Your questions/comments

IMPORTANT ANNOUNCEMENTS:
EXAM 3 next weeks on Lect. 13 (Lenz' law) – Lect. 21 (Optical instruments)
Review next Tuesday 6-8pm, in 141 Loomis

"Take it easy on us next week okay? There is a ton of material for this upcoming exam. Also can you not make the review session on the night of the Calculus III exam?"

"Unfortunately it's that time of the semester again where MCB354 haunts us all. Thus, leaving us no choice but to drop all other aspects of our life which includes, unfortunately, Phys102"

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

"I have no idea what's going on with the intensities of the slit interference."

"Please explain the slits. I am a bit confused."

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

- 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

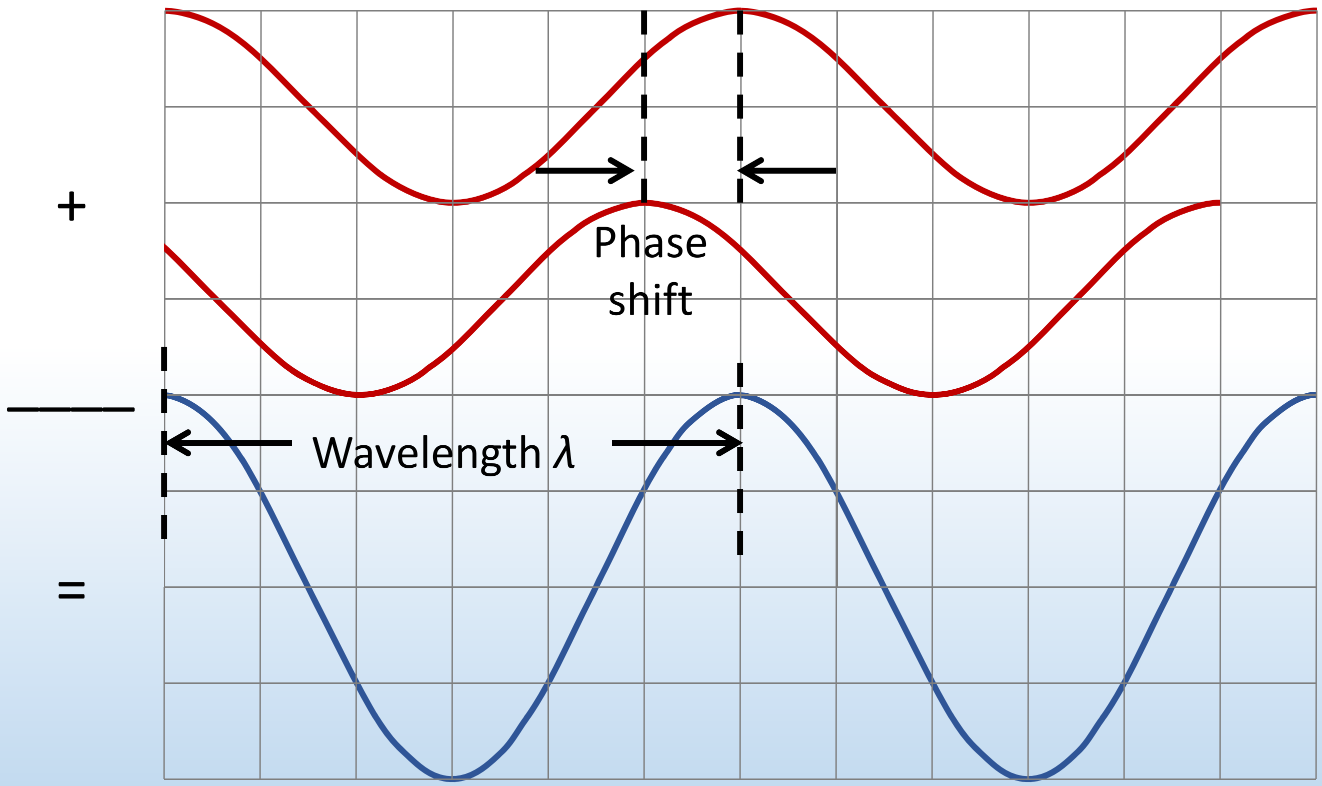
Interference

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

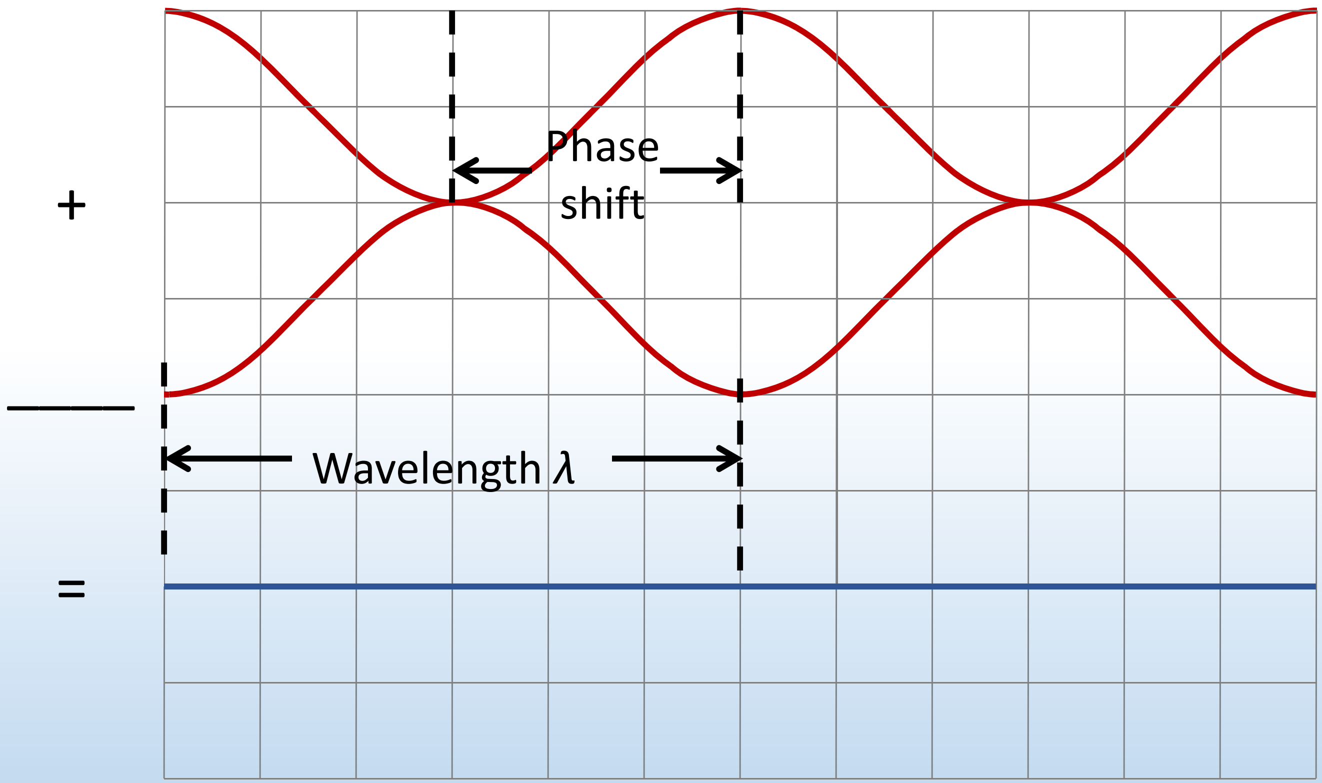


Waves remain in phase with shift of 1λ, 2λ ... *m*λ

Constructive interference – waves combine to give larger wave

Superposition of waves

Two waves are *out of phase* when phase shift is λ/2



With phase shift of ½ λ, 1½ λ, 2½ λ ... (*m* + ½)λ, 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?

