Recap I

Lecture 33

- Sources of phase shifts between two waves: $\Delta\phi_{A,B} = \phi_B - \phi_A$

(1) waves start out with different phases

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

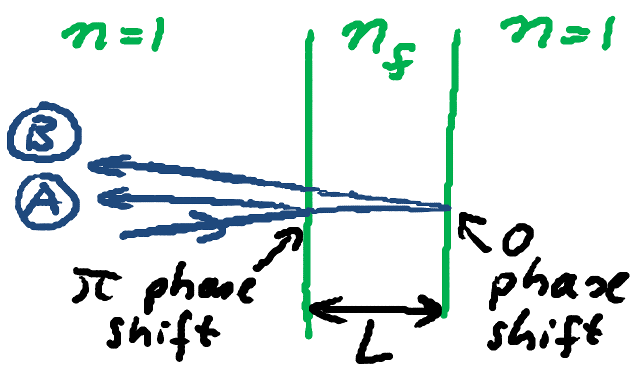
(3) waves travel through mediums with different index of refraction: $\lambda = \frac{\lambda_{vacuum}}{n}$

(4) phase shift upon reflection

Reflection Type	Phase Shift
slow → fast $n_{incident} > n_{transm.}$	0
fast → slow $n_{incident} < n_{transm.}$	π

Recap II

- Thin-Film Interference:



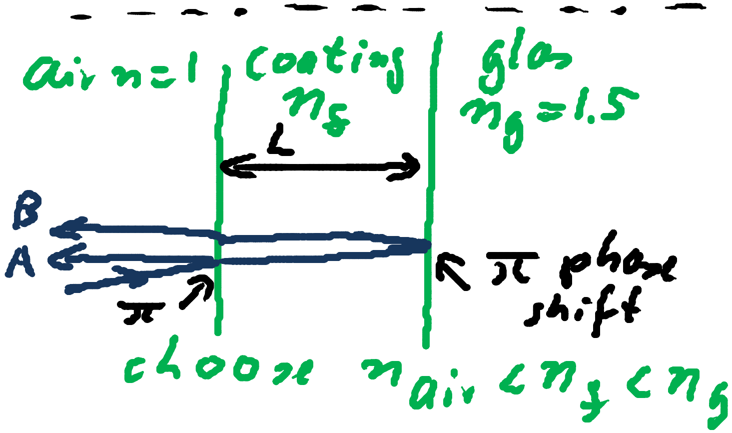
Total phase shift between reflected waves (A) and (B) results from

- Path length difference = 2L
- Different wavelength in film: $\lambda_f = \frac{\lambda_{vacuum}}{n_f}$
- Phase shifts upon reflection

⇒ here:

$2L_{constructive,m} = (m+\frac{1}{2})\frac{\lambda_{vacuum}}{n_{film}}$ $2L_{destructive,m} = m\frac{\lambda_{vacuum}}{n_{film}}$

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



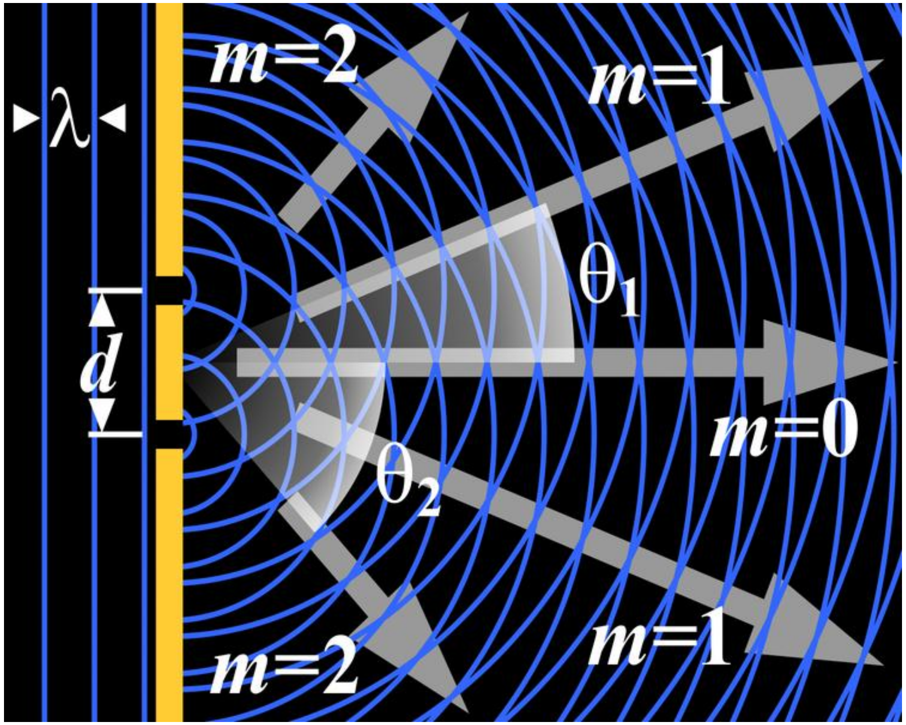
Antireflective Coating on Glass:

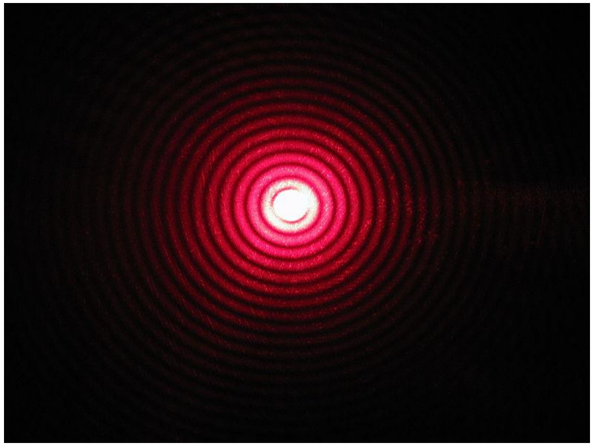
choose L to get destructive interference between waves (A) and (B) for visible light:

