Speed of Sound

¤ The <u>speed</u> of sound in a material is determined by the properties of the material, specifically the elasticity of the medium and the mass density of the medium.

Material	**Speed (m/s)**
Aluminum	6420
Granite	6000
Steel	5960
Pyrex glass	5640
Copper	5010
Plastic	2680
Fresh water (20 °C)	1482
Fresh water (0 °C)	1402
Hydrogen (0 °C)	1284
Helium (0 °C)	965
Air (20 °C)	343
Air (0 °C)	331

- Typically, sound travels fastest in solids (because of the high elasticity and greater density) and slowest in gases (because of the low elasticity and lesser density).

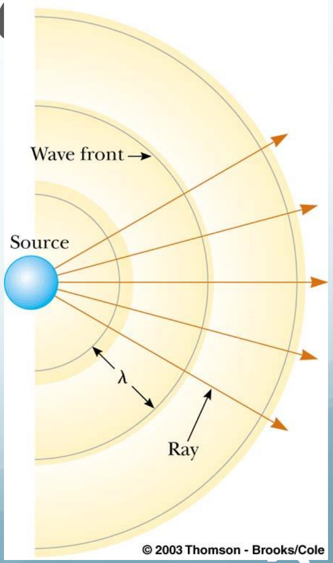
Speed of Sound

- At normal atmospheric pressure and a temperature of 20° C, sound waves travel at 343 m/s (about 750 mph) through the air.
- Increasing the temperature of the air causes an increase in the speed of sound at a rate of 0.6 m/s for every degree above 20° C.
- The speed of sound is <u>much</u> slower than the speed of light. You *hear* thunder after you *see* a flash of lightning.

Sound Intensity

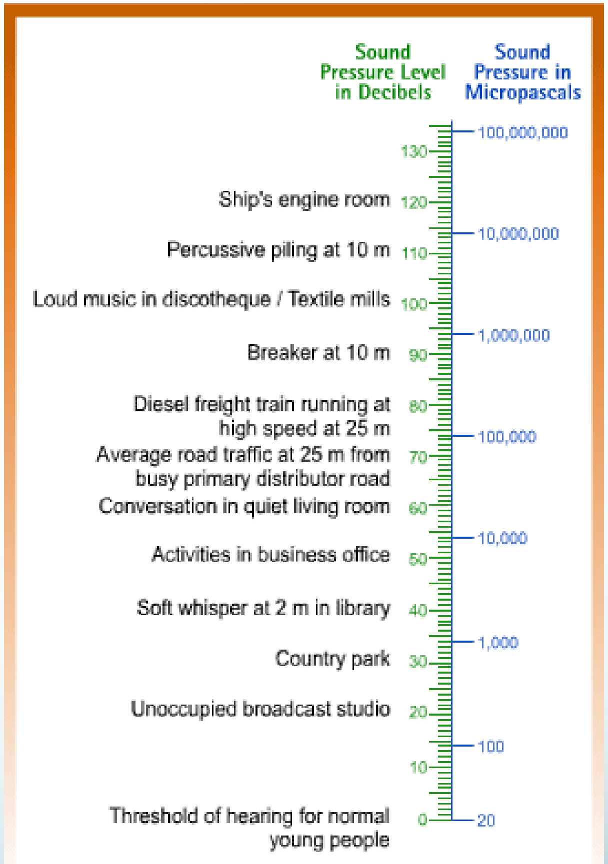
- Sound intensity is proportional to the square of the amplitude of the sound wave.
- As sound waves travel away from their source, the energy is spread over a greater and greater surface area causing a reduction in the intensity of the sound wave.

- Sound intensity is measured in Watts per square meter (W/m^2).
- The lowest intensity sound that can be detected by the human ear is 1×10^{-12} W/m^2. This is referred to as the *threshold of hearing*.



