

Your questions/comments

IMPORTANT ANNOUNCEMENTS:

EXAM 3 Thursday on Lect. 13 (Lenz' law) – Lect. 19 (refraction & lenses) -> [website](#)
Review Tuesday 5:30-7:30pm in 151 Loomis -> will review Fall '14 EX3

“very confused by this wizardry. can you please go over maxima and minima?”

“I had no idea how to do the last checkpoint set of problems...PLEASE HELP”

“Wait a second.. Is this how x-ray crystallography works... except the slits are actually "slits" created by the crystallized molecule...” *Yes! Next lecture*

“biochemistry is the end of me RIP. Maybe I should just be a physicist instead.”

“This checkpoint is INTERFERING with my studying, which hopefully won't be too INTENSE.”

“Sorry, I rushed through these. I have multiple exams this week that I need to study for.”

Physics 102 lectures on light

Light as a wave

- Lecture 15 – EM waves
- Lecture 16 – Polarization
- Lecture 22 & 23 – Interference & diffraction

Light as a ray

object $\gg \lambda$

- Lecture 17 – Introduction to ray optics
- Lecture 18 – Spherical mirrors
- Lecture 19 – Refraction & lenses
- Lecture 20 & 21 – Your eye & optical instruments

Light as a particle

- Lecture 24 & 25 – Quantum mechanics



Phys 102 – Lecture 22

Interference

Today we will...

- Learn how waves interfere

In phase vs. out of phase

Constructive vs. destructive interference

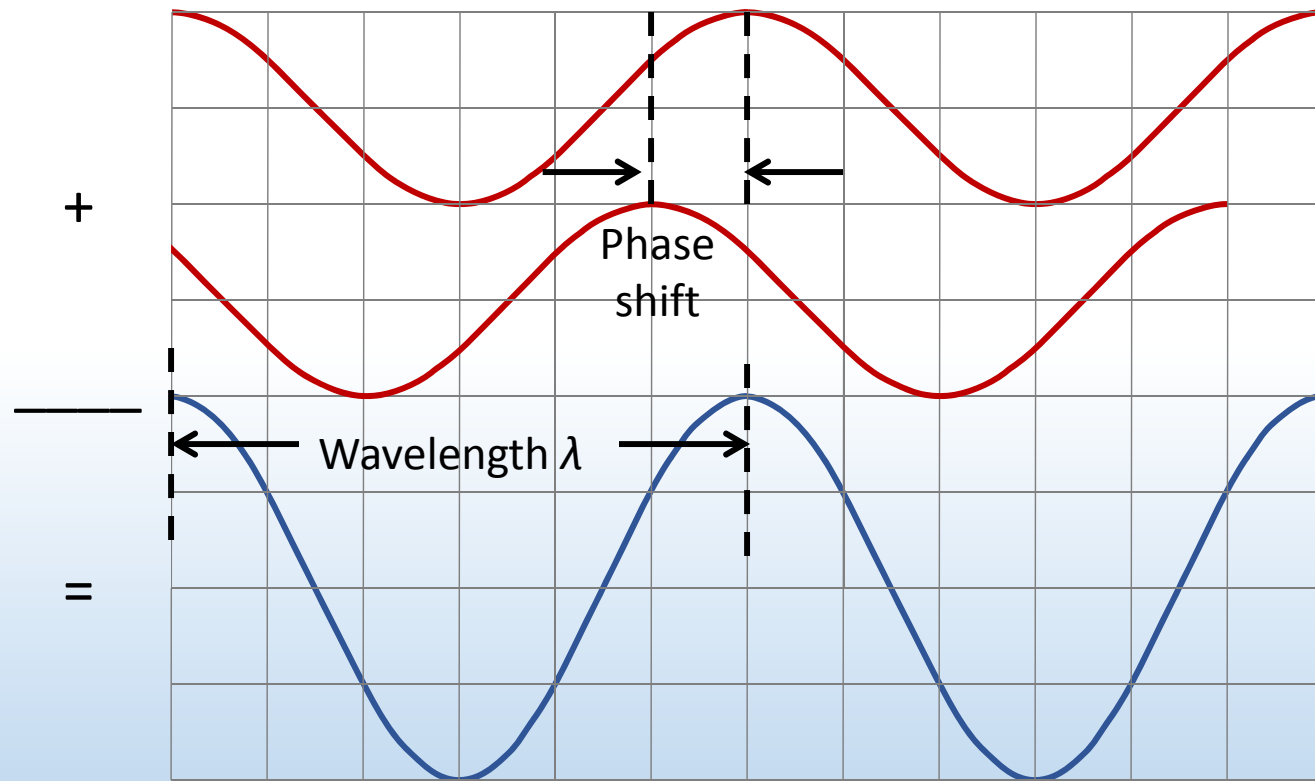
- Apply these concepts

Young's double slit interference

Multiple slit interference

Superposition of waves

Two waves are in phase when phase shift is 0



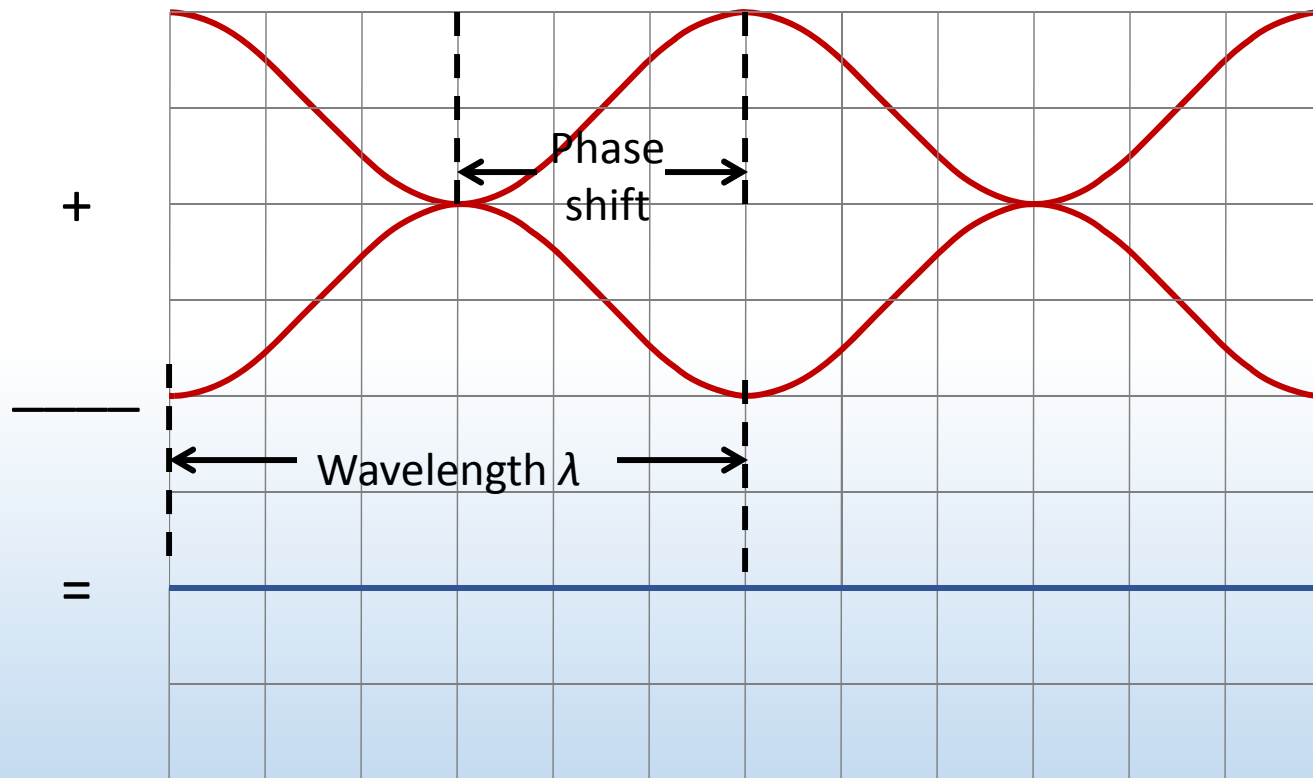
Waves remain in phase with shift of $1\lambda, 2\lambda \dots m\lambda$

