Mechanical Waves

A wave is a **disturbance** or **variation** that transfers energy progressively from point to point in a medium.

The medium through which the wave travels may experience some local oscillations as the wave passes, but the particles in the medium do **not** travel with the wave. The disturbance may take any of a number of shapes, from a finite width pulse to an infinitely long sine wave.

The particles of a medium **OSCILLATE.**

Mechanical Waves are waves which propagate through a material medium (solid, liquid, or gas) at a wave speed which depends on the elastic and inertial properties of that medium. There are two basic types of wave motion for mechanical waves: **longitudinal** waves and **transverse** waves.

https://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html

https://physics.nyu.edu/~ts2/Animation/waves.html#

In a longitudinal wave the particle displacement is parallel to the direction of wave propagation.

In a transverse wave the particle displacement is perpendicular to the direction of wave propagation.

Water waves are an example of waves that involve a combination of both longitudinal and transverse motions. As a wave travels through the waver, the particles travel in *clockwise circles*. The radius of the circles decreases as the depth into the water increases.

Other type of waves:

Electromagnetic *waves* do not require a medium to travel (ex: light, radio waves).

Wave Characteristics

By moving a rope once, a single vibration is produced.
This is a pulse.

https://physics.nyu.edu/~ts2/Animation/waves.html#

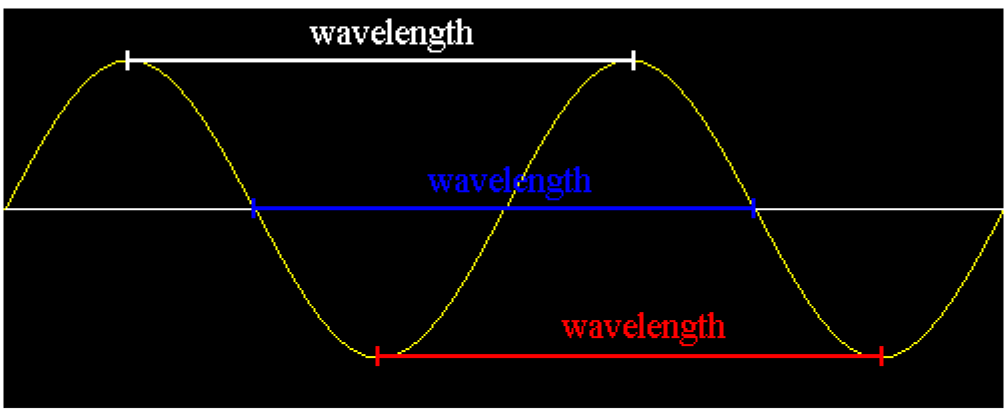
Any point on a transverse wave moves up and down in a repeating pattern or vibration.

The time that a point takes to complete one vibration is called *period*, T.

The number of vibrations per second is called frequency and is measured in hertz (Hz). Here's the equation for frequency:

$$f = 1 / T$$

The shortest distance between consecutive crests, the highest points, or consecutive troughs, the lowest points, is the *wavelength*.



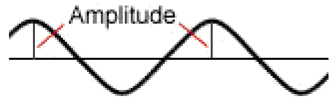
By knowing the frequency of a wave and its wavelength, we can find its velocity. Here is the equation for the ***velocity*** of a wave, the universal wave equation:

$$v = \lambda f$$

The velocity of a wave is only affected by the properties of the medium.

It is not possible to increase the speed of a wave by increasing its wavelength. By doing this, the number of vibrations per second decreases and therefore the velocity remains the same.

The ***amplitude*** of a wave is the distance from a crest to where the wave is at equilibrium. The amplitude is used to measure the energy transferred by the wave. The bigger the amplitude, the greater the energy transferred.



Moving from one medium to another – boundary behavior

https://www.acs.psu.edu/drussell/demos/reflect/reflect.html

https://www.physicsclassroom.com/mmedia/waves/fix.cfm

Once a wave (incident wave) has reached the end of a medium, part of the energy is transferred to the medium that is immediately next to it (***transmitted wave***) and part is reflected backward (***reflected wave***).

Fixed-end reflection is reflection from a rigid obstacle when the pulse is inverted.

Free-end reflection occurs when the wave moves from one medium to another medium that is free to move and the pulse of the reflected wave is not inverted.

The energy transferred depends on the difference between the mediums.

If there is a significant difference, almost all the energy will be reflected.

