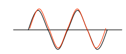
Sound II.

Interference of sound waves
Standing waves
Complex sound waves

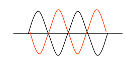
Interference of sound waves

Two sound waves superimposed

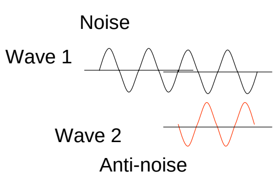
Constructive Interference



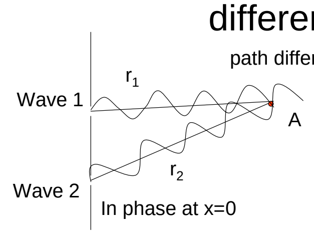
Destructive Interference



Noise canceling headphones



Interference due to path difference



Superposition of waves at A shows interference due to path differences

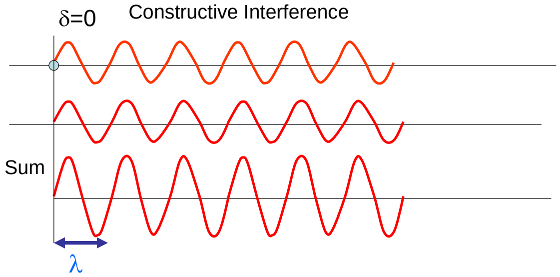
Condition for constructive interference $\delta = m\lambda$

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

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

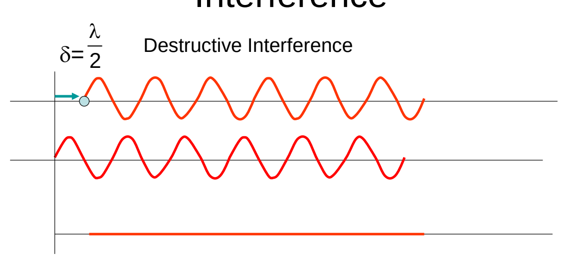
Interference

$\delta=0$ Constructive Interference



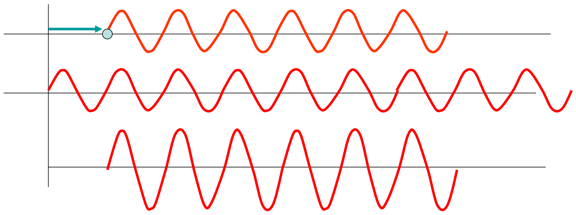
Interference

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



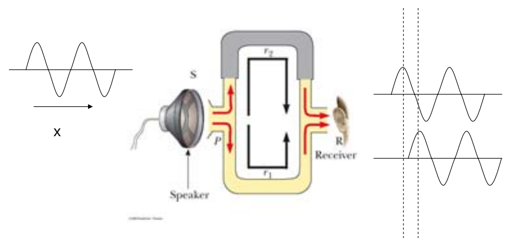
Interference

$\delta = \lambda$ Constructive Interference

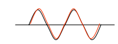


Interference of sound waves

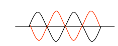
Phase shift due to path differences



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);

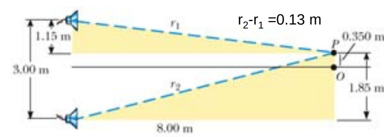
A) What would the smallest path difference be to observe a minimum in intensity

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

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

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

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

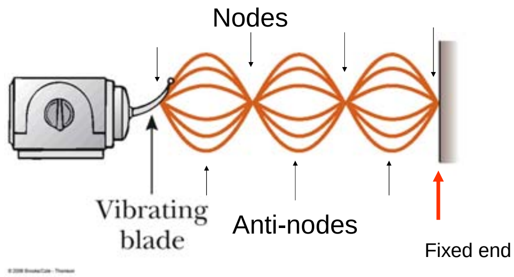
Standing waves (waves on a string)

Standing waves in air columns.

Standing Wave

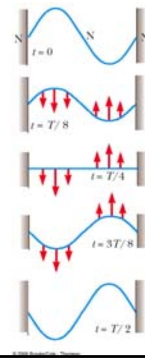
- A standing wave is formed by reflections back and forth at the boundaries of a media.
- The standing wave does not carry energy but serves to store energy.
- The standing wave stores energy of waves with specific wavelengths.

