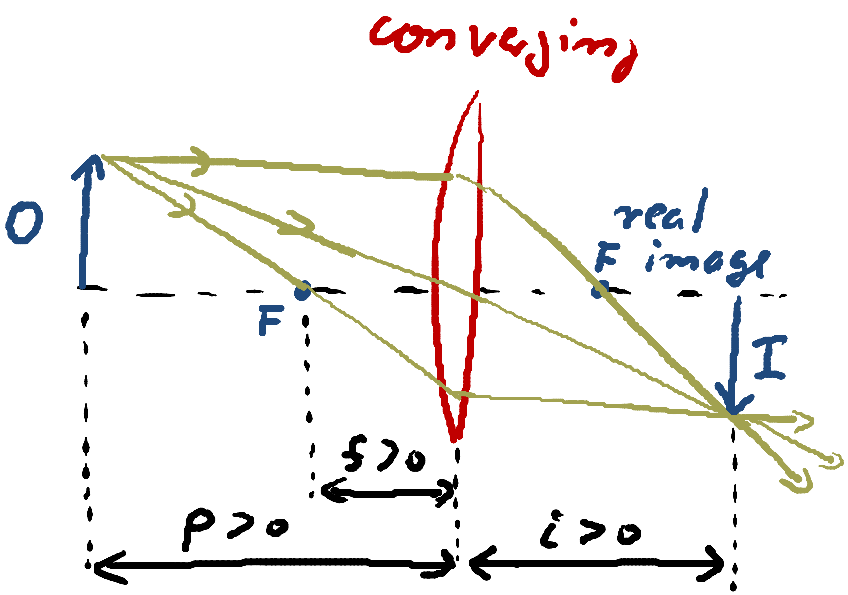
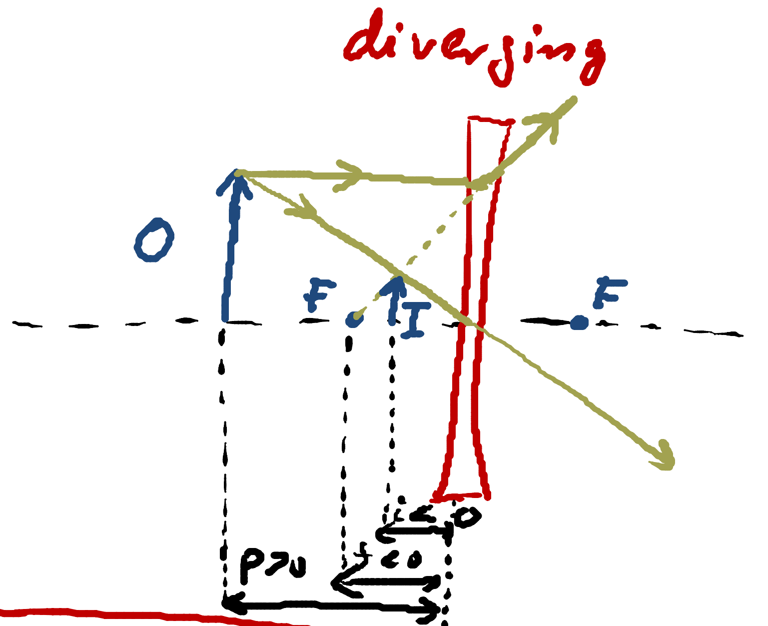
Recap I

Lecture 31

- Images from thin Lenses:

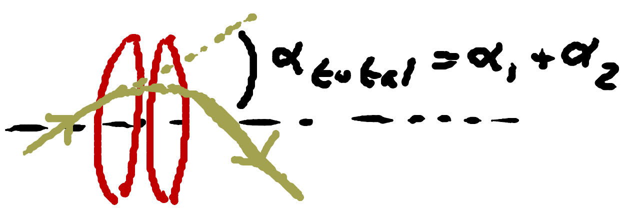




$$\frac{1}{p} = \frac{1}{i} + \frac{1}{f}$$

$$m = \frac{\text{image height}}{\text{object height}} = -\frac{i}{p}$$

- Thin lenses in contact:

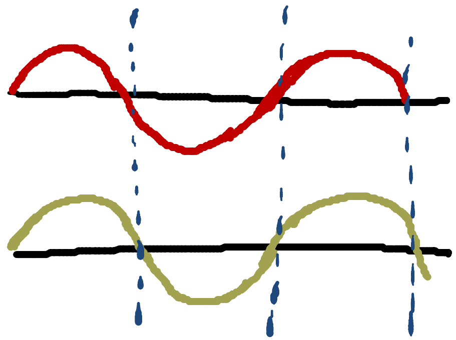


$P_{total} = P_1 + P_2$ } lens power P

$\frac{1}{f_{eff}} = \frac{1}{f_1} + \frac{1}{f_2}$ } focal length

Recap II

- Interference: – result of overlapping (EM) waves
  – need to add up fields of individual waves
- For two EM waves: (of equal frequency, amplitude, polarization)