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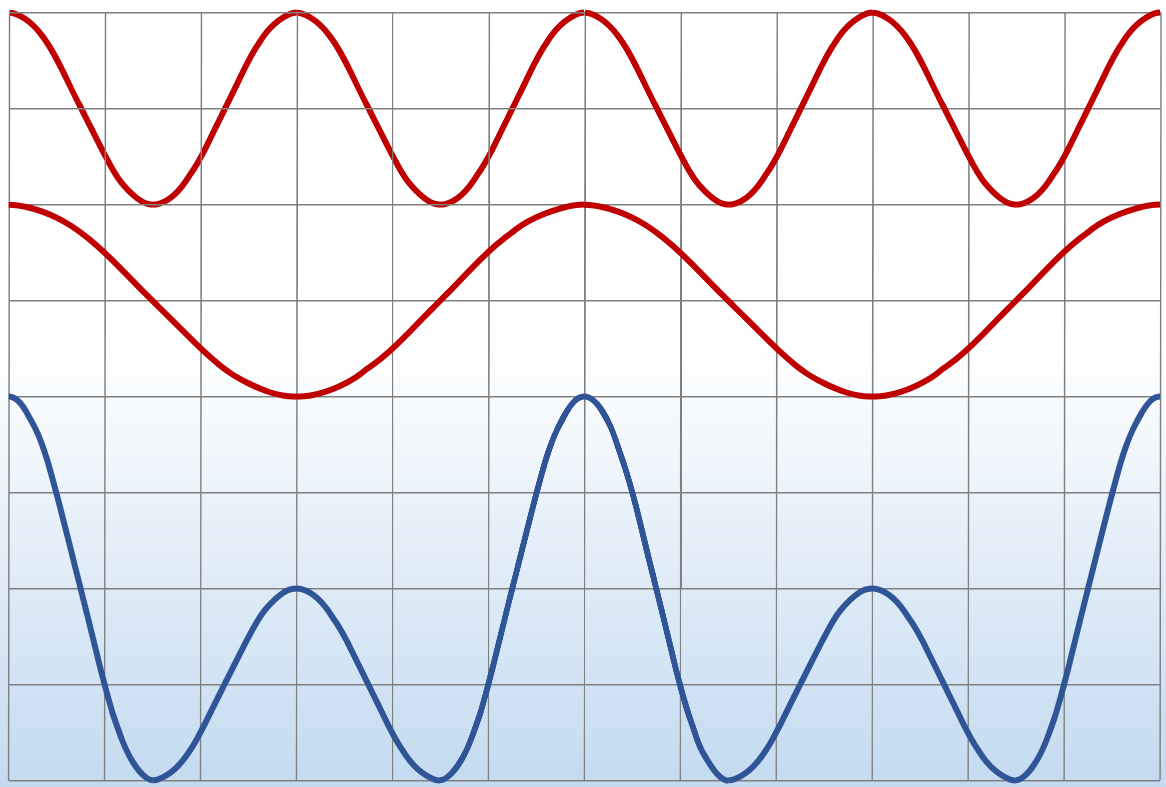


Different *f* and λ!