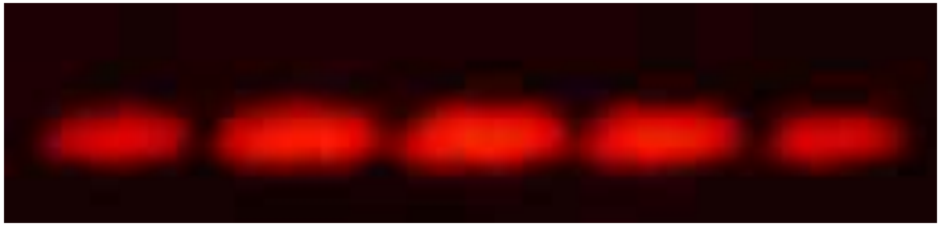
$2L_{destructive,m} = (m+\frac{1}{2})\frac{\lambda_{vacuum}}{n_{film}}$ $m=0,1,2,\ldots$

Today:

- **Diffraction**
  - Single slit
  - Circular aperture
  - Double slit (again)







What is the smallest object (finest detail) the human eye can resolve?

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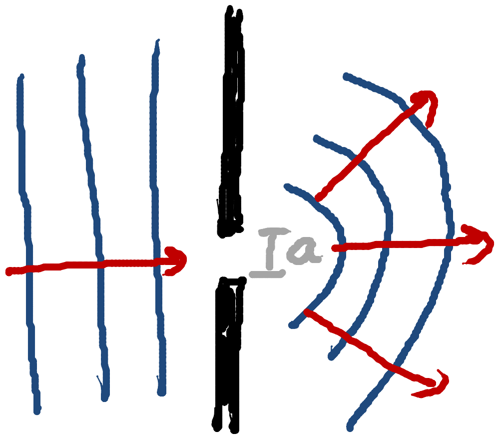
A. ~1 mm
B. ~0.5 mm
C. ~0.05 mm
D. ~0.005 mm

~0.01° angular resolution
⇒ ~0.05 mm at near point distance of 25 cm

Diffraction:

Wavefronts are 'bent' near edges & apertures.

Example: Diffraction of wave passing through a narrow slit:



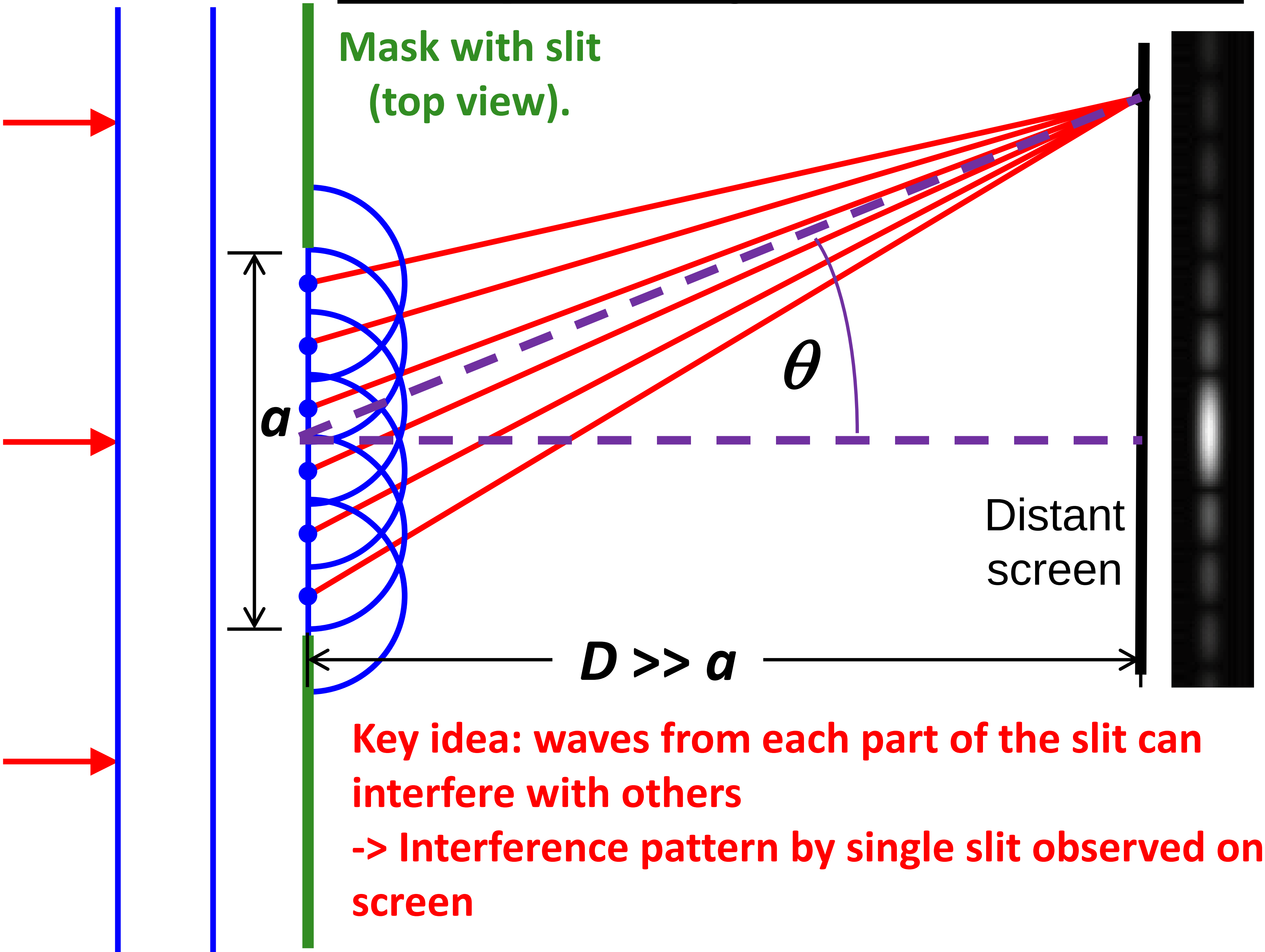
Recall: Huygens' Principle

All points on a wavefront act as point sources

⇒ Light emerges in all directions rather than just passing straight through the narrow slit!

⇒ Important for apertures/objects/slits of size ~ λ.

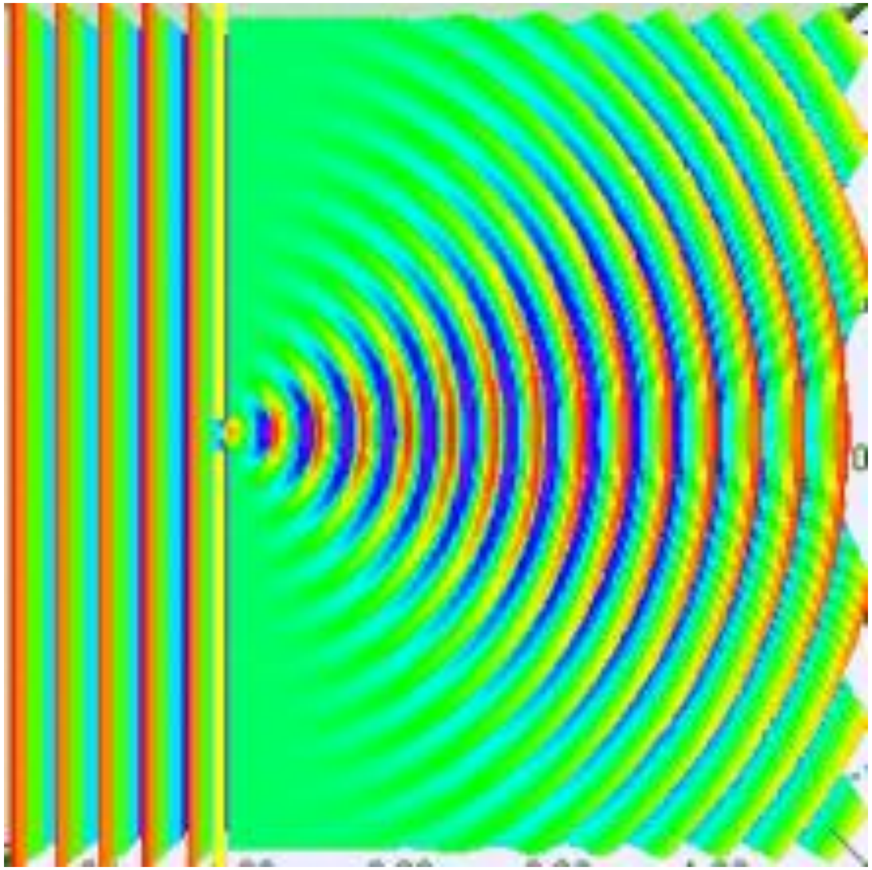
Example: Single-slit diffraction:

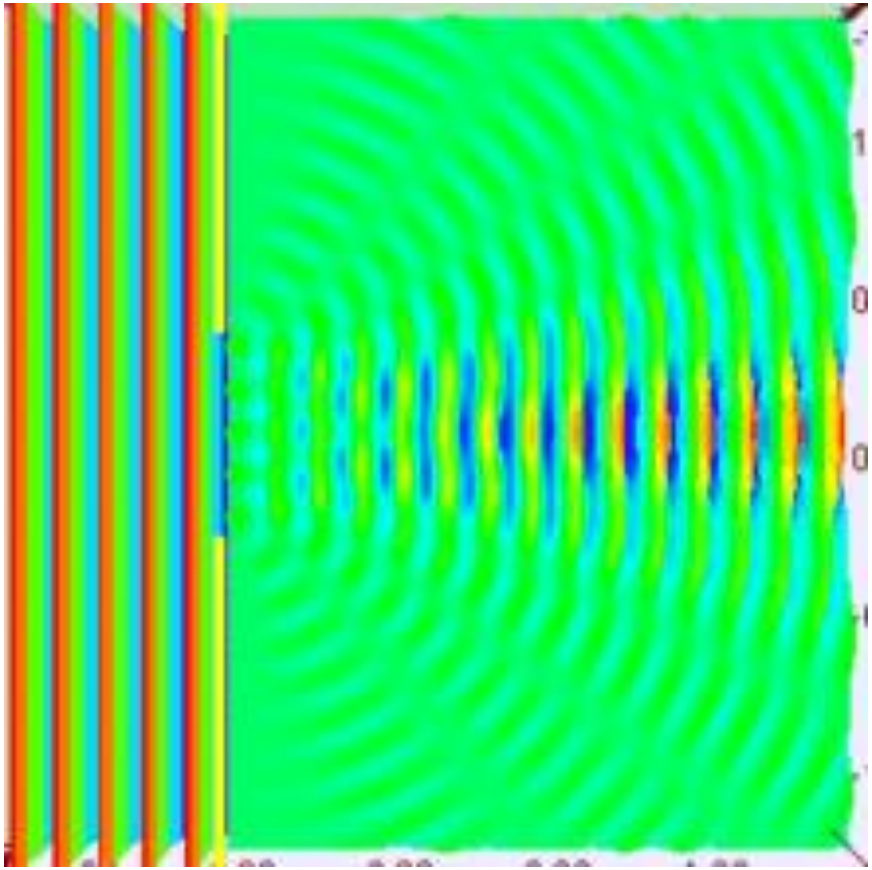


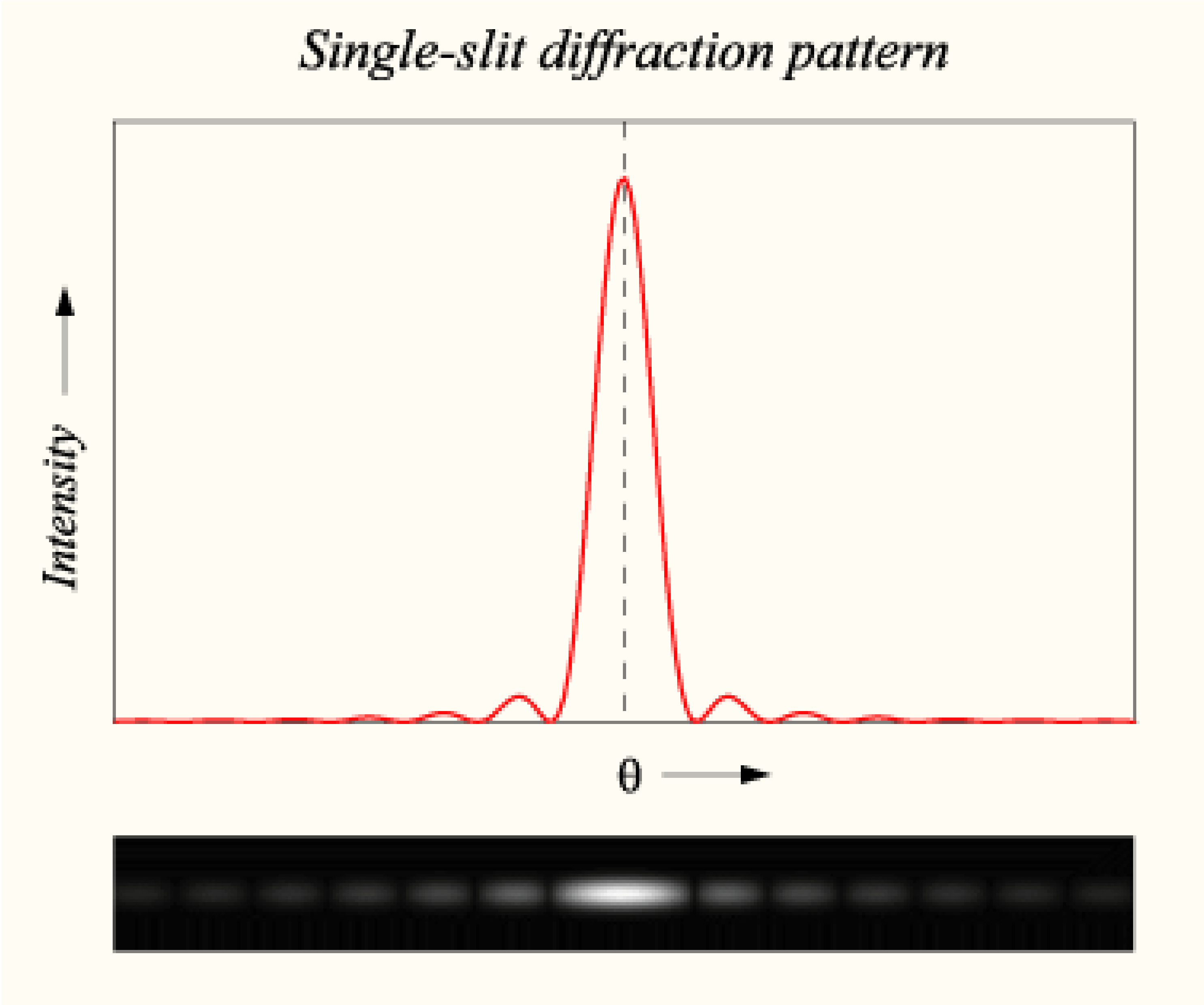
Key idea: waves from each part of the slit can interfere with others

-> Interference pattern by single slit observed on screen

Single slit diffraction:

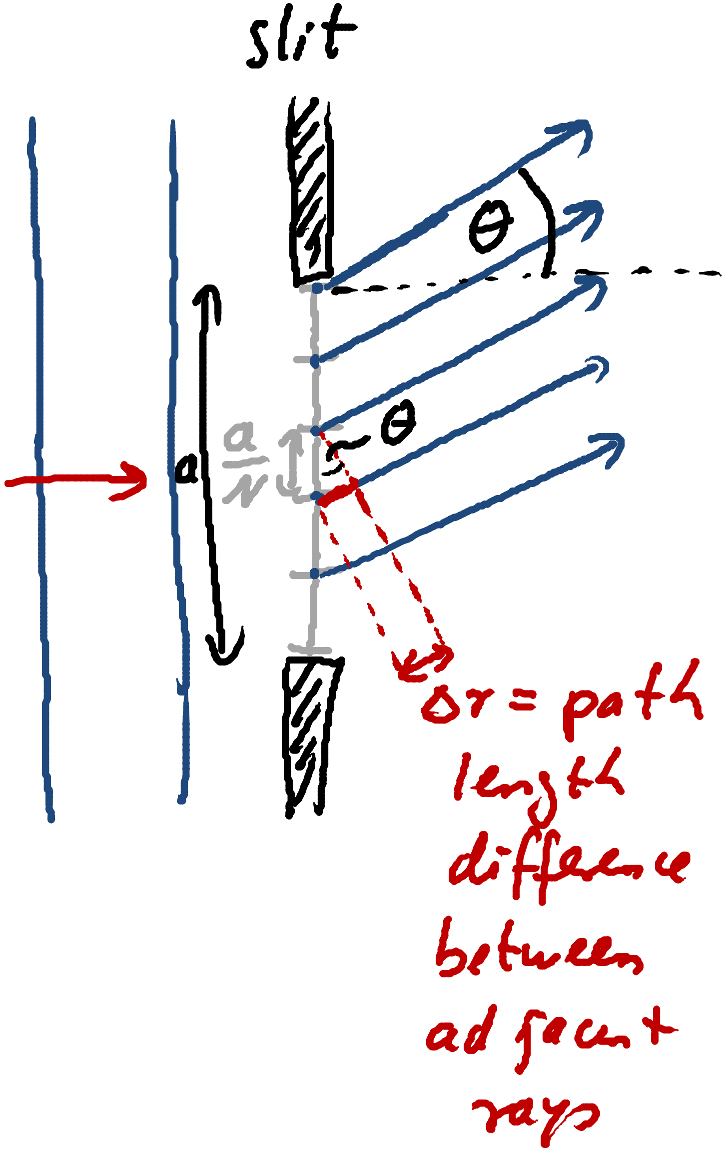






Single-slit diffraction pattern
Intensity
θ

Interference Pattern from a Single Slit:



- Break slit into N zones, each of width a/N
- Rays from different zones interfere on distant screen

Path length difference between two adjacent rays:

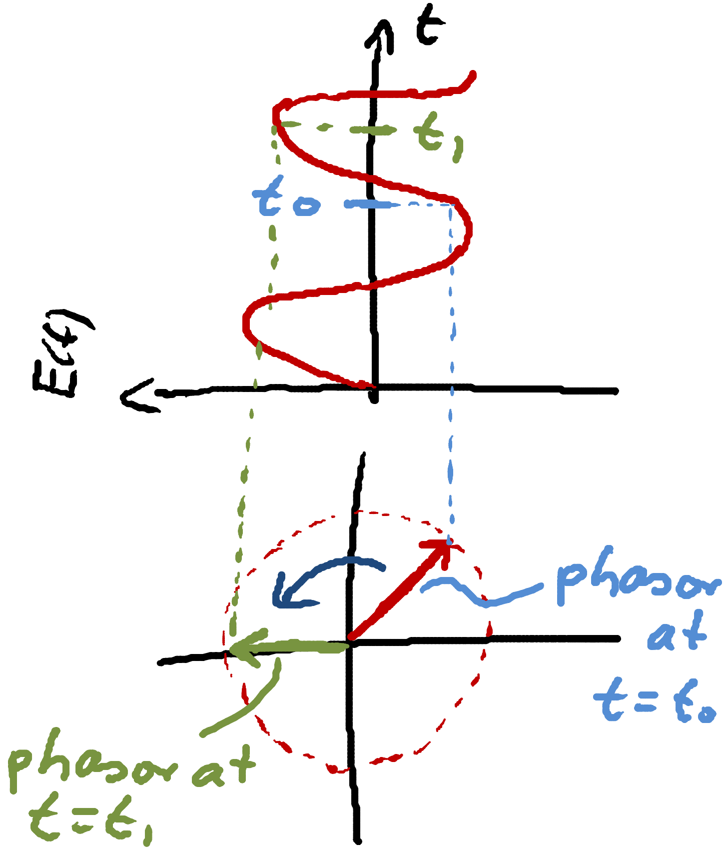
$$\Delta path = \frac{a}{N} \cdot \sin\theta$$

⇒ phase difference between waves of adjacent rays:

$$\Delta\phi_{\text{adjacent rays}} = \frac{2\pi}{\lambda}\Delta path = \frac{2\pi}{\lambda}\frac{a}{N}\sin\theta$$

