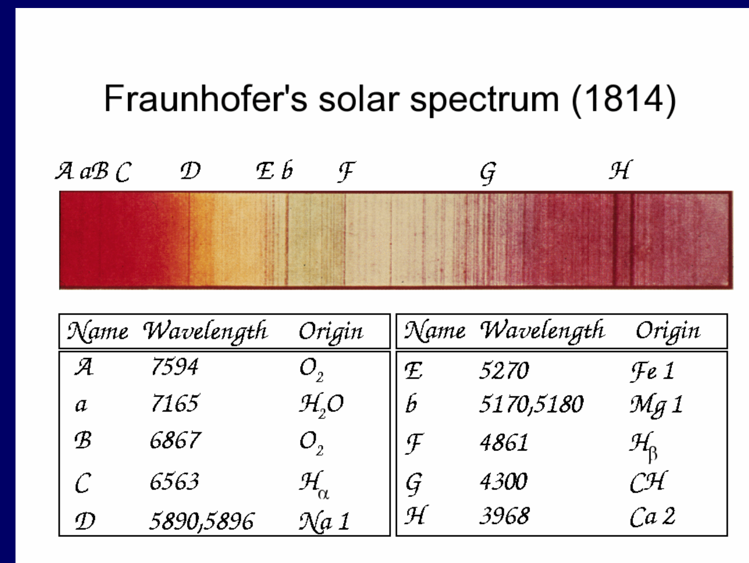
Physics 102: Lecture 21

Thin Films & Diffraction Gratings



Name	Wavelength	Origin	Name	Wavelength	Origin
A	7594	O_2	E	5270	Fe 1
a	7165	H_2O	b	5170,5180	Mg 1
B	6867	O_2	F	4861	H_β
C	6563	H_α	G	4300	CH
D	5890,5896	Na 1	H	3968	Ca 2

Stelzer moved office hour from April 14th (Monday) to April 11th (Friday) 4-5 pm See Website.

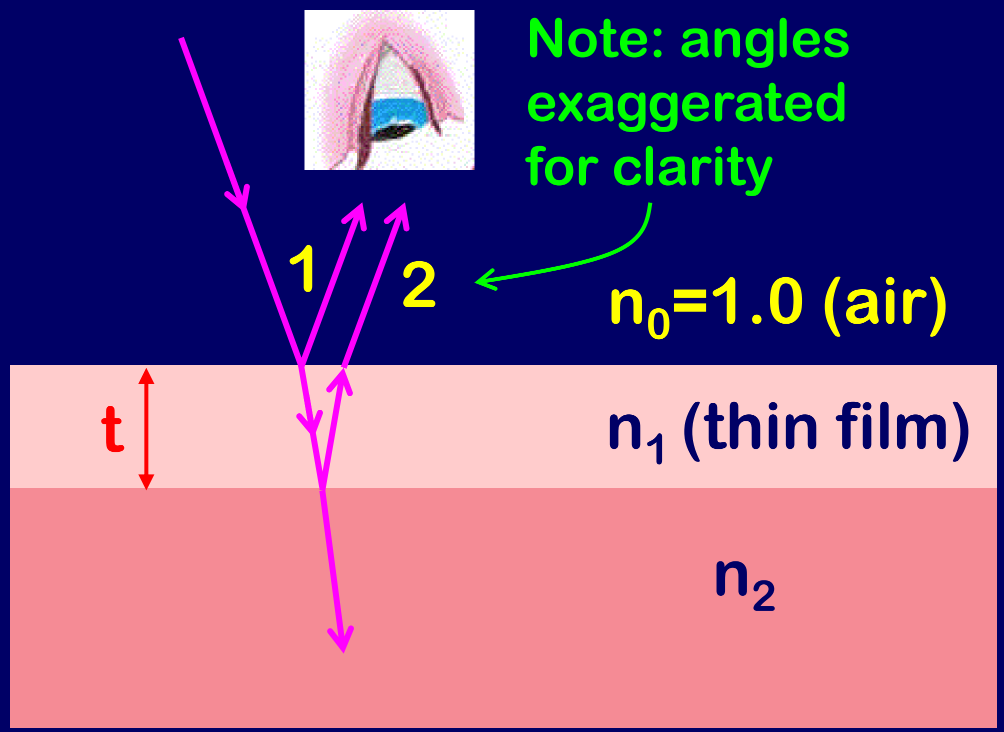
Recall

- 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

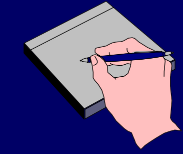
Thin Film Interference

Light is incident normal to a thin film



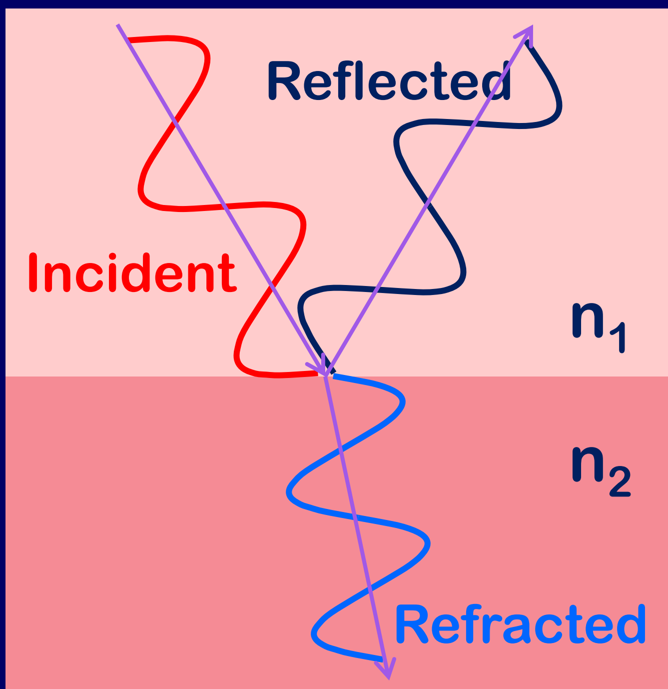
Get two waves by reflection off two different interfaces: interference!

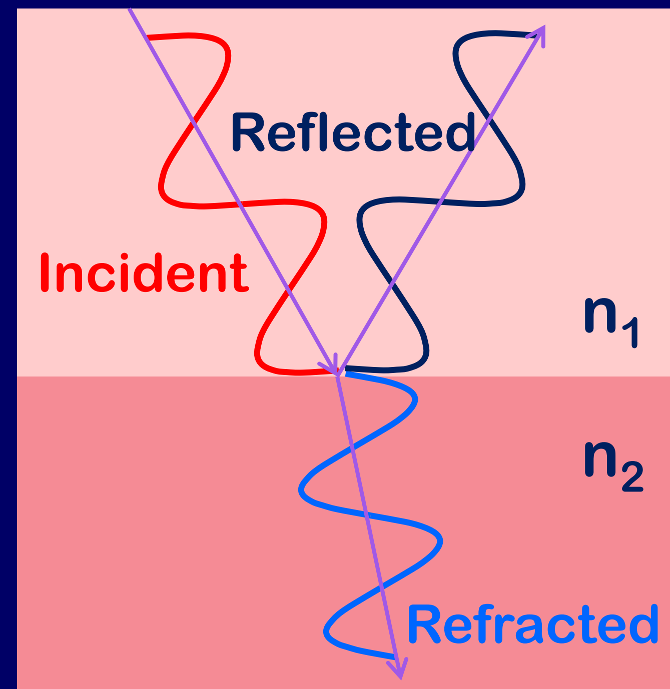
Ray 2 travels approximately 2t further than ray 1.



