

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

“The breaking of a wave cannot explain the whole sea.”

-Vladimir Nabokov

David J. Starling
Penn State Hazleton
PHYS 213

Objectives for Chapter 17

- (a) Describe the properties of a wave, e.g., longitudinal or transverse, wavefronts, speed, wavelength, wave number, frequency and period.
- (b) Apply the displacement function $s(x, t)$ to describe a traveling wave and relate this to pressure variation.
- (c) Using the concept of phase difference, describe the production of interference.
- (d) Relate the concepts of power, surface area, intensity, sound level and the displacement amplitude.
- (e) Apply the concepts of standing waves and interference to describe musical instruments and beats.
- (f) Calculate and describe the measured frequency of a wave when the source or detector are in motion; for motion exceeding the speed of sound, describe the shock wave and Mach cone angle.

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Objectives (Ch 17)

Sounds Waves

Interference

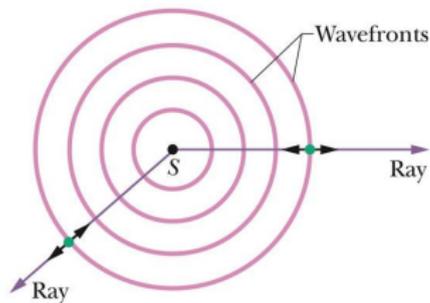
Intensity and Level

Music and Beats

Doppler Effect

A physics professor breathes in a small amount of helium and begins to talk. The result is that the professor's normally low, baritone voice sounds quite high pitched. Why did this occur?

Sound waves are longitudinal waves that travel through solids and fluids.



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

Objectives (Ch 17)

Sounds Waves

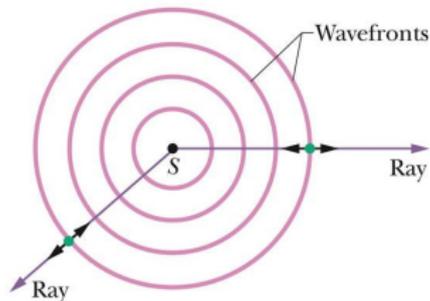
Interference

Intensity and Level

Music and Beats

Doppler Effect

Sound waves are longitudinal waves that travel through solids and fluids.



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

The source is at S and the wave propagates outward in a sphere. The pink lines are *wavefronts*.

Objectives (Ch 17)

Sounds Waves

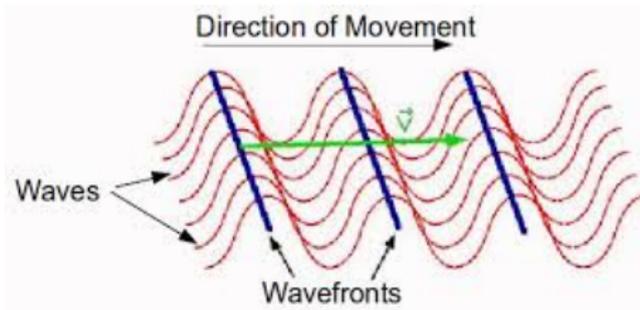
Interference

Intensity and Level

Music and Beats

Doppler Effect

A wavefront is a surface over which the oscillations have the same value (density, in the case of sound).



Objectives (Ch 17)

Sounds Waves

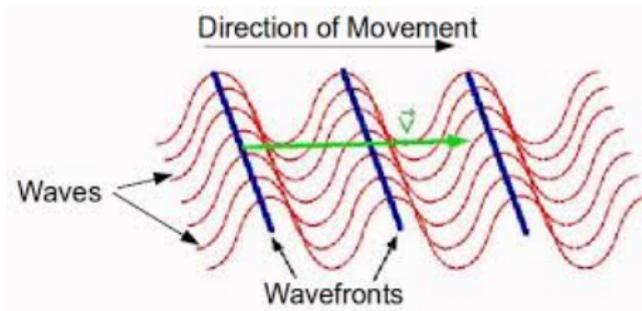
Interference

Intensity and Level

Music and Beats

Doppler Effect

A wavefront is a surface over which the oscillations have the same value (density, in the case of sound).



The direction of propagation is perpendicular to the wavefront.