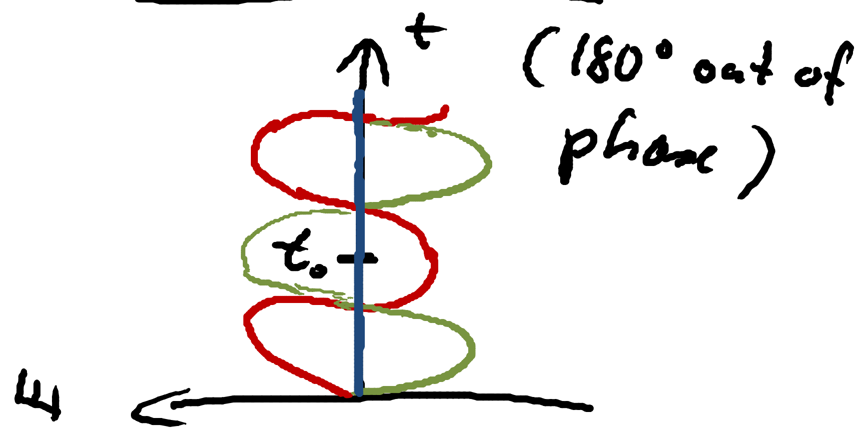
$$\propto \sin\theta$$

Side Note: Phasors

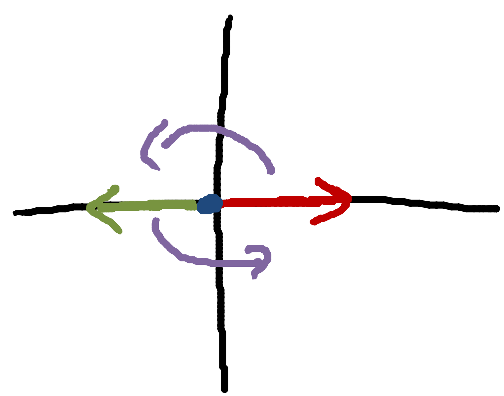


$E(t) = E_{max} \cos(kx_0 - \omega t + \phi)$

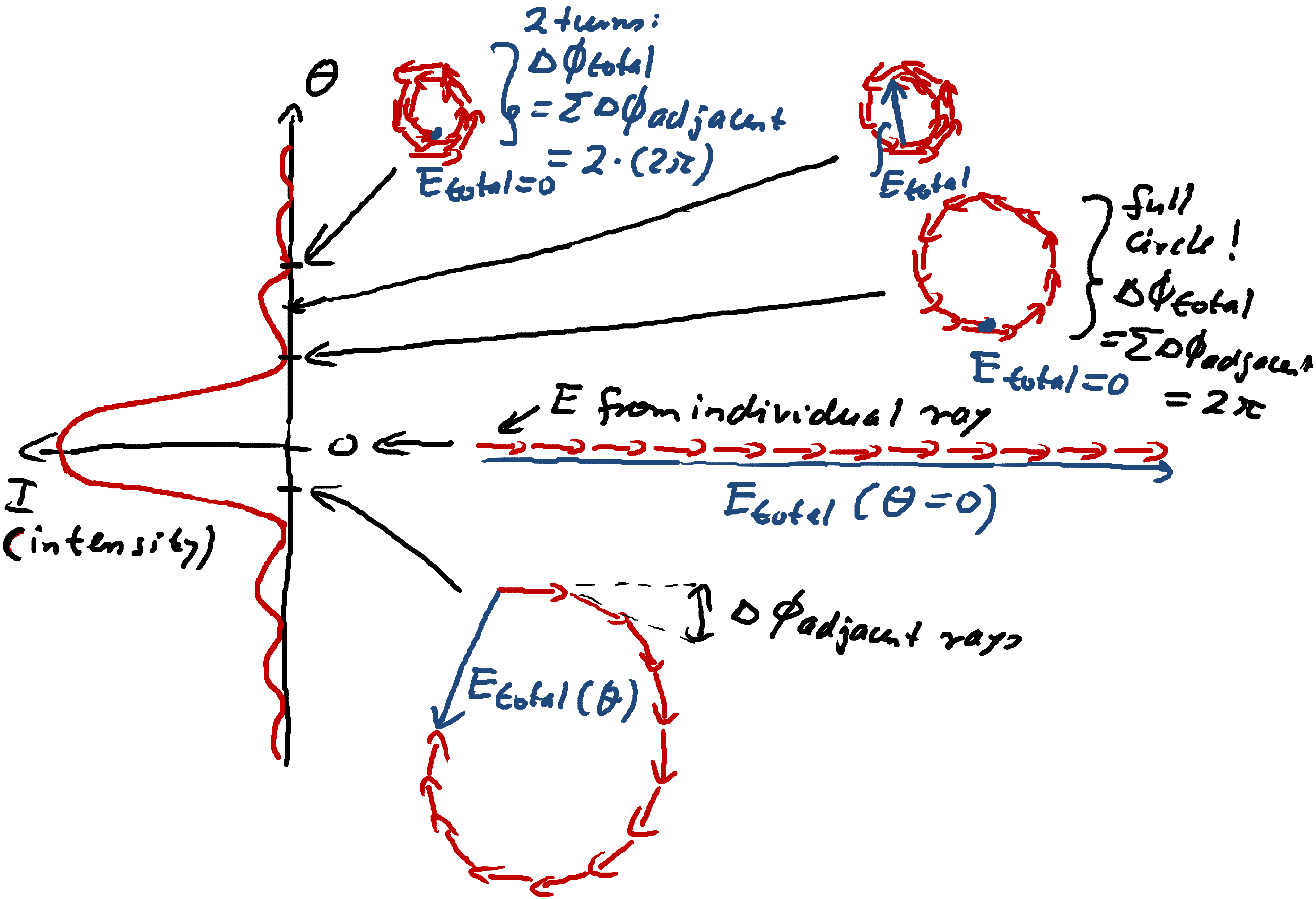
to add two waves:



at t=t0



$E_{sum} = 0 = E_1(t) + E_2(t)$



2 turns:
Δφtotal
= ΣΔφadjacent
= 2·(2π)
Etotal=0
Etotal
full circle!
Δφtotal
= ΣΔφadjacent
= 2π
Etotal=0
θ
E from individual ray
0
Etotal (θ=0)
I
(intensity)
Δφadjacent rays
Etotal(θ)

⇒ Constructive Interference at highest intensity at $\theta = 0$

⇒ Dark Fringes (Intensity minima) each time the electric field vectors of the individual waves add up to zero:

⇒ for $\Delta\phi_{total} = \sum_{i=1}^{N} \Delta\phi_{i,\text{adjacent rays}} = m\,(2\pi)$

$m = \pm 1, \pm 2, \pm 3 \ldots$ but not $m = 0$

⇒ $\Delta\phi_{total} = N \cdot \Delta\phi_{\text{adjacent rays}}$

$$= N \cdot \frac{2\pi}{\lambda} \frac{a}{N} \sin\theta = m\,(2\pi)$$

Minima for single slit diffraction:

$$a \sin\theta = m\lambda$$

$m = \pm 1, \pm 2, \pm 3 \ldots$ (but not $m = 0$)

(a = width of slit)

