New Jersey Center for Teaching and Learning

Progressive Science Initiative

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Sound Waves

http://njc.tl/oy

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Characteristics of Sound

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Characteristics of Sound

Speed of Sound in Different Materials (20°C and 1 atm)	
Material	**Speed (m/s)**
Air	343
Air (0 °)	331
Helium	1005
Hydrogen	1300
Water	1400
Sea Water	1560
Iron and Steel	≈ 5000
Glass	≈ 4500
Aluminum	≈ 5100
Hardwood	≈ 4000
Concrete	≈ 3000

Sound can travel through any kind of matter, but not through a vacuum.

The speed of sound is different in different materials; in general, it is slowest in gases, faster in liquids, and fastest in solids.

The speed depends somewhat on temperature, especially for gases.

Click here for a video on sound waves moving in various materials

http://njc.tl/oy

1 Sound waves travel with the greatest velocity in

- A gases
- B liquids
- C solids

Answer

http://njc.tl/oz

Characteristics of Sound

Loudness: related to intensity of the sound wave (as the volume increases, the amplitude of the waves increases)

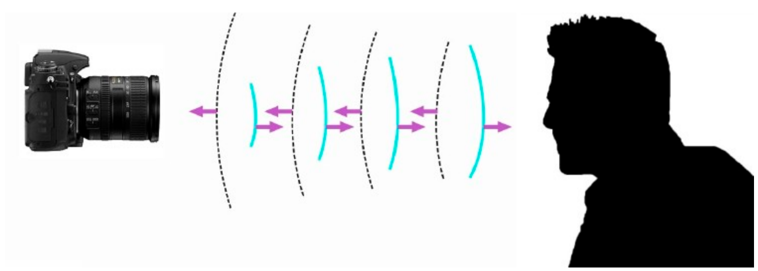
Sound waves are produced by vibrations that occur between 20 to 20,000 vibrations per second.

Pitch: related to frequency.

Audible range: about 20 Hz to 20,000 Hz; upper limit decreases with age

Ultrasound: above 20,000 Hz; see ultrasonic camera focusing below

Infrasound: below 20 Hz



http://njc.tl/p0

Click here for a video on how our vocal cords vibrate and produce sound

2 Which of the following frequencies can be perceieved by humans?

- A 10 Hz
- B 1,000 Hz
- C 100,000 Hz

Answer

Intensity of Sound: Decibels

Intensity of Different Sounds		
Source of the Sound	Sound Level (dB)	Intensity (W/m^2)
Jet Plane at 30 m	140	100
Threshold of pain	135	1
Loud rock concert	120	1
Siren at 30 m	100	1×10^{-2}
Auto interior, At 90 km/ h	75	3×10^{-5}
Busy street traffic	70	1×10^{-5}
Talk, at 50 cm	65	3×10^{-6}
Quiet Radio	40	1×10^{-8}
Whisper	20	1×10^{-10}
Rustle of leaves	10	1×10^{-11}
Threshold of hearing	0	1×10^{-12}

The intensity of a wave is the energy transported per unit time across a unit area.

The human ear can detect sounds with an intensity as low as 10^{-12} W/m^2 and as high as 1 W/m^2. Perceived loudness, however, is not proportional to the intensity.

http://njc.tl/p2

Intensity of Sound: Decibels

An increase in sound level of 3 dB, which is a doubling in intensity, is a very small change in loudness.
In open areas, the intensity of sound diminishes with distance:

$$I \propto \frac{1}{r^2}$$

However, in enclosed spaces this is complicated by reflections, and if sound travels through air the higher frequencies get preferentially absorbed.

3 Doubling the distance from a sound source will change the intensity (volume) by a factor of the original value

- A 2
- B 4
- C 1/4
- D 1/2

Answer

http://njc.tl/p3

4 As you walk toward a sound source the volume will

- A increase
- B decrease
- C will not change

Answer

http://njc.tl/p4

5 Reducing the distance from a sound source to one half the original value will change the intensity (volume) by what factor?

- A 2
- B 4
- C 1/4
- D 1/2

Answer

http://njc.tl/p5

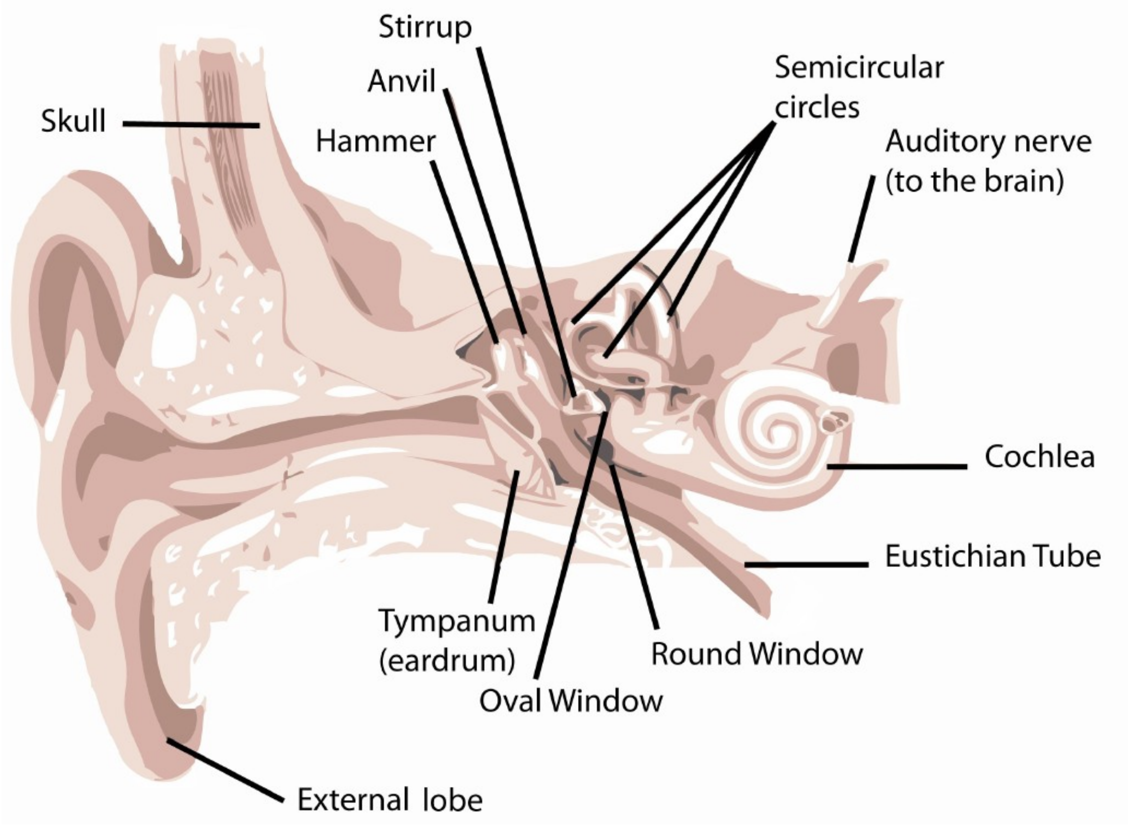
6 Cutting the distance from a sound source by a factor of 1/3 will change the intensity (volume) by a factor of the original value

- A 3
- B 9
- C 1/3
- D 1/9

Answer

http://njc.tl/p6

The Ear and Its Response; Loudness



http://njc.tl/p7

The Ear and Its Response; Loudness

Outer ear: sound waves travel down the ear canal to the eardrum, which vibrates in response

Middle ear: hammer, anvil, and stirrup transfer vibrations to inner ear

Inner ear: cochlea transforms vibrational energy to electrical energy and sends signals to the brain

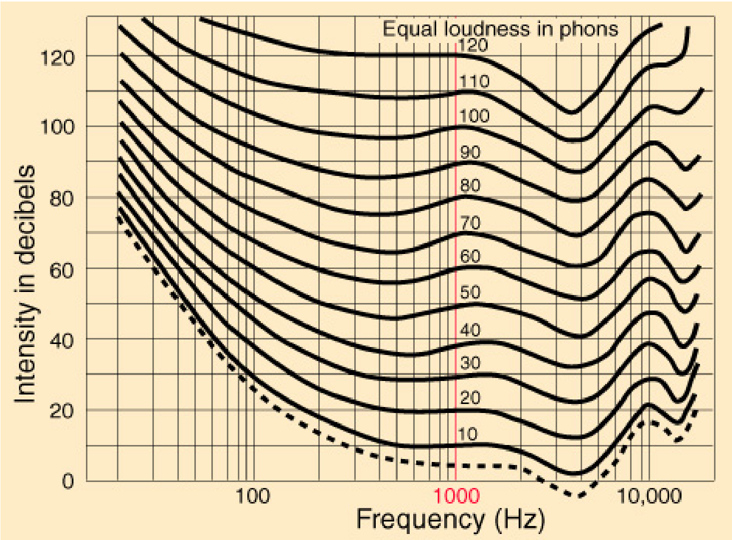
Click here for a video on hearing

http://njc.tl/p7

The Ear and its Response; Loudness

The ear's sensitivity varies with frequency.

