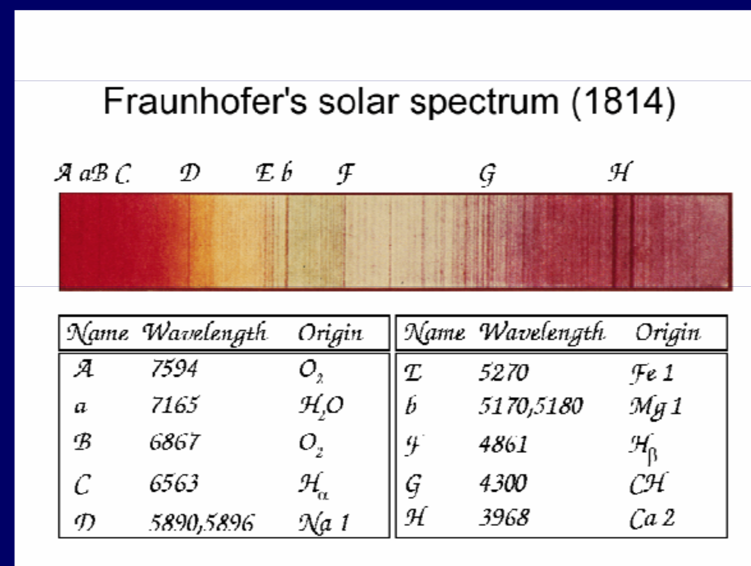
Exam 3 Monday April 15!

- Material covered
  - RLC circuits (Lect. 12) – Thin film interference (Lect. 21)
  - Discussion 7 – 10 & HW 7 – 11 (first half)
- Review session Sunday, April 14, 3pm, 141 Loomis
  - Sara Rose will review HE3 from Fall '12 (PLUS questions in HE2 Fall '12 pertaining to Lect. 12 – 15)
- James Scholar proposals due April 7
- Final Exam dates set!
  - A1/A11: Thursday May 9, 1:30-4:30pm
  - A2/A22: Tuesday May 7, 1:30-4:30pm

Thin Films & Diffraction Gratings



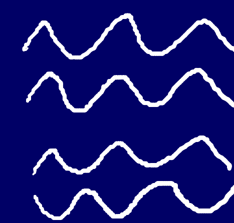
Name	Wavelength	Origin
A	7594	O_2
a	7165	H_2O
B	6867	O_2
C	6563	H_α
D	5890,5896	Na 1

Name	Wavelength	Origin
E	5270	Fe 1
b	5170,5180	Mg 1
F	4861	H_β
G	4300	CH
H	3968	Ca 2

Recall

same f, λ

- Interference (at least 2 coherent waves)
  - Constructive (full wavelength difference)
  - Destructive (half wavelength difference)

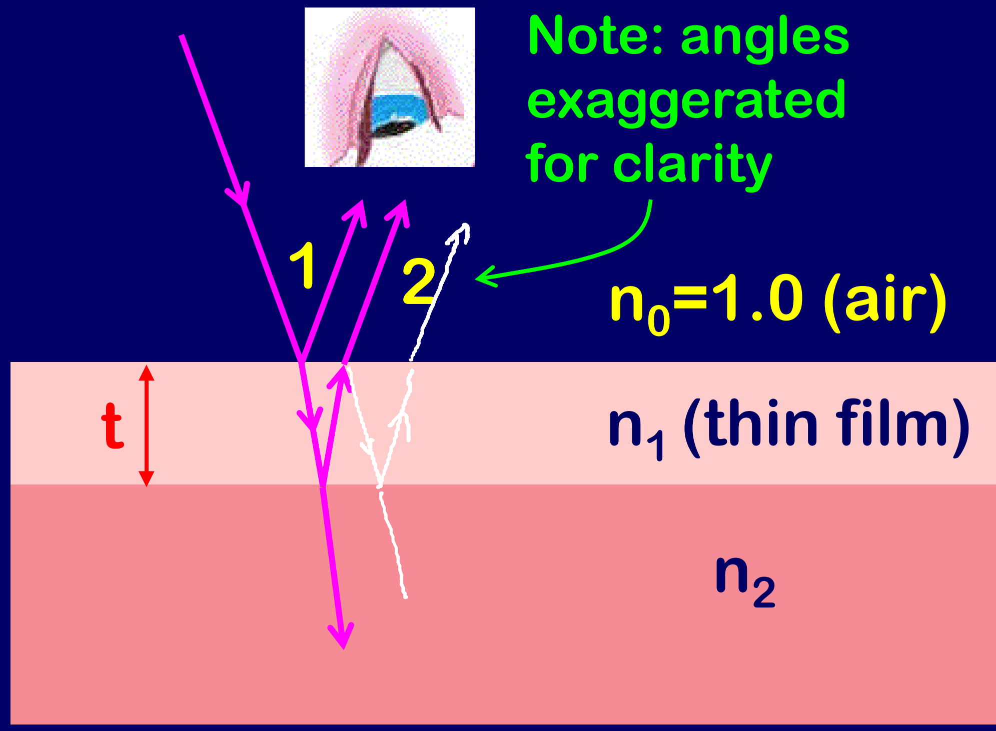


- Light (1 source, but different paths)
  - Young's double slit — Last lecture
  - Thin films
  - Multiple slit
  - X-ray diffraction from crystal
  - Diffraction/single slit

  } Today's lecture

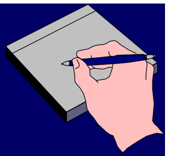
Thin Film Interference

Light is incident normal to a thin film



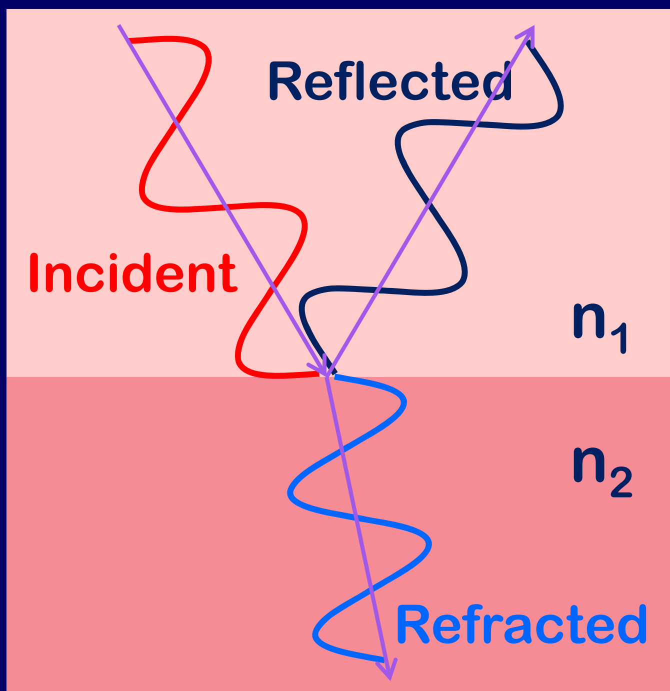
Get two waves by reflection off two different interfaces: interference!

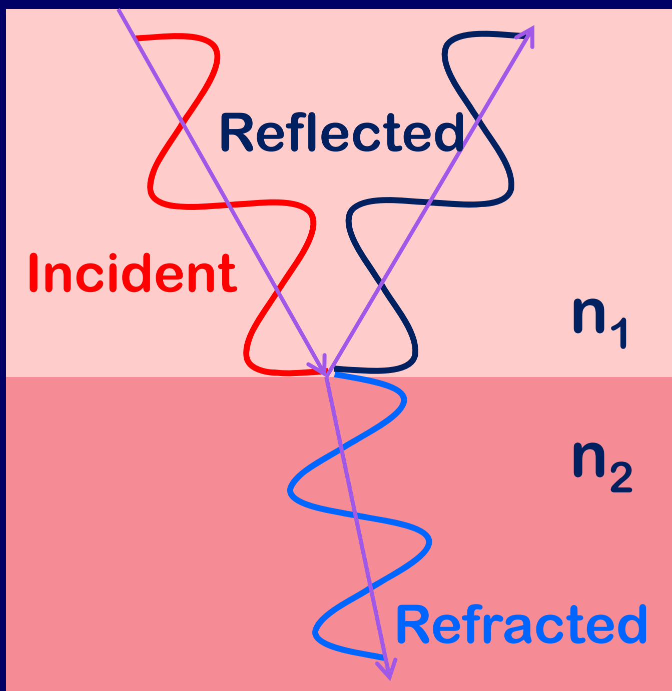
Ray 2 travels approximately 2t further than ray 1.



