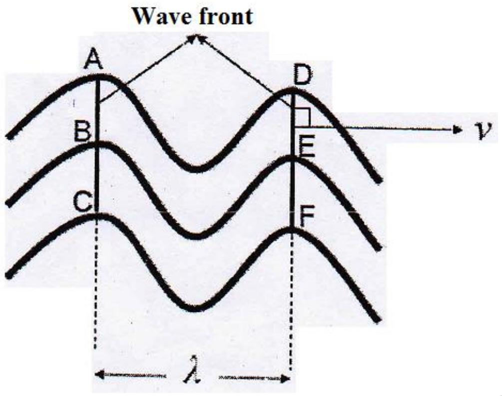
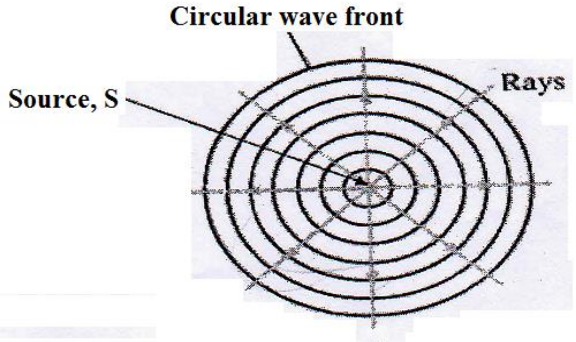
1.6 Wave fronts

- 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 wave front of the sinusoidal waves.



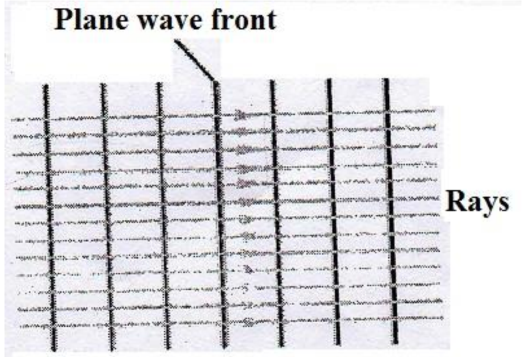
- Line joining all points of adjacent wave, e.g. A, B and C or D, E and F are in phase.
- Wave front always perpendicular to the direction of wave propagation.
- Types of wave fronts

(a) Circular wave front



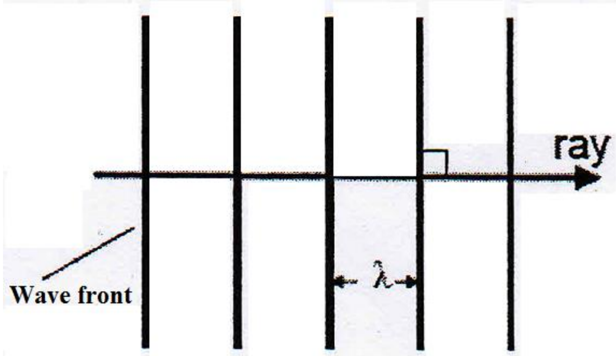
(a)

(b) Plane wave front



(b)

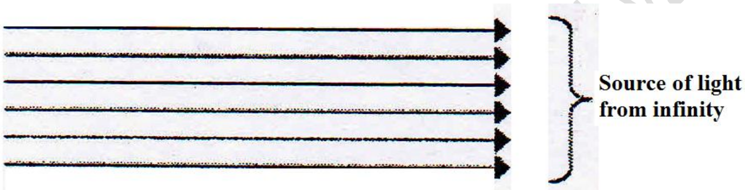
- **Ray**
- Definition- A ray is a line represents the direction of travel of a wave. It is at right angle to the wave front.