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

Constructive interference – waves combine to give larger wave

Superposition of waves

Two waves are out of phase when phase shift is $\lambda/2$



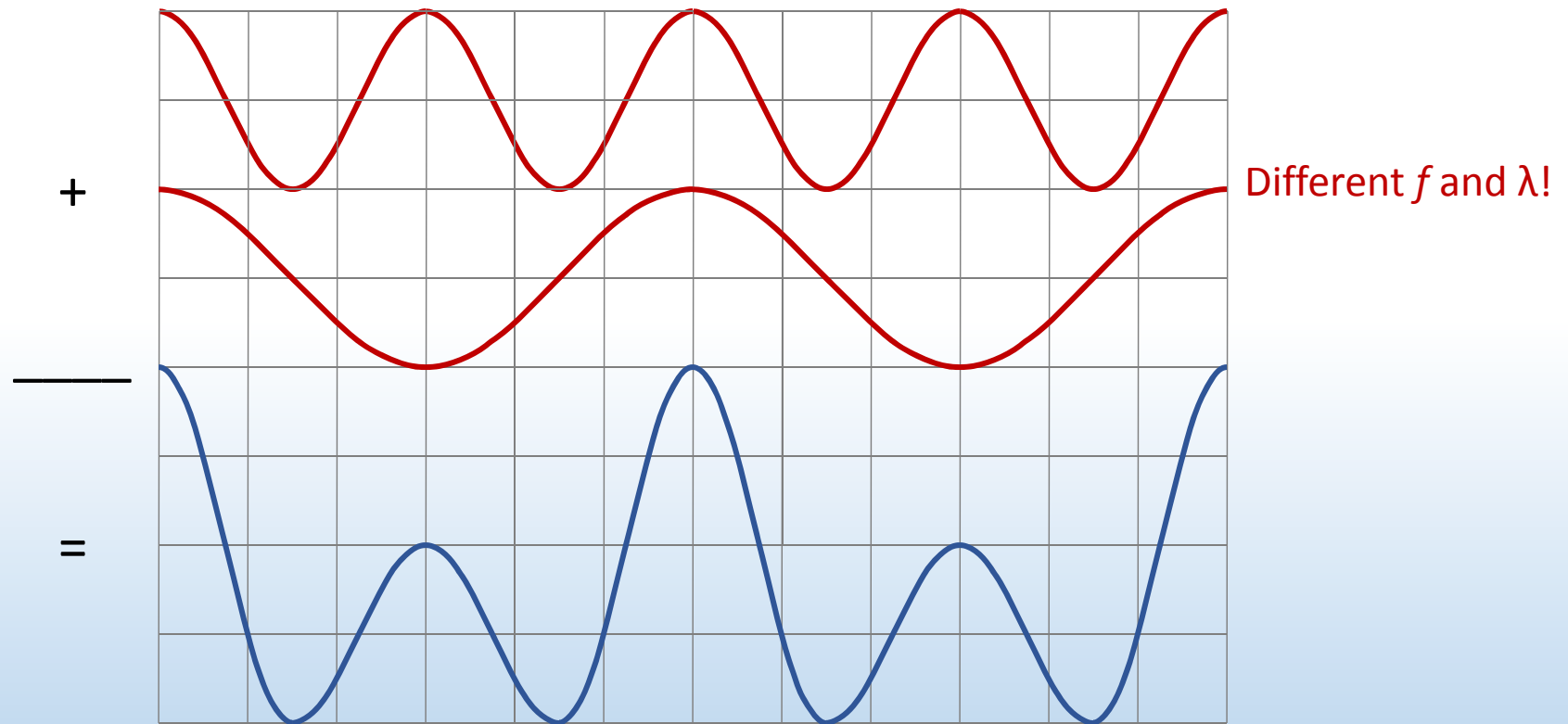
With phase shift of $\frac{1}{2}\lambda$, $1\frac{1}{2}\lambda$, $2\frac{1}{2}\lambda$... $(m + \frac{1}{2})\lambda$, waves are out of phase

Destructive interference – waves combine to give no wave



ACT: Superposition of waves

What kind of interference do these two waves produce?



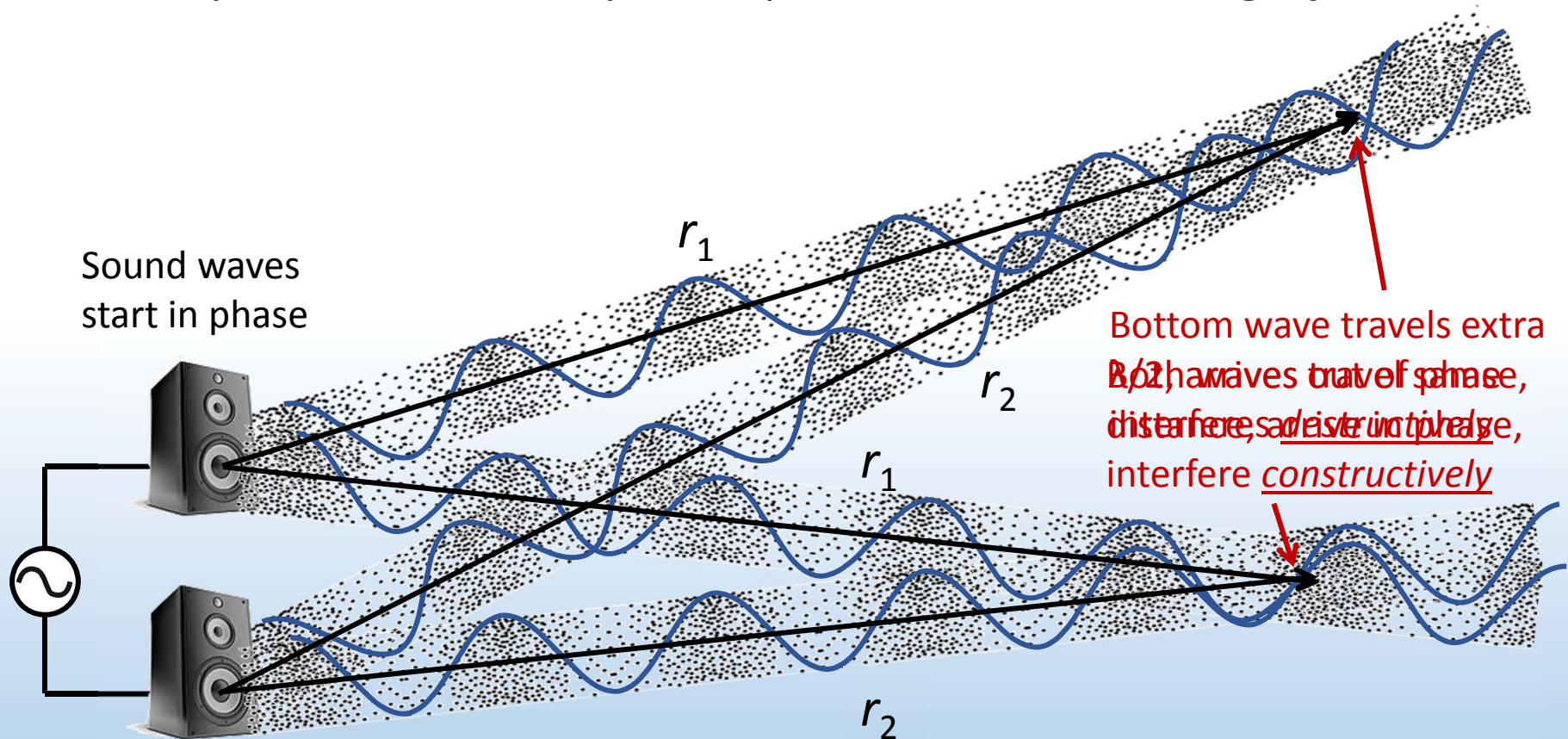
A. Constructive

B. Destructive

C. Neither

Demo: Interference for sound

Pair of speakers driven in phase, produce a tone of single f and λ :



