Ch 17: Waves II

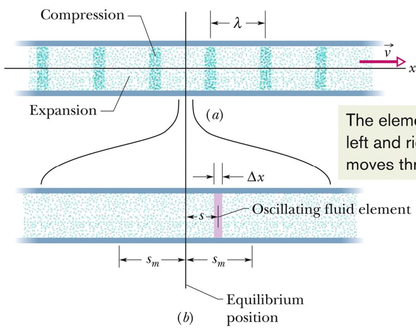
The Exciting World of Sound Waves

In this Chapter, We Explore:

- How do we relate the transverse wave function to sound waves?
- How do we experience sound wave interference?
- How does the human ear interpret the intensity of sound waves?
- How cool are the Doppler Effect and Supersonic Shock Waves? (Answer: Very!)

Traveling Sound Waves

- Two points of view:
  - how the pressure changes (Δp) as a function of traveled distance (x) and time (t)
  - how the displacement of the medium (s) as a function of traveled distance (x) and time (t).



The element oscillates left and right as the wave moves through it.

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

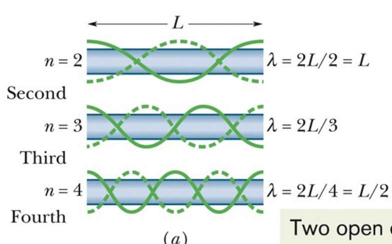
$$\Delta p(x,t) = \Delta p_m \sin(kx - \omega t)$$

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

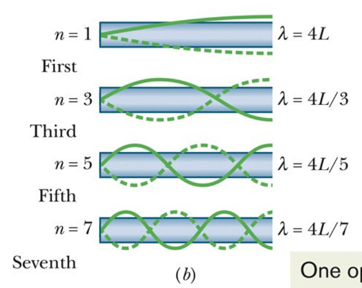
Density of medium

- Since the displaced medium "rides" at the end of the pressure wave, the two functions are out of phase with each other by $\pi/2$.

Sound Waves can make Standing Waves



Two open ends—any harmonic

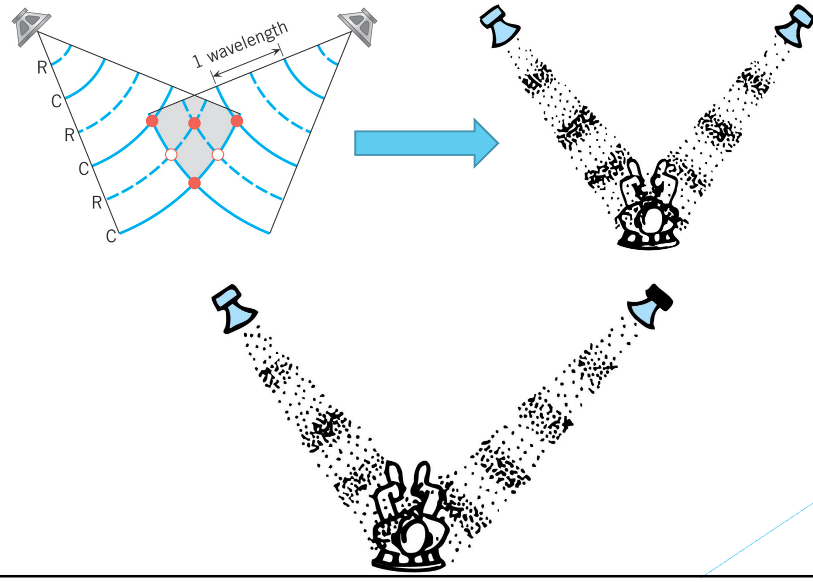


One open end—only *odd* harmonics

$$f = \frac{v}{\lambda} = \frac{nv}{2L}, \qquad n = 1, 2, 3, \ldots,$$

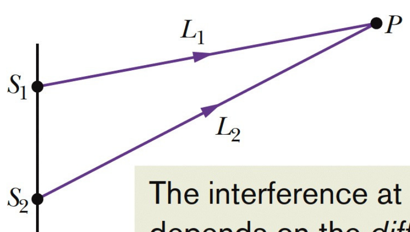
$$f = \frac{v}{\lambda} = \frac{nv}{4L}, \qquad n = 1, 3, 5, \ldots.$$

Experiencing Sound Wave Interference



Destructive or Constructive Experience?