These curves translate the intensity into sound level at different frequencies.



http://njc.tl/p7

Sources of Sound

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Sources of Sound:
Vibrating Strings and Air Columns

Musical instruments produce sounds in various ways – vibrating strings, vibrating membranes, vibrating metal or wood shapes, vibrating air columns.

The vibration may be started by plucking, striking, bowing, or blowing. The vibrations are transmitted to the air and then to our ears.

Sources of Sound: Vibrating Strings and Air Columns

The strings on a guitar can be effectively shortened by fingering, raising the fundamental pitch.

The pitch of a string of a given length can also be altered by using a string of different density.

Click here for a video on guitar string pitch

http://njc.tl/p8

Sources of Sound:
Vibrating Strings and Air Columns

A piano uses both methods to cover its more than seven-octave range – the lower strings (at bottom) are both much longer and much thicker than the higher ones.

Sources of Sound: Vibrating Strings and Air Columns

Length

Pitch

A piano uses both methods to cover its more than seven-octave range – the lower strings (at bottom) are both much longer and much thicker than the higher ones.

The product of length and pitch is a constant.

Observe relationship between wavelength and frequency

http://njc.tl/p8

Sources of Sound: Vibrating Strings and Air Columns

Wind instruments create sound through standing waves in a column of air.

Click here for a video on sound in air columns

http://njc.tl/p8

Open Tubes

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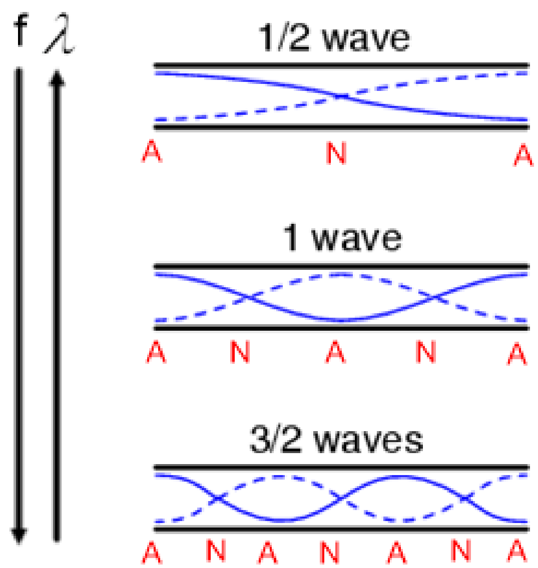
Sources of Sound: Vibrating Strings and Air Columns

A tube open at both ends (most wind instruments) has pressure nodes, and therefore displacement antinodes, at the ends.



$$\lambda = 2L \qquad f' = \frac{v}{\lambda} = \frac{v}{2L} = f$$

$$\lambda = L \qquad f' = \frac{v}{\lambda} = \frac{v}{L} = 2f$$

$$\lambda = \frac{2}{3}L \qquad f' = \frac{v}{\lambda} = \frac{3v}{2L} = 3f$$

http://njc.tl/p8

Sources of Sound: Open Tubes

The general equation for the wavelength of an open tube is:

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

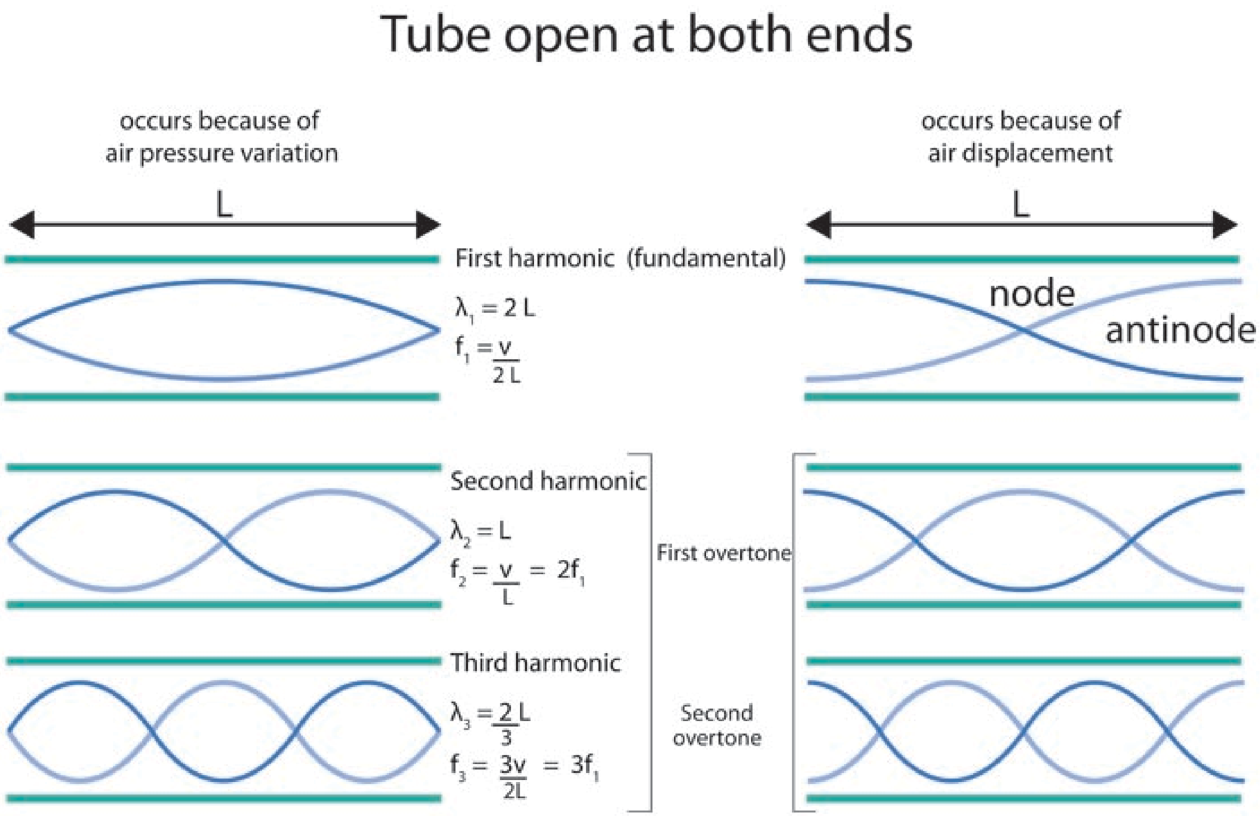
$$f_n = \frac{v}{\lambda_n} = \frac{v}{\frac{2L}{n}} = n\frac{v}{2L} = nf_1$$

$$n = 1, 2, 3, \ldots$$

Where n is the number of nodes.

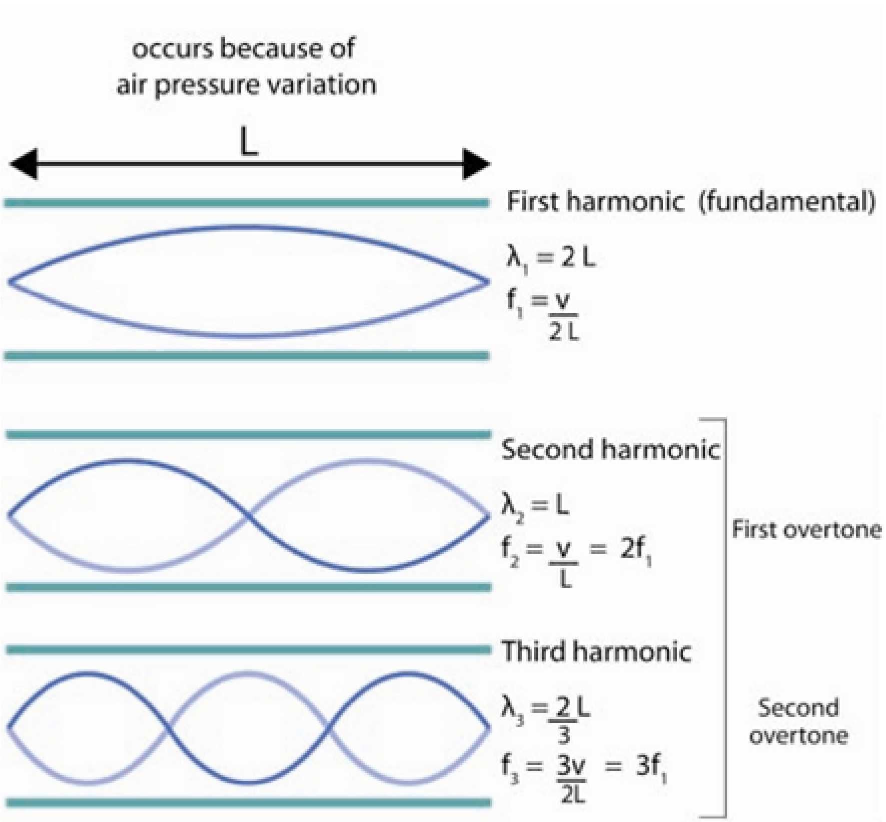
Sources of Sound: Vibrating Strings and Air Columns