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

The speed of a sound wave in a given material depends on that material's density ρ and its bulk modulus B .

$$v = \sqrt{\frac{B}{\rho}} \quad (1)$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

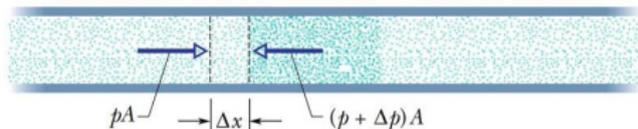
Music and Beats

Doppler Effect

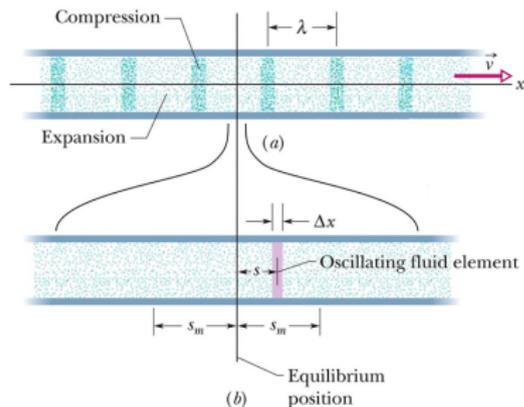
The speed of a sound wave in a given material depends on that material's density ρ and its bulk modulus B .

$$v = \sqrt{\frac{B}{\rho}} \quad (1)$$

A formal derivation of the wave velocity involves the use of $F_{net} = ma$ on an element of gas and the definition of $B = -\Delta p / (\Delta V / V)$.



A sound wave is a compression wave where the molecules oscillate back and forth around an equilibrium, like a spring.



Objectives (Ch 17)

Sounds Waves

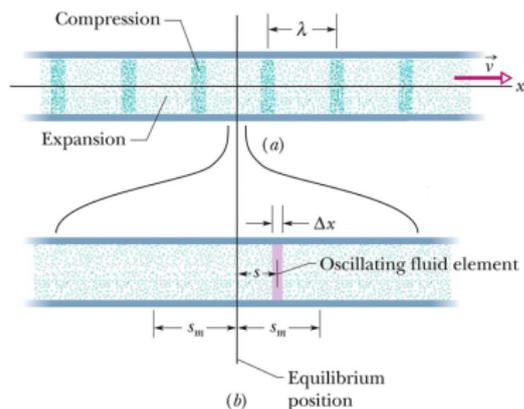
Interference

Intensity and Level

Music and Beats

Doppler Effect

A sound wave is a compression wave where the molecules oscillate back and forth around an equilibrium, like a spring.



- ▶ the distance between two high pressure points is the wavelength
- ▶ the molecules don't travel very far

Objectives (Ch 17)

Sounds Waves

Interference

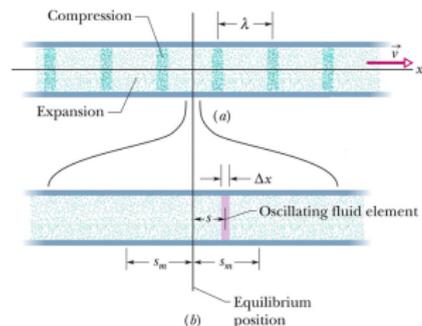
Intensity and Level

Music and Beats

Doppler Effect

The particles in a sound wave behave like a traveling wave, described by the usual equation:

$$s(x, t) = s_m \cos(kx - \omega t)$$



Objectives (Ch 17)

Sounds Waves

Interference

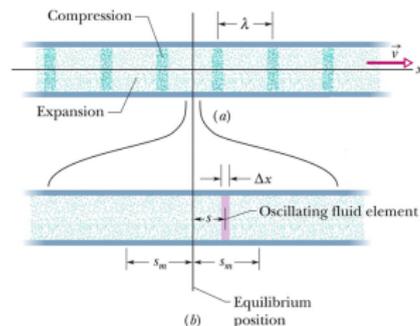
Intensity and Level

Music and Beats

Doppler Effect

The particles in a sound wave behave like a traveling wave, described by the usual equation:

$$s(x, t) = s_m \cos(kx - \omega t)$$



- ▶ wavenumber $k = 2\pi/\lambda$
- ▶ angular frequency $\omega = 2\pi f$
- ▶ displacement amplitude s_m