- It's all about the path length difference (ΔL) between the traveling waves.



The interference at *P* depends on the *difference* in the path lengths to reach *P*.

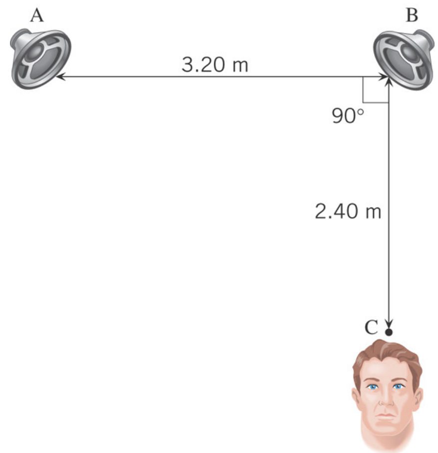
$$\frac{\Delta L}{\lambda} = 0, 1, 2, \ldots \quad \text{(fully constructive interference).}$$

$$\frac{\Delta L}{\lambda} = 0.5, 1.5, 2.5, \ldots \quad \text{(fully destructive interference).}$$

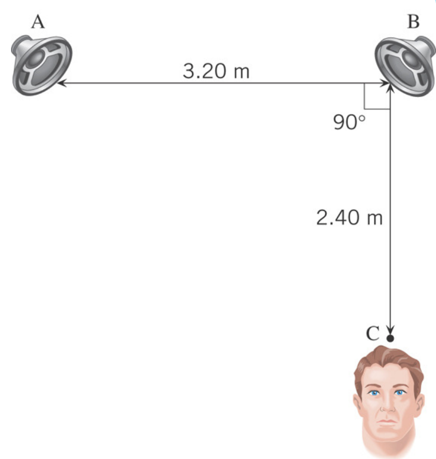
Example: What does a listener hear?

Two in-phase loudspeakers, A and B, are separated by *3.20 m*. A listener is stationed at C, which is *2.40 m* in front of speaker B. Both speakers are playing identical *214-Hz* tones, and the speed of sound is *343 m/s*.

Does the listener hear a loud sound, or no sound?



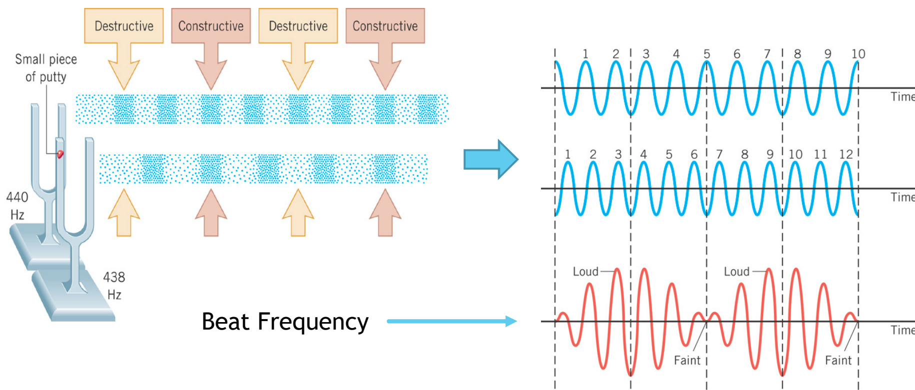
Work the Example:



Resonance & Beats

- **Resonance:** When a source matches the natural frequency of another object and causes vibrations in that object w/o physical contact.
- **Beat Frequency:** When two sound sources have frequencies close enough such that their interference create a new repeated pattern within their two sounds.

$$f_{beat} = f_1 - f_2 \quad \text{(beat frequency).}$$



Intensity & Sound Level

- **Intensity**: the average rate of change if energy per unit area.