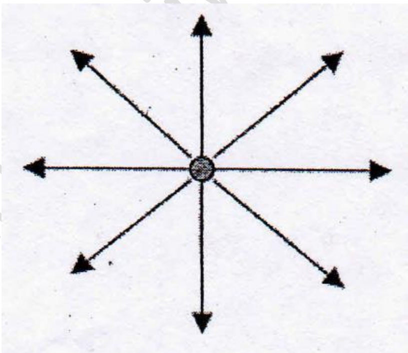
- **Beam of light**

A collection of rays or a column of light

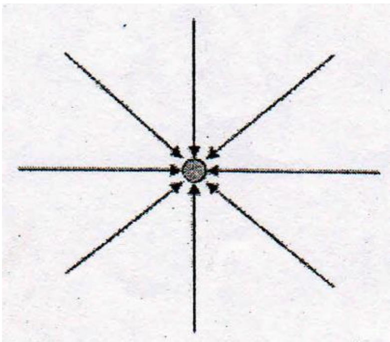
(a) Parallel beam, e.g. a laser beam.



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

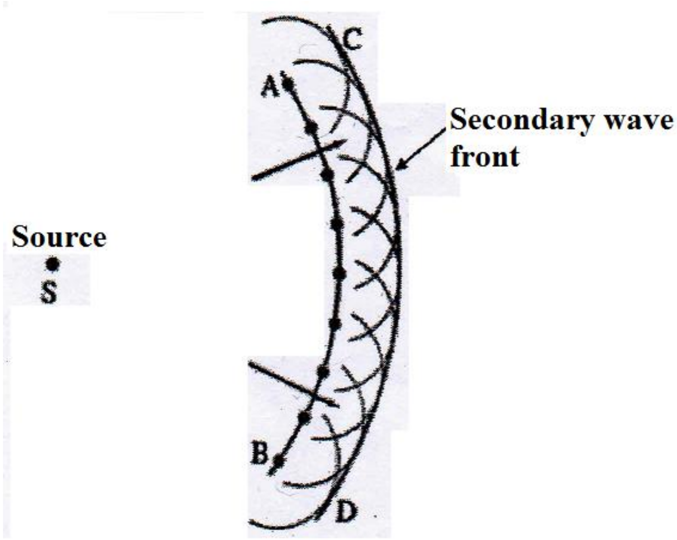


(c) Convergent beam

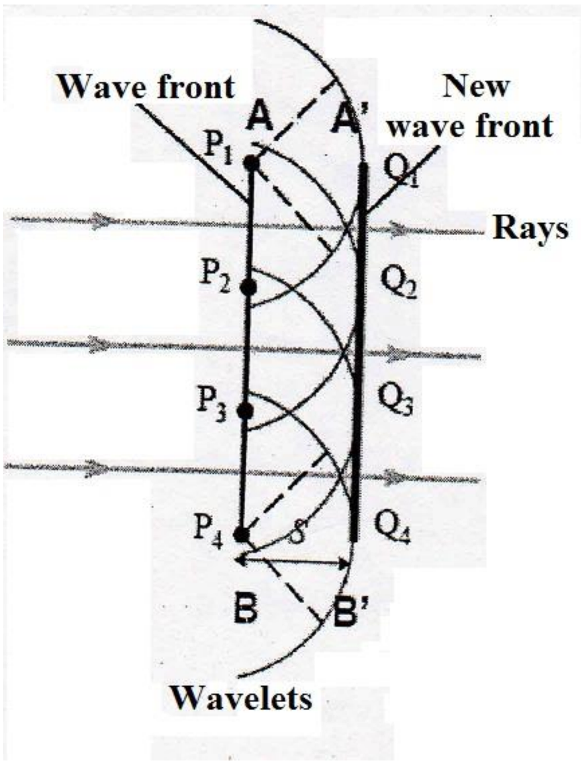


2.6 Huygens' Principle

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



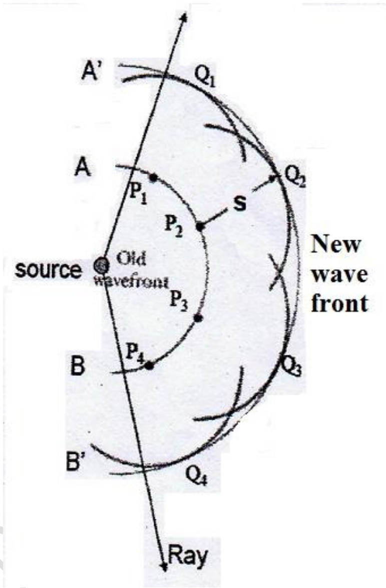
(a) Construction of new wave front for a plane wave



