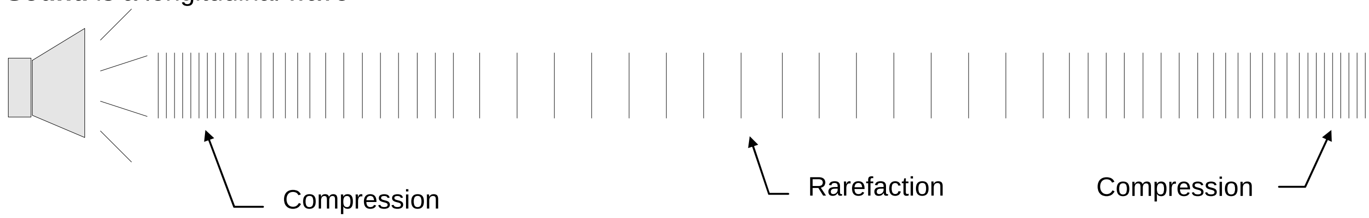
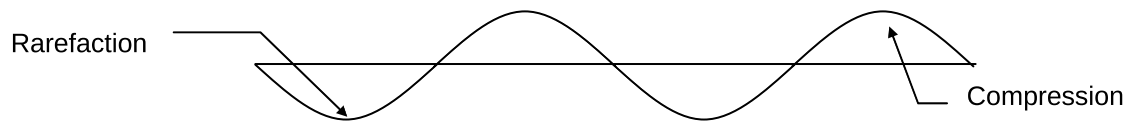
::Sound::

Sound is a longitudinal wave



Sound consists of a series of compressions and rarefactions. However, for simplicity sake, sound is usually represented as a transverse wave as exemplified by the oscilloscope.



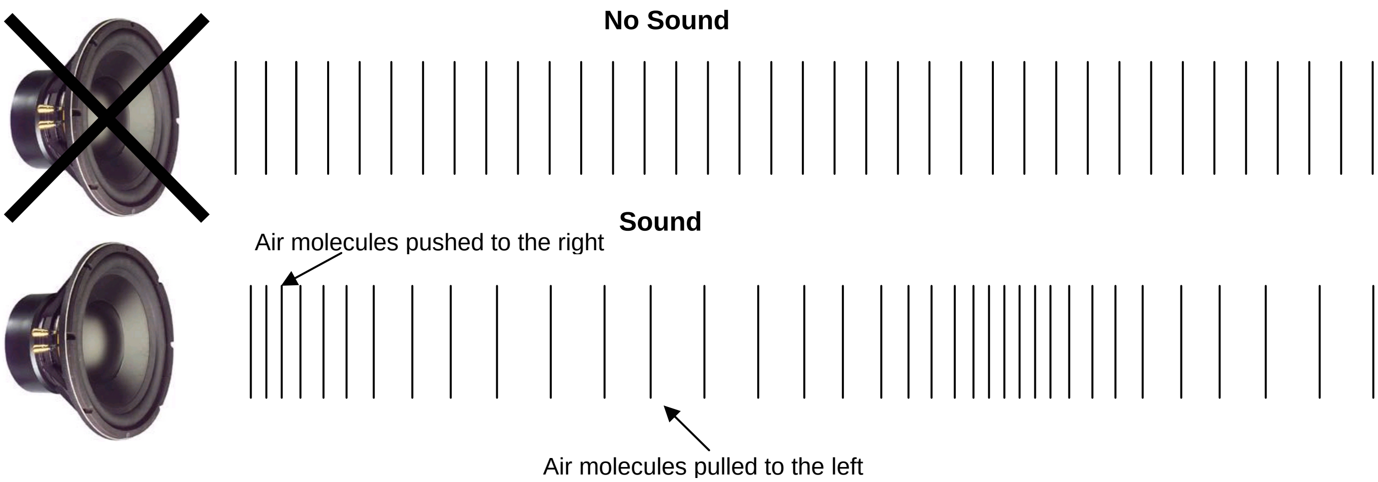
Speed: The speed of sound is given by the equation

