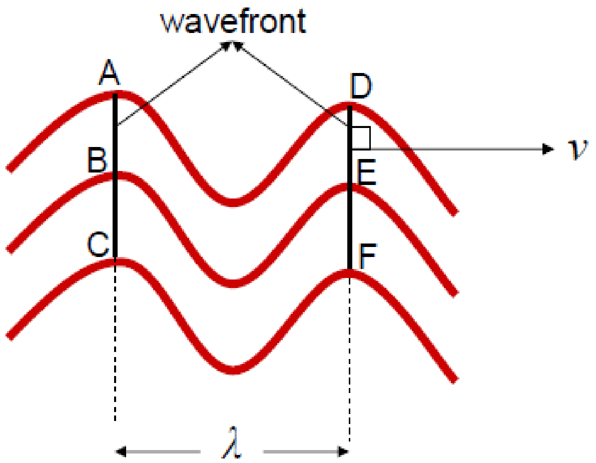
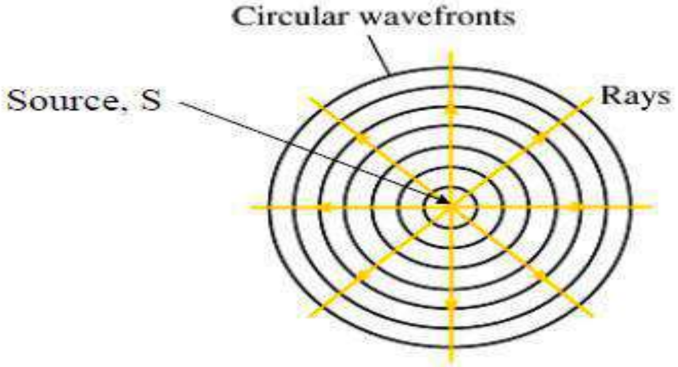
1.4.Wavefronts

- Definition – is defined as *a line or surface, in the path of a wave motion, on which the disturbances at every point have the same phase.*
- Figure below shows the wavefront of the sinusoidal waves.



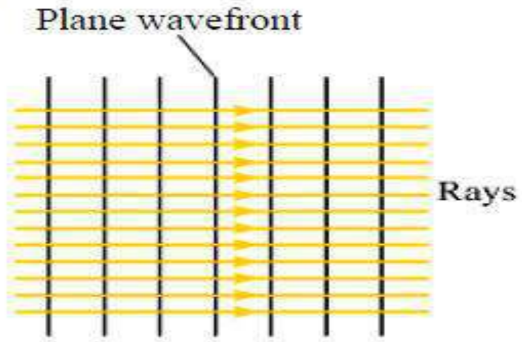
- Line joining all point of adjacent wave, e.g. A, B and C or D,E and F are in phase
- Wavefront always perpendicular to the direction of wave propagation.

- Type of wavefronts
  (a) Circular Wavefront



(a)

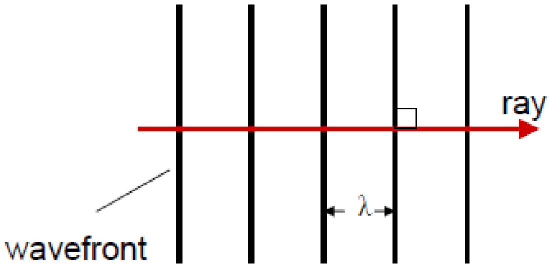
(b) Plane wavefront



(b)

- **Ray**

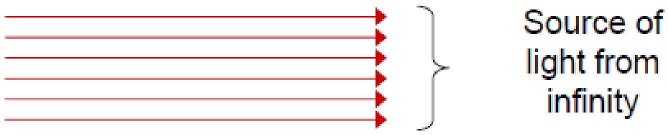
  Definition - *A ray is a line represents the direction of travel of a wave.*
  It is at right angle to the wavefronts



