# Lecture 12 Chapter 17 Waves II



A rope under tension of 200 Newtons and fixed at both ends, oscillates in a second harmonic standing wave pattern. The displacement of the rope is given by

 $y = (0.10m)(\sin \pi x / 2)(\sin 12\pi t)$ 

where x=0 at one end of the rope, x is in meters, and t is in seconds.

#### What is:

(a) the length of the rope,

A rope under tension of 200 Newtons and fixed at both ends, oscillates in a second harmonic standing wave pattern. The displacement of the rope is given by

 $y = (0.10m)(\sin \pi x / 2)(\sin 12\pi t)$ 

where x=0 at one end of the rope, x is in meters, and t is in seconds. What is:(b) the speed of the waves on the rope,

A rope under tension of 200 Newtons and fixed at both ends, oscillates in a second harmonic standing wave pattern. The displacement of the rope is given by

 $y = (0.10m)(\sin \pi x / 2)(\sin 12\pi t)$ 

Where x=0 at one end of the rope, x is in meters, and t is in seconds. What is: (c) the mass of the rope?

A rope under tension of 200 Newtons and fixed at both ends, oscillates in a second harmonic standing wave pattern. The displacement of the rope is given by

 $y = (0.10m)(\sin \pi x / 2)(\sin 12\pi t)$ 

where x=0 at one end of the rope, x is in meters, and t is in seconds.

(d) If the rope oscillates in a third Harmonic standing wave pattern, what will be the period of oscillation?

# Sound Waves

- Speed of sound
- Bulk modulus and Young's modulus
- Traveling sound waves
- Interference
- Intensity and sound level decibel scale
- Musical sound and harmonics
- Beats
- Doppler Effect

# Demos

- Bell in a Vacuum
- Doppler Buzzer
- Interference of Sound Waves two speakers
- Tuning Fork Beats
- Sound Intensity Simpson sound level meter

# Demo 1 Bell in a vacuum

Sound waves require a medium to travel in. Here is proof.

# Spherical wavefront from a point source of sound





v = 343 m/s  
v = 
$$\sqrt{\frac{B}{\rho}} = \sqrt{\frac{2.2.10^9}{1000}} = 1483$$
 m/s

$$v = \sqrt{\frac{Y}{\rho}} = \sqrt{\frac{70.10^9}{2800}} = 5000 \text{ m/s}$$

Aluminum:



 $\Delta p_m = v \rho \omega s_m$ 

displacement and pressure

# Difference in phase between displacement and pressure is $\Delta p = -B \frac{\Delta V}{V}$ $\Delta V = \partial s$

$$\frac{\Delta V}{V} = \frac{\partial s}{\partial x}$$
$$\Delta p = -B\frac{\partial s}{\partial x}$$

Turns  $\cos(kx - \omega t)$  into  $\sin(kx - \omega t)$ 

$$s(x,t) = s_m \cos(kx - \omega t)$$
$$\frac{\partial s}{\partial x} = ks_m \sin(kx - \omega t)$$
$$\Delta p = \Delta p_m \sin(kx - \omega t)$$

# Phase and Interference: What makes waves get out of phase?

- a. Each wave travels a different distance to get to the point where you detect it.
- b. The outcome at P depends on what the phase difference is between the two waves.





 $y'(x,t) = 2y_m \cos \frac{1}{2}\phi \sin(kx - \omega t + \frac{1}{2}\phi)$ Amplitude =  $2y_m \cos \frac{1}{2}\phi$ 

# **Constructive Interference**



 $Amplitude = 2y_m \cos\frac{1}{2}\phi$ 

Constructive interference occurs at P when

$$\frac{\phi}{2} = m\pi, \quad m = 0, 1, 2, 3, 4...$$
  
 $\frac{\Delta L}{\lambda} = 0, 1, 2, 3...$ 



 $Amplitude = 2y_m \cos\frac{1}{2}\phi$ 

Destructive interference at P occurs when  $\frac{\varphi}{2}$ 

$$\frac{\phi}{2} = (m + \frac{1}{2})\pi, \quad m = 0, 1, 2, 3, 4...$$
$$\frac{\Delta L}{\lambda} = 0.5, 1.5, 2.5, ...$$

# Problem 20 Chpt 17

The figure shows two point sources  $s_1$  and  $s_2$  that emit sound waves of  $\lambda = 2$  m. The emissions are isotropic and in phase and the line separation between the sources is d=16 m. (a) Find an expression for the path length difference of the two sources at p. (b) At what value of x is the phase difference 0.5 $\lambda$  and 1.0 $\lambda$ ? Is this constructive or destructive Interference?



(a) Find an expression for the path length difference of the two sources at p.  $\Delta L=L_2-x$  and d=16 m



(b) At what value of x is the phase difference  $0.5\lambda$  and  $1.0\lambda$ ? Is this constructive or destructive Interference?  $\Delta L=L_2-x$  and d=16 m



# Intensity of Sound I and Power P:Inverse Square Law



Suppose we have a point source of sound. The sound waves will propagate outward like spherically shaped wavefronts. A wave front is a region where every point is vibrating in phase. The direction of propagation is perpendicular to the wavefront.