Power = Energy/time

Area depends on how wave is being emitted or through what kind of opening the wave passes.

$$I = \frac{P}{A}$$

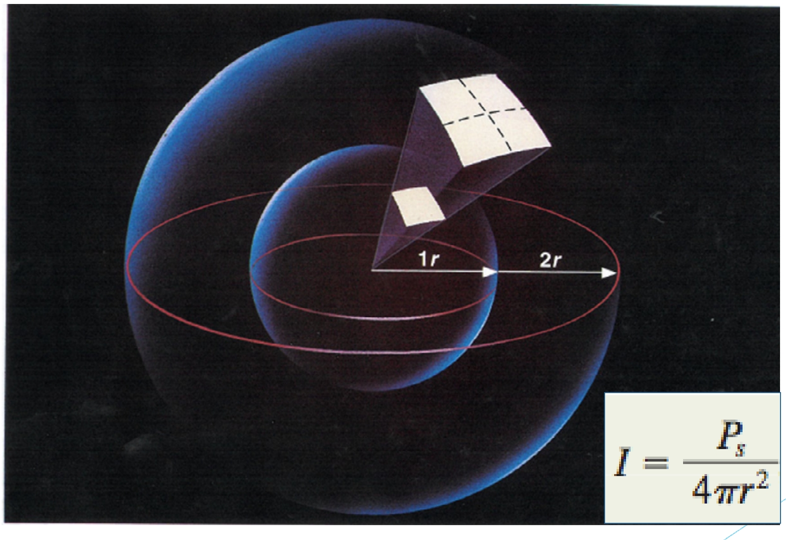
Unit: W/m^2

- Intensity and displacement (s_m) amplitude are related.

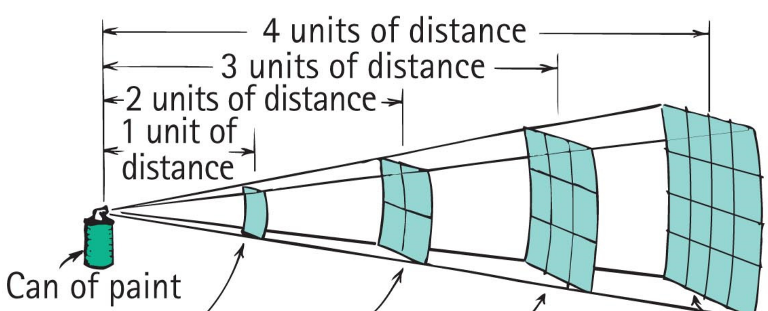
$$I = \tfrac{1}{2}\rho v \omega^2 s_m^2$$

The 1/r² Dependency

- Example: Imagine a points source S that emits sound uniformly in all directions.



The 1/r² Dependency



	1 area unit	4 area units	( ) area units	( ) area units
Paint spray	1 layer thick	¼ layer thick	( ) layer thick	( ) layer thick

How Human Ears Experience Intensity

- The Decibel Scale measures intensity by taking into account how the human ear experiences intensity.
- The sound level β in decibels (dB) is defined as:

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

I_0 (= 10^{-12} W/m^2) = reference intensity level and is near the lower limit of human hearing

+**3 dB** = doubling of the sound intensity (acoustic energy)

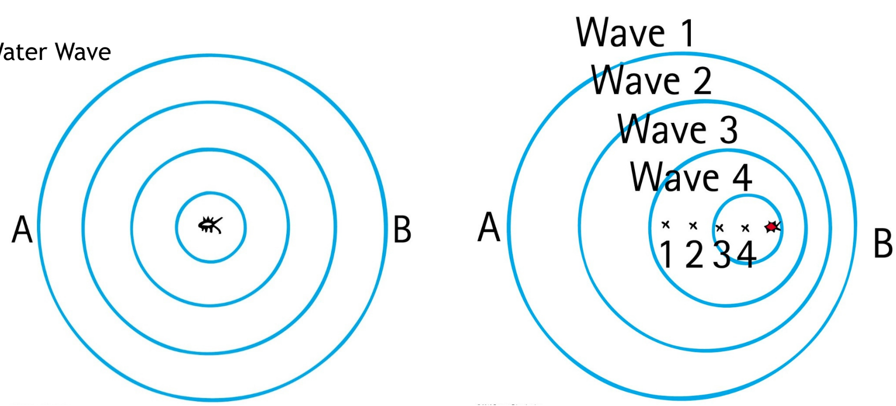
+**10 dB** = we perceive the volume as twice as loud