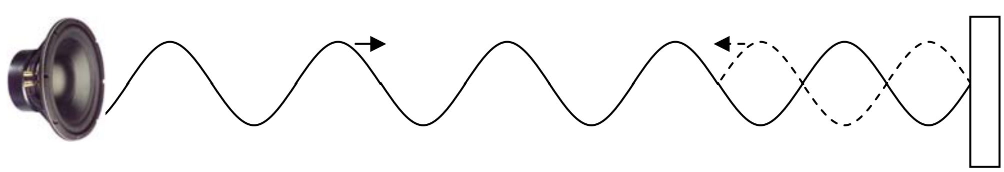
$$v_s = 332 + 0.6T$$

Where v_s is the speed of sound in m/s and T is the ambient temperature in degrees Celsius

Standing Waves: These occur when sound waves encounter a barrier of some sort. The diagrams below are a representation of the relative positions of the air molecules with and without a sound source present.

Under these conditions, the air molecules are free to move back and forth. However if the sound wave hit a barrier, the air molecules cannot move. Therefore any time sound hits a wall, a **node** is formed. Using a sin wave to represent the displacement of the air molecules, the following diagram represents how a standing wave can start to from.

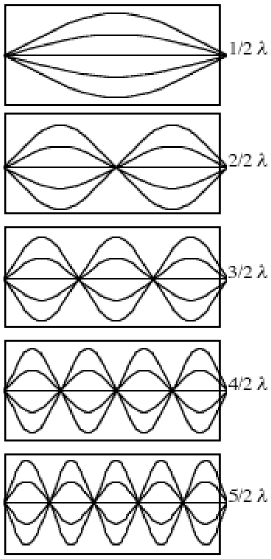




::Standing waves::

Sealed air column

Standing waves in a sealed air column behave like standing waves on a guitar string. Since the air column is sealed, a node is formed at the boundaries. Drums and guitar cabinets resonate in this manner



1^{st} harmonic (fundamental, n=1)

2^{nd} harmonic (1^{st} overtone, n=2)

3^{rd} harmonic (2^{nd} overtone, n=3)

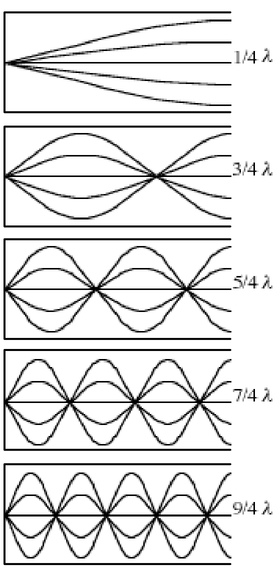
4^{th} harmonic (3^{rd} overtone, n=4)

5^{th} harmonic (4^{th} overtone, n=5)

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

Where L is the length of the air column
n represents the mode of resonance
λ represents the wavelength of the wave

Air column- open one end
Air molecules are free to move at the open end so an anti node is formed at the opening and a node is formed at the closed end. **Example**: The clarinet



1^{st} harmonic (fundamental, n=1)

3^{rd} harmonic (1^{st} overtone, n=2)

5^{th} harmonic (2^{nd} overtone, n=3)

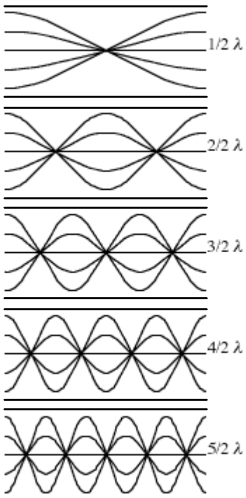
7^{th} harmonic (3^{rd} overtone, n=4)

9^{th} harmonic (4^{th} overtone, n=5)

$$L = \frac{(2n-1)}{4}\lambda$$

Where L is the length of the air column
n represents the mode of resonance
λ represents the wavelength of the wave

Air Column – open both ends
Air molecules are free to move at both ends of the air column; therefore an anti node is formed at each opening.
Example: the Flute