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

But how does the pressure change? To connect position of particles to pressure, let's use the bulk modulus:

$$\Delta p = -B \frac{\Delta V}{V}$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

But how does the pressure change? To connect position of particles to pressure, let's use the bulk modulus:

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

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

But how does the pressure change? To connect position of particles to pressure, let's use the bulk modulus:

$$\Delta p = -B \frac{\Delta V}{V}$$

$$V = A\Delta x$$

$$\Delta V = A\Delta s$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

But how does the pressure change? To connect position of particles to pressure, let's use the bulk modulus:

$$\Delta p = -B \frac{\Delta V}{V}$$

$$V = A\Delta x$$

$$\Delta V = A\Delta s$$

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

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

But how does the pressure change? To connect position of particles to pressure, let's use the bulk modulus:

$$\begin{aligned}\Delta p &= -B \frac{\Delta V}{V} \\ V &= A \Delta x \\ \Delta V &= A \Delta s \\ \Delta p &= -B \frac{A \Delta s}{A \Delta x} \approx -B \frac{\partial s}{\partial x}\end{aligned}$$

Taking a derivative of $s(x, t)$ w.r.t. x , we find:

$$\Delta p = B k s_m \sin(kx - \omega t) = v^2 \rho k s_m \sin(kx - \omega t) \quad (2)$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

But how does the pressure change? To connect position of particles to pressure, let's use the bulk modulus:

$$\begin{aligned}\Delta p &= -B \frac{\Delta V}{V} \\ V &= A \Delta x \\ \Delta V &= A \Delta s \\ \Delta p &= -B \frac{A \Delta s}{A \Delta x} \approx -B \frac{\partial s}{\partial x}\end{aligned}$$

Taking a derivative of $s(x, t)$ w.r.t. x , we find:

$$\Delta p = B k s_m \sin(kx - \omega t) = v^2 \rho k s_m \sin(kx - \omega t) \quad (2)$$

We typically write $v^2 \rho k s_m = \Delta p$.

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Two fans are watching a baseball game from different positions. One fan is located directly behind home plate, 18.3 m from the batter. The other fan is located in the centerfield bleachers, 127 m from the batter. Both fans observe the batter strike the ball at the same time, but the fan behind home plate hears the sound first. What is the time difference between hearing the sound at the two locations?

- (a) 0.316 s
- (b) 0.368 s
- (c) 0.053 s
- (d) 0.189 s
- (e) 0.632 s

(note: use 345 m/s as the speed of sound.)

Objectives (Ch 17)

Sounds Waves

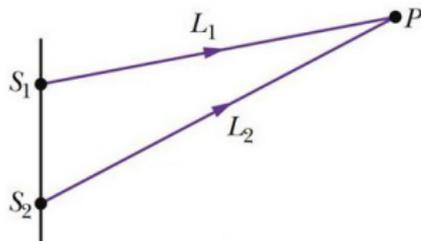
Interference

Intensity and Level

Music and Beats

Doppler Effect

When two “coherent” waves combine at a common location, they undergo interference.



Objectives (Ch 17)

Sounds Waves

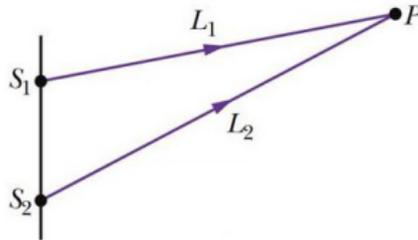
Interference

Intensity and Level

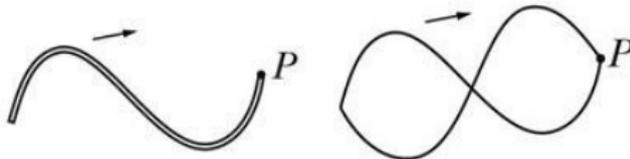
Music and Beats

Doppler Effect

When two “coherent” waves combine at a common location, they undergo interference.



If the waves arrive in phase, they add—out of phase, they subtract.



