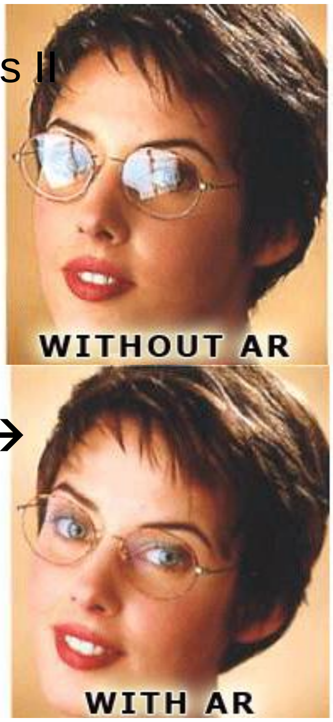
PHY132 Introduction to Physics II
Class 4 – **Outline:**

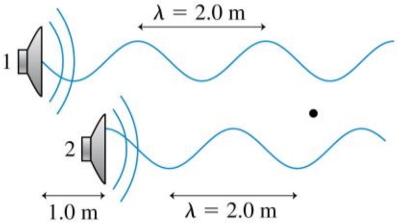
- Ch. 21, sections 21.5-21.8
- Wave Interference
- Constructive and Destructive Interference
- **Thin-Film Optical Coatings →**
- Interference in 2 and 3 Dimensions
- Beats



It's my birthday! I am 43 today!

Clicker Question

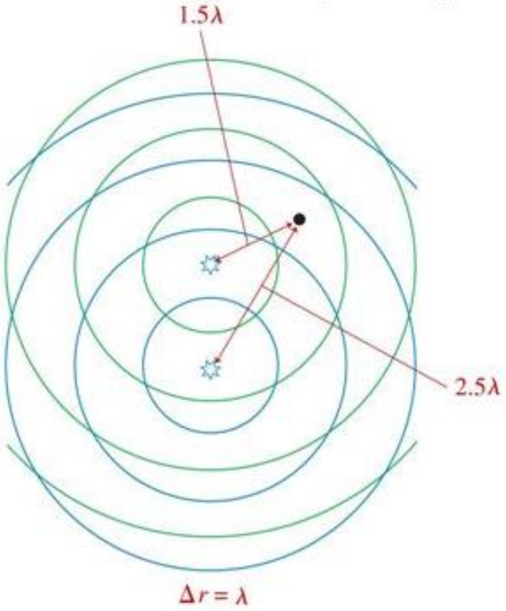
Two loudspeakers emit sound waves with the same wavelength and the same amplitude. Which of the following would cause there to be completely destructive interference at the position of the dot? (zero resulting amplitude)



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.

Class 4 Preclass Quiz on MasteringPhysics

- This was due this morning at 8:00am
- 672 students submitted the quiz on time
- Two in-phase sources emit sound waves of equal wavelength and intensity.
- 71% of students got: The interference is **constructive**.



Class 4 Preclass Quiz on MasteringPhysics

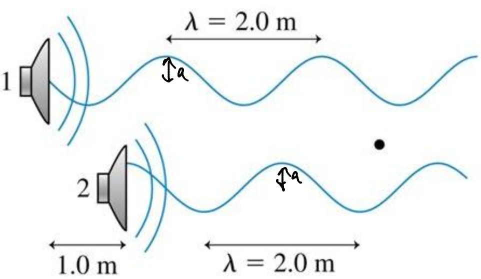
- Two loudspeakers emit sound waves with the same wavelength and the same amplitude, a. The waves are shown displaced, for clarity, but assume that both are traveling along the same axis. At the point where the dot is,
- 71% of students got: The amplitude of the combined wave is between 0 and 2a.

