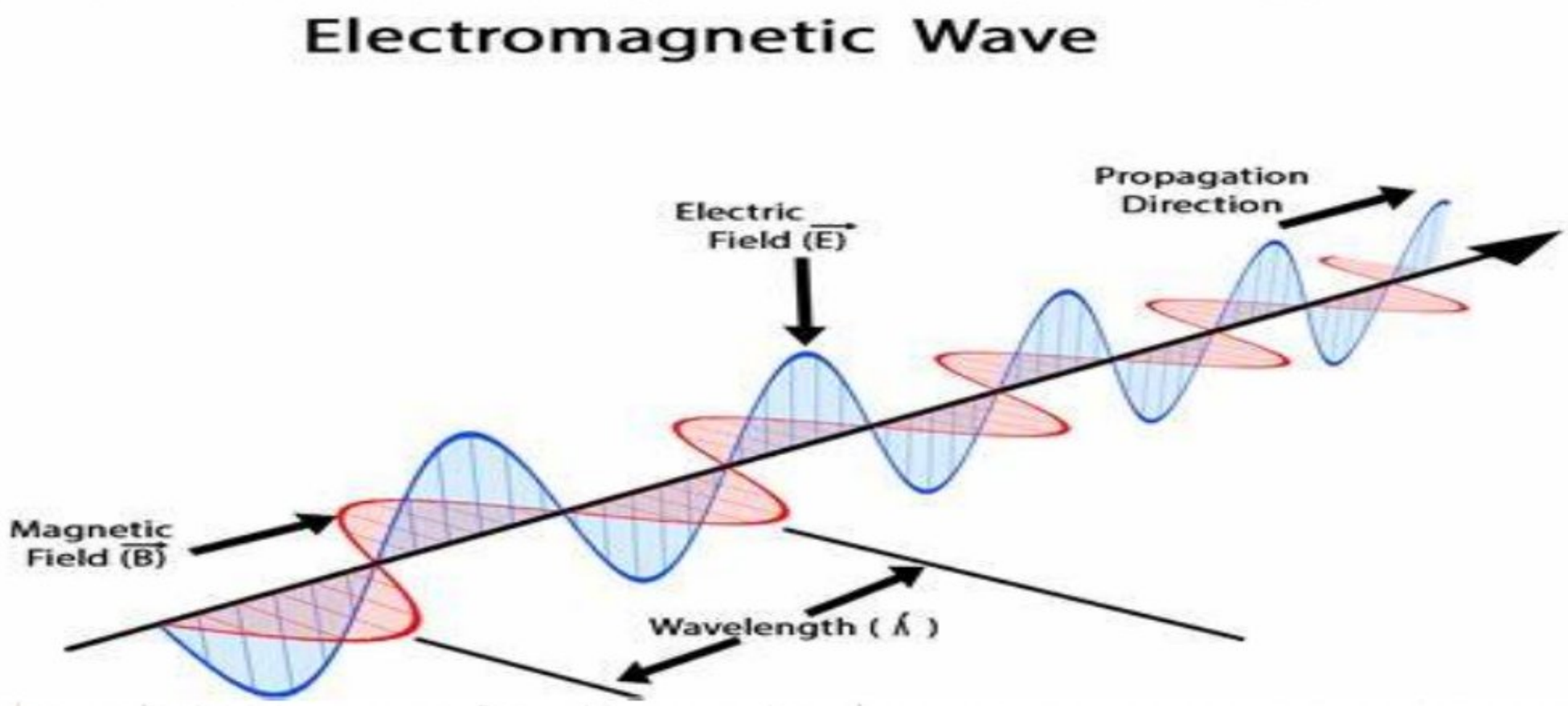
Electro- Magnetic Waves

The Transverse, Non-Mechanical wave which contains Electric and Magnetic fields and both are ⊥er to each other. & ⊥er to direction of propagation.



Some important points about EM. wave.

* speed of Electro. Magnetic waves in Vaccum ~~is~~ be $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3\times10^8$ m/s.

Where, μ_0 = permeability of free space. $= 4\pi\times10^{-7}$ TmA^{-1}

ϵ_0 = permittivity of free space. $= 8.85\times10^{-12}\ \frac{C^2}{Nm^2}$

* The Relation between Electric & Magnetic field is given by $E = \frac{B}{c}$

* The Relation between speed of light, frequency & wavelength is given by $c = \nu\lambda$

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* Accelerated charge radiates Electro-Magnetic waves.

Electro-Magnetic Spectrum.

classification of Electro-Magnetic waves on the basis of frequency or wavelength is known as Electro-Magnetic Spectrum.

Gamma Rays — 10^{-14} m - 10^{-11} m - Wavelength
- produce in Nuclear Reaction
- highly Energetic, short Wavelength
- Use in Radiation Therapy.

X-rays ⇒ 10^{-12} m - 10^{-9} m - wavelength.
⇒ produced by bombarding a heavy metal target with high Energy electrons.
⇒ They are Also short wavelength EM wave.
⇒ used as a diagnostic tool in medicine.

Ultra-violet-rays ⇒ 10^{-9} m - 4×10^{-7} m - wavelength.
⇒ Main source is sun.
⇒
⇒ used in photocell and UV purifiers.

Light rays ⇒ 4000 Å - 7500 Å - wavelength.
⇒ Transition of electrons in outer shell producing visible light Rays
⇒ only part of EM spectrum which is visible.

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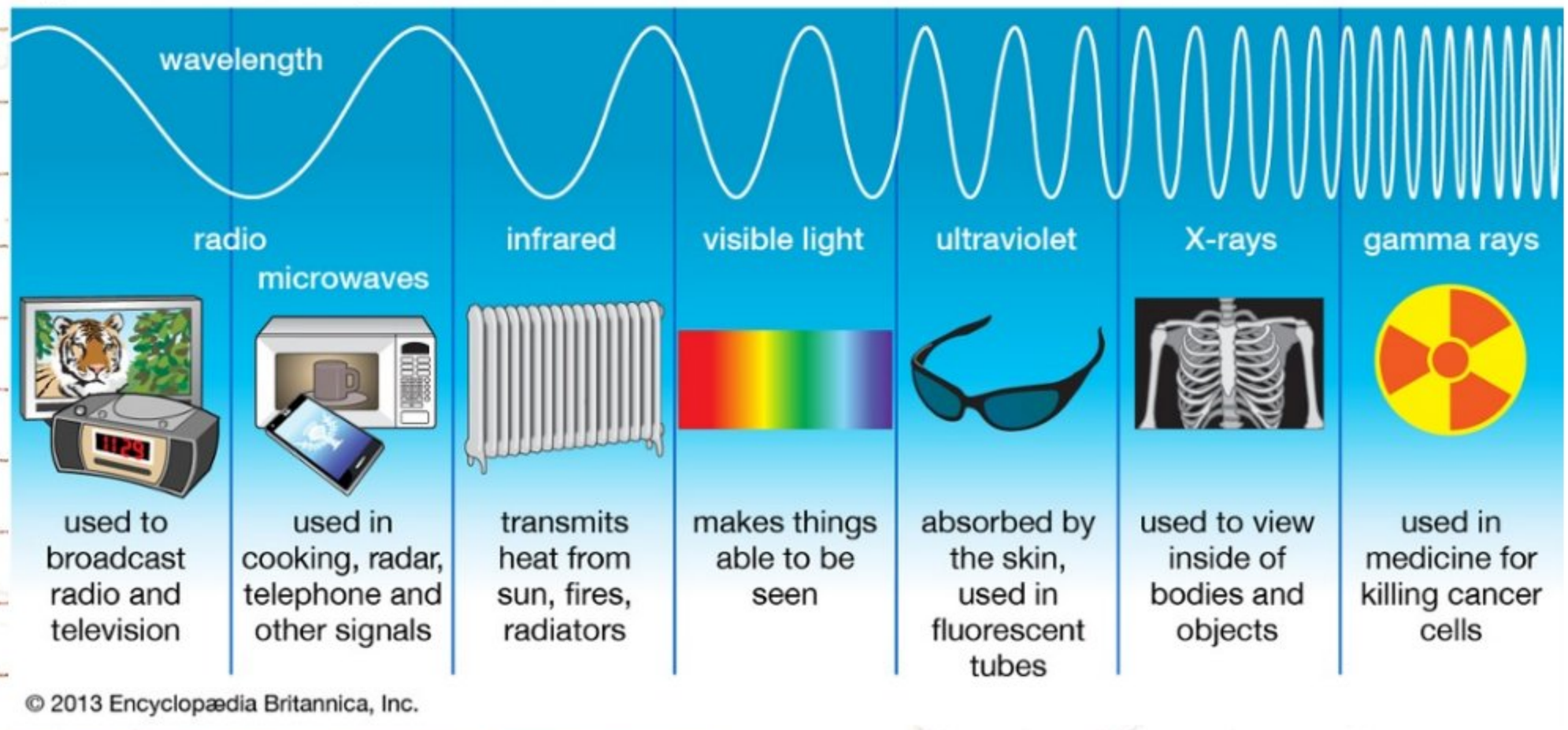
- **Infra-red Rays** ⇒ 7×10^{-7} m - 10^{-3} m - Wavelength.
  ⇒
  ⇒ Also known as heat waves.
  ⇒ used in night vision cameras.