If the mediums are similar, most of the energy will be transferred.

However, the reflected waves will be inverted if the medium that comes next is more dense or it won't be inverted if the medium is less dense.

Interference

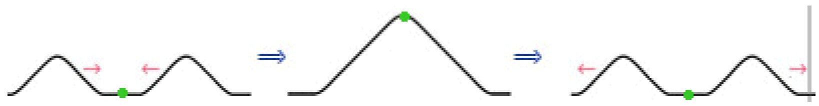
When two waves traveling in opposite directions through the same medium collide, the amplitude of the resulting wave will be the sum of the two initial waves.

This is called ***interference*** and there are of two types:

Constructive interference is when the amplitudes of the initial waves are in the same direction.

The resulting wave will be larger than the original waves.

The highest point of a constructive interference is called an ***antinode***.

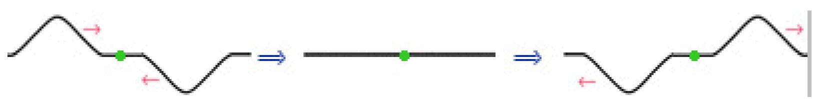


https://physics.nyu.edu/~ts2/Animation/waves.html#

Destructive interference is when the amplitudes of the initial waves are opposite.

The amplitude of the resulting wave will be zero.

The point in the middle of a destructive interference is called a ***node*** and it never moves.



Interference from two circular periodic waves:

https://www.youtube.com/watch?v=fjaPGkOX-wo

https://www.physicsclassroom.com/mmedia/waves/ipd.cfm

Reflection, Refraction and Diffraction of waves of two dimensions (waves on water surface)

Vocabulary:

wavefront: the leading edge of a wave

wave ray: a straight line drawn perpendicular to a wavefront that indicates the direction of transmission

normal: a straight line drawn perpendicular to a barrier struck by a wave

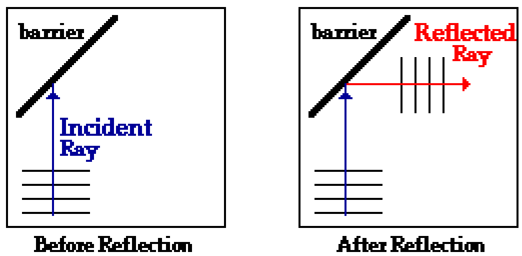
http://www.physics.usyd.edu.au/teach_res/hsp/sp/mod31/m31_RRN.htm

Reflection:

When a wave hits a barrier, it will be reflected depending on the direction of the barrier. The angle between the incident wave and the normal is the same as the angle between the normal and the reflected wave.

http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=16

The Law of Reflection



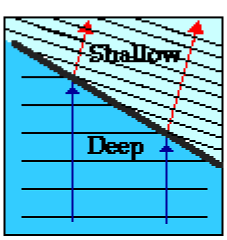
Refraction and diffraction:

Vocabulary:

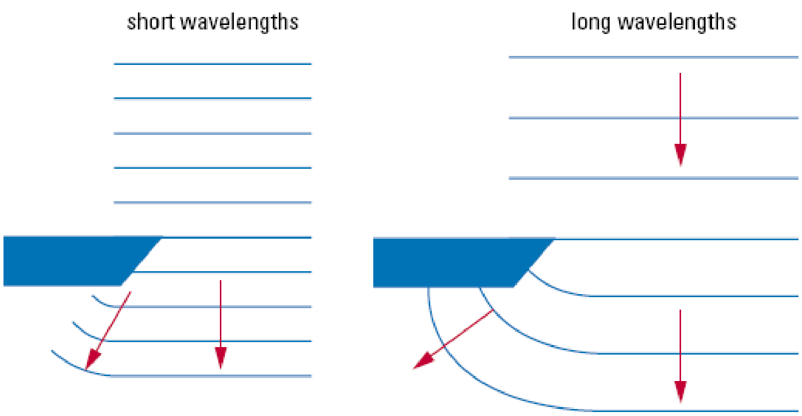
refraction: the bending effect on a wave's direction that occurs when the wave enters a different medium at an angle

diffraction: the bending effect on a wave's direction as it passes through an opening or by an obstacle

When a wave enters a different medium (from a shallow region to a deeper region or the other way around)) at an angle, the direction of waves changes. This change is called **refraction**.