I =average rate energy is being transferred per unit area through or onto a surface.

$$I = \frac{1}{2}\rho v \omega^2 s_m^2$$

P = I A where A is the total area the energy is passing through. For a point source the area A of the sphere at r that the sound is passing through is  $4\pi r^2$ . Or we can say that the  $I = P / 4\pi r^2$ . The further from the source the less the intensity. It gets weaker by  $1/r^2$ . This is another inverse square law.

### Sound level intensity is measured in dB.

 $\beta = (10 \text{ dB}) \log \text{I/I}_0$ 

 $I_0$  is a reference level equal to 10<sup>-12</sup> W/m<sup>2</sup>

Suppose  $\beta$ =50

 $50= (10 \text{ dB}) \log I / I_0$   $5 = \log I / I_0$   $I/I_0 = 10^5$  $I=10^5 \ 10^{-12}=10^{-7} \text{ W/m}^2$ 

Every time the level increases by a factor of 10,  $\beta$  increases by 10 dB

#### Show Simpson decibel meter

# Problem 26 Chpt 17

The source of a sound wave has a power of P=1  $\mu$ W. If it is a point source, a) What is the intensity 3 m away and b) what is the sound level in decibels at that distance?



# Problem 26 Chpt 17

The source of a sound wave has a power of P=1  $\mu$ W. If it is a point source, a) What is the intensity 3 m away and b) what is the sound level in decibels at that distance?



# Example of a sound line source: Inverse r Law



$$L = 10m$$
$$P = 1.6 \times 10^4 W$$
 at the line

What is the intensity I at r =12 m from the spark?

$$I = \frac{P}{A} = \frac{P}{2\pi rL}$$
  
=  $\frac{1.6 \times 10^4 W}{(2\pi)(12m)(10m)} = 21W / m^2$ 

# Othe types of resonances and harmonics Differences between musical instruments



Same fundamental – same note, but sound different due to different combination of harmonics

# Open Pipes as Sources of sound Demo Whirling tube

Both ends open : Antinodes at both ends



#### Harmonics



# Beats Demo Tuning Fork Beats

 $\int \int \int f_1 = 440 Hz$  $\int f_2 = 444 Hz$  $f^{+} = 442 Hz$ (c)  $f^{-} = 2Hz$   $f^{-} = \frac{1}{2\pi} (\omega_{2} - \omega_{1})$ Time  $f_{heat} = 2f^- = 4Hz$ 

$$y = y_0 \cos \omega_1 t + y_0 \cos \omega_2 t$$
$$y = 2y_0 \cos \frac{1}{2} (\omega_1 - \omega_2) t \ \cos \frac{1}{2} (\omega_1 + \omega_2) t$$

# **Doppler Effect**

Demonstrate with a rotating whistle.





Source moving away from detector in the opposite direction of v, then frequency is lower X

#### Doppler Effect with detector moving





 $v_{\rm D}$  is moving opposite to velocity of wavefront

$$f' = f \frac{v - v_D}{v}$$

 $v_D$  is moving in the same direction as the velocity of wavefront.

### Problem 18-49

A whistle of 540 Hz is rotating around a circle of radius 60 cm with angular speed of 15.0 rad/s. What are the lowest and highest frequencies heard by a listener far away.



 $V_s$ = 15 rad/s 0.60 m =9 m/s V speed of sound = 343 m/s

Demo Doppler Buzzer

### Problem 18-49

A whistle of 540 Hz is rotating around a circle of radius 60 cm with angular speed of 15.0 rad/s. What are the lowest and highest frequencies heard by a listener far away.



 $V_s$ = 15 rad/s 0.60 m =9 m/s V speed of sound = 343 m/s

Demo Doppler Buzzer

#### Problem 18-49

A whistle of 540 Hz is rotating around a circle of radius 60 cm with angular speed of 15.0 rad/s. What are the lowest and highest frequencies heard by a listener far away.



V speed of sound = 343 m/s

#### Demo Doppler Buzzer

# Problem 52 Chpt 17

52) A stationary motion detector sends sound waves of frequencies 0.150 MHz toward a truck approaching at a speed of 45.0 m/s. What is the frequency of the waves sent back towards the detector?

# ConcepTest 14.13 Open and Closed Pipes

You blow into an open pipe and produce a tone. What happens to the frequency of the tone if you close the end of the pipe and blow into it again?

