Phys 102 – Lecture 22

Interference

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

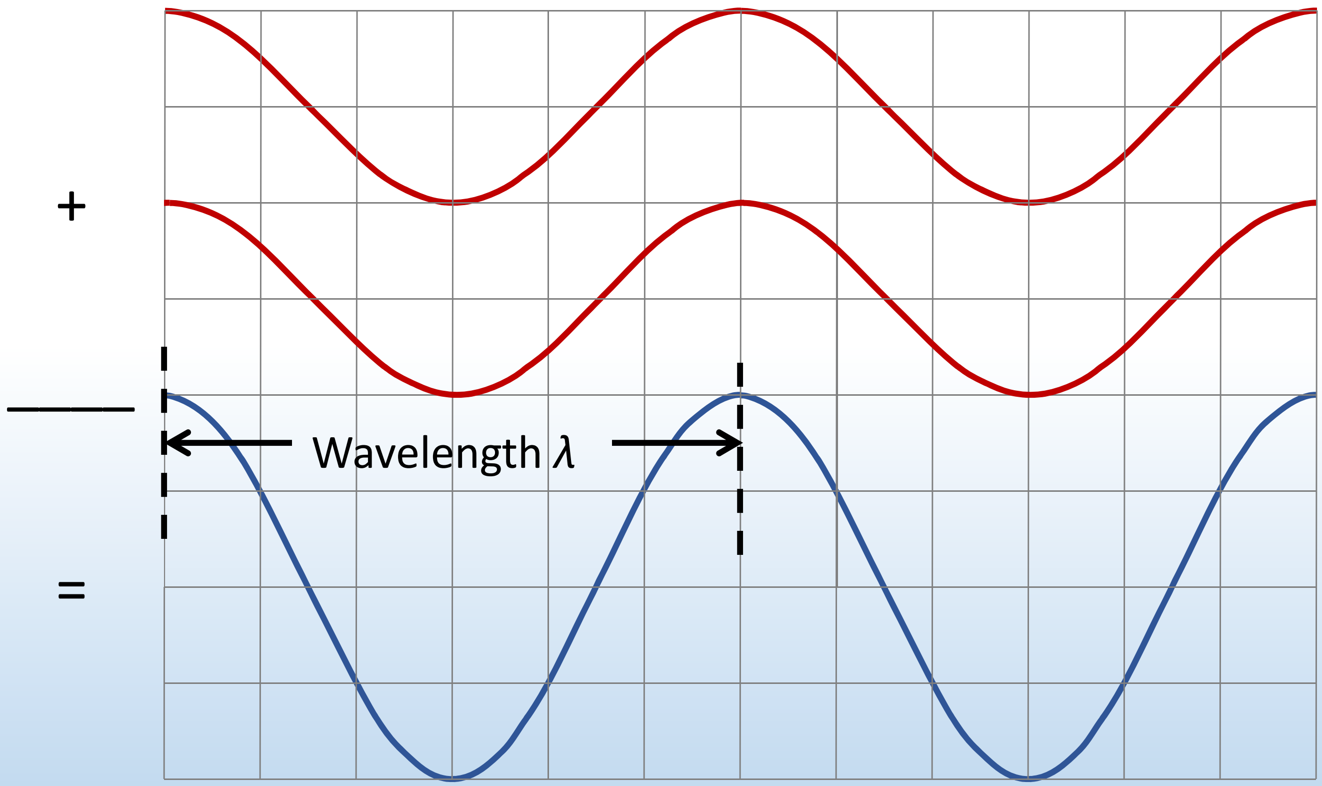
- Lecture 24 & 25 – Quantum mechanics

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

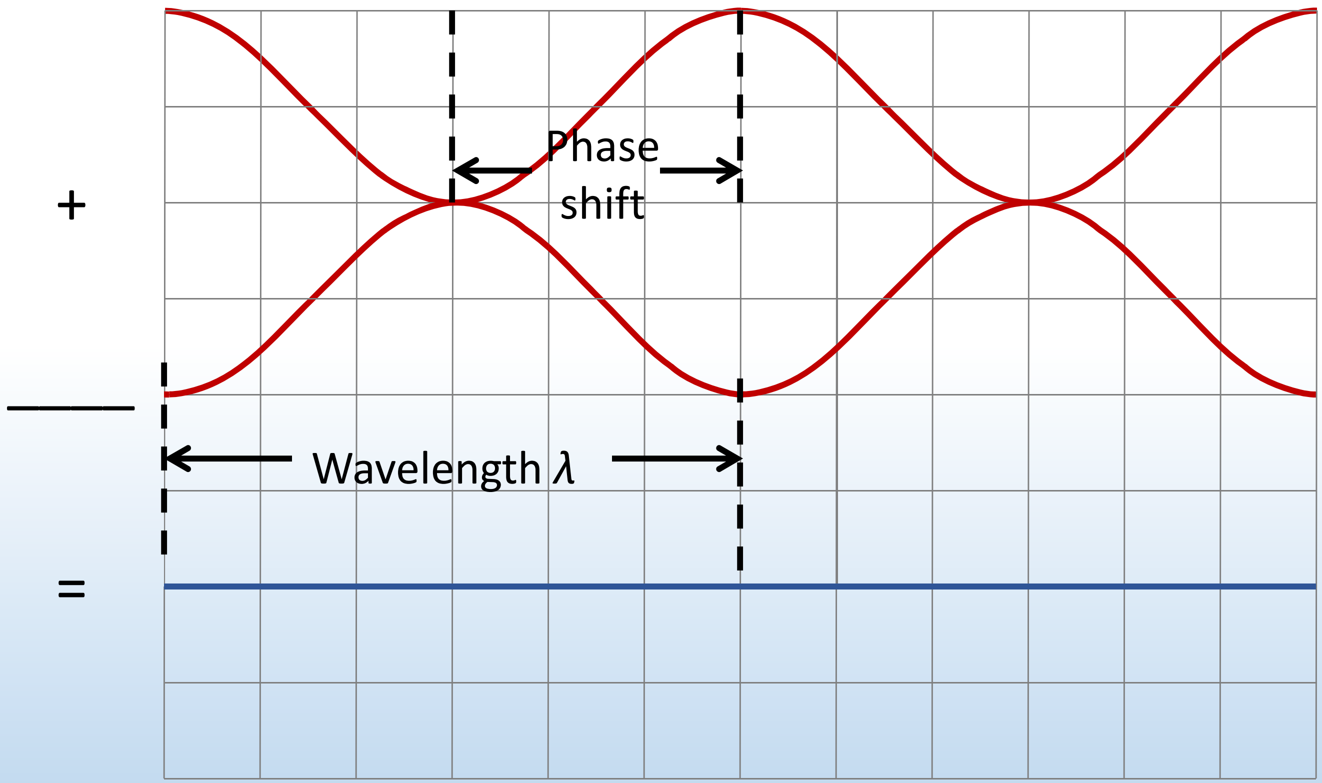


Waves remain in phase with shift of 1λ, 2λ ... *m*λ

Constructive interference – waves combine to give larger wave

Superposition of waves

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

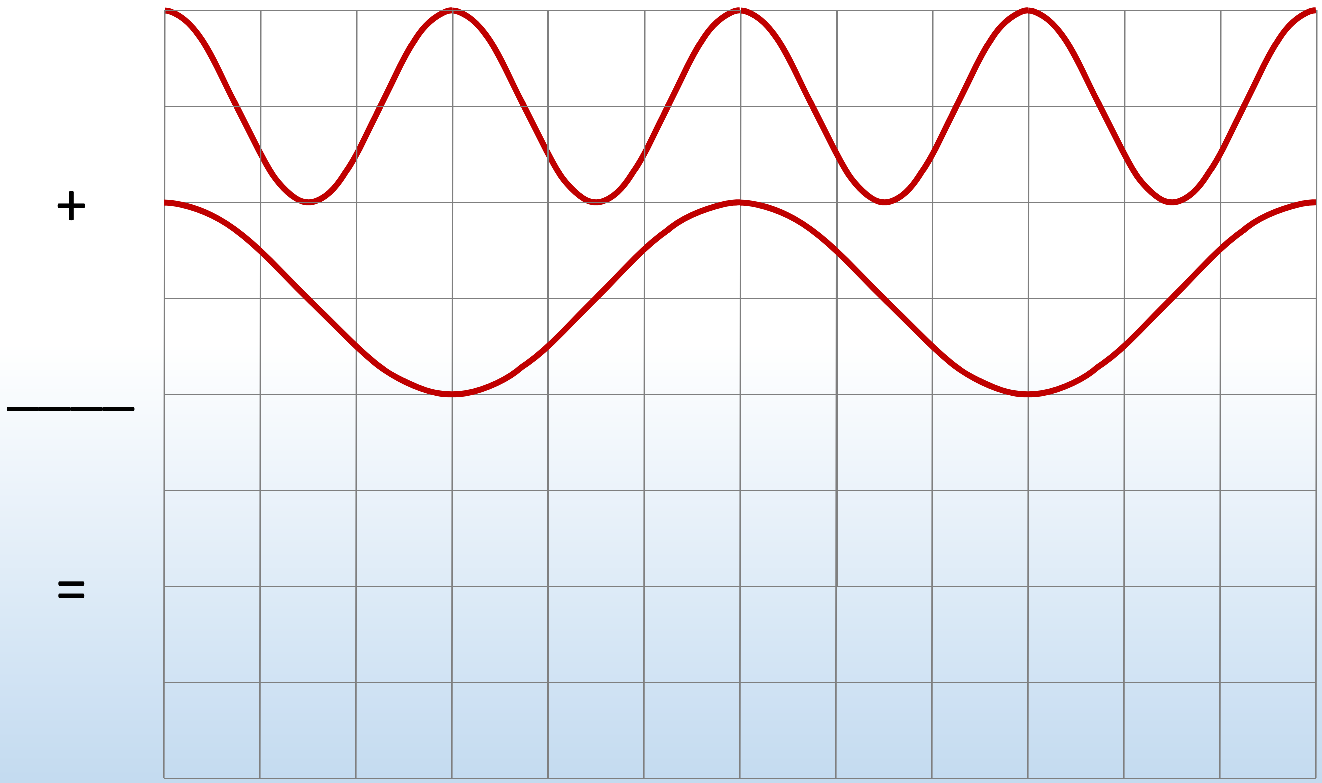


With phase shift of ½ λ, 1½ λ, 2½ λ ... (*m* + ½)λ, waves are out of phase

Destructive interference – waves combine to give no wave

ACT: Superposition of waves

What kind of interference do these two waves produce?



