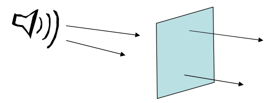
Sound II.

Energy and Intensity
Interference of sound waves
Standing waves
Complex sound waves

Energy and Intensity of sound waves

power $P = \frac{\text{energy}}{\text{time}}$

area A



Intensity $I = \frac{\text{power}}{\text{area}} = \frac{P}{A}$ (units W/m^2)

Sound intensity level

$$\beta = 10\log\left(\frac{I}{I_o}\right)$$ decibels (dB)

$I_o = 10^{-12}$ W/m^2 the threshold of hearing

decibel is a logarithmic unit. It covers a wide range of intensities.

The ear is capable of distinguishing a wide range of sound intensities.

$$\beta = 10\log\left(\frac{I}{I_o}\right)$$

$$\frac{I}{I_o} = 10^{\frac{\beta}{10}}$$

TABLE 14.2

Intensity Levels in Decibels for Different Sources

Source of Sound	β(dB)
Nearby jet airplane	150
Jackhammer, machine gun	130
Siren, rock concert	120
Subway, power mower	100
Busy traffic	80
Vacuum cleaner	70
Normal conversation	50
Mosquito buzzing	40
Whisper	30
Rustling leaves	10
Threshold of hearing	0

Question

What is the intensity of sound at a rock concert? (W/m^2)

$$\beta = 10\log\left(\frac{I}{I_o}\right) = 120$$

$$\log\left(\frac{I}{I_0}\right) = \frac{120}{10} = 12$$

$$\frac{I}{I_0} = 10^{12}$$

$I = 10^{12} I_0 = 10^{12} \cdot 10^{-12} = 1$ W/m^2

Question

The sound intensity of an ipod earphone can be as much as 120 dB. How is this possible?

A) The ipod is very powerful
B) The area of the earphone is very small
C) The ipod is a digital device
D) Rock music can be very loud

The sound intensity of an ipod earphone can be as much as 120 dB. How is this possible?

The earphone is placed directly in the ear. The intensity at the earphone is the power divided by a small area.

Say the area is about 1cm^{2}.

$$P = IA = 1w/m^2(10^{-4}m^2) = 10^{-4}W$$

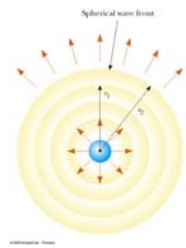
A small amount of power produces a high intensity.

Spherical and plane waves

$A = 4\pi r^2$ area of sphere

For a point source the intensity decreases as $1/r^2$

$$I = \frac{P}{4\pi r^2}$$



P = power of source

Suppose you are standing near a loudspeaker that can is blasting away with 100 W of audio power. How far away from the speaker should you stand if you want to hear a sound level of 120 dB. (assume that the sound is emitted uniformly in all directions.)

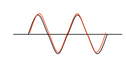
$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$

$$r = \sqrt{\frac{P}{4\pi I}} = \sqrt{\frac{100W}{4\pi(1W/m^2)}} = 2.8m$$

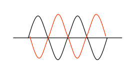
Interference of sound waves

Two sound waves superimposed

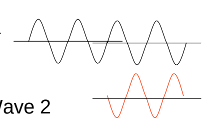
Constructive Interference



Destructive Interference

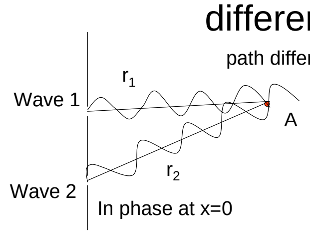


Noise canceling headphones



Interference due to path difference

path difference $=\delta = r_2 - r_1$



Superposition of waves at A shows interference due to path differences

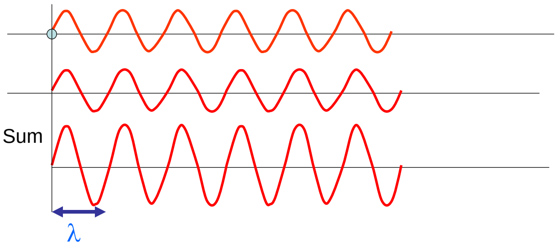
Condition for constructive interference $\delta = m\lambda$