The Decibel Scale

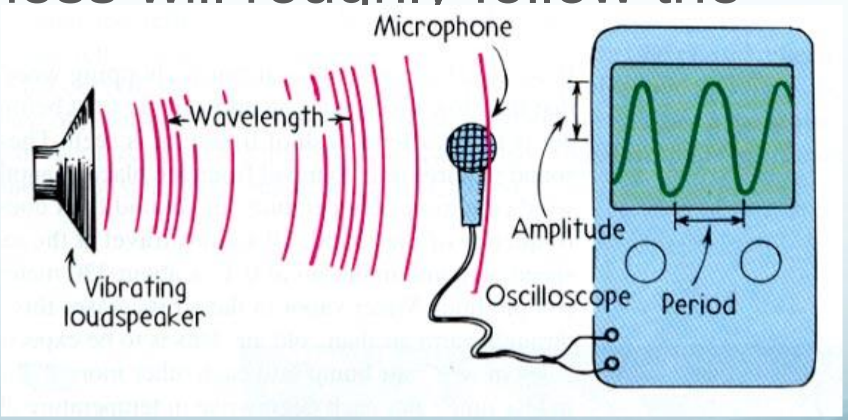
- Since the range of intensities that can be detected by the human ear is very large, a logarithmic scale, based on powers of ten, is used to measure intensity levels. This intensity level is measured in decibels (dB).
- A 50 dB sound is 100 times more intense than a 30 dB sound and 1000 times more intense than a 20 dB sound.



Relation between sound pressure in micropascals and sound pressure level in decibels re 20 µPa.

Loudness

- While the intensity of a sound is a very objective quantity which can be measured with sensitive instrumentation, the *loudness* of a sound is more of a subjective response which will vary with human perception.
- The sensation of loudness will roughly follow the decibel scale.



Forced Vibrations

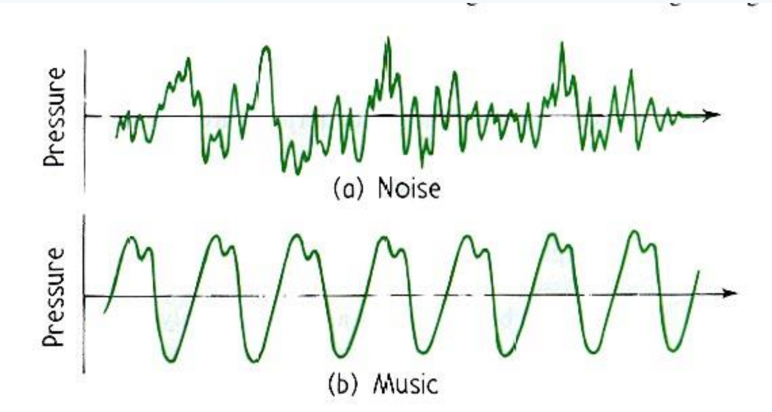
- The tendency of one object to force another adjoining or interconnected object into vibrational motion is referred to as a *forced vibration*.
- Press the base of a vibrating tuning fork against a tabletop and the tabletop will be forced into vibration – the tabletop serves as a *sounding board* amplifying the sound.
  - ¤ The wooden body of an acoustic guitar will be forced to vibrate at the same frequency as a vibrating string on the guitar.

Natural Frequency

- When an object composed of an elastic material is disturbed it will tend to vibrate at its *natural frequency*.
- If the amplitude of the vibrations are large enough and if the frequency is within the audible portion of the sonic spectrum, then the object will produce sound waves which are audible.
- The natural frequency is the frequency at which minimum energy is required to force the object into vibration.

Natural Frequency

- A bell, a tuning fork and a flute all produce vibrations at a single frequency and are said to produce a pure tone.
- Other instruments produce a set of frequencies that are multiples of one another to generate a rich sound.
- Some objects produce a set of frequencies that have no simple relationship and generate a sound that is not at all musical – instead they produce noise.