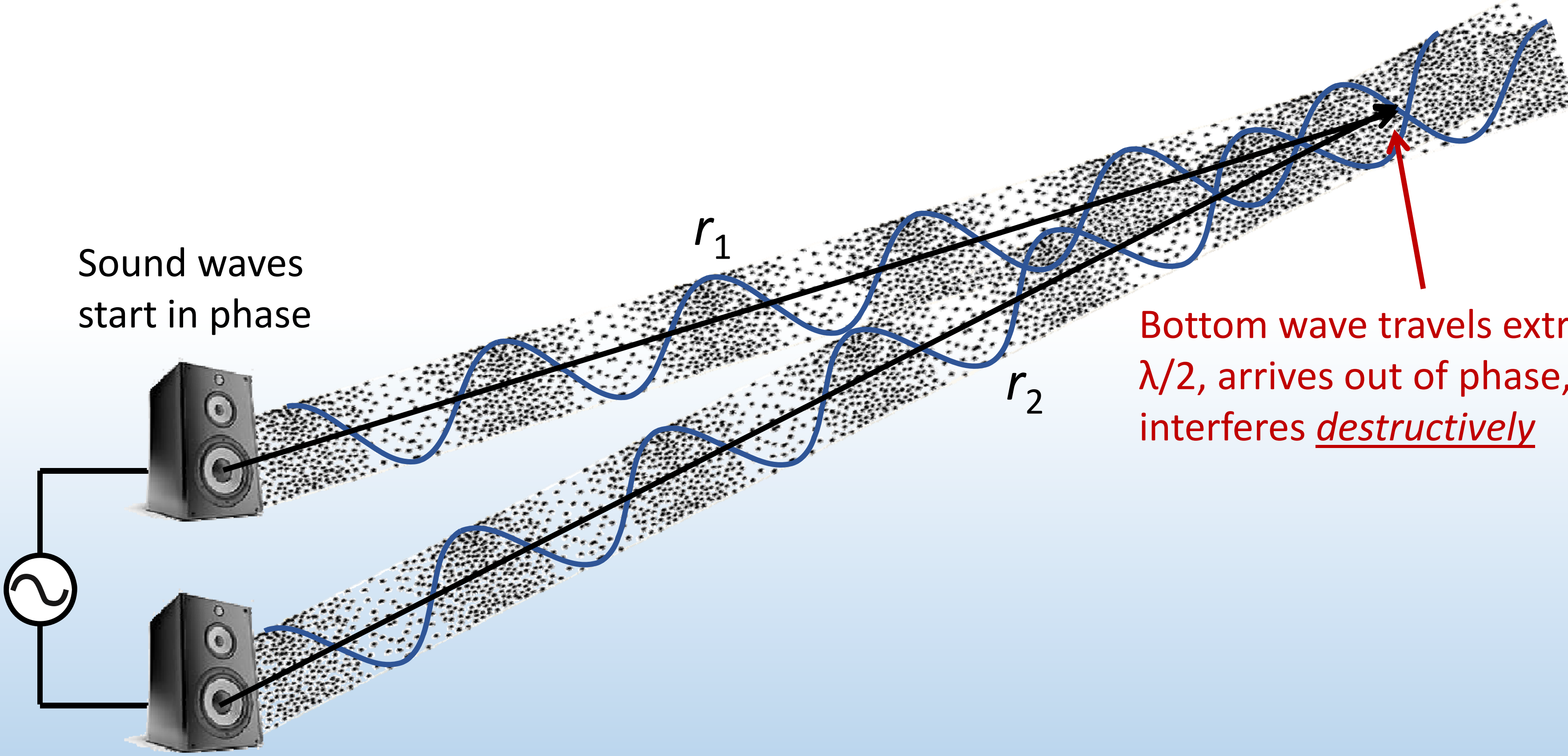
A. Constructive

B. Destructive

C. Neither

Demo: Interference for sound

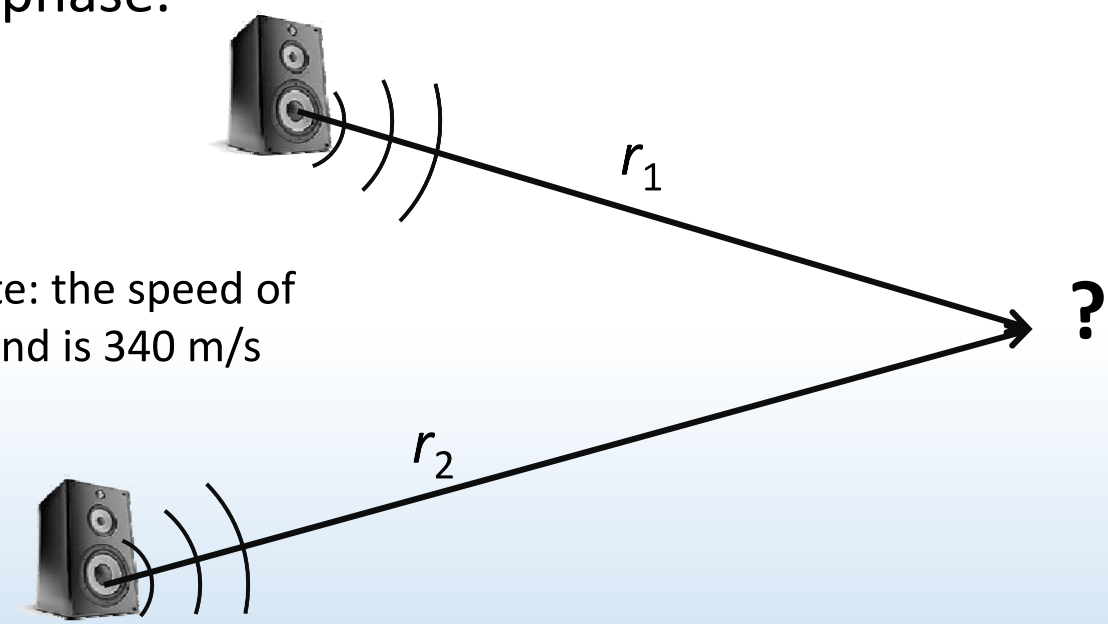
Pair of speakers driven in phase, produce a tone of single *f* and λ:



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

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?