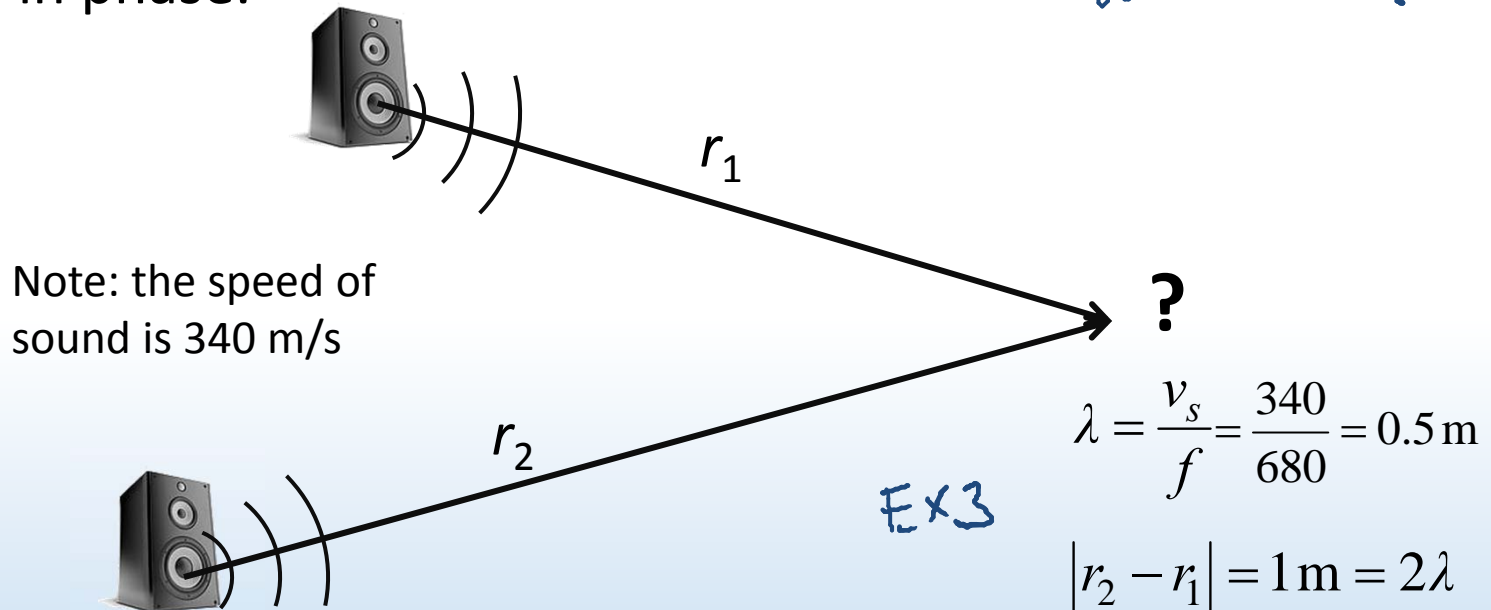
* Key is path difference between two waves $|r_1 - r_2|$ *



ACT: Sound interference

Two speakers are set up in a room and emit a single 680 Hz tone in phase.

What is λ ?



If you stand a distance $r_1 = 4 \text{ m}$ from one speaker and $r_2 = 5 \text{ m}$ from the other, how will the sound waves interfere?

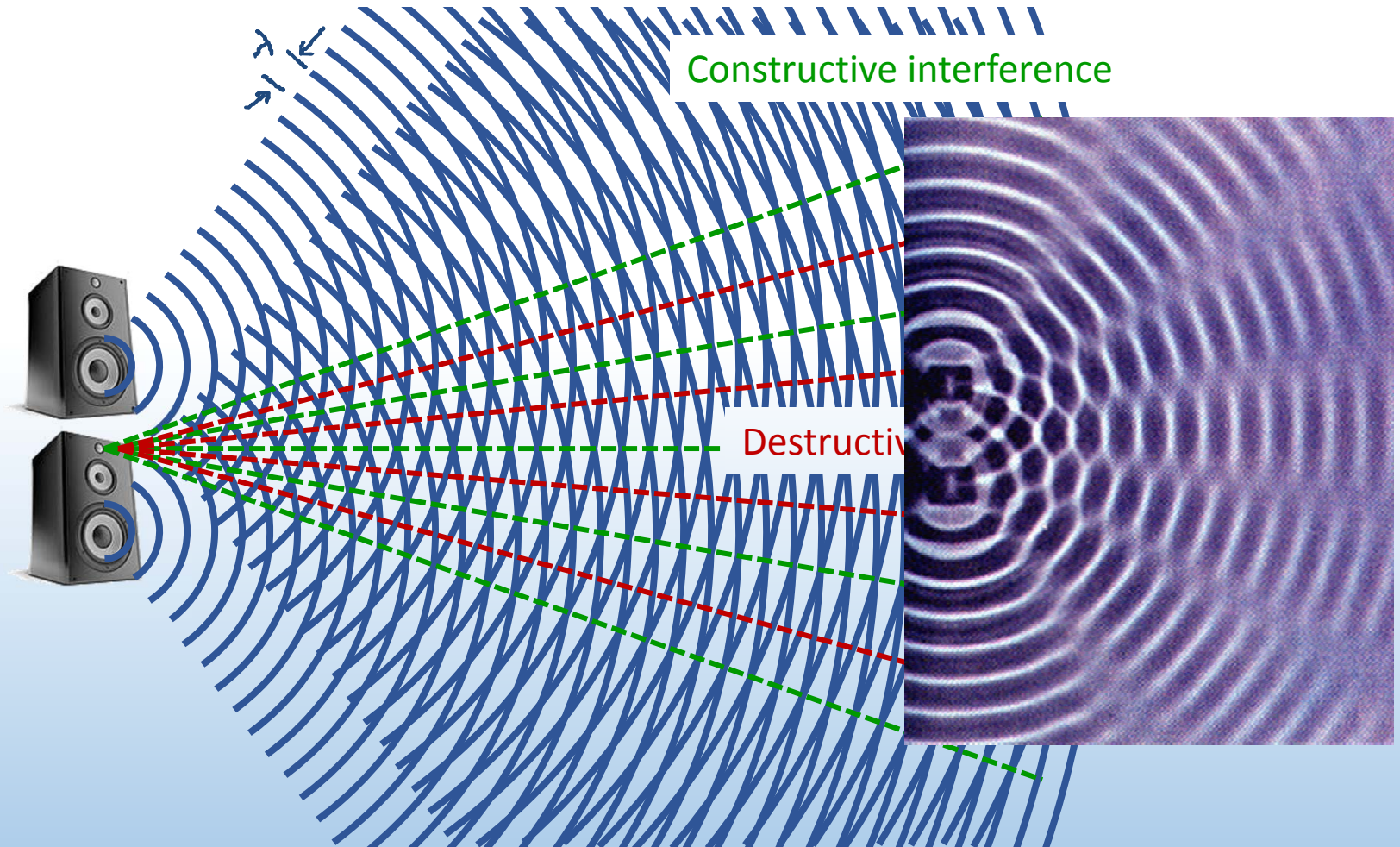
A. Constructive

B. Destructive

C. Neither

Two-wave interference pattern

Interference depends on waves traveling different distances



Interference requirements

Interference is a property of waves. How do we get interference with light?