Objectives (Ch 17)

Sounds Waves

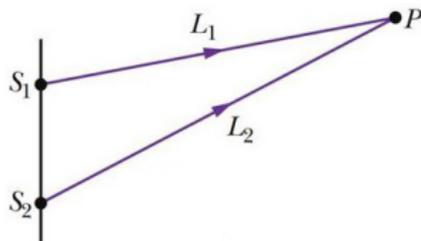
Interference

Intensity and Level

Music and Beats

Doppler Effect

For two waves of the same wavelength passing through a common point, the result depends entirely on their phase difference ϕ .



Objectives (Ch 17)

Sounds Waves

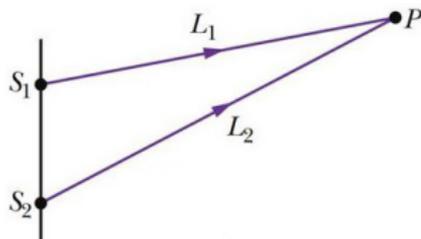
Interference

Intensity and Level

Music and Beats

Doppler Effect

For two waves of the same wavelength passing through a common point, the result depends entirely on their phase difference ϕ .



The path length difference $\Delta L = L_2 - L_1$ determines the phase difference:

$$\phi = \frac{\Delta L}{\lambda} 2\pi \quad (3)$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

When ϕ is an integer multiple of 2π , the waves combine constructively.

$$\phi = m(2\pi) \text{ or } \frac{\Delta L}{\lambda} = 0, 1, 2, \dots$$

$$m \in (0, 1, 2, ..)$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

When ϕ is an integer multiple of 2π , the waves combine constructively.

$$\phi = m(2\pi) \text{ or } \frac{\Delta L}{\lambda} = 0, 1, 2, \dots$$

.....

When ϕ is an odd multiple of π , the waves combine destructively.

$$\phi = (2m + 1)\pi \text{ or } \frac{\Delta L}{\lambda} = 0.5, 1.5, 2.5, \dots$$

$$m \in (0, 1, 2, \dots)$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

A radio station has two transmitting towers that transmit electromagnetic waves uniformly in all directions on the west end and east end of Main Street. The same signal is broadcast at the same time from both towers. As you drive ten miles east to west on Main Street, what would you hear as you listen to the radio station broadcast from these two towers?

- (a) The signal gets stronger as you drive the first five miles, but then the signal decreases as you travel the final five miles.
- (b) The signal is somewhat stronger than compared to a single tower, with no variation.
- (c) The signal alternates between increasing strength and decreasing strength as you drive the ten miles.
- (d) The signal is the same as only one tower since you switch from one tower to the next when you cross half way.
- (e) To answer this question, one must know the amplitude of the broadcast signal.

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Traveling waves carry energy at a particular rate known as power P . When concentrated over a certain area A , we get intensity:

$$I = \frac{P}{A} \text{ W/m}^2 \quad (4)$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Traveling waves carry energy at a particular rate known as power P . When concentrated over a certain area A , we get intensity:

$$I = \frac{P}{A} \text{ W/m}^2 \quad (4)$$

This energy can be absorbed by an object (e.g., a microphone) or passed through an object (e.g., an open window).

Intensity and Level

We can expand this relationship using conservation of energy:

$$I = \frac{P}{A} = \frac{1}{A} \frac{dK}{dt}$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

We can expand this relationship using conservation of energy:

$$\begin{aligned} I &= \frac{P}{A} = \frac{1}{A} \frac{dK}{dt} \\ &= \frac{2}{A} \frac{(0.5dm v_s^2)}{dt} \end{aligned}$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

We can expand this relationship using conservation of energy:

$$\begin{aligned} I &= \frac{P}{A} = \frac{1}{A} \frac{dK}{dt} \\ &= \frac{2}{A} \frac{(0.5dm v_s^2)}{dt} \\ &= \frac{1}{A} \frac{[(\rho A dx)(-\omega s_m \sin(kx - \omega t))^2]}{dt} \end{aligned}$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