Condition for destructive interference $\delta = (m + \frac{1}{2})\lambda$

where m is any integer $m = 0 \pm 1, \pm 2, \ldots$

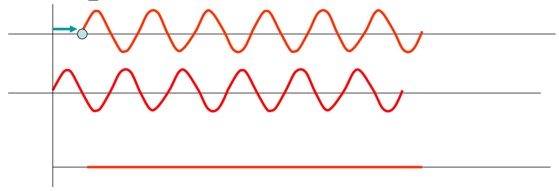
Interference

$\delta=0$ Constructive Interference



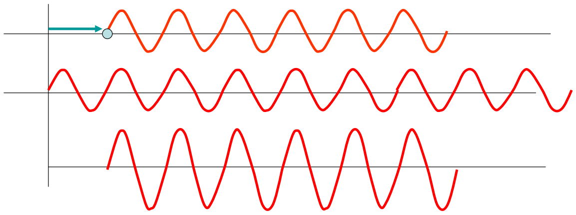
Interference

$\delta=\frac{\lambda}{2}$ Destructive Interference



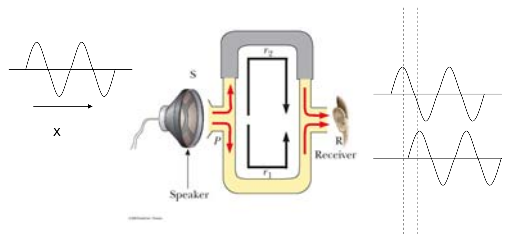
Interference

$\delta=\lambda$ Constructive Interference

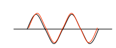


Interference of sound waves

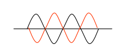
Phase shift due to path differences



When $r_2 - r_1 = m\lambda$ Constructive Interference



When $r_2 - r_1 = (m+½)\, \lambda$ Destructive Interference



m is any integer

Example

An experiment is performed to measure the speed of sound using by separating the sound from a single source along two separate paths with different path lengths and combining them at the detector. For a frequency of 3.0 kHz (assume v_{sound} =340 m/s);

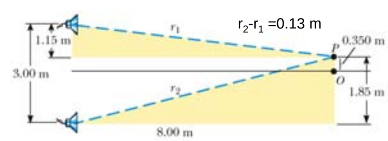
A) What would the smallest path difference be to observe a minimum in intensity

$$r_2 - r_1 = \frac{\lambda}{2} = \frac{v}{2f} = \frac{340\,m/s}{2(3x10^3 s^{-1})} = 5.7cm$$

B) What would the smallest (non-zero) path difference be to observe a maximum in intensity.

$$r_2 - r_1 = \quad \lambda = 11cm$$

Example 14.6 Path difference for two sources.



At position P the listener hears the first minimum in sound intensity. Find the frequency of the oscillation. v_{sound} =340 m/s

At position P the path difference is equal to $\lambda/2$. (first minimum) destructive interference.

$$\frac{\lambda}{2} = r_2 - r_1 = 0.13m$$

$$\lambda = 2(0.13) = 0.26m$$

$$f = \frac{v}{\lambda} = \frac{340m/s}{0.26m} = 1.31x10^3 Hz$$

Standing Waves

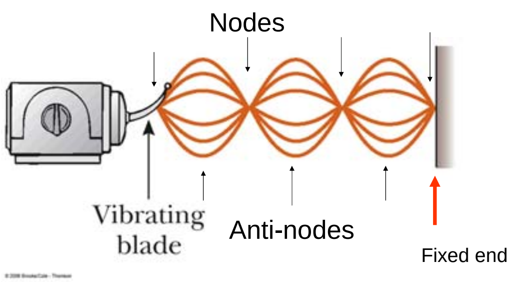
Standing waves (waves on a string)

Standing waves in air columns.

Standing Wave

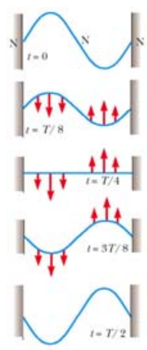
- A standing wave is formed by reflections back and forth at the boundaries of a media.
- The standing wave does not carry energy but serves to store energy.
- The standing wave stores energy of waves with specific wavelengths.

Standing wave on a string



Standing Wave with 3 nodes
– At different times.

The Standing wave doesn't "move" it just stands in one place



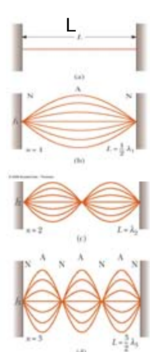
Standing Waves

- A standing wave is generated by superposition of two waves with the same frequency and wavelength traveling in opposite directions.

Simulation of a standing wave.

http://www.walter-fendt.de/ph14e/stwaverefl.htm

Standing Wave Conditions



n=1

n=2

n=3

One node at each end with additional nodes only at specific positions

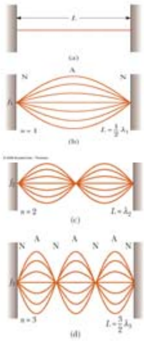
Distance between nodes = $\lambda/2$

A string with length L can support standing waves of only certain wavelengths.

$$L = \frac{\lambda}{2} n$$

where n=1, 2, 3… integer values
n=1 called the fundamental
n=2 called the second harmonic etc.

Standing wave frequencies and wavelengths



n=1

n=2

n=3

$L = \frac{\lambda}{2} n$

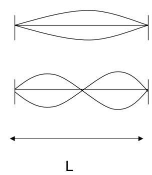
$\lambda_n = \frac{2L}{n}$

$f_n = \frac{v}{\lambda} = \frac{v}{2L} n$

where n = 1, 2, 3......