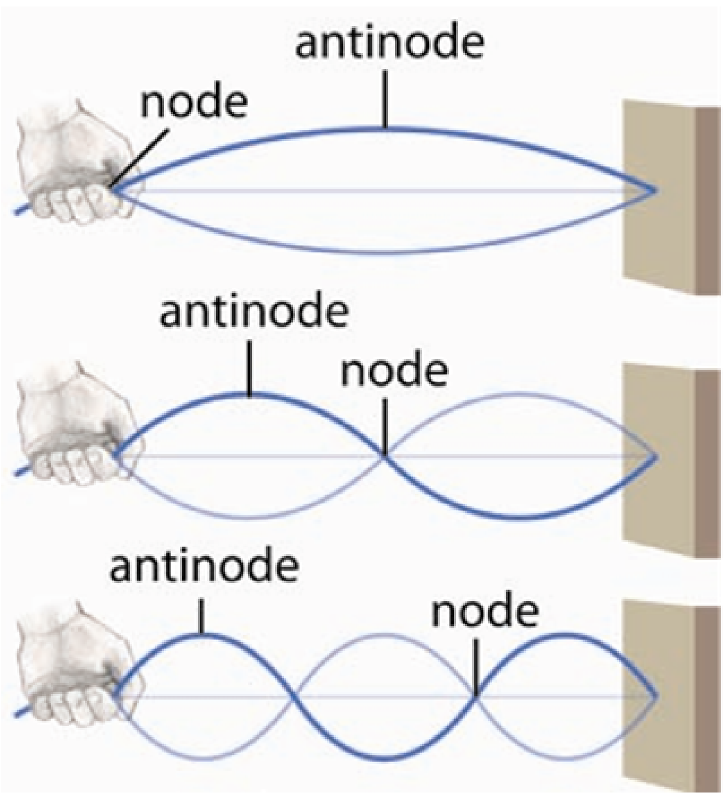
If instead of air displacement, you look at air pressure variation the nodes and antinodes are switched.



Sources of Sound: Vibrating Strings and Air Columns

An open tube has the same harmonic structure as a string.





7 A sound wave resonates in a tube of length 2m with two open ends. What is the wavelength of the lowest resonating frequency of the tube?

- A 1m
- B 1.5m
- C 2m
- D 4m
- E 8m

Answer

http://njc.tl/pa

8 A sound wave resonates in a tube of length 2m with two open ends. What is the lowest resonating frequency of the tube if the speed of sound in air is 340m/s?

Answer

http://njc.tl/pb

9 A sound wave resonates in a tube of length 6m with two open ends. What is the wavelength of the lowest resonating frequency of the tube?

- A 6m
- B 12m
- C 18m
- D 24m
- E 3m

Answer

10 A sound wave resonates in a tube of length 6m with two open ends. What is the lowest resonating frequency of the tube if the speed of sound in air is 340m/s?

Answer

http://njc.tl/pc

Closed Tubes

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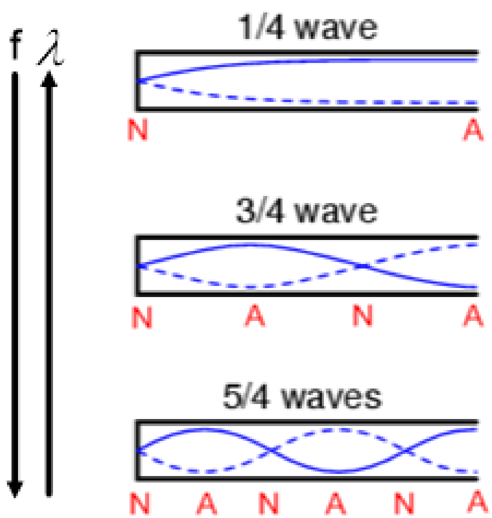
Sources of Sound: Vibrating Strings and Air Columns

A tube closed at one end (some organ pipes) has a displacement node (and pressure antinode) at the closed end.

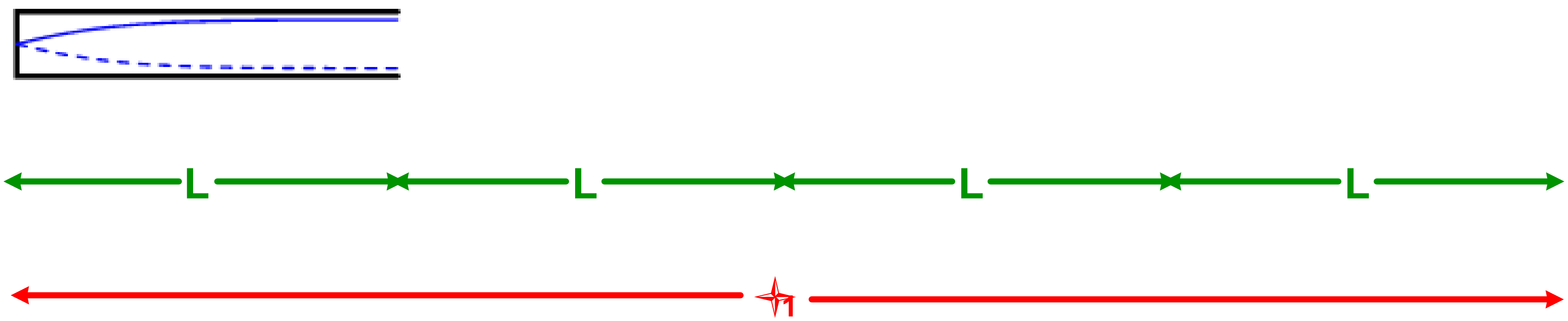


$$\lambda = 4L \qquad f' = \frac{v}{\lambda} = \frac{v}{4L} = f$$

$$\lambda = \frac{4}{3}L \qquad f' = \frac{v}{\lambda} = \frac{3v}{4L} = 3f$$

$$\lambda = \frac{4}{5}L \qquad f' = \frac{v}{\lambda} = \frac{5v}{4L} = 5f$$

Sources of Sound: Closed Tubes



$$\lambda_n = \frac{4L}{n}$$

$$f_n = \frac{v}{\lambda_n} = \frac{v}{\frac{4L}{n}} = n\frac{v}{4L} = nf_1$$

$$n = 1, 3, 5, \ldots$$

http://njc.tl/pc

11 A sound wave resonates in a tube of length 2m with one open end. What is the wavelength of the lowest resonating frequency of the tube?

- A 1m
- B 1.5m
- C 2m
- D 4m
- E 8m

Answer

http://njc.tl/pd

12 A sound wave resonates in a tube of length 2m with one open end. What is the lowest resonating frequency of the tube if the speed of sound in air is 340 m/s?

Answer

http://njc.tl/pe

13 A sound wave resonates in a tube of length 2m with one open end. What is the next lowest resonating frequency of the tube if the speed of sound in air is 340 m/s?

Answer

14 A sound wave resonates in a tube of length 1/2m with one open end. What is the wavelength of the lowest resonating frequency of the tube?

- A 1m
- B 1.5m
- C 2m
- D 4m
- E 8m

Answer

http://njc.tl/pg

15 A sound wave resonates in a tube of length 1/2m with one open end. What is the lowest resonating frequency of the tube if the speed of sound in air is 340 m/s?