- Need two (or more) waves
- Must have same wavelength
- Must be coherent (waves must have definite phase relation)
- Use one light source with waves taking different paths:

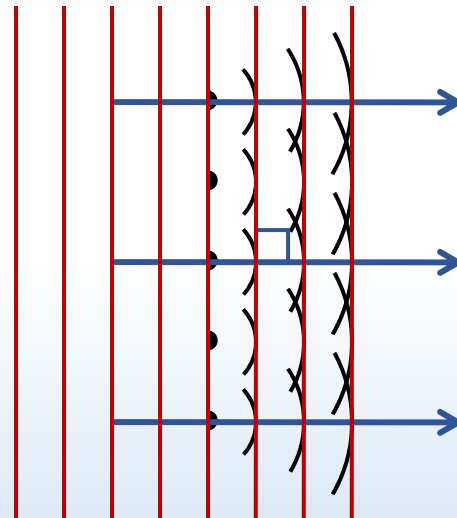
Two slits ~ today

Two different refractive indices

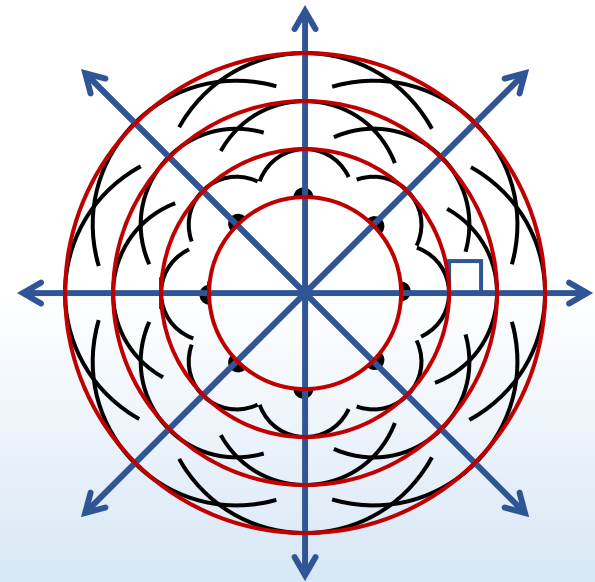
Reflection off of two different surfaces

Recall: Huygens' Principle

Every point on a wavefront acts as a source of tiny spherical “wavelets” that spread outward



Planar wavefronts



Spherical wavefronts

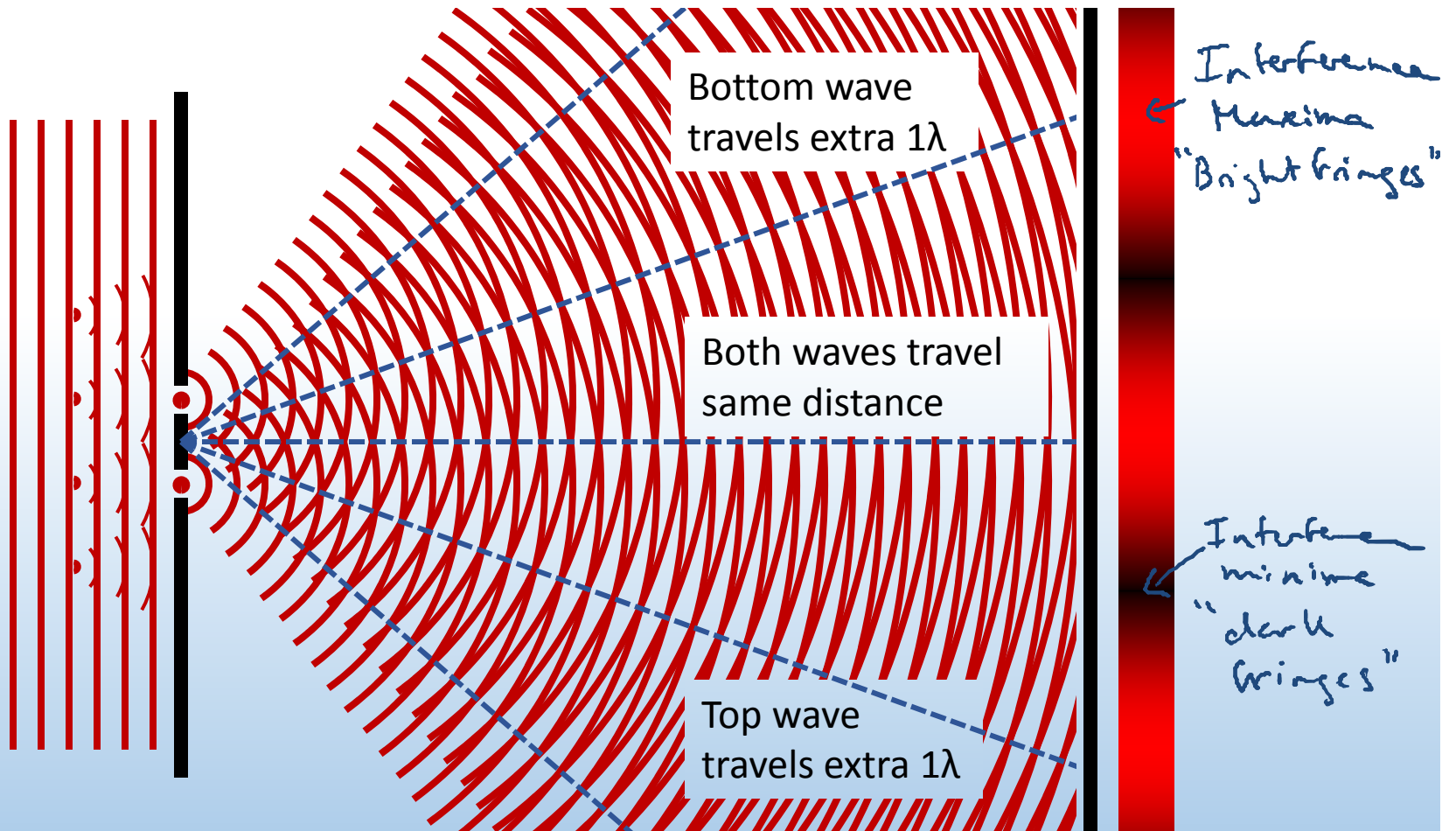
The shape of the wavefront at a later time is tangent to all the wavelets