We can expand this relationship using conservation of energy:

$$\begin{aligned} I &= \frac{P}{A} = \frac{1}{A} \frac{dK}{dt} \\ &= \frac{2}{A} \frac{(0.5dm v_s^2)}{dt} \\ &= \frac{1}{A} \frac{[(\rho A dx)(-\omega s_m \sin(kx - \omega t))^2]}{dt} \\ &= \frac{dx}{dt} \rho \omega^2 s_m^2 \sin^2(kx - \omega t) \end{aligned}$$

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

We can expand this relationship using conservation of energy:

$$\begin{aligned} I &= \frac{P}{A} = \frac{1}{A} \frac{dK}{dt} \\ &= \frac{2}{A} \frac{(0.5dm v_s^2)}{dt} \\ &= \frac{1}{A} \frac{[(\rho A dx)(-\omega s_m \sin(kx - \omega t))^2]}{dt} \\ &= \frac{dx}{dt} \rho \omega^2 s_m^2 \sin^2(kx - \omega t) \\ I_{avg} &= \frac{1}{2} \rho v \omega^2 s_m^2. \end{aligned}$$

Objectives (Ch 17)

Sounds Waves

Interference

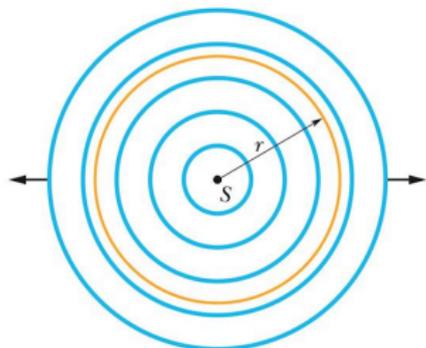
Intensity and Level

Music and Beats

Doppler Effect

If a source emits sound isotropically (equal in all directions), then the intensity drops as:

$$I = \frac{P_s}{4\pi r^2} \quad (5)$$



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

Objectives (Ch 17)

Sounds Waves

Interference

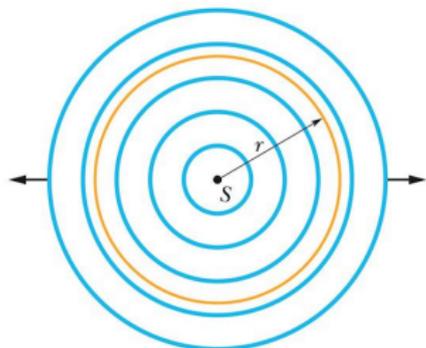
Intensity and Level

Music and Beats

Doppler Effect

If a source emits sound isotropically (equal in all directions), then the intensity drops as:

$$I = \frac{P_s}{4\pi r^2} \quad (5)$$



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

This is due to the area of the sphere increasing with r .

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Sound level β is defined based on a logarithmic scale:

$$\beta = (10 \text{ dB}) \log \frac{I}{I_0}. \quad (6)$$

I_0 is a standard reference set to 10^{-12} W/m^2 .

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Sound level β is defined based on a logarithmic scale:

$$\beta = (10 \text{ dB}) \log \frac{I}{I_0}. \quad (6)$$

I_0 is a standard reference set to 10^{-12} W/m^2 .

Table 17-2 Some Sound Levels (dB)

Hearing threshold	0
Rustle of leaves	10
Conversation	60
Rock concert	110
Pain threshold	120
Jet engine	130

Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

Objectives (Ch 17)

Sounds Waves

Interference

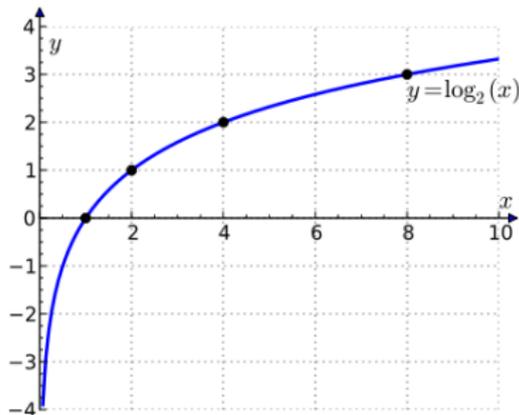
Intensity and Level

Music and Beats

Doppler Effect

Intensity and Level

Why logarithmic? The human ear can detect intensities in a range spanning 12 orders of magnitude!