Reflection & Phase Shifts

Upon reflection from a boundary between two transparent materials, the phase of the reflected light may change.



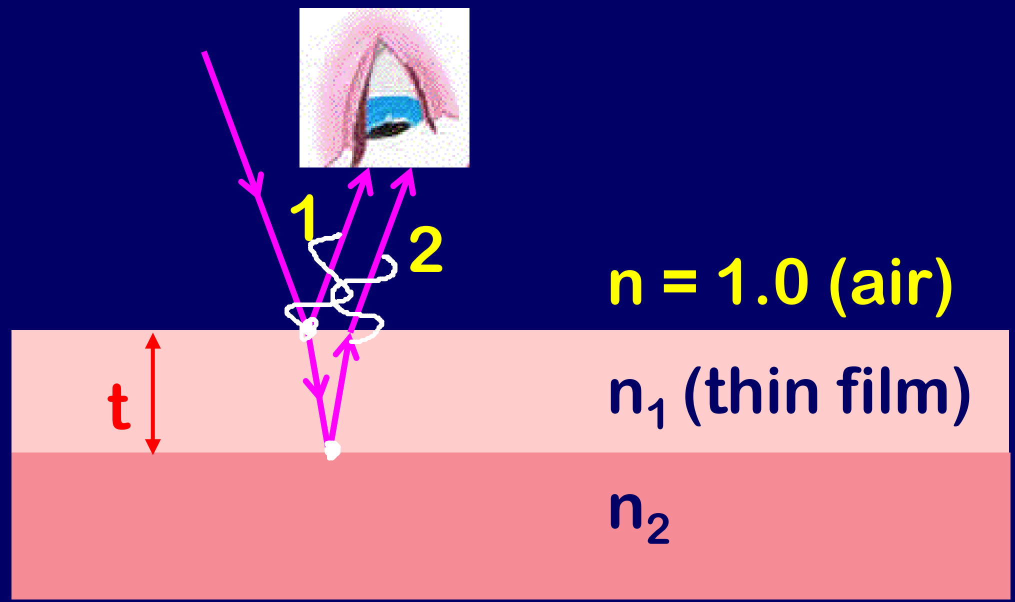


- If $n_1 > n_2$ – no phase change upon reflection

- If $n_1 < n_2$ – 180° phase change upon reflection
- This is like the wave went an extra $\lambda/2$; $\delta=1/2$

Thin Film Summary

Determine δ, number of extra wavelengths for each ray.



This is important!

Reflection / Distance

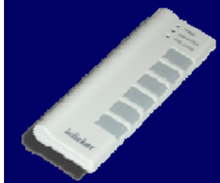
Ray 1: $\delta_1 = 0 \text{ or } \frac{1}{2} + 0$

Ray 2: $\delta_2 = 0 \text{ or } \frac{1}{2} + 2t/\lambda_{film}$

Note: this is wavelength in film! ($\lambda_{film} = \lambda_o/n_1$)

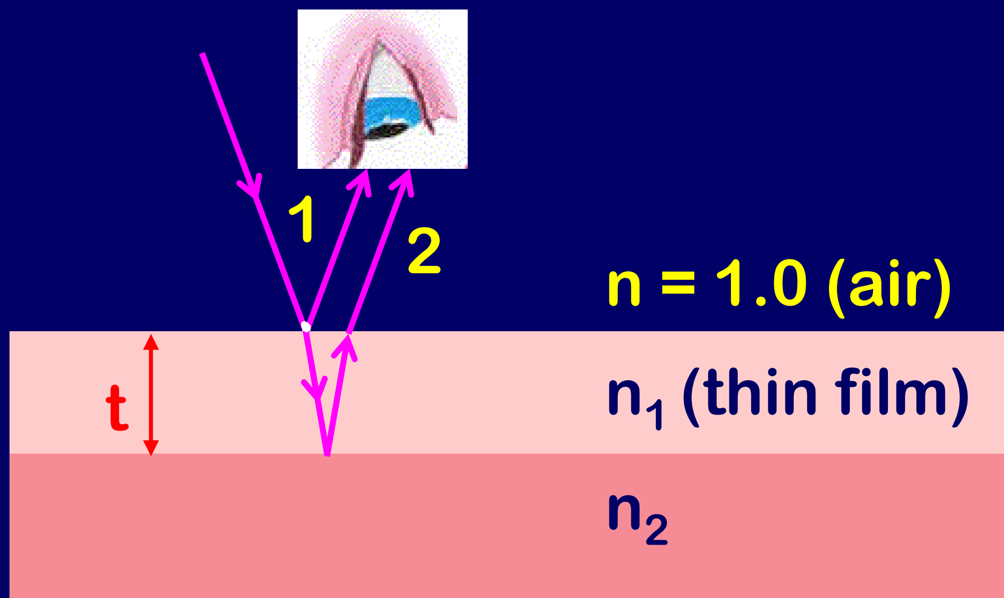
If $|\delta_2 - \delta_1| = 0, 1, 2, 3 \ldots$ (m) constructive

If $|\delta_2 - \delta_1| = \frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2} \ldots$ (m + ½) destructive



ACT: Thin Film Practice

Blue light (λ_0 = 500 nm) incident on a glass (n_1 = 1.5) cover slip (t = 167 nm) floating on top of water (n_2 = 1.3).



What is δ_1, the total phase shift for ray 1

A) $\delta_1 = 0$

B) $\delta_1 = ½$

C) $\delta_1 = 1$

Thin Film Practice

Example

Blue light (λ_0 = 500 nm) incident on a glass (n_1 = 1.5) cover slip (t = 167 nm) floating on top of water (n_2 = 1.3).

Is the interference constructive or destructive or neither?

$\delta_1 = ½$

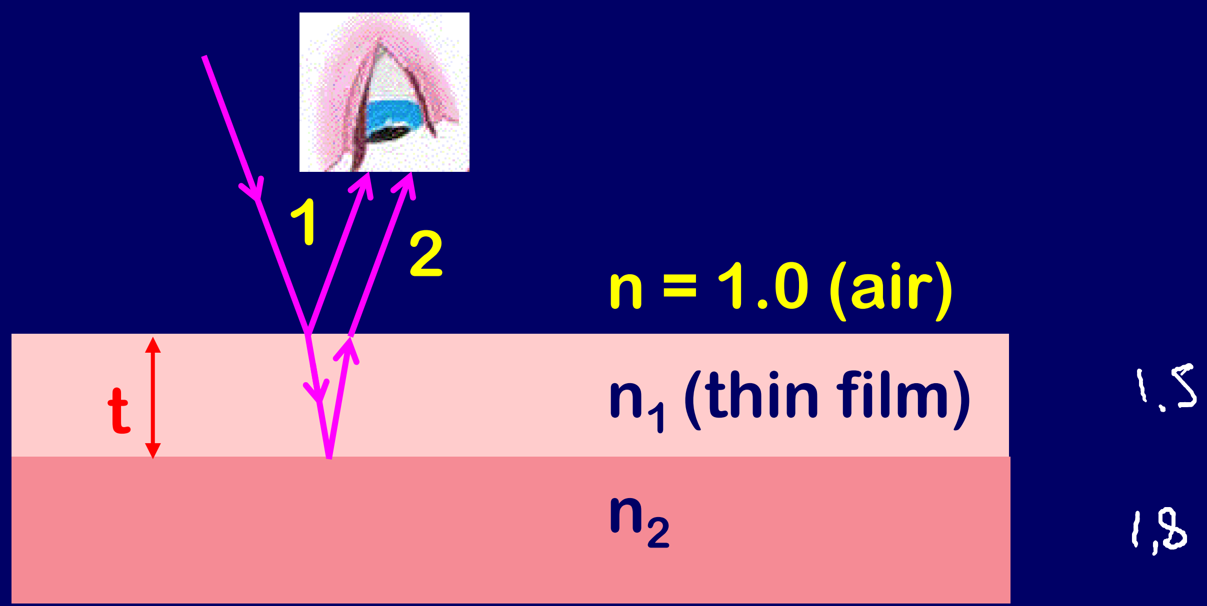
$\delta_2 = 0 + 2t / \lambda_{glass} = 2t\, n_{glass} / \lambda_0 = (2)(167)(1.5)/500 = 1$

Phase shift = $|\delta_2 - \delta_1|$ = ½ wavelength

ACT: Thin Film Practice II

Example

Blue light (λ_0 = 500 nm) incident on a glass (n_1 = 1.5) cover slip (t = 167 nm) floating on top of **plastic** (n_2 = 1.8).