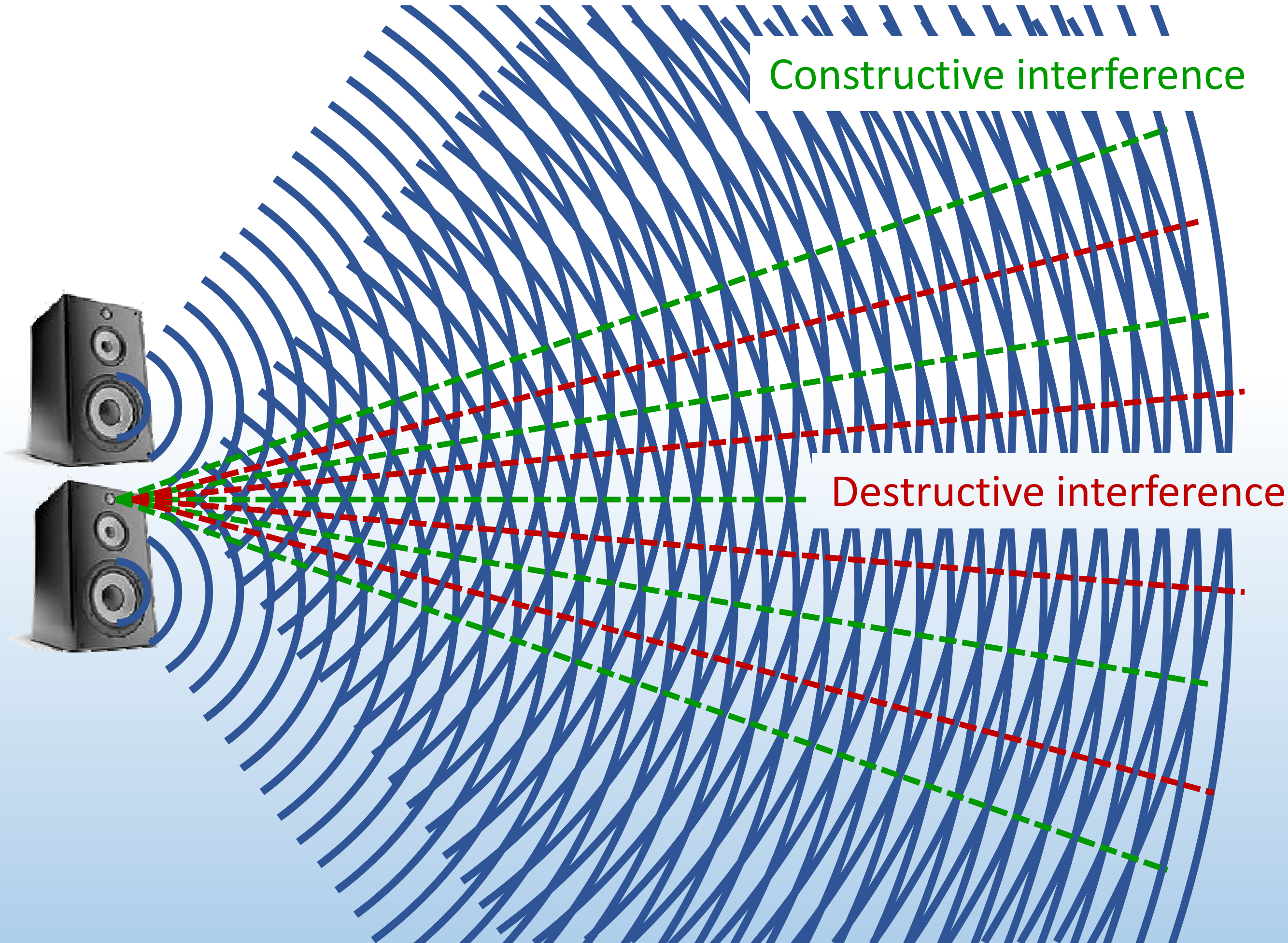
A. Constructive

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

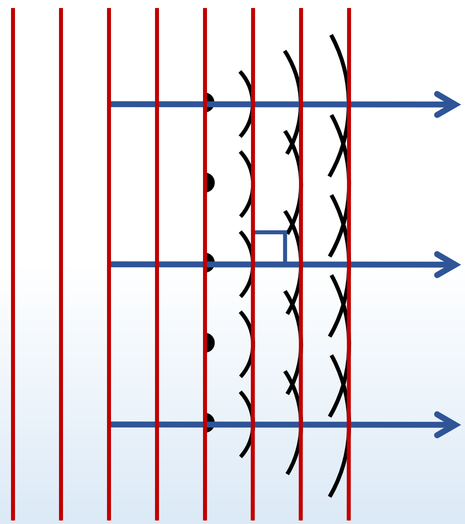
  Two different refractive indices

  Reflection off of two different surfaces

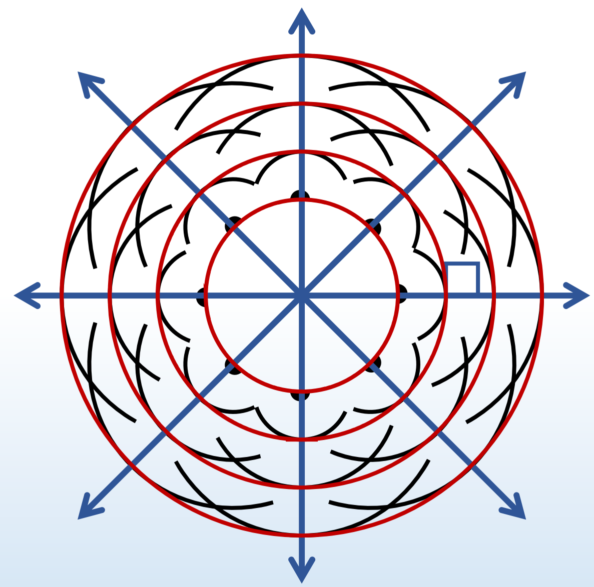
Recall: Huygens' Principle

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

"wavelet"