- ✓ If the wave speed is *v*, hence in time *t* the distance travels by the wavelet is ***s = vt***.
- ✓ From Huygens' principle, points P1, P2, P3 and P4 on the wave front AB are the source of secondary wavelets.
- ✓ From the points, draw curves of radius s.
- ✓ Then draw a straight line A'B' which is tangent to the curves at point Q_1, Q_2, Q_3 and Q_4.
- ✓ Hence, line A'B' is the new wave front after t second.

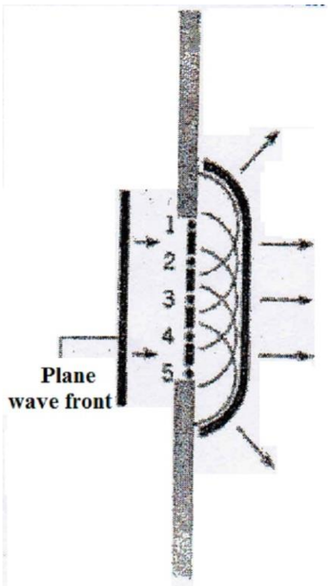
(b) Construction of new wave front for a circular wave

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

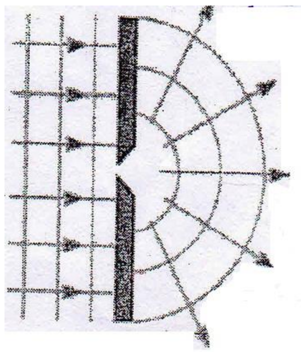


(c) Diffraction of wave at a single slit

- ✓ Huygens' principle can 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 wave front.
- ✓ 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 wave front bends or diffract around edges applied to all kinds of waves.

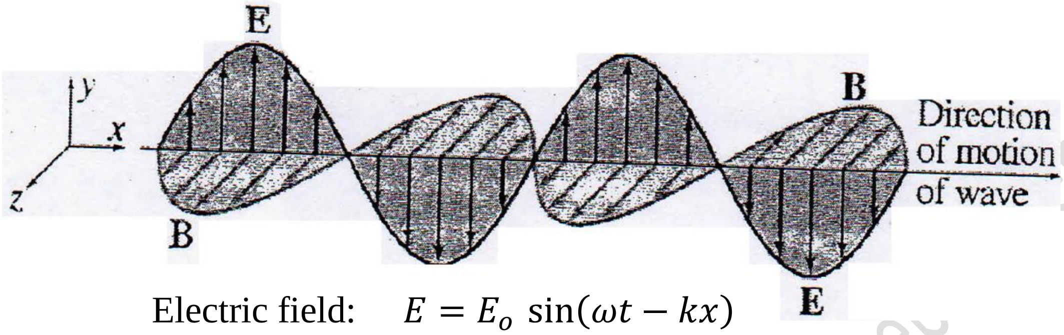


If the size of the still is small (a << λ), then diffraction will occur as shown in figure.



3.6 Interference of Light Waves

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



Electric field: $E = E_o \sin(\omega t - kx)$

Magnetic field: B = $B_o \sin(\omega t - kx)$

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

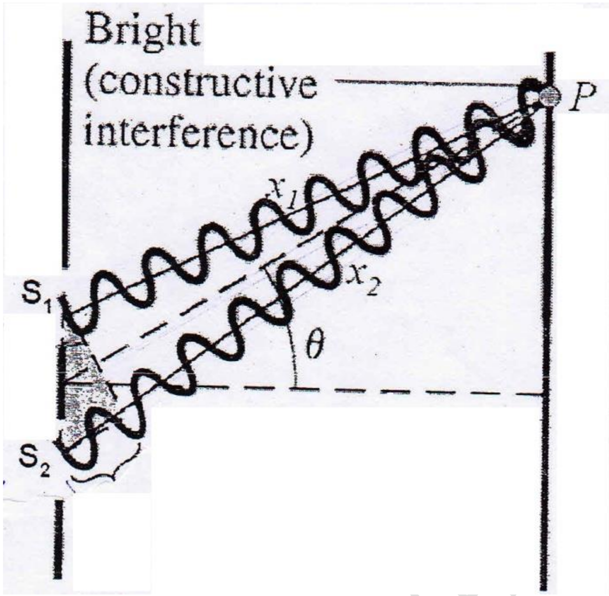
4.6 Condition of fixed interference

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.