Reflection & Phase Shifts

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



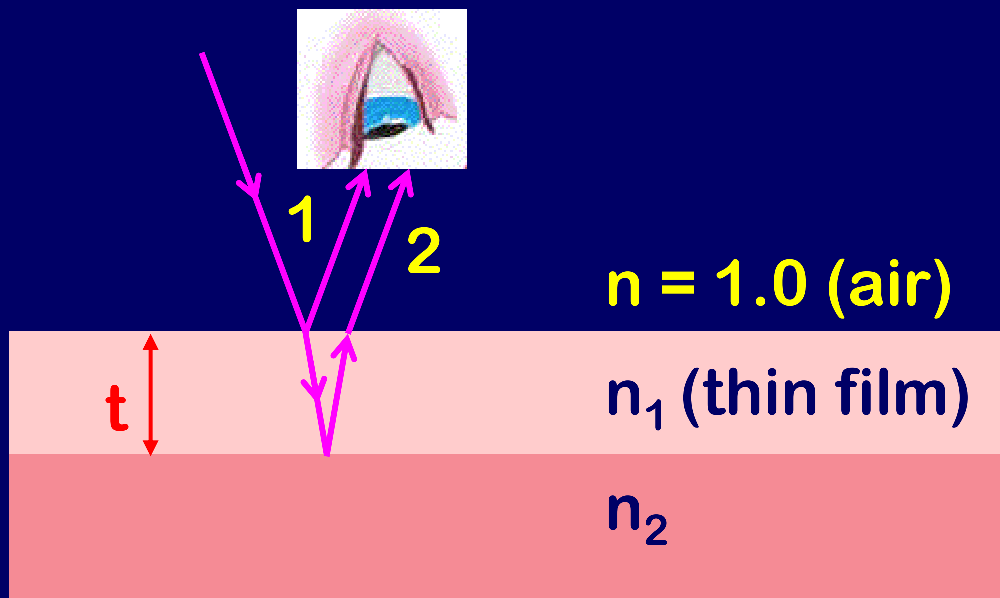


- If $n_1 > n_2$ – no phase change upon reflection

- 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!

Ray 1: $\delta_1 = \overbrace{0 \text{ or } \tfrac{1}{2}}^{\text{Reflection}} + \overbrace{0}^{\text{Distance}}$

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

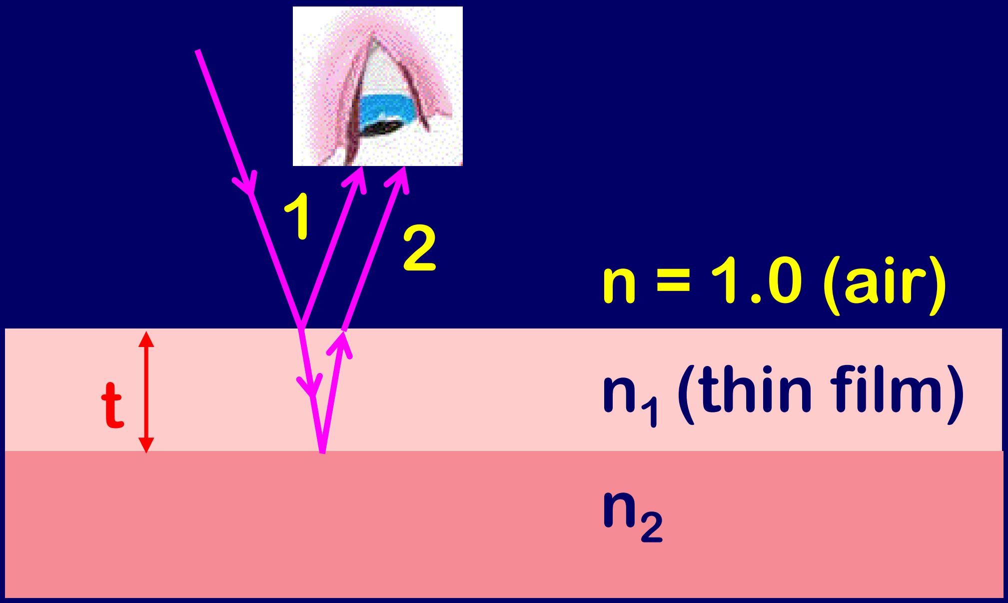
Note: this is wavelength in film! ($\lambda_{film} = \lambda_o / n_1$)

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

If $|\delta_2 - \delta_1| = \tfrac{1}{2}, 1\tfrac{1}{2}, 2\tfrac{1}{2} \ldots$ $(m + \tfrac{1}{2})$ **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).

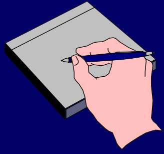


What is δ_1, the total phase shift for ray 1

A) $\delta_1 = 0$ **B) $\delta_1 = ½$** **C) $\delta_1 = 1$**

Reflection off higher n material

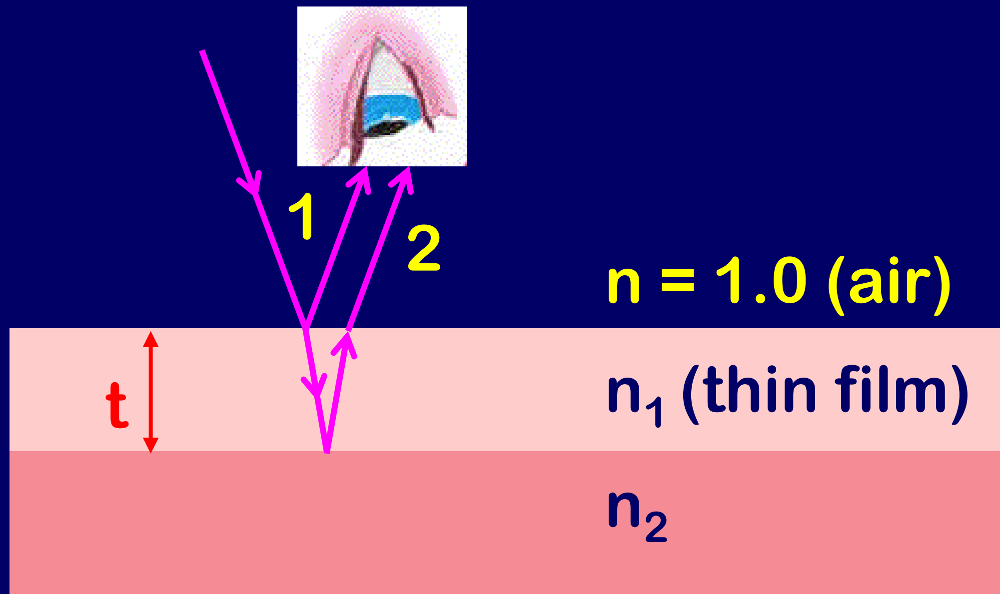
Example



Thin Film Practice

Checkpoint 1.2

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?