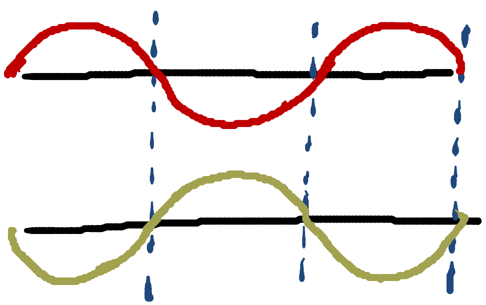


Constructive Interference:

for phase difference:

$$\Delta\phi = \phi_2 - \phi_1 = m(2\pi)$$

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



Destructive Interference:

for phase difference:

$$\Delta\phi = \phi_2 - \phi_1 = \left(m + \frac{1}{2}\right)(2\pi)$$

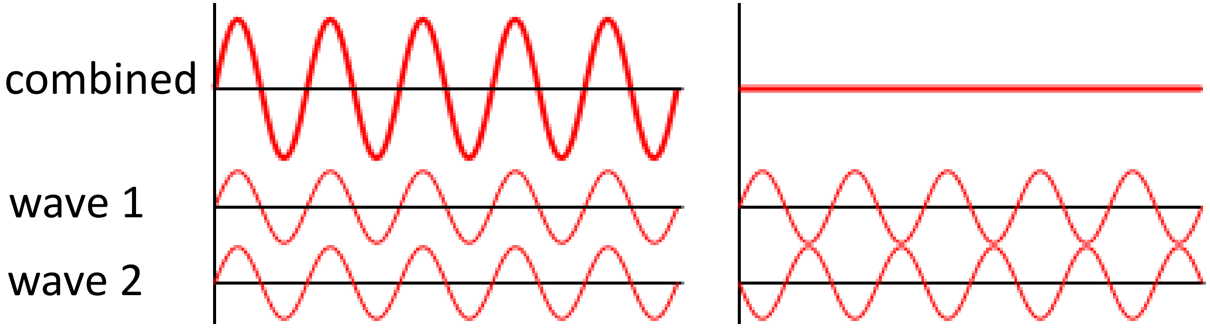
$m = 0, \pm 1, \pm 2, \ldots$

Phase difference between two waves may be caused by path length difference:

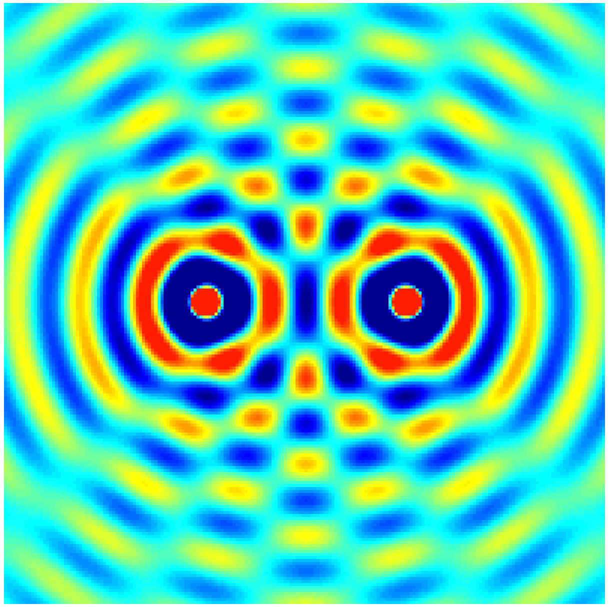
$$\Delta\Phi = \frac{2\pi}{\lambda}(\Delta \text{ path length})$$

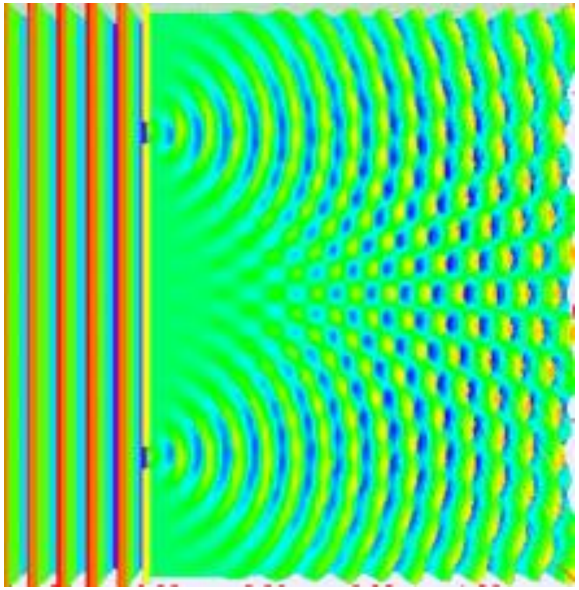
Today:

- **Interference**



Constructive **Destructive**



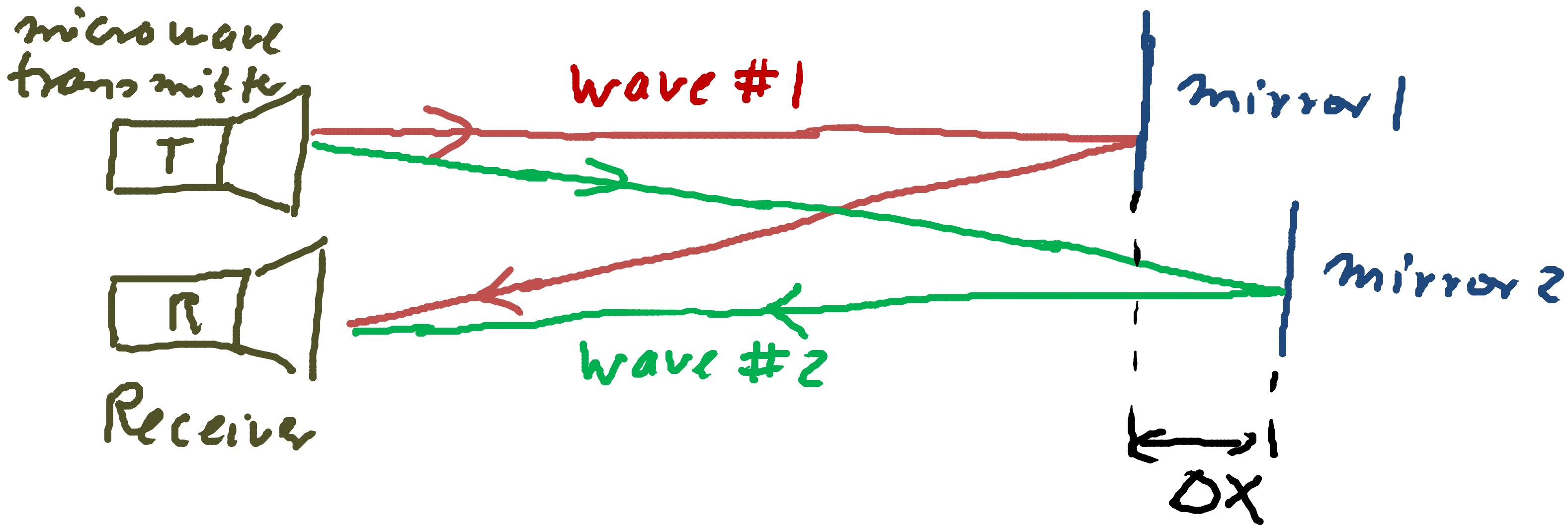


Phase shift between two waves may be introduced when the waves comming from a source travel along paths of differing lenghts before arriving at a common location:

$$\Delta\phi = \frac{2\pi}{\lambda}(\Delta \text{ path length})$$

$\frac{2\pi}{\lambda}$: k = wavenumber

1st Example:



$\Rightarrow$ path length difference of the two waves $= 2Dx$

$\Rightarrow$ (phase difference of the two waves at location of receiver) $= \Delta\phi = \frac{2\pi}{\lambda}(2Dx)$

Note: both waves started out in phase at the transmitter

$\Rightarrow$ Constructive Interference, if:

$\Delta\phi = \frac{2\pi}{\lambda} 2Dx = m(2\pi) \Rightarrow$

$\Delta path = 2Dx = m\lambda$
with $m = 0, \pm 1, \pm 2 \ldots$

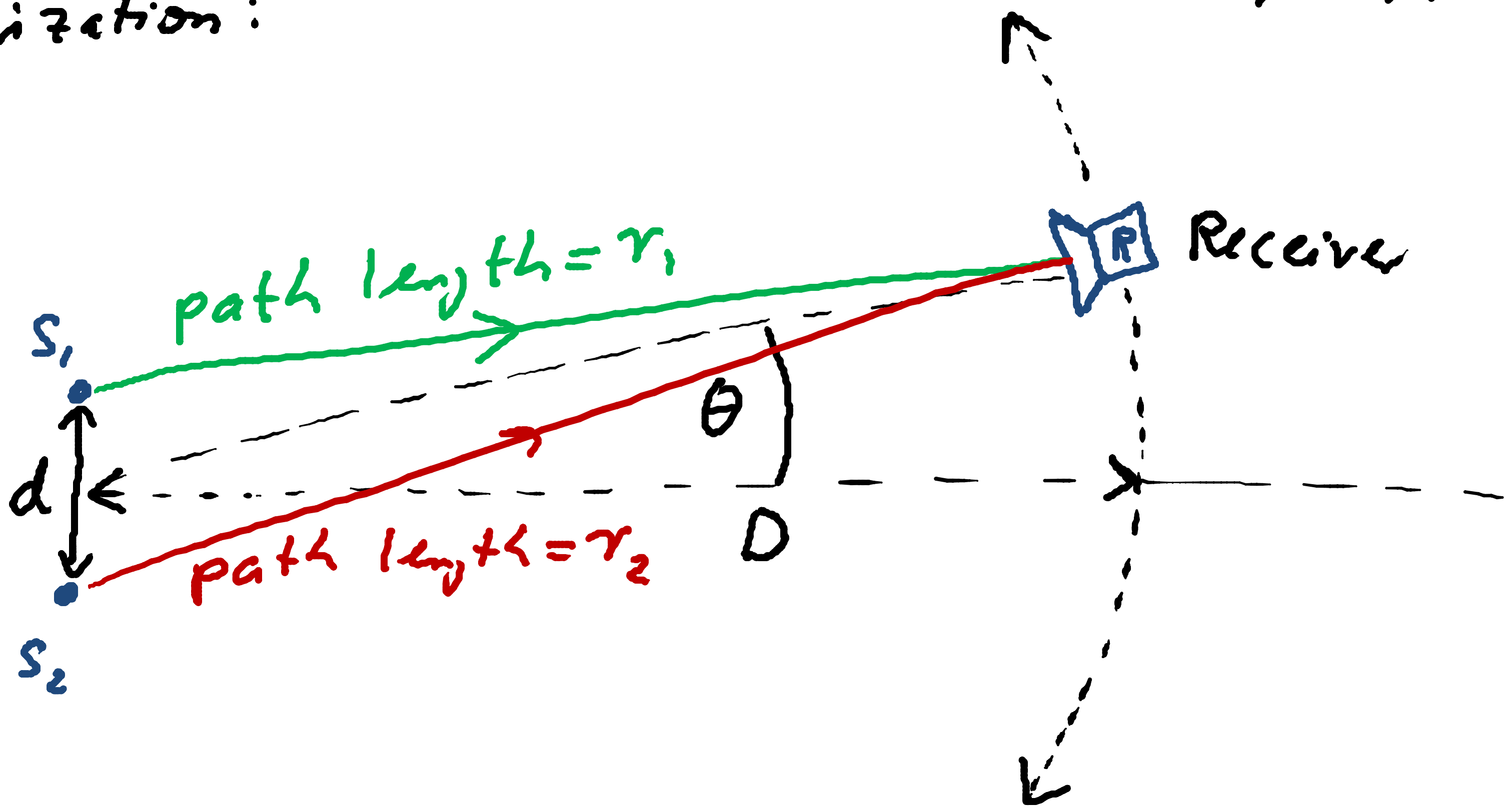
$\Rightarrow$ Destructive Interference, if

