Types by medium:
1. Mechanical waves
2. Electromagnetic waves

Types by orientation of change
1. Transverse waves
2. Longitudinal waves

\[ \nu = \lambda f = \frac{\lambda}{T} \]

\[ m/s = m.s^{-1} \]
Doppler effect

\[ f = \left( \frac{v + v_r}{v + v_s} \right) f_0 \]

Receiver

Source
Sound Pressure Level

- \( P_{\