- **Micro-Waves.** ⇒ 10^{-3} m - 10^{-1} m - Wavelength.
  ⇒
  ⇒
  ⇒ used in Communication.

- **Radio-Waves** - 10 cm m - Wavelength.
  ⇒
  ⇒
  ⇒ used in Mobile / Radio communication



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Interference.

Super-position principle.

When two or More wave ~~Are~~ Meet at a point Each wave produces its own displacement independent of other waves. The Resultant displacement of these wave Can be findout by ~~indindut~~ A vector addition of amplitude of both the waves.

Interference →

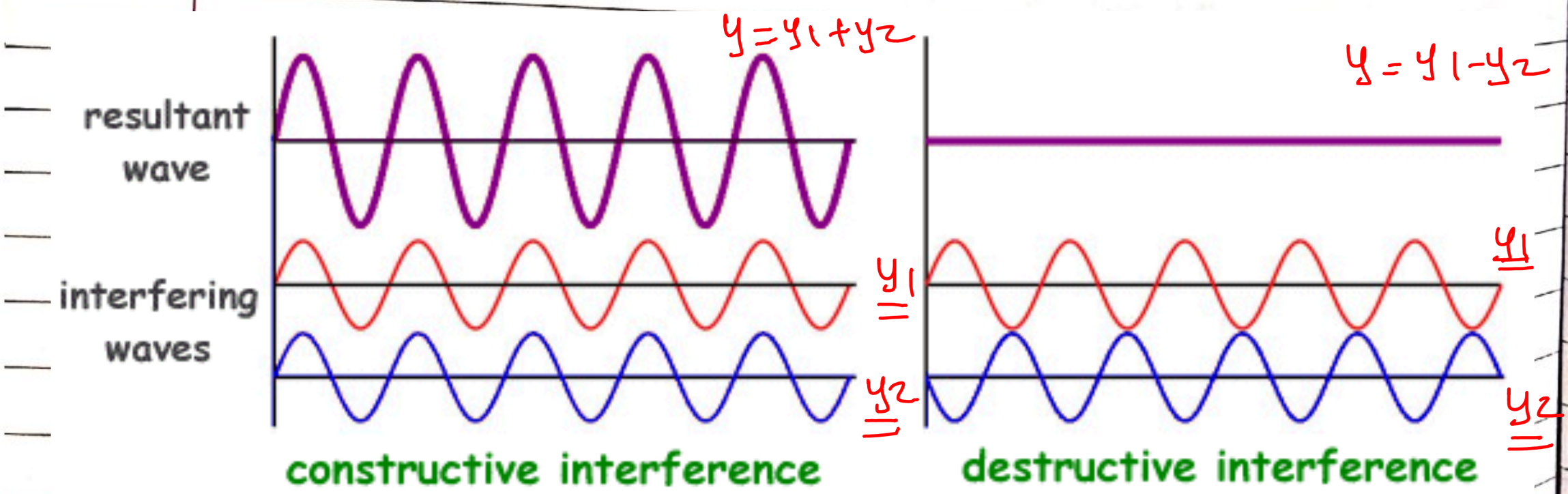
Re-distribution of light intensity due to superposition of two or more waves is called interference.

There are 2 Types of Interference.

Remember

$$E \propto I \propto A^2$$

How to understand superposition principle using Interference



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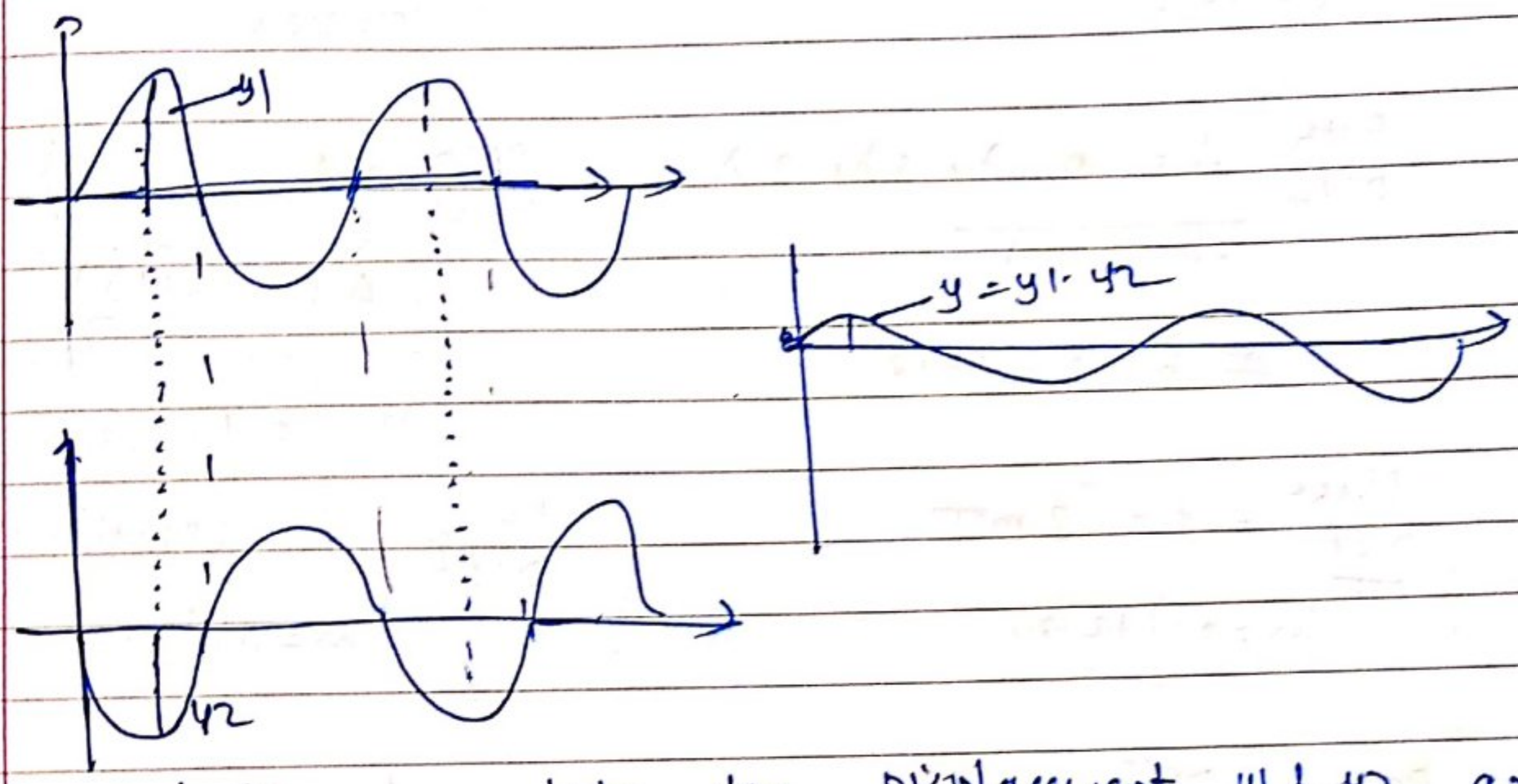
So we can say that two vectors in same direction get Added so. Resultant Amplitude is $y = y_1 + y_2$



In this case both the Displacement y_1 & y_2 are in opposite directions so we know when 2 vectors are opposite to each other They cancel each other.

Types of Interference & conditions

Constructive	Destructive
1) When Crest of 1 wave coincide with the crest of Another wave they Constructive interference takes place.	1) When crest of 1 wave coincide with the trough of another wave then destructive interference takes place.
2) In Constructive Interference Addition of Amplitude takes place	2) In Destructive Interference Substraction of Amplitude takes place.

