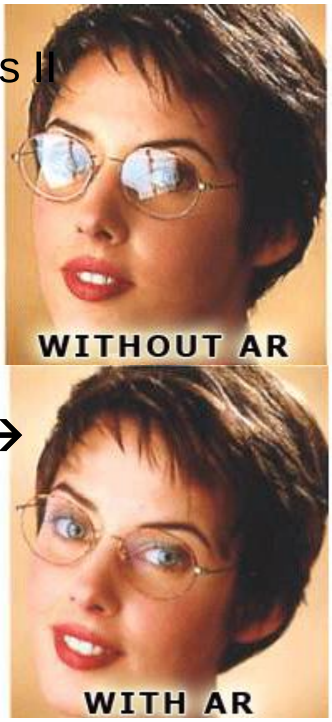
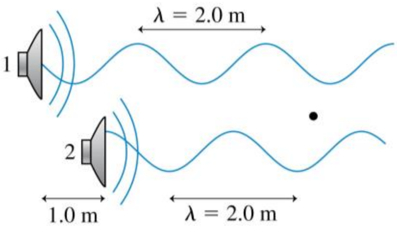
PHY132 Introduction to Physics II
Class 4 – **Outline:**

- Ch. 21, sections 21.5-21.8
- Wave Interference
- Constructive and Destructive Interference
- **Thin-Film Optical Coatings →**
- Interference in 2 and 3 Dimensions
- Beats



Clicker Question

Two loudspeakers emit sound waves with the same wavelength and the same amplitude. Which of the following would cause there to be completely destructive interference at the position of the dot? (zero resulting amplitude)



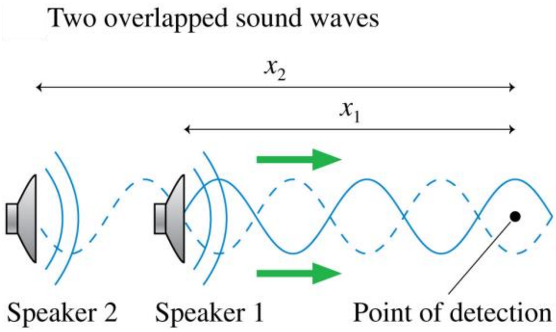
A. Move speaker 2 forward (right) 1.0 m.
B. Move speaker 2 forward (right) 0.5 m.
C. Move speaker 2 backward (left) 0.5 m.
D. Move speaker 2 backward (left) 1.0 m.
E. Nothing. Destructive interference is not possible in this situation.

Wave Interference

• The pattern resulting from the superposition of two waves is called interference. Interference can be

• ***constructive***, meaning the disturbances **add** to make a resultant wave of **larger** amplitude, or

• ***destructive***, meaning the disturbances **cancel**, making a resultant wave of **smaller** amplitude.



Wave Interference

$$D_1 = a\, sin(kx_1 - \omega t + \phi_{10})$$

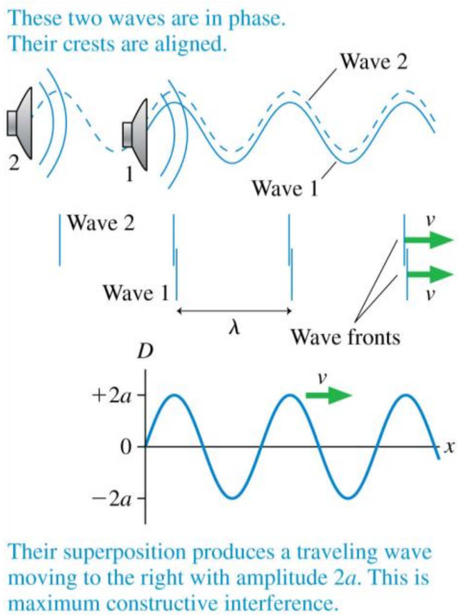
$$D_2 = a\, sin(kx_2 - \omega t + \phi_{20})$$