Planar wavefronts

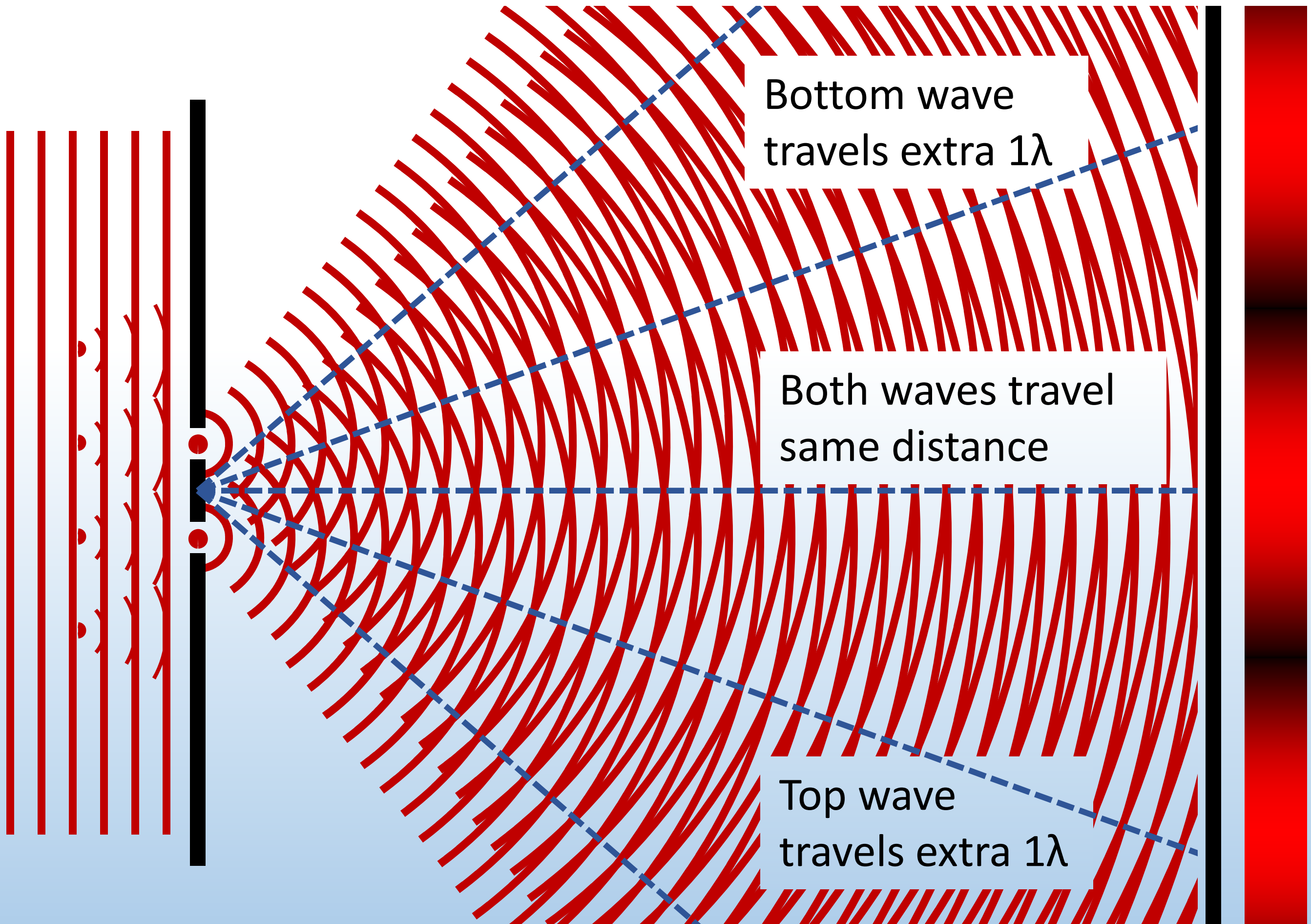


Spherical wavefronts

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

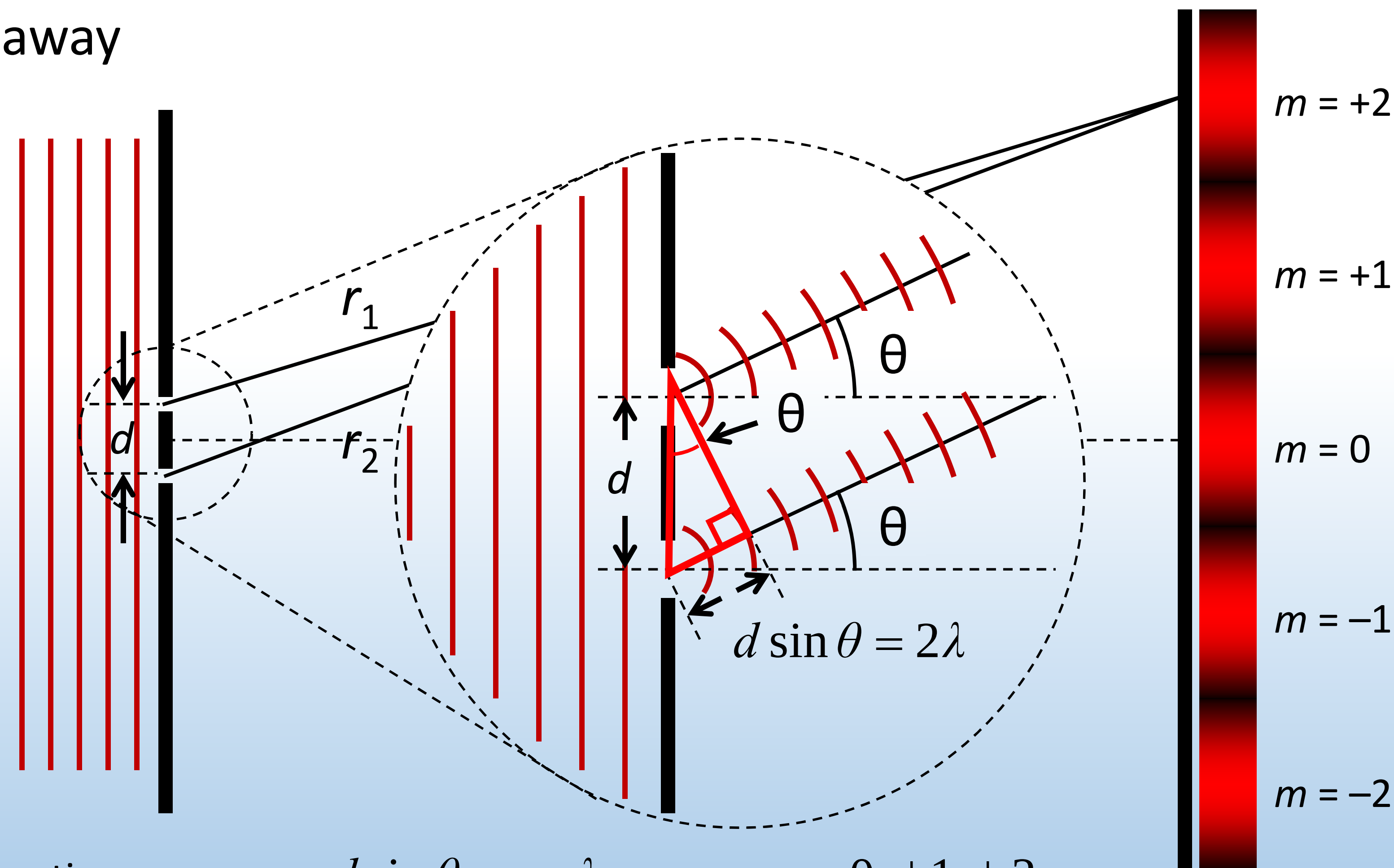
Young's double slit

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

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?

A. The pattern is the same