A B C

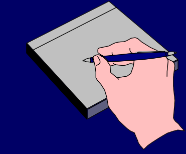
$\delta_1 = \frac{1}{2}$

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

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

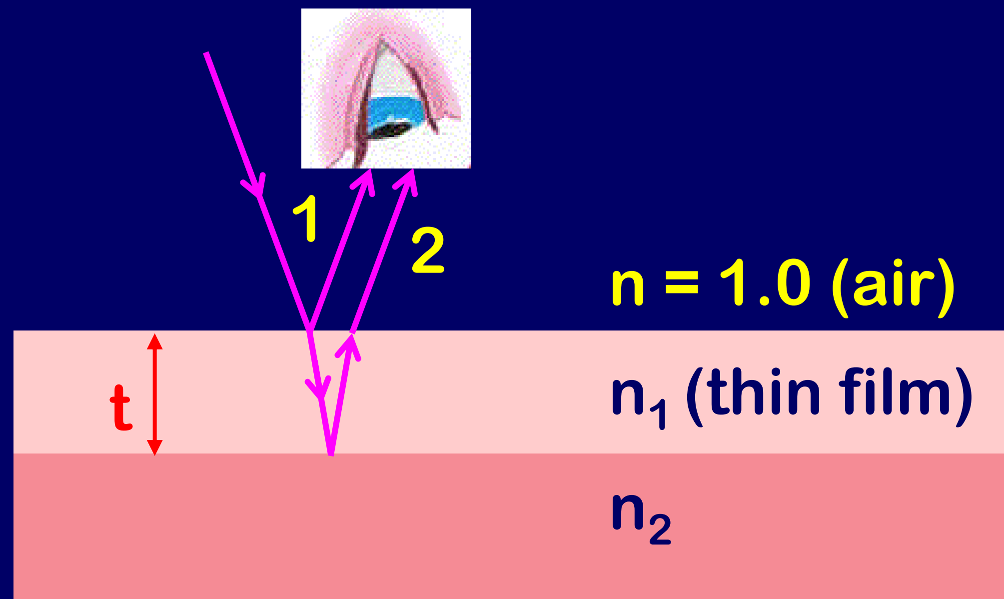
Example

ACT: Thin Film Practice II



Checkpoint 1.1

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



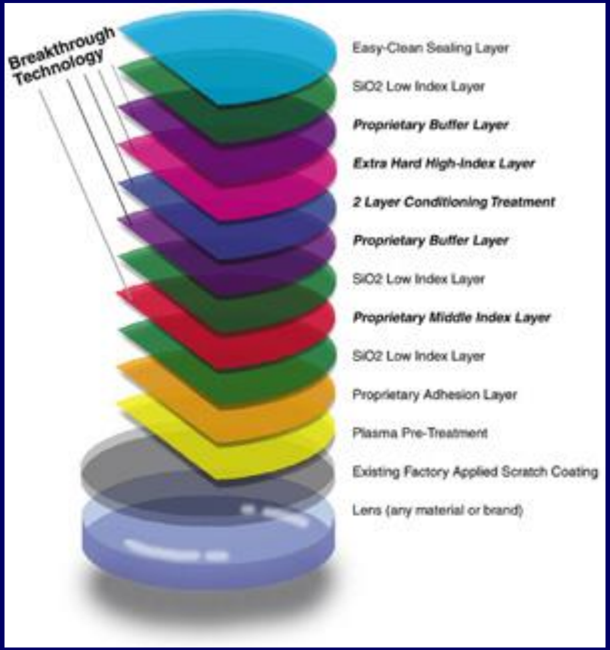
Is the interference : A) constructive B) destructive C) neither?

$\delta_1 = ½$

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

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

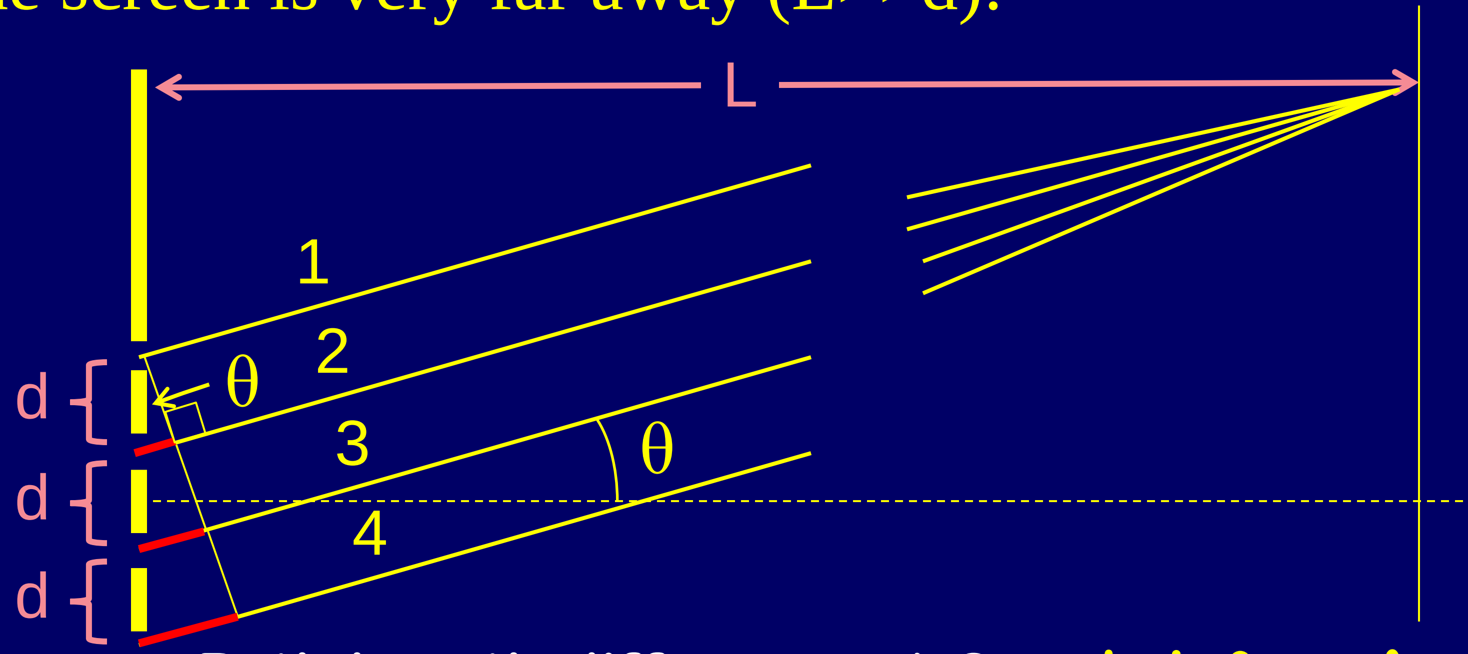
Thin film application: Anti-reflection coatings



