Engg. Physics (TPH 101)

UNIT 1 INTERFERENCE OF LIGHT

Interference is the superimposition of two or more light waves travelling either is in same phase or having a constant phase relation between them resulting into non-uniform distribution of intensity.

The region in which the light intensity is maximum results into **Constructive Interference.** The region in which the light intensity is minimum results into **Destructive Interference.**

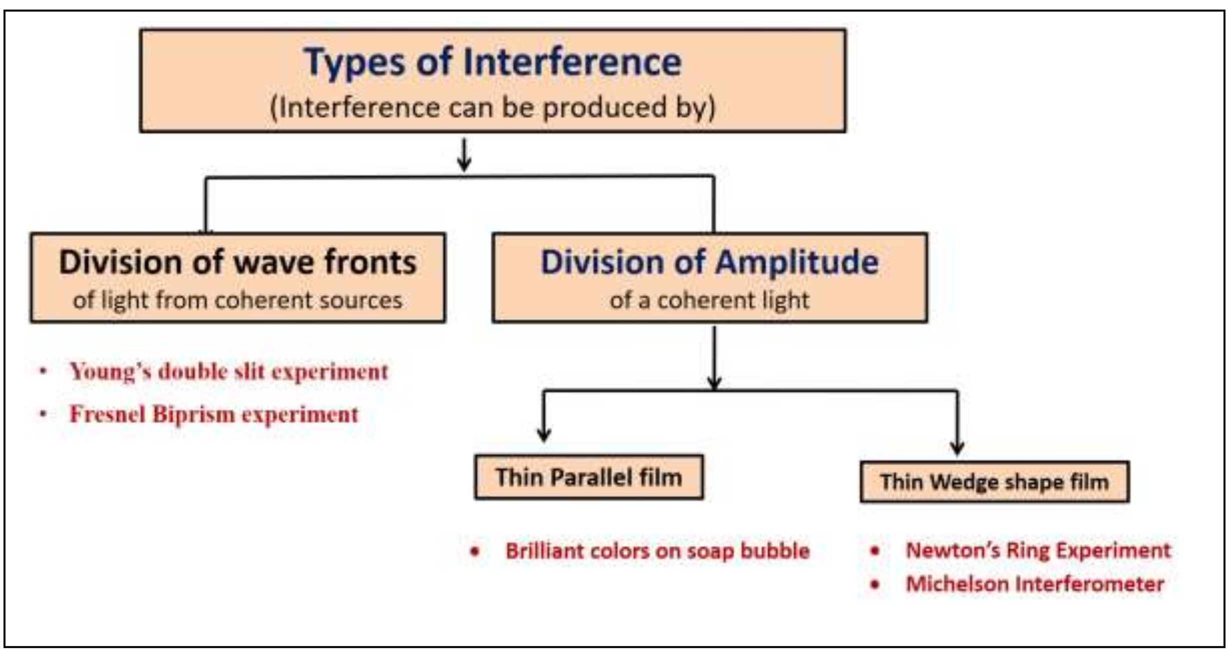
When two light waves are made to interfere the alternate bright and dark bands are formed called fringes.