$\Delta\phi = \frac{2\pi}{\lambda} 2Dx = (m + \frac{1}{2})(2\pi) \Rightarrow$

$\Delta path = 2Dx = (m + \frac{1}{2})\lambda$
with $m = 0, \pm 1, \pm 2 \ldots$

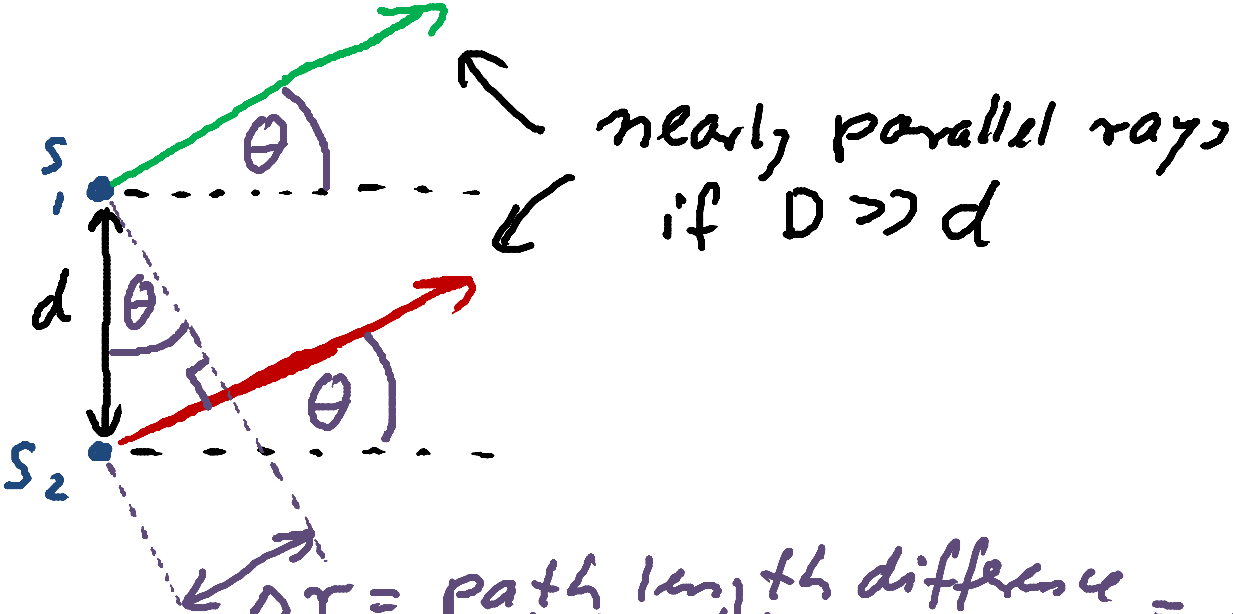
2nd Example:

Consider two sources of EM waves, emitting waves that are in phase and have equal amplitudes, frequency, and polarization:



In the following: Assume that receiver is far away:

$D \gg d \qquad D \gg \lambda$



Δr = path length difference of the two waves $= d \sin\theta$

$\Rightarrow$ <u>At distant receiver:</u>

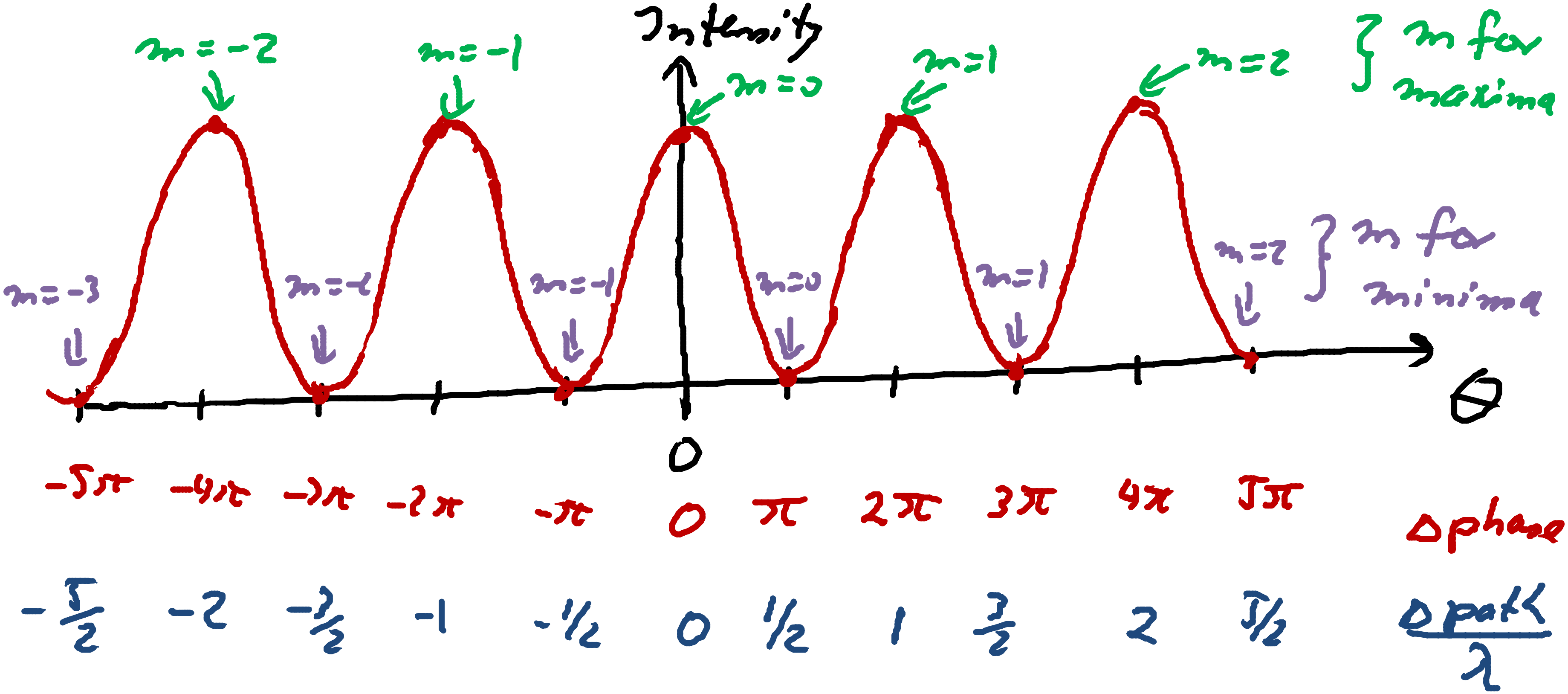
<u>Constructive Interference, if:</u>
(maxima of intensity)