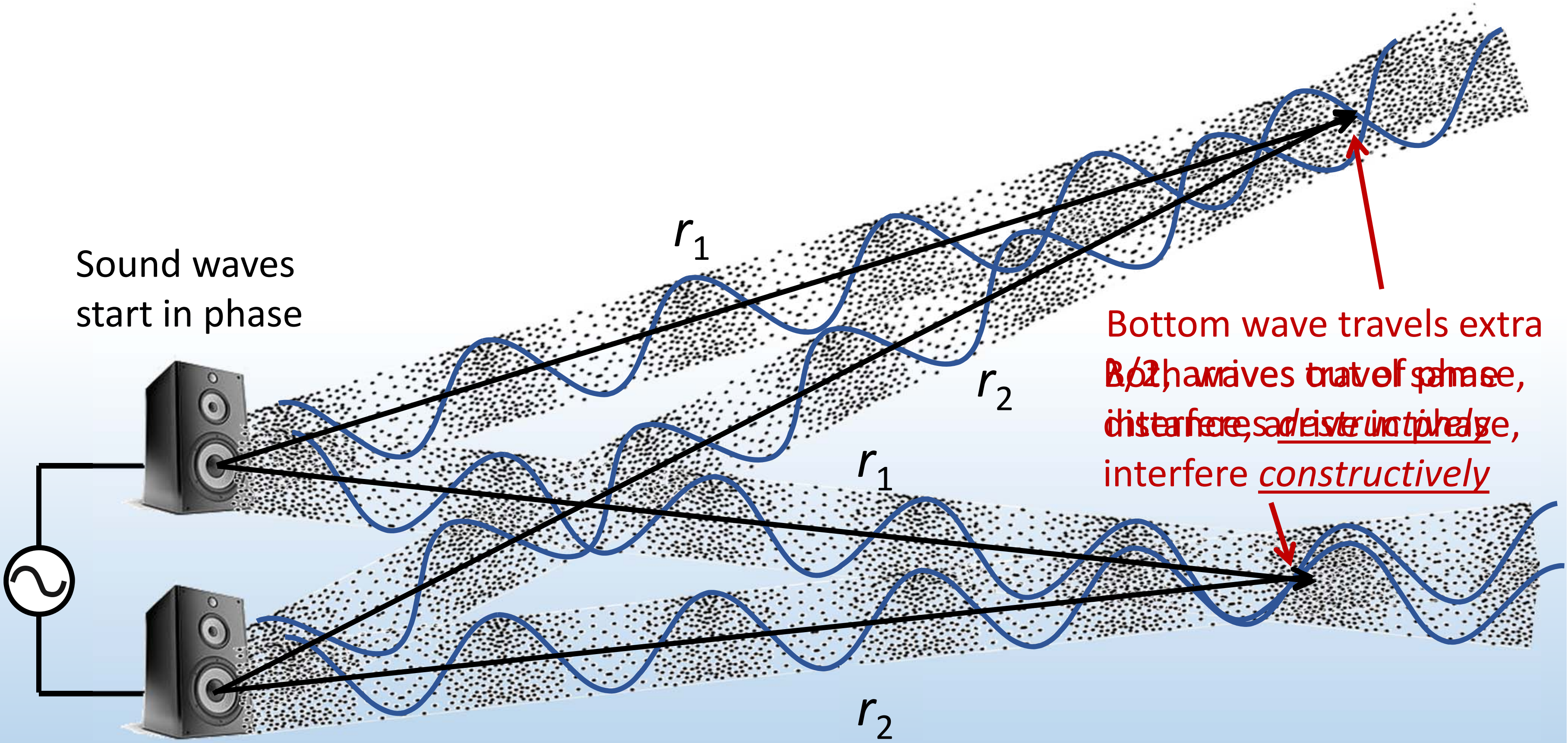
A. Constructive

B. Destructive

C. Neither

Demo: Interference for sound

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

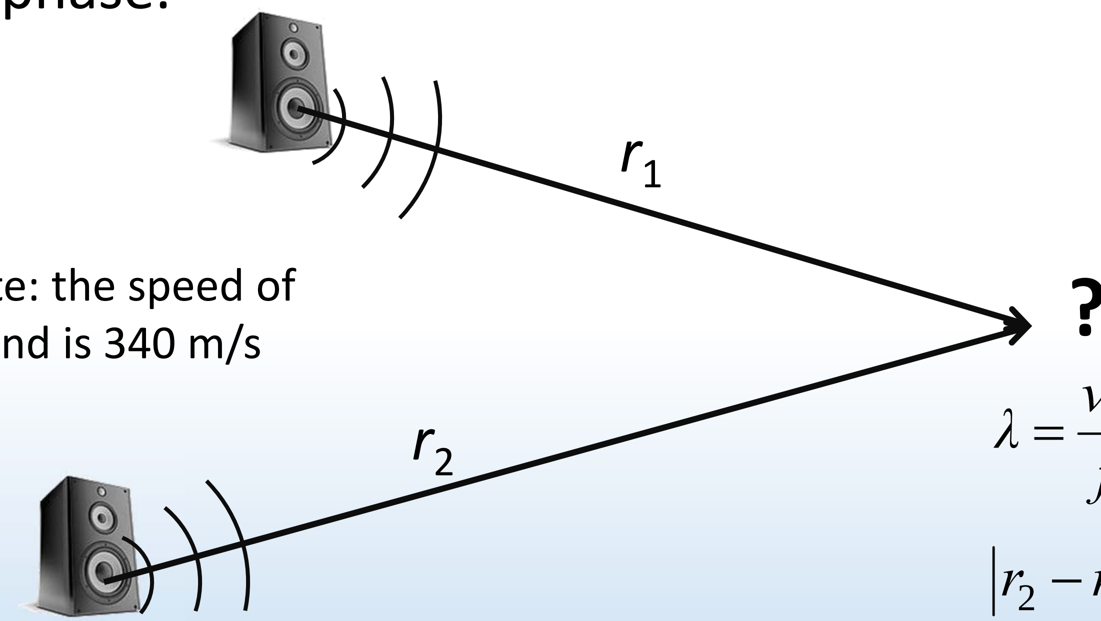


Key is path difference between two waves $|r_1 - r_2|$

ACT: Sound interference

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

Note: the speed of sound is 340 m/s



$$\lambda = \frac{v_s}{f} = \frac{340}{680} = 0.5\,\mathrm{m}$$

$$|r_2 - r_1| = 1\mathrm{m} = 2\lambda$$

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

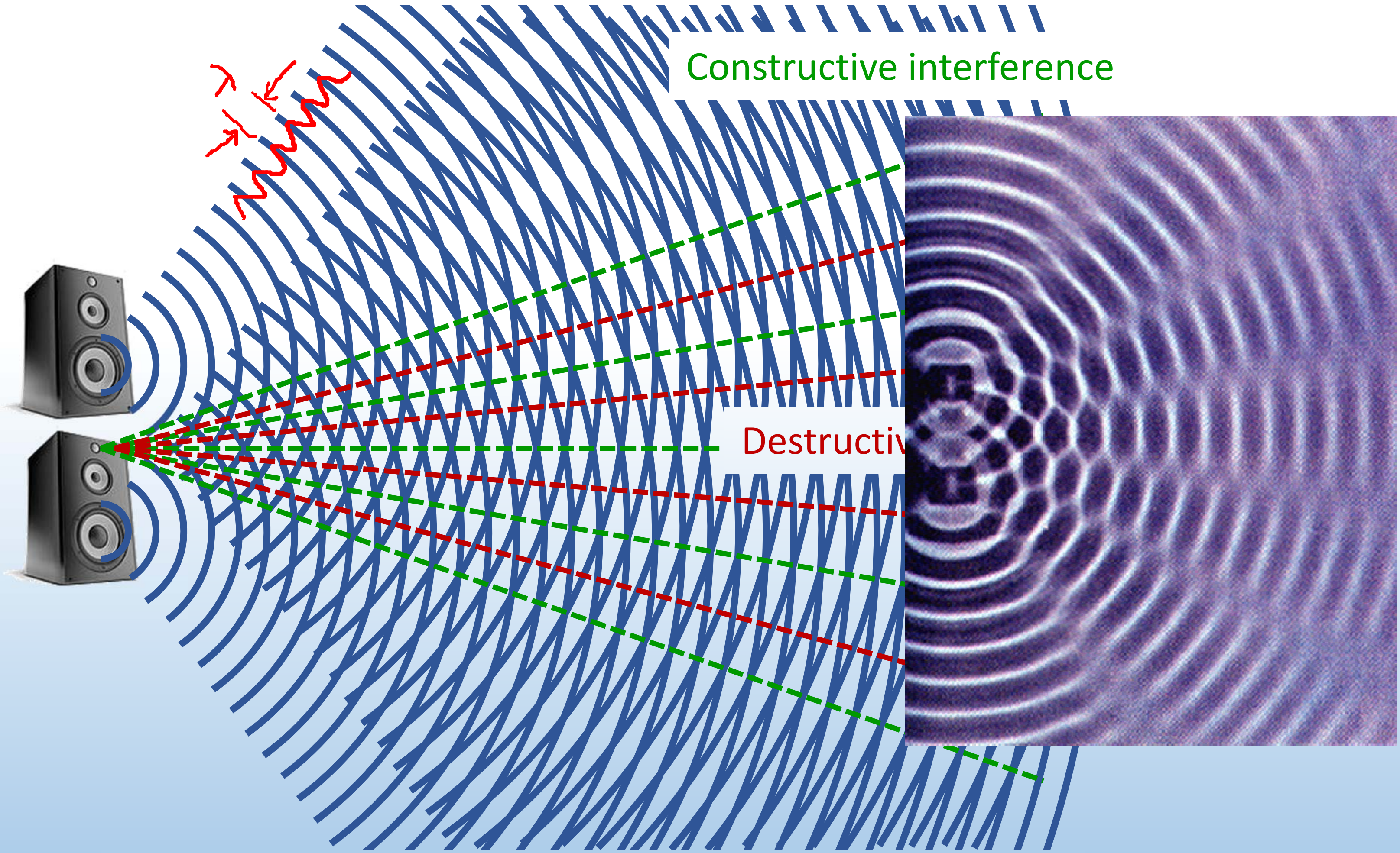
A. Constructive

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

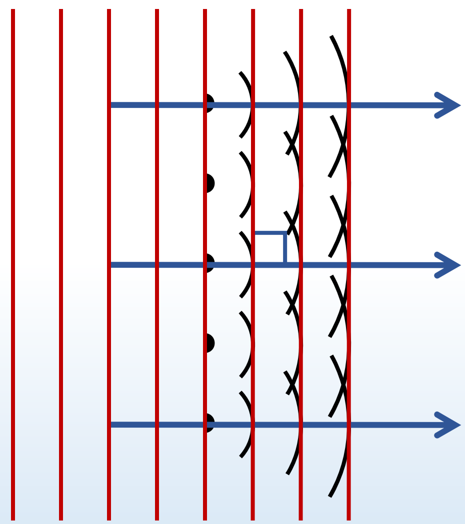
  Two different refractive indices

  Reflection off of two different surfaces

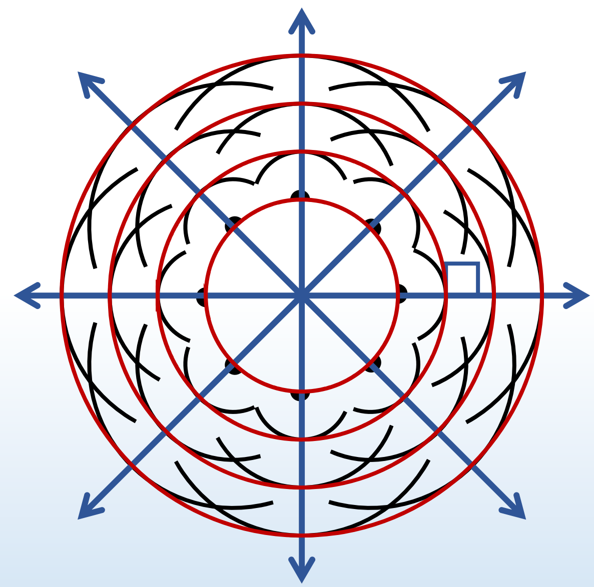
Recall: Huygens' Principle

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

"wavelet"