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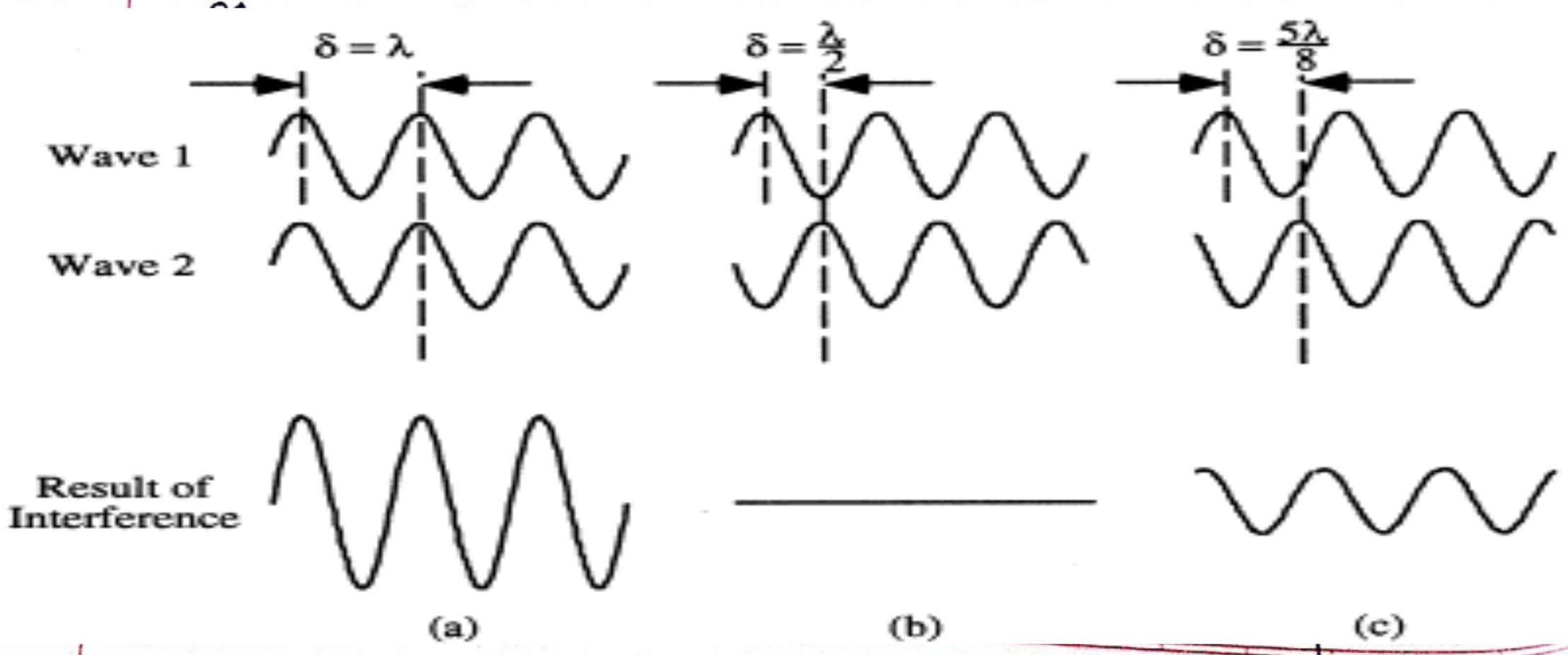
As $A\uparrow$. ~~$I \propto$~~ & $I \propto A^2$ $I\uparrow$ & Energy Also increases	As $A\downarrow$ $I \propto A^2$. So $I\downarrow$ & Energy Also decreases.
Path Diff $\Delta = 0, \lambda, 2\lambda, 3\lambda$ $\boxed{\Delta = n\lambda}$ $n = 0, 1, 2, 3$	Path Diff $\Delta = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ $\boxed{\Delta = (2n+1)\frac{\lambda}{2}}$ $n = 0, 1, 2, 3 \ldots$
Phase Diff. $= \phi = 2m\pi$ $m = 0, 1, 2, 3 \ldots$	Phase Diff $\phi = (2m+1)\cdot\pi$ $m = 0, 1, 2, 3 \ldots$

- **Path Difference** $\Rightarrow$ Basically describes the distance travelled by both waves with respect to each other

If path diff $= 0$ — Both waves have travel same distance

path diff $= \lambda$ — 1 wave is traveling extra distance λ compared to other wave



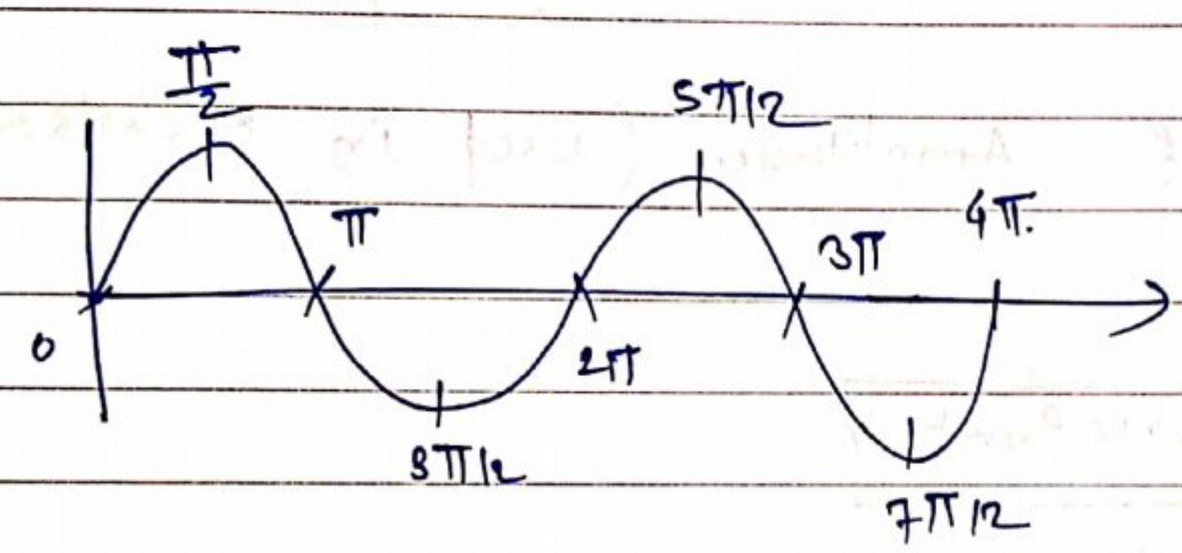
All the waves.

Thus path Difference introduced due to diff positions of sources / starting point of waves.

Phase Difference

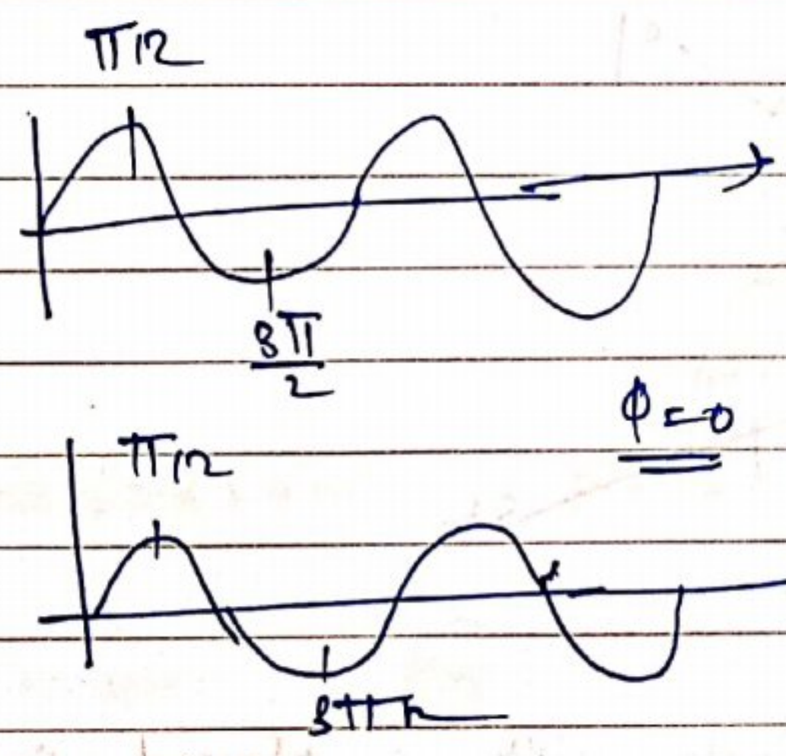
The difference between the phase of two waves at any instance is called phase difference.

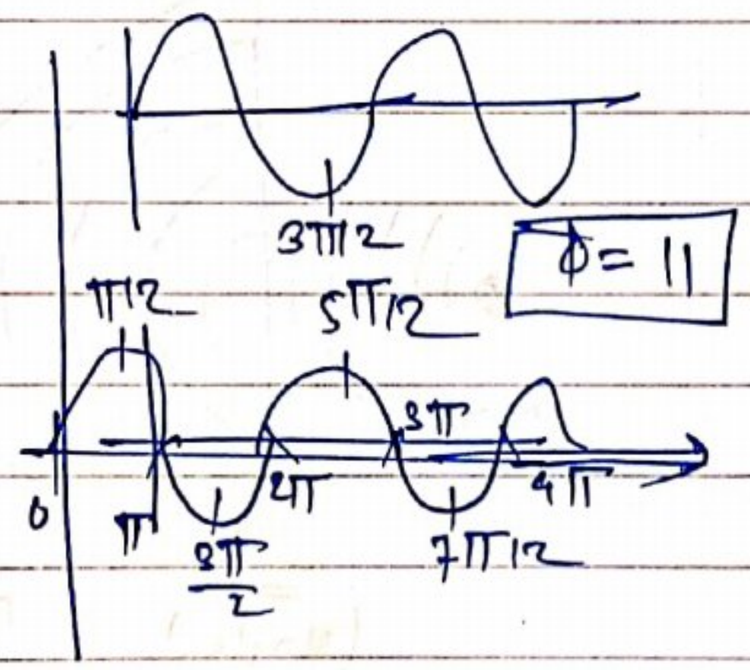
eg. phase means → crest & Trough.