When a wave travels through a small hole in a barrier, it bends around the edges. This is called **diffraction**.



<u>Mechanical Resonance</u>

Mechanical Resonance occurs when an object that is free to vibrate is acted on by a periodic force that has the same frequency as the object's natural frequency.

<u>Standing Waves</u>

http://zonalandeducation.com/mstm/physics/waves/standingWaves/understandingSWDia1/UnderstandingSWDia1.html

Standing waves are created when waves traveling in opposite direction have the same amplitude and wavelength.

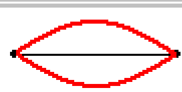
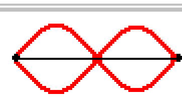
Nodes or nodal points are points of the medium that remain at rest.

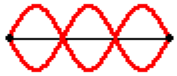
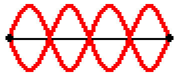
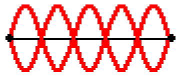
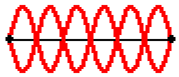
Antinodes: points midway between nodes where maximum constructive interference occurs.

https://www.youtube.com/watch?v=ieheeeKTbac

Each frequency is associated with a different standing wave pattern. These frequencies and their associated wave patterns are referred to as **harmonics**.

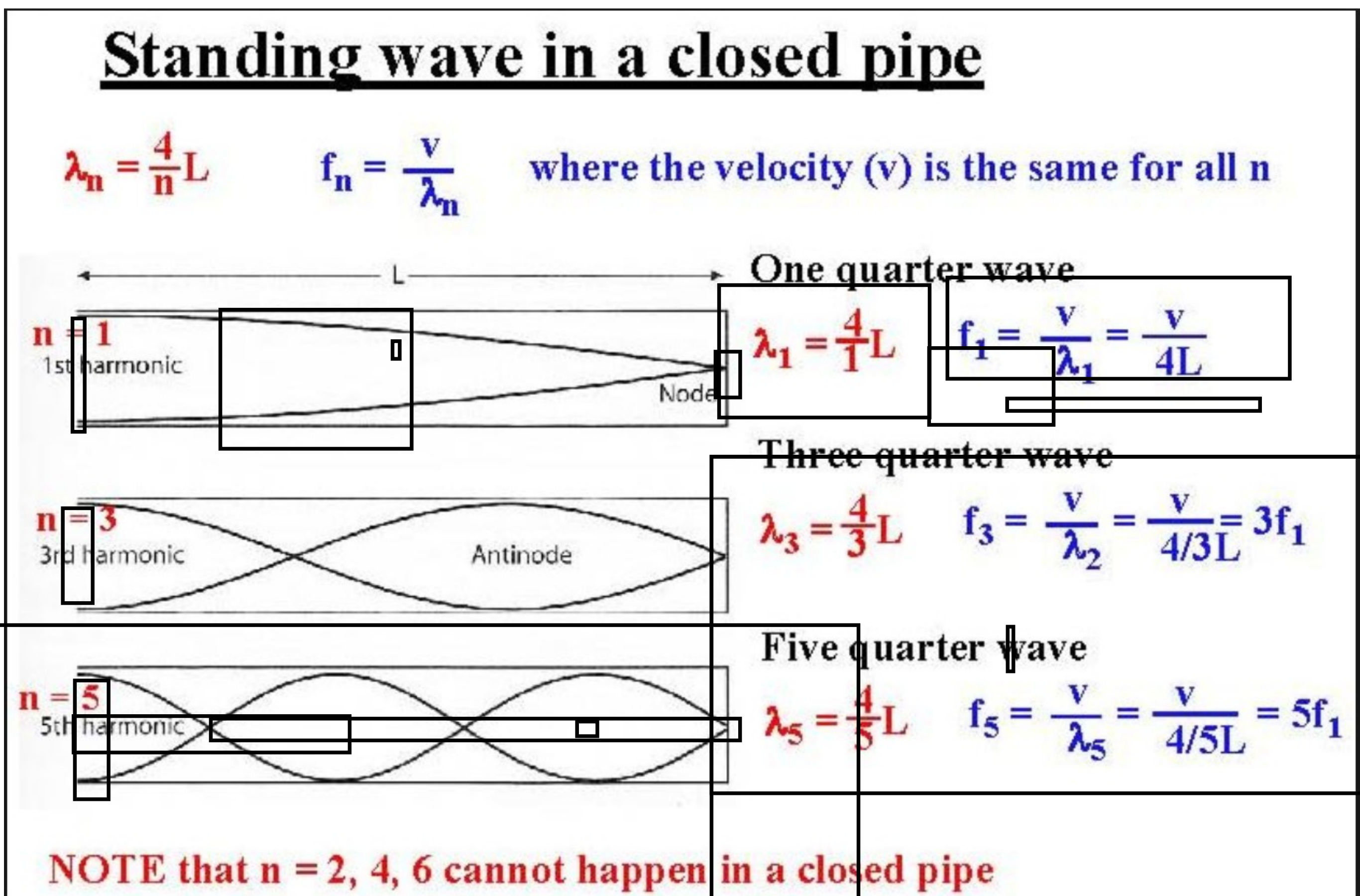
https://www.physicsclassroom.com/Class/waves/u10l4d.cfm