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



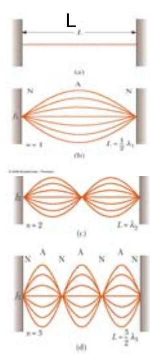
Standing Waves

- 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

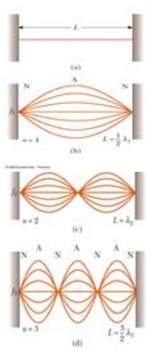
Distance between nodes = $\lambda/2$

A string with length L can support standing waves of only at 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 $f_1 = \frac{v}{2L}$

n=2 $f_2 = \frac{v}{L} = 2f_1$

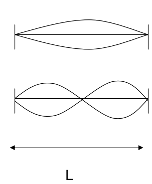
n=3 $f_3 = \frac{3v}{2L} = 3f_1$

Generally

$$f_n = \frac{v}{\lambda} = \frac{v}{2L} n = nf_1$$

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

Example
Find the fundamental and second harmonics of a steel wire 1.0m long fixed at both ends. The speed of the wave in the string is v=200 m/s

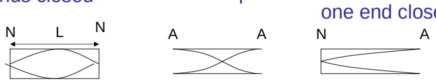


$\lambda_1 = 2L$ $f_1 = \frac{v}{2L} = \frac{200}{2(1)} = 100Hz$

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

Standing waves in air columns Fundamental Frequency

2 ends closed | 2 ends open | one end open one end closed



$L = \frac{\lambda_1}{2}$ | $L = \frac{\lambda_1}{2}$ | $L = \frac{\lambda_1}{4}$

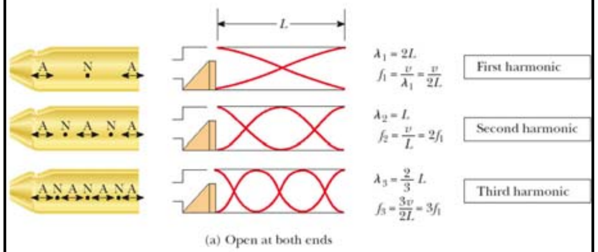
$\lambda_1 = 2L$ | $\lambda_1 = 2L$ | $\lambda_1 = 4L$

$F_1 = \frac{v}{2L}$ | $F_1 = \frac{v}{2L}$ | $F_1 = \frac{v}{4L}$

v is the speed of sound in air

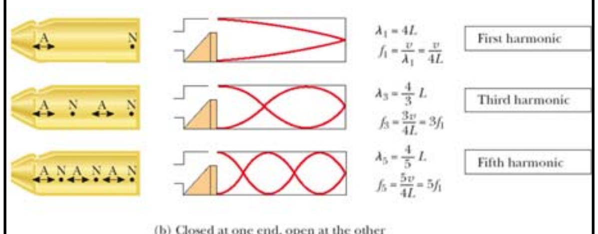
F_1 lower by a factor of 2

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

Frequency

Both ends open/ closed: $5f_1$, $4f_1$, $3f_1$, $2f_1$, f_1, 0

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

$f_n = f_1 n$

n=1,2,3...

all harmonics

One open one closed: $7f_1$, $5f_1$, $3f_1$, f_1, 0

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

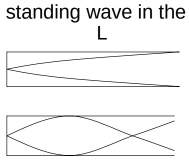
n=1, 3, 5.......

only odd harmonics

both ends open/ closed | one open one closed

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



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

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

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 element (reed, vocal chord) and certain specific frequencies are enhanced by resonance in the air column

Complex waves

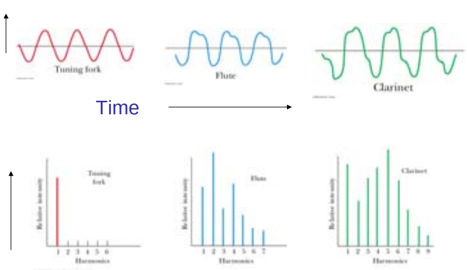
- In general sound waves are a combination of different frequencies.
- The superposition of waves with different frequencies gives rise to the characteristic quality (timbre) of the sound.
- The different frequencies can be determined by mathematical procedure called a Fourier Transform.

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

displacement

Time

relative amplitude



Frequency