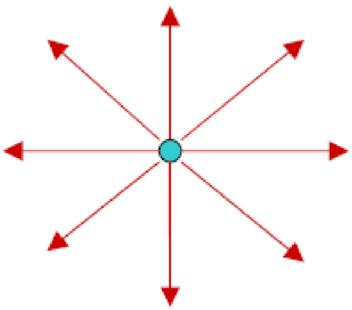
- **Beam of light**

  A collection of rays or a column of light

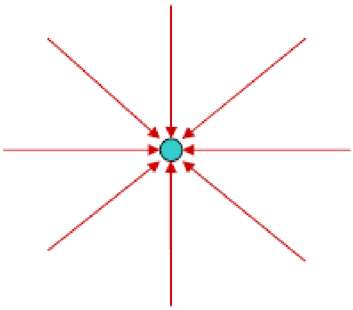
  (a) parallel beam, e.g. a laser beam



(b) divergent beam, e.g. a lamp near you

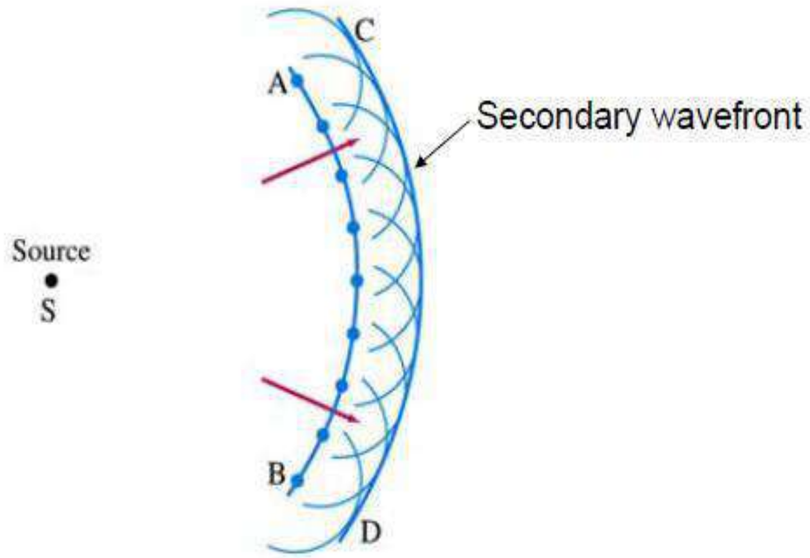


(c) convergent beam

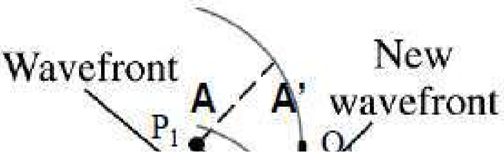


2.4.Huygen's Principle

- State – *Every point on a wavefront can be considered as a source of secondary wavelets that spread out in the forward direction at the speed of the wave. The new wavefront is the envelope of all the secondary wavelets - i.e. the tangent to all of them.*

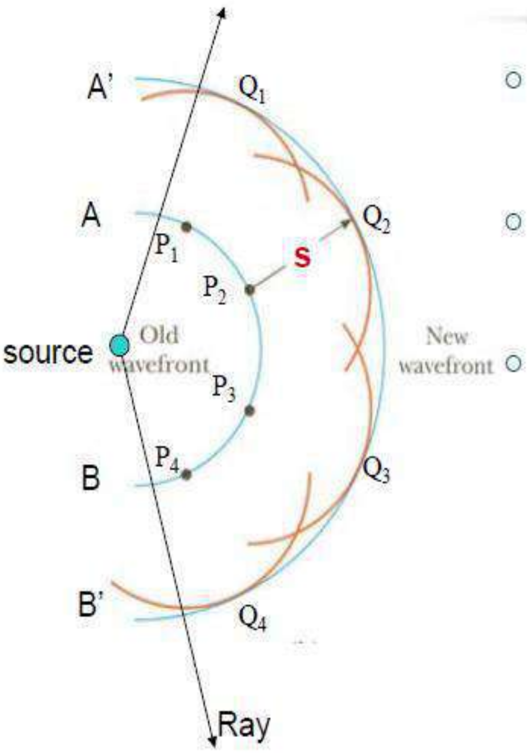


(a) Construction of new wavefront for a plane wave



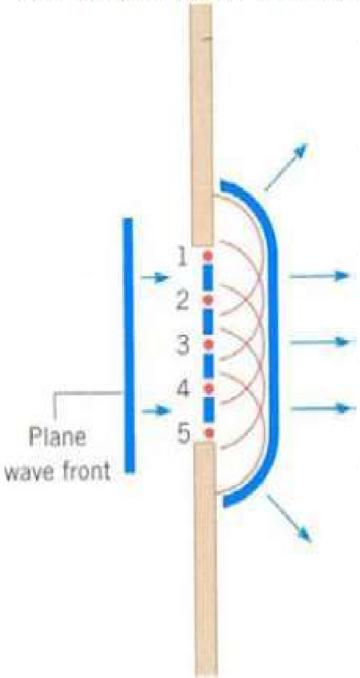
- If the wave speed is v, hence in time t the distance travels by the wavelet is $s = vt$.