Some Sound Levels (dB)

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

Doppler Shift = Motion Between Sound Source and Sound Detector (Observer/Listener)

2D Water Wave



3D Sound Wave

Doppler Shift

Speed of Detector (Observer/Listener)

$$f' = f\frac{v \pm v_D}{v \pm v_S} \quad \text{(general Doppler effect)}$$

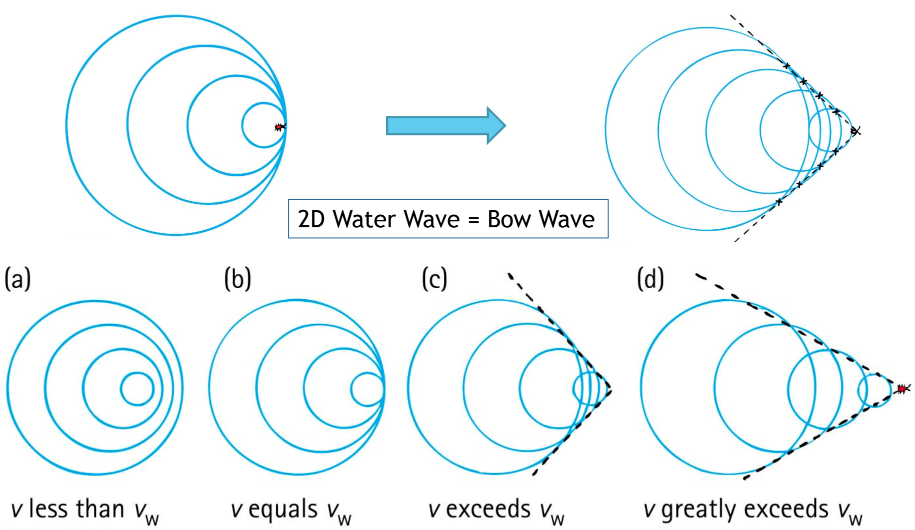
Doppler Effect = Perceived Frequency

Speed of Source

Numerator: + Toward
- Away

Denominator: + Away
- Toward

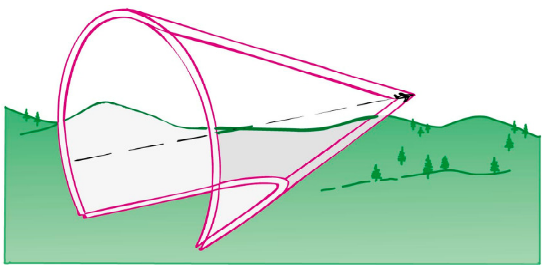

Shock Wave: When the Source Moves Faster than the Wave

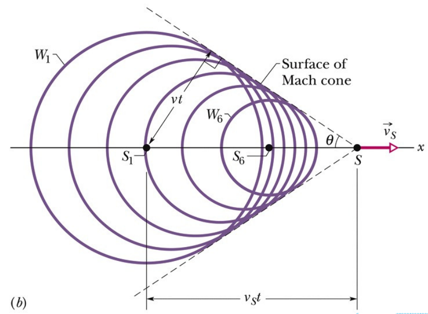


Shock Wave: When the Source Moves Faster than the Wave

$$\sin\theta = \frac{vt}{v_S t} = \frac{v}{v_S} \quad \text{(Mach cone angle).}$$

3D Sound Wave = Shock Wave





Shock Wave: When Source Moves Faster than the Wave