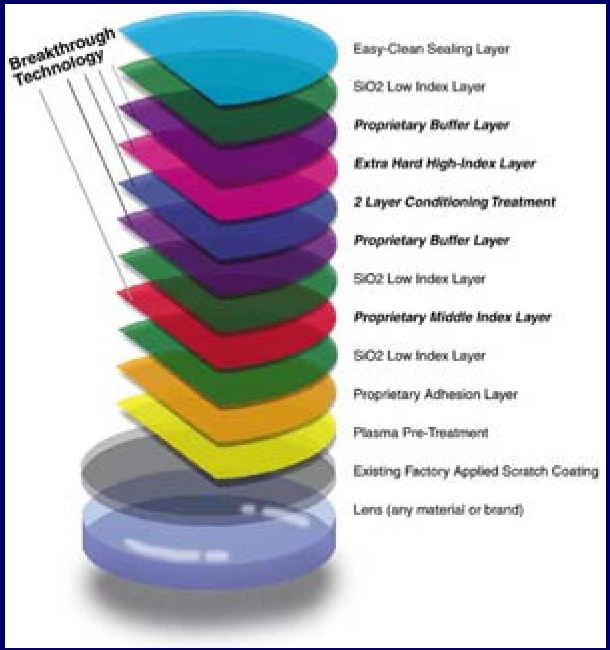
Is the interference : A) constructive B) destructive C) neither?

$\delta_1 = ½$

$\delta_2 = ½ + 2t / \lambda_{glass} = ½ + 2t\, n_{glass} / \lambda_0 = (2)(167)(1.5)/500) = 3/2$

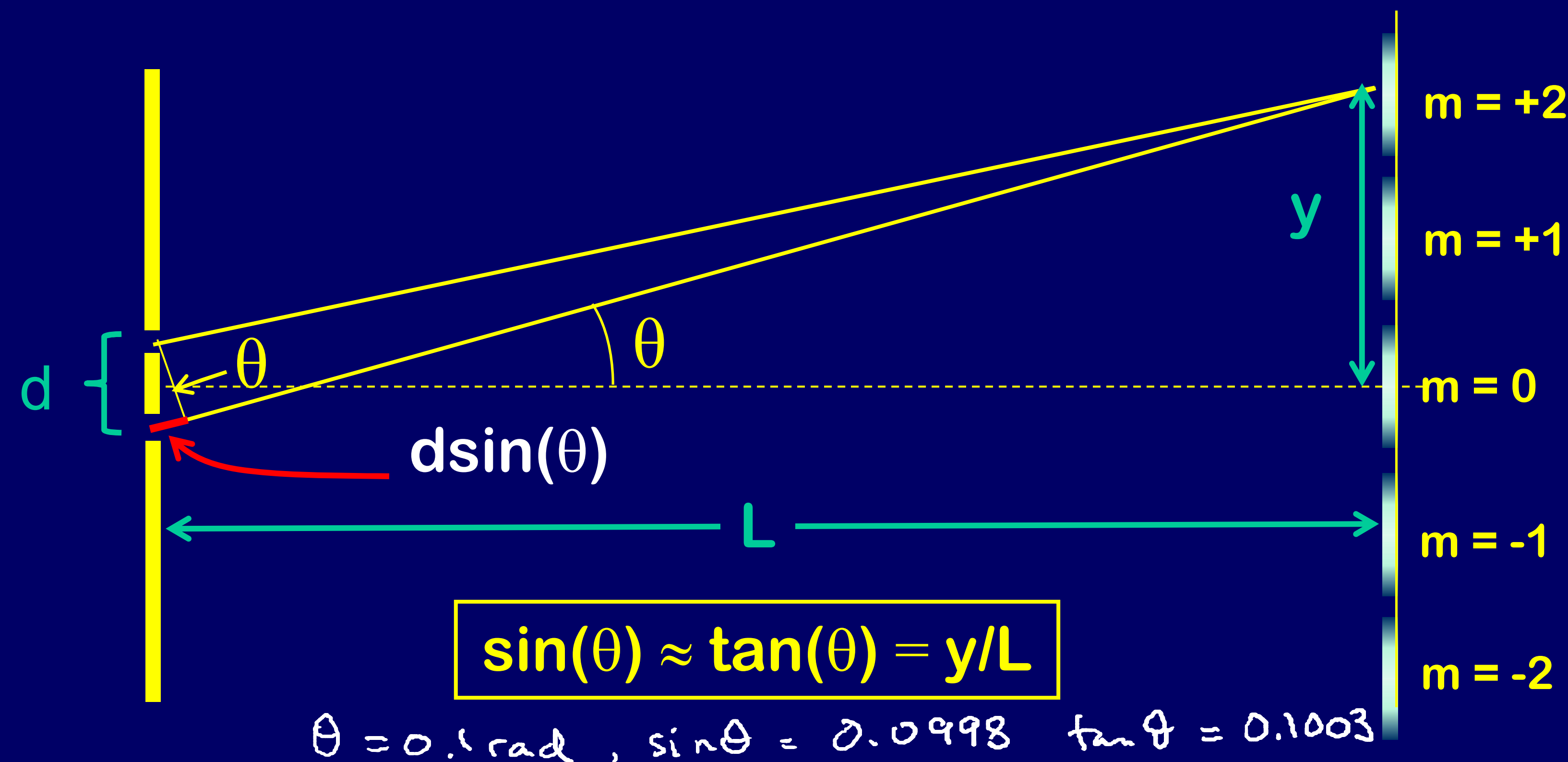
Phase shift = $|\delta_2 - \delta_1|$ = 1 wavelength

Thin film application: Anti-reflection coatings



Young's double slit: Review

Assume screen is very far away (L>>d), angles θ are small:



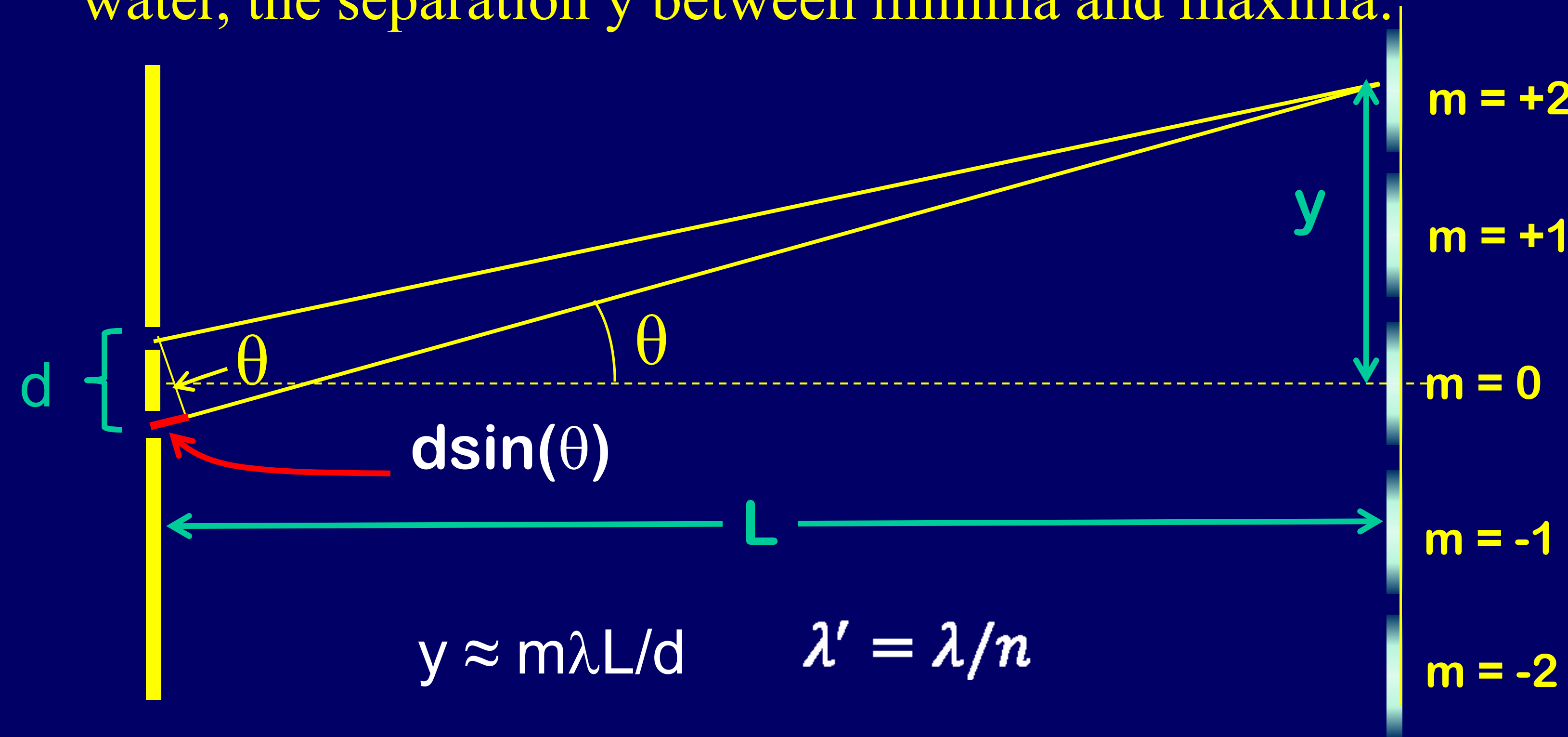
Constructive: $d\sin(\theta) = m\lambda$ $\quad y \approx m\lambda L/d$