(b) Construction of new wavefront for a circular wave



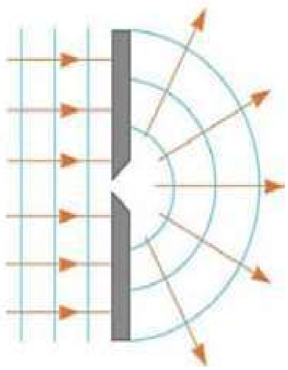
- Explanation as in the construction of new wavefront for a plane wavefront
- But the wavefront A'B' is a curve touching points Q_1,Q_2,Q_3 and Q_4.
- The curve A'B' is the new (circular) wavefront after t second.

(c) Diffraction of wave at a single slit

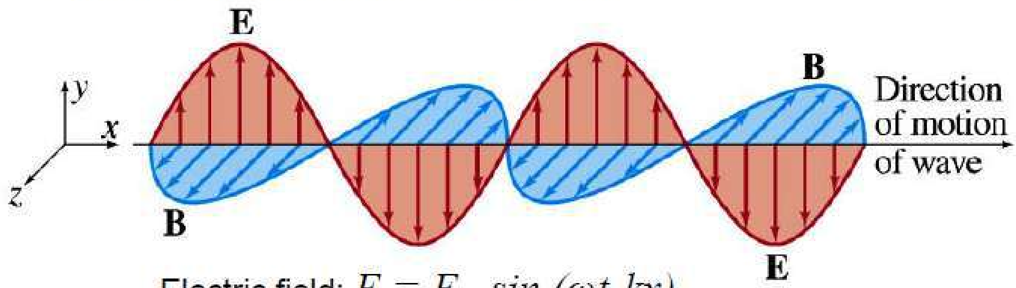


- Huygens' principle can be used to explain the diffraction of wave.
- Each of the point in figure shown, acts as a secondary source of wavelets (red circular arc)
- The tangent to the wavelets from points 2, 3 and 4 is a plane wavefront.
- But at the edges, points 1 and 5 are the last points that produce wavelets.
- Huygens' principle suggest that in conforming to the curved shape of the wavelets near the edges, the new wavefront bends or diffracts around the edges - applied to all kinds of waves.

If the size of the slit is small ($a << \lambda$), then diffraction will occur as shown in figure .



- Light waves are electromagnet waves.
- Consists of varying electric field E and varying magnetic field B which are perpendicular to each other



Electric field: $E = E_O \sin(\omega t\text{-}kx)$

Magnetic field: $B = B_O \sin(\omega t\text{-}kx)$

- **Interference**

  When two light waves meet at a point, a bright or a dark region will be produced in accordance to the *Principle of Superposition*.

- ***Principle of Superposition***:

  The resultant displacement at any point is the vector sum of the displacements due to the two light waves. 10

- **Constructive interference**
  - Reinforcement of amplitudes of light waves that will produce a bright fringe (maximum).
- **Destructive interference**
  - Total cancellation of amplitudes of light waves that will produce a dark fringe (minimum).

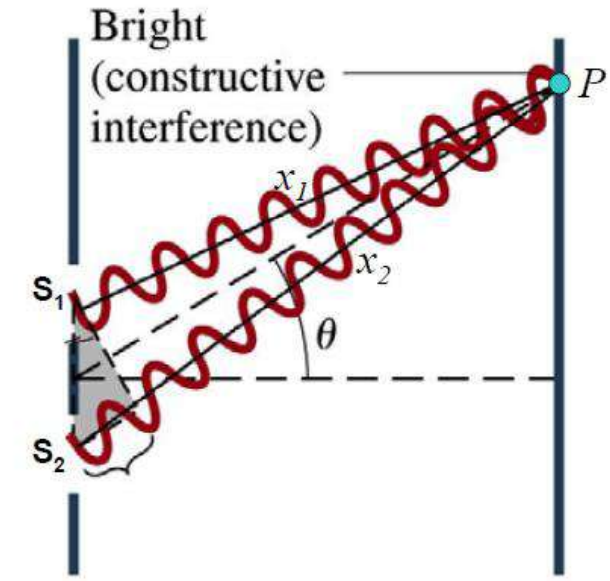
4.4. Condition for Fixed Interference

(a) Two coherent sources,
- The sources must have the same wavelength (monochromatic).
- the sources must have a constant phase difference between them.