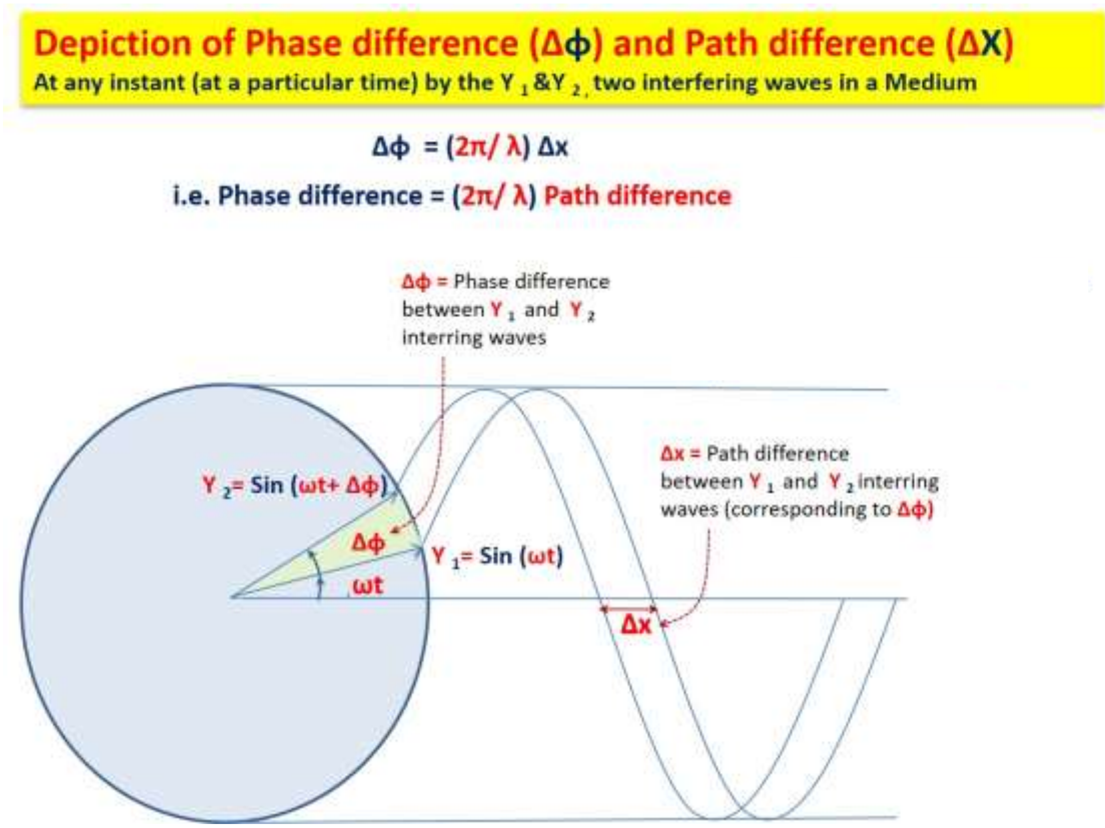
Coherence

Two light waves of same or nearly same frequency/wavelength are coherent when the phase difference between them is constant or the two waves travel in same phase. On the other hand, the two waves are **incoherent** if there is a random or changing phase relationship between them.
In practical two independent sources cannot produce coherent light.

Methods to produce Coherent Sources-

1. Lloyd's Single mirror method
2. Fresnel's Double mirror method
3. Michelson interferometer
4. Young's double slit experiment
5. Fresnel Biprism experiment





Conditions of Interference:

Expression of resultant wave (Y) due to interference of two waves:

To find the expression of interference of two waves, we consider Y_1 and Y_2 waves of **same frequency (ω)** with slight difference in their amplitude (let amplitudes a_1 and a_2 respectively).

According to superposition theorem

$Y = Y_1 + Y_2$

$Y = a_1 \sin \omega t + a_2 \sin (\omega t + \phi)$ (**ϕ** = phase difference between the interfering waves)

$= a_1 \sin \omega t + a_2 (\sin \omega t \cos \phi + \sin \phi \cos \omega t)$

$= \sin \omega t\, (\mathbf{a_1 + a_2 \cos \phi}) + \mathbf{a_2 \sin \phi} \cos \omega t$

Let $\mathbf{A \cos \theta = a_1 + a_2 \cos \phi}$ …….[1]

And $\mathbf{A \sin \theta = a_2 \sin \phi}$ …….[2]

$Y = A \sin \omega t \cos \theta + A \cos \omega t \sin \theta$ (***since Sin (A+B) = sin A cos B + Cos A sin B***)

$\mathbf{Y = A \sin (\omega t + \theta)}$

It shows that again the resultant is a sinusoidal wave with amplitude A.