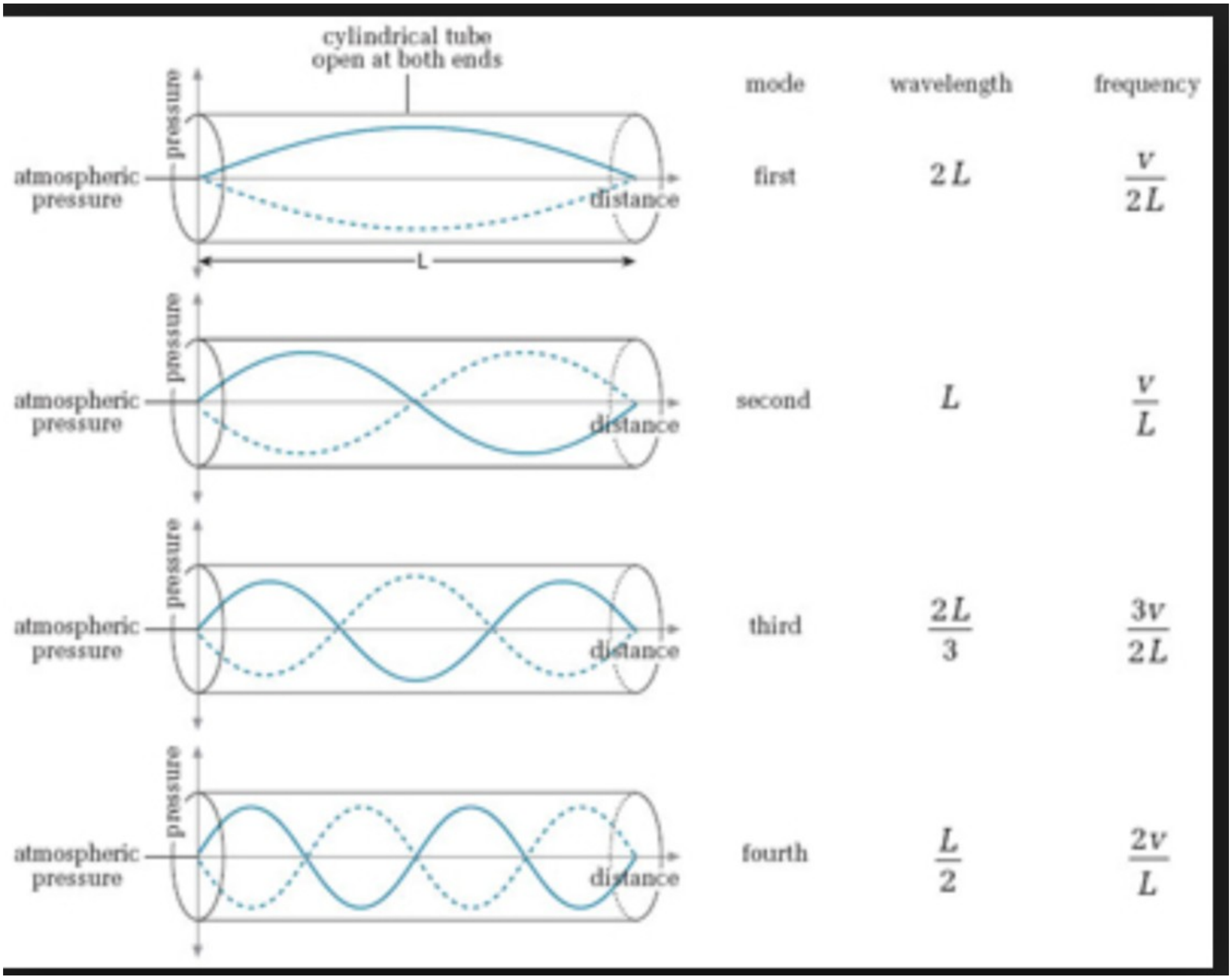
Harmonic	**Pattern**	**# of Loops**	**Length-Wavelength Relationship**
1st		1	**L** = 1 / 2 • λ
2nd		2	**L** = 2 / 2 • λ