$$\Delta\phi = \frac{2\pi}{\lambda}\,\Delta path = \frac{2\pi}{\lambda}\Delta r$$
$$= \frac{2\pi}{\lambda} d \sin\underline{\theta} = m\,(2\pi)$$
$$\Rightarrow \theta_{const} = \sin^{-1}\left(m\frac{\lambda}{d}\right)$$
$m = 0, \pm 1, \pm 2 \ldots$

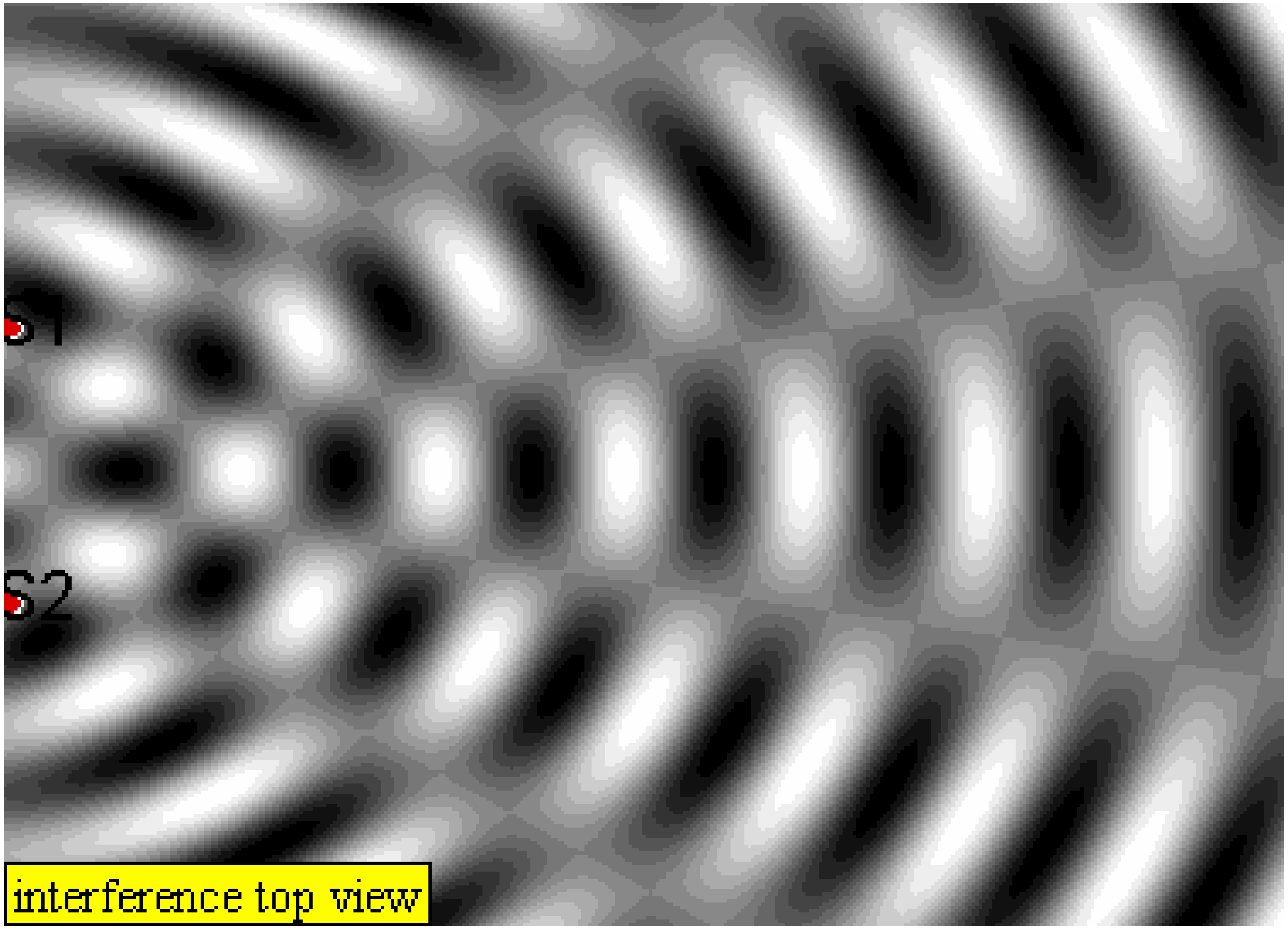
<u>Destructive Interference, if:</u>
(minima in intensity)

$$\Delta\phi = \frac{2\pi}{\lambda} d \sin\underline{\theta} = \left(m+\frac{1}{2}\right)(2\pi)$$
$$\Rightarrow \theta_{dest} = \sin^{-1}\left[\left(m+\frac{1}{2}\right)\frac{\lambda}{d}\right]$$
$m = 0, \pm 1, \pm 2 \ldots$