From eq. [1] and [2] we can find the **Amplitude of Resultant wave (A)** (squaring and adding [1] & [2])

$(A \sin \theta)^2 + (A \cos \theta)^2 = (a_2 \sin \phi)^2 + (a_1 + a_2 \cos \phi)^2$

$A^2 = a_2^2 \sin^2 \phi + a_1^2 + a_2^2 \cos^2 \phi + 2a_1 a_2 \cos \phi$

$A^2 = a_1^2 + a_2^2 (\sin^2\phi + \cos^2\phi) + 2a_1 a_2 \cos\phi$

$A^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi$

[**Discussion:** *Since Intensity of a sinusoidal wave =* ***$2\pi^2 n^2 a^2 \rho v$***

Since in our case the frequency of wave is fixed (means constant) and for a electromagnetic wave (EM) does not depend upon density of medium (ρ) and its velocity (v) is fixed in a medium. Therefore, only variable parameter in above expression is amplitude. Therefore, intensity can be taken proportional to amplitude. Therefore, ***Intensity α Amplitude²*** *]*

Since **Intensity = $A^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi$.**

Above expression shows that **Intensity of light in medium depends upon the Intensity of two coherent sources ($I_1 = a_1^2$ and $I_2 = a_2^2$) and Phase difference (ϕ)** between them.

Intensity = $A^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi$.

Different phase values (**ϕ**) provides the following

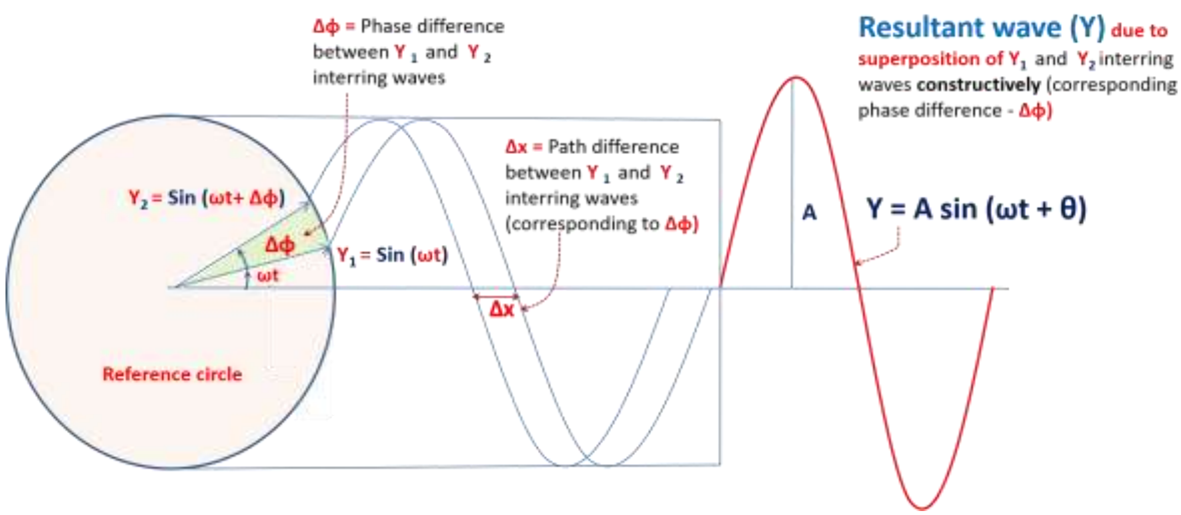
1. If ϕ = 0,2π, 4π … **2nπ**

   then $I_{max} = a_1^2 + a_2^2 + 2a_1 a_2 = (a_1 + a_2)^2$

   Or corresponding path difference [$\Delta x = (\lambda/2\pi).\phi$]