B. Maxima & minima become minima & maxima

Checkpoint 1.2

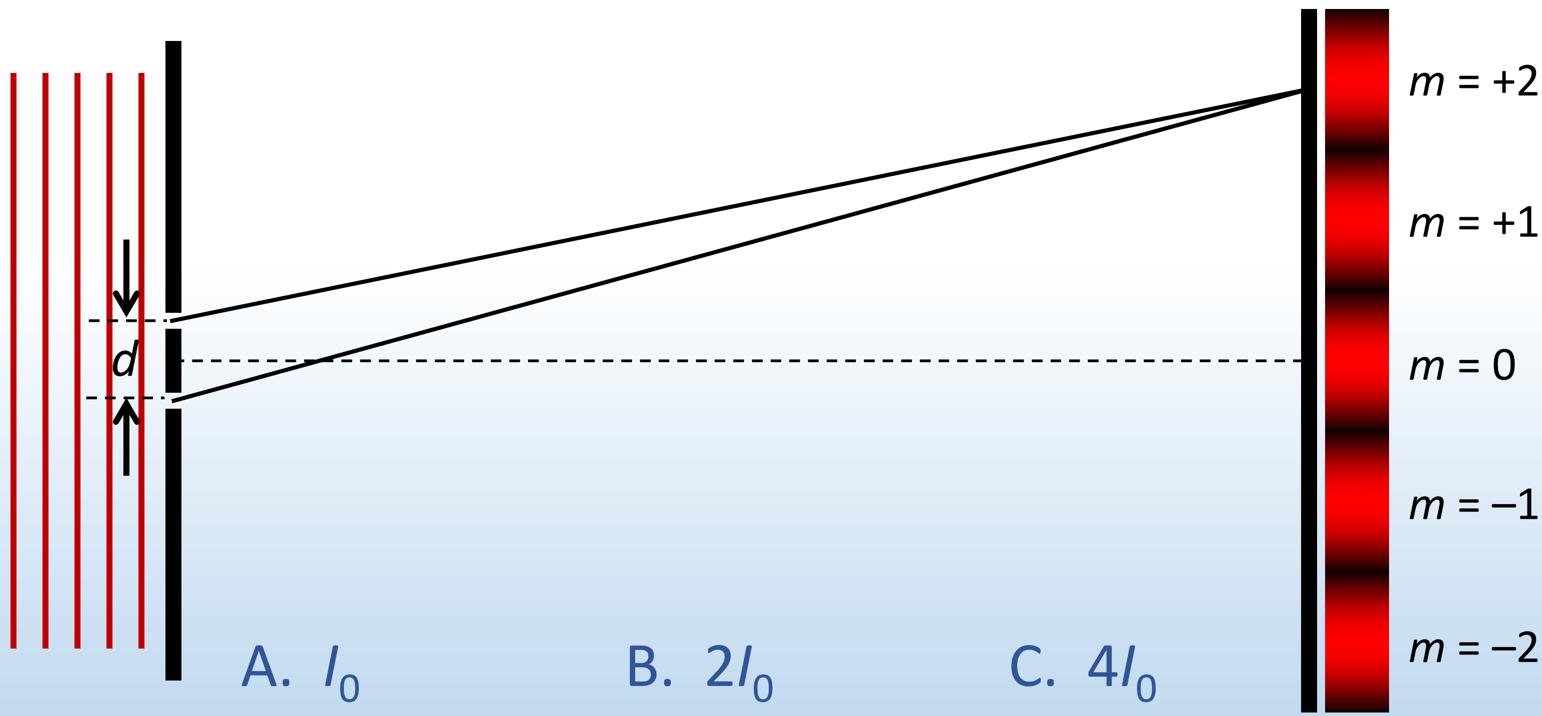
In the Young's double slit experiment, is it possible to see interference maxima when the distance *d* between slits is less than the wavelength of light λ?

A. Yes

B. No

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?



