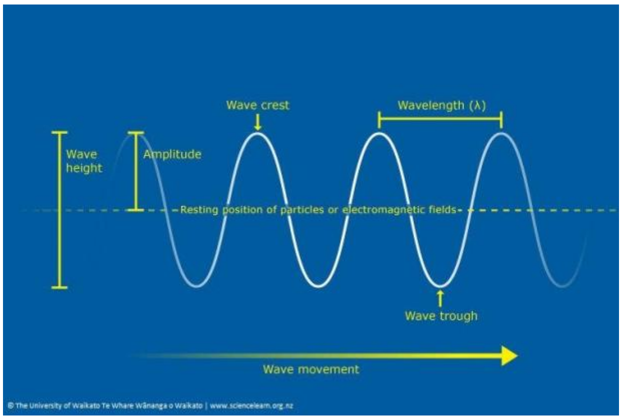
Introduction

Vibrations and waves are extremely important phenomena in physics. In nature, oscillations are found everywhere. From the jiggling of atoms to the large oscillations of sea waves, we find examples of vibrations in almost every physical system.



In physics a wave can be thought of as a disturbance or oscillation that travels through space-time accompanied by a transfer of energy. Wave motion transfers energy from one point to another, often with no permanent displacement of the particles of the medium-that is, with no associated mass transport. They consist, instead, of oscillations or vibrations around almost fixed locations.

Waves transfer energy not mass. An easy way to see this is to imagine a floating ball a few yards out to sea. As the waves propagate (i.e., travel) towards the shore, the ball will not come towards the shore. It may come to shore eventually due to the tides, current or wind, but the waves themselves will not carry the ball with them. A wave only moves mass perpendicular to the direction of propagation-in this case up and down

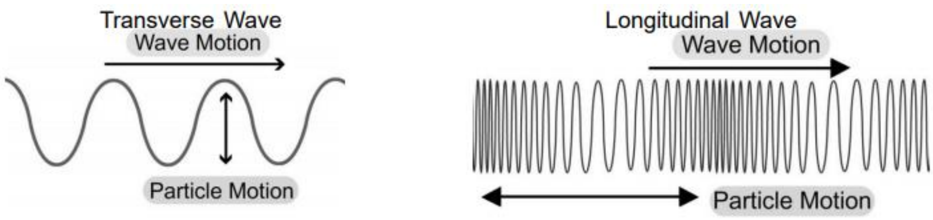
Type of waves:

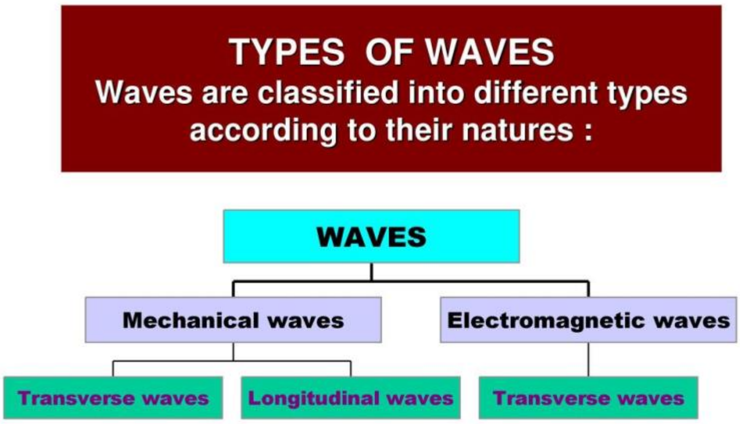
A wave can be transverse or longitudinal depending on the direction of its oscillation.

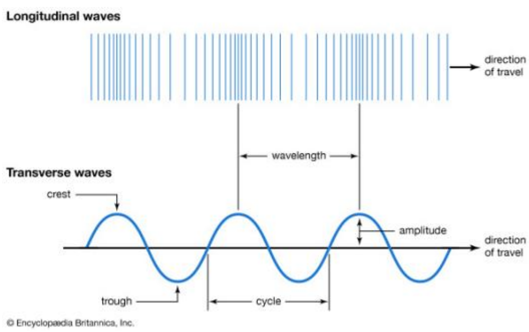
1.Transverse waves occur when a disturbance causes oscillations perpendicular (at right angles) to the propagation (the direction of energy transfer).