Answer

http://njc.tl/ph

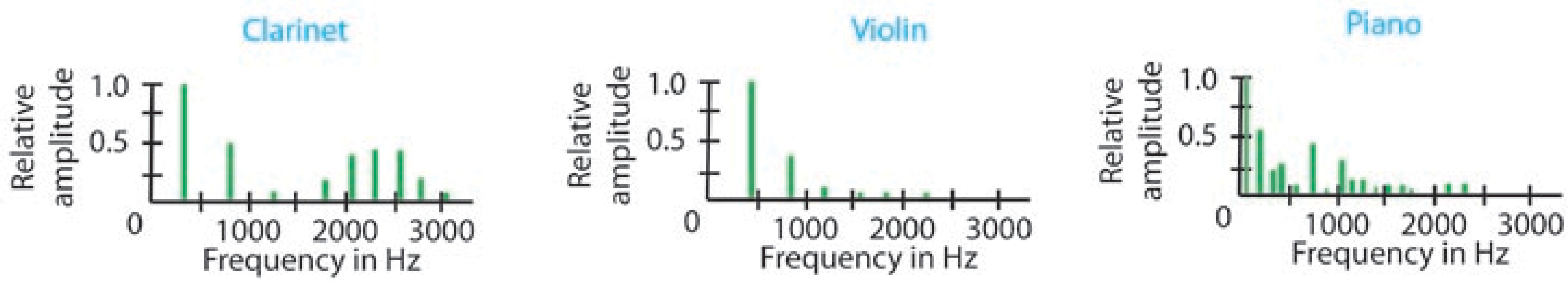
16 A sound wave resonates in a tube of length 1/2m with one open end. What is the next lowest resonating frequency of the tube if the speed of sound in air is 340 m/s?

Answer

Quality of Sound, and Noise; Superposition

So why does a trumpet sound different from a flute? The answer lies in overtones – which ones are present, and how strong they are, makes a big difference.

The plot below shows frequency spectra for a clarinet, a piano, and a violin. The differences in overtone strength are apparent.



http://njc.tl/pj

Click here for a video on sound and timbre

Musical instruments have characteristic sounds due to the relative amounts of each harmonic present. Notice that the guitar sting contains many standing waves of a variety of frequencies. What we hear is the mixture of these frequencies and this is called timbre. (Pronounced "Tamber")

Problem Solving:
Open and closed tubes

1. Note if the tube is open or closed.

2. Determine λ_1; 2L or open tubes, 4L for closed tubes.

3. Use v to determine f_1.

4. For open tubes, harmonics are multiples of f_1.

5. For closed tubes, harmonics are odd multiples of f_1.

http://njc.tl/pj

Interference

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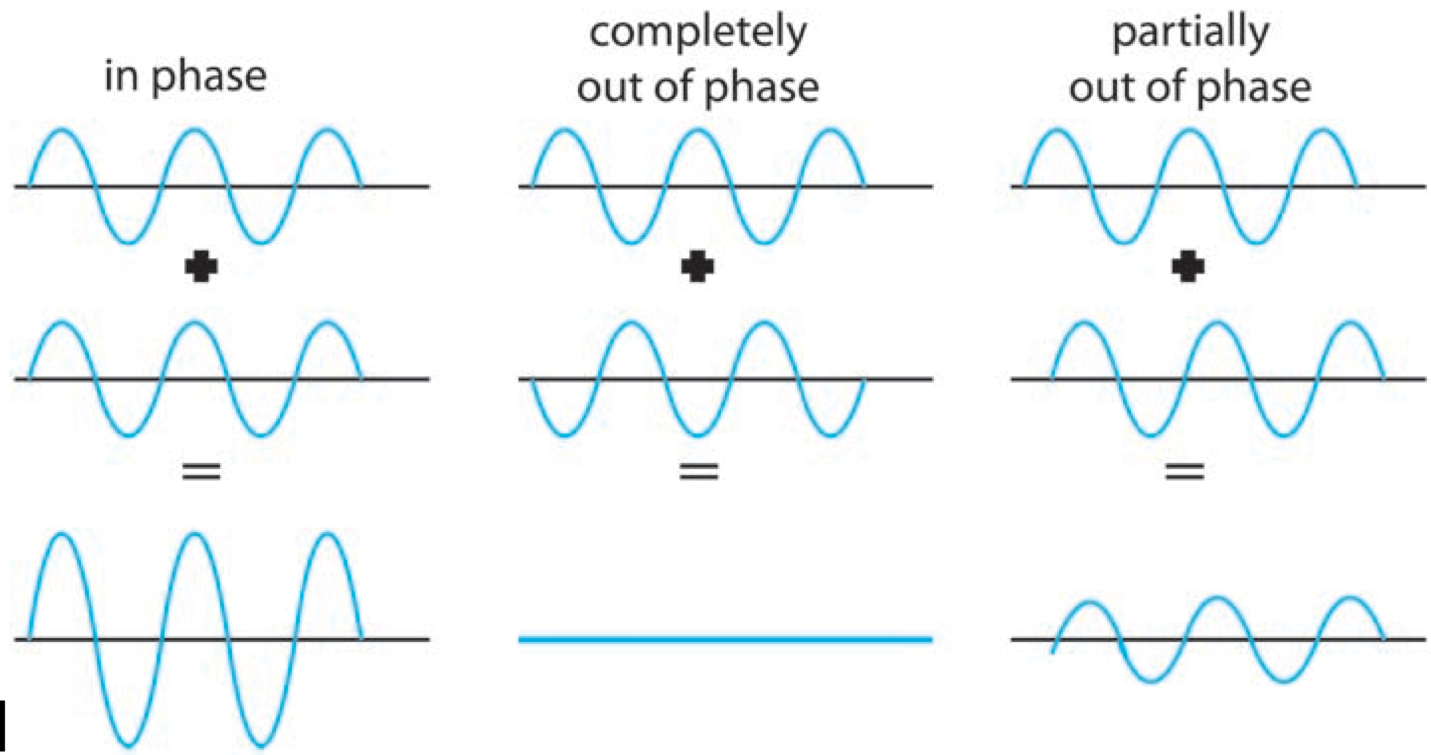
Interference; Principle of Superposition

These figures show the sum of two waves. In (a) they add constructively; in (b) they add destructively ; and in (c) they add partially destructively .



Interference

If two sources emit the same wavelength sound, and it travels the same distance to the listener, they will add together, constructively interfere.

17 When sound waves emitted from a source travel similar distances to listerner they will interfere...

- A Constructively
- B Destructively

Interference

If two sources emit the same wavelength sound, and the path length to the listener is 1/2 ✦different, they will destructively interfere, if the amplitudes are the same, they will cancel and the sound won't be heard.