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 $= 3\lambda$

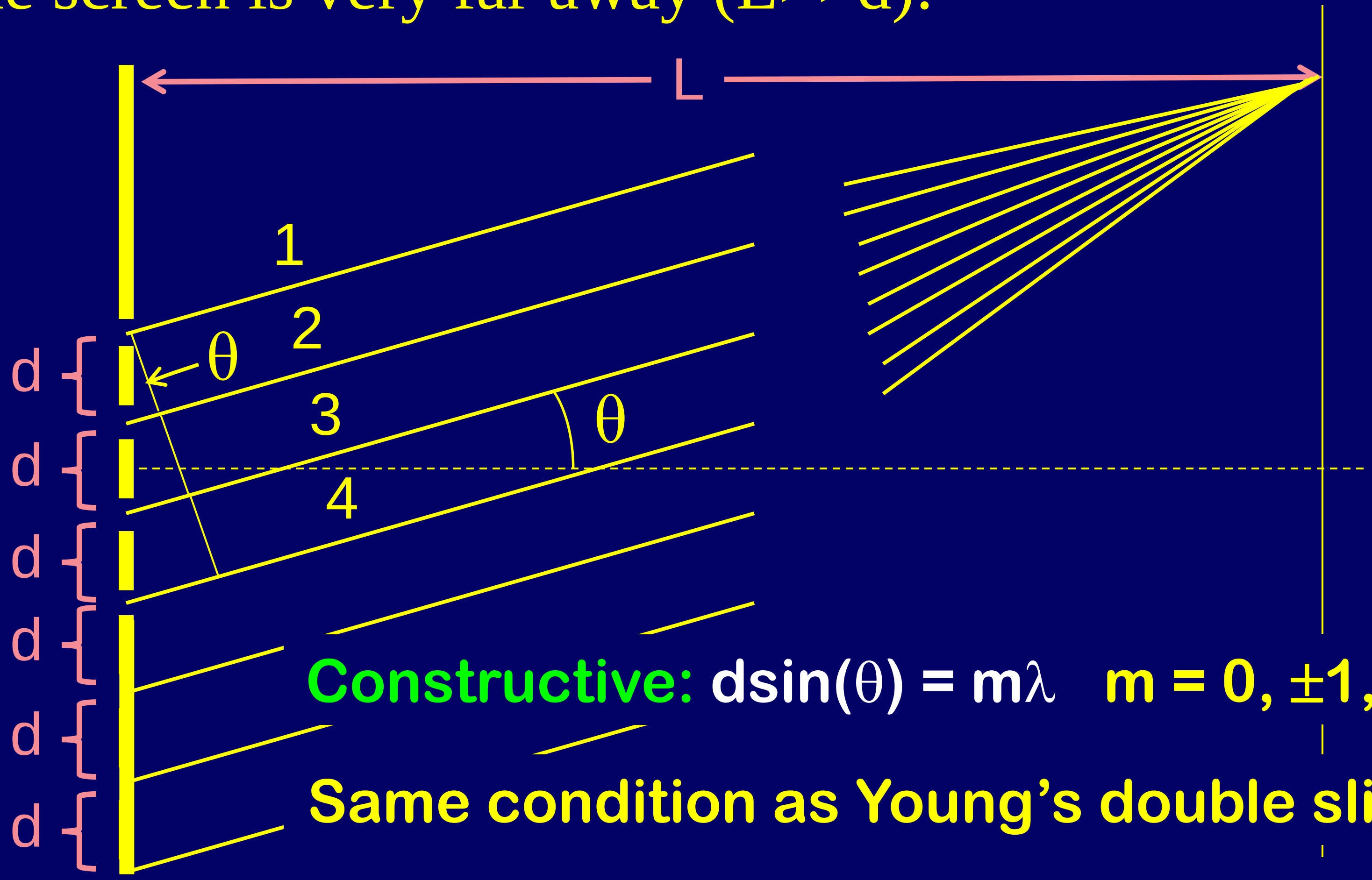
Constructive interference for all paths when

dsin(θ) = mλ   m = 0, ±1, ±2

Multiple Slits:

(Diffraction Grating – N slits with spacing d)

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

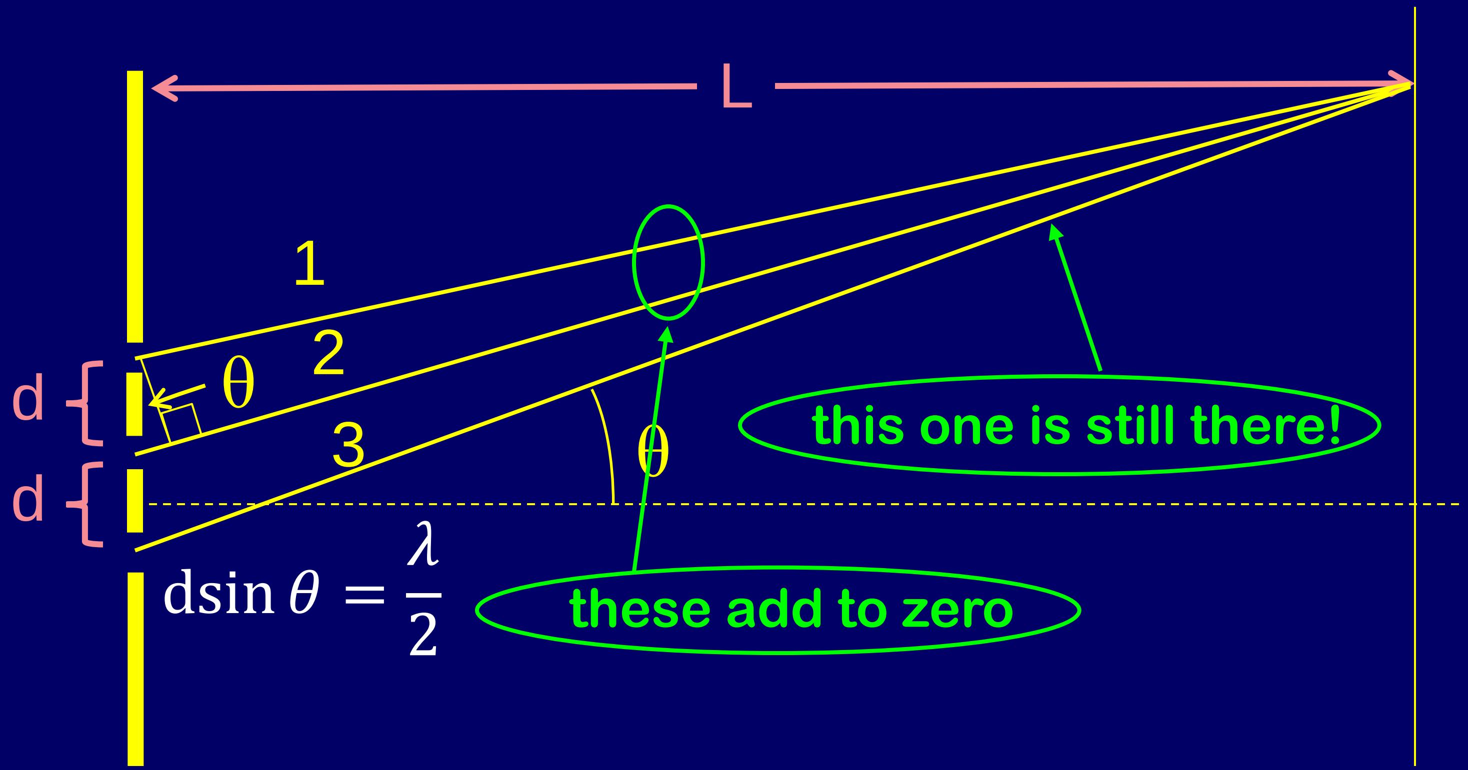


Constructive: **d sin(θ) = mλ** **m = 0, ±1, ±2**

Same condition as Young's double slit!