5.6 Path difference (ΔL)

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



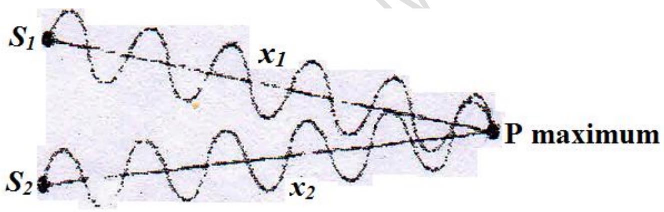
Path difference, ΔL = $|S_2P - S_1P|$

$$= |x_2 - x_1|$$

6.6 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:

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

- At P,

$$E_{1P} = E_o \sin(\omega t - Kx_1)$$
$$E_{2P} = E_o \sin(\omega t - Kx_2)$$

then

$$\Delta\emptyset = (\omega t - Kx_2) - (\omega t - Kx_1)$$
$$\Delta\emptyset = K(x_1 - x_2)$$

since $K = \frac{2\pi}{\lambda}$ and $\Delta L = (x_1 - x_2)$

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

- Therefore

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

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

Where m =0, 1, 2,...

- Note

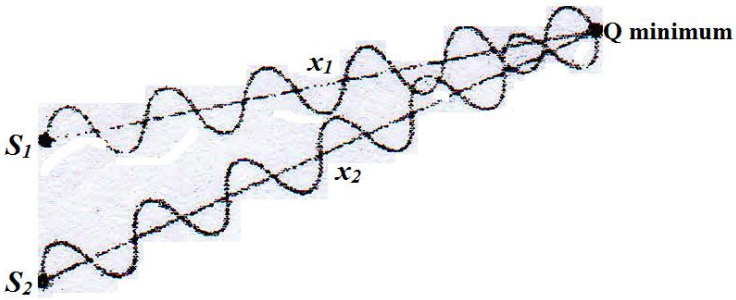
When

m = 0 ⇨ Central bright fringe

m = 1 ⇨ 1st bright fringe

m = 2 ⇨ 2nd bright fringe

- **Path difference for destructive interference**



❖ A dark fringe at Q if:

$\Delta\phi = (2m + 1)\,\pi$ where m = 0, 1, 2,.....

❖ At Q,

$$E_{1Q} = E_o \sin(\omega t - Kx_1)$$

$$E_{2Q} = E_o \sin(\omega t - Kx_2)$$

then

$$\Delta\phi = (\omega t - Kx_2) - (\omega t - Kx_1)$$

$$\Delta\phi = K(x_1 - x_2)$$

since $K = \frac{2\pi}{\lambda}$ and $\Delta L = (x_1 - x_2)$

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

❖ 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, ...