$$D = D_1 + D_2$$

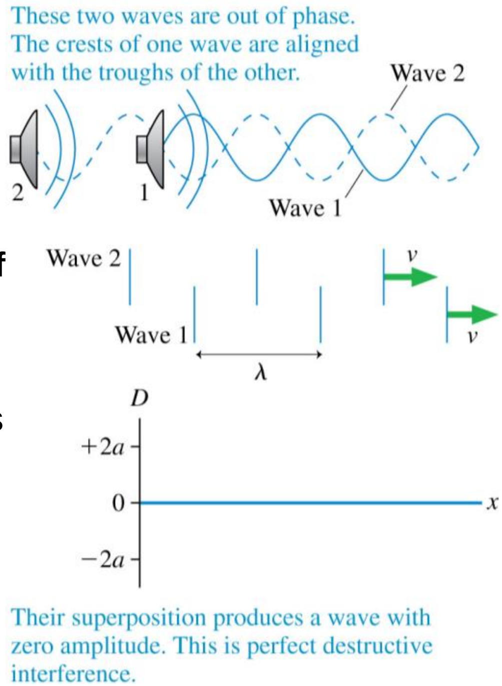
- The two waves are **in phase**, meaning that

$$D_1(x) = D_2(x)$$

- The resulting amplitude is $A = 2a$ for *maximum constructive interference*.



Wave Interference



- The two waves are **out of phase**, meaning that

  $$D_1(x) = -D_2(x).$$

- The resulting amplitude is $A = 0$ for *perfect destructive interference.*

The Mathematics of Interference

As two waves of equal amplitude and frequency travel together along the *x*-axis, the net displacement of the medium is:

$$D = D_1 + D_2 = a\sin(kx_1 - \omega t + \phi_{10}) + a\sin(kx_2 - \omega t + \phi_{20})$$

$$= a\sin\phi_1 + a\sin\phi_2$$

$$= 2a\cos\left[\tfrac{1}{2}(\phi_2 - \phi_1)\right]\sin\left[\tfrac{1}{2}(\phi_2 + \phi_1)\right]$$

The phase difference $\Delta\phi = \phi_2 - \phi_1$

$$D = \left[2a\cos\left(\frac{\Delta\phi}{2}\right)\right]\sin(kx_{\text{avg}} - \omega t + (\phi_0)_{\text{avg}})$$

The amplitude depends on the phase difference

The Mathematics of Interference

$$A = 2a\cos\left(\frac{\Delta\phi}{2}\right)$$

- The amplitude has a maximum value $A = 2a$ if $\cos(\Delta\phi/2) = \pm 1$.
- This is maximum constructive interference, when:

$$\Delta\phi = m \cdot 2\pi \quad \text{(maximum amplitude } A = 2a\text{)}$$

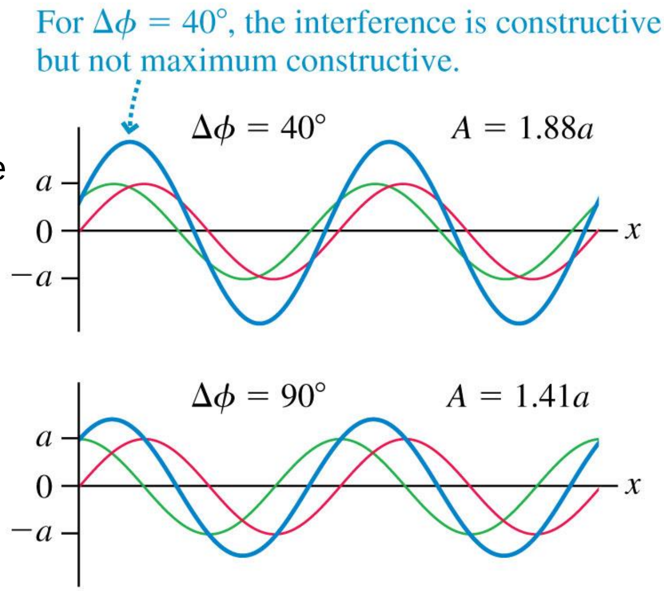
where m is an integer.

- Similarly, perfect destructive interference is when:

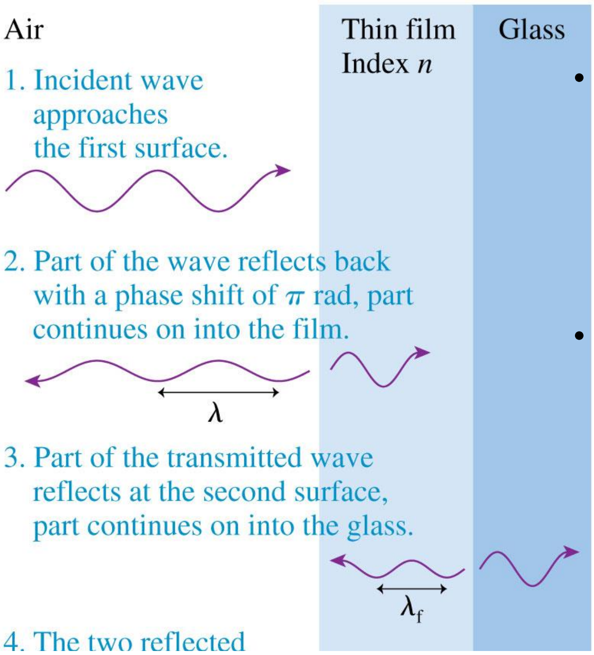
$$\Delta\phi = \left(m + \tfrac{1}{2}\right) \cdot 2\pi \quad \text{(minimum amplitude } A = 0\text{)}$$