Planar wavefronts

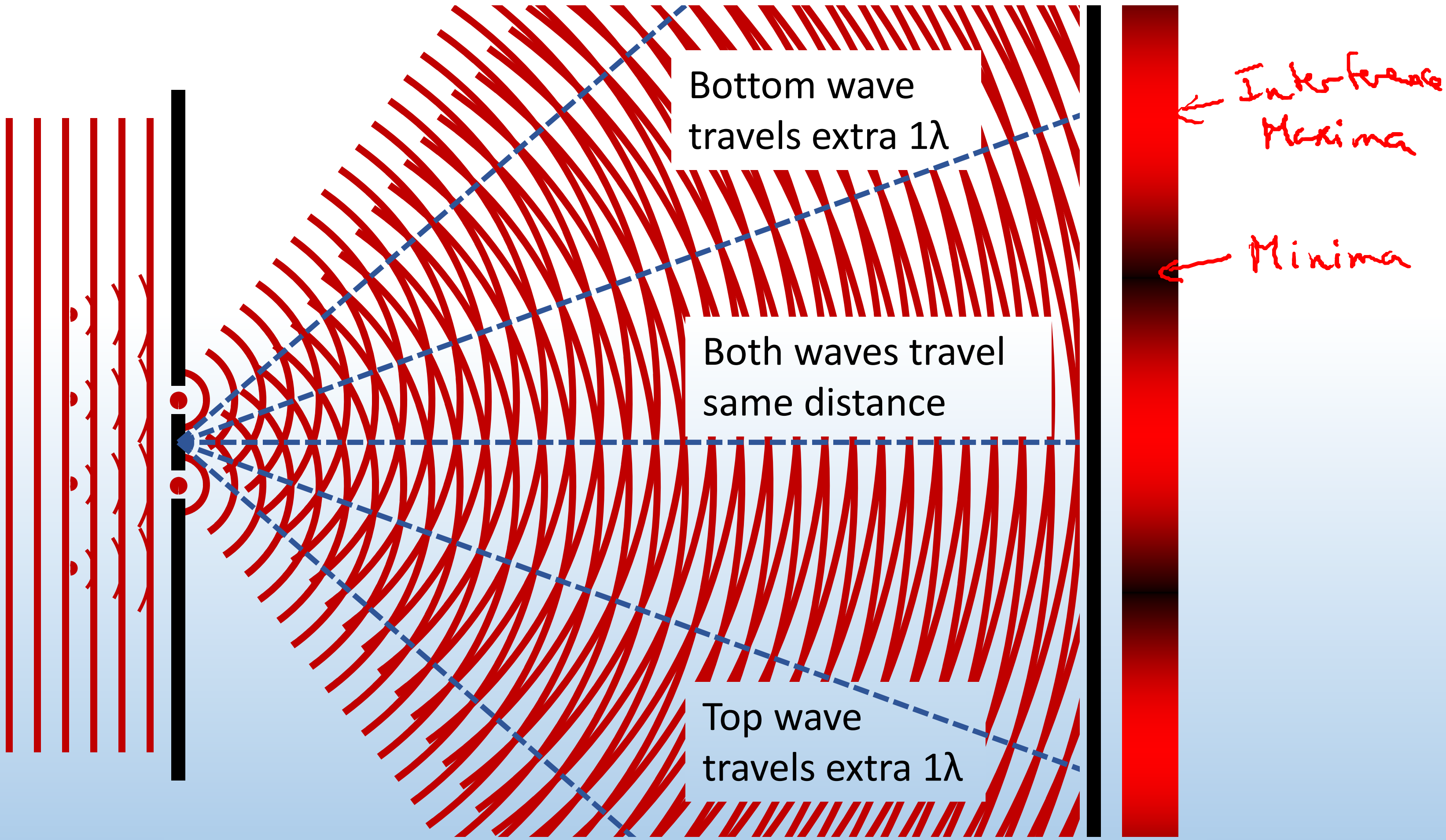


Spherical wavefronts

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

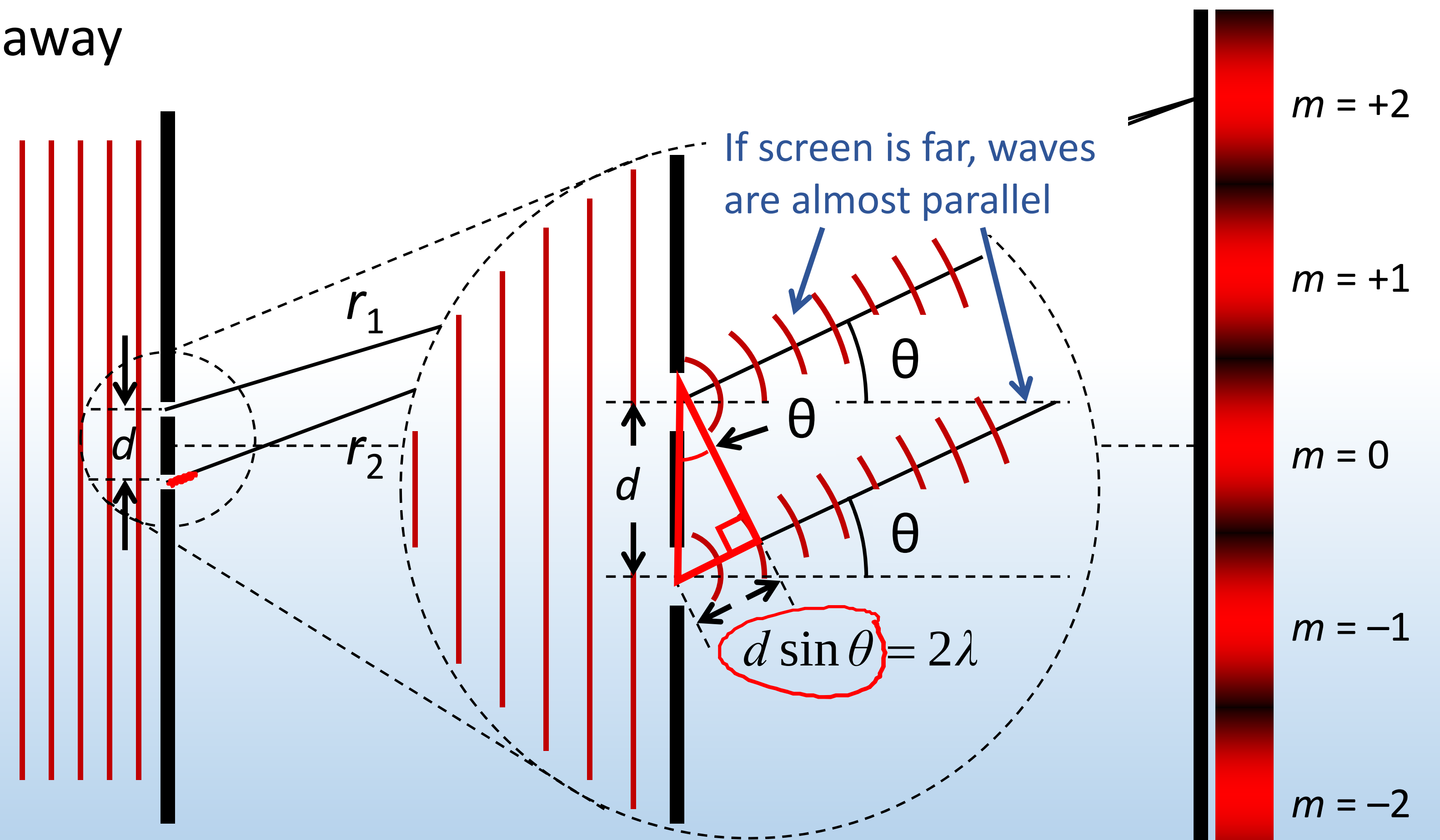
Young's double slit

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: $r_2 - r_1 = d\sin\theta_m = m\lambda \qquad m = 0, \pm 1, \pm 2 \ldots$