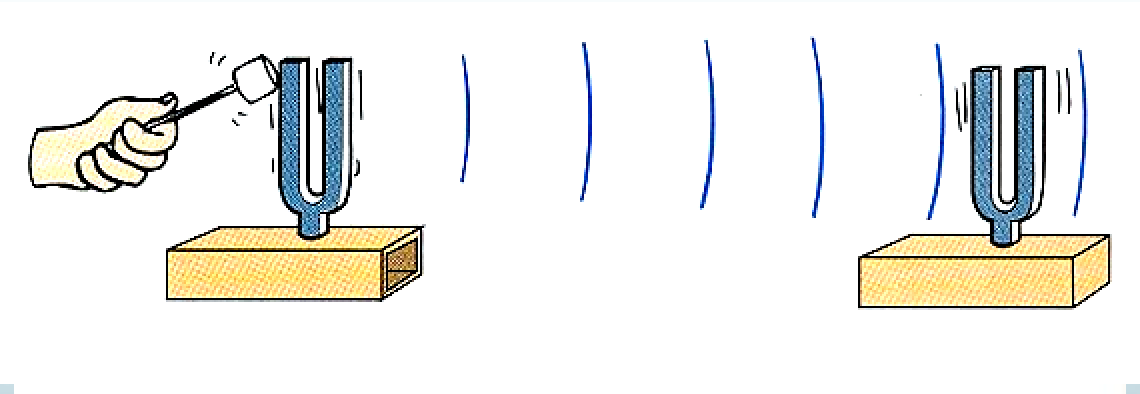
Resonance

- When one object vibrates at the same natural frequency of a second object and forces that second object into vibrational motion, *resonance* occurs.
- Resonance can lead to a dramatic increase in the amplitude of the vibration.

¤ A child on a swing can swing through a larger motion if she pumps her legs or if she is pushed by someone else. If the rhythm of the pushing matches the natural frequency of the swing, the amplitude of the swing can grow quite large.

Resonance

- Two tuning forks of the same frequency are mounted on identical open wooden boxes and separated by a short distance. When one of the tuning forks is struck it will set the other tuning fork into vibration.



- With each compression that passes the second tuning fork, a tiny pushing force acts on the tines of this tuning fork.
- Since the frequency of these pushes corresponds to the natural frequency of the second tuning fork, the pushes will successively increase the amplitude of vibration.
- Air molecules surrounding the first tuning fork are set into vibration with the same frequency as that of the tuning fork.

Resonance

An air column in an open-ended tube or soda bottle can be made to resonate if the input frequency matches the natural frequency of the air column.

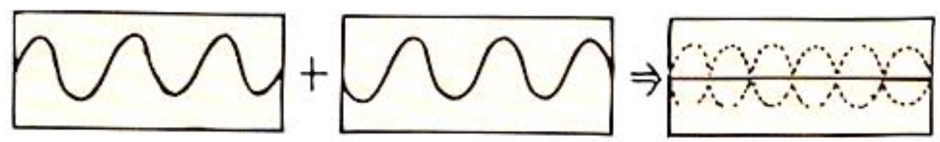
Resonance

In 1940, the Tacoma Narrows Bridge in the state of Washington collapsed due to resonance! The wind speeds that caused the collapse were only 40 mph, but the frequency of the wind pulses matched the natural frequency of the bridge.

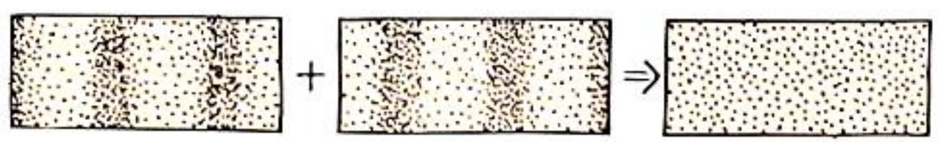
Interference

- Interference occurs in longitudinal waves as it does in transverse waves.
- When sound waves interfere, the loudness of the sound is effected.

- When two sound waves are out of phase, compressions will match with rarefactions leading to *destructive interference* and decreased intensity – the sound will be **softer**.
- When two sound waves are *in phase*, compressions will match with compressions leading to *constructive interference* and increased intensity – the sound will be **louder**.