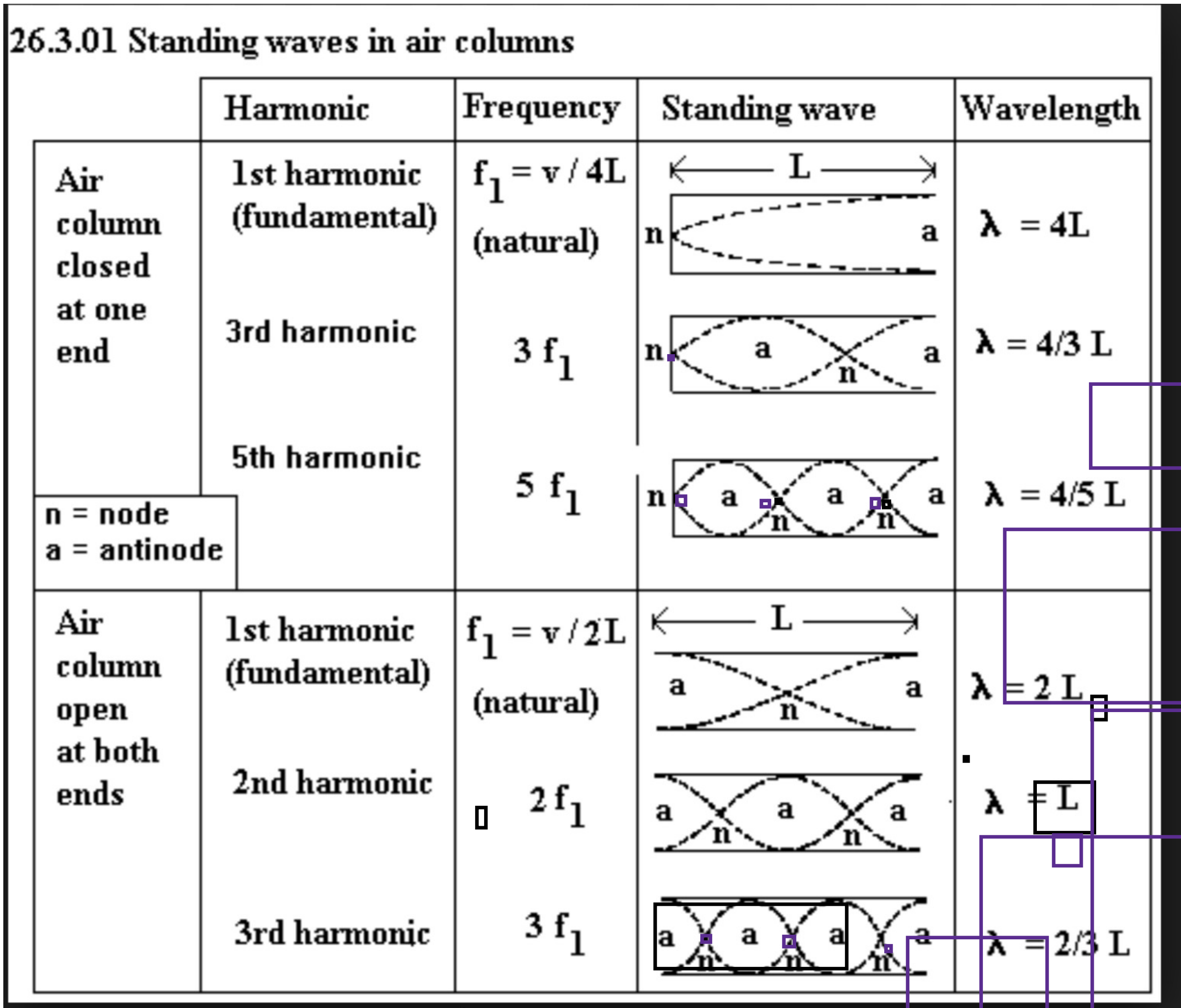
3rd		3	$L = 3 / 2 \cdot \lambda$
4th		4	$L = 4 / 2 \cdot \lambda$
5th		5	$L = 5 / 2 \cdot \lambda$
6th		6	$L = 6 / 2 \cdot \lambda$
nth	--	n	$L = n / 2 \cdot \lambda$