Holds for arbitrary N

ACT/Checkpoint 2



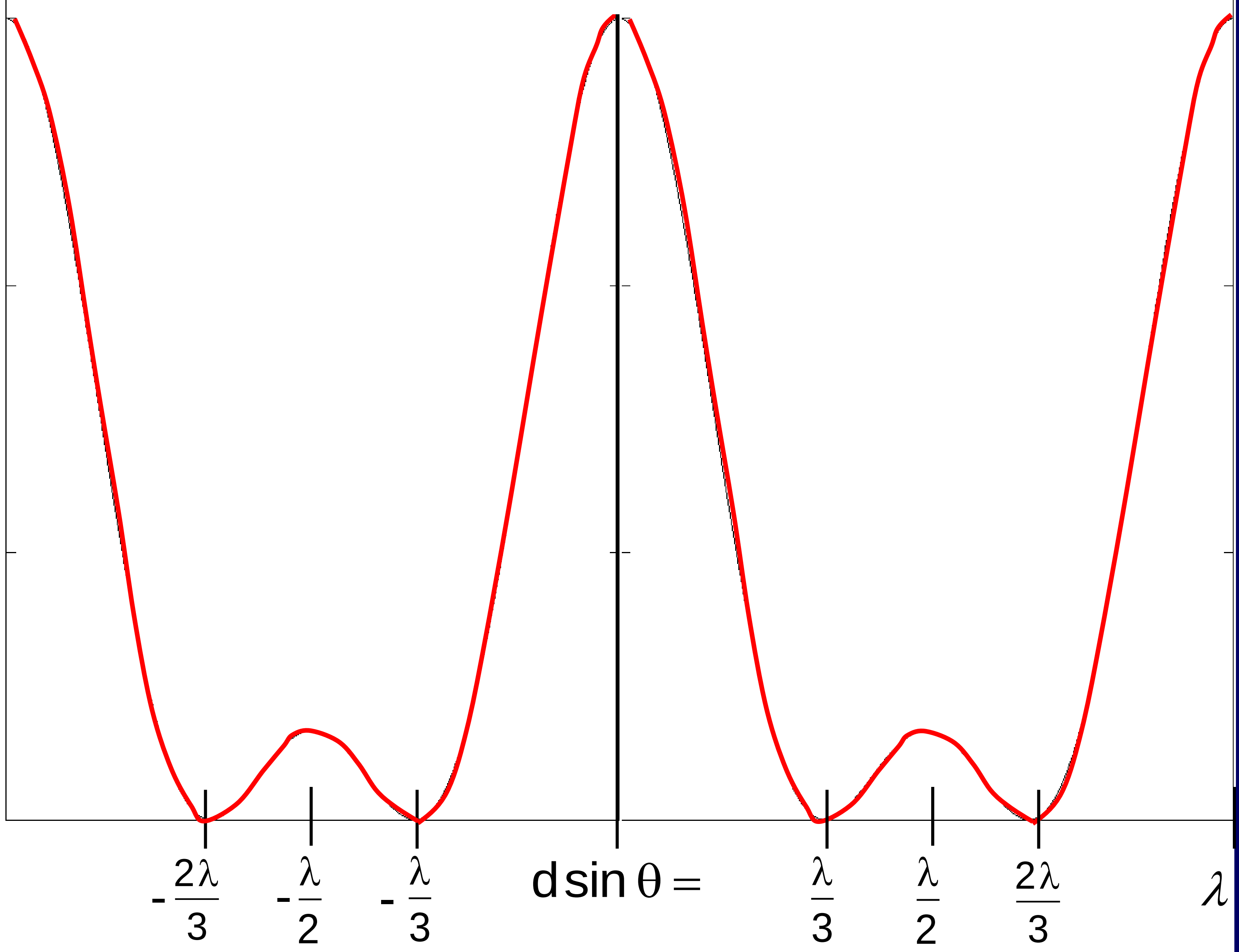
When rays 1 and 2 are interfering destructively, is the intensity from the <u>three</u> rays a minimum?

A) Yes 45%

B) No 55%

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

Three slit interference



Multiple Slit Interference

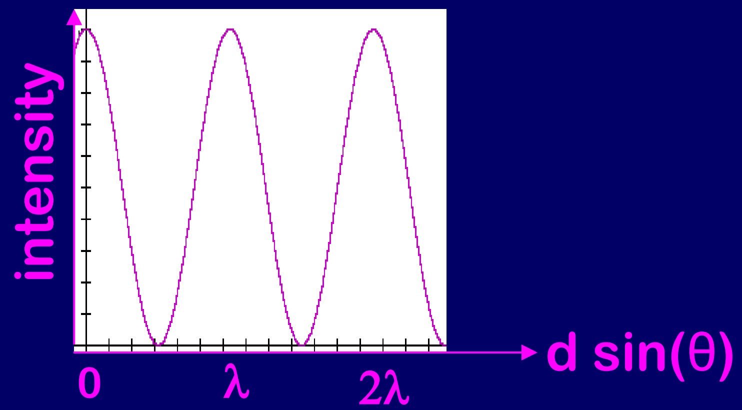
(Diffraction Grating)

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

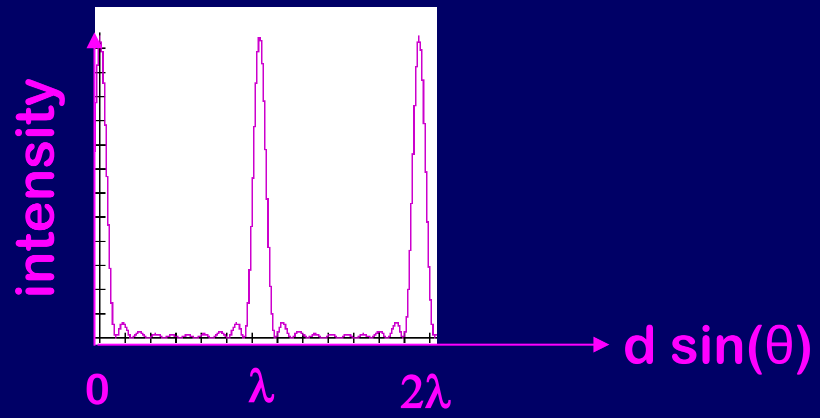
Peak location depends on wavelength!

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

2 slits (N=2)