(b) The waves that are interfering must have the same or approximately the same amplitude to obtain total cancellation at minimum or to obtain a good contrast at maximum.

5.4. Path Difference (ΔL)

- Definition – is defined as *the difference in distance from each source to a particular point.*

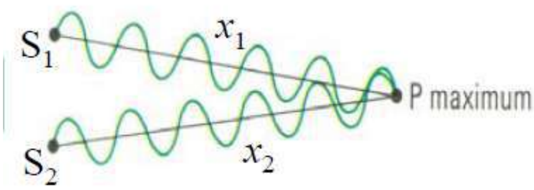


$$\text{Path Difference, } \Delta L = |S_2P - S_1P|$$
$$= |x_2 - x_1|$$

6.4. Interference of Two Coherent Sources in phase

- **Path difference for constructive interference**

S_1 and S_2 are coherent sources in phase



- A bright fringe at P if

$\Delta\Phi = 2m\pi$ where $m = 0,1,2,...$

- At P,

$$E_{1P} = E_0 \sin(\omega t - kx_1)$$
$$E_{2P} = E_0 \sin(\omega t - kx_2)$$

then

$$\Delta\Phi = (\omega t - kx_2) - (\omega t - kx_1)$$
$$\Delta\Phi = k(x_1 - x_2) \text{ since } k = \frac{2\pi}{\lambda} \text{ and}$$
27 $$\Delta\Phi = \frac{2\pi}{\lambda}\Delta L \qquad (x_1 - x_2) = \Delta L$$

- Therefore

$$2m\pi = \frac{2\pi}{\lambda}\Delta L$$
$$\boxed{\Delta L = m\lambda}$$

where $m = 0,1,2,.....$

λ : wavelength

- Note

When

$m = 0$ ⇨ Central bright fring

$m = 1$ ⇨ 1st bright fringe

$m = 2$ ⇨ 2nd bright fringe

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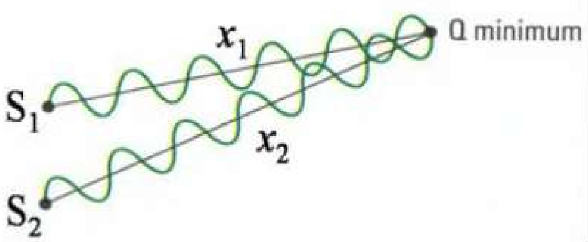
○ Path difference for destructive interference



- A dark fringe at Q if

$$\Delta\Phi = (2m+1)\pi$$

where $m = 0,1,2,\ldots$

- At Q,

$$E_{1Q} = E_0 \sin(\omega t - kx_1)$$
$$E_{2Q} = E_0 \sin(\omega t - kx_2)$$

then

$$\Delta\Phi = (\omega t - kx_2) - (\omega t - kx_1)$$

$\Delta\Phi = k(x_1 - x_2)$ since $k = \dfrac{2\pi}{\lambda}$ and $(x_1 - x_2) = \Delta L$