   $\Delta x = (\lambda/2\pi)2n\pi$

   or $\Delta x = 2n\lambda/2$



2. If ϕ = π, 3π … (2n+1) π

   then $I_{min} = a_1^2 + a_2^2 - 2a_1 a_2 = (a_1 - a_2)^2$

   Or corresponding path difference

   $\Delta x = (\lambda/2\pi).(2n+1)\pi$

   or **$\Delta x = (2n+1)\lambda/2$**

Learning Outcome:

(a) For condition of constructive interference,

(i) Phase difference (ϕ) = **2n**π and (i.e. phase diff. (ϕ) should be even (2n) multiple of π) And corresponding

(ii) Path difference (Δx) = **(2n)** λ/2 (i.e. path diff. (Δx) should be even (2n) multiple of λ/2)

(b) For condition of destructive interference,

(i) Phase difference (ϕ) = (2n + 1) π and corresponding

(ii) Path difference (Δx) = (2n + 1) λ/2 **(i.e. Δx should be odd (2n + 1) multiple of λ/2)**

Lecture 2- Engineering Physics (TPH 101)

Interference- Introduction

When we talk of interference of light, we must understand the meaning of light. How is it defined. Is it what make us able to see the things? Huygens in 1670 explained the laws of reflection and refraction. In 1801Young's Experiment demonstrated the Interference property. What we know today that light is an electromagnetic (EM) wave (proved by Maxwell (1873)). **In 1905, Albert Einstein** used the concept of energy packets of EM energy (Photon) to explain the **photoelectric effect**. **In 1923 Arthur H. Compton demonstrated** the **corpuscular nature (particle nature)** of **X-RAYS**.

In this lecture notes we have,

- Determination of average intensity in interference,
- Demonstration of Young's double slit experiment and
- Determination of fringe width (ω) in Young's double slit experiment.
- Types of coherency.

Average Intensity:

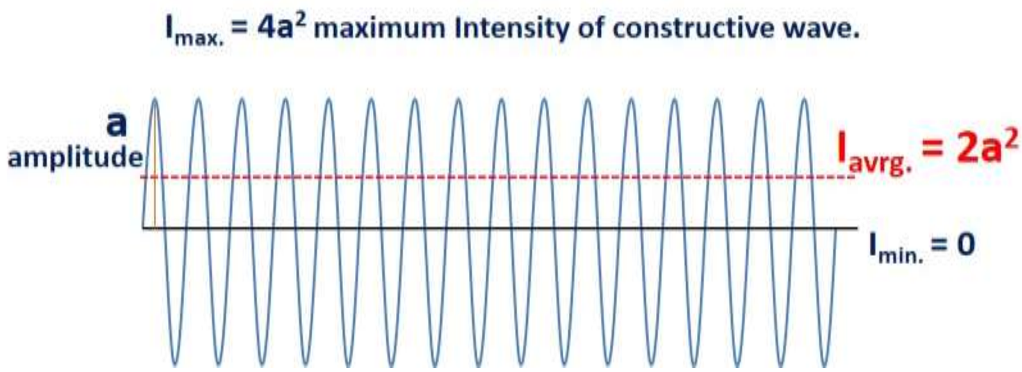
$$\mathbf{I_{avrg.}} = \frac{\int_0^{2\pi} I\, d\delta}{\int_0^{2\pi} d\delta} = \frac{\int_0^{2\pi} (a_1^2 + a_2^2 + 2\, a_1\, a_2 \cos\delta\ )\, d\delta}{\int_0^{2\pi} d\delta}$$