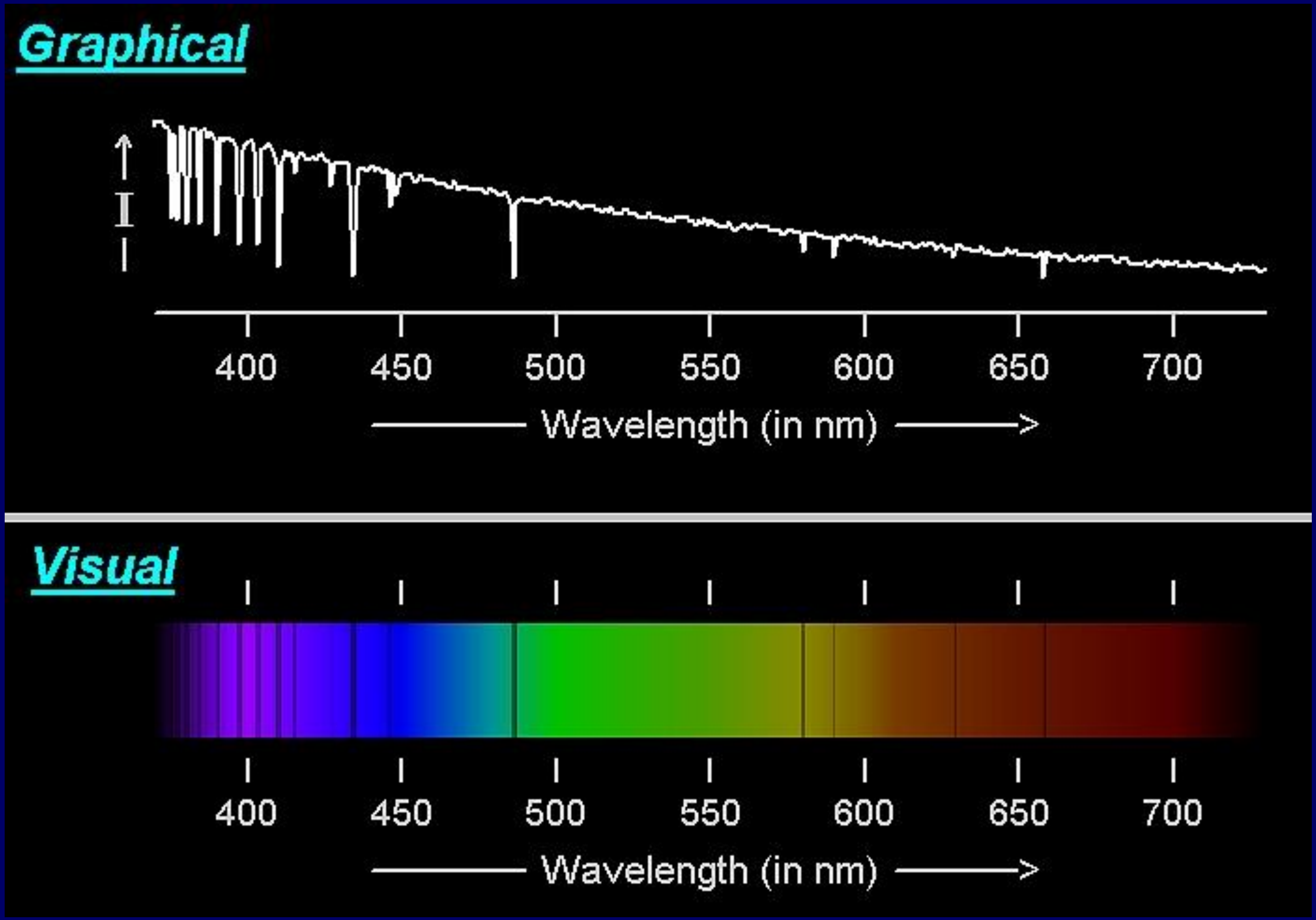


10 slits (N=10)

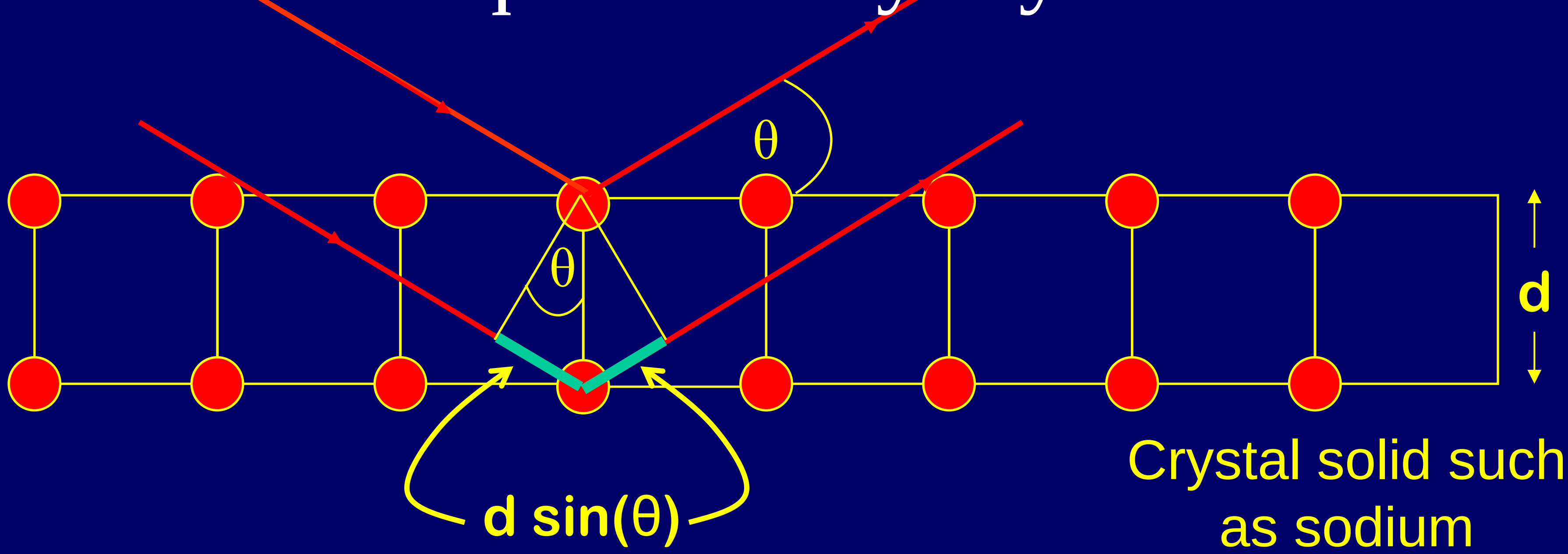


Diffraction grating:
spreads out different wavelengths, determine spectrum

Solar spectrum!



X-Ray Diffraction: A technique to study crystal structure



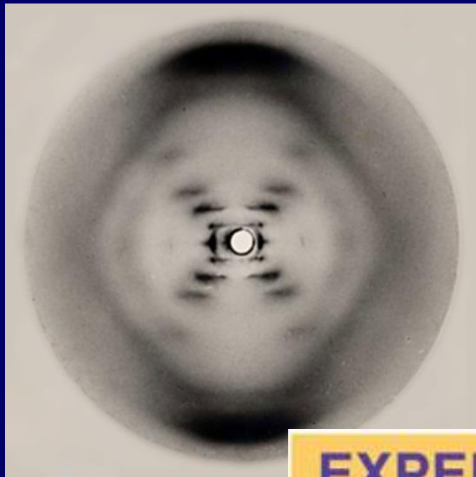
Constructive interference: $2d\sin(\theta) = m\lambda$