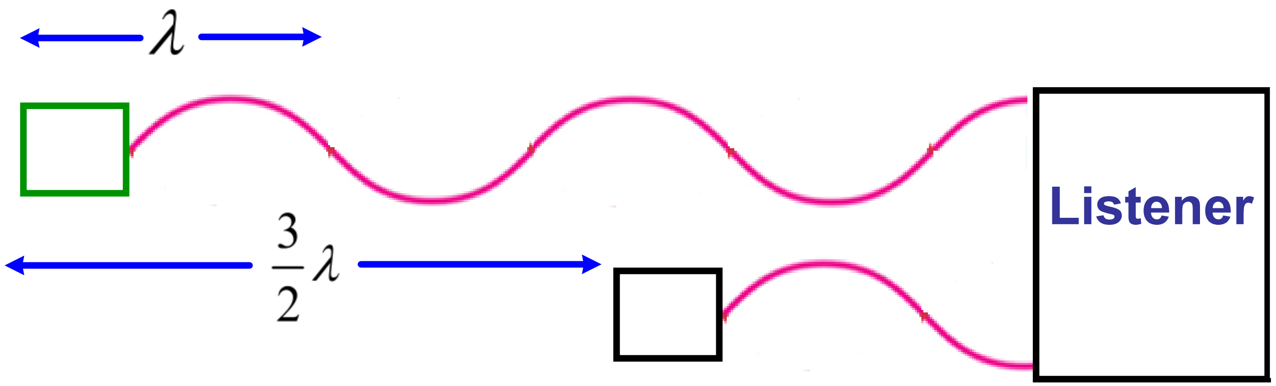
http://njc.tl/pk

18 When waves emitted from two sound sources travel distances that differ by one-half of a wavelength to the listener...

- A constructively
- B destructively

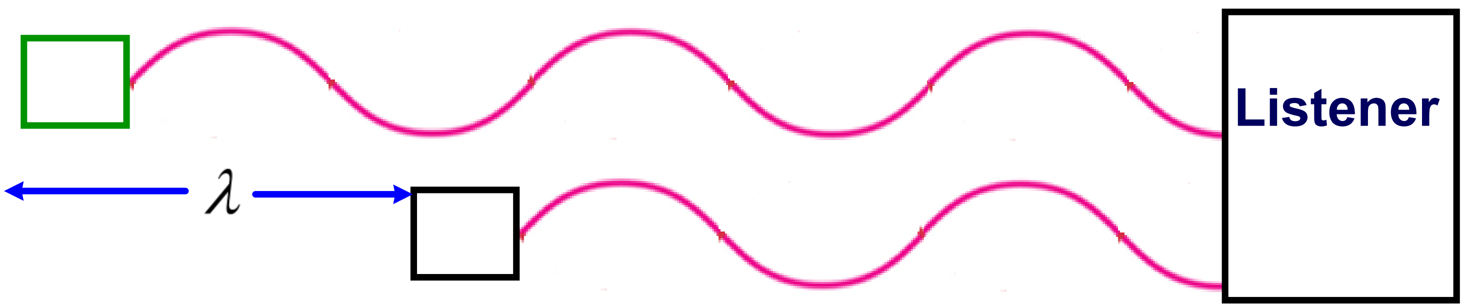
Interference

Any odd multiple of 1/2 λ results in destructive interference



Interference

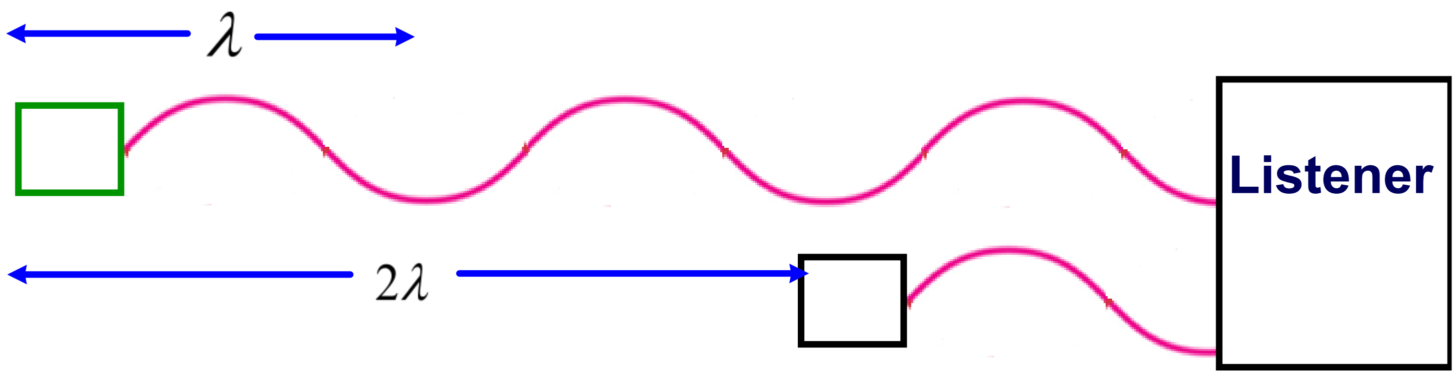
If two sources emit the same wavelength sound, and the path length to the listener is different, they will constructively interfere, the combined sound will be louder.



http://njc.tl/pm

Interference

If two sources emit the same wavelength sound, and the path length to the listener is λ different, they will constructively interfere, the combined sound will be louder. This will be true of all integer multiples of λ .



http://njc.tl/pm

19 If two travelling waves arrive at a listener's location out of phase by 1 wavelengths they will experience

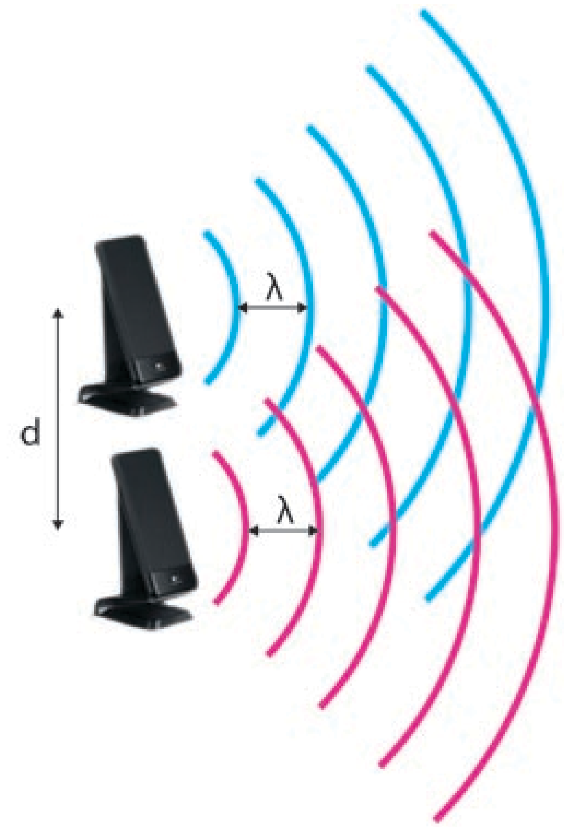
- A Constructive Interference
- B Destructive Interference

20

- Constructive Interference
- Destructive Interference

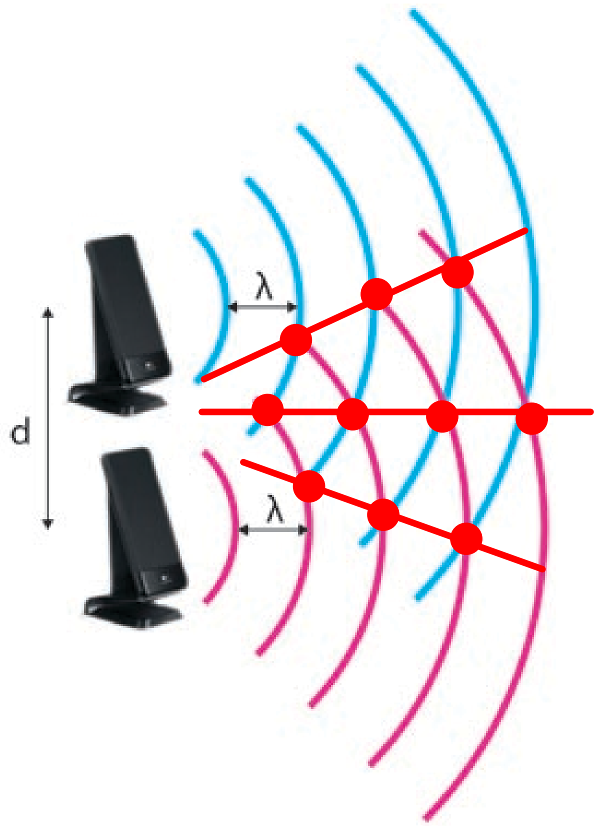
http://njc.tl/po

Interference of Sound Waves



Sound waves interfere in the same way that other waves do in space.

Interference of Sound Waves



Constructive interference occurs when two crests meet and destructive interference occurs where a crest and a trough meet.

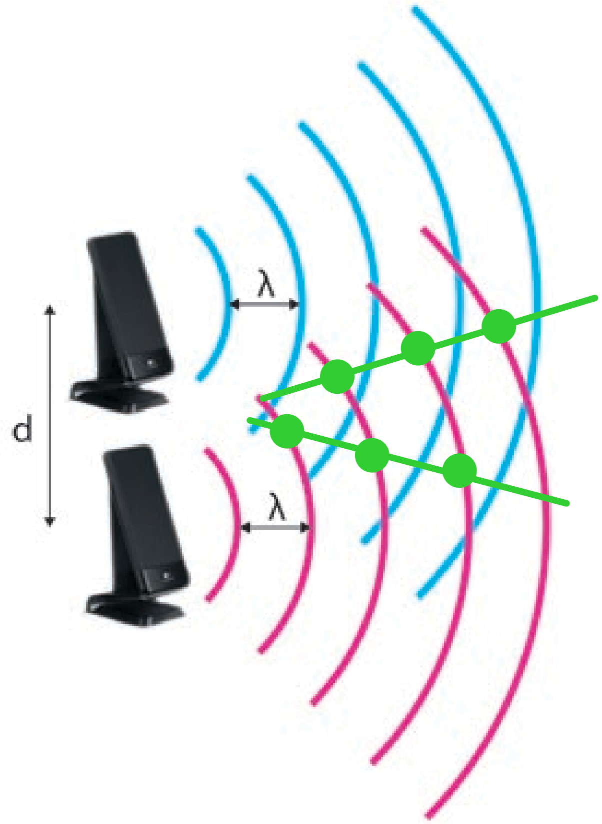
This means that when a listener is located where constructive interference is occurring, there will be a loud spot.