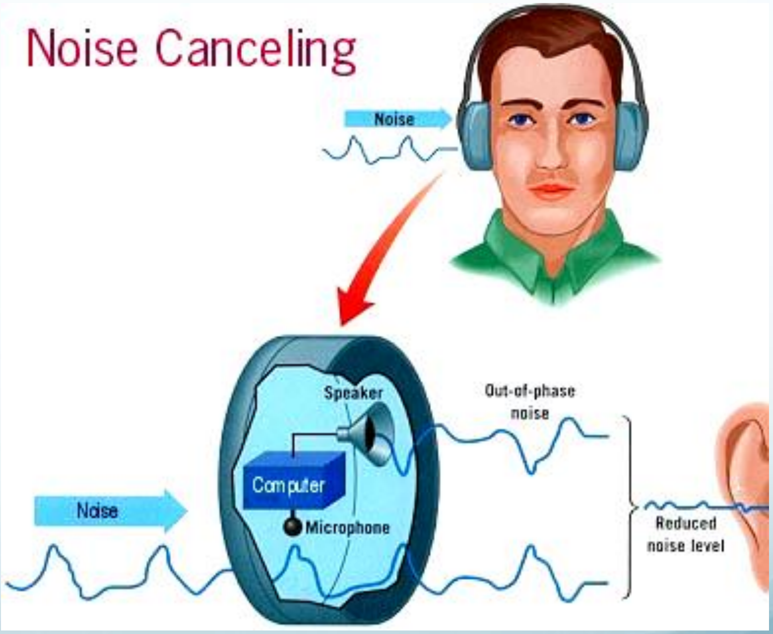
Two identical transverse waves that are out of phase destroy each otherwhen they are superimposed.



Two identical longitudinal waves that are out of phase destroy each other when they are superimposed.

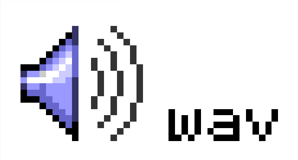
Interference

- Destructive interference between reflected and non-reflected sound waves can cause *dead spots* in some poorly designed auditoriums or theaters.
- Noise-canceling headphones produce a mirror image of any external noises to generate destructive interference

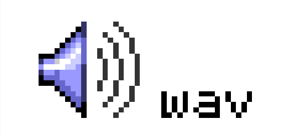


Beats

- When two sound waves differing slightly in frequency are superimposed they will not maintain a constant phase relationship.
- This leads to alternating reinforcement and cancellation of the sound energy.
- The audible result is a series of pulsations called beats.