Resonance in Air Columns

A **pipe** that is **closed** at one end is said to be stopped while an open **pipe** is open at both ends. Modern orchestral flutes behave as open cylindrical **pipes**; clarinets and lip-reed **instruments** (brass **instruments**) behave as **closed** cylindrical **pipes**; and saxophones, oboes, and bassoons as **closed** conical **pipes**.




cylindrical tube
open at both ends
mode
wavelength
frequency
pressure
atmospheric pressure
distance
L
first
$2L$
$\frac{v}{2L}$
second
L
$\frac{v}{L}$
third
$\frac{2L}{3}$
$\frac{3v}{2L}$
fourth
$\frac{L}{2}$
$\frac{2v}{L}$



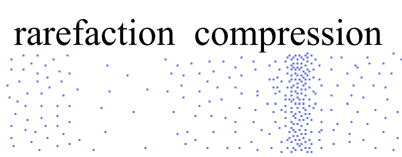
26.3.01 Standing waves in air columns

	Harmonic	Frequency	Standing wave	Wavelength
Air column closed at one end	1st harmonic (fundamental)	$f_1 = v / 4L$ (natural)	L; n a	$\lambda = 4L$
	3rd harmonic	$3 f_1$	n a n a	$\lambda = 4/3\ L$
n = node a = antinode	5th harmonic	$5 f_1$	n a n a n a	$\lambda = 4/5\ L$
Air column open at both ends	1st harmonic (fundamental)	$f_1 = v / 2L$ (natural)	L; a n a	$\lambda = 2\ L$
	2nd harmonic	$2 f_1$	a n a n a	$\lambda = L$
	3rd harmonic	$3 f_1$	a n a n a n a	$\lambda = 2/3\ L$

https://www.acs.psu.edu/drussell/Demos/hockey/hockey.html

Sound waves

Sound is a form of energy produced by rapidly vibrating objects.
A vibrating source pushes molecules in air back and forth, creating areas of compression and rarefaction.



The energy of a sound wave travels away from the source through a series of molecule collisions parallel to the direction of the wave.
Sound cannot travel through a vacuum.

Sound waves can also travel trough liquids and solids.

The speed of sound depends on the temperature of the medium and its elasticity (more elasticity means that molecules will move easily).

The speed of sound in air at normal atmospheric pressure can be calculated using the formula:

$$v = 331.4\text{m/s} + (0.606\text{m/s°C})t$$

where t is the air temperature in degrees Celsius.

Sound waves move faster through liquids and solids than through gases.

Measuring Sound Waves

Sounds may be generally characterized by pitch, loudness, and quality. The perceived pitch of a sound is just the ear's response to frequency, i.e., for most practical purposes the pitch is just the frequency.

In music, different pitches (C, D, E, etc.) are represented by notes. For example, middle C in equal temperament = 261.6 Hz.

Humans can hear frequencies between 20 Hz to 20 000 Hz, depending on the age of the person. Sound waves with a frequency above 20 000 Hz, are called *ultrasonic* waves. Sound waves with a frequency below 20 Hz are called *infrasonic* waves.

Intensity of Sound

Sound intensity represents the power of a sound per unit area in watts per meter squared.

Decibel (db) is the unit used to measure sound intensity level. On the decibel scale, 0 db is the threshold of hearing (10^{-12} W/m^2). The scale is not linear but is a logarithmic scale, that is: 0db = 10^{-12}W/m^2