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

combined amplitude

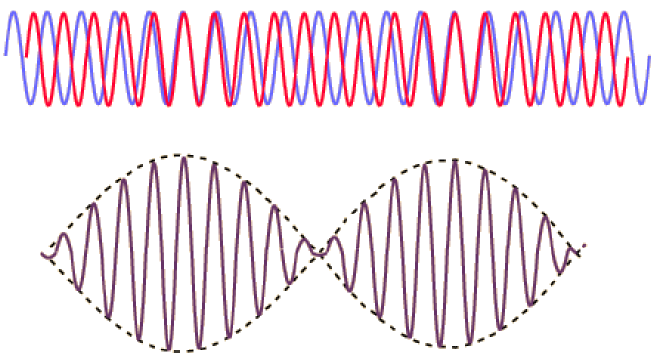
max : $\Delta\phi = 0$ $A = 2a$

min : $\Delta\phi = \pi$ $A = 0$



Class 4 Preclass Quiz on MasteringPhysics

- Two sound waves of nearly equal frequencies are played simultaneously. What is the name of the acoustic phenomenon you hear if you listen to these two waves?
- 79% of students got: **Beats.**

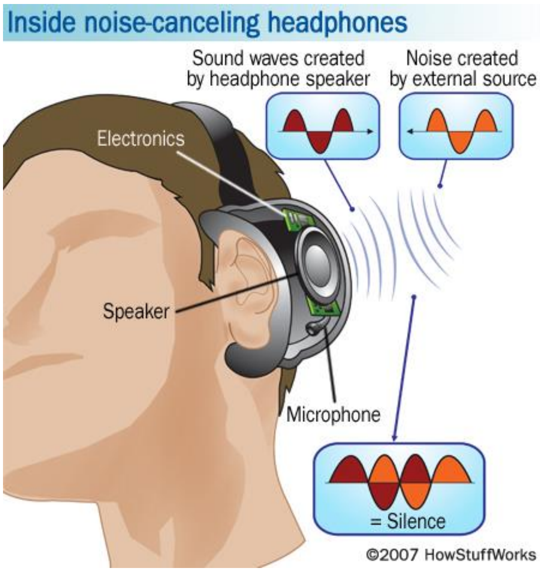


Class 4 Preclass Quiz – Student Comments…

- *"You were saying in the pre-class video that during a destructive interference you get a straight line which accounts for no sound hear (silence), i just wanted to ask if there are real life examples to that, i just can't think of two sounds played together that would create silence."*

Class 4 Preclass Quiz – Student Comments…

- **Harlow answer:** It is really rare because pure sinusoidal waves are very rare. In reality, noise-canceling headphones must exactly recreate wave patterns and then invert them – this takes some complicated and fast electronics, and even still it isn't perfect.
- *"OMG there's only 2 weeks left to the first term test !"*