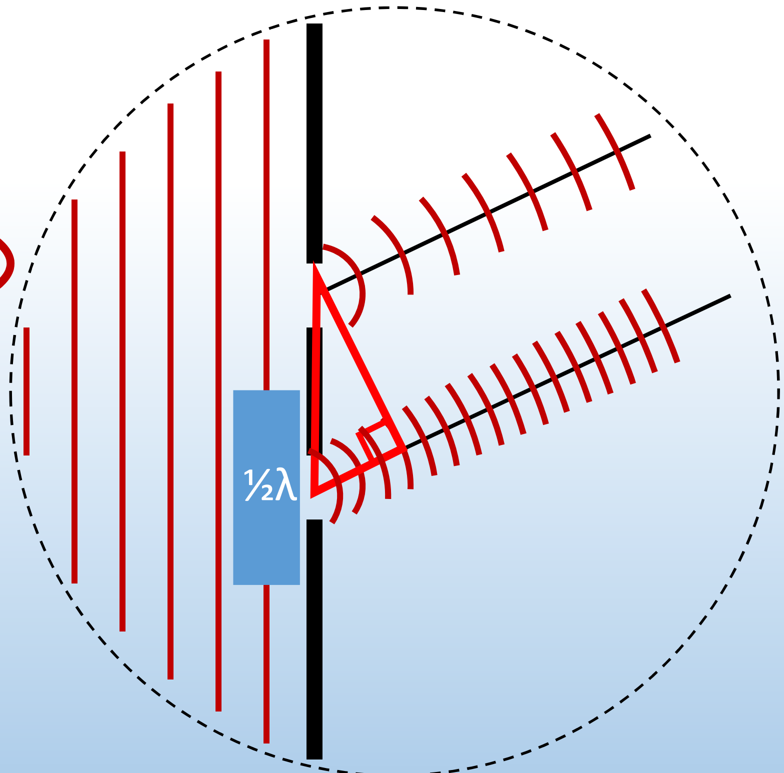
Destructive: $d\sin\theta_m = (m + \frac{1}{2})\lambda$

CheckPoint 1.1

Now, the light coming to the lower slit has its phase shifted by ½λ relative to the light coming to the top slit. Compared to the usual Young's experiment, what happens?

47% A. The pattern is the same

53% B. Maxima & minima become minima & maxima

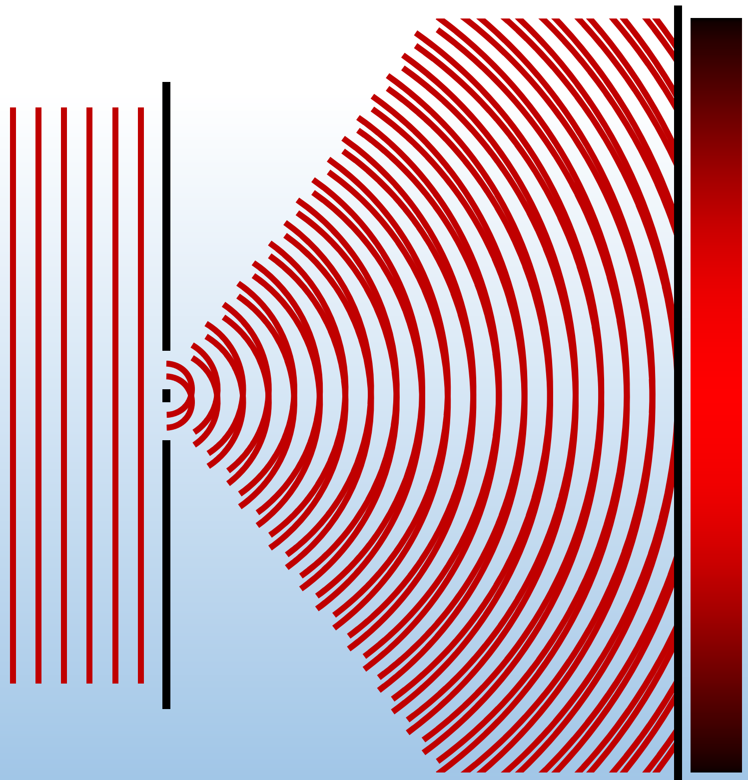


Checkpoint 1.2

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 45%

B. No 55%



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

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

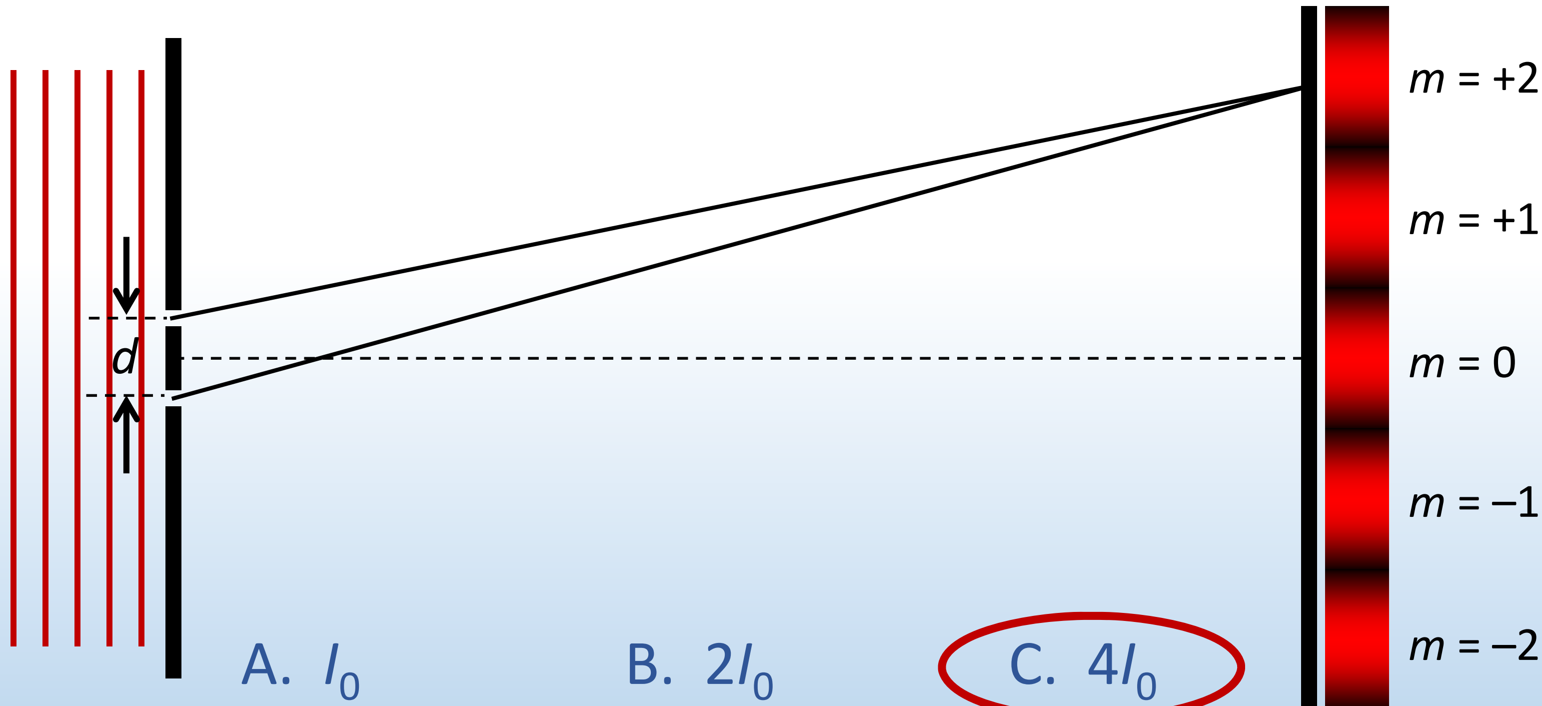
For $m = 1, 2$ ... there is no solution:

$$\sin\theta_m > 1$$

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?