Destructive: $d\sin(\theta) = (m+1/2)\lambda$ $\quad y \approx (m+1/2)\lambda L/d$

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

ACT: Checkpoint 2

When this Young's double slit experiment is placed under water, the separation y between minima and maxima:



$y \approx m\lambda L/d$ $\lambda' = \lambda/n$

A) increases

B) same

C) decreases

Under water λ decreases so y decreases!

Checkpoint 1.2

In the Young double slit experiment, is it possible to see interference maxima when the distance between slits is smaller than the wavelength of light?

1) Yes

2) No

Need: $d \sin\theta = m\lambda$ => $\sin\theta = m\lambda / d$

If $\lambda > d$ then $\lambda / d > 1$

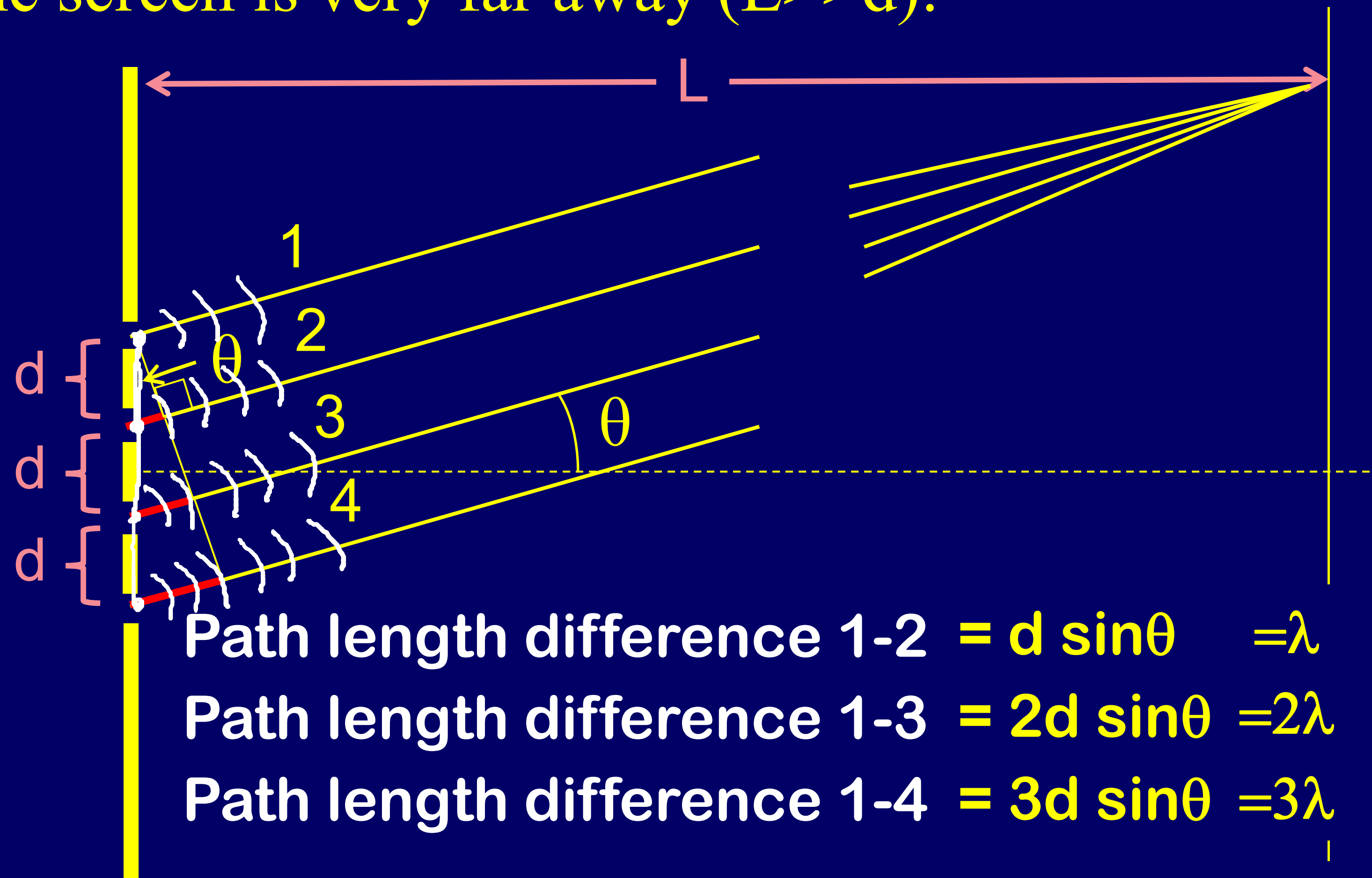
so $\sin\theta > 1$

Not possible!

Diffraction Gratings: multiple slits

(N slits with spacing d)

Assume screen is very far away (L>>d):