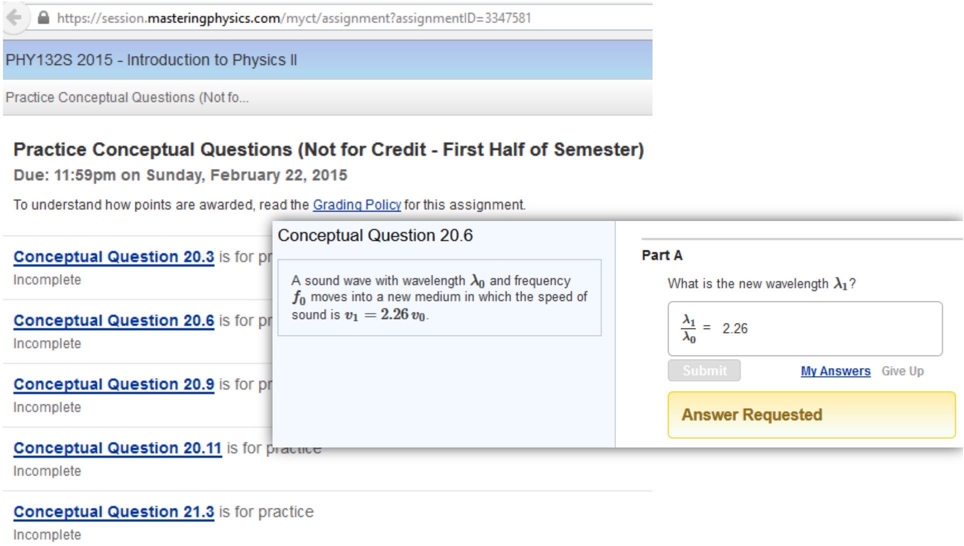
Announcement

- Test 1 is Tuesday Jan. 27h from 6:00-7:30pm.
- Room To Be Announced

- If you have a conflict with the above time, the **alternate sitting** will be from 4:30-6:00pm on Tuesday Jan. 27th
  - To register, students should submit the Alternate Sitting Registration Form, available now in the PHY132S Portal course menu.
  - The location will be emailed no later than Jan. 26 to the people who have registered.
  - You have until Jan. 22 at 4:00pm to do it (the form will not be available after).

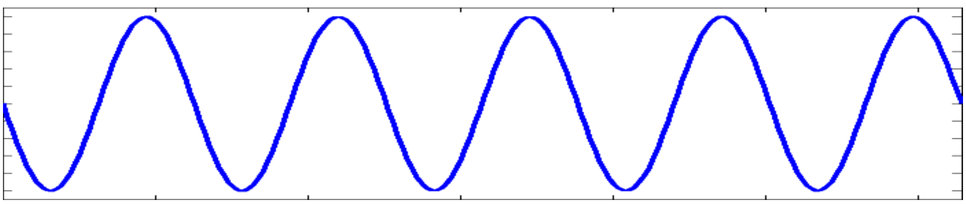
Piazza Question

- *"Does anyone know where can I find the answers for the conceptual questions in Knight?"*

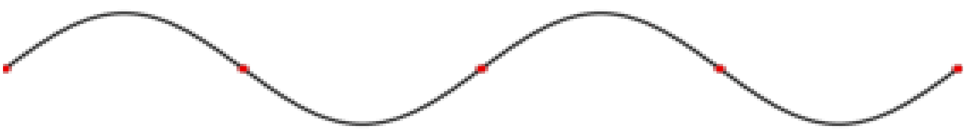


Piazza Question

- *"What's the difference between a sinusoidal wave and a standing wave?"*



$$D = A\sin(kx - \omega t)$$



$$D = [2a\sin(kx)]\cos(\omega t)$$

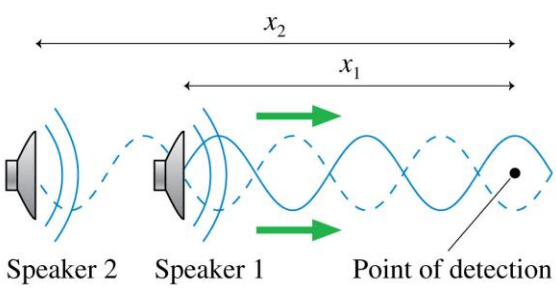
Wave Interference

• 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.

Two overlapped sound waves



Wave Interference

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

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

$$D = D_1 + D_2$$

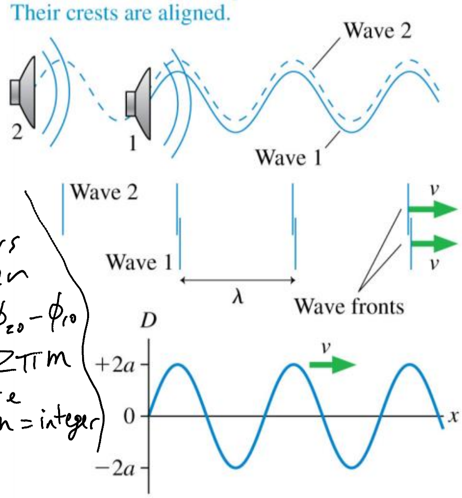
- The two waves are **in phase**, meaning that