Complete sinusoidal wave with phase

Now lets take eg. for phase difference.





Conditions for steady interference pattern.

→ Two sources should be 1) Coherent.
2) Monochromatic
3) Equal Amplitude.
4) Sources should be Narrow

5) Distance between screen & source should be infinite.

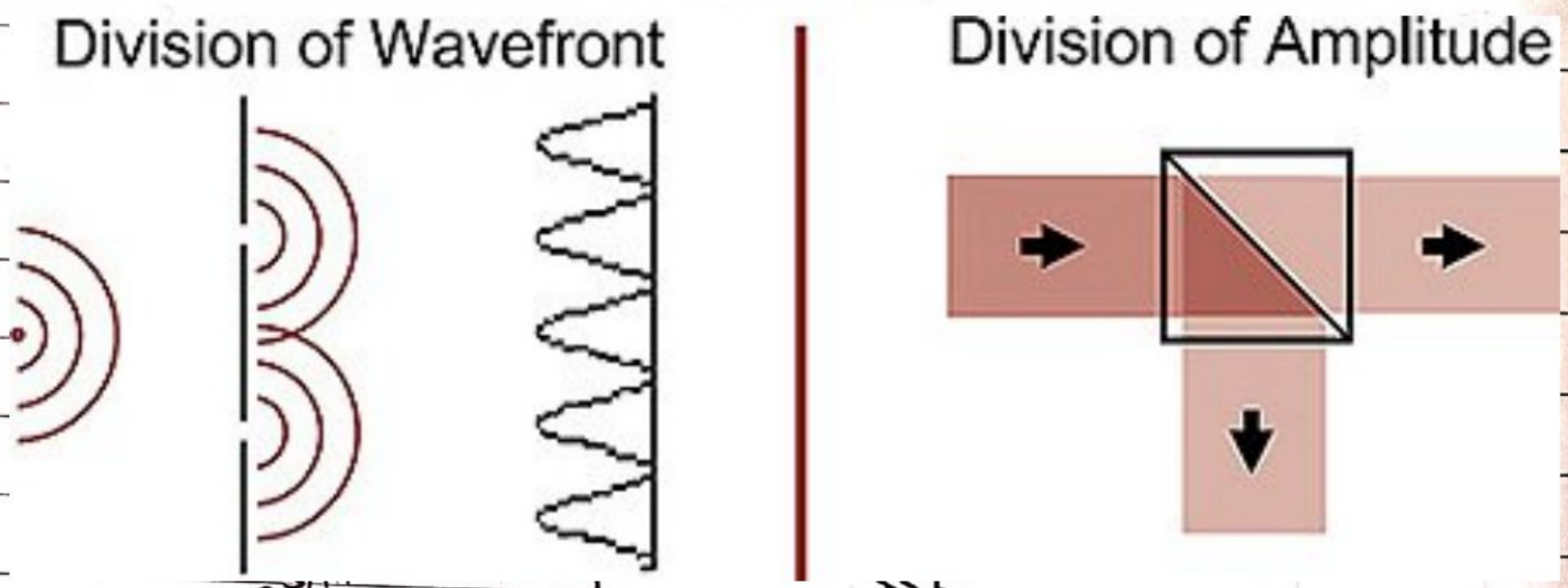
How to obtain two coherent waves of equal Amplitude ?

There are 2 methods.

1) Division of A Wave front. (used in Youngs Expt.)

2) Division of Amplitude. (used in Michelson Expt.)

Division of wave front



(single) Double slit

In this Expt. Double slit is placed in front of source. The slits S1 & S2 Are Also Acts as a point source emitting waves in All Direction.

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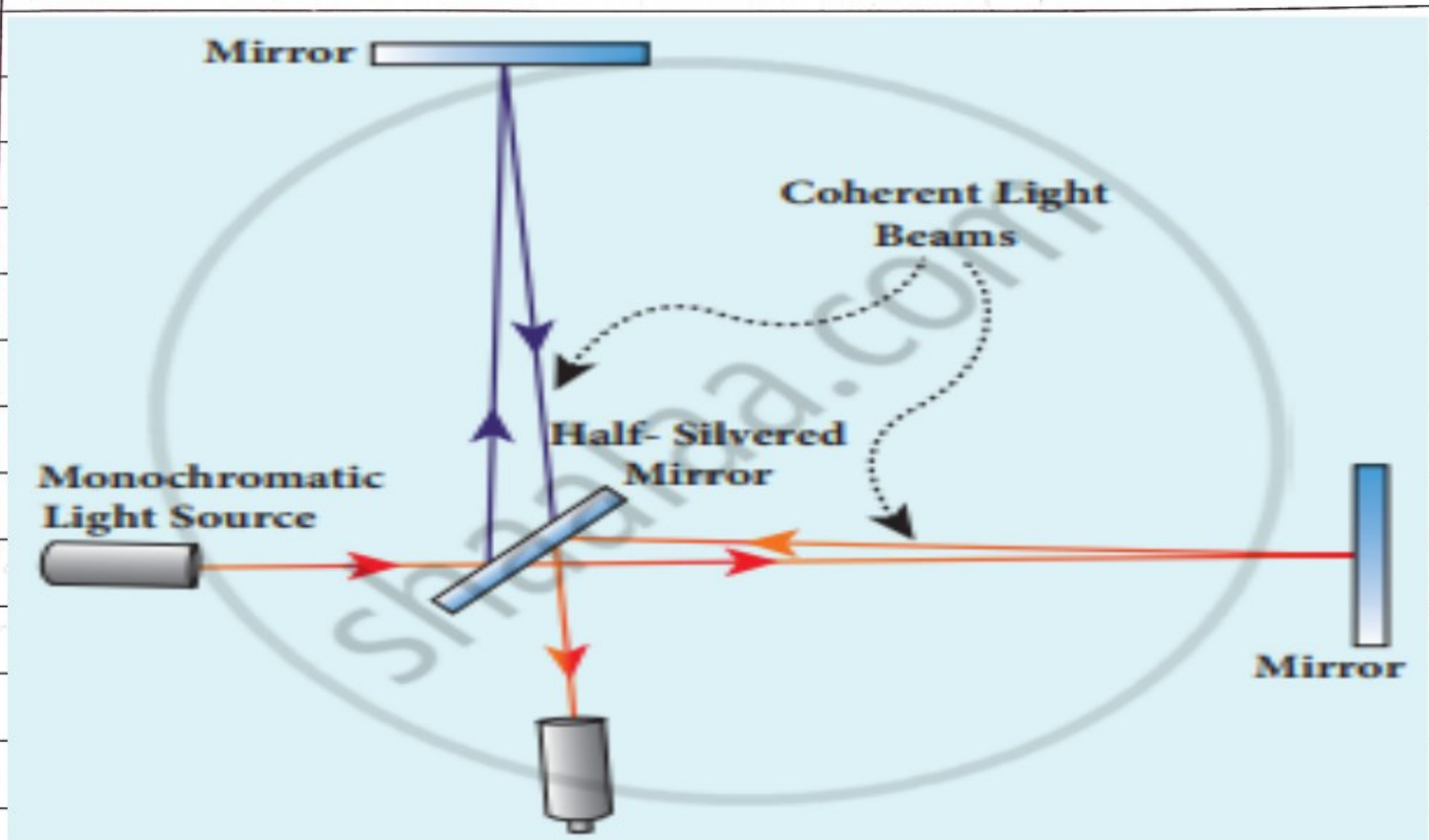
Division of Amplitude

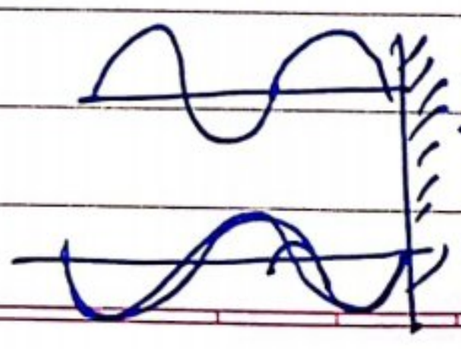
In this Method light is made to incident on semi-silvered surface of a glass plate.