$$\Delta\Phi = \frac{2\pi}{\lambda}\Delta L$$

- Therefore

$$(2m+1)\pi = \frac{2\pi}{\lambda}\Delta L$$

$$\boxed{\Delta L = \left(m + \frac{1}{2}\right)\lambda}$$

where $m = 0,1,2,\ldots\ldots$

- Note

When

$m = 0$ ⇨ 1st dark fringe

$m = 1$ ⇨ 2nd dark fringe

$m = 2$ ⇨ 3rd dark fringe

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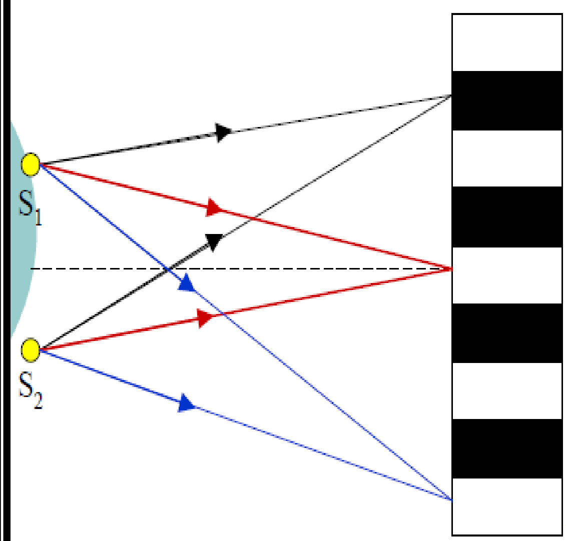
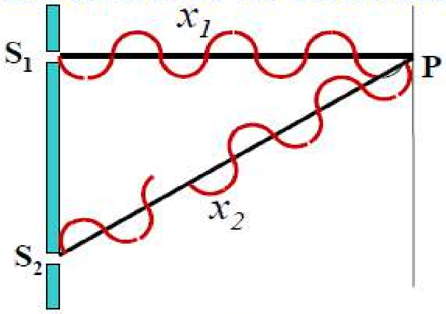


	$\Delta\Phi$	m	ΔL
2nd bright fringe	4π	2	2λ
2nd dark fringe	3π	1	$\frac{3}{2}\lambda$
1st bright fringe	2π	1	λ
1st dark fringe	π	0	$\frac{1}{2}\lambda$
Central bright fringe	0	0	0
1st dark fringe	π	0	$\frac{1}{2}\lambda$
1st bright fringe	2π	1	λ
2nd dark fringe	3π	1	$\frac{3}{2}\lambda$
2nd bright fringe	4π	2	2λ

7.4. Interference of Two Coherent Sources in antiphase

- **Path difference for constructive interference**



- A bright fringe at P if

$$\Delta\Phi = 2m\pi \quad \text{where } m = 1,2,...$$

- At P,

$$E_{1P} = E_0 \sin(\omega t - kx_1)$$
$$E_{2P} = E_0 \sin(\omega t - kx_2 - \pi)$$

then

$$\Delta\Phi = (\omega t - kx_2 - \pi) - (\omega t - kx_1)$$
$$\Delta\Phi = k(x_1 - x_2) - \pi \quad \text{since } k = \frac{2\pi}{\lambda} \text{ and}$$
7 $$\Delta\Phi = \left(\frac{2\pi}{\lambda}\Delta L\right) - \pi \qquad (x_1 - x_2) = \Delta L$$

- Therefore

$$2m\pi = \left(\frac{2\pi}{\lambda}\Delta L\right) - \pi$$

$$\boxed{\Delta L = \left(m + \frac{1}{2}\right)\lambda}$$

where $m = 0,1,2,.....$

- Note

When

$m = 0$ ⇨ 1st bright fringe
$m = 1$ ⇨ 2nd bright fringe
$m = 2$ ⇨ 3rd bright fringe

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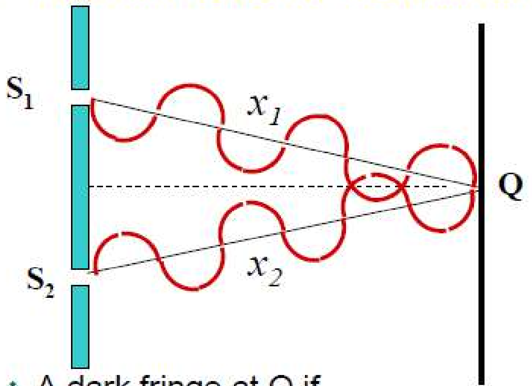
- **Path difference for destructive interference**



- A dark fringe at Q if

$$\Delta\Phi = (2m + 1)\pi$$

where $m = 0,1,2,...$

- At Q, $E_{1Q} = E_0 \sin(\omega t - kx_1)$

$$E_{2Q} = E_0 \sin(\omega t - kx_2 + \pi)$$

then

$$\Delta\Phi = (\omega t - kx_2 + \pi) - (\omega t - kx_1)$$
$$\Delta\Phi = k(x_1 - x_2) + \pi \quad \text{since } k = \frac{2\pi}{\lambda} \text{ and}$$
$$\Delta\Phi = \left(\frac{2\pi}{\lambda}\Delta L\right) + \pi \qquad (x_1 - x_2) = \Delta L$$