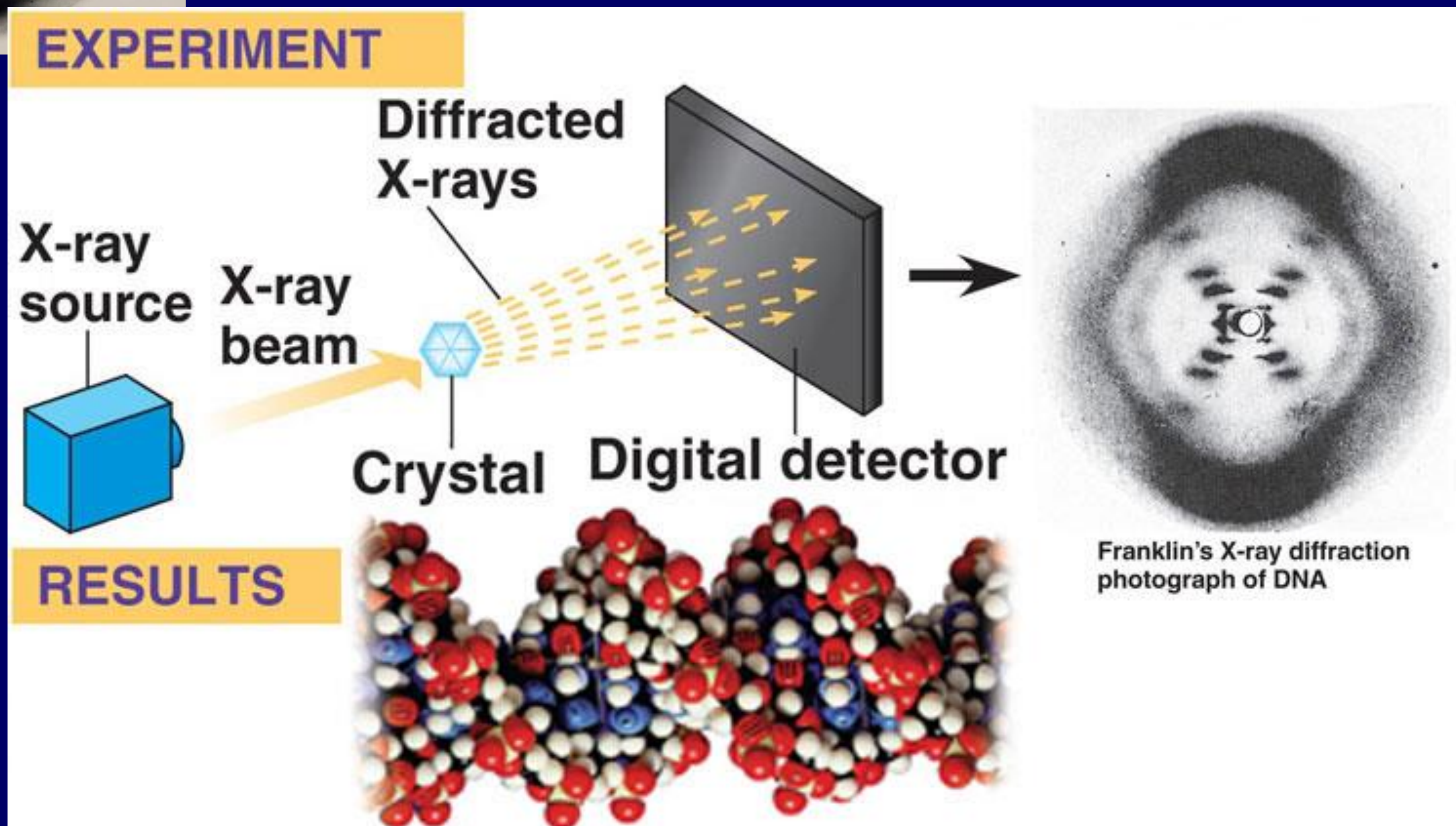
$d \approx 0.5$nm in NaCl

For $\underbrace{\lambda=0.017\text{nm}}_{\text{X-ray}}$

1st maximum will be at 10^0

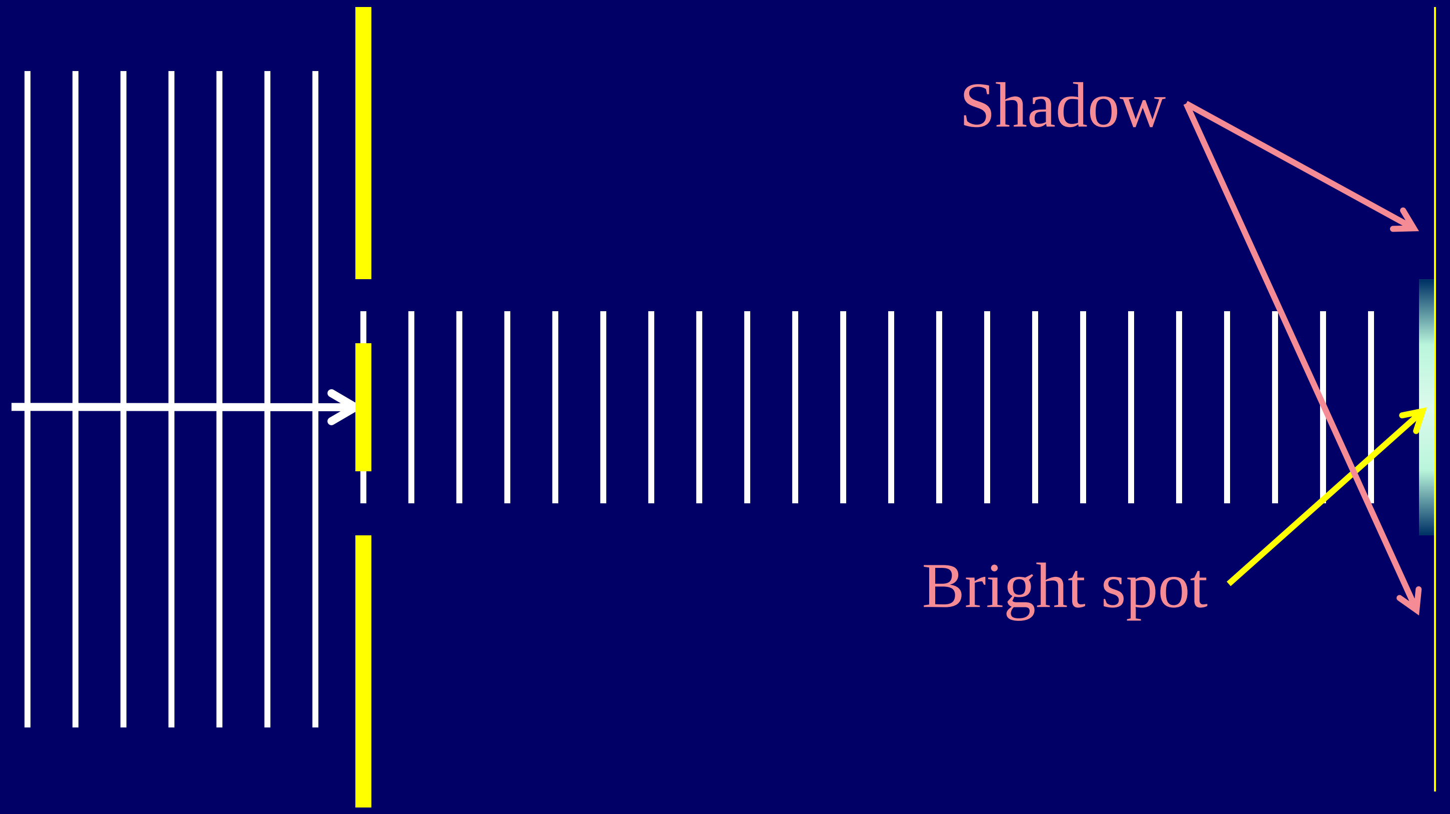
$\boxed{\text{Measure } \theta \text{, determine d}}$




EXPERIMENT
Diffracted X-rays
X-ray source
X-ray beam
Crystal
Digital detector
RESULTS
Franklin's X-ray diffraction photograph of DNA

Single slit interference?