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

occurs when $\Delta\phi = \phi_{20} - \phi_{10} = 2\pi m$ where m = integer

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

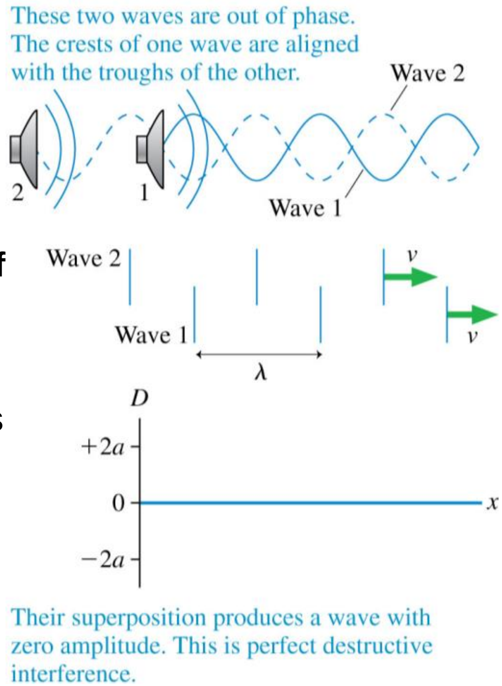
These two waves are in phase. Their crests are aligned.



Their superposition produces a traveling wave moving to the right with amplitude $2a$. This is maximum constructive interference.

Wave Interference

→ occurs when
$\Delta\phi = \phi_{20} - \phi_{10} = \pi m$
where m = odd integer



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

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

- 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 $\Delta\phi = \phi_2 - \phi_1$

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

$(\phi_0)_{avg} = \frac{\phi_{10} + \phi_{20}}{2}$

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:

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

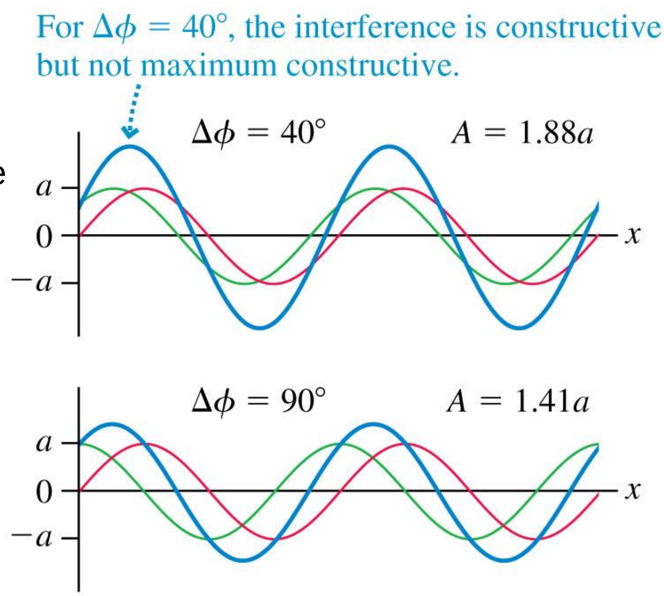
where m is an integer.

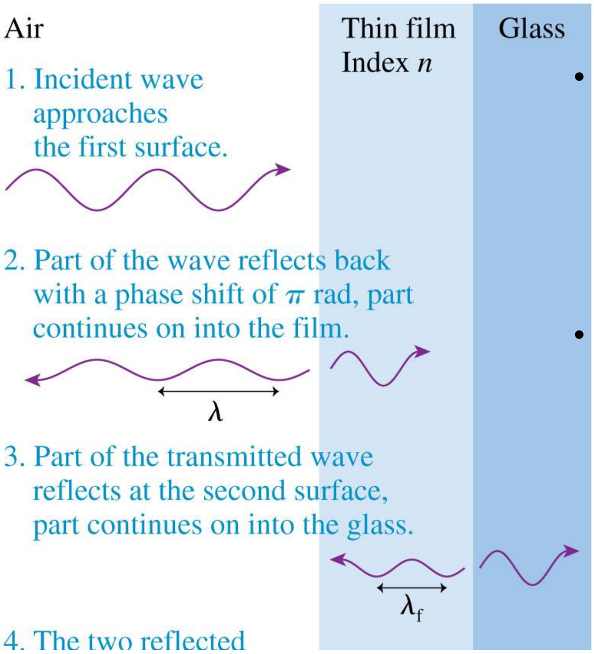
- Similarly, perfect destructive interference is when:

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

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. $\frac{\lambda}{n}$ = wavelength in thin film

- 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? ↖vacuum wavelength.