Young's double slit

single λ

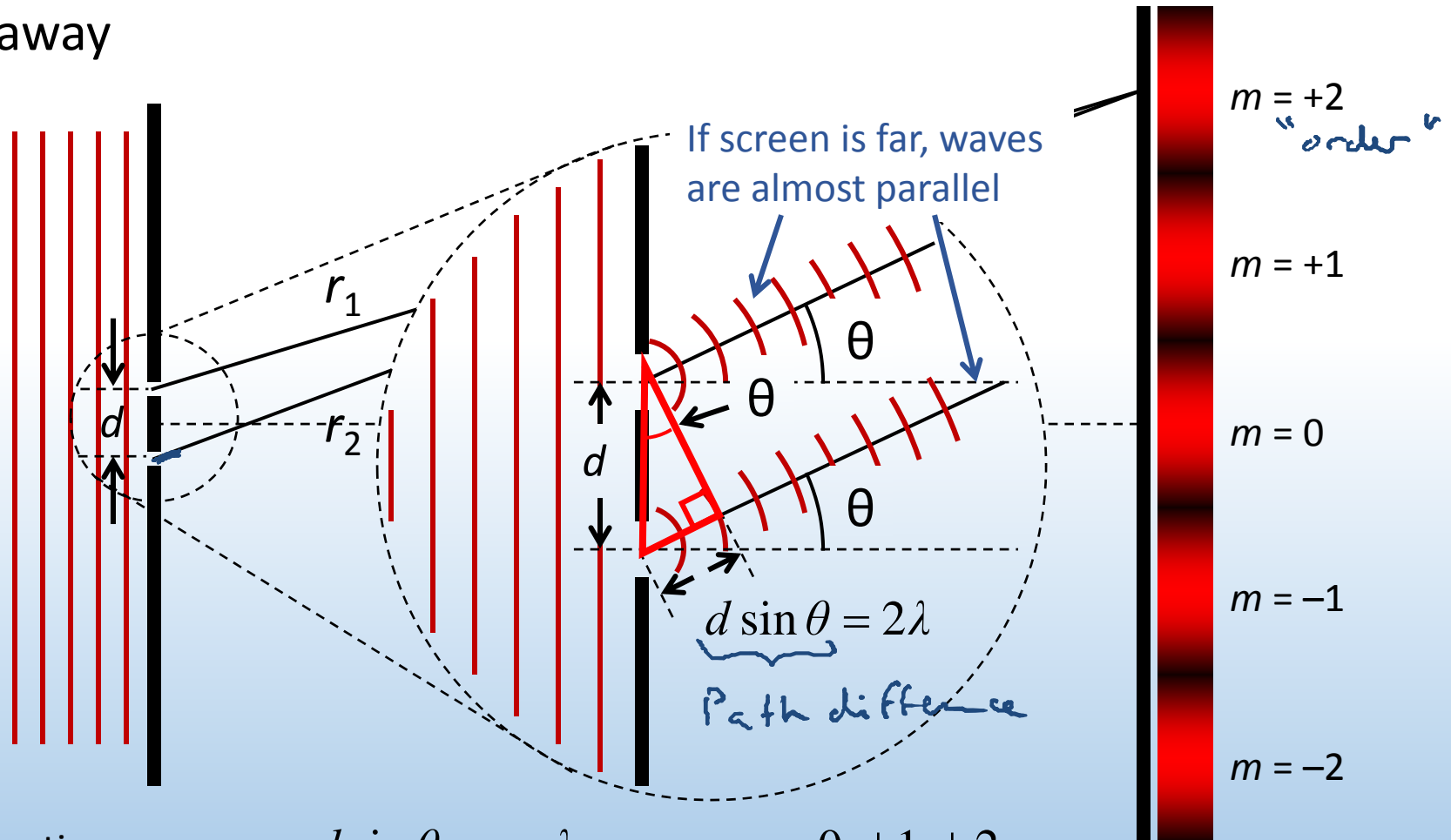
width $< \lambda$

Coherent, monochromatic light passes through two narrow slits



Young's double slit

Consider the interference pattern from a double slit on a screen far away



Constructive: $r_2 - r_1 = d \sin \theta_m = m\lambda$

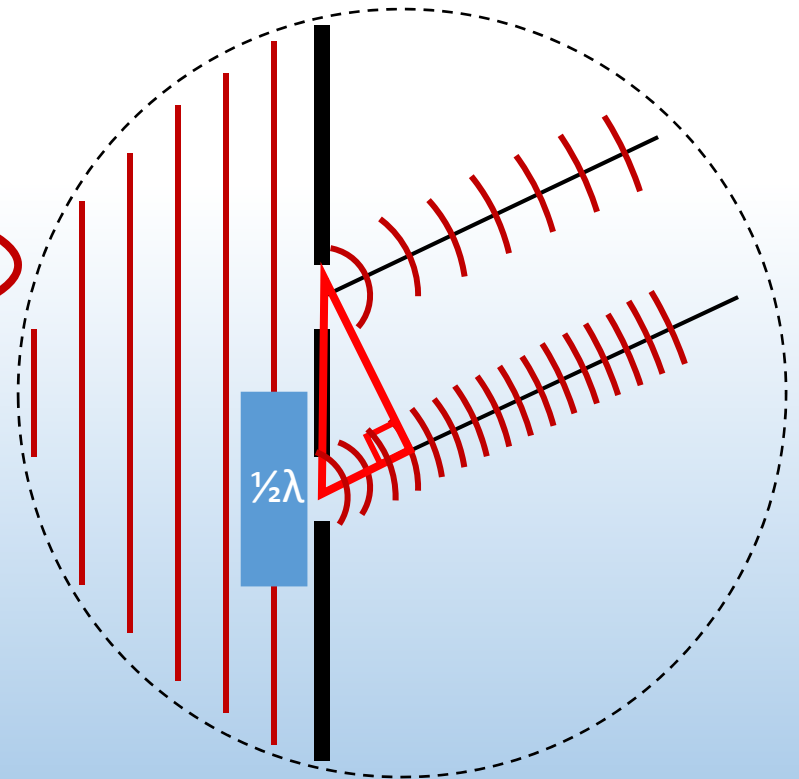
$m = 0, \pm 1, \pm 2 \dots$

Destructive: $d \sin \theta_m = (m + \frac{1}{2})\lambda$

Checkpoint 1.1

Now, the light coming to the lower slit has its phase shifted by $\frac{1}{2}\lambda$ relative to the light coming to the top slit. Compared to the usual Young's experiment, what happens?

- 45% A. The pattern is the same
- 55% B. Maxima & minima become minima & maxima

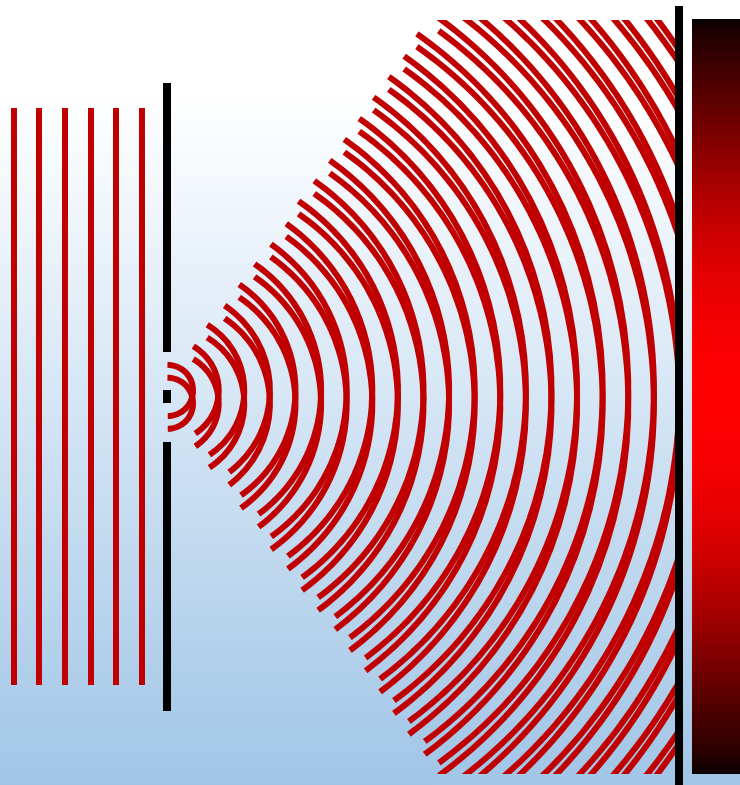


Checkpoint 1.2

In the Young's double slit experiment, is it possible to see interference maxima when the distance d between slits is less than the wavelength of light λ ?

A. Yes 51%

B. No 49%



$$\sin \theta_m = m \frac{\lambda}{d} \quad \frac{\lambda}{d} > 1$$

Get central maximum $\theta_0 = 0$ for $m = 0$

For $m = 1, 2 \dots$ there is no solution:

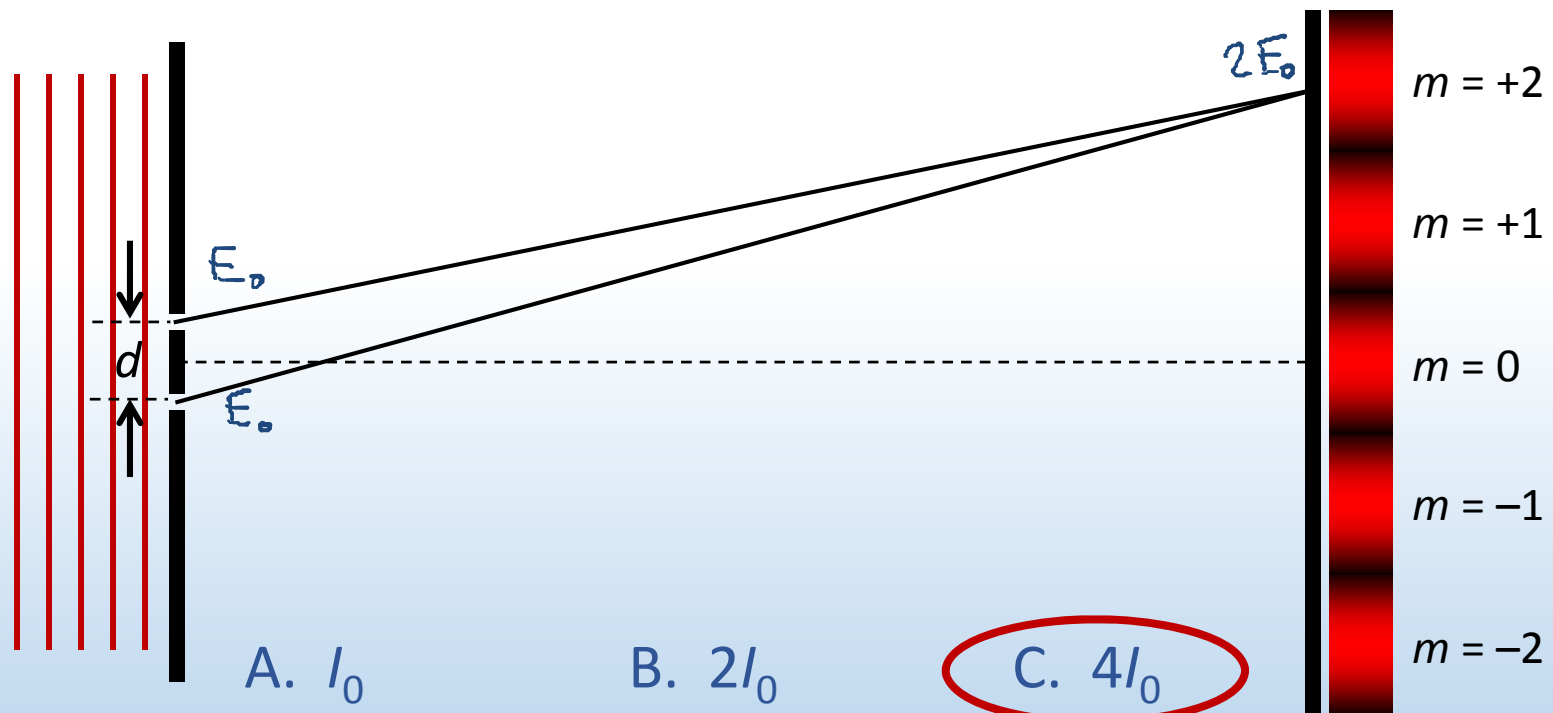
$$\sin \theta_m > 1$$

Impossible!



ACT: Interference & intensity

The two waves are interfering constructively at the point shown. If the intensity of each is I_0 , what is the total intensity on screen?



Each slit contributes E field amplitude E_0 at screen. $E_{tot} = 2E_0$.

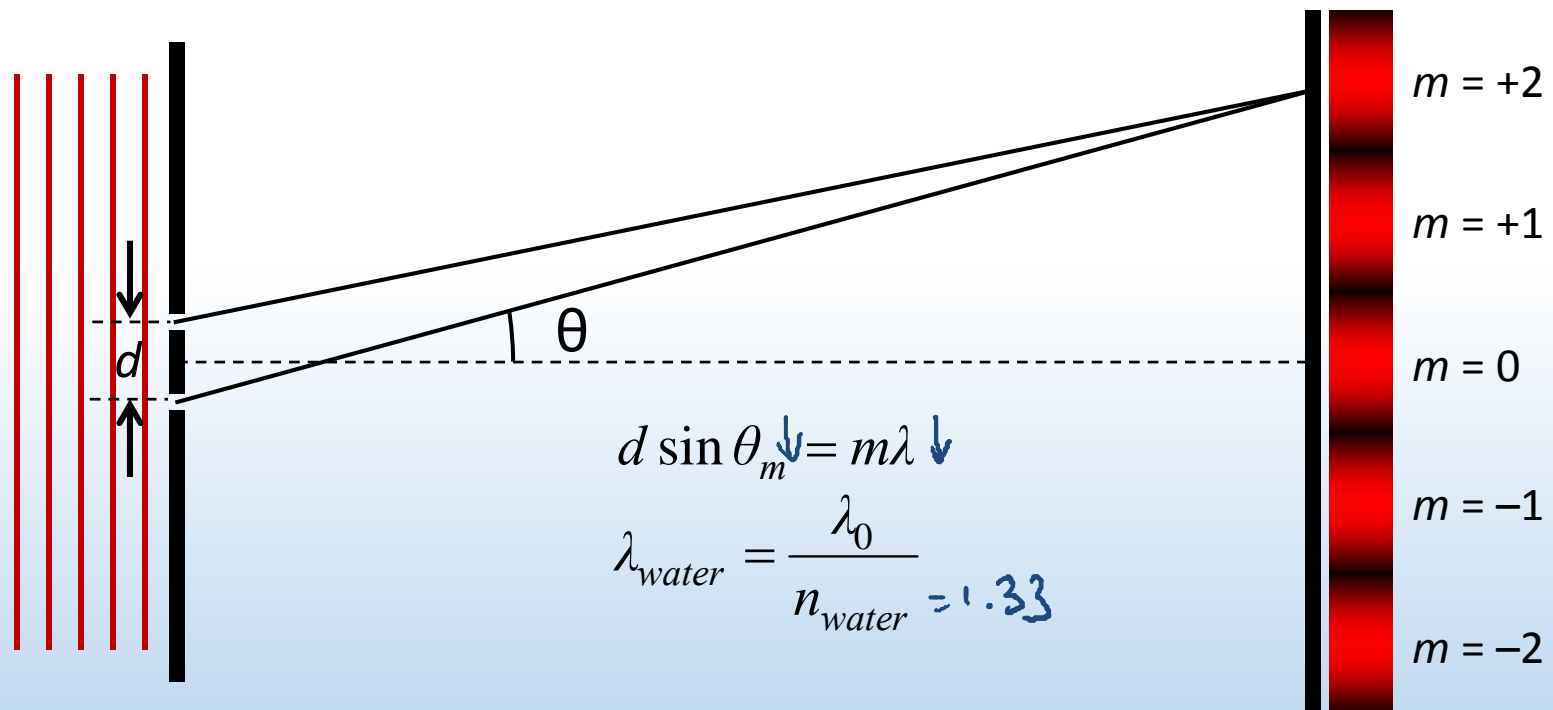
Recall that $I \propto E^2$, so $I_{tot} = (2E_0)^2 = 4E_0^2 = 4I_0$

EX3



ACT: CheckPoint 2.1

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



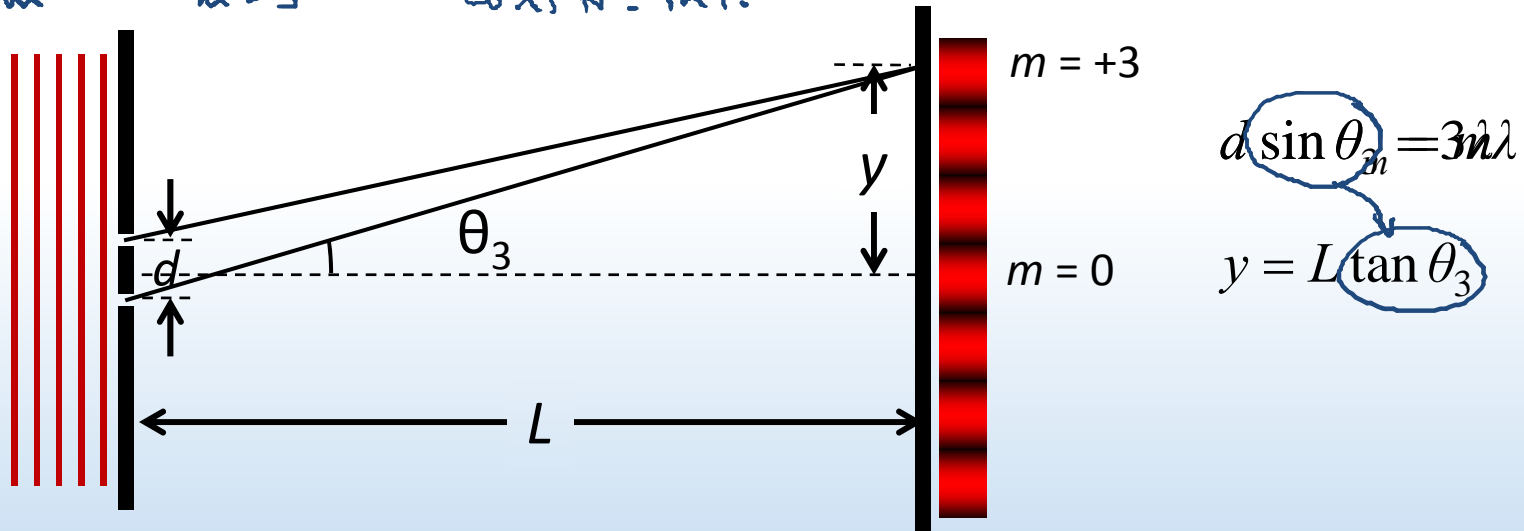
- 25% A. Increases
57% B. Remains the same
18% C. Decreases

In water, λ decreases, so θ and separation decrease

Calculation: Young's double slit HW

Light of wavelength $\lambda = 650 \text{ nm}$ passes through two narrow slits separated by $d = 0.25 \text{ mm}$. Determine the spacing y between the 0^{th} and 3^{rd} order bright fringe on a screen $L = 2\text{m}$ away.