1st harmonic (fundamental, n=1)

2nd harmonic (1st overtone, n=2)

3rd harmonic (2nd overtone, n=3)

4th harmonic (3rd overtone, n=4)

5th harmonic (4th overtone, n=5)

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

Where L is the length of the air column
n represents the mode of resonance
λ represents the wavelength of the wave

::Factors That Affect Resonance in Guitar Strings::

Table of Proportionality of Variables for Strings

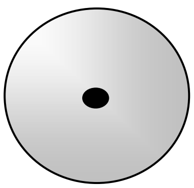
Variable	Proportionality	Description	Comparative equation
Length (L)	$f \propto \frac{1}{L}$	If the length is halved, the frequency doubles. Frequency increases when the length decreases.	$\frac{f_1}{f_2} = \frac{L_2}{L_1}$
Tension (T)	$f \propto \sqrt{T}$	Frequency varies directly as the square root of the tension. Frequency increases when the tension increases. If tension increases by a factor of four, the frequency doubles.	$\frac{f_1}{f_2} = \frac{\sqrt{T_1}}{\sqrt{T_2}}$
Diameter (d)	$f \propto \frac{1}{d}$	Frequency varies inversely as the diameter. Frequency increases when the diameter of a string decreases. If the diameter is halved, then the frequency doubles.	$\frac{f_1}{f_2} = \frac{d_2}{d_1}$
Density (ρ)	$f \propto \frac{1}{\sqrt{\rho}}$	Frequency varies inversely as the square root of the density. Frequency increases when density decreases. If the density is quartered, then the frequency doubles.	$\frac{f_1}{f_2} = \frac{\sqrt{\rho_2}}{\sqrt{\rho_1}}$

::Intensity of sound::

From previous section we have seen that power is defined as work over time and is measured in ***Joules per second*** or ***Watts*** ($P = \frac{W}{t}$).

From experience, most people are aware that most sound systems are measured in Watts. 100 linear Watts of audio is quite loud for a home stereo, but 100W is quite insufficient for a live performance. Take for example concerts in the 60s. The Beatles used 100W Vox amplifiers in their early days. 100W does not seem like much but these amplifiers were pushed well into the saturation region (distortion), which meant they produced sound levels closer to what 300W home stereos would produce. In a club, those sound levels would tear your head off but when the Beatles played Madison Square Gardens, in New York in the early 60s, no one could hear them. Literally!
Q: Why? A: Intensity!

The intensity of sound is defined as the power per surface area of a sound wave. Consider a point source. The sound from the source spreads out in three dimensions. The waves will spread out in the shape of a shell. This means the energy must be spread across the surface are of this shell.



$I = \frac{P}{A}$ ⟶ $I = \frac{P}{4\pi r^2}$ ⟵ Surface Area of a Sphere

Intensity is measured in Watts/ square metre (W/m^2)

Like gravity, sound intensity follows the inverse square law; where by the relative volume of from a sound source can be related to proximity by the following relationship.

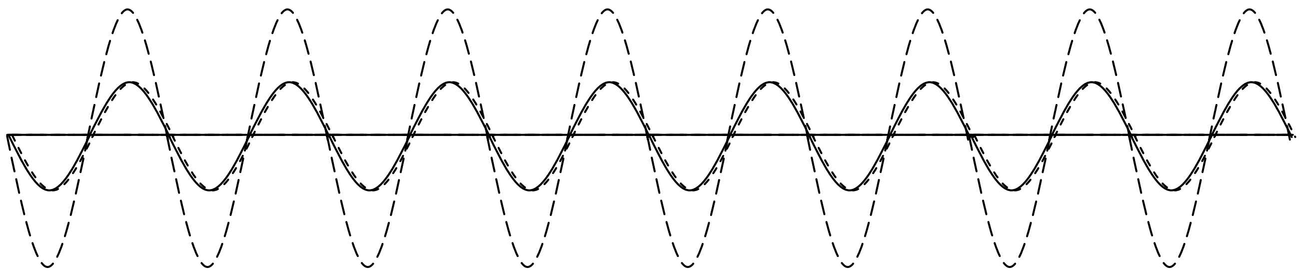
$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$ However, sound intensity is more commonly expressed using the **Decibel System**. The human ear can hear a range of sound intensities ranging from $10^{-12} W/m^2$ to $1.0 W/m^2$. As a result a logarithmic scales is used, called the decibel.