When light is incident on semi-silvered glass plate some of the light get transmitted & some of the light get Reflected. by ~~this~~ ~~max.~~ ~~diff~~ ~~be~~



Brewsters Law / phase change due to Reflection

Whenever a light travelling from rarer medium incident on the boundary of denser medium & when it get Reflected from boundary of denser medium there will be an phase change of π is introduced in both waves



Denser Medium. → phase change of π.

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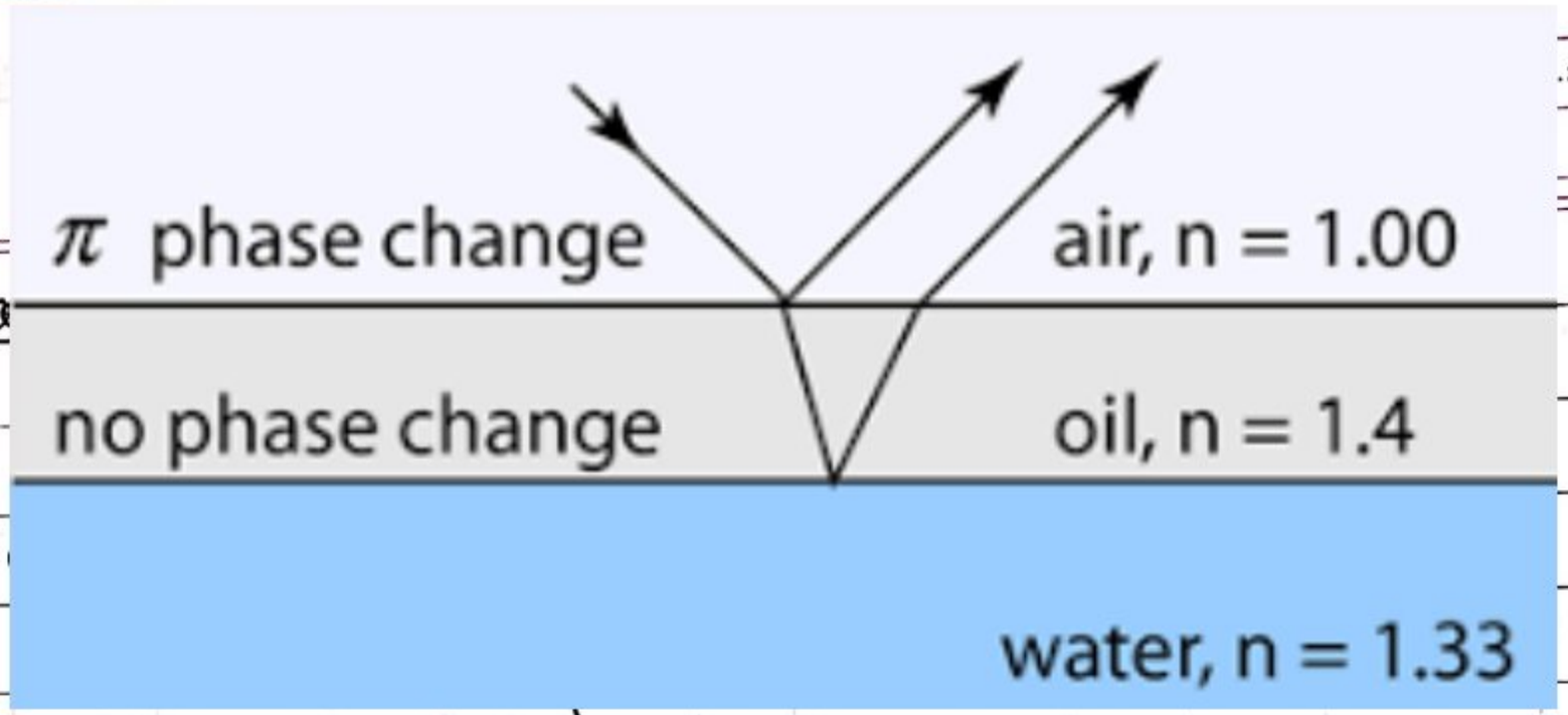
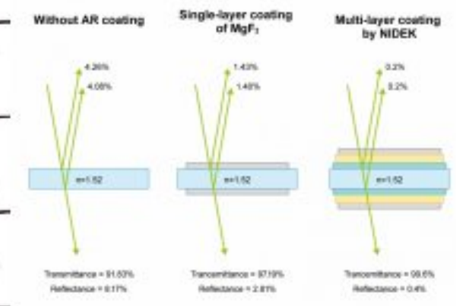




Relation between phase diff. & path difference

$$\boxed{\phi = \frac{2\pi}{\lambda} \times \Delta}$$

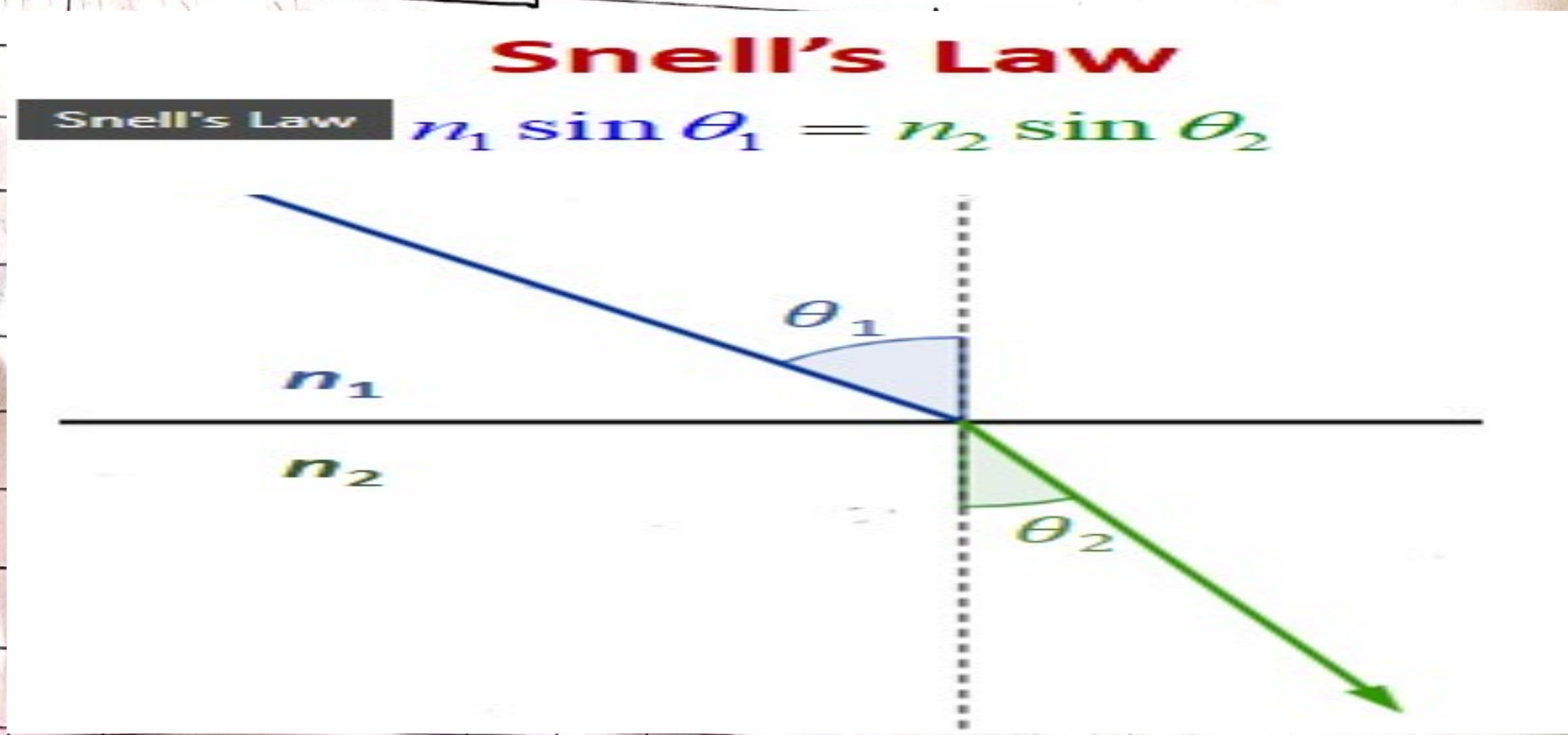
for a $\phi = \pi$, The corresponding $\Delta = \frac{\lambda}{2\pi} \times \phi$

$$\Delta = \frac{\lambda}{2\pi} \times \pi$$

$$\boxed{\Delta = \frac{\lambda}{2}}$$

Thus in Brewsters Law $\Delta = \frac{\lambda}{2}$, $\phi = \pi$ is introduced between incident & Reflected wave, Reflected from boundary of denser medium.