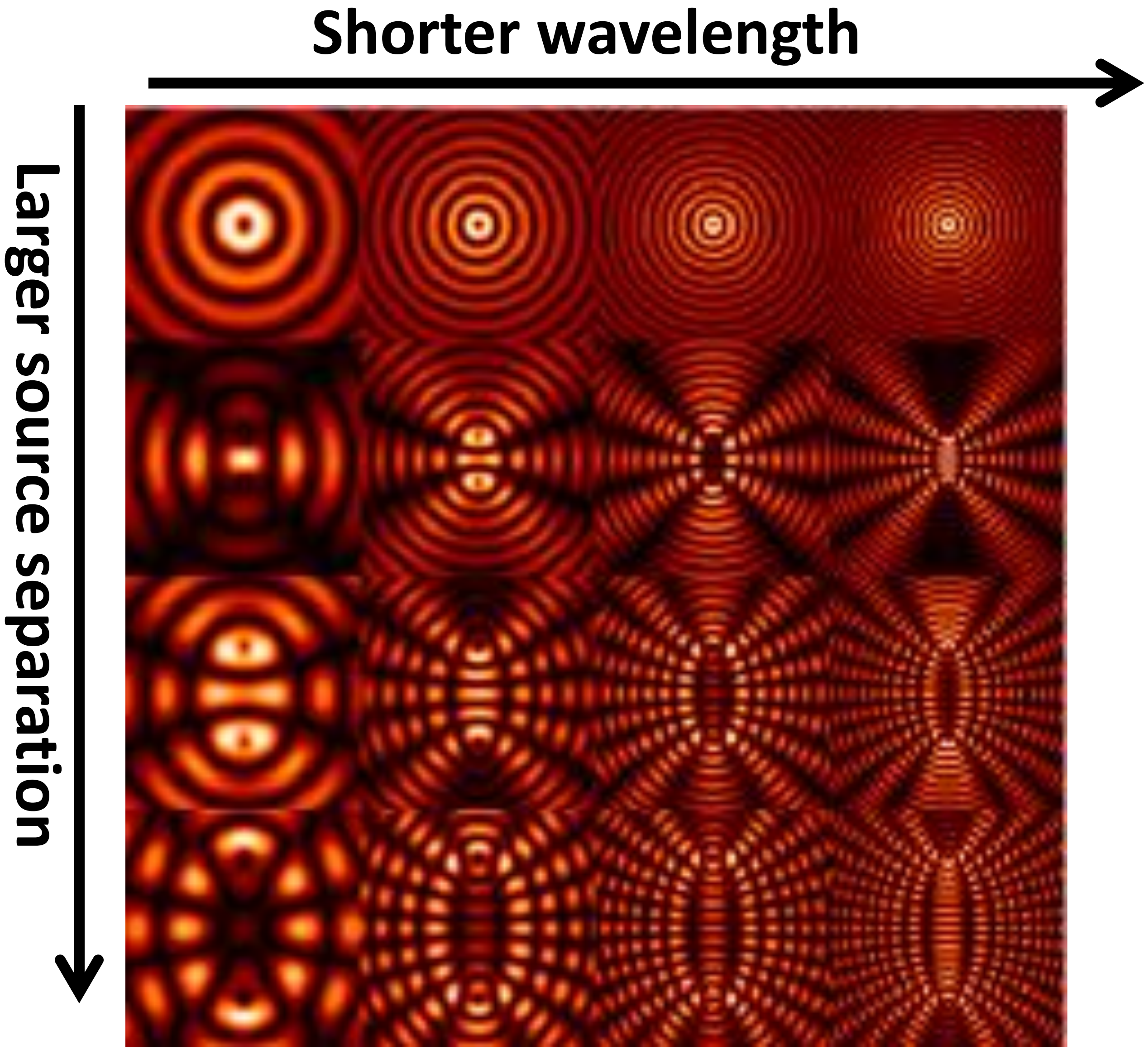
⇒ Intensity measured at receiver:



Interference between two point sources



Optical interference between two point sources for different wavelengths and source separations



Two vertical electric dipole antennas located 300 m apart transmit radio waves of wavelength $\lambda = 100\,\mathrm{m}$. Each antenna transmits the same power in every horizontal direction.

Suppose that the electric currents in the antennas that produce the waves are in phase with each other.

A detector is moved around a circle of radius 100 km from the midpoint between the antennas.

At how many points along the entire circle would intensity maxima be detected?