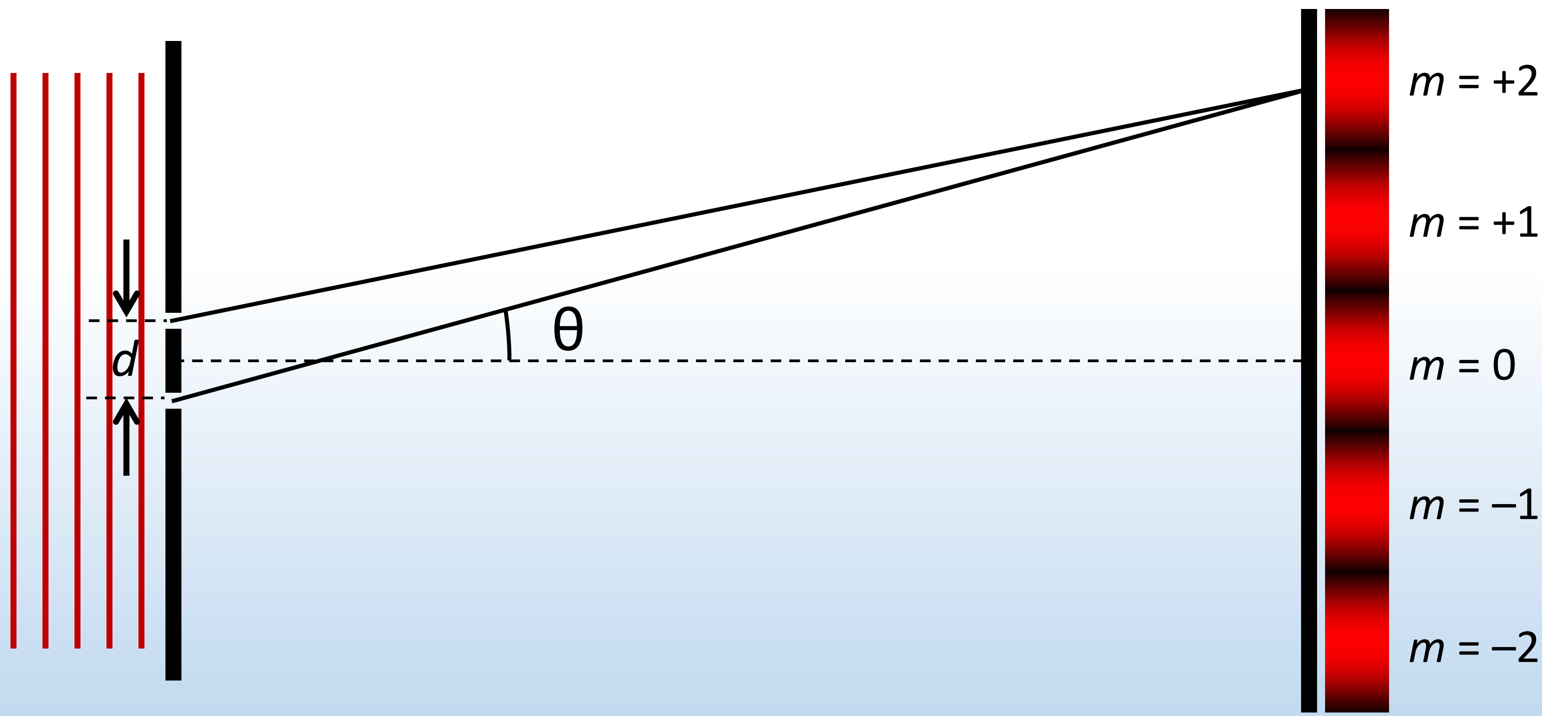
A. I_0

B. $2I_0$

C. $4I_0$

ACT: CheckPoint 2.1

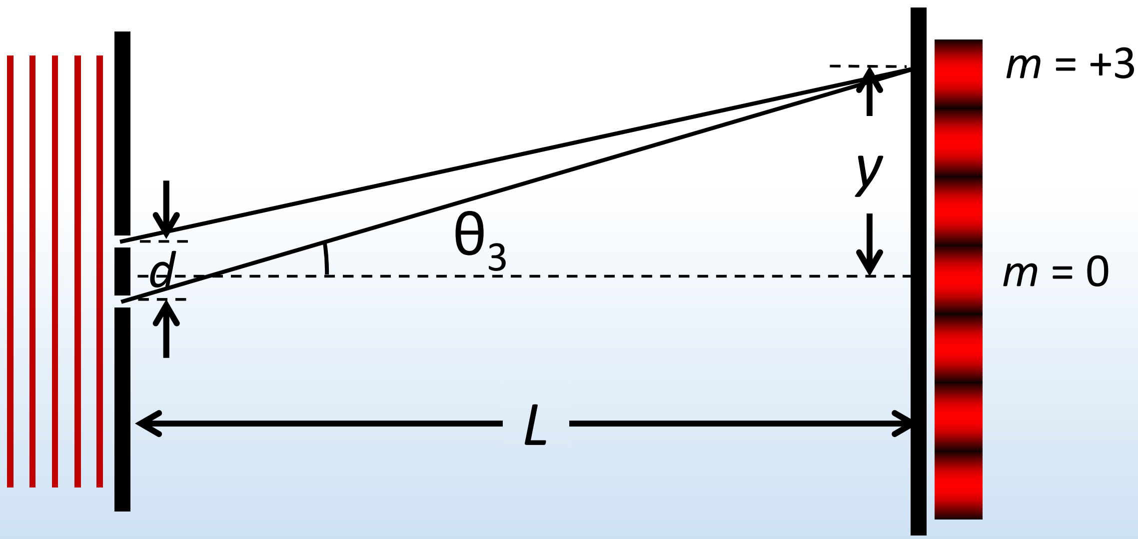
When this Young's double slit experimental setup is placed under water, the separation *y* between minima and maxima:



A. Increases
B. Remains the same
C. Decreases

Calculation: Young's double slit

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.