$m=0$ $m=3$ const. int.



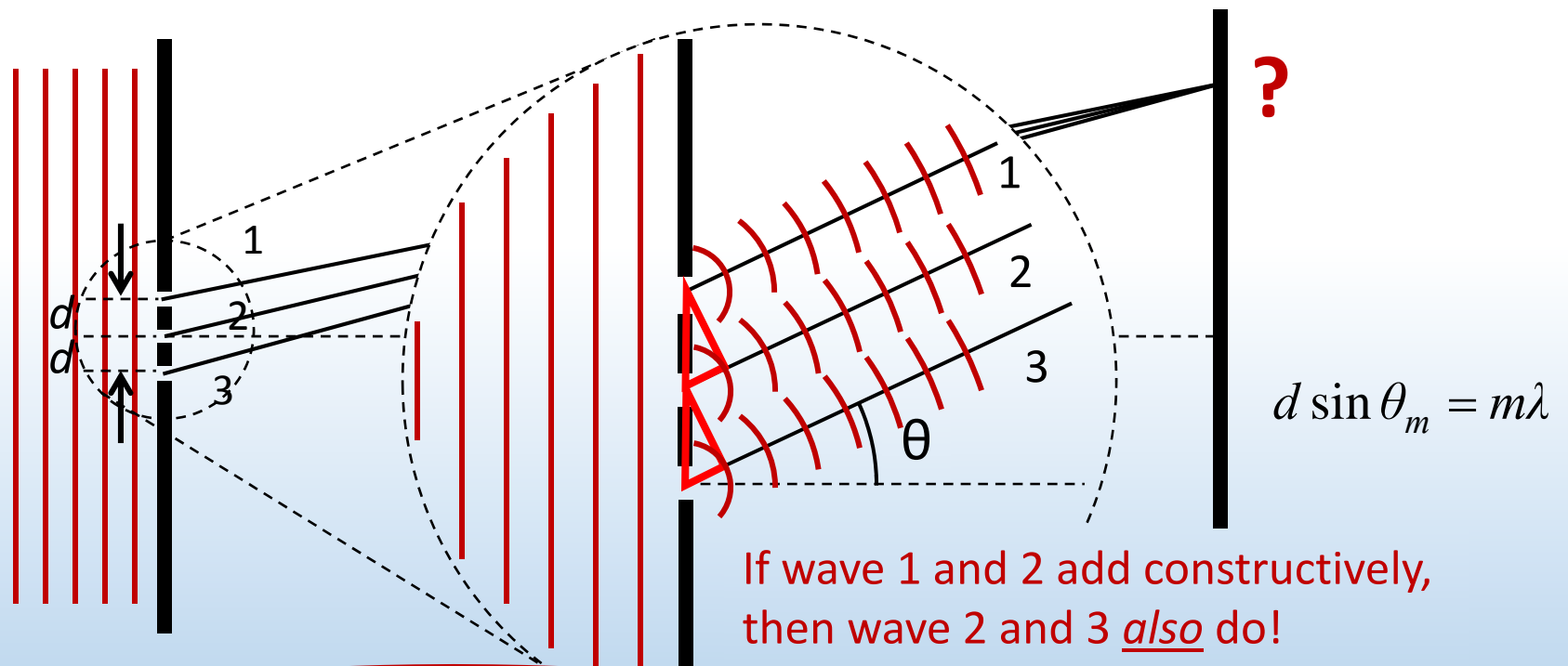
Since $L \gg d$, angles θ_m are small: $\theta \approx \sin \theta \approx \tan \theta$ $\theta (\text{rad})$

$$y \approx m \frac{\lambda L}{d} = 3 \frac{650 \times 10^{-9} \cdot 2}{0.25 \times 10^{-3}} = 1.56 \text{ cm}$$



ACT: CheckPoint 3.1

Light is incident on three evenly separated slits. If wave 1 and 2 interfere constructively at angle θ , what appears on the screen?



- 52% A. Interference maximum
26% B. Interference minimum
21% C. Somewhere in between

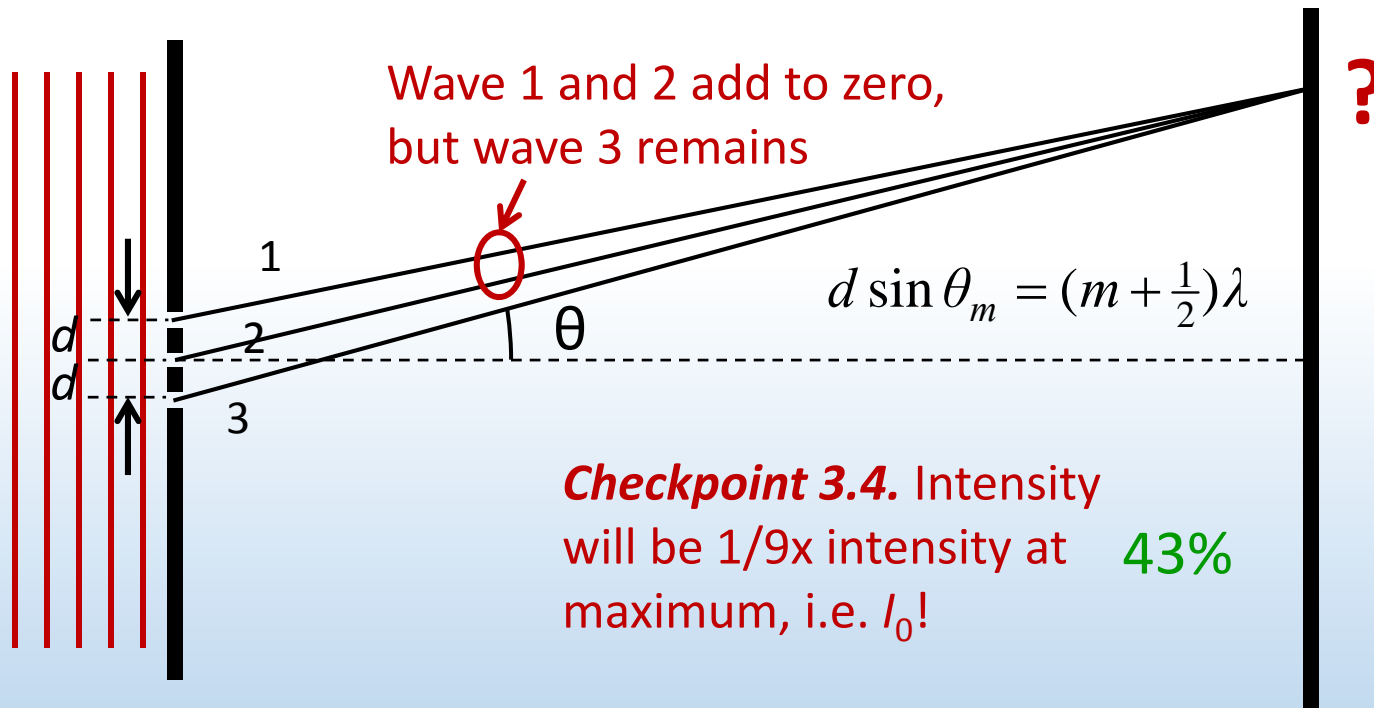
Checkpoint 3.2. $E_{tot} = 3E_0$.
 $I_{tot} = (3E_0)^2 = 9E_0^2 = 9I_0$

25%



ACT: CheckPoint 3.3

Light is incident on three evenly separated slits. If wave 1 and 2 interfere destructively at angle θ , what appears on the screen?