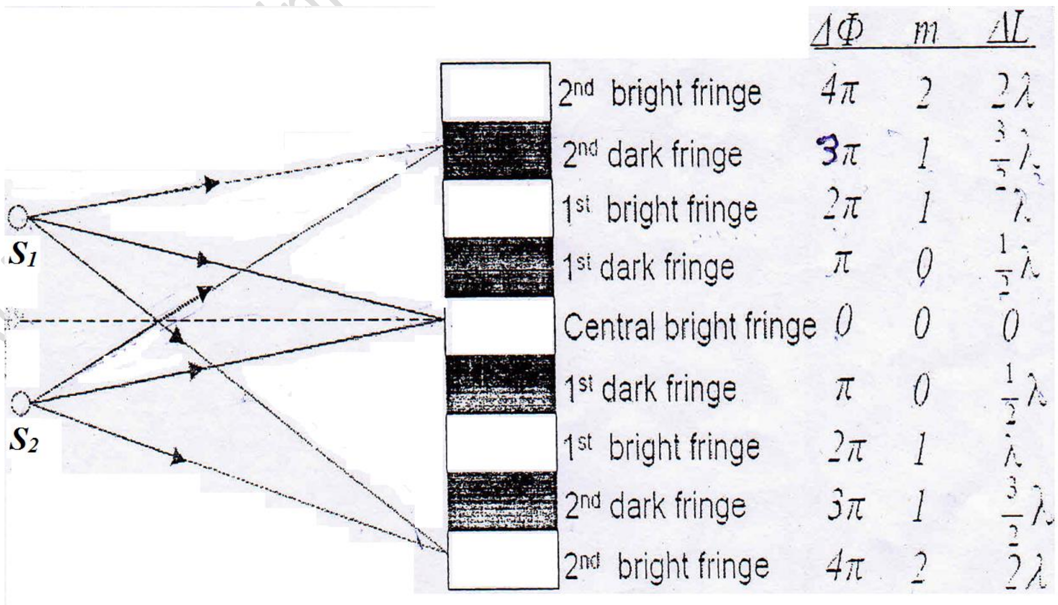
❖ Note

When

$m = 0$ ⇨ 1st dark fringe

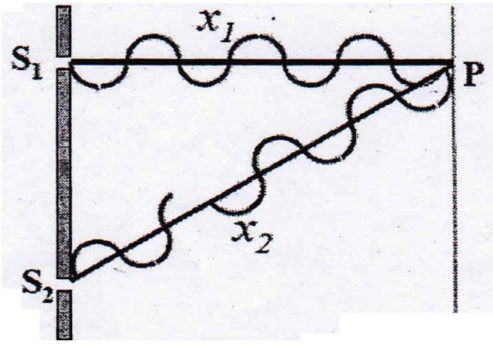
$m = 1$ ⇨ 2nd dark fringe

$m = 2$ ⇨ 3rd dark fringe



7.6 Interference of two coherent sources in antiphase

- **Path difference for constructive interference**



❖ A bright fringe at P if:
$\Delta\emptyset = 2m\pi$ where $m = 1, 2, ...$

❖ At P,

$$E_{1P} = E_o \sin(\omega t - Kx_1)$$
$$E_{2P} = E_o \sin(\omega t - Kx_2 - \pi)$$

then

$$\Delta\emptyset = (\omega t - Kx_2 - \pi) - (\omega t - Kx_1)$$
$$\Delta\emptyset = K(x_1 - x_2) - \pi$$

since $K = \frac{2\pi}{\lambda}$ and $\Delta L = (x_1 - x_2)$

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

❖ 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

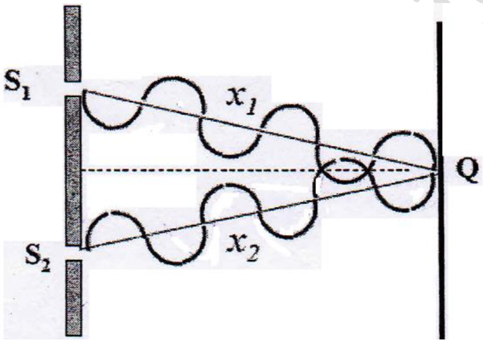
When

$m = 0$ ⇨ 1st bright fringe

$m = 1$ ⇨ 2nd bright fringe

$m = 2$ ⇨ 3rd bright fringe

- **Path difference for constructive interference**



❖ A dark fringe at Q if:
$\Delta\emptyset = (2m + 1)\pi$ where $m = 0, 1, 2, ...$