⇒ Also can find the single-slit diffraction intensity pattern: $I(\theta) \propto (E_{total}^2)_{avg}$

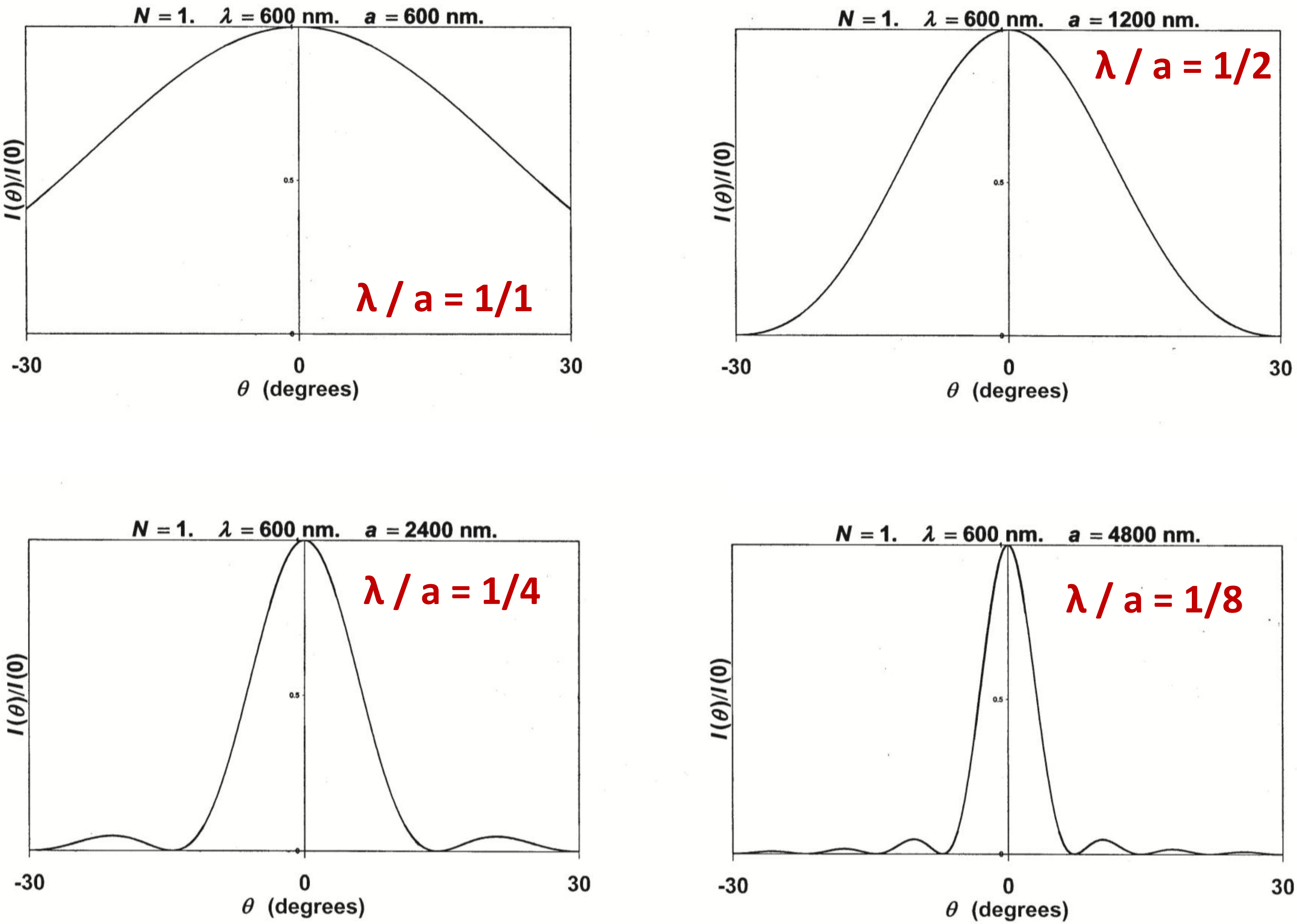
$$I(\theta) = I_{max}\left(\frac{\sin\alpha}{\alpha}\right)^2$$