2.Longitudinal waves occur when the oscillations are parallel to the direction of propagation.

Mechanical waves can be both transverse and longitudinal, all electromagnetic waves are transverse.







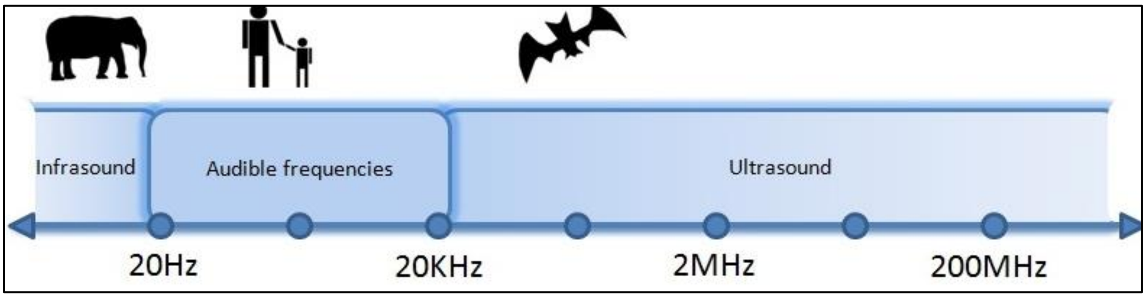
Sound

Sound is a series of compressions and rarefactions that travel in medium

- The compression is a region where the molecules of the medium are very close to each other and the pressure is higher than normal pressure.
- The rarefaction is a region where the molecules are farther away from each other and the pressure is lower than the normal pressure

Sound propagates in the form of longitudinal waves through a medium. In such a wave, the particles of the disturbed medium move parallel to the wave velocity. The sound waves have the following categories:

- Audible sound has a frequency from 20 Hz to 20,000 Hz.
- Infrasonic are the frequencies lower than 20 Hz,
- ultrasonic are frequencies higher than 20,000



Sound waves properties:

Sound waves have the following properties:

1.They can travel through solids, liquids or gasses, but not vacuum.

2.The speed of sound is a constant for a given material at a given pressure and temperature.

For example, the speed of sound in air, v_o, at 1 atmospheric pressure and 0 C^o is equal to 331 m/s.

3.Speed of sound in air (v_{air}) < speed of sound in liquid (v_{liquid}) < speed of sound in solid (v_{solid}). This is mainly related to the intermolecular spaces in a substances.

4.When sound goes from low dense medium (e.g. air) into a higher dense medium (e.g. liquid) the frequency stays unchanged, the velocity increases, and thus the wavelength must increases, recall the relation $f\lambda=v$

5.Speed of sound increases with increasing the temperature. Recall the empirical formula

Energy is carried by the wave as potential and kinetic energy. The intensity I of a sound wave is energy passing through $1m^2/s$. Or watts per square meter for plane wave

Speed of Sound.

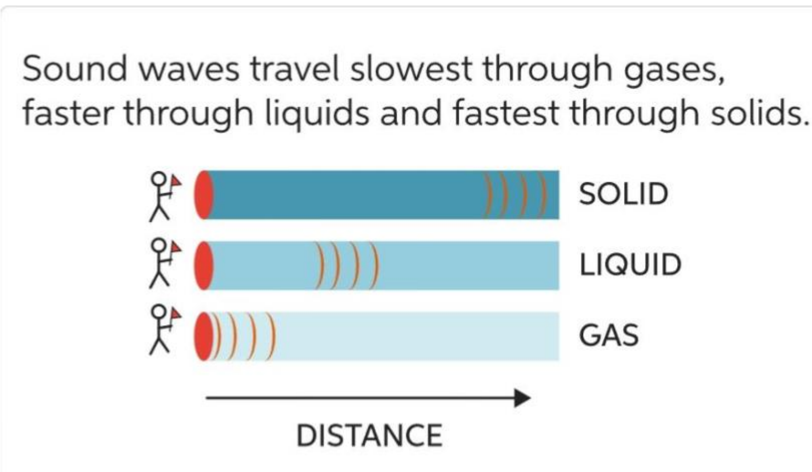
Sound waves move at a speed $v$that is determined by the properties of the medium.