$$10\text{db} = 10^{-12}\text{W/m}^2 \text{ x } 10 = 10^{-11}\text{W/m}^2$$

$$20\text{db} = 10^{-12}\text{W/m}^2 \text{ x } 10^2 = 10^{-10}\text{W/m}^2$$

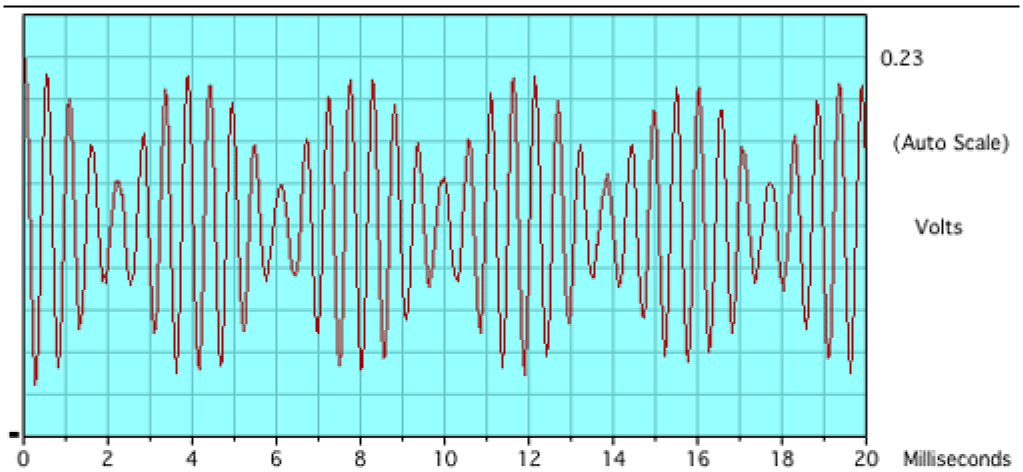
The intensity of sound decreases as the distance from the source increases.

Beat Frequency

When two sound waves of different frequency approach your ear, the alternating constructive and destructive interference causes the sound to be alternatively soft and loud - a phenomenon which is called "beating" or producing beats. The beat frequency is equal to the absolute value of the difference in frequency of the two waves.

$$f_{beat} = |f_2 - f_1|$$

The image below is the beat pattern produced by a London police whistle, which uses two short pipes to produce a unique and piercing three-note sound.



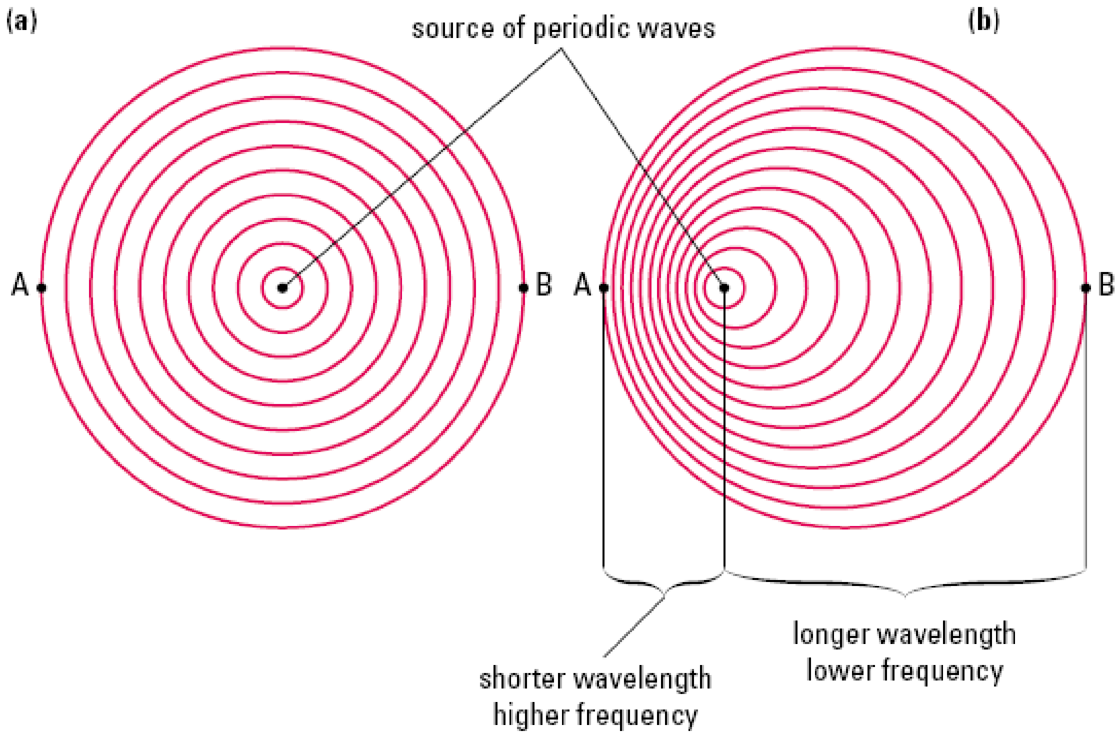
to hear beats:

Doppler Effect

If you've ever been to an automobile race, you probably noticed that when a racing car streaks past you, you can detect a change in frequency of the sound from the car. As the car approaches, the sound becomes higher in frequency. At the instant the car passes you, the frequency drops noticeably. The apparent changing frequency of sound in relation to an object's motion is called the Doppler effect, named after Christian Doppler (1803–53), an Austrian physicist and mathematician who first analyzed the phenomenon.