Objectives (Ch 17)

Sounds Waves

Interference

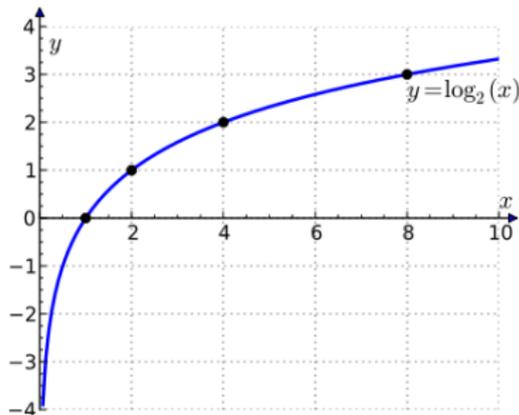
Intensity and Level

Music and Beats

Doppler Effect

Intensity and Level

Why logarithmic? The human ear can detect intensities in a range spanning 12 orders of magnitude!



A large change in intensity results in a small change in sound level.

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Software is used to amplify a digital sound file on a computer by 20 dB. By what factor has the intensity of the sound been increased as compared to the original sound file?

- (a) 2
- (b) 5
- (c) 10
- (d) 20
- (e) 100

A sound level meter is used measure the sound intensity level. A sound level meter is placed an equal distance in front of two speakers (assume no interference). A signal of constant power may be sent to each of the speakers independently or at the same time. When either speaker is turned on, the sound level meter reads 90.0 dB. What will the sound level meter read when both speakers are turned on at the same time?

- (a) 90.0 dB
- (b) 93.0 dB
- (c) 96.0 dB
- (d) 100.0 dB
- (e) 180.0 dB

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

When sound waves oscillate in a pipe (or on a string), the geometry of the object determines the possible wavelengths.

Objectives (Ch 17)

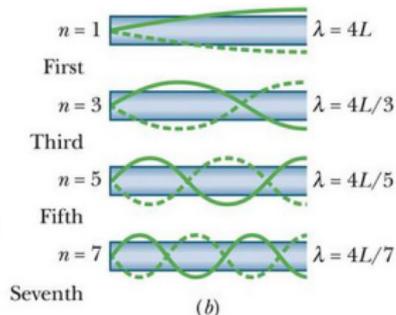
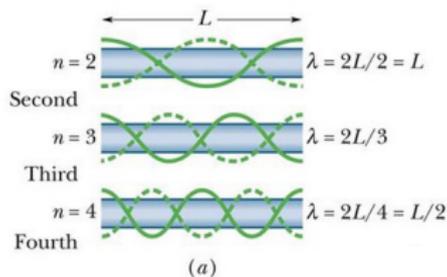
Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect



When sound waves oscillate in a pipe (or on a string), the geometry of the object determines the possible wavelengths.

Objectives (Ch 17)

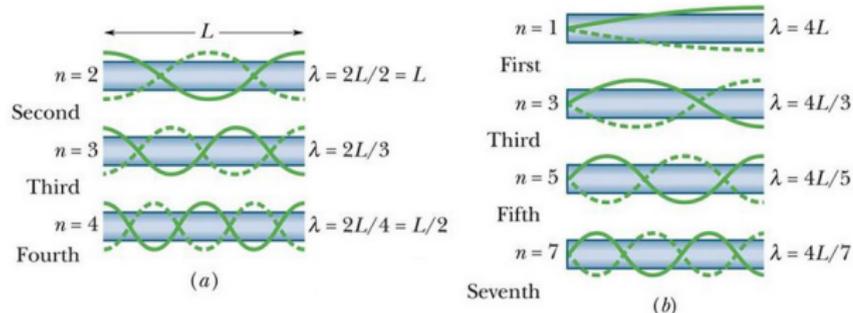
Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

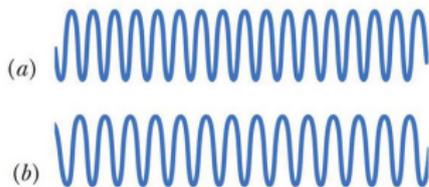


In terms of frequency ($f = v/\lambda$):

$$f = \frac{n\nu}{2L}, n = 1, 2, 3, \dots \text{ Open at both ends.}$$

$$f = \frac{n\nu}{4L}, n = 1, 3, 5, \dots \text{ Open at one end.}$$

When two waves of slightly different frequency mix, we see/hear a pattern that oscillates at the beat frequency $f_{beat} = f_1 - f_2$.