- Therefore

$$(2m + 1)\pi = \left(\frac{2\pi}{\lambda}\Delta L\right) + \pi$$

$$\boxed{\Delta L = m\lambda}$$

where

$m = 0,1,2,.....$

- Note

When

$m = 0$ ⇨ Central dark fringe
$m = 1$ ⇨ 1st dark fringe
$m = 2$ ⇨ 2nd dark fringe

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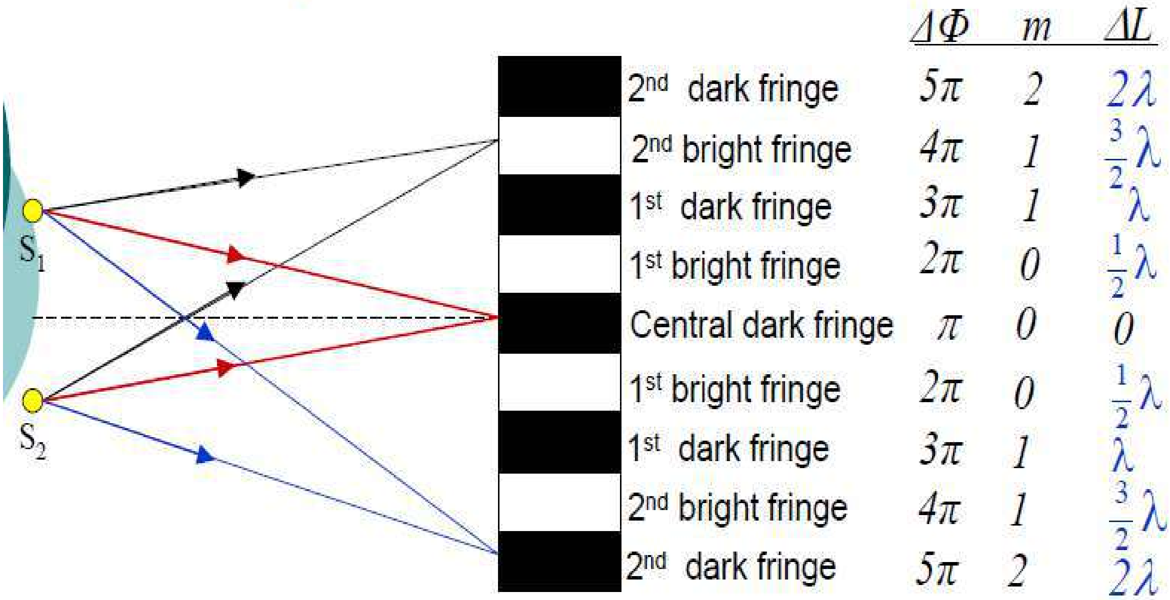
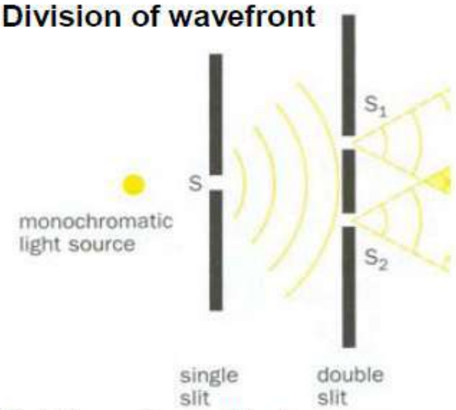
- **Interference pattern for two coherent sources in antiphase**



2 Coherent sources	Bright fringe	Dark fringe
In phase	$\boxed{\Delta L = m\lambda}$ $m = 0,1,2,.....$ $\Delta\Phi = 2m\pi$ $m = 0,1,2,...$	$\boxed{\Delta L = \left(m + \frac{1}{2}\right)\lambda}$ $m = 0,1,2,.....$ $\Delta\Phi = (2m+1)\pi$ $m = 0,1,2,...$
Antiphase	$\boxed{\Delta L = \left(m + \frac{1}{2}\right)\lambda}$ $m = 0,1,2,.....$ $\Delta\Phi = 2m\pi$ $m = 1,2,...$	$\boxed{\Delta L = m\lambda}$ $m = 0,1,2,.....$ $\Delta\Phi = (2m+1)\pi$ $m = 0,1,2,...$