A. 8	**B. 10**	**C. 12**	**D. 14**	**E. 16**

$\lambda = 100\,m$

$d = 300\,m$

for maxima:
constructive interference

$$\sin\theta_{const} = m\frac{\lambda}{d}$$

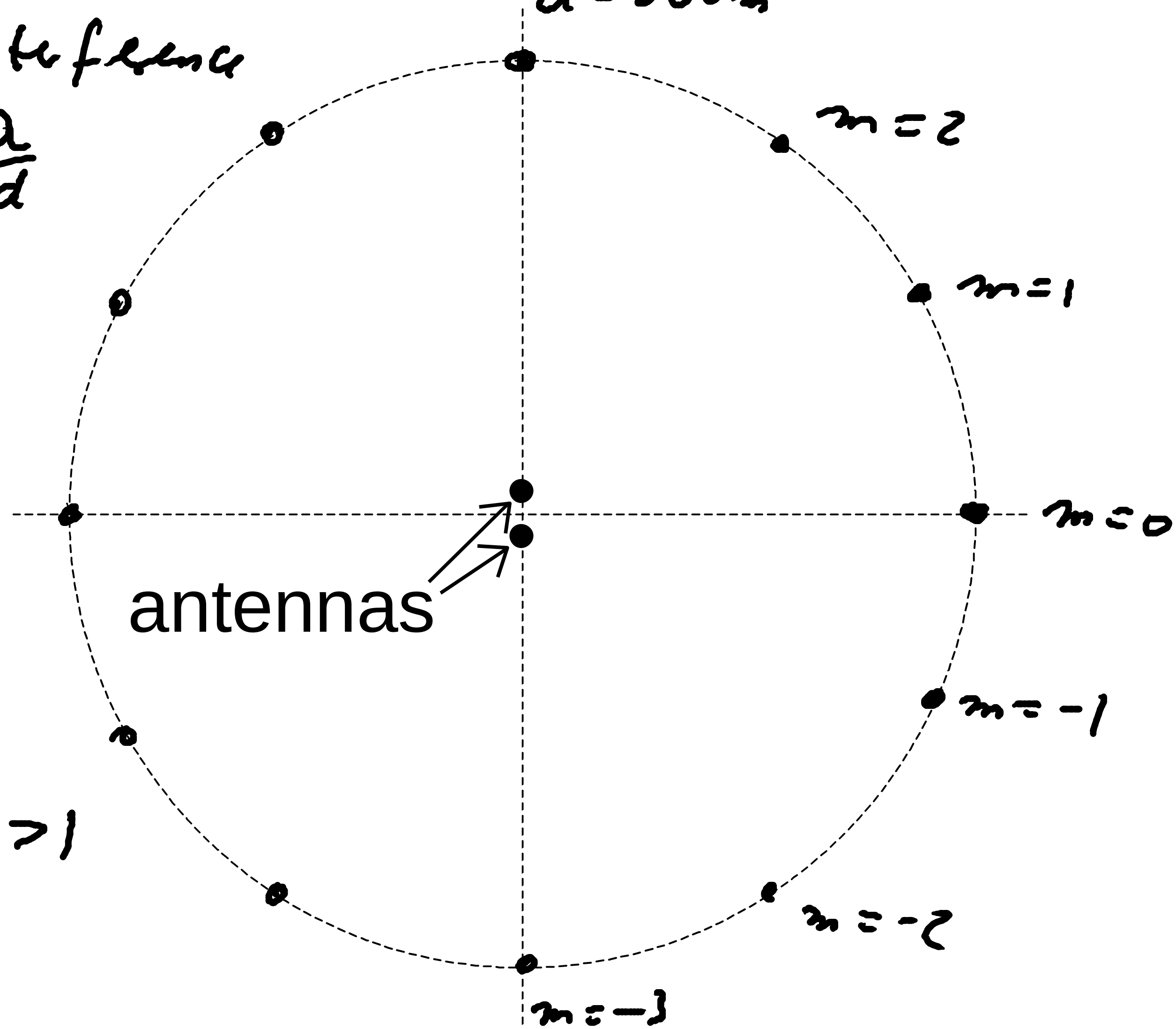
$$\sin\theta_0 = 0\frac{\lambda}{d} = 0$$

$$\sin\theta_1 = 1\frac{\lambda}{d} = \frac{1}{3}$$

$$\sin\theta_2 = 2\frac{\lambda}{d} = \frac{2}{3}$$

$$\sin\theta_3 = 3\frac{\lambda}{d} = 1$$

~~$$\sin\theta_4 = 4\frac{\lambda}{d} = \frac{4}{3} > 1$$~~



$\Rightarrow$ **12 maxima!**

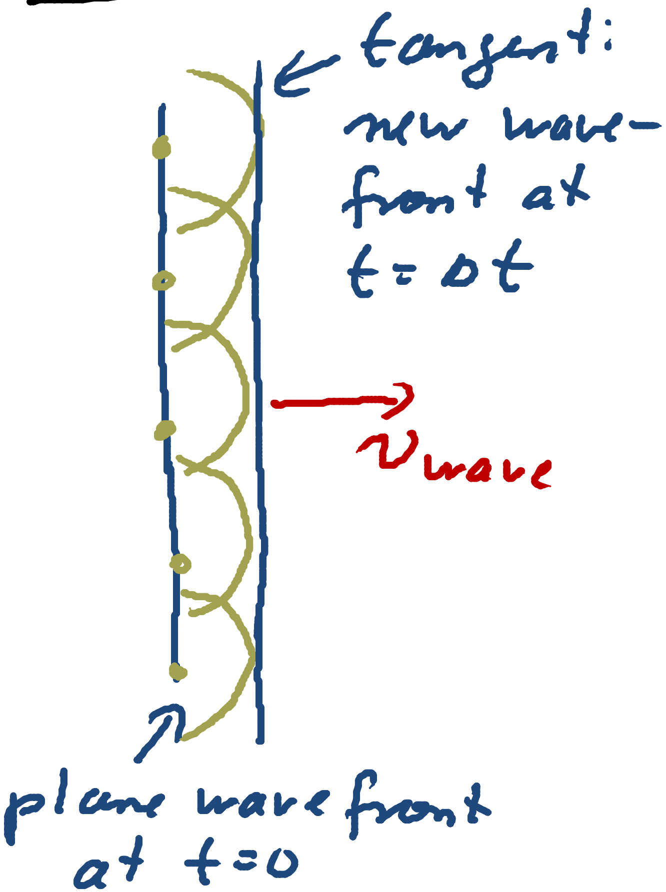
Huygens' Principle:

Method for determining how wavefronts propagate (Christian Huygens, 1678):