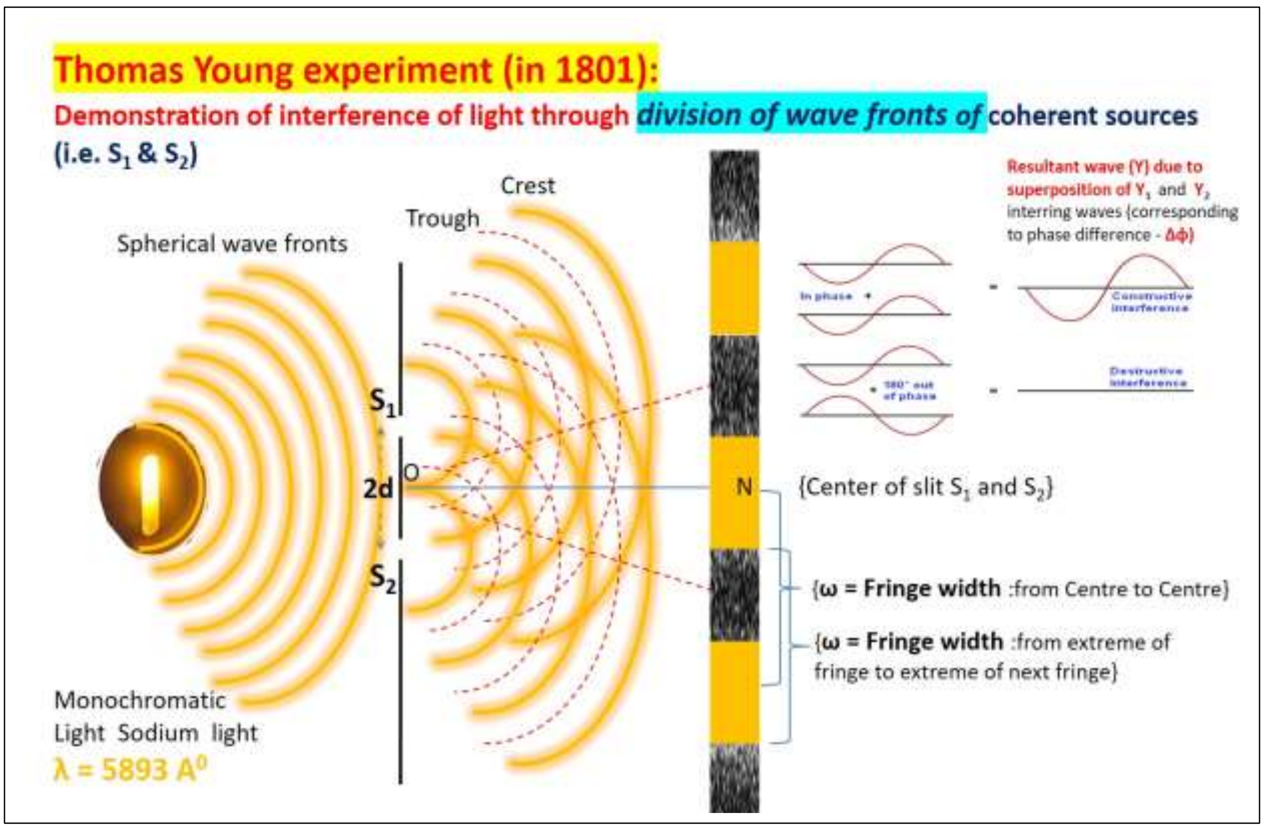
$$= \frac{(a_1^2\, [\delta]_0^{2\pi}) \ +\ (a_2^2\, [\delta]_0^{2\pi}) + \ (2a_1 a_2\, [sin\delta]_0^{2\pi})}{[\delta]_0^{2\pi}}$$

$$= \frac{2\pi\, (a_1^2 + a_2^2)}{2\pi} = a_1^2 + \ a_2^2 \ = I_1 + \ I_2$$

If $a_1 = a_2 = a$ and then $\mathbf{I_{avrg.}} = a^2 + a^2 = \mathbf{2a^2}$

(Since if $a_1 = a_2 = a$ and then $\mathbf{I_{max.}} = a^2 + a^2 + 2a.a = (a+a)^2 = (2a)^2 = \mathbf{4a^2}$)





In Young's double slit experiment the interference takes place due to division of wave fronts from Slit S1 and S2. The superimposition of waves fronts from coherent sources i.e. S1 and S2 results into redistribution of energy.