A. I_0

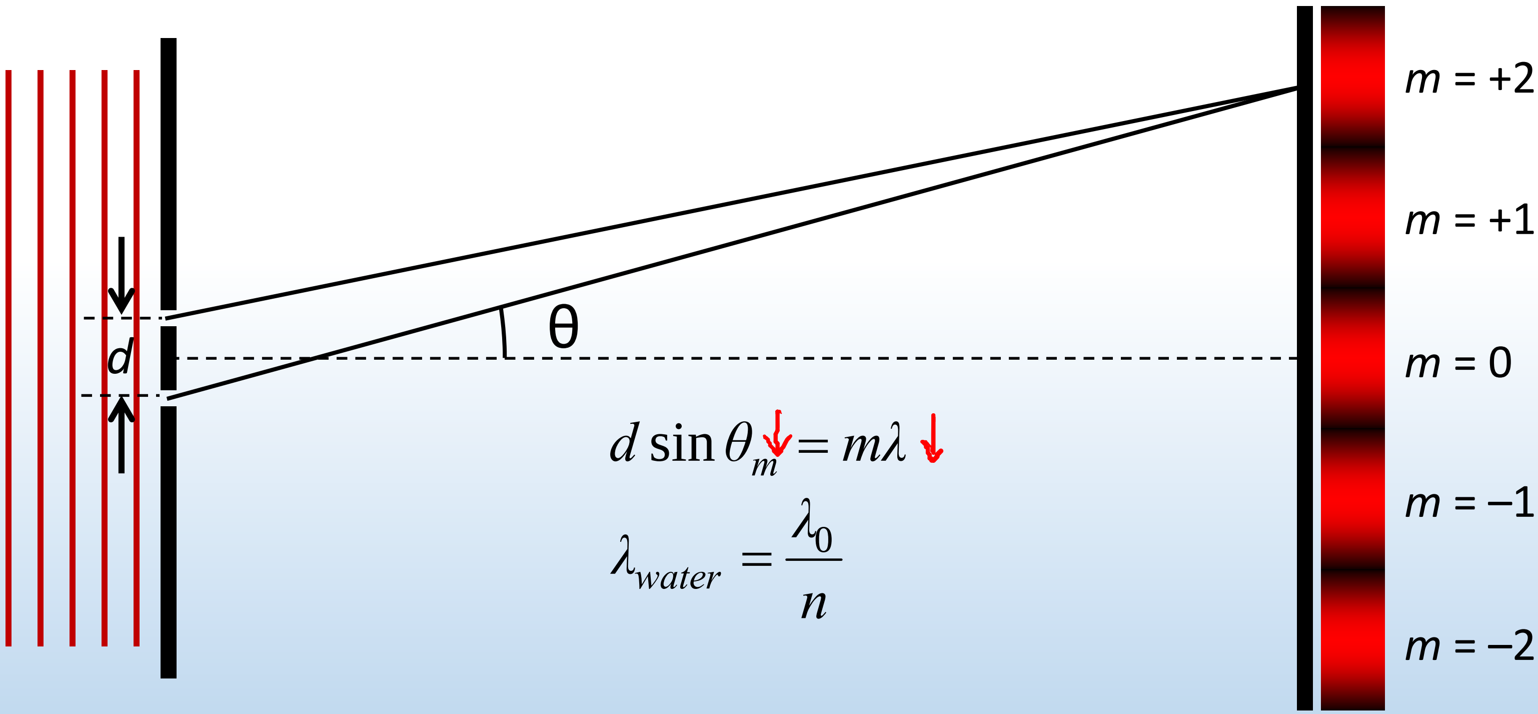
B. $2I_0$

C. $4I_0$

Each slit contributes E field amplitude E_0 at screen. $E_{tot} = 2E_0$.
Recall that $I \propto E^2$, so $I_{tot} = (2E_0)^2 = 4E_0^2 = 4I_0$

ACT: CheckPoint 2.1

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



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

$$\lambda_{water} = \frac{\lambda_0}{n}$$

26% A. Increases

52% B. Remains the same

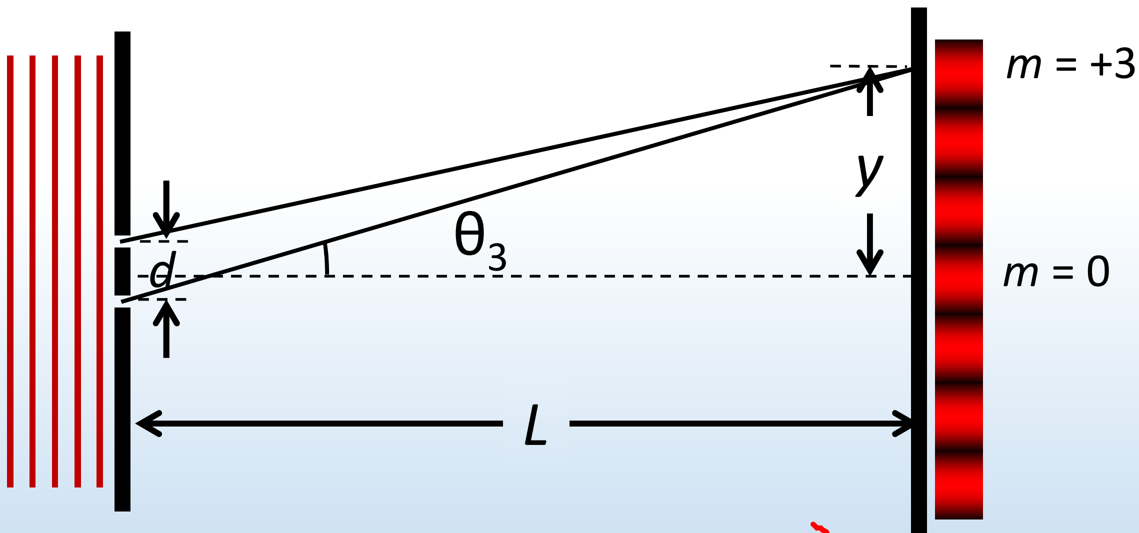
22% C. Decreases

In water, λ decreases, so θ and separation decrease

Calculation: Young's double slit

HW

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



$$d\sin\theta_3 = 3\lambda$$

$$y = L\tan\theta_3$$

$$= L\theta_3 = \frac{3\lambda L}{d}$$

(rad)

