linear polarizer & B - quarter wave plate.

[Polarized light angle 45°] [fast axis = y axis]





$\boxed{I_A = I_0/2}$ $\quad \boxed{I_B = I_0}$

E_x is absorbed and thus; $\quad (E_x, E_y)$ phase changed

$I_A = I_0 \cos^2(45°)$

$\Rightarrow \boxed{I_A < I_B}$ //

QUE: Unpolarized light falls on 2 polarizing sheets, one on top of the other. What must be the angle between the characteristic directions of the sheets if the I of the transmitted light is one-third of the incident beam?

$I = I_0 \cos^2\theta$

$\xrightarrow{I_0}$ | $\xrightarrow{I_0/2}$ | $\rightarrow I_2 = \frac{I_0}{2}\cos^2\theta$

$I_2 = I_0/3 = I_0/2 \cos^2\theta$

$\cos^2\theta = 2/3$

$\cos\theta = \sqrt{2/3}$ $\quad \boxed{\theta = \cos^{-1}(\sqrt{2/3})}$ //

QUE: Natural light falls on 3 identical polaroids, the principle dir of the mid one forming an angle $\phi = 60°$ with those of the others. Max transmission coeff of each $P \Rightarrow T = 0.81$ when plane pol light falls on them

$I = ?$

| $\rightarrow I_1$ | $\rightarrow I_2$ | $\rightarrow I_3$

100W $\rightarrow$ | $\rightarrow$ 81W $\quad \boxed{T = 0.81}$

$I_1 = I_0/2 \, T$; $\quad I_2 = \frac{I_0}{2}\cos^2\theta \times T^2$; $\quad I_3 = I_2 \times T \times \cos^2\theta$

$= I_1 T^2 \cos^4\theta$

$= \frac{I_0}{2} T^3 \cos^4\theta$

$= \frac{I_0}{2} \times (0.81)^3 \times (\frac{1}{2})^4$ //

$\%\ dec = \frac{I_0}{I_3} = \frac{I_0 \times 2 \times 16}{I_0 (0.81)^3}$

$\boxed{\%\ dec = 60.2 \text{ times}}$ //

QUE: Light beam travelling in water enters glass

$\theta_i = ?$ for which reflected light is completely plane polarized.

$$\tan\theta_2 = \frac{1.55}{1.33} = 1.127$$

$$\Rightarrow \theta_i = \tan^{-1}(1.127) \Rightarrow$$

QUE: $\lambda = 5400$ Å (Plane polarized light)

$\phi = 60^\circ \rightarrow$ phase diff b/w e & o (for incident on quartz)

$n_e = 1.553$

$n_o = 1.544$

[L = thickness of crystal = ?]

$$\phi = \frac{2\pi \Delta n L}{\lambda}$$

$$60 = \frac{\pi}{3} = \frac{2\pi \times 0.009 \times L}{5400 \times 10^{-10}}$$

$$\frac{1}{\cancel{2}} = \frac{\cancel{2} \times \cancel{9} \times 10^{-3} \times L}{\cancel{54}\ 18 \times 10^{-8}}$$

$$L = \frac{10^{-8}}{10^{-3}}$$

$$\Rightarrow \boxed{L = 10^{-5} m} //$$

$$\boxed{L = 10\ \mu m} //$$

QUE: $\lambda = 6000$ Å for ly on calcite $D = 0.04$ mm

$\mu_o = 1.642$ $\mu_e = 1.478$

$$\phi = \frac{2\pi \Delta \mu L}{\lambda} = \frac{2\pi \times 0.164 \times 4 \times 10^{-5}}{6000 \times 10^{-10}}$$

$$= \frac{\pi \times 0.164 \times 4 \times 10^{-5} \times 10^{7}}{3}$$

$$= \pi \times 0.2186 \times 10^{2}$$

$$= \cancel{218\pi}\ 21.86 \times 3.14$$

$$\boxed{\phi \Rightarrow 68.64 \text{ rad}} //$$

QUE: Left circularly polarized beam ($\lambda = 5893 Å$) is incident on calcite (optic axis $\parallel^{el}$ to surface) $L = 0.005141 m$

State of polarization of emergent beam?

$$E_x = E_0 \sin\omega t \quad ; \quad E_y = E_0(\sin\omega t + \pi/2) = E_0 \cos\omega t$$

emergent beam $\Rightarrow$ $E_y = \frac{E_0}{\sqrt{2}} \sin\omega t \qquad E_z = \frac{E_0}{\sqrt{2}} \cos\omega t$

$[\Delta n = 0.17195]$

$$\theta = \frac{\Delta n \times L \times 2\pi}{\lambda_0}$$

$$= \frac{0.17195 \times 0.05141 \times 2\pi}{5893 \times 10^{-7}}$$

$$\boxed{\theta = 3\pi} \; //$$

Thus, emergent wave will be;

$$E_y = \frac{E_0}{\sqrt{2}} \sin(\omega t - 3\pi) = \frac{-E_0}{\sqrt{2}} \sin(\omega t)$$

$$\boxed{E_y = -\frac{E_0}{\sqrt{2}} \sin\omega t} \; // \qquad \boxed{E_z = \frac{E_0}{\sqrt{2}} \cos\omega t} \; //$$

Ans $\Rightarrow$ which represents a right circularly polarized beam

QUE: A half wave plate is fabricated for a $\lambda = 3800 Å$. For what λ, it works as quarter wave plate?

$$\frac{\pi}{2} = \frac{\Delta n L 2\pi}{\lambda_0} = \frac{1}{3800} = \frac{\pi}{2} \qquad \left[\pi = \frac{2}{3800}\right]$$

$$\frac{\pi}{4} = \frac{2\pi \Delta n L}{\lambda_1}$$

$$\frac{\cancel{\pi}}{4} \times \frac{2}{\cancel{\pi}} = \frac{1}{\lambda_1} \times 3800$$

$$\frac{1}{2} = \frac{3800}{\lambda_1}$$

$$\Rightarrow \boxed{\lambda_1 = 7600 Å} \; //$$