- Sound waves are the most common examples of longitudinal waves. The speed of sound waves in a particular medium depends on The speed of sound depends on three factors:

1) Elasticity: higher elasticity= faster.
2) Density: higher density=faster.
3) Temperature=higher temp. =faster.

Sound velocity is determined by the properties of the medium:

$$v_{s_{solid}} > v_{s_{liquid}} > v_{s_{gas}}$$



In general, the sound speed is given by: $v_s = f\lambda$

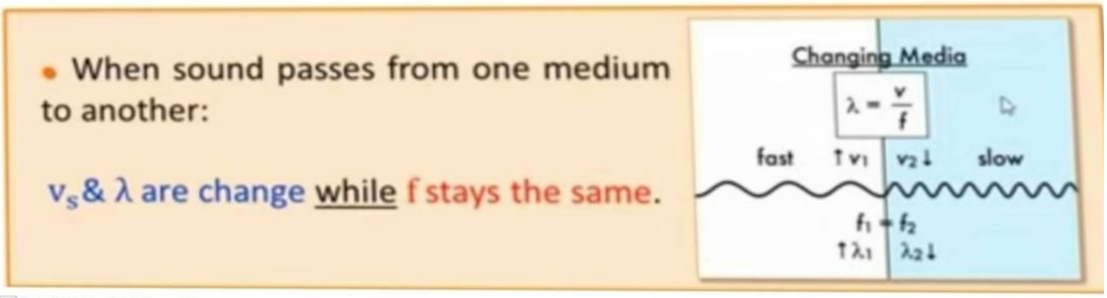
Where :

ν_s : frequency

λ: the wavelength of the sound waves.

-When sound passes from one medium to another, and change $\nu \& \lambda$ while f stays the same. The frequency does not change because it depends on the body that generated the sound

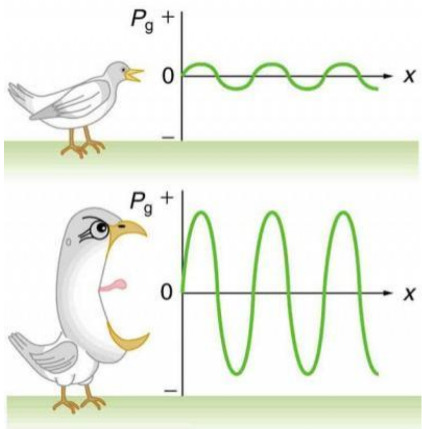
-The more elasticity of the medium, the faster the sound speed tends to be. So, the sound in solid is faster than liquid than in gas consequently.



Effect the nature of sound on human hearing

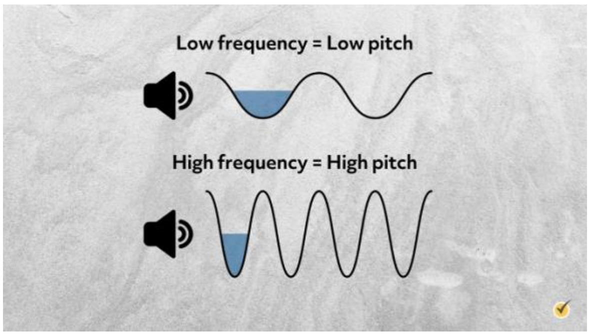
Sounds differ from each other in three basic characteristics (loudness, pitch, and type). And the ear can feel it and distinguish between one sound and another. The intensity of the sound has an effect on the ear, which gives us a sense of loudness or fading. Also, the frequency of the sound is an effect in the ear called the degree, because the frequency of a woman's voice is higher than that of a man.