And that when a listener is located where destructive interference is occurring, there will be little or no sound.

● **constructive interference (loud)**

http://njc.tl/pp

Interference of Sound Waves



Constructive interference occurs when two crests meet and destructive interference occurs where a crest and a trough meet.

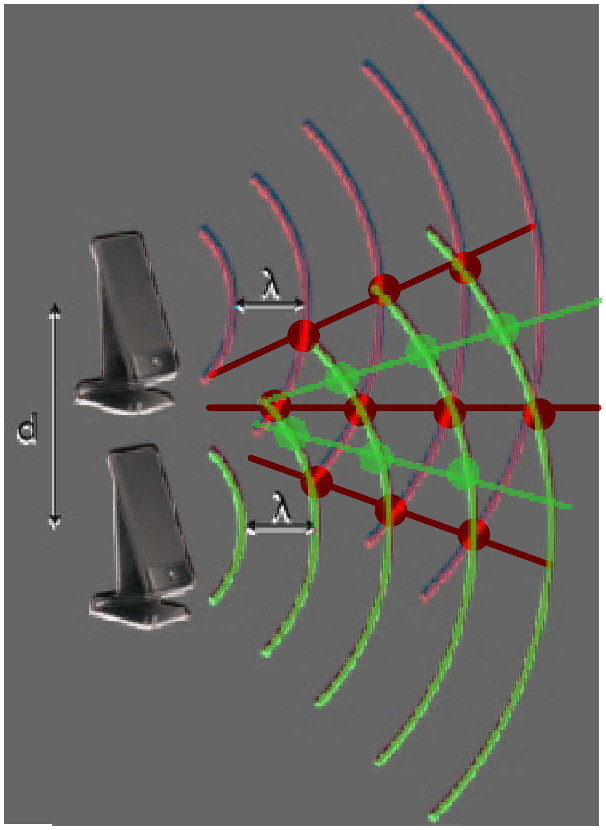
This means that when a listener is located where constructive interference is occurring, there will be a loud spot.

And that when a listener is located where destructive interference is occurring, there will be little or no sound.

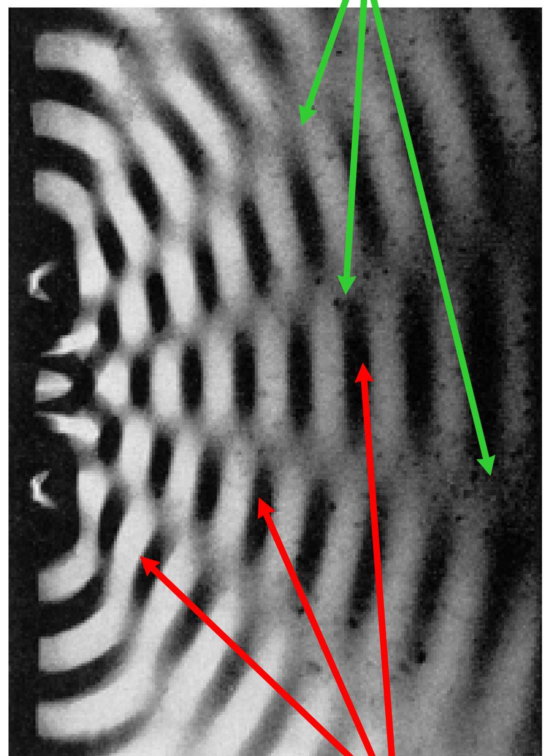
● **destructive interference (no sound)**

http://njc.tl/pp

Interference of Sound Waves



Destructive Interference

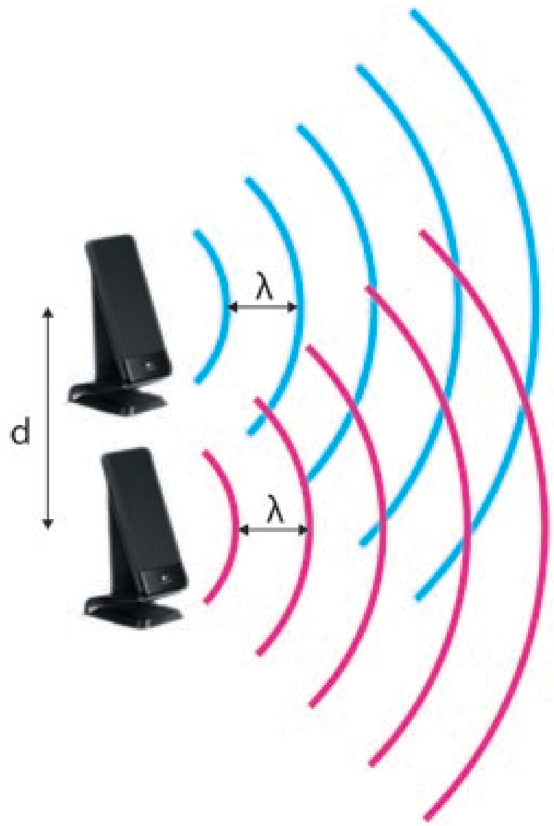


Constructive Interference


http://njc.tl/pp

Click here for a PhET simulation
Sound and Interference

Interference of Sound Waves



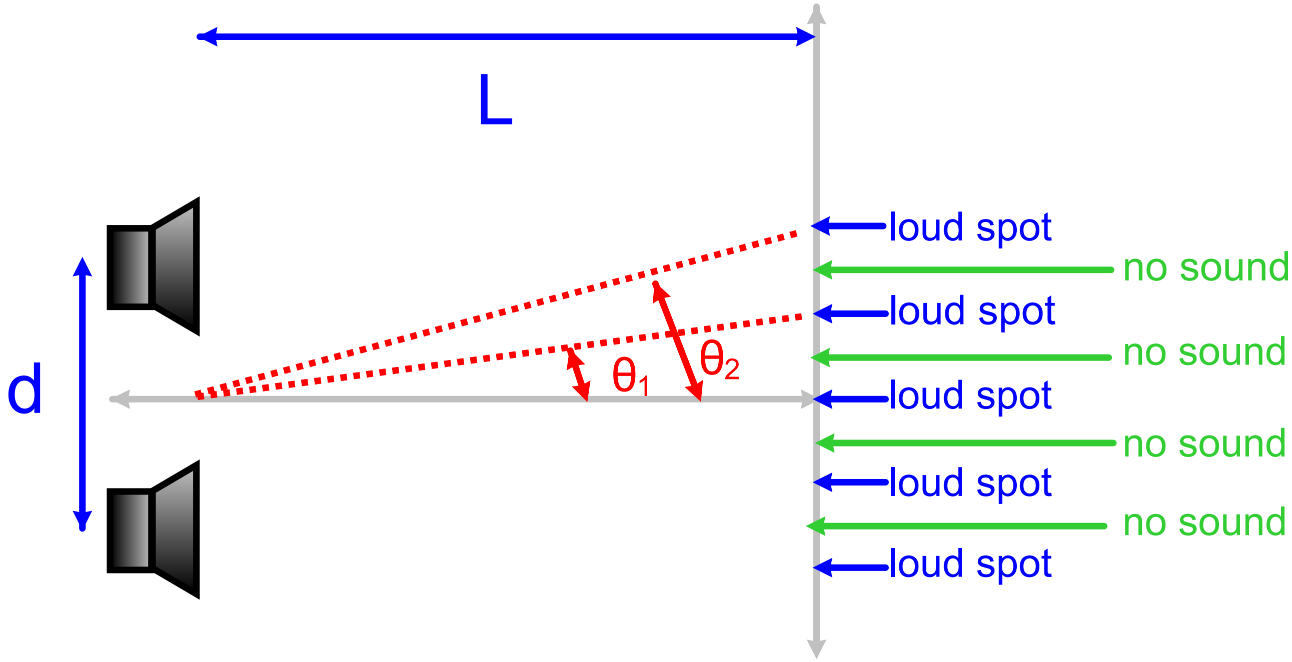
Constructive interference occurs when two crests meet and destructive interference occurs where a crest and a trough meet.

This means that when a listener is located where constructive interference is occurring, there will be a loud spot.