Path length difference 1-2 = d sinθ $=\lambda$

Path length difference 1-3 = 2d sinθ $=2\lambda$

Path length difference 1-4 = 3d sinθ $=3\lambda$

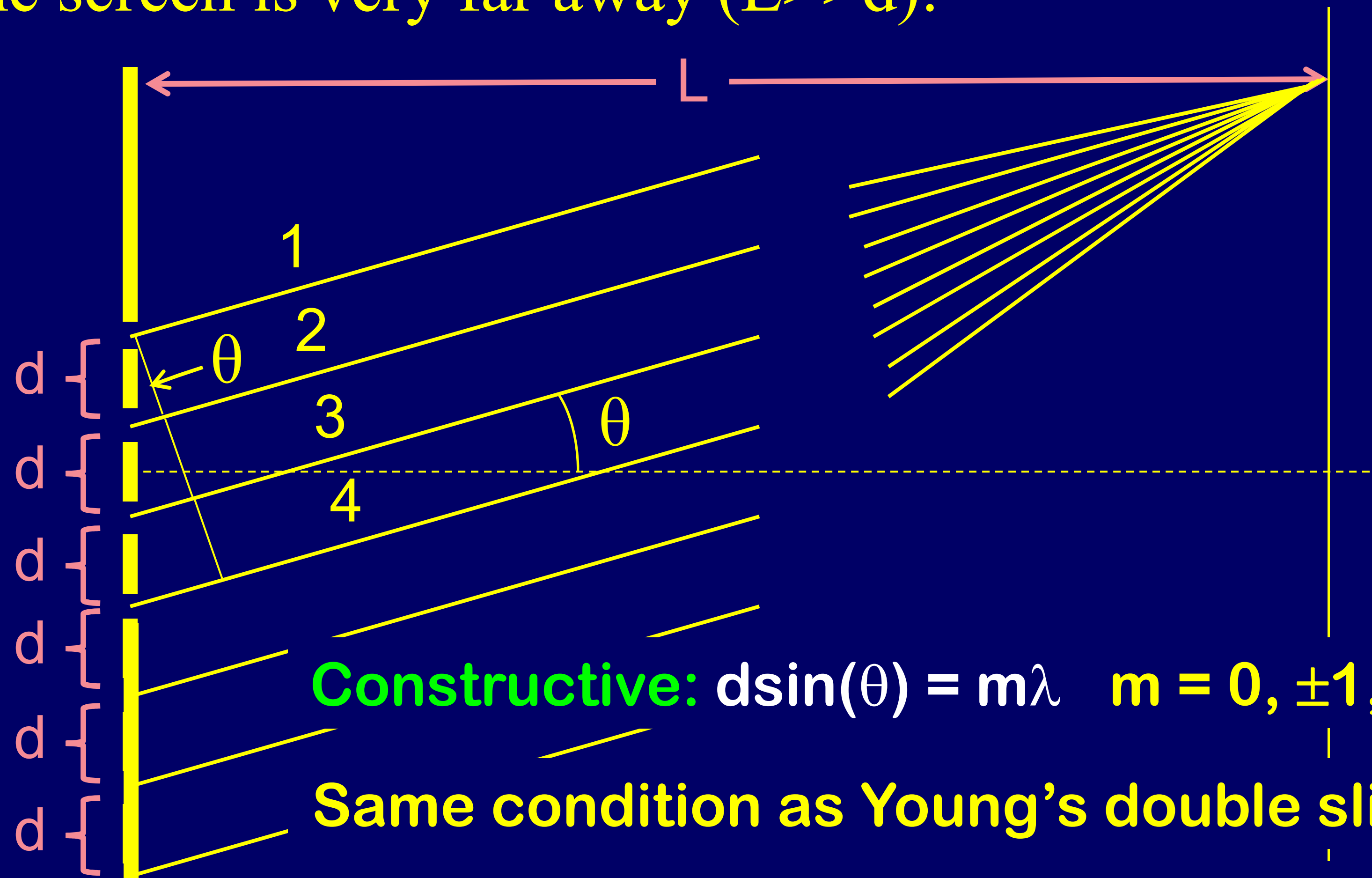
Constructive interference for all paths when

dsin(θ) = mλ   m = 0, ±1, ±2

Multiple Slits:

(Diffraction Grating – N slits with spacing d)

Assume screen is very far away (L>>d):

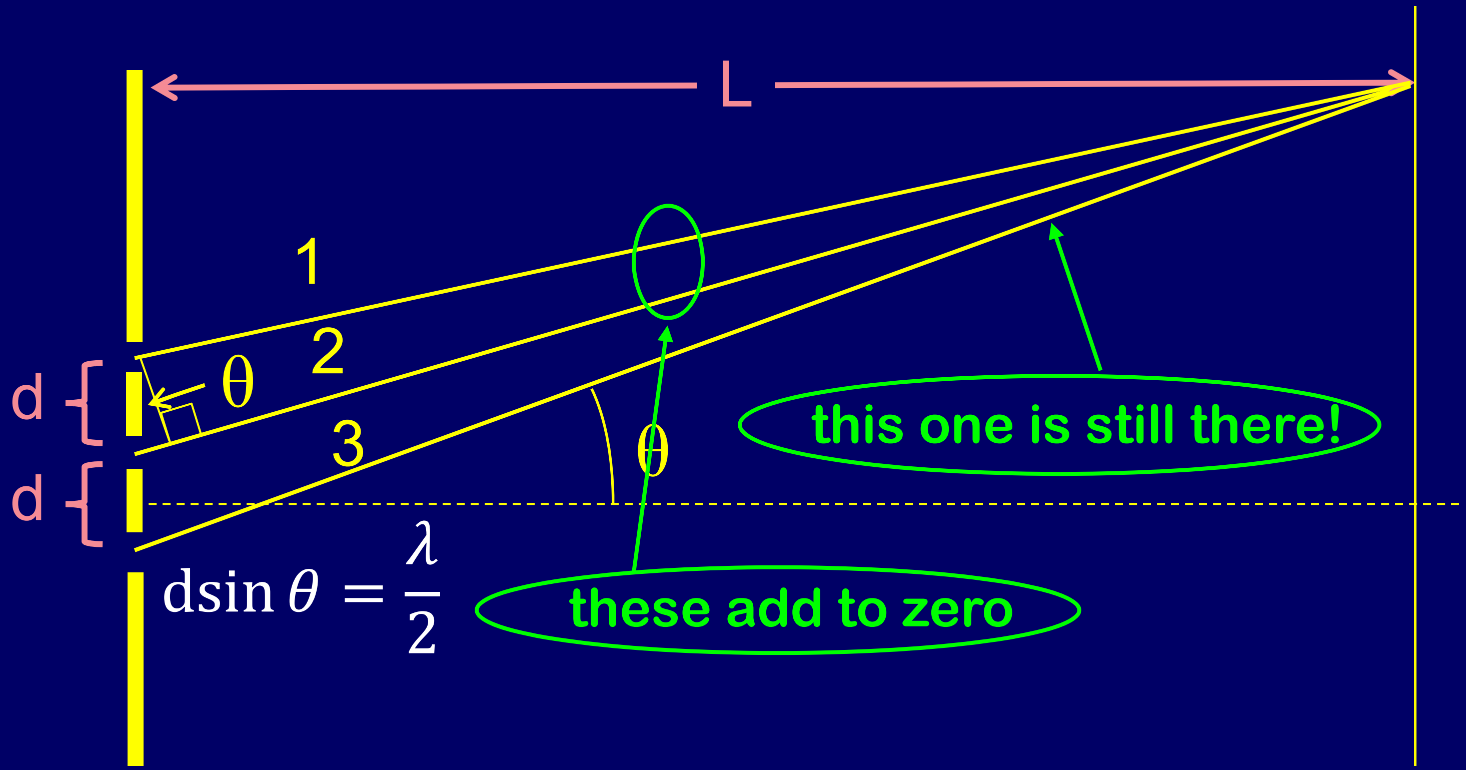


Constructive: $d\sin(\theta) = m\lambda$ **m = 0, ±1, ±2**

Same condition as Young's double slit!