Objectives (Ch 17)

Sounds Waves

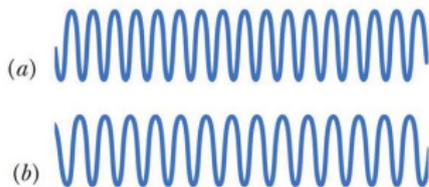
Interference

Intensity and Level

Music and Beats

Doppler Effect

When two waves of slightly different frequency mix, we see/hear a pattern that oscillates at the beat frequency $f_{beat} = f_1 - f_2$.



The beat frequency is always less than the other two frequencies.

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Given that the first three resonant frequencies of an organ pipe are 200, 600, and 1000 Hz, what can you conclude about the pipe?

- (a) The pipe is open at both ends and has a length 0.95 m.
- (b) The pipe is closed at one end and has a length 0.95 m.
- (c) The pipe is closed at one end and has a length 0.475 m.
- (d) The pipe is open at both ends and has a length 0.475 m.
- (e) It is not possible to have a pipe with this combination of resonant frequencies.

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

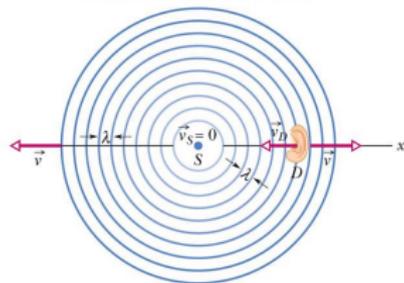
Music and Beats

Doppler Effect

Doppler Effect

When an object emits sound while moving, the observed sound depends on the velocity of the source and detector in the medium (e.g., air).

Shift up: The detector moves toward the source.



Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect

Doppler Effect

When an object emits sound while moving, the observed sound depends on the velocity of the source and detector in the medium (e.g., air).

Objectives (Ch 17)

Sounds Waves

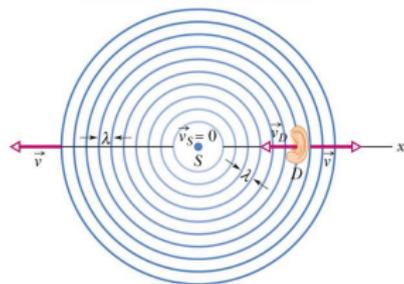
Interference

Intensity and Level

Music and Beats

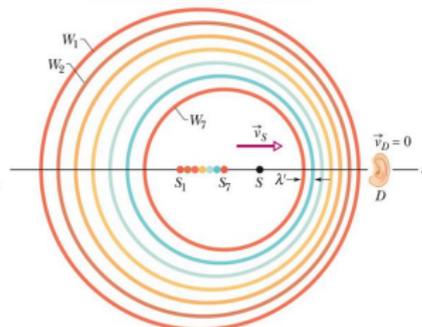
Doppler Effect

Shift up: The detector moves toward the source.



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

Shift up: The source moves toward the detector.



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

Doppler Effect

When an object emits sound while moving, the observed sound depends on the velocity of the source and detector in the medium (e.g., air).

Objectives (Ch 17)

Sounds Waves

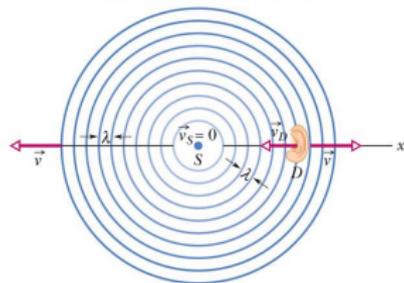
Interference

Intensity and Level

Music and Beats

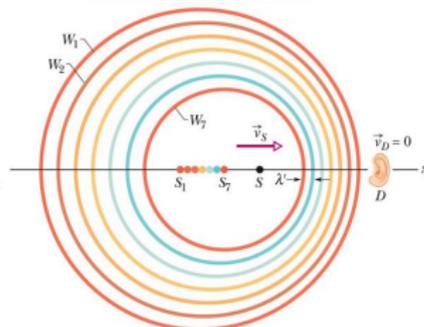
Doppler Effect

Shift up: The detector moves toward the source.