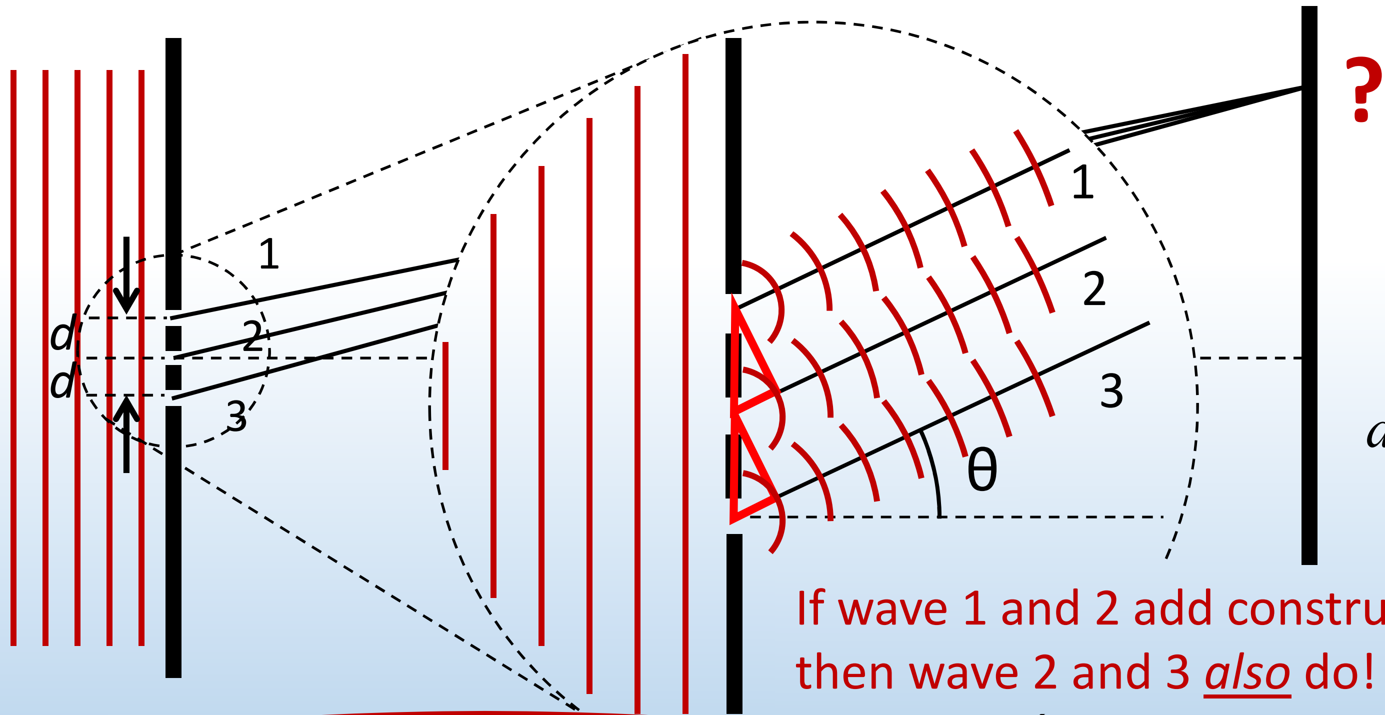
Since *L* >> *d*, angles θ_m are small: $\theta \approx \sin\theta \approx \tan\theta$

θ ≤ 0.3 rad

$$y \approx \underset{=3}{m}\frac{\lambda L}{d} \qquad = 3\frac{650\times10^{-9}\cdot 2}{0.25\times10^{-3}} = 1.56\,\text{cm}$$

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?



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

If wave 1 and 2 add constructively, then wave 2 and 3 *also* do!

48% A. Interference maximum

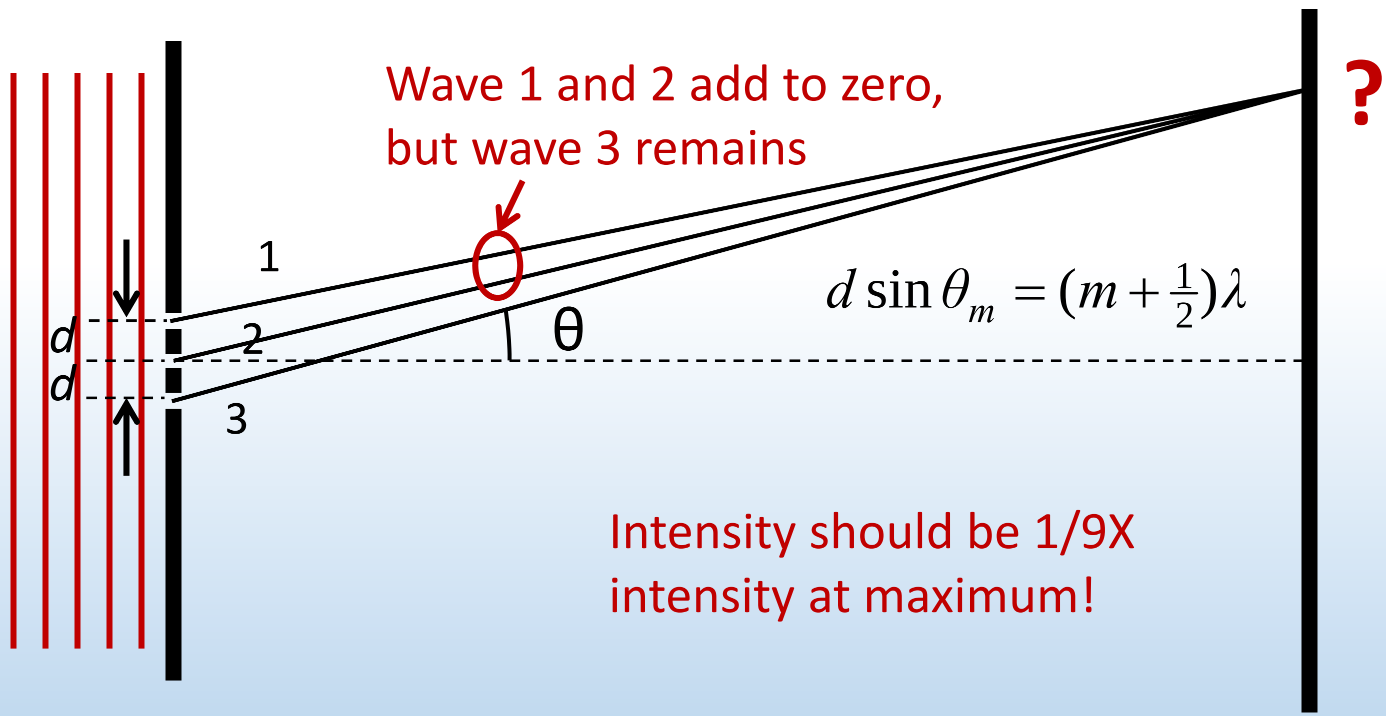
30% B. Interference minimum

22% C. Somewhere in between

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

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?