❖ At Q, $E_{1Q} = E_o \sin(\omega t - Kx_1)$

$$E_{2Q} = E_o \sin(\omega t - Kx_2 + \pi)$$

then: $\Delta\emptyset = (\omega t - Kx_2 + \pi) - (\omega t - Kx_1)$

$$\Delta\emptyset = K(x_1 - x_2) + \pi$$

since $K = \frac{2\pi}{\lambda}$ and $\Delta L = (x_1 - x_2)$

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

❖ Therefore

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

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

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

❖ Note

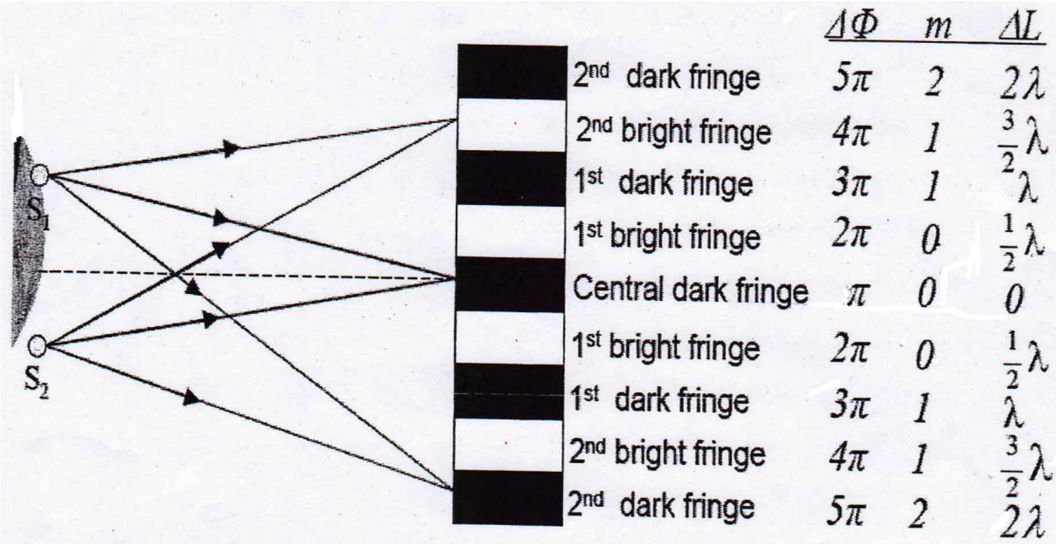
When

$m = 0$ ⇨ Central dark fringe

$m = 1$ ⇨ 1st dark fringe

$m = 2$ ⇨ 2nd dark fringe

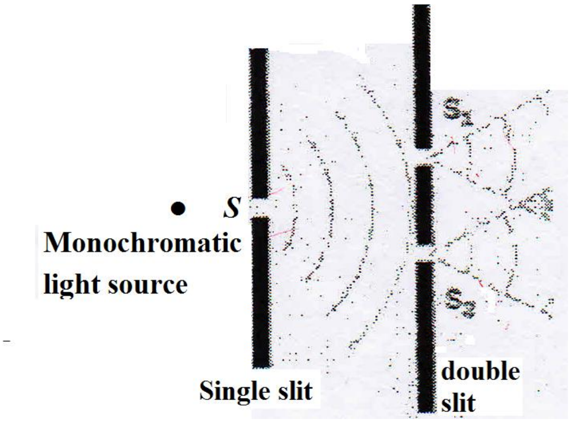
- **Interference Pattern for two coherent sources in antiphase**



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

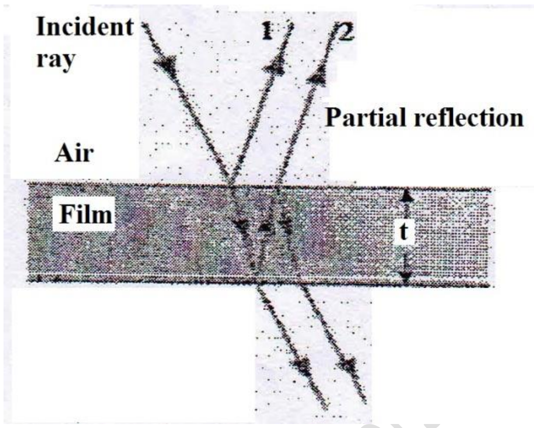
8.6 Methods of obtaining two coherent sources

(a) Division of wave front



- A slit S is placed at equal distance from silts 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 slits.

(b) Division of amplitude



- The incident wave front 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.