The Doppler Effect is the change in the apparent frequency of a wave as the observer and source move towards or away from each other.
If the source moves at the same speed as the sound that it emits, it "breaks the sound barrier". This speed is called Mach 1.

Figure 1
The Doppler effect
(a) The source is stationary. Both observers A and B hear the same frequency of sound.
(b) The source is moving to the left. Observer A hears a higher frequency and Observer B hears a lower frequency.



It can be shown that the following relationship describes the effect on frequency. When a source either moves toward or away from a stationary observer,

$$f_2 = f_1\left(\frac{v}{v \pm v_s}\right)$$

where v is the speed of sound in the medium and v_s is the speed of the source through the medium. The denominator $v + v_s$ is used if the source is moving away from the observer, the denominator $v - v_s$ is used if the source is moving toward the observer.

Supersonic Travel

Objects travelling at speeds less than the speed of sound in air have subsonic speeds.When the speed of an object equals the speed of sound in air at that location, the speed is called Mach 1. The Mach number of a source of sound is the ratio of the speed of the source to the speed of sound in air at that location. Thus, at 0°C near the surface of Earth,Mach 2 is 2 × 332 m/s = 664 m/s. Speeds greater than Mach 1 are supersonic.

When an airplane is flying at the speed of sound, the wavefronts in front of the airplane pile up, producing an area of very dense air, or intense compression, called the **sound barrier**. To exceed the speed of sound, extra thrust is needed until the aircraft “breaks through” the sound barrier. Unless the aircraft has been designed to cut through this giant compression, it will be buffeted disastrously.

Only specially constructed aircraft can withstand the vibrations caused in breaking through the sound barrier to reach supersonic speeds. In present-day supersonic aircraft, such as the Concorde, only slight vibration is noticed when the sound barrier is crossed.

At supersonic speeds, the spheres of sound waves are left behind the aircraft (Figure 4(c)). These sound waves interfere with one another constructively, producing large compressions and rarefactions along the sides of an invisible double cone extending behind the airplane, from the front, and from the rear. This intense acoustic pressure wave sweeps along the ground (Figure 5) in a swath having a width of approximately five times the altitude of the aircraft. This is usually referred to as a **sonic boom**. The sonic boom is heard as two sharp cracks, like thunder or a muffled explosion.

7.10

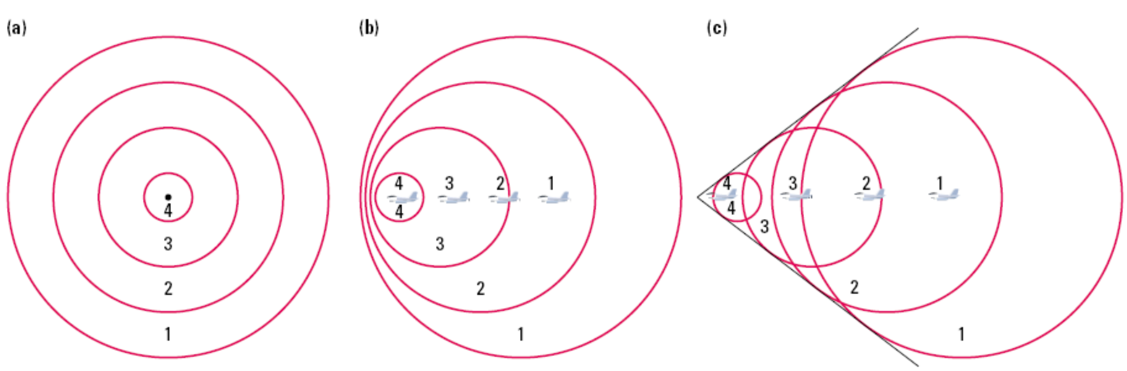


Figure 4
(a) Stationary source
(b) Subsonic source
(c) Supersonic source