The Mathematics of Interference

- It is entirely possible, of course, that the two waves are neither exactly in phase nor exactly out of phase.
- (as we learned from today's pre-class quiz!)



Thin-Film Optical Coatings



- Thin transparent films, placed on glass surfaces, such as lenses, can control reflections from the glass.
- Antireflection coatings on the lenses in cameras, microscopes, and other optical equipment are examples of thin-film coatings.

Application: Thin-Film Optical Coatings

- The phase difference between the two reflected waves is:

$$\Delta\phi = 2\pi \frac{2d}{\lambda/n} = 2\pi \frac{2nd}{\lambda}$$

where n is the index of refraction of the coating, d is the thickness, and λ is the wavelength of the light in vacuum or air.

- For a particular thin-film, constructive or destructive interference depends on the wavelength of the light:

$$\lambda_C = \frac{2nd}{m} \qquad m = 1, 2, 3, \ldots \qquad \text{(constructive interference)}$$

$$\lambda_D = \frac{2nd}{m - \frac{1}{2}} \qquad m = 1, 2, 3, \ldots \qquad \text{(destructive interference)}$$

Example

A thin coating of Magnesium Flouride (MgF_2) is deposited on the surface of some eyeglasses which have an index of refraction of 1.6. The MgF_2 has an index of refraction of 1.38. What is the minimum thickness of the coating so that green light of wavelength 500 nm has minimal reflectance?

Interference in Two and Three Dimensions

The mathematical description of interference in two or three dimensions is very similar to that of one-dimensional interference. The conditions for constructive and destructive interference are

Maximum constructive interference:

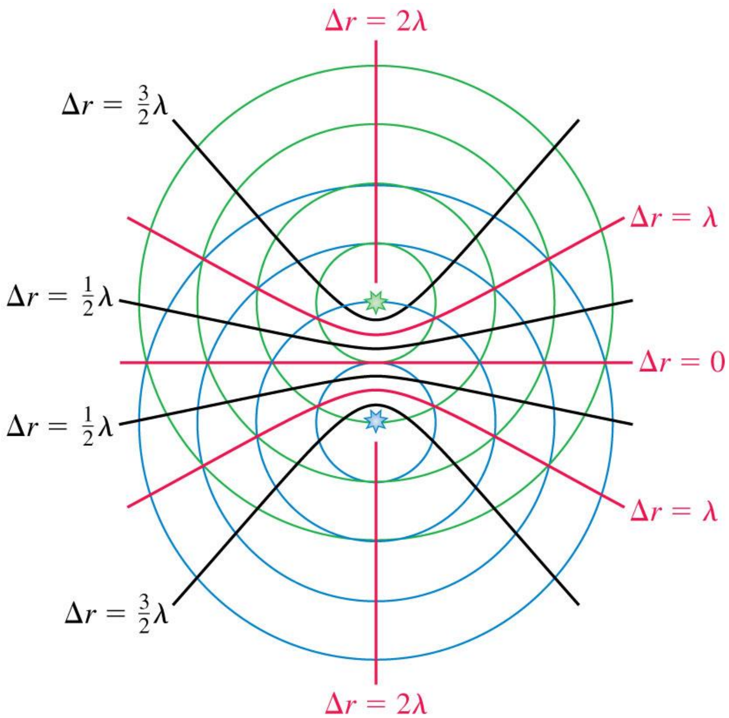
$$\Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m \cdot 2\pi$$

Perfect destructive interference:

$$\Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = \left(m + \frac{1}{2}\right) \cdot 2\pi$$

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

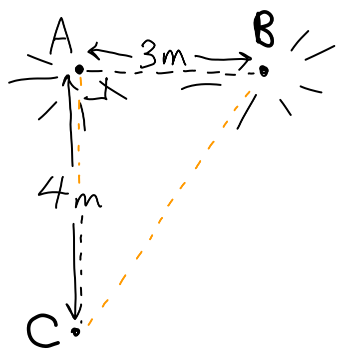
where Δr is the *path-length difference*.