Example

Find the fundamental and second harmonics of a steel wire fixed at both ends. The speed of the wave in the string is v=200 m/s

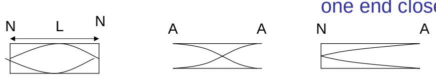


$\lambda_1 = 2L \quad f_1 = \frac{v}{2L} = \frac{200}{2(1)} = 100\text{Hz}$

$\lambda_2 = L \quad f_2 = \frac{v}{L} = 2f_1 = 200\text{ Hz}$

Standing waves in air columns Fundamental Frequency

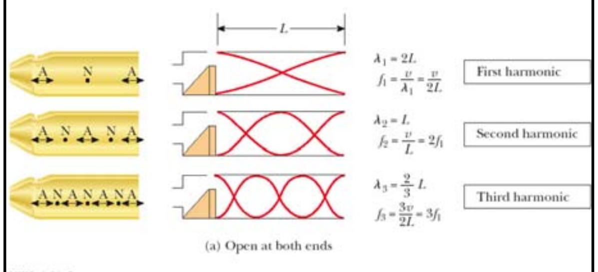
2 ends closed	2 ends open	one end open one end closed
$L = \frac{\lambda_1}{2}$	$L = \frac{\lambda_1}{2}$	$L = \frac{\lambda_1}{4}$
$\lambda_1 = 2L$	$\lambda_1 = 2L$	$\lambda_1 = 4L$
$F_1 = \frac{v}{2L}$	$F_1 = \frac{v}{2L}$	$F_1 = \frac{v}{4L}$



v is the speed of sound in air

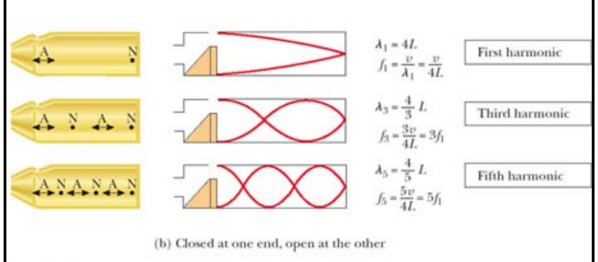
F_1 lower by a factor of 2

Cylinder open at both ends Harmonics



$f_n = n f_1$ n = 1, 2, 3, 4 .... All harmonics

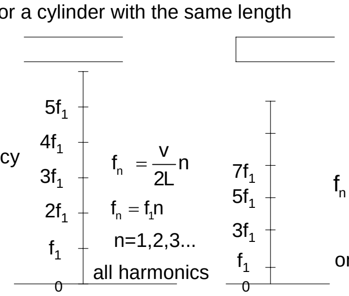
Cylinder open at one end closed at one end - Harmonics



$f_n = nf_1$ n= 1, 3, 5, 7 .... Only odd harmonics

Summary

For a cylinder with the same length



$f_n = \frac{v}{2L} n$

$f_n = f_1 n$

n=1,2,3...

all harmonics

both ends open/ closed

one open one closed

$f_n = \frac{v}{4L} n = f_1 n$

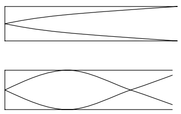
n=1, 3, 5.......

only odd harmonics

Example

A cylinder 5.0 cm in length is closed at one end and open at the other end. Find the frequency of the third harmonic of the standing wave in the column. v_{air} =340 m/s

L

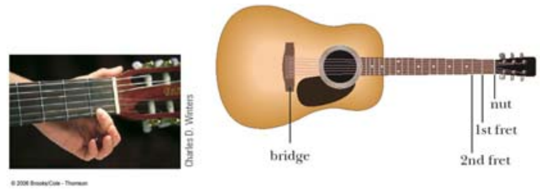


$\lambda_1 = 4L \qquad f_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$

$\lambda_3 = \frac{4L}{3} \qquad f_3 = 3f_1 = \frac{3v}{4L} = \frac{3(340)m/s}{4(0.05)m} = 5.1x10^3 Hz$

Musical Instruments

String Instruments

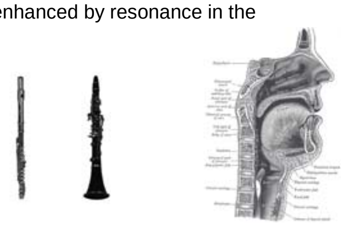


Frequency due to standing waves on the string.
The body of the instrument acts as a resonator to move air to amplify the sound.

Musical Instruments

Wind instruments

The sound is produced by vibrating air and the frequency is enhanced by resonance in the air column

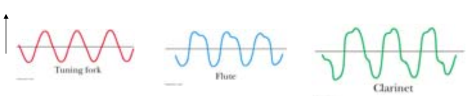


Complex waves

- In general sound waves are a combination of different frequencies.
- The superposition of waves with different frequencies gives rise to the characteristic quality (timbre) of the sound.
- The different frequencies can be determined by mathematical procedure called a Fourier Transform.

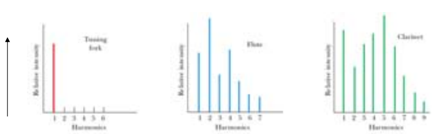
Complex waves consist of different frequency components , i.e. harmonics.

displacement



Time

relative amplitude



Frequency