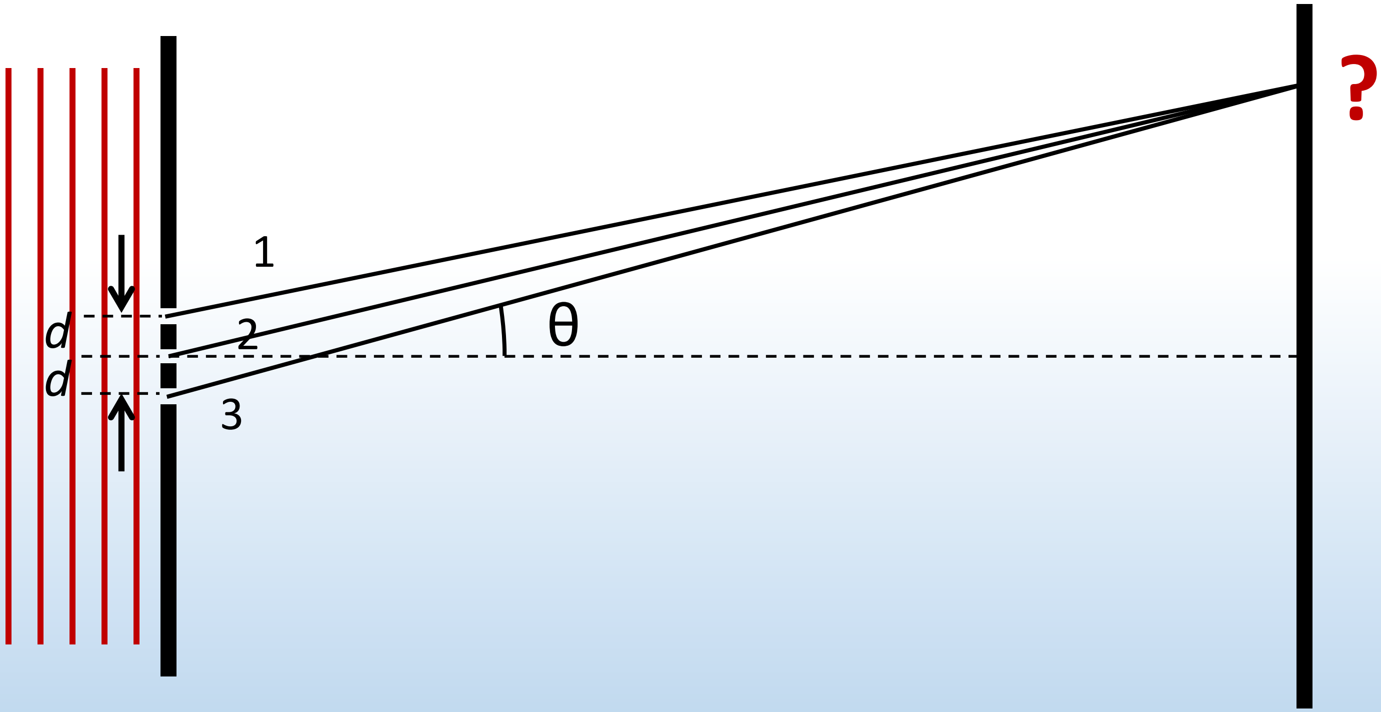
$$d \sin\theta_3 = 3\lambda$$

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

$$y \approx m\frac{\lambda L}{d}$$

ACT: CheckPoint 3.1

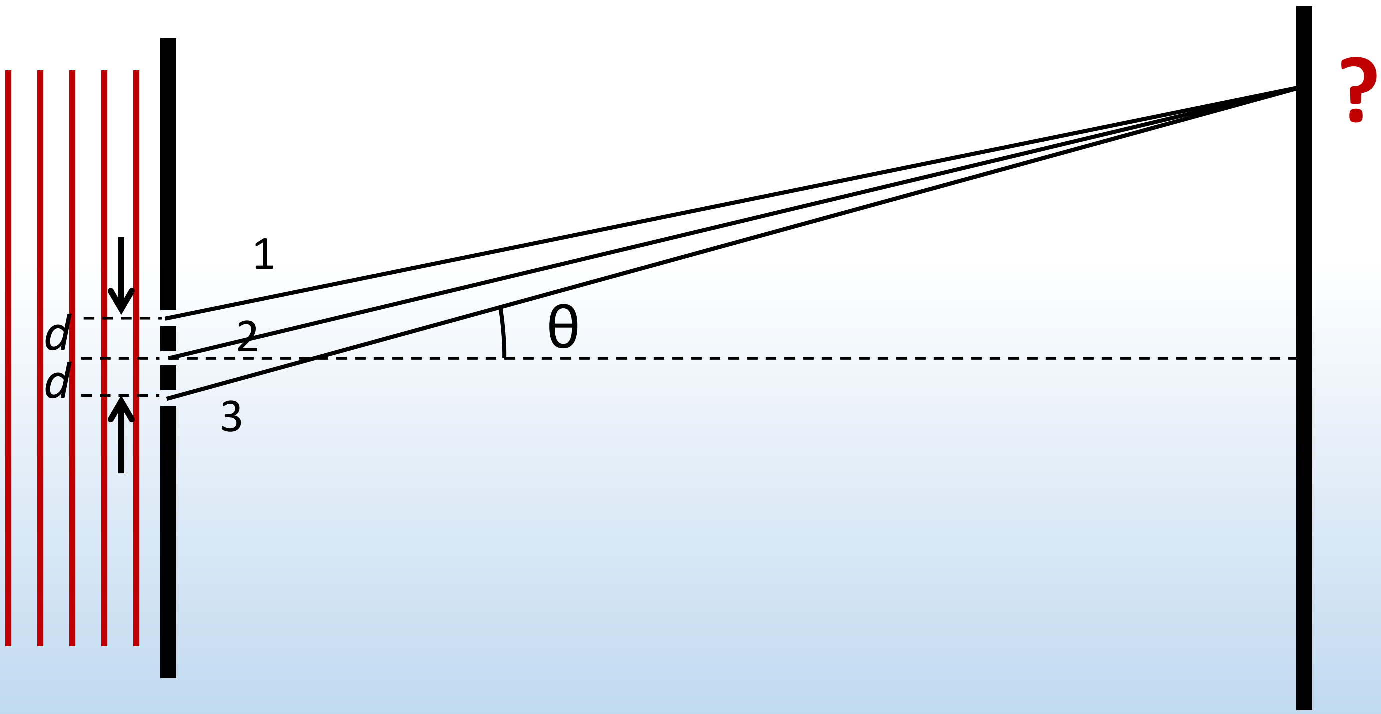
Light is incident on three evenly separated slits. If wave 1 and 2 interfere *constructively* at angle θ, what appears on the screen?