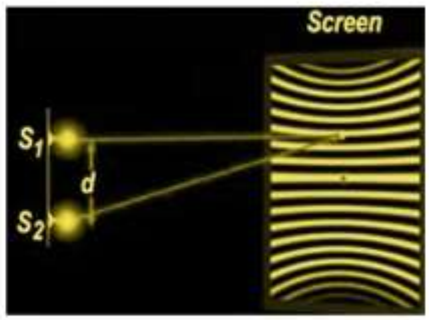
The region in which the light intensity is increased or maximum than the intensity of individual wave (the region where the waves superimposes having same phase difference) results into **Constructive Interference.**

The region in which the light intensity is zero or minimum than the intensity of individual wave (the region where the waves superimposes having opposite phase difference) results into **Destructive Interference.**

When two light waves are made to interfere the alternate bright and dark bands are formed called fringes and this phenomena of modification of light intensity in medium is called Interference.

Shape of Fringes

The shape of the fringes theoretically should be hyperbola but due to the large eccentricity of the hyperbolic fringes appear like straight lines.



Conditions to Obtained Sustained Interference pattern

- The two superimposing waves must be coherent
- The two waves must be of same or same frequency
- If the waves are polarized, then the plane of polarization of both the waves must be same

Conditions to Obtained Distinct Interference pattern

- The amplitude of the superimposing wave must be same
  Since $I_{max} = (a_1 + a_2)^2$ $I_{min} = (a_1 - a_2)^2$
  If $a_1 = a_2 = a$ $I_{max} = 4a^2$ $I_{min} = 0$
  Under such condition the maxima's will be extremely bright and minima would be completely dark. This suggest that net energy conserve in medium only redistribution of intensity takes place.
- $\beta \propto D$
  The distance between the source and the screen must be large
- $\beta \propto \frac{1}{d}$
  The distance between the two slits must be small

Two independent sources cannot produce interference because they do not maintain a steady phase difference between them.

Learning Outcome:

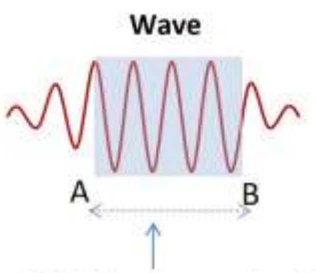
Phenomenon of Interference is in accordance with Law of Conservation of Energy.

All the bright and dark fringes formed are equally spaced.

Questions:

1. What is light (define).
2. Why the fringes are parabolic (answer is in your text book).
3. What will happen, if the radio waves of same frequency which are having slight difference in their amplitude are cast in the medium simultaneously by two broadcasters?
4. Conditions to Obtained Sustained Interference pattern.

Notes on coherency for perusal and to understand the types



AB is the coherence length

Wave interference is strong when the paths taken by all the interfering waves differ by less than the coherence length.

Coherence length : It is the distance up to which a photon maintains its constant amplitude. A to B is called *coherence length* of this photon **coherence length** is the propagation distance over which a coherent wave (e.g. an electromagnetic wave) maintains a specified degree of coherence. Wave interference is strong when the paths taken by all the interfering waves differ by less than the coherence length.