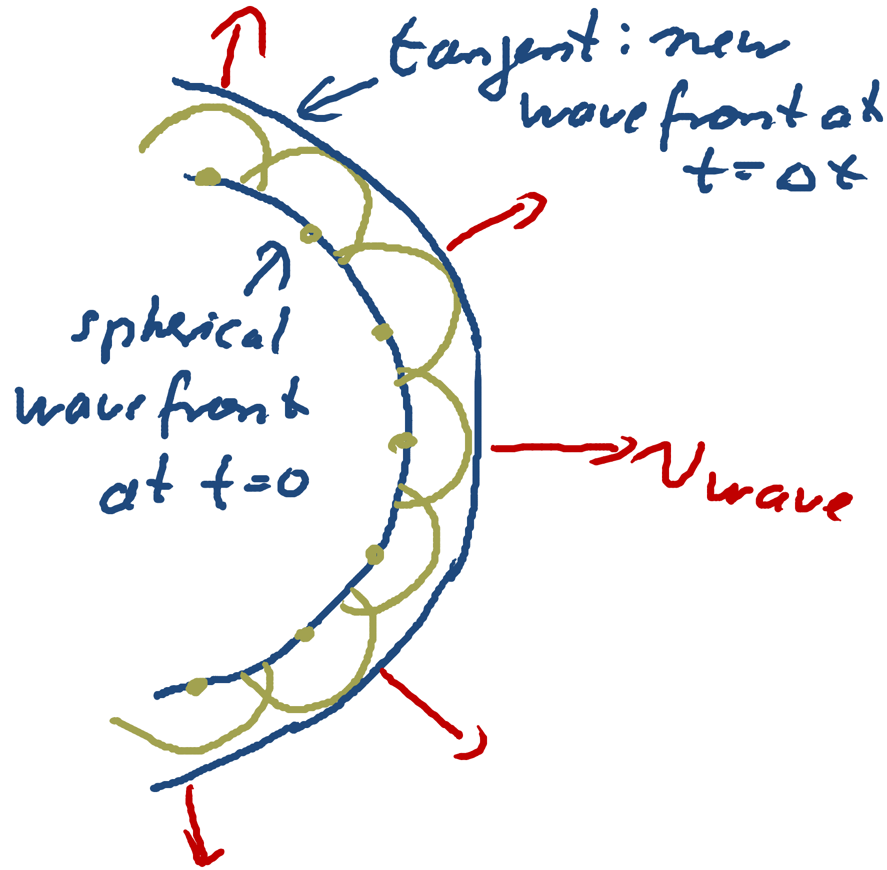
- All points on a wavefront serve as a point source of spherical secondary wavelets.
- After a time t, the new position of the wavefront will be that of a surface that is tangent to these secondary wavelets.
- <u>wavefront</u>: curve formed by points in a wave that have the same phase.

Examples:

Plane Wave:

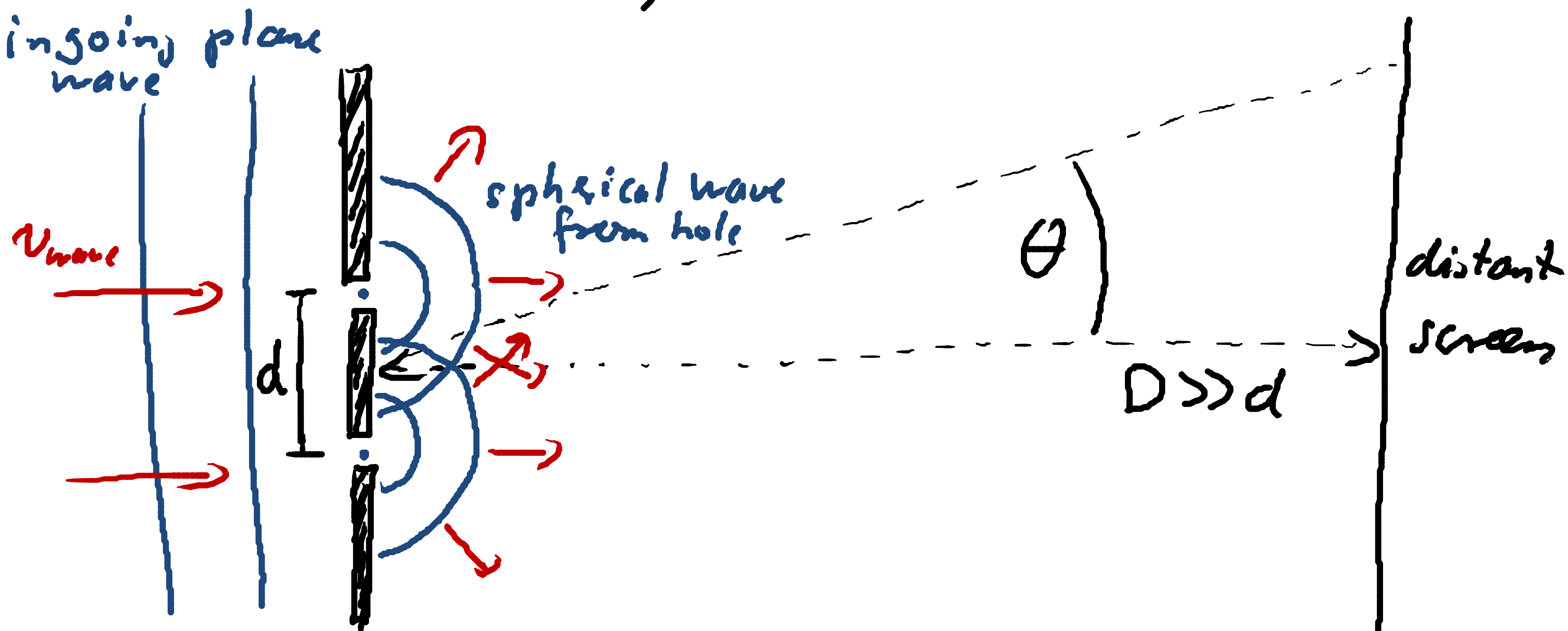


Spherical Wave:



Double Slit Interference:

Consider a plane wave incident on a barrier that has two very narrow holes / slits:



very narrow slits behave like two point sources

⇒ get interference from two point sources as before

⇒ from above for two point sources:

Angles of constructive Interference (maxima):

$$\sin\theta_{constructive} = m\frac{\lambda}{d} \qquad m = 0, \pm 1, \pm 2 \ldots$$

Angles of destructive Interference (minima):

$$\sin\theta_{destructive} = \left(m+\frac{1}{2}\right)\frac{\lambda}{d} \qquad m = 0, \pm 1, \pm 2 \ldots$$

Interference between waves from two narrow slits