→ Destructive

$\lambda_0 = \frac{2nd}{m-\frac{1}{2}}$

n = index of refraction of film = 1.38

m = integer = 1, 2, 3, ...

Solve for d:

$d = \frac{\lambda(m-\frac{1}{2})}{2n}$

as m increases, d increases.

minimum thickness is when m = 1.

$d = \frac{(500\times10^{-9}\text{ m})(1-\frac{1}{2})}{2(1.38)}$

$= 91\times10^{-9}$ m

d = 91 nm ← nanometers

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

Δr = path difference

Maximum constructive interference:

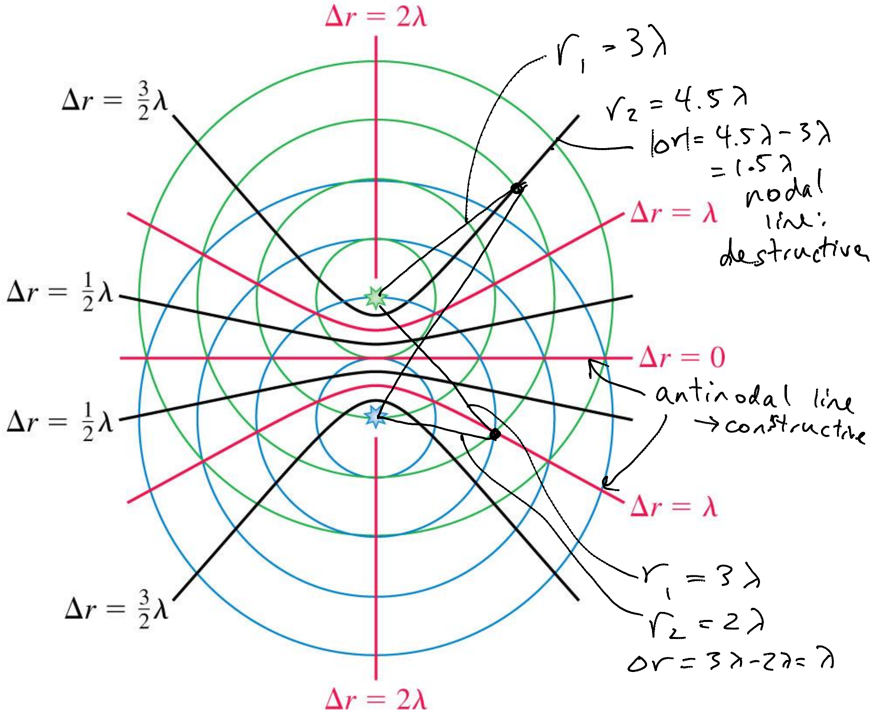
$$\Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m\cdot 2\pi$$

Perfect destructive interference:

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

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

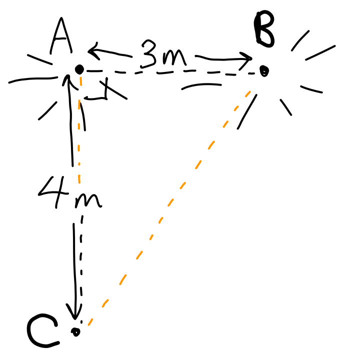
where Δr is the *path-length difference*.



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.

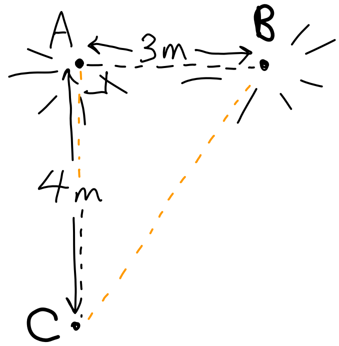
Will a listener at point C hear constructive or destructive interference?