Holds for arbitrary N

ACT/Checkpoint 2



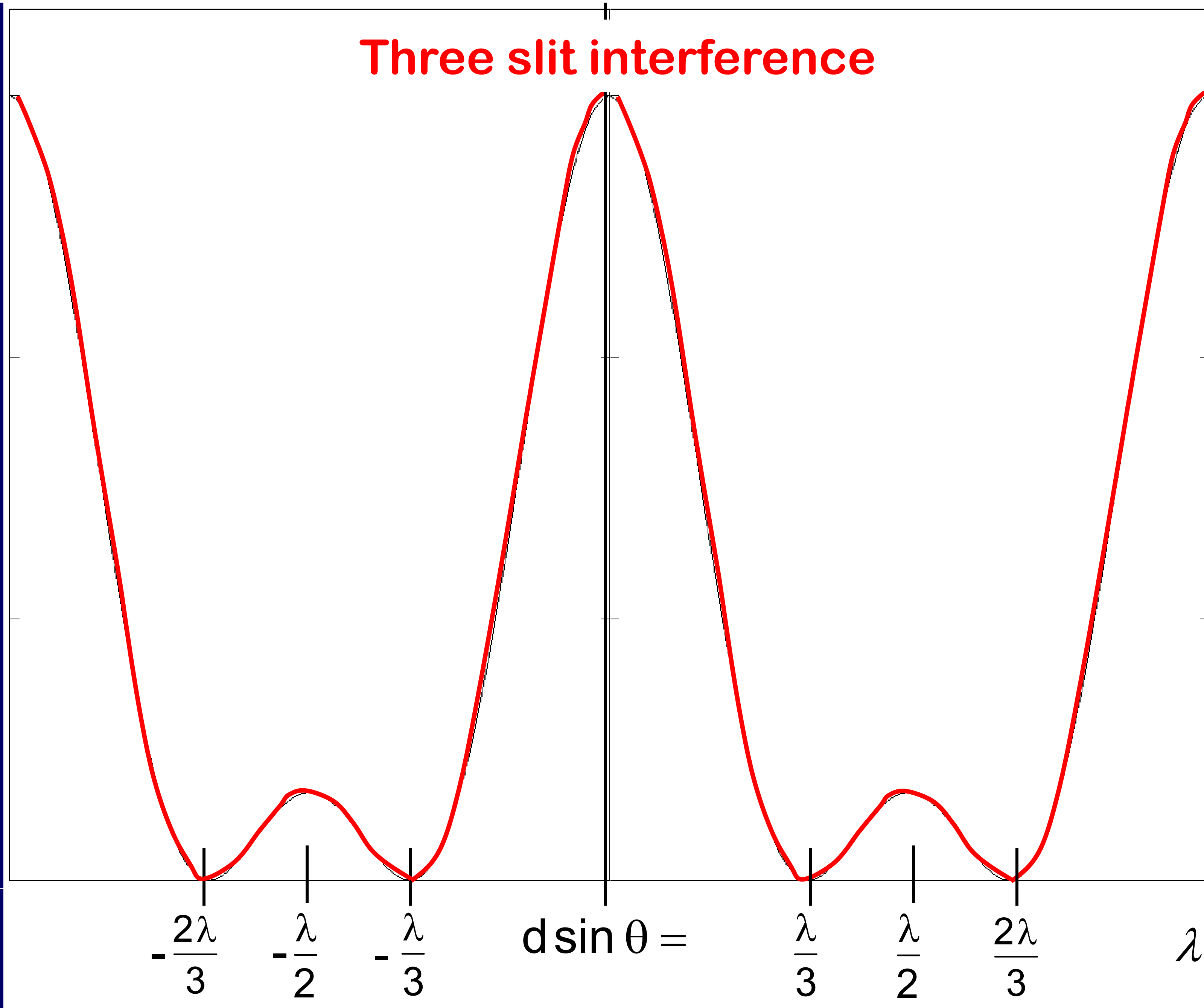
$$d\sin\theta = \frac{\lambda}{2}$$

When rays 1 and 2 are interfering destructively, is the intensity from the <u>three</u> rays a minimum?

A) Yes 46%

B) No 54%

Rays 1 and 2 completely cancel, but ray 3 is still there.


Three slit interference
$-\frac{2\lambda}{3}$
$-\frac{\lambda}{2}$
$-\frac{\lambda}{3}$
$d\sin\theta =$
$\frac{\lambda}{3}$
$\frac{\lambda}{2}$
$\frac{2\lambda}{3}$
λ

Multiple Slit Interference

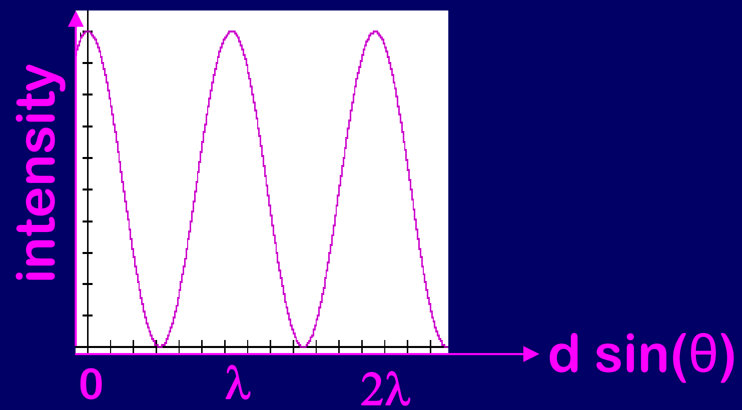
(Diffraction Grating)

For many slits, maxima are still at $\sin\theta = m\frac{\lambda}{d}$

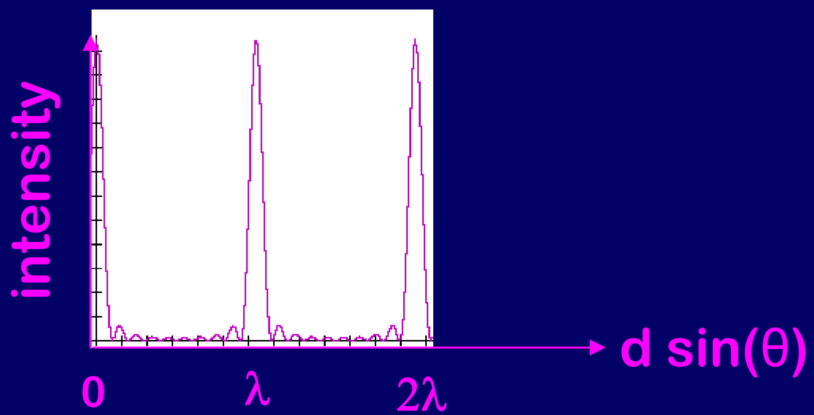
Peak location depends on wavelength!

Region between maxima gets suppressed more and more as no. of slits increases – bright fringes become narrower and brighter.

2 slits (N=2)

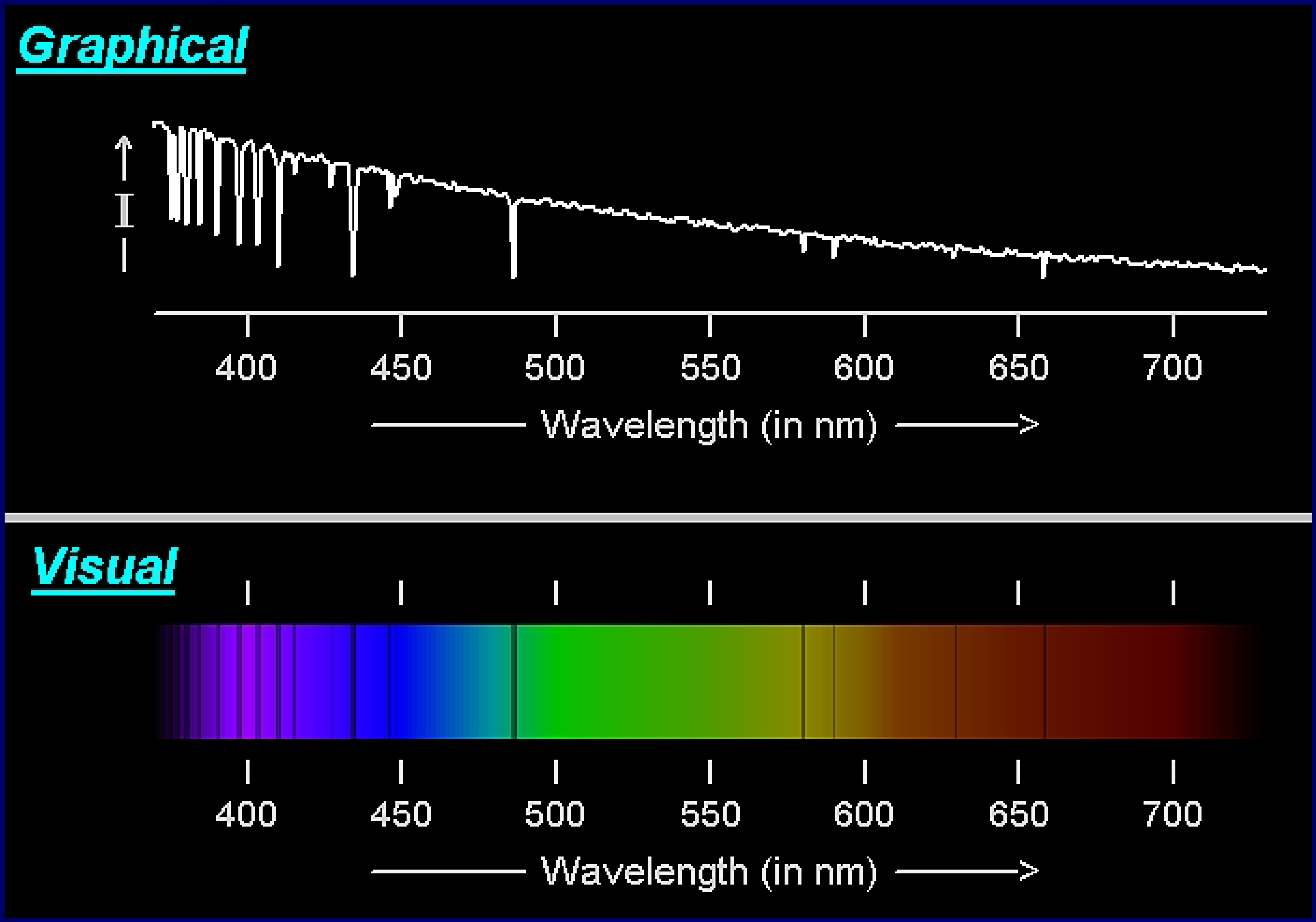


10 slits (N=10)