Snells Law



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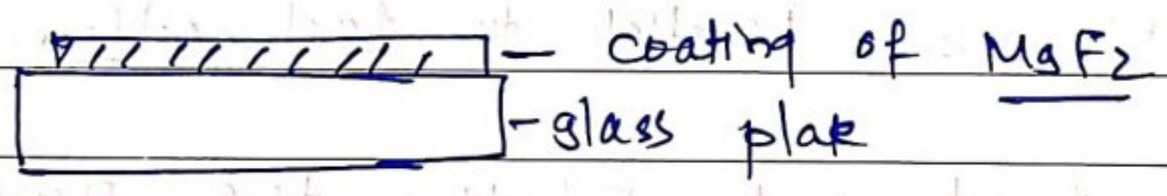
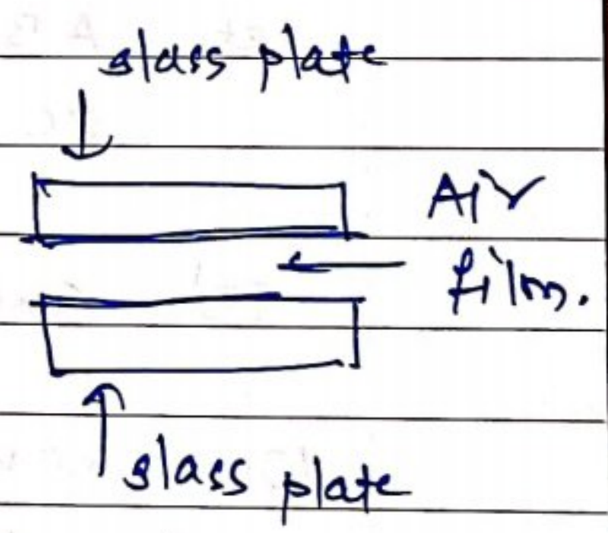
Concept of Thin & Thick film.

Thin film - film of Any Medium having thickness of the order of 5500 Å

Thick film is film of Any Medium having thickness of the film is order of

Examples of film.

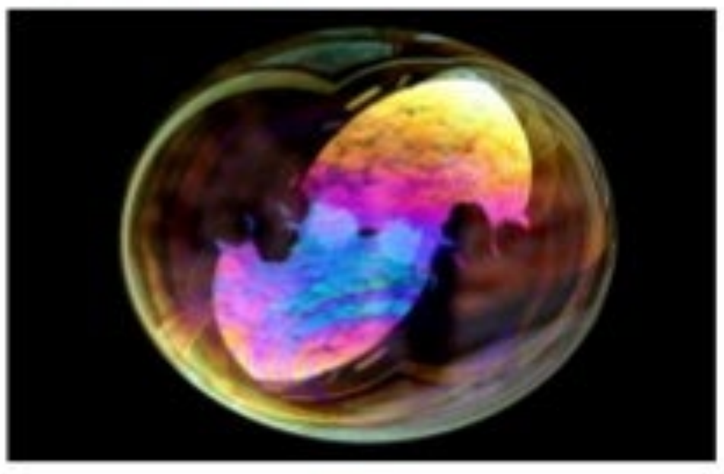




An optical medium is called a thin film when its thickness is about the order of 1 wavelength of light in visible region

Examples

SOAP BUBBLES



http://graphics.ucsd.edu/~iman/SoapBubbles/

MIXTURE OF OIL & WATER

http://en.wikipedia.org/wiki/Diesel_fuel

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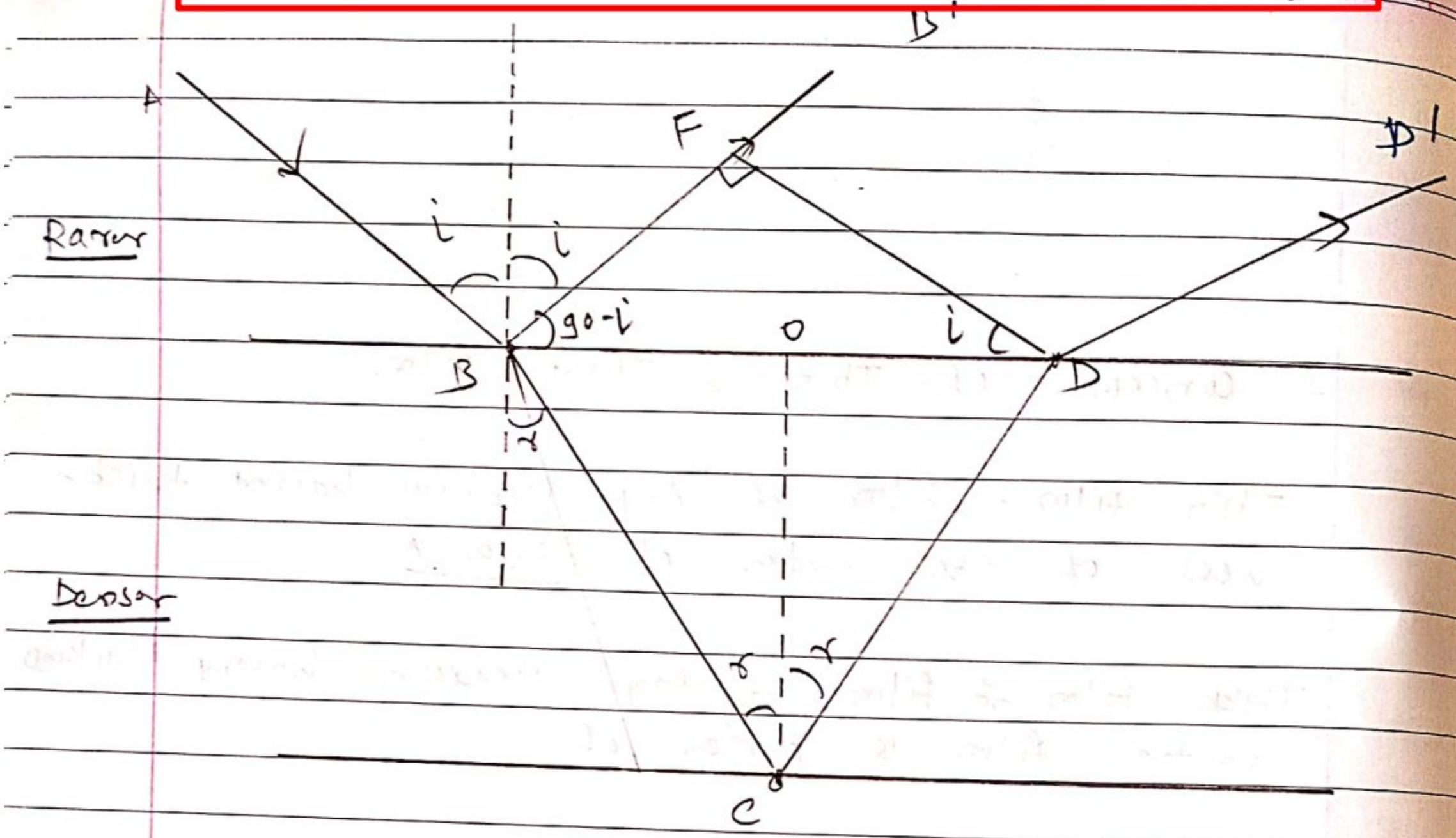
Interference in thin film of uniform Thickness-



Let AB = incident rays, BB' = reflected Rays.
BC = Refracted ray,

BB' and DD' are parallel to each other.

We have to find out whether the Rays BB' and DD' Reflected from Thin film forms constructive or Destructive interference.

To do that first we have to findout optical path Diff. between These two waves.

$$\Delta = \mu (BC + CD) - BF \quad \text{—(1)}$$

First find BC, CD then BF.

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ΔBCO

$\cos r = \frac{t}{BC}$

$BC = \frac{t}{\cos r}$

ΔPCO

$\cos r = \frac{t}{CD}$

$CD = \frac{t}{\cos r}$

$$\boxed{BC = CD = \frac{t}{\cos r}} \quad -(2)$$

$\sin r = \frac{BO}{BC}$

$BO = BC \sin r$

$\sin r = \frac{OD}{CD}$

$OD = CD \sin r$

$$BO = OD = BC \sin r.$$

Now consider $\Delta = BDF$

$\sin i = \frac{BF}{BD}$

$BF = BD \sin i$

$BF = (BO + OD) \sin i$

$$\boxed{BF = 2BC \sin r \sin i} \quad -(3)$$

$BF = \frac{2 \times t}{\cos r} \cdot \sin r \sin i$

Put (2) & (3) into (1)

$$\Delta = \mu\left(\frac{t}{\cos r} + \frac{t}{\cos r}\right) - 2BC \sin r \sin i$$

$$\Delta = \frac{2\mu t}{\cos r} - \frac{2t}{\cos r} \sin r \sin i \times \frac{\sin r}{\sin r}$$

$$\Delta = \frac{2\mu t}{\cos r} - \frac{2\mu t}{\cos r} \sin 2r$$

$$\Delta = \frac{2\mu t}{\cos r}(1 - \sin 2r)$$

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$$\Delta = \frac{2\mu t}{\cos r} \times \cos^2 r$$

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

This is the optical path Diff. between the ray 1 & 2 due to distance travelled in the thin film.