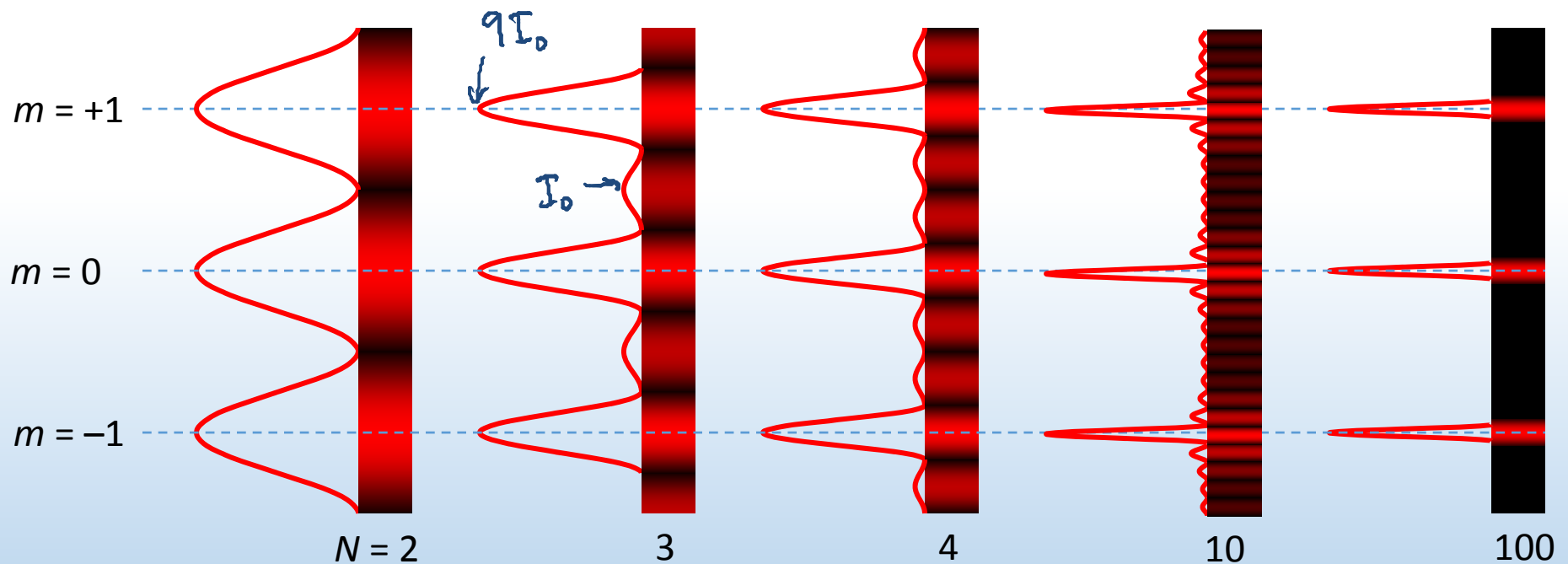


Checkpoint 3.4. Intensity
will be 1/9x intensity at maximum, i.e. I_0 ! **43%**

- 25% A. Interference maximum
- 49% B. Interference minimum
- 26% C. Somewhere in between

Interference pattern vs. slit number

As number of slits N increases (d remaining the same) angles for interference maxima are unaffected: $d \sin \theta_m = m\lambda$

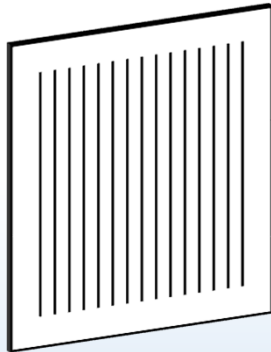


As N increases, more minima appear and bright fringes narrow

DEMO

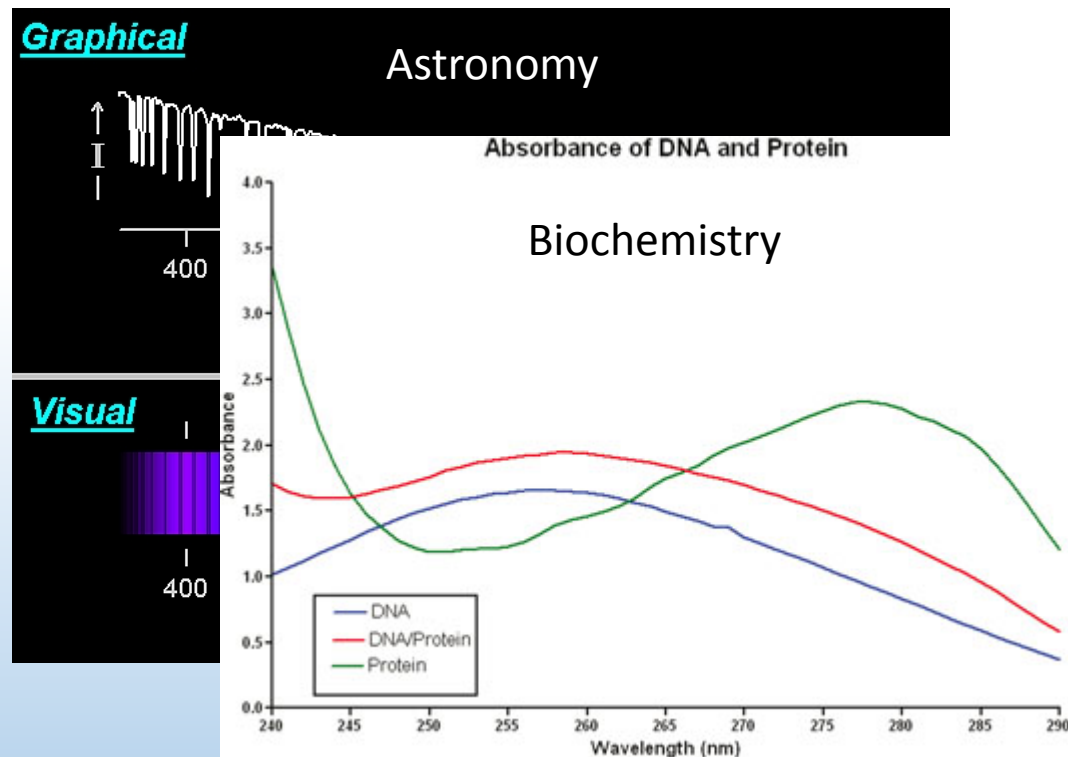
Diffraction grating

A diffraction grating has a large number N (>100) of evenly spaced slits



Ex: $1/d = 500$ lines/mm

$$d \sin \theta_m = m\lambda$$



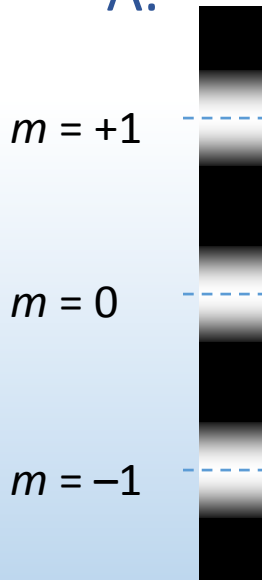
Used in spectroscopy – analysis of absorption/emission spectra



ACT: Diffraction grating

White light passes through a diffraction grating and is projected on a screen. Which diagram most accurately represents the pattern on the screen?

A.



B.



C.



$$d \sin \theta_m = m\lambda$$

Large/small λ = large/small θ

Blue light (400 nm) = small θ

Red light (700 nm) = large θ



Diffraction gratings separate wavelengths of light like a prism!

DEMO

Summary of today's lecture

- Constructive vs. destructive interference

Constructive if waves are in phase (phase shift = $0, \lambda, 2\lambda \dots$)

Destructive if waves are out of phase (phase shift = $\frac{1}{2}\lambda, 1\frac{1}{2}\lambda \dots$)

- Two slit interference **Key is path length difference**

Interference maxima: $d \sin \theta_m = m\lambda$

Interference minima: $d \sin \theta_m = (m + \frac{1}{2})\lambda$

- Multiple slit interference

Interference maxima: $d \sin \theta_m = m\lambda$