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?

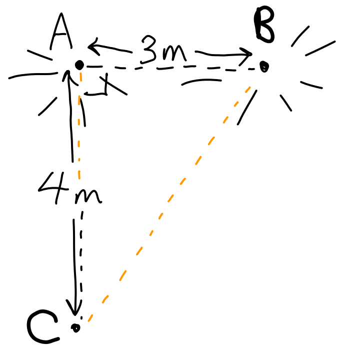


A. 0.5
B. 1.0
C. 1.5
D. 2.0
E. 2.5

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?

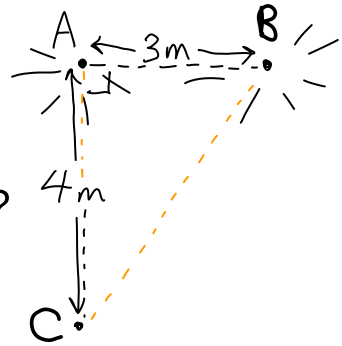


A. 0.5
B. 1.0
C. 1.5
D. 2.0
E. 2.5

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

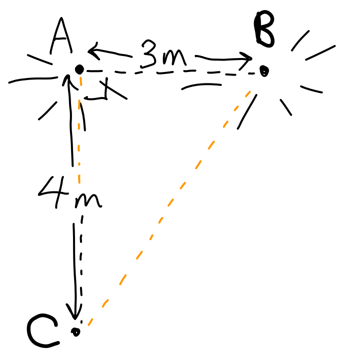
Clicker Question 6

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

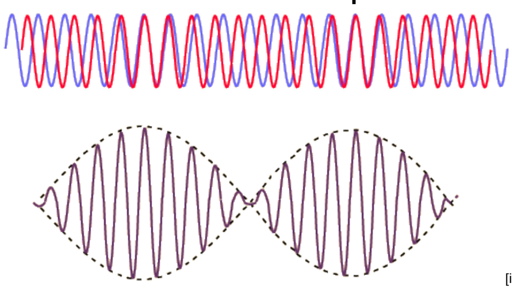
A. Constructive interference

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.



$$f_{beat} = |f_2 - f_1|$$

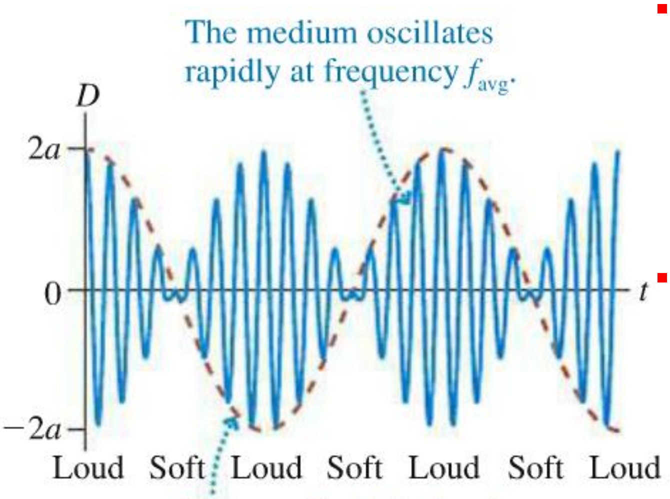
[image from http://hyperphysics.phy-astr.gsu.edu/hbase/sound/beat.html]

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

Class 4 Preclass Quiz – Student Comments…

- *"In the end of the pre-class quiz, …You say that the beat frequency is 2 Hz, but the formula gave me 1 Hz...so are those two different frequencies?"*



- The amplitude is slowly modulated with a frequency $f_{mod} = \Delta f/2$ (red-dashed line)
- Beats are heard at $f_{beat} = 2f_{mod} = \Delta f$ $= |f_1 - f_2|$

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**?