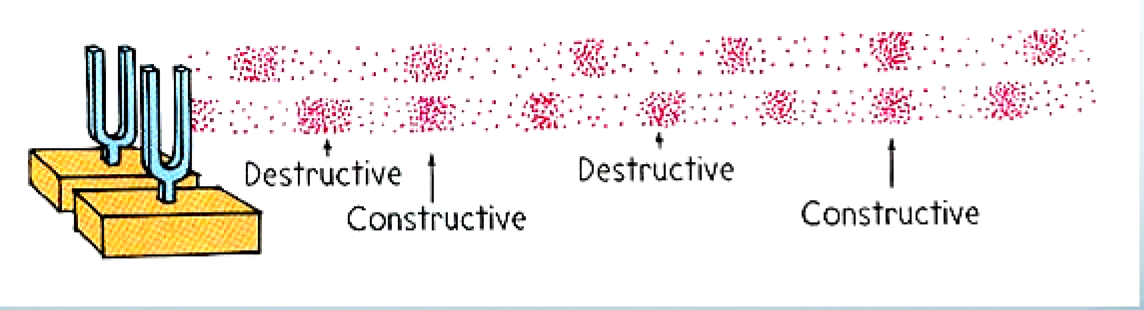


400 & 401 Hz sounds – 1 beat per second



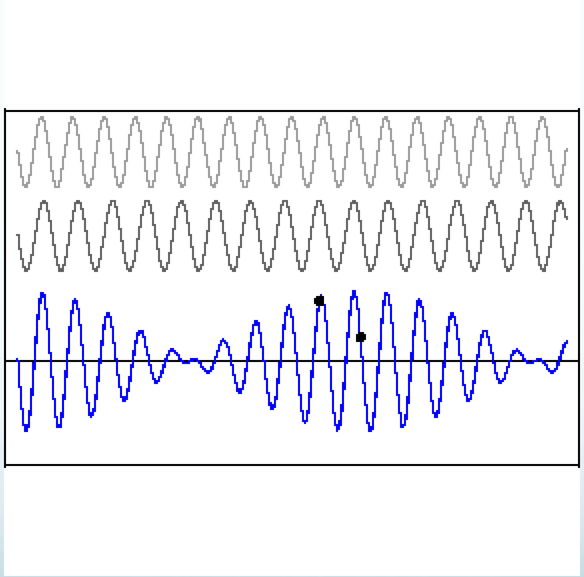
400 & 403 Hz sounds – 3 beats per second

400 & 410 Hz sounds – 10 beats per second



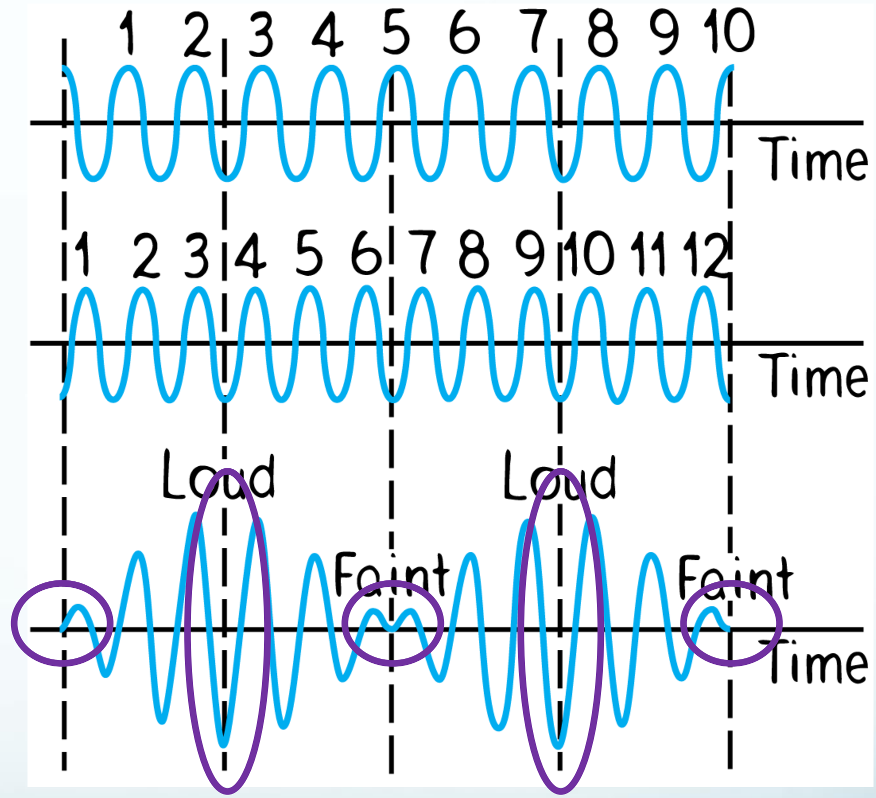
Beats

- The pattern of alternating constructive and destructive interference can be found from applying the law of superposition to the interfering waves.



Beats

- The beat frequency is equal to the difference between the frequencies of the interfering sound waves.



- Minimum amplitude occurs when both waves are completely out of phase.
- Maximum amplitude of the composite wave occurs when both waves are in phase.
- Although the separate waves are of constant amplitude, we see amplitude variations in a superposed wave form.
- This variation is produced by the interference of the two superposed waves.

Beats

- Beats can occur with any kind of wave and are a practical way to compare frequencies.
- To tune a piano, a piano tuner listens for beats produced between a standard tuning fork and a particular string on the piano.
- When the frequencies are identical, the beats disappear.
- The members of an orchestra tune up by listening for beats between their instruments and a standard tone.