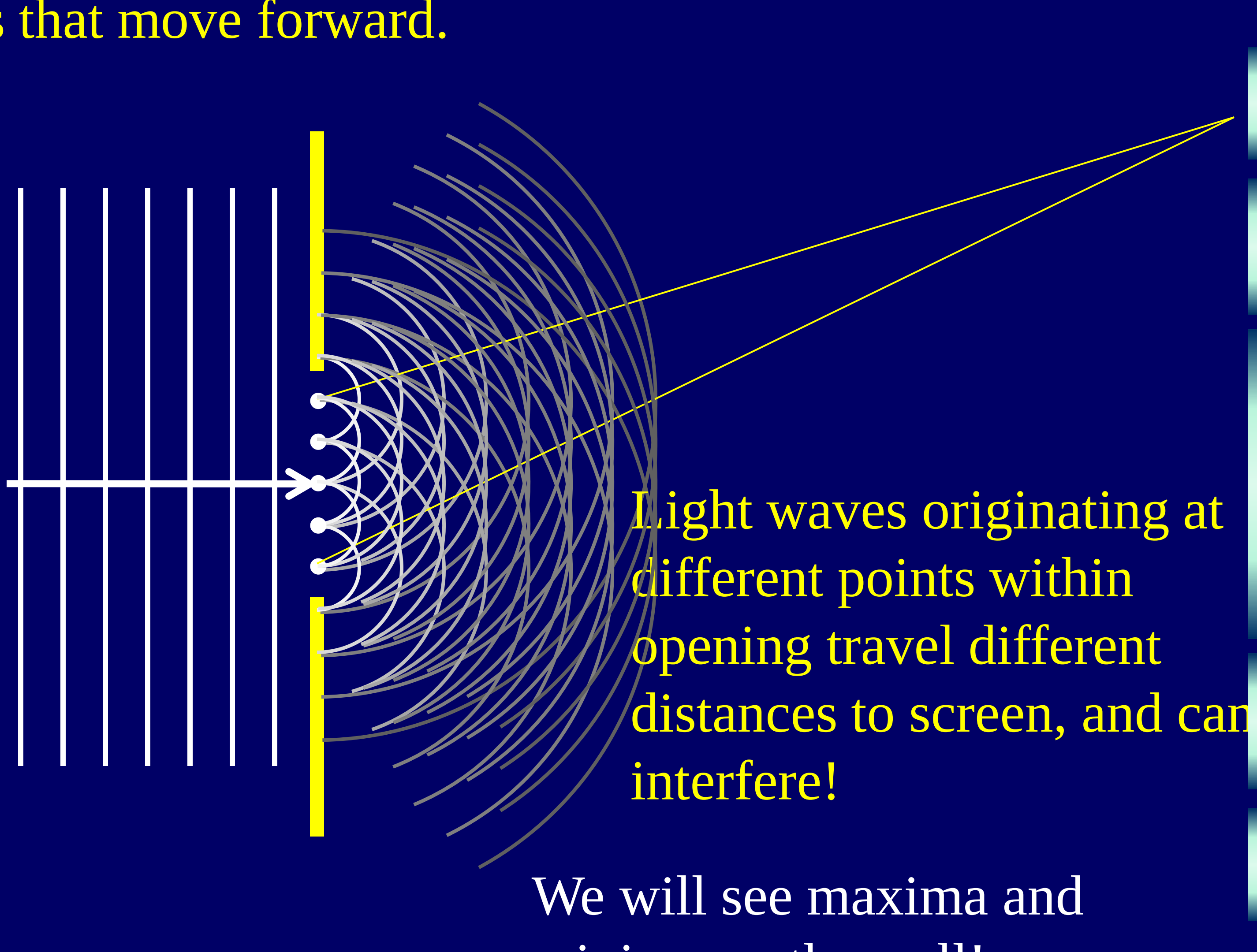
Monochromatic light travels through a screen with opening



This is not what is actually seen!

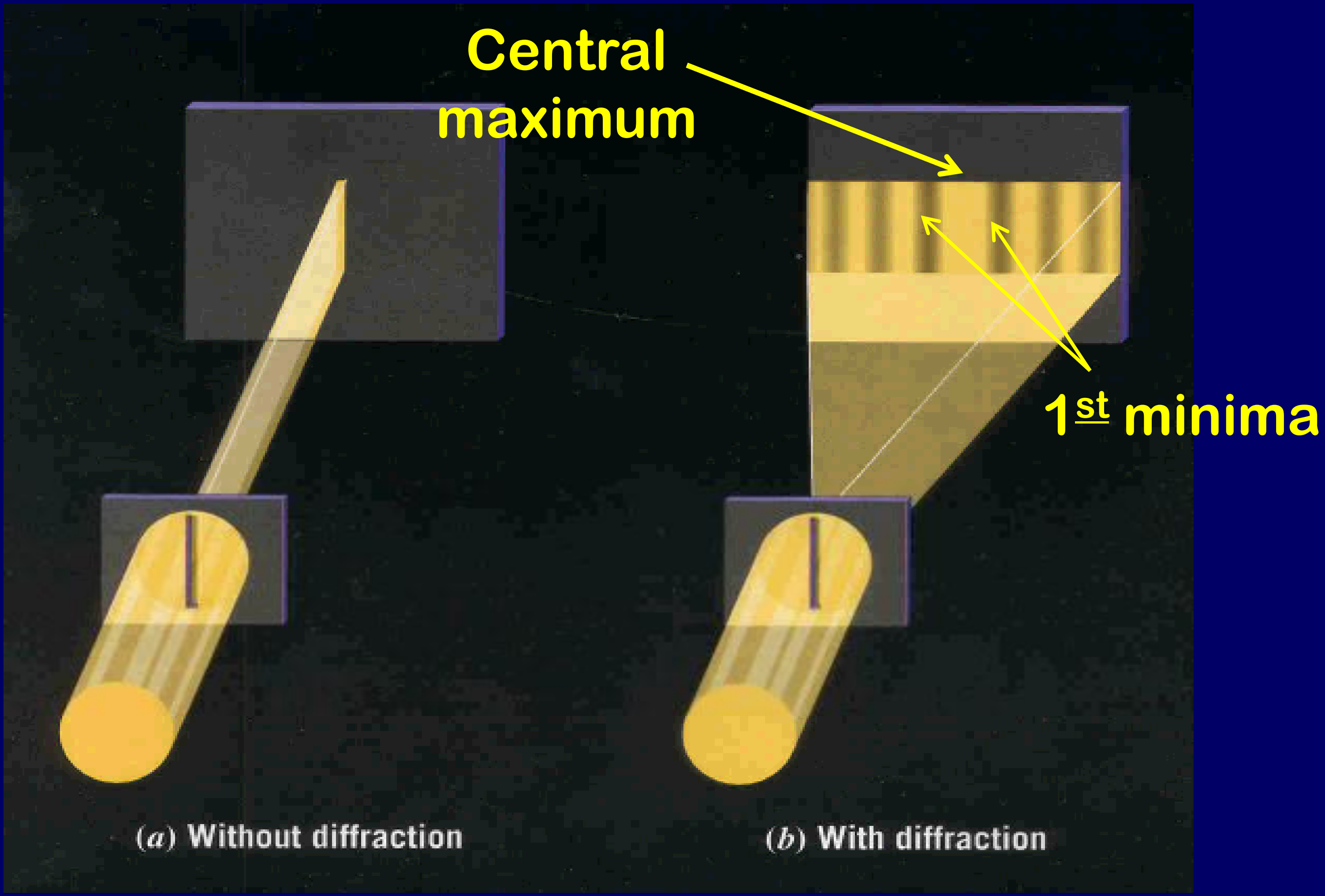
Diffraction/Huygens' principle

Huygens: Every point on a wave front acts as a source of tiny wavelets that move forward.



Light waves originating at different points within opening travel different distances to screen, and can interfere!

We will see maxima and minima on the wall!



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