The loudness (or volume) is a physiological response of the ear to the intensity of sound.It depends on amplitude.

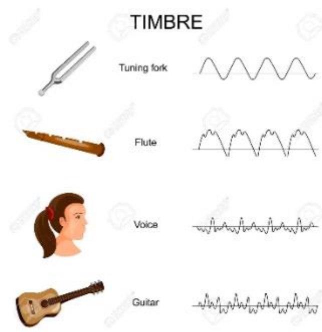


Dr. Sarah Khudhair Taha

The pitch of the sound is a characteristic that depends on the frequency of the waves reaching the ear, so that the thin sounds are distinguished from the thick ones



Quality of sound is a property of sound that depends on the type of material source and the method of sound generation



Sound Reflection and transmission :

When the sound wave is applied in a perpendicular way on the interface between two media which have different acoustic impedance (Z1 and Z2) a portion of this wave will pass through and another one will reflect

(large difference in Z → high reflection ratio .

The ratio of reflected; I_{ref} (or transmitted; I_{tran}) and the incident waves (I_{in}) can be measured as following,

$$R = \frac{I_{ref}}{I_{in}} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 , \quad T = \frac{I_{trans}}{I_{in}} = 2Z_2/(Z_2 + Z_1)$$

If Z1 = Z2 There is no reflected wave and transmission to the second medium is complete .

Note :If Z2 < Z1 The sign change indicates a phase change of reflected wave .

If $\Delta \boldsymbol{Z}$ large ⟹ High reflection &low transmission ⟹ Mismatching.

Example

Calculate the ratios of reflected and transmitted sound waves from air to muscle. Where

$\mathbf{Z_{air}} = \mathbf{430}\,\frac{\mathbf{kg}}{\mathbf{m^2.sce}}$, $\mathbf{Z_{muscle}} = \mathbf{1.64 * 10^6}\,\frac{\mathbf{kg}}{\mathbf{m^2.sce}}$

Solution

$$R = \left(\frac{1.64 * 10^6 - 430}{1.64 * 10^6 + 430}\right)^2 = 0.99895$$

$$T = \frac{2(1.64 * 10^6)}{1.64 * 10^6 + 430} = 1.9995$$

H.W

Calculate the reflected and transmitted sound waves from water to muscle.

Where $Z_{water} = 1.48 * 10^6 \frac{kg}{m^2.sce}$, $Z_{muscle} = 1.64 * 10^6 \frac{kg}{m^2.sce}$

H.W

Calculate the reflected and transmitted sound waves from fat to muscle.

Sound wave intensity

The intensity I of a sound wave is the energy carried by the wave per unit area and per unit time (in units W/m^2). It may be expressed by the maximum change in pressure; p_o as following:

$$I = \frac{P_0^2}{2Z}$$

Where, I: intensity and Z acoustic impedance of the medium. Acoustic impedance (Z) = ρv_s is the measure of the opposition that a system presents to the sound when flow through a medium.

Intensity of audible sound is ranged between :

hearing threshold $= \mathbf{I_{min} = 10^{-12}(W/m^2)}$

pain threshold $= \mathbf{max = 1(W/m^2)}$

Sound Intensity Level [Ratio]

The absolute value of sound intensity (I) cannot be measured, instead we can compare it with a reference intensity; (I,)

$$\mathbf{I_0 = I_{min} = 10^{-12}(W/m^2)}$$

$$\mathbf{intensity\ ratio = 10\log\frac{I}{I_0}}$$

$$\mathbf{= 10\log\frac{I}{10^{-12}} \qquad unit: decibel(dB)}$$

Example

Calculate hearing threshold intensity level ?

Sol:

$$\mathbf{I_0 = I_{min} = 10^{-12}(W/m^2)}$$

$$\text{intensity ratio} = 10\log\frac{I}{I_0} = 10\log\frac{10^{-12}}{10^{-12}}$$

$$= 10\log 1$$

$$= 10 \times 0$$

$$= 0\ dB$$

Example

Calculate pain threshold intensity level ?

Sol:

$$I_0 = I_{min} = 10^{-12}\left(\frac{W}{m^2}\right)$$

$$I\ max = 1\left(\frac{W}{m^2}\right)$$

$$\text{intensity ratio} = 10\log\frac{I}{I_0} = 10\log\frac{1}{10^{-12}}$$

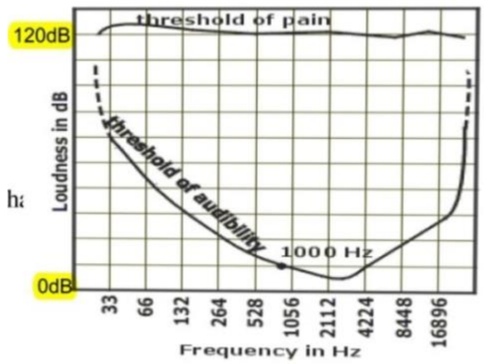
$$= 10\log 10^{+12}$$

$$= 10 \times 12$$

$$= 120\ dB$$

An audiogram for the normal human ear is given as in the below figure, where :

-The lower curve gives the faintest sounds that can be heard (hearing threshold), and The upper curve gives the loudest sounds that ca be heard without pain (pain threshold) .



Taha

Application s of audible sound in medicine (Stethoscope):

Stethoscopes are diagnostic instruments that amplify sounds made by the body from the heart, lungs, or other body sites.

Modern stethoscope consists of, bell which closed by a thin diaphragm, tubing and earpieces.

In stethoscope, sound is received by chest piece and sent to the earpieces by multiple reflecting through a long tube.

The bell serves as impedance matcher between body and the air in the tube. This requires that the frequency of the sounds must resonate in the bell membrane. The natural frequency F_{res} of the bell depends and tension T of the diaphragm .

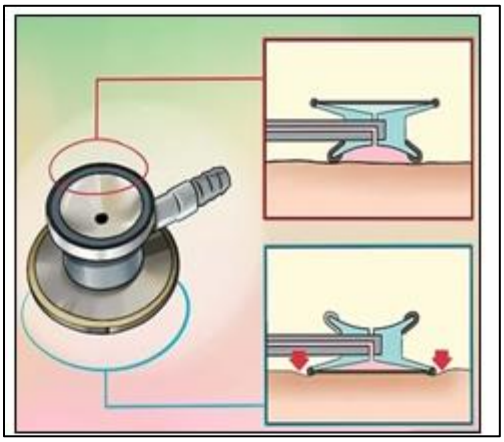
$$f_{res}\ \alpha \frac{\sqrt{T}}{d}$$

To selectivity pick up certain frequency ranges (low frequency heart murmur, high frequency lung sounds) the appropriate bell size and diaphragm tension must be chosen.

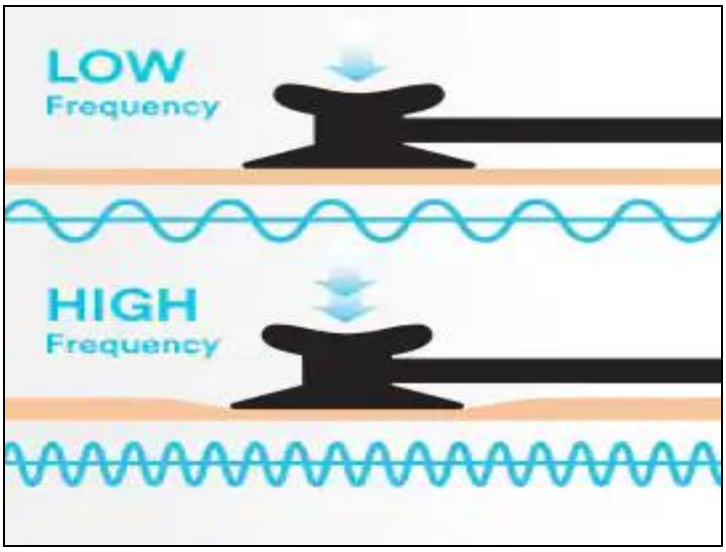
The bell diameter :The skin diaphragm has natural resonance frequency at which it most effectively transmits sound, the larger the bell diameter, the lower the skin's resonant frequency.

$$f_{res}\ \alpha \frac{1}{d}$$

i.e the closed bell stethoscope (large d) is used for listening to lung sound, which are higher frequency than heart sound, while the open bell(small d) is used for listening to heart sound.



- Tension T of the diaphragm: Low frequency heart murmur will appear if the stethoscope is pressed hard against the skin (large tension).

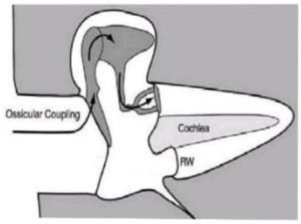


Mechanism of hearing

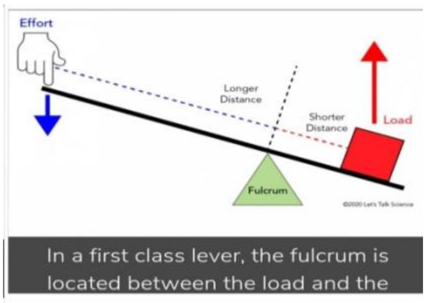
Hearing depends on a series of complex steps that change sound waves in the air into electrical signals. Our auditory nerve then carries these signals to the brain

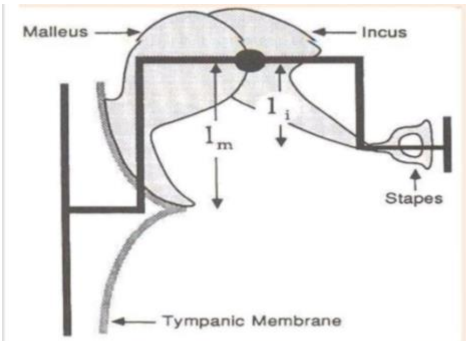
1. Sound waves enter the outer ear and travel through a pinna which receives specific frequencies then the waves travel through a narrow passageway called the ear canal, which leads to the eardrum.

   eardrum has a conical shape ,the conical shape is superior to the flat shape in terms of enlarging the vibrations and A buckling motion of tympanic membrane result in an increased force and decreased velocity to produce a fourfold increase in effectiveness of energy transfer.



2. The eardrum vibrates from the incoming sound waves and sends these vibrations to three tiny bones in the middle ear which act according to first lever principle. These bones are called the malleus, incus, and stapes.





3. The bones in the middle ear amplify, or increase, the sound vibrations and send them to the cochlea, a snail-shaped structure filled with fluid, in the inner ear. An elastic partition runs from the beginning to the end of the cochlea, splitting it into an upper and lower part. This partition is called the basilar membrane because it serves as the base, or ground floor, on which key hearing structures sit.
4. Once the vibrations cause the fluid inside the cochlea to ripple, a traveling wave forms along the basilar membrane. Hair cells—sensory cells sitting on top of the basilar membrane—ride the wave. Hair cells near the wide end of the snail-shaped cochlea

detect higher-pitched sounds, such as an infant crying. Those closer to the center detect lower-pitched sounds, such as a large dog barking.

5. As the hair cells move up and down, microscopic hair-like projections (known as stereocilia) that perch on top of the hair cells bump against an overlying structure and bend. Bending causes pore-like channels, which are at the tips of the stereocilia, to open up. When that happens, chemicals rush into the cells, creating an electrical signal.
6. The auditory nerve carries this electrical signal to the brain, which turns it into a sound that we recognize and understand