- 1) depends on the speed of sound in the pipe
- 2) you hear the same frequency
- 3) you hear a higher frequency
- 4) you hear a lower frequency

# ConcepTest 15.2a Standing Waves I

A string is clamped at both ends and plucked so it vibrates in a standing mode between two extreme positions *a* and *b*. Let upward motion correspond to positive velocities. When the string is in position *b*, the instantaneous velocity of points on the string:

- 1) is zero everywhere
- 2) is positive everywhere
- 3) is negative everywhere
- 4) depends on the position along the string



# ConcepTest 15.3 Beats

The traces below show beats that occur when two different pairs of waves interfere. For which case is the *difference in frequency* of the original waves *greater*?

- 1) pair 1
- 2) pair 2
- 3) same for both pairs
- 4) impossible to tell by just looking



# ConcepTest 14.10a Sound Intensity I

You stand a certain distance away from a speaker and you hear a certain intensity of sound. If you double your distance from the speaker, what happens to the sound intensity at your new position?

- 1) drops to 1/2 its original value
- 2) drops to 1/4 its original value
- 3) drops to 1/8 its original value
- 4) drops to 1/16 its original value
- 5) does not change at all

### ConcepTest 14.11a Decibel Level I

When Mary talks, she creates an intensity level of 60 dB at your location. Alice talks with the same volume, also giving 60 dB at your location. If both Mary and Alice talk simultaneously from the same spot, what would be the new intensity level that you hear?

- 1) more than 120 dB
- 2) 120 dB
- 3) between 60 dB and 120 dB
- 4) 60 dB
- 5) less than 60 dB

# ConcepTest 14.15a Doppler Effect I

Observers A, B and C listen to a moving source of sound. The location of the wave fronts of the moving source with respect to the observers is shown below. Which of the following is true?

- 1) frequency is highest at A
- 2) frequency is highest at **B**
- 3) frequency is highest at C
- 4) frequency is the same at all three points



# ConcepTest 14.13 Open and Closed Pipes

You blow into an open pipe and produce a tone. What happens to the frequency of the tone if you close the end of the pipe and blow into it again?

- 1) depends on the speed of sound in the pipe
- 2) you hear the same frequency
- 3) you hear a higher frequency

4) you hear a lower frequency

In the open pipe, 1/2 of a wave "fits" into the pipe, while in the closed pipe, only 1/4 of a wave fits. Because the wavelength is larger in the closed pipe, the frequency will be lower.

Follow-up: What would you have to do to the pipe to increase the frequency?



## ConcepTest 15.2a Standing Waves I

A string is clamped at both ends and plucked so it vibrates in a standing mode between two extreme positions *a* and *b*. Let upward motion correspond to positive velocities. When the string is in position *b*, the instantaneous velocity of points on the string:

1) is zero everywhere

- 2) is positive everywhere
- 3) is negative everywhere
- 4) depends on the position along the string



# ConcepTest 15.3 Beats

The traces below show beats that occur when two different pairs of waves interfere. For which case is the *difference in frequency* of the original waves *greater*? 1) pair 1

2) pair 2

- 3) same for both pairs
- 4) impossible to tell by just looking

Recall that the beat frequency is the difference in frequency between the two waves:  $f_{beat} = f_2 - f_1$ 

Pair 1 has the greater beat frequency (more oscillations in same time period), so Pair 1 has the greater frequency difference.



### ConcepTest 14.10a Sound Intensity I

You stand a certain distance away from a speaker and you hear a certain intensity of sound. If you double your distance from the speaker, what happens to the sound intensity at your new position?

1) drops to 1/2 its original value

- 2) drops to 1/4 its original value
  - 3) drops to 1/8 its original value
  - 4) drops to 1/16 its original value
  - 5) does not change at all

For a source of a given power *P*, the intensity is given by  $I = P/4pr^2$ . So if the **distance doubles**, the intensity must **decrease to one-quarter** its original value.

**Follow-up:** What distance would reduce the intensity by a factor of 100?

### ConcepTest 14.11a Decibel Level I

When Mary talks, she creates an intensity level of 60 dB at your location. Alice talks with the same volume, also giving 60 dB at your location. If both Mary and Alice talk simultaneously from the same spot, what would be the new intensity level that you hear?



2) 120 dB

- 3) between 60 dB and 120 dB
  - 4) 60 dB
  - 5) less than 60 dB

Recall that a difference of 10 dB in intensity level b corresponds to a factor of  $10^1$  in intensity. Similarly, a difference of 60 dB in b corresponds to a factor of  $10^6$  in intensity!! In this case, with two voices adding up, the intensity increases by only a factor of 2, meaning that the intensity level is higher by an amount equal to: Db = 10 log(2) = 3 dB. The new intensity level is b = 63 dB.

# ConcepTest 14.15a Doppler Effect I

Observers A, B and C listen to a moving source of sound. The location of the wave fronts of the moving source with respect to the observers is shown below. Which of the following is true?

- 1) frequency is highest at A
- 2) frequency is highest at **B**

3) frequency is highest at C

4) frequency is the same at all three points

The number of wave fronts hitting **observer C** per unit time is greatest – thus the observed frequency is highest there.



**Follow-up:** Where is the frequency lowest?