$\beta = 10\log\left(\frac{I_2}{I_1}\right)$ where β is measured in **dB**. Note: 10dB means a factor of 10 where 3dB means a factor of 2.

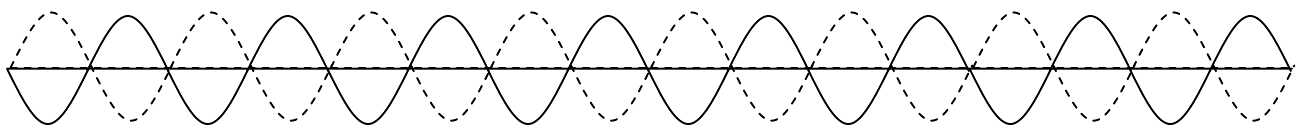
Interference and Beat Frequency

When two waves interfere with each other, two phenomena may occur: **Constructive interference** or **Destructive Interference**.

Constructive Interference

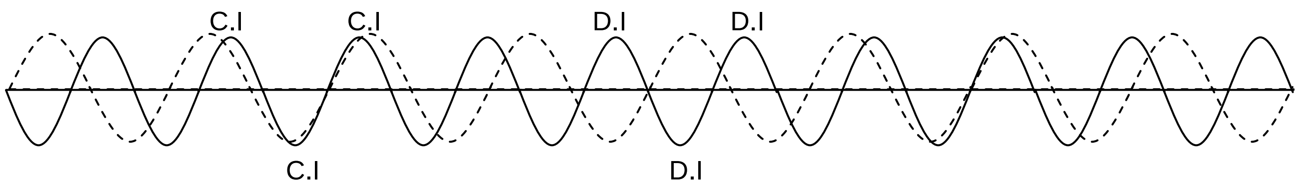


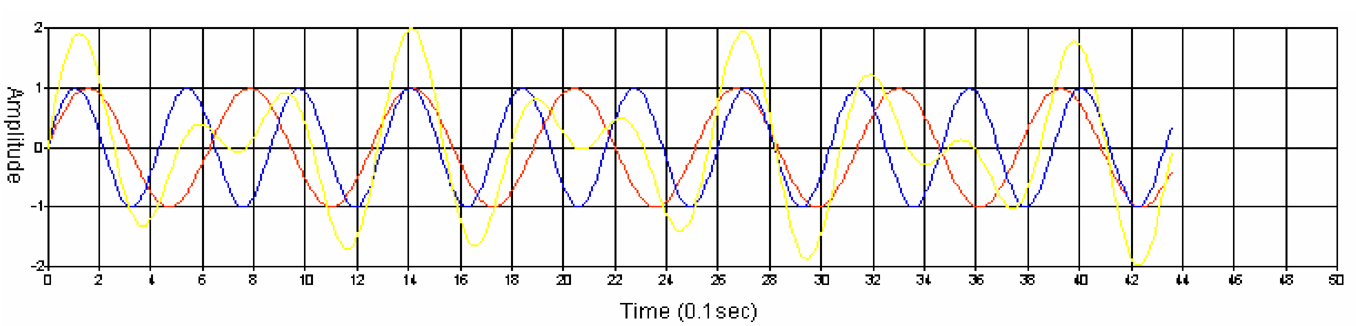
Destructive Interference



Beat Frequency

We get what is called a ***beat frequency*** when two wave of **slightly** different frequency interfere with each other. Because of the differences in the wavelength of the two waves, the interference will **oscillate between constructive** and **destructive** interference.





The beat frequency will occur in regular patterns, defined by the formula

$$f_{beat} = \left| f_1 - f_2 \right|$$