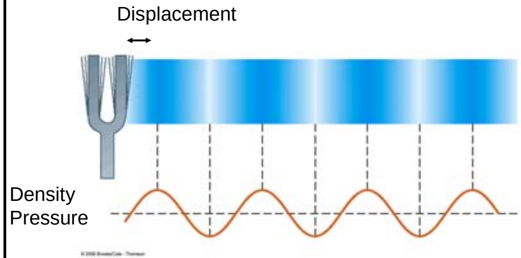
- Producing sound waves
- Speed of sound
- Energy and Intensity
- Spherical and Plane waves.
- Interference of sound waves

Producing sound waves



- Produced by compression and rarefaction of media (air)
- Sound waves are longitudinal
  resulting in displacement in the direction of propagation.
- The displacements result in oscillations in density and pressure.

Frequencies of sound wave

infra-sonic | Audible Sound | ultra- sonic

10 | 20,000

Frequency (Hz) →

30 | 0.015

Wavelength (m) in air

Speed of sound

Speed of sound in a fluid

$$v = \sqrt{\frac{B}{\rho}}$$

$$B = -\frac{\Delta P}{\Delta V / V}$$ Bulk modulus

$$\rho = \frac{m}{V}$$ Density

Similarity to speed of a transverse wave on a string

$$v = \sqrt{\frac{elastic\_property}{intertial\_property}}$$

$$v = \sqrt{\frac{B}{\rho}}$$

Why is the speed of sound higher in Helium than in air?
Why is the speed of sound higher in water than in air?

TABLE 14.1
Speeds of Sound in Various Media

Medium	v (m/s)
Gases	
Air (0°C)	331
Air (100°C)	386
Hydrogen (0°C)	1 290
Oxygen (0°C)	317
Helium (0°C)	972
Liquids at 25°C	
Water	1 490
Methyl alcohol	1 140
Sea water	1 530
Solids	
Aluminum	5 100
Copper	3 560
Iron	5 130
Lead	1 320
Vulcanized rubber	54

Speed of sound in air

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

γ is a constant that depends on the nature of the gas γ =7/5 for air.

P - Pressure
ρ - Density

Since P is proportional to the absolute temperature T by the ideal gas law. PV=nRT

v is dependent on T $$v = 331\sqrt{\frac{T}{273}}$$ (m/s)

Find the speed of sound in air at 20º C.

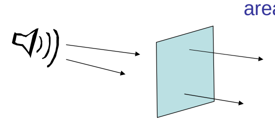
$$v = 331\sqrt{\frac{T}{273}}$$

$$v = 331\sqrt{\frac{273+20}{273}} = 343 m/s$$

For calculations use v=340 m/s

Energy and Intensity of sound waves

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



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

Sound intensity level

The decibel is a measure of the 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

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

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

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)

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

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

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

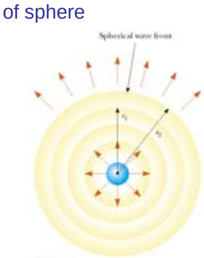
$$I = 10^{12} I_0 = 10^{12} \cdot 10^{-12} = 1 \quad W/m^2$$

Spherical and plane waves

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

As sound spreads out uniformly from a point source
The intensity decreases as $1/r^2$

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



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.)

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

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

Question 1

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.

Question 2

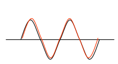
The sound level in a truck is 20 dB greater than the sound level in a Strarbucks cafe. If the intensity in the cafe is 10^{-7} W/m^2 the intensity in the truck is_______ W/m^2.

A) $20 X10^{-7}$
B) 10^{-9}
C) 10^{-5}
D) 20

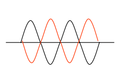
Interference of sound waves

Two sound waves superimposed

Constructive Interference



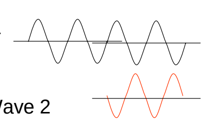
Destructive Interference



Noise canceling headphones

Noise

Wave 1

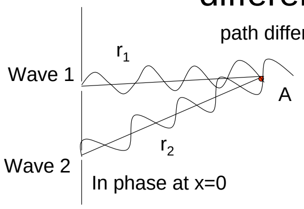


Wave 2

Anti-noise

Interference due to path difference

path difference $=\delta = r_2 - r_1$



Superposition of waves at A shows interference due to path differences

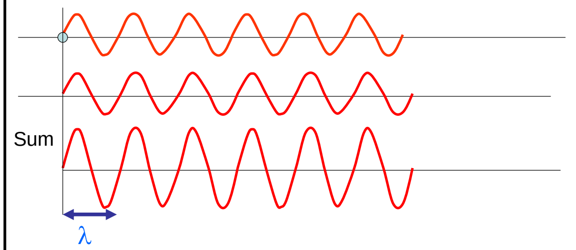
Condition for constructive interference $\delta = m\lambda$

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

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

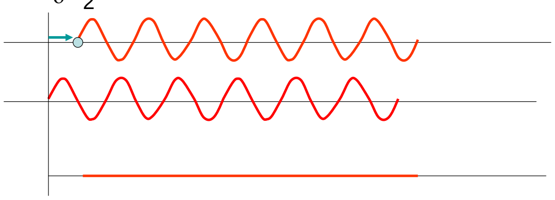
Interference

$\delta = 0$ Constructive Interference



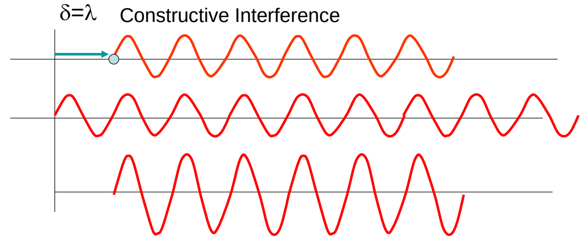
Interference

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



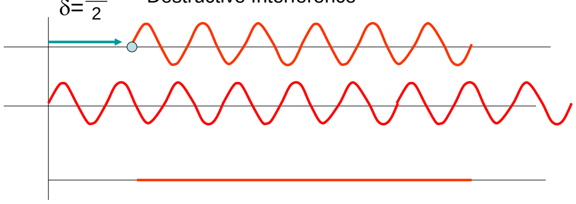
Interference

$\delta = \lambda$ Constructive Interference



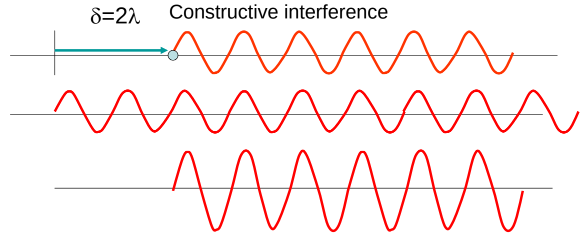
Interference

$\delta = \frac{3\lambda}{2}$ Destructive Interference



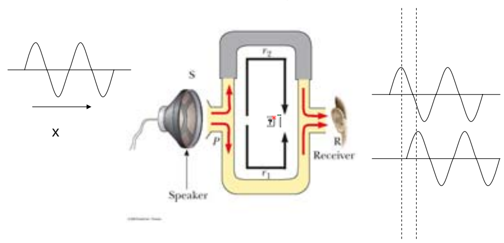
Interference

$\delta = 2\lambda$ Constructive interference



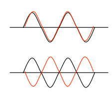
Interference of sound waves

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);

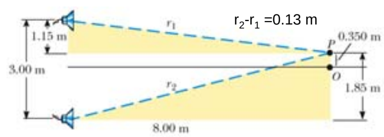
A) What would the smallest path difference be to observe a minimum in intensity

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

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.

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

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

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