And that when a listener is located where destructive interference is occurring, there will be little or no sound.

http://njc.tl/pp

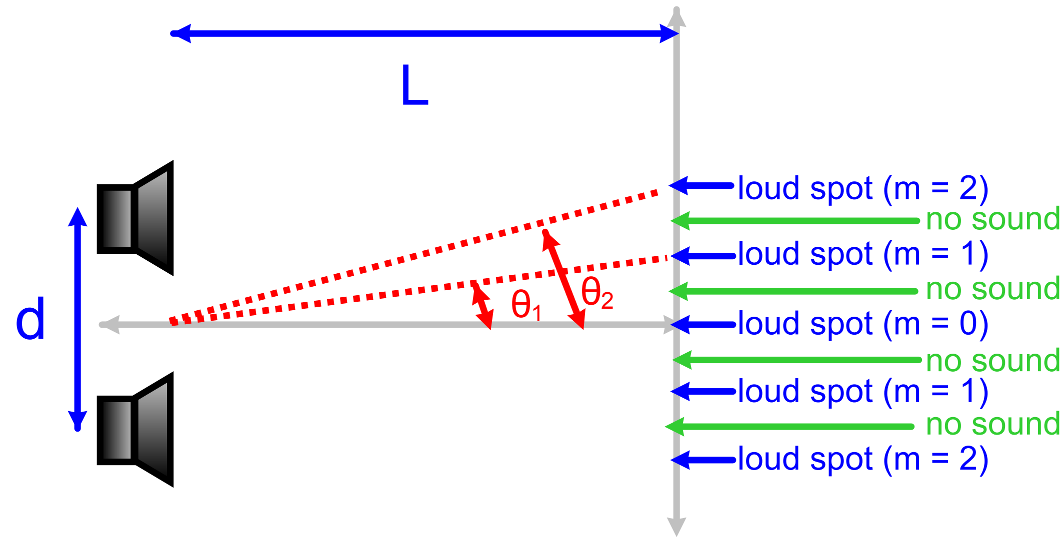
Interference of Sound Waves



You can see that the interference alternates between loud spots and spots of no sound.

http://njc.tl/pq

Interference of Sound Waves



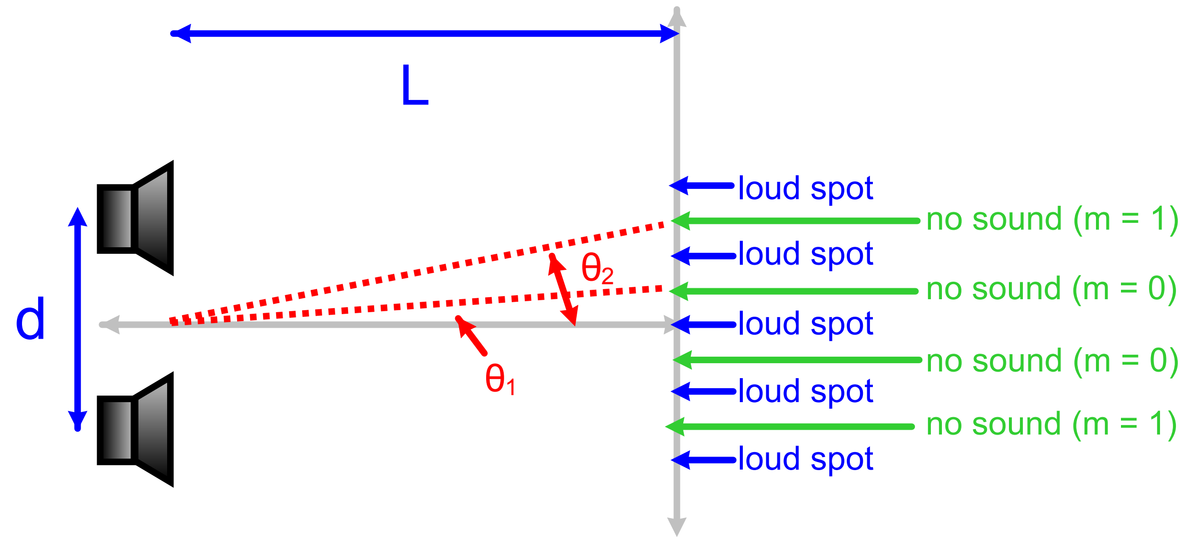
A constructive interference pattern is given by: $d\sin\theta = m\lambda$

$\tan\theta = \dfrac{x}{L}$ **and for small angles** $\sin\theta = \tan\theta$ **so:** $x = \dfrac{m\lambda L}{d}$

Where m is called the order of the interference fringe and x is the location of the loud spot.

http://njc.tl/pq

Interference of Sound Waves



A destructive interference pattern is given by: $d\sin\theta = \left(m + \frac{1}{2}\right)\lambda$

$\tan\theta = \frac{x}{L}$ **and for small angles** $\sin\theta = \tan\theta$ **so:** $x = \frac{\left(m + \frac{1}{2}\right)\lambda L}{d}$

Where m is called the order of the interference fringe and x is the location of the spot with no sound is heard.

http://njc.tl/pq

21 Two speakers separated by a distance of 2m areplaced at a distance 5m from a wall. The speakers are generating a sound with a frequency of 1500 Hz.

What is the wavelength of the sound wave?

Answer

22 Two speakers separated by a distance of 2m areplaced at a distance 5m from a wall. The speakers are generating a sound with a frequency of 1500 Hz.

What is the distance between the central maximum and the first place when a listener detects no sound?

Answer

23 Two speakers separated by a distance of 2.5m areplaced at a distance 10m from a wall. The speakersare generating a sound with a frequency of 2500 Hz.

What is the wavelength of the sound wave?

Answer

$$\lambda = \frac{v}{f} = \frac{340m/s}{2500Hz} = 0.136m$$

http://njc.tl/ps

24 Two speakers seperated by a distance of 2.5m areplaced at a distance 10m from a wall. The speakers are generating a sound with a frequency of 2500 Hz.

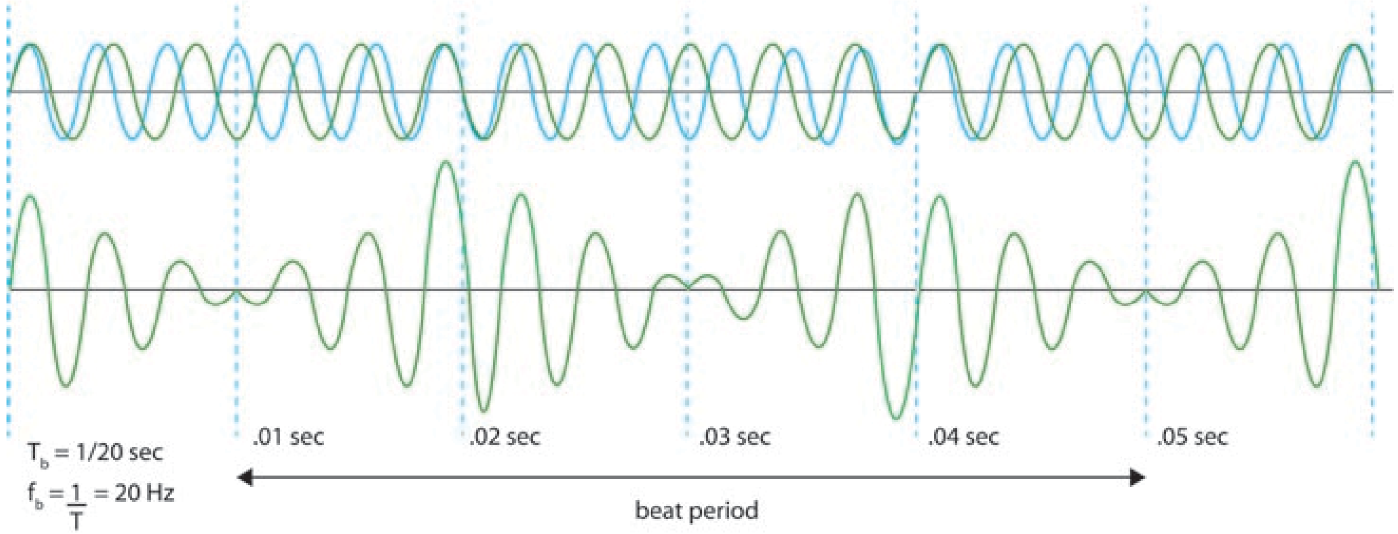
What is the distance between the central maximum and the first place when a listener detects no sound?

Answer

Interference of Sound Waves; Beats

Waves can also interfere in time, causing a phenomenon called beats. Beats are the slow “envelope” around two waves that are relatively close in frequency.