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

Shift up: The source moves toward the detector.



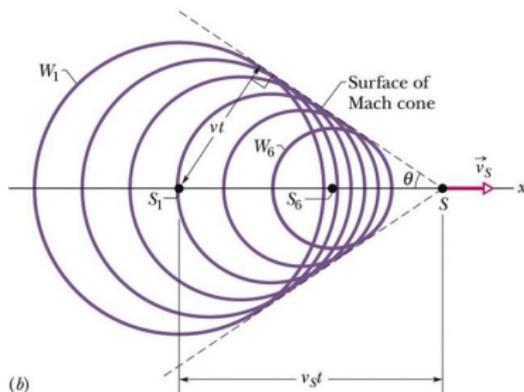
Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

$$f' = f \frac{v \pm v_D}{v \mp v_S} \quad (7)$$

(top sign: toward—bottom sign: away)

Doppler Effect

When a source is moving at a speed v_s faster than the speed of sound v , the sound waves pile up producing a shock wave.



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

Objectives (Ch 17)

Sounds Waves

Interference

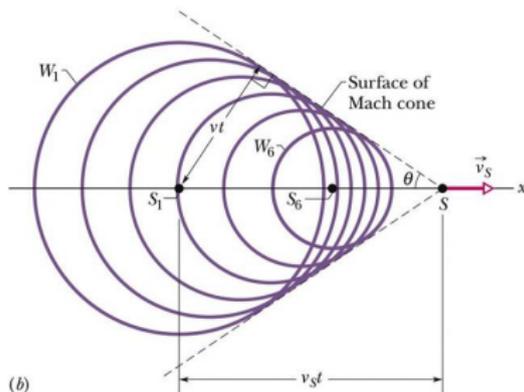
Intensity and Level

Music and Beats

Doppler Effect

Doppler Effect

When a source is moving at a speed v_s faster than the speed of sound v , the sound waves pile up producing a shock wave.



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

Objectives (Ch 17)

Sounds Waves

Interference

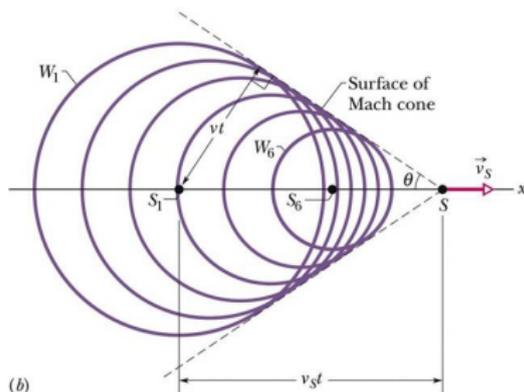
Intensity and Level

Music and Beats

Doppler Effect

Doppler Effect

When a source is moving at a speed v_s faster than the speed of sound v , the sound waves pile up producing a shock wave.



Copyright © 2014 John Wiley & Sons, Inc. All rights reserved.

The mach cone has a half-angle:

$$\sin(\theta) = \frac{v}{v_s} \quad (8)$$

Objectives (Ch 17)

Sounds Waves

Interference

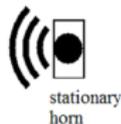
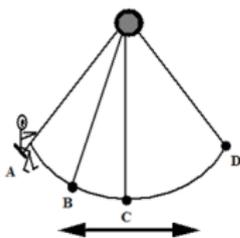
Intensity and Level

Music and Beats

Doppler Effect

Doppler Effect

A child is swinging back and forth with a constant period and amplitude. A stationary horn is emitting a constant tone of frequency f . At which position(s) will the child hear the lowest frequency for the sound from the whistle?



- (a) at B when moving toward A
- (b) at B when moving toward C
- (c) at C when moving toward B
- (d) at C when moving toward D
- (e) at both A and D

Objectives (Ch 17)

Sounds Waves

Interference

Intensity and Level

Music and Beats

Doppler Effect