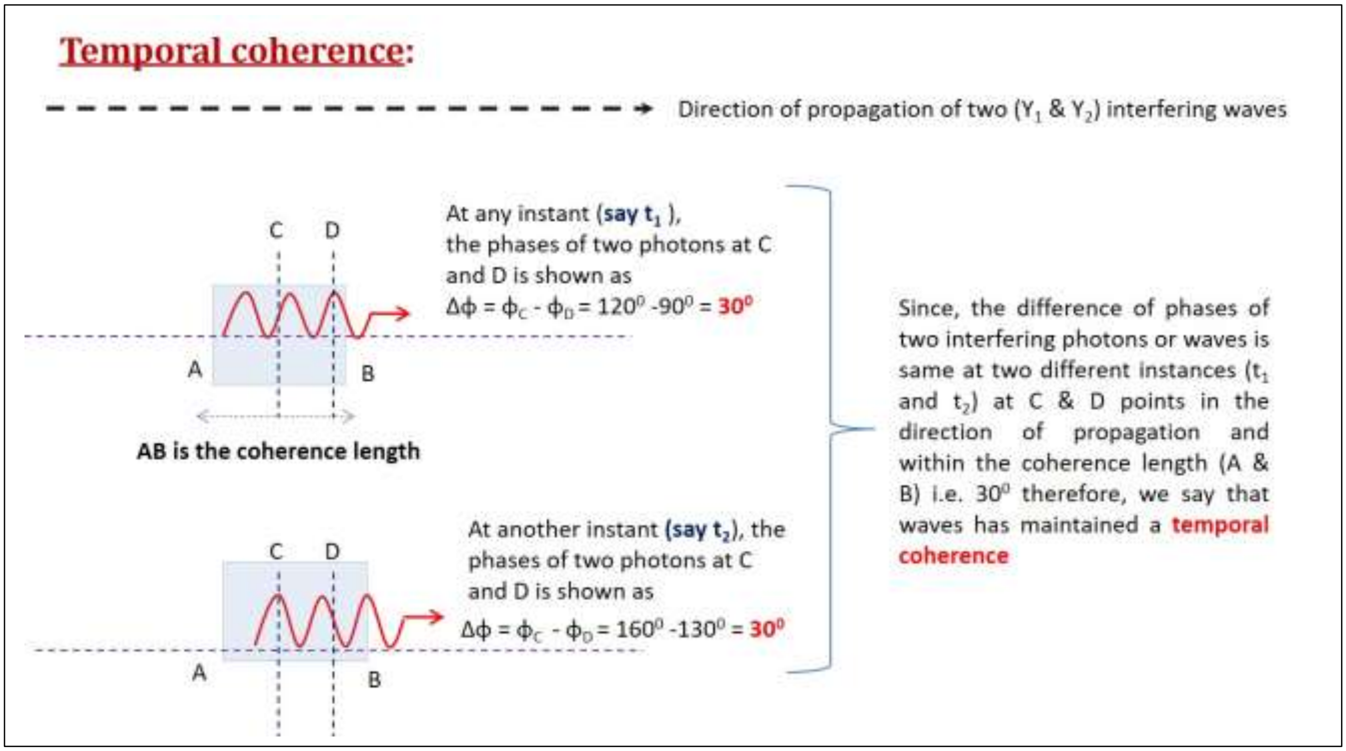
Coherency : Coherency is the condition of maintaining ***constant phase difference*** (or path difference) between two interfering Wave

✓The condition of constant phase can be obtained only within distance AB or in other words between the coherence length.

✓**Coherency is of two types: *Temporal* and *Spatial* *coherency.***

LASER *is* ***highly coherent light*** *in which both the spatial and temporal coherency is maintained therefore, for producing the interference patterns laser is best among coherent sources. Sodium light is used as coherent light in Laboratory to demonstrate interference phenomena of light.*

Temporal coherency: In the direction of propagation of waves, we take two points (C & D) such that they are within the coherence length. If the phase difference ($\Delta\phi$) at different instances (say time t1 and t2) remains same, then it said that source has Temporal coherency. (See Fig. below)



Spatial coherency: A plane is introduced perpendicular to the direction of propagation of waves, and we take two points (C & D) on this plane (See Fig. below). If phase difference (Δϕ) at these points at different instances (say time t1 and t2) remains same, then it said that source has Spatial coherency. (See Fig. below)