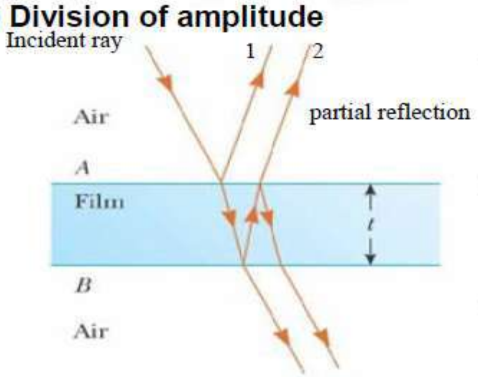
8.4. Methods of obtaining two coherent sources

(a) Division of wavefront



- A slit S is placed at equal distance from slits S_1 and S_2 as shown in figure.
- Light waves from S that arrived at S_1 and S_2 are in phase.
- Therefore, both slits S_1 and S_2 are two new coherent sources, e.g. in Young's double slit experiment

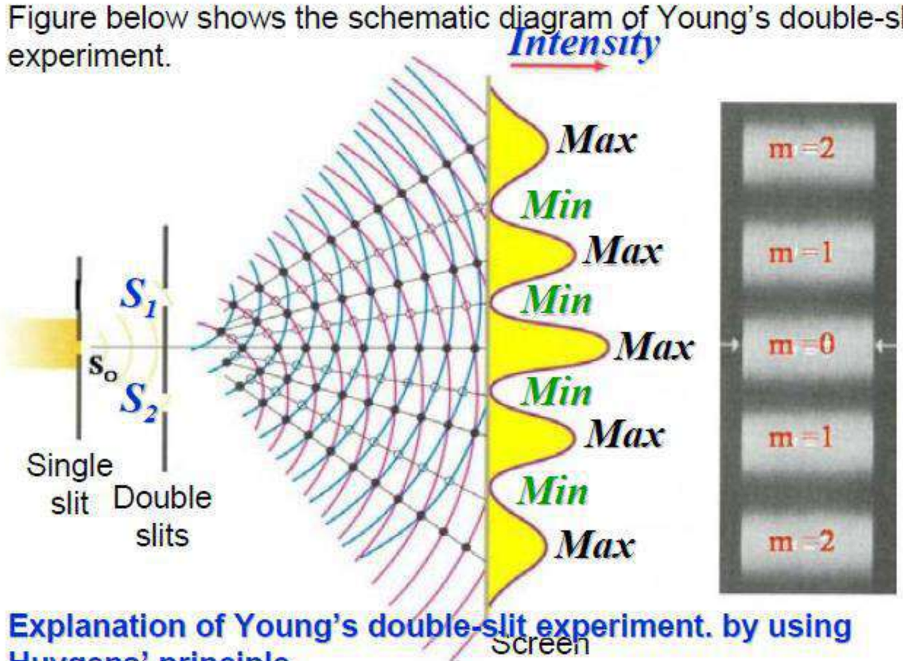
(b) Division of amplitude



- The incident wavefront is divided into two waves by partial reflection and partial transmission.
- Both reflected waves 1 and 2 are coherent and will result in interference when they superpose.
- e.g. Newton's ring, air wedge fringes and thin film interference.

9.4. Young's Double- Slit Experiment

- Figure below shows the schematic diagram of Young's double-slit experiment.



- **Explanation of Young's double-slit experiment. by using Huygens' principle**
  - Wavefront from light source falls on S_O and diffraction occurs.
  - Every point on the wavefront that falls on S_O acts as sources of secondary wavelets that will produce a new wavefront that propagate to slits S_1 an S_2 .