Example

Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A.

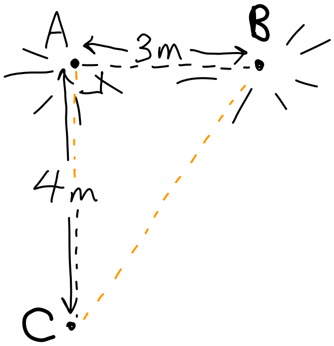
Will a listener at point C hear constructive or destructive interference?



Clicker Question 3

Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A.

How many wavelengths are between Speaker A and Point C?

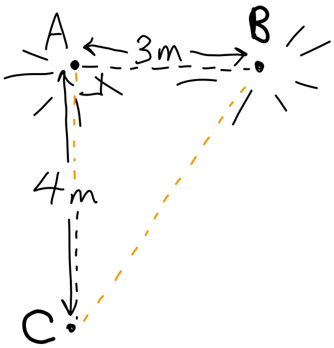


A. 0.5
B. 1.0
C. 1.5
D. 2.0
E. 2.5

Clicker Question 4

Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A.

How many wavelengths are between Speaker B and Point C?



A. 0.5
B. 1.0
C. 1.5
D. 2.0
E. 2.5

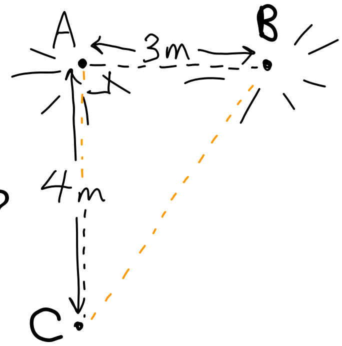
Clicker Question 5

Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A.

At point C, what is the path difference between the sounds received from speakers A and B, as measured in wavelengths?

A. 0.5 B. 1.0 C. 1.5

D. 2.0 E. 2.5



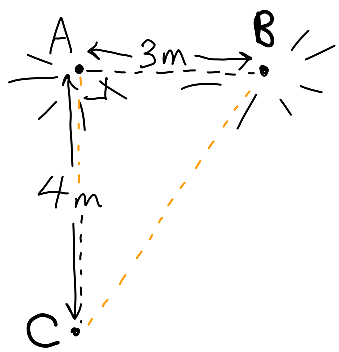
Clicker Question 6

Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A.

At point C, there will be

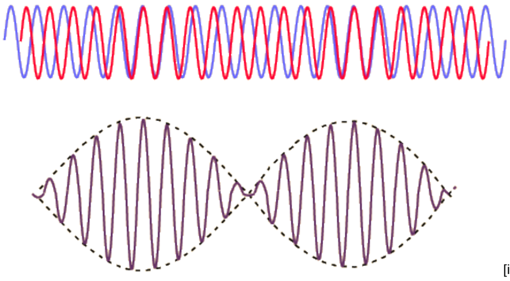
A. Constructive interference

B. Destructive interference



Beats

- Periodic variations in the loudness of sound due to interference
- Occur when two waves of similar, but not equal frequencies are superposed.
- Provide a comparison of frequencies
- Frequency of beats is equal to the **difference** between the frequencies of the two waves.



[image from http://hyperphysics.phy-astr.gsu.edu/hbase/sound/beat.html]

Beats

- Applications
  - Piano tuning by listening to the disappearance of beats from a known frequency and a piano key
  - Tuning instruments in an orchestra by listening for beats between instruments and piano tone

Clicker Question 7

Suppose you sound a 1056-hertz tuning fork at the same time you strike a note on the piano and hear 2 beats/second. What is the frequency of the piano string?

A. 1054 Hz
B. 1056 Hz
C. 1058 Hz
D. Either A or C
E. Either A, B or C

Clicker Question 8

Suppose you sound a 1056-hertz tuning fork at the same time you strike a note on the piano and hear 2 beats/second. You tighten the piano string very slightly and now hear 3 beats/second. What is the frequency of the piano string?

A. 1053 Hz
B. 1056 Hz
C. 1059 Hz
D. Either A or C
E. Either A, B or C

Before Class 5 on Monday

- Complete Problem Set 1 on MasteringPhysics due Sunday at 11:59pm on Chs. 20, 21. This is a rather long one so definitely get started early!
- Please read Knight Ch. 22, sections 22.1-22.4
- Please do the short pre-class quiz on MasteringPhysics by Monday morning at the latest.

- Something to think about: Light is a wave. So is it possible for two beams of light to meet at the same place, destructively interfere, and produce **darkness**?