In general, the beat frequency is the difference in frequency of the two waves.



http://njc.tl/pt

25 Two tuning forks produce two frequencies of 500 Hz and 450 Hz. What is the beat frequency?

Answer

http://njc.tl/pt

26 Two tuning forks produce two frequencies of 50 Hz and 48Hz. What is the beat frequency?

Answer

Doppler Effect

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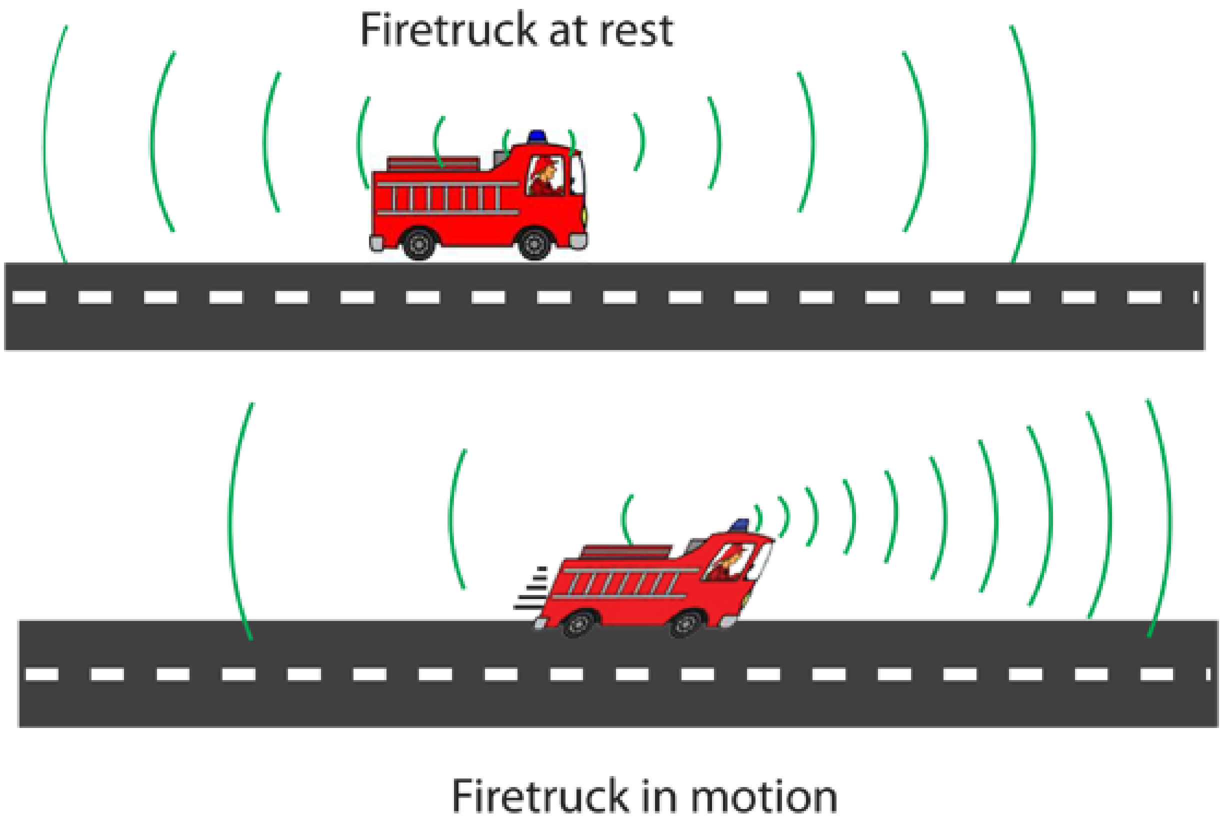
Doppler Effect

The Doppler effect occurs when a source of sound is moving with respect to an observer.



Click here for a video on the doppler effect

http://njc.tl/pu

Doppler Effect

As can be seen in the previous image, a source moving toward an observer has a higher frequency and shorter wavelength; the opposite is true when a source is moving away from an observer.

27

- increase
- decrease

Answer

http://njc.tl/pv

28 If a sound source is moving away from the listener. The listener will experience an ___________ in the pitch of sound that he or she hears.

- increase
- decrease

Answer

http://njc.tl/pw

Doppler Effect

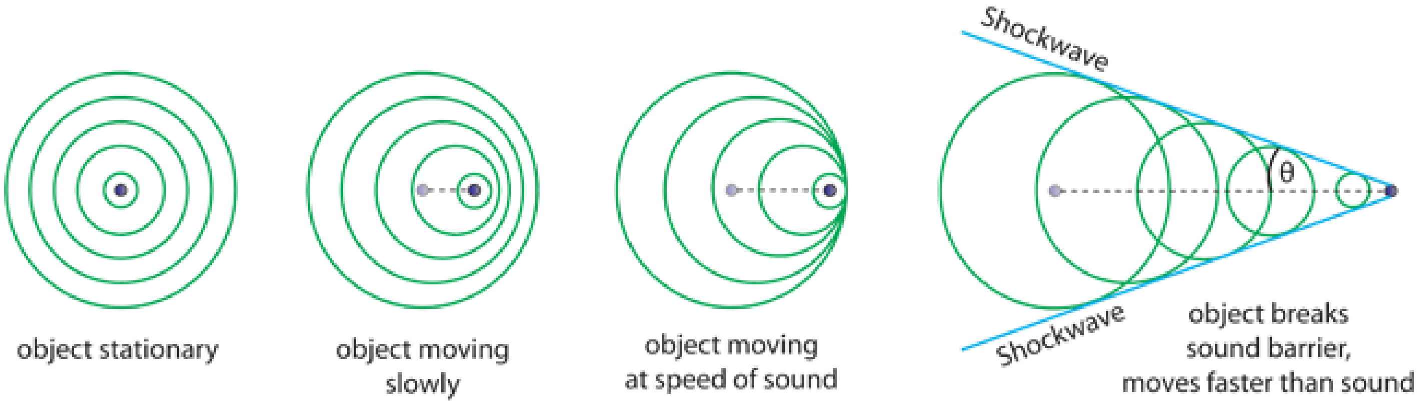
If the observer is moving with respect to the source, things are a bit different. The wavelength remains the same, but the wave speed is different for the observer.

However, the effect is much the same. The observed frequency goes up as you go towards a sound source, and down if you go way from one.

http://njc.tl/px

Shock Waves and the Sonic Boom

If a source is moving faster than the wave speed in a medium, waves cannot keep up and a shock wave is formed.



Click here for a video on the sound barrier

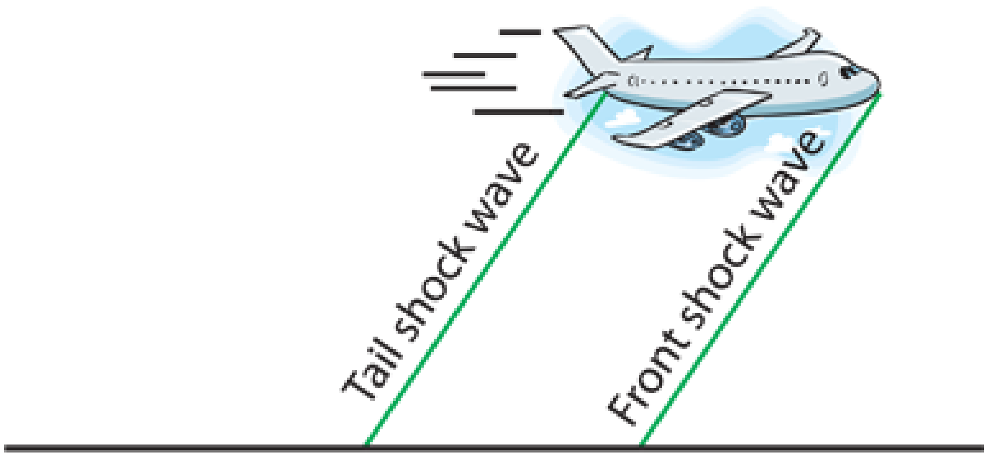
http://njc.tl/py

Shock Waves and the Sonic Boom

Shock waves are analogous to the bow waves produced by a boat going faster than the wave speed in water.

Shock Waves and the Sonic Boom

Aircraft exceeding the speed of sound in air will produce two sonic booms, one from the front and one from the tail.



Summary (1 of 2)

- Sound is a longitudinal wave in a medium.

- The pitch of the sound depends on the frequency.

- The loudness of the sound depends on the intensity and also on the sensitivity of the ear.

- The strings on stringed instruments produce a fundamental tone whose wavelength is twice the length of the string; there are also various harmonics present.

Summary (2 of 2)

- Wind instruments have a vibrating column of air when played. If the tube is open, the fundamental is twice its length; if it is closed the fundamental is four times the tube length.

- Sound waves exhibit interference; if two sounds are at slightly different frequencies they produce beats.

- The Doppler effect is the shift in frequency of a sound due to motion of the source or the observer.