A. Interference maximum
B. Interference minimum
C. Somewhere in between

ACT: CheckPoint 3.3

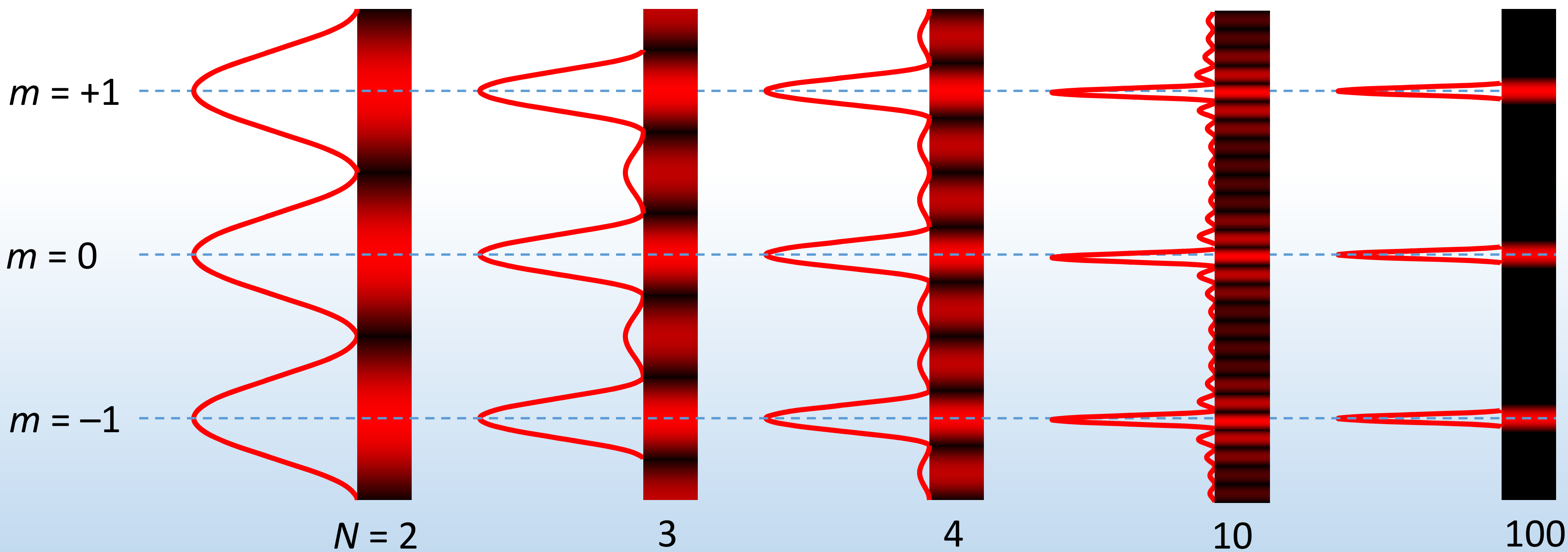
Light is incident on three evenly separated slits. If wave 1 and 2 interfere ***destructively*** at angle θ, what appears on the screen?



A. Interference maximum
B. Interference minimum
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: $d \sin\theta_m = m\lambda$

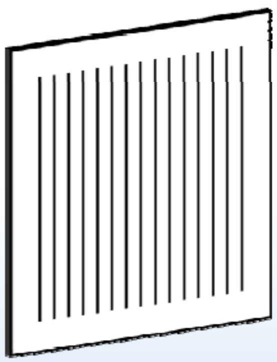


As *N* increases, more minima appear and bright fringes narrow

DEMO

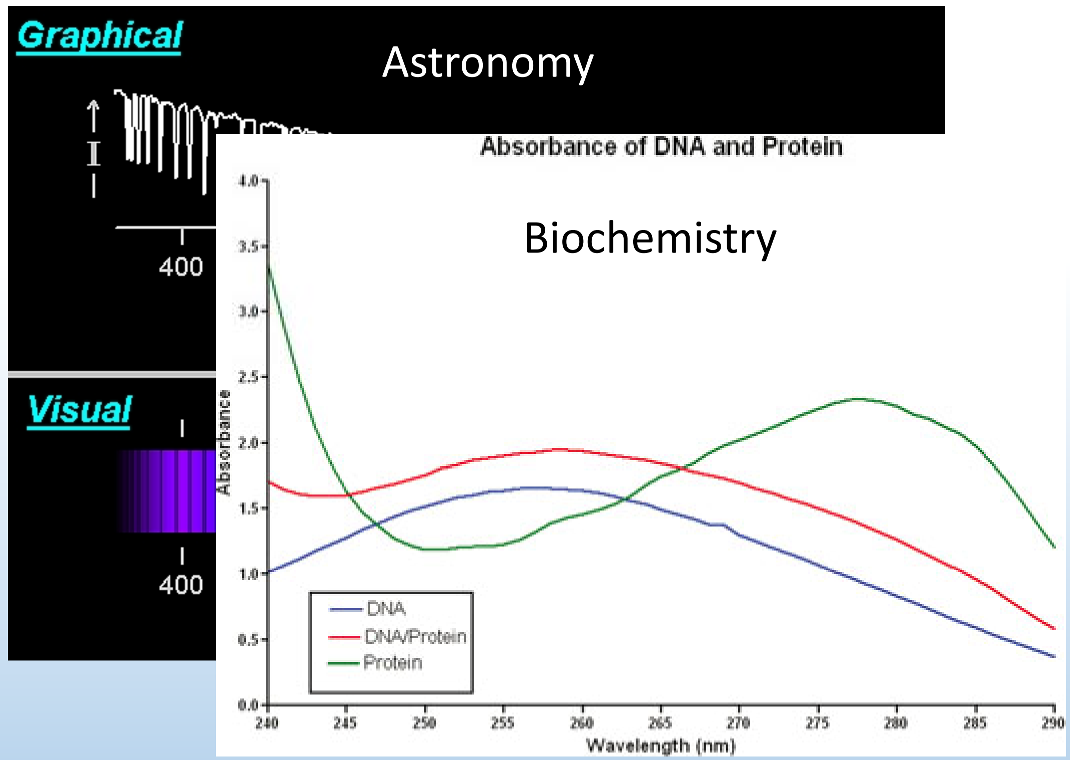
Diffraction grating

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



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

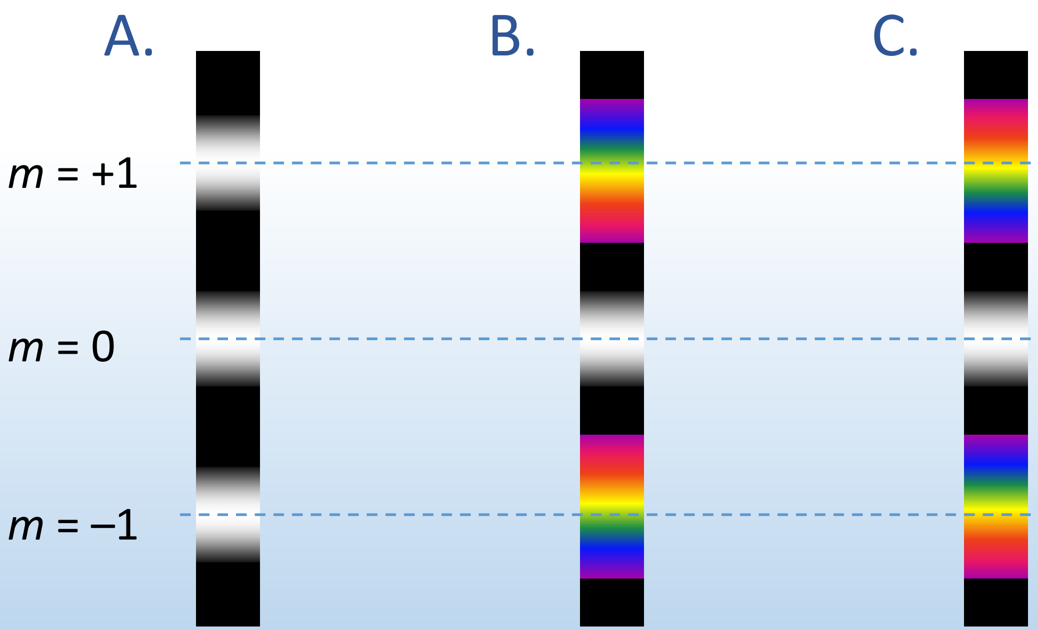
$$d \sin\theta_m = m\lambda$$



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?



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