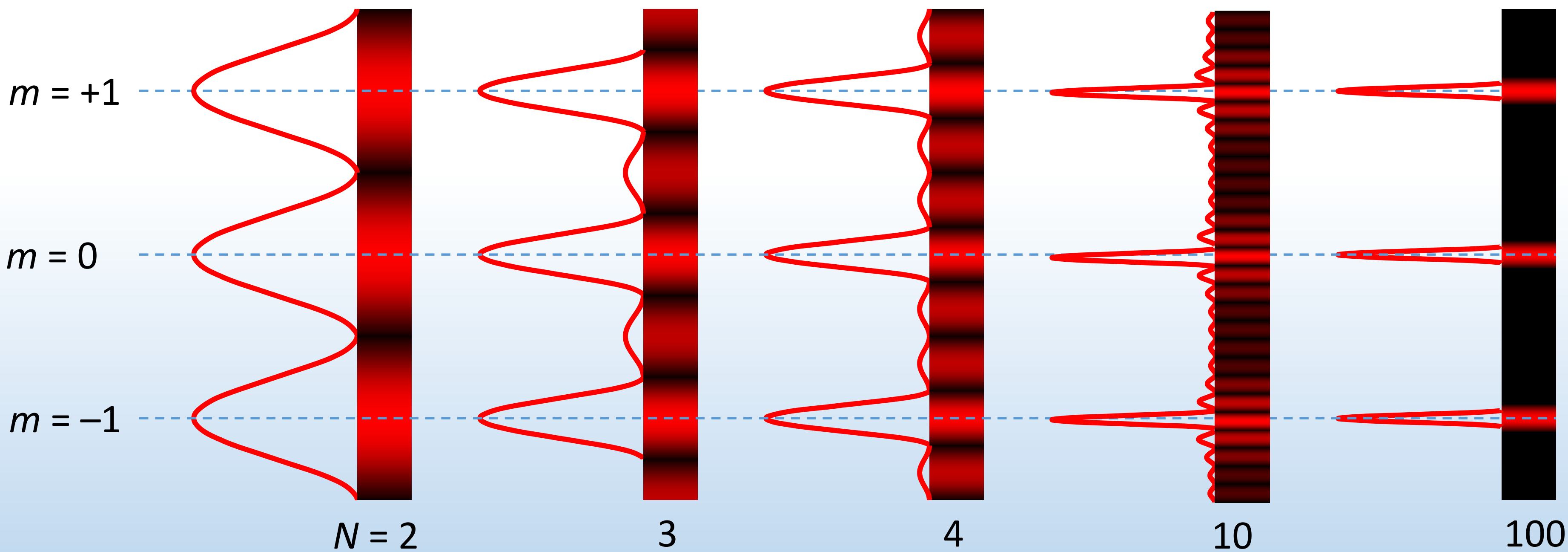
16% A. Interference maximum

55% B. Interference minimum

29% 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: $\boxed{d\sin\theta_m = m\lambda}$

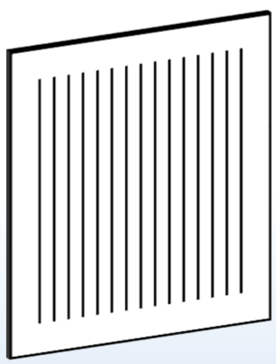


As *N* increases, more minima appear and bright fringes narrow

DEMO

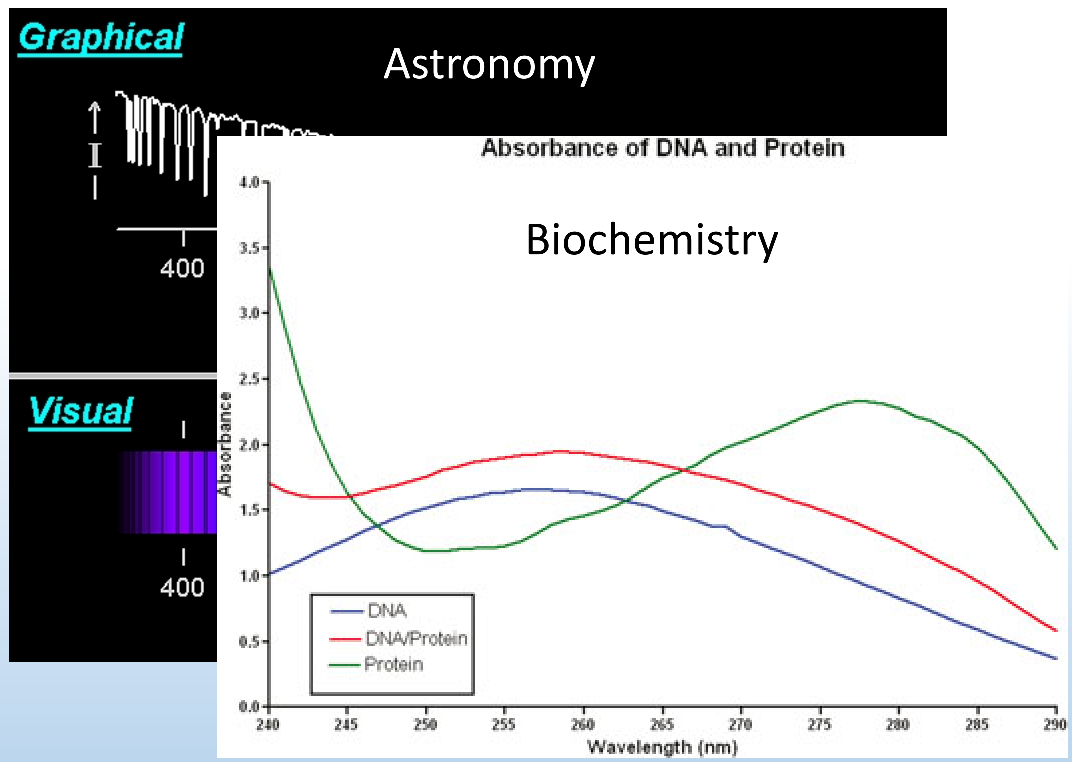
Diffraction grating

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



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

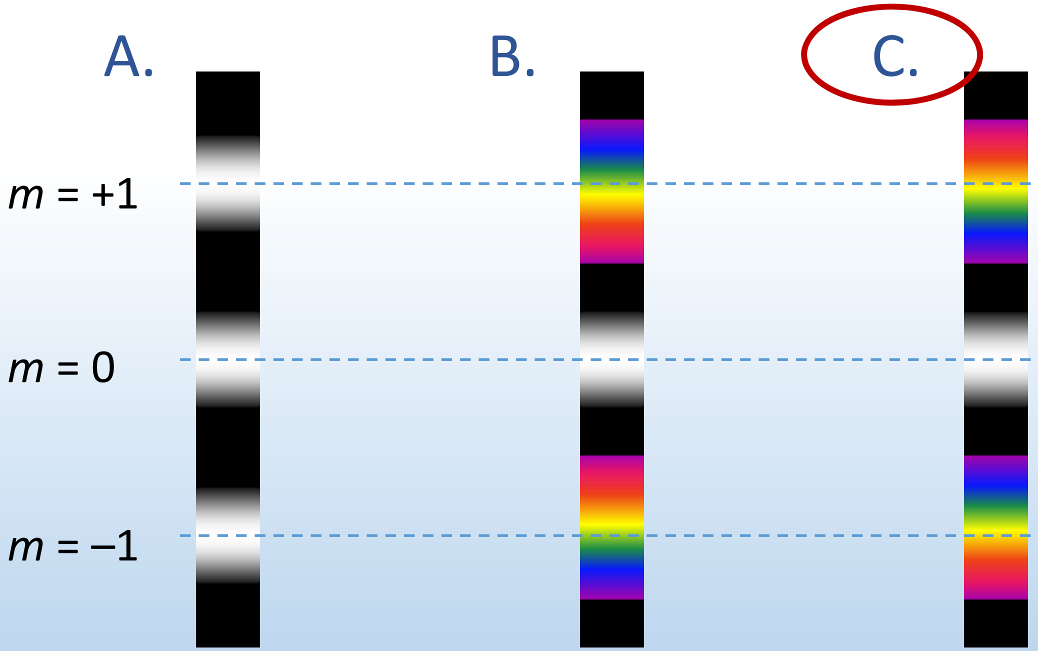
$$d \sin\theta_m = m\lambda$$



Used in spectroscopy – analysis of absorption/emission spectra

ACT: Diffraction grating

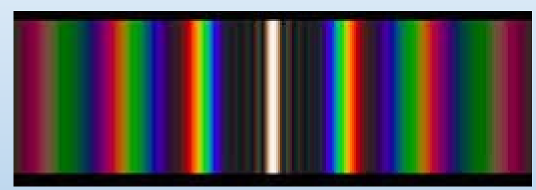
White light passes through a diffraction grating and is projected on a screen. Which diagram most accurately represents the pattern on the screen?



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

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, λ, 2λ ...)

  Destructive if waves are out of phase (phase shift = ½λ, 1½λ ...)

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