Now In Reflected system.

Total Δ = Δ Due to Dist. travelled in Thin film + Δ Due to Reflection

$$\boxed{\Delta = 2\mu t \cos r \pm \frac{\lambda}{2}}$$

Condition for

In Transmitted system

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

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Conditions for constructive & Destructive interference in Reflected & Transmitted system.

Transmitted.	Reflected.
$\Delta = 2\mu t\cos r$	$\Delta = 2\mu t\cos r \pm \frac{\lambda}{2}$
Constructive, $\Delta = n\lambda$	Constructive, $\Delta = n\lambda$
$2\mu t\cos r = n\lambda$.	$2\mu t\cos r \pm \frac{\lambda}{2} = n\lambda$
	$2\mu t\cos r = n\lambda \pm \frac{\lambda}{2}$
	$2\mu t\cos r = (2n \pm 1)\frac{\lambda}{2}$
$\Delta = 2\mu t\cos r = n\lambda$ for constructive	$2\mu t\cos r = (2n\pm1)\frac{\lambda}{2}$ for constructive

For Destructive interference

Destructive $\Delta = (2n\pm1)\frac{\lambda}{2}$	Destructive $\Delta = (2n\pm1)\frac{\lambda}{2}$
$2\mu t\cos r = \left(2n\frac{\lambda}{2} \pm \frac{\lambda}{2}\right)$	$2\mu t\cos r \pm \cancel{\frac{\lambda}{2}} = \cancel{2}n\cdot\frac{\lambda}{\cancel{2}} \pm \cancel{\frac{\lambda}{2}}$
$2\mu t\cos r = \left(n\lambda \pm \frac{\lambda}{2}\right)$	$2\mu t\cos r = n\lambda$
$2\mu t\cos r = (2n\pm1)\frac{\lambda}{2}$ for Destructive.	$2\mu t\cos r = n\lambda$ for Destructive.

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Wedge shaped film

* Interference in wedge shaped film.

A wedge shaped film is a film whose thickness is zero At 1 end and whose thickness increases as we Move to other end.

eg. When two glass placed is in contact with each other separated by spacer forms wedge shaped Air film.

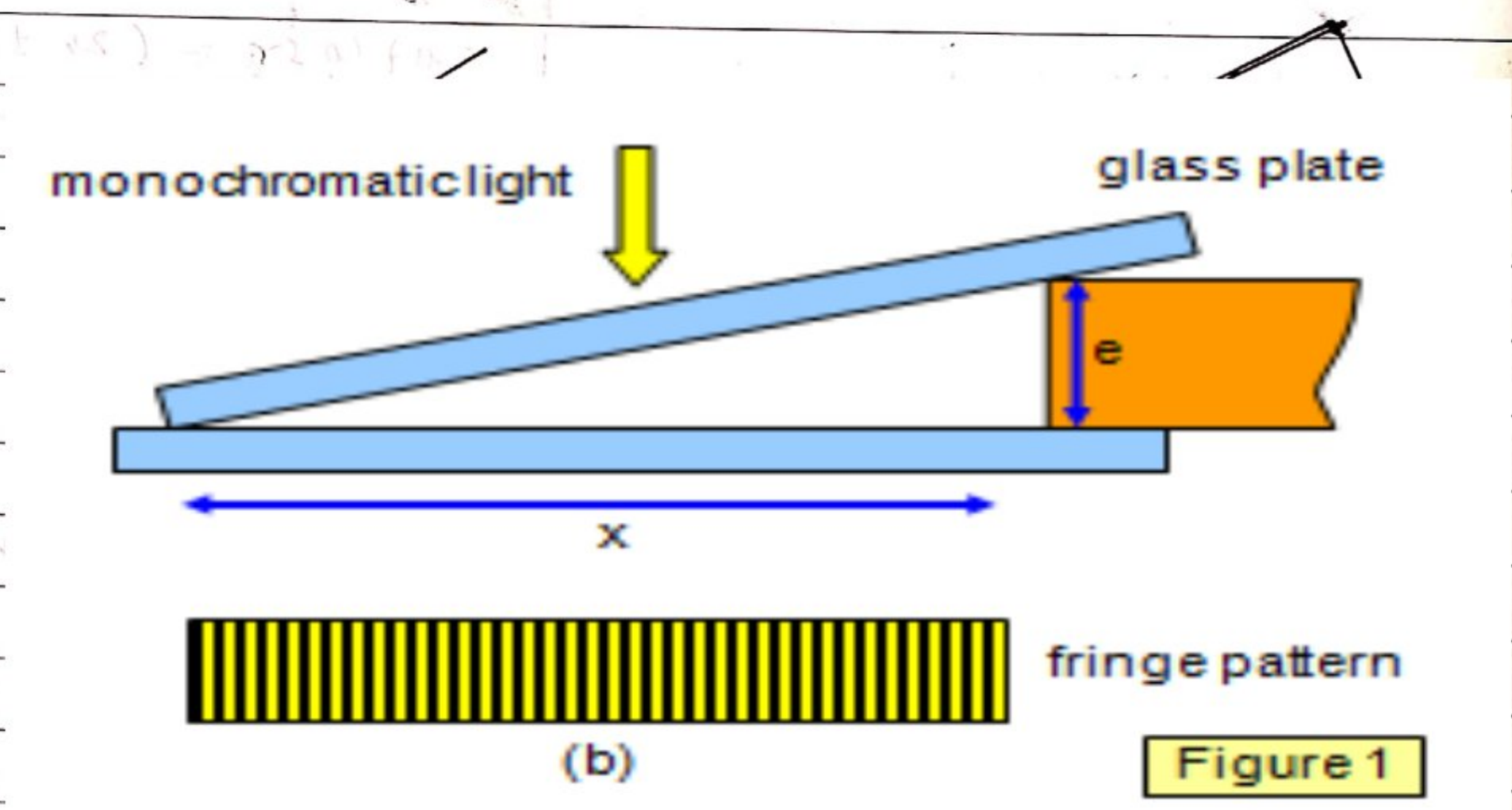


Figure 1

$\Delta e \rightarrow t\uparrow$

α = Angle of wedge.

Path Difference in wedge shaped film is $\Delta = 2\mu t\cos(r+\alpha)$

Wedge shaped Air film.

Reflected system.

~~$\Delta = 2\mu t\cos r \pm \frac{\lambda}{2}$~~

$\Delta = 2\mu t\cos(r+\alpha) \pm \frac{\lambda}{2}$

Interference — constructive

$\Delta = n\lambda$

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

$$\boxed{2\mu t\cos(r+\alpha) = (2n\pm1)\frac{\lambda}{2}}$$

Now for Destructive

$\Delta = (2n\pm1)\frac{\lambda}{2}$

$2\mu t\cos(r+\alpha) \pm \frac{\lambda}{2} = (2n\pm1)\frac{\lambda}{2}$

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

Transmitted system.