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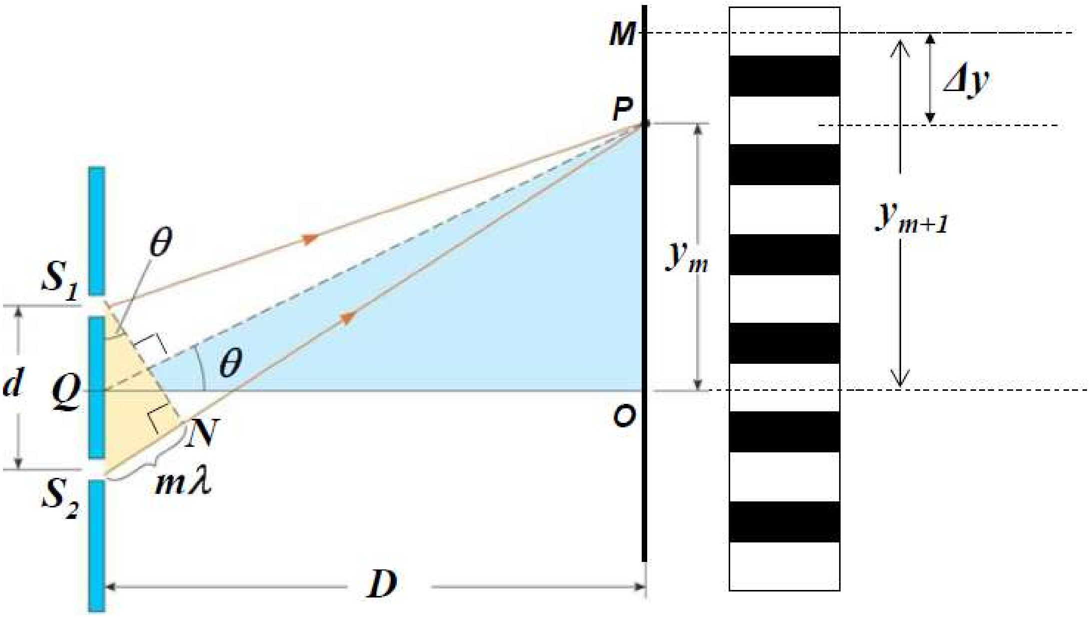

- Suppose P as shown in figure is the m[th] bright fringe, so that

$$S_2P - S_1P = m\lambda$$

- Let OP = y_m = distance from P to O .
- If $NP = S_1P$ then $S_2N = S_2P\text{-}NP = m\lambda$.
- In practice d is very small (<1mm) and $D>>d$, then S_1N meets PQ at right angle. Therefore,

$$\boxed{\text{angle PQO = angle } S_2S_1N = \theta}$$

- From the figure,

$$\Delta\, S_2S_1N \Rightarrow \sin\theta = \frac{S_2N}{S_2S_1} = \frac{m\lambda}{d}$$

$$\Delta PQO \Rightarrow \tan\theta = \frac{PO}{QO} = \frac{y_m}{D}$$

Since θ is small, $\tan\,\theta = \sin\,\theta$

$$\therefore \frac{y_m}{D} = \frac{m\lambda}{d}$$

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- Therefore, the separation between central bright fringe with m^th^ and (m+1)^th^ bright fringe is given by

  For the **m^{th} bright fringe** :

$$\boxed{y_m = \frac{m\lambda D}{d}}$$

  For the **$(m+1)^{th}$ bright fringe** :

$$\boxed{y_{m+1} = \frac{(m+1)\lambda D}{d}}$$

- The **separation between successive (consecutive) bright or dark fringes, Δy** is given by

$$\Delta y = y_{m+1} - y_m = \frac{(m+1)\lambda D}{d} - \frac{m\lambda D}{d}$$

$$\boxed{\Delta y = \frac{\lambda D}{d}}$$

where

m : order $= 0, 1, 2, \ldots\ldots$

λ : wavelength

D : distance between double - slits and the screen

d : separation between double - slits

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- The separation between **m^{th} dark fringe and central bright fringe** is given by

$$\boxed{x_m = \left(m + \tfrac{1}{2}\right)\frac{\lambda D}{d}}$$

where

m : order $= 0, 1, 2, \ldots\ldots$

- From the equation below,

$$\Delta y = \frac{\lambda D}{d}$$

- Δy depends on :
  - i) the wavelength of light, λ
  - ii) the distance apart, d of the double slits,
  - iii) distance between slits and the screen, D
- Explanation for the above factors:
  - (a) if λ is short and hence Δy decreases for fixed D and d. The interference fringes are closer to each other and vice-versa.
  - (b) if the distance apart d of the slits diminished, Δy increased for fixed D and λ and vice-versa.