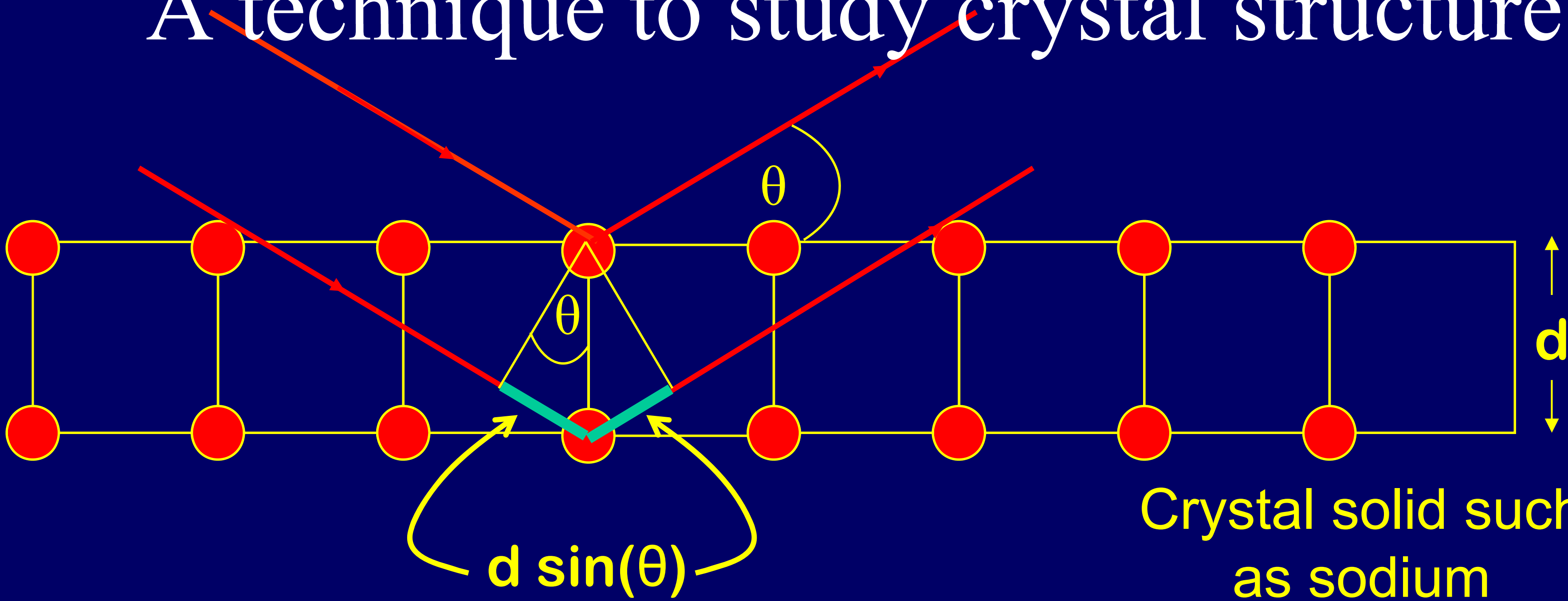


Diffraction grating:
spreads out different wavelengths, determine spectrum

Solar spectrum!