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

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

Interference - constructive

$\Delta = n\lambda$

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

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

Destructive Interference

$\Delta = (2n\pm1)\frac{\lambda}{2}$

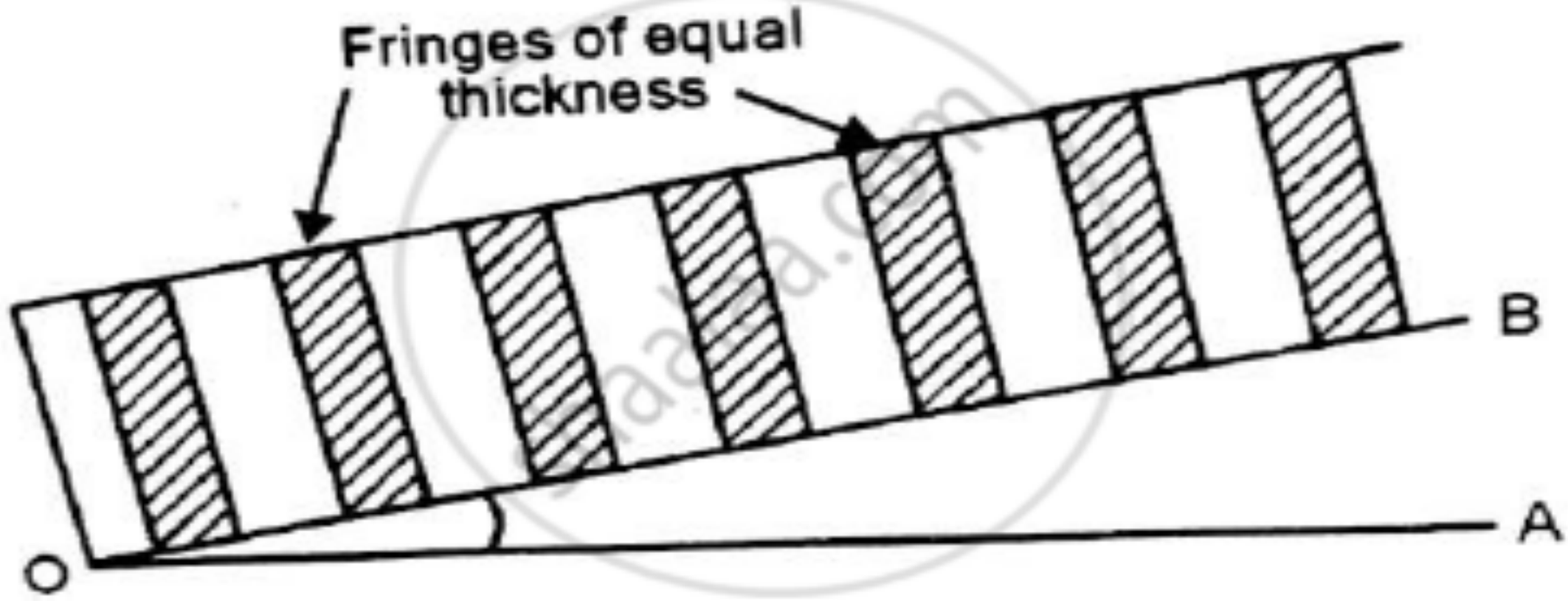
$2\mu t\cos(r+\alpha) = (2n\pm1)\frac{\lambda}{2}$

$$\boxed{2\mu t\cos(r+\alpha) = (2n\pm1)\frac{\lambda}{2}}$$

NOT NEEDED

Nature of Interference pattern.

Interference of wedge shaped Air film gives us



Straight and parallel fringes consist of Alternate Dark and Bright fringes of equal thickness

Bandwidth / fringe width.

The distance between two successive Dark fringes or bright fringes is called as Bandwidth or fringe width.

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

If α is very small $\sin\alpha \simeq \alpha$

$$\beta = \frac{\lambda}{2\mu\alpha}$$

μ = Refractive index of thin film.

Applications of Interference.

1) Testing of optical flatness of surfaces.

Flatness of optical surfaces such as glass plates can be Tested by using the phenomenon of interference.

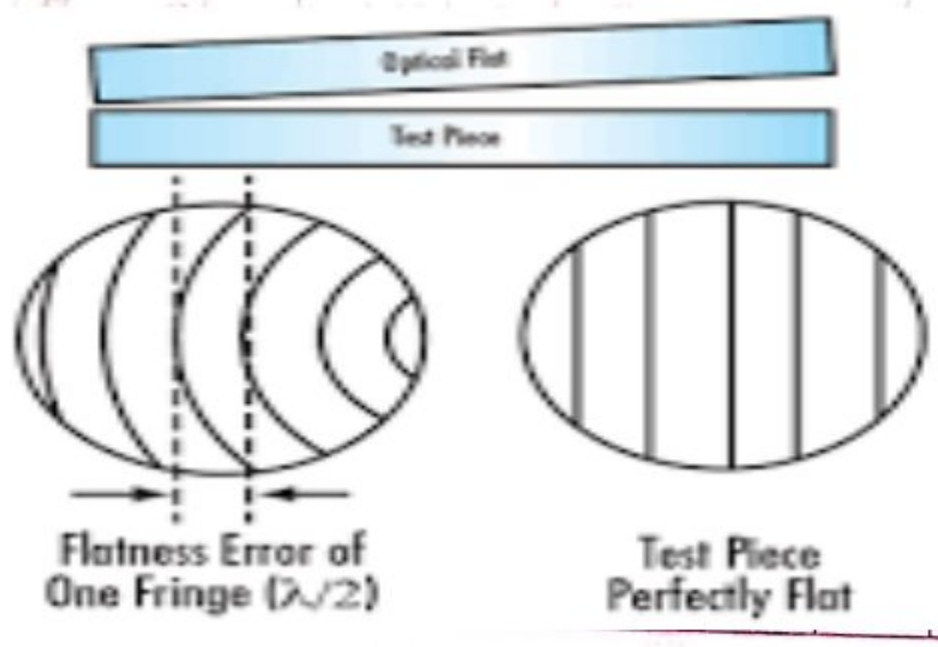
A wedge shaped Air film is formed between Test piece glass plate whose optical flatness we have to check and standard optically flat glass plate. Both the glass plates have separated by spacer.

This set-up is then illuminated by a Monochromatic source of light.

If The Test piece is optically flat the interference pattern will consist of straight fringes of equal width.

If the test piece is not optically flat then fringes will have irregular shape.

Thus the Test piece is polished and Tested again till fringes of equal width are observed.



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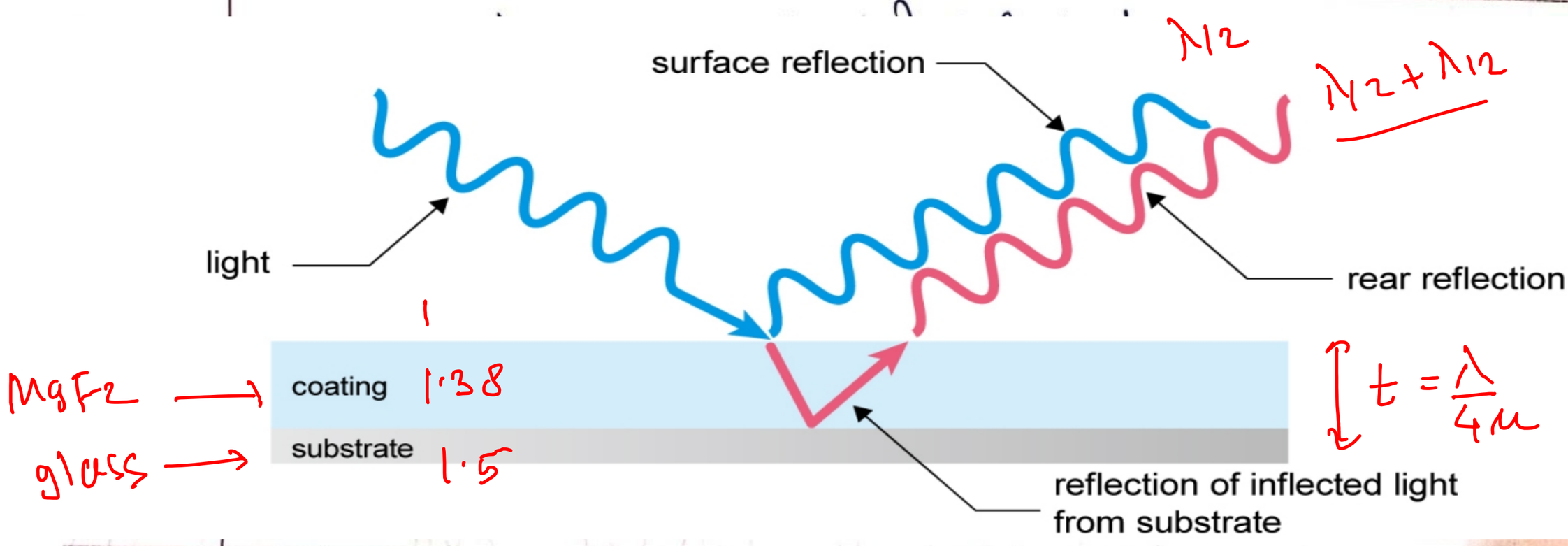
Anti - Reflection Coating.

Anti - Reflection Coating used to

1) Reduced Intensity of light by destructive interf

How Anti - reflection Coating can be prepared?

Take a glass and deposite thin film of MgF_2 having Refractive index 1.38 on it. So that two boundaries of denser Medium are formed as shown in fig.



Both the rays 1 & 2 Reflected from the Boundary of denser Medium so path difference of $\frac{\lambda}{2}$ is introduced in both of them.

We have to select thickness of MgF_2 in a such a way that the Additional path Difference of $\frac{\lambda}{2}$ is introduced

Path difference for thin film of uniform thickness is ,

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

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For destructive interference.

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

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

for normal incidence .r=0

and we take n=0

$$2\mu t = \frac{\lambda}{2}$$

$$t = \frac{\lambda}{4\mu}$$

μ = Refractive index of coating.

This is the required thickness of MgF2.

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