where $\alpha = \frac{\pi a}{\lambda}\sin\theta$

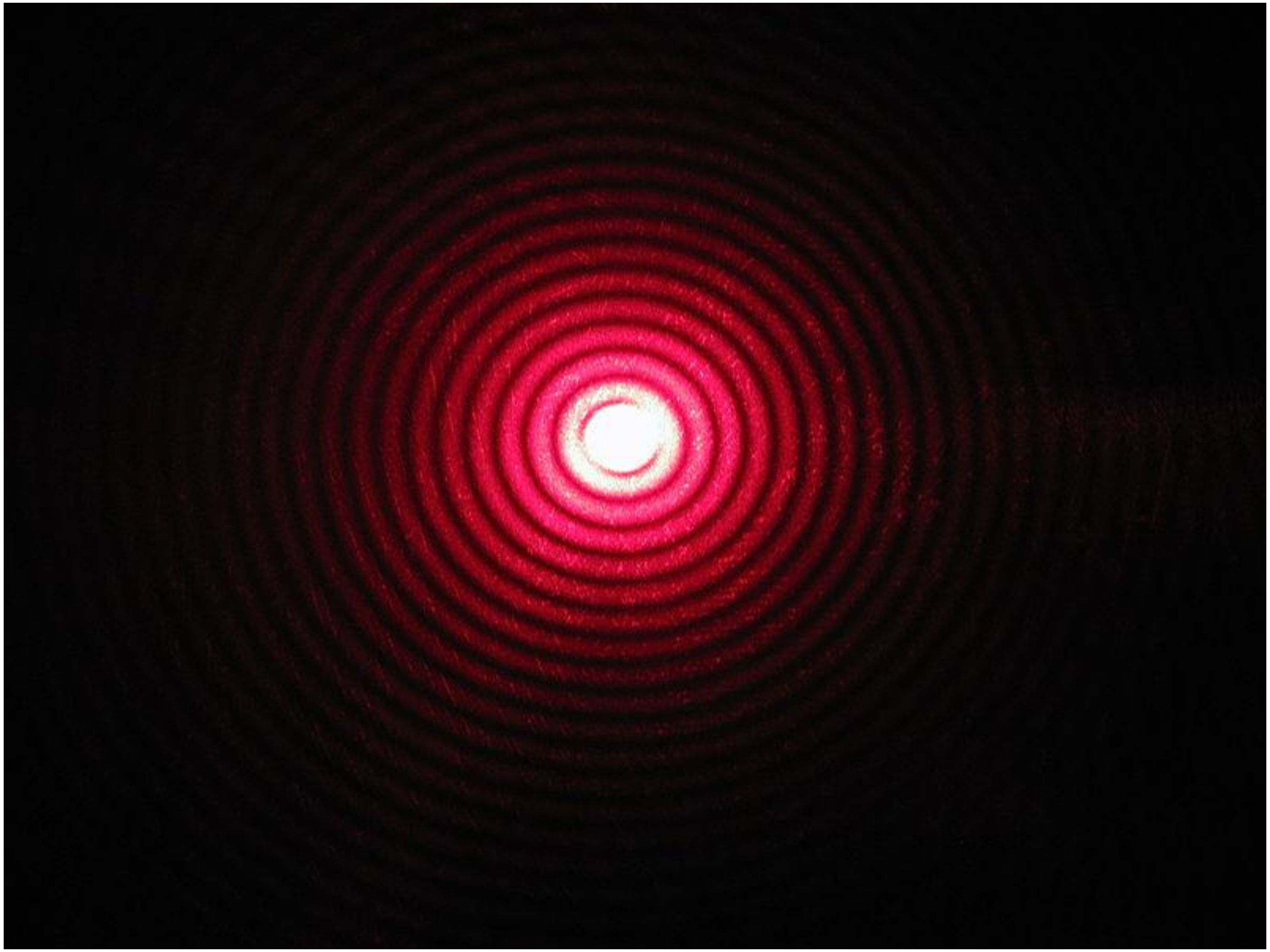
Note: wider slit (larger a) → more, sharper intensity maxima and minima

minima: $\sin\theta_{min} = m\frac{\lambda}{a} \leq 1$

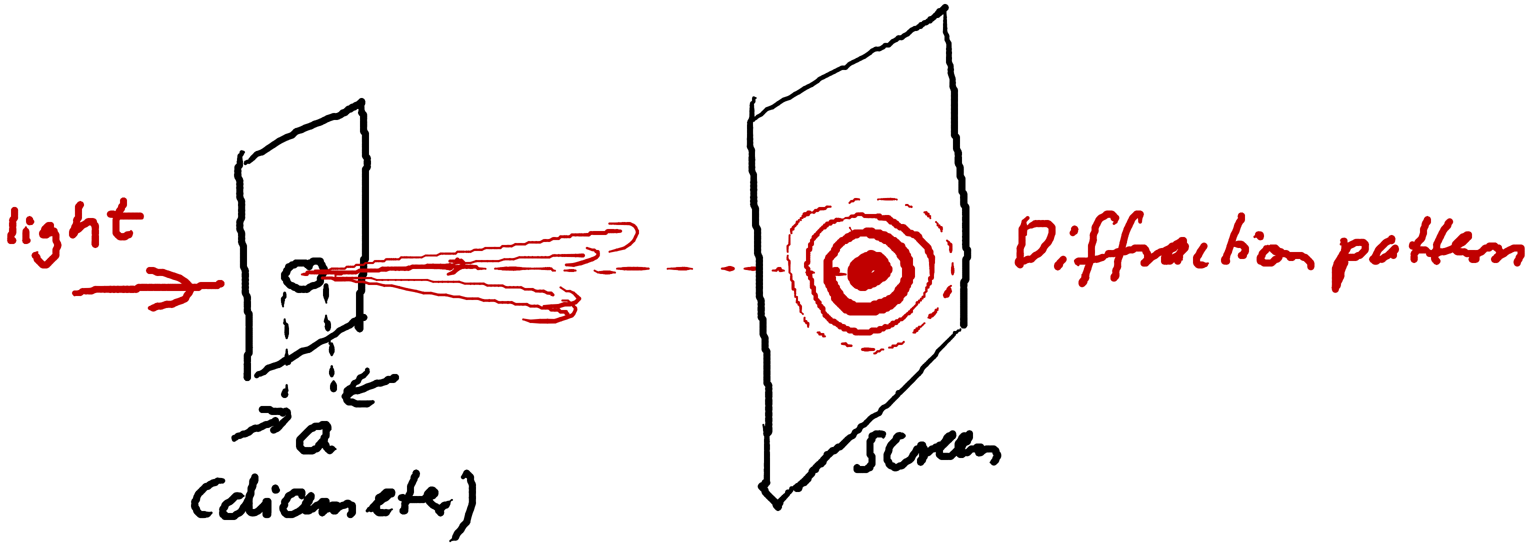
Single-slit diffraction pattern for different slit widths:



Diffraction of red laser beam on a Hole (Circular Aperture)



Diffraction by a circular Aperture



Interference of waves diffracted by the hole results in circular intensity pattern on the screen.

⇒ 1st intensity minimum at angle:

$$\sin\theta_1 = 1.22\,\frac{\lambda}{a}$$

a = diameter of hole