X-Ray Diffraction:
A technique to study crystal structure



Crystal solid such as sodium

Constructive interference: 2d sin(θ) = mλ

$2d > \lambda$

d ≈ 0.5nm in NaCl

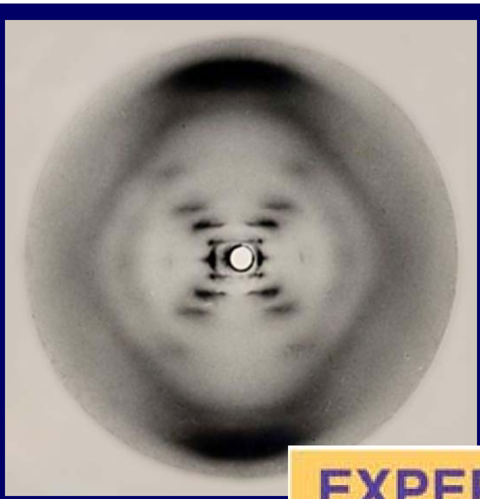
$m = 1$

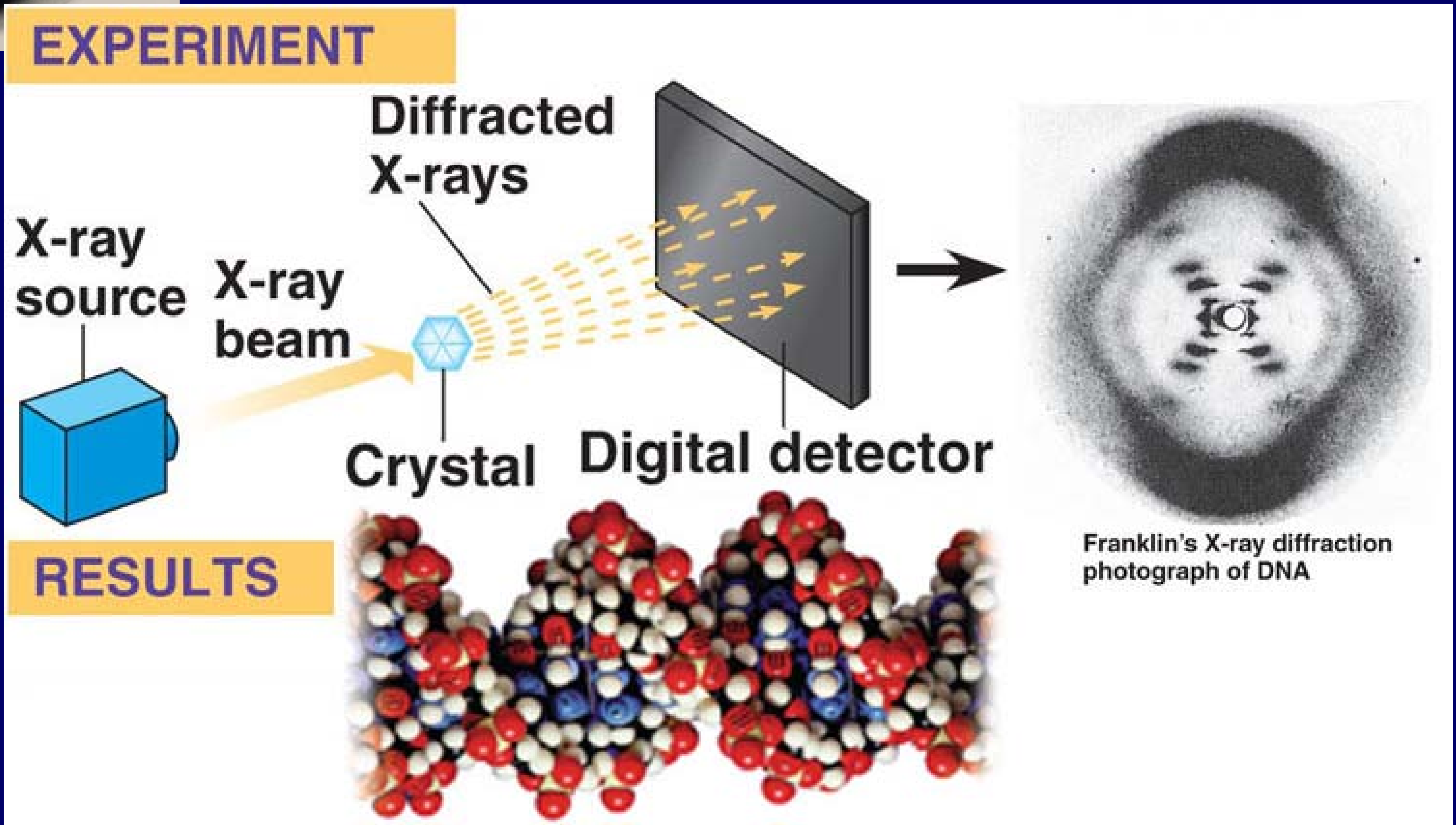
1st maximum will be at 10°

For λ=0.017nm

X-ray

Measure θ, determine d

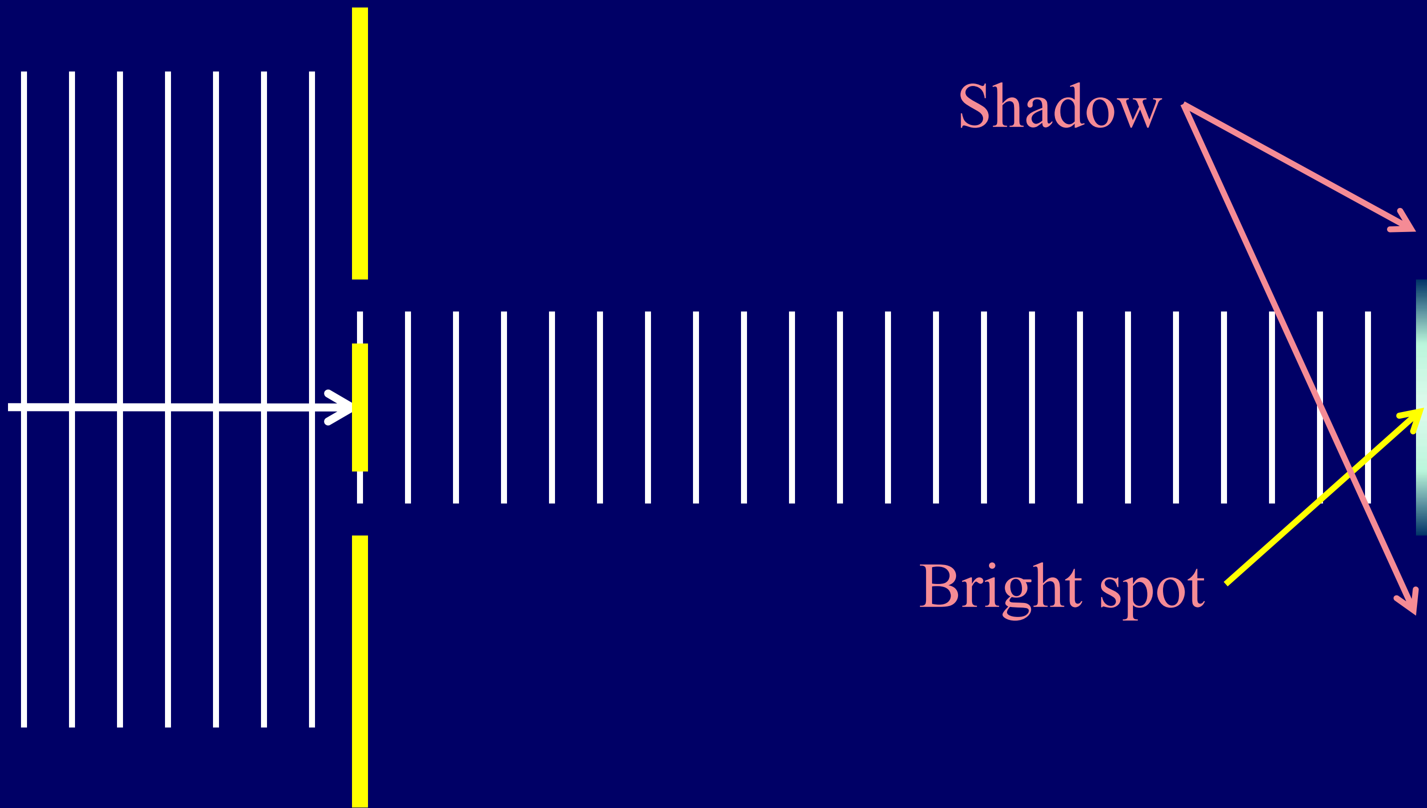




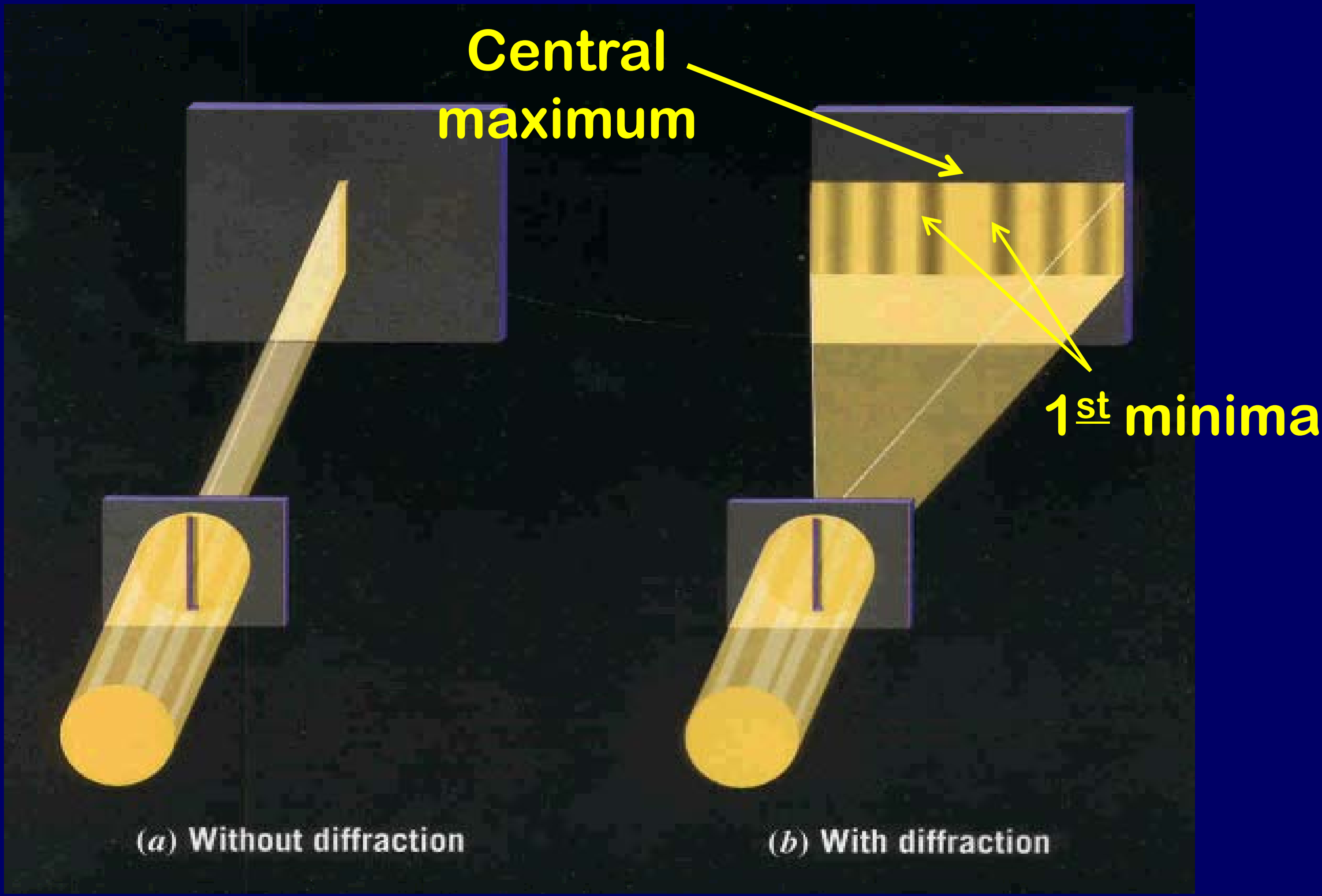
Franklin's X-ray diffraction photograph of DNA

Single slit interference?

Monochromatic light travels through a screen with opening



This is not what is actually seen!



Next lecture: quantitative single-slit diffraction

Recap

- Interference: Coherent waves
  - Full wavelength difference = Constructive
  - ½ wavelength difference = Destructive
- Multiple Slits
  - Constructive $d \sin(\theta) = m \lambda$ (m=1,2,3…)
  - Destructive $d \sin(\theta) = (m + 1/2) \lambda$ 2 slit only
  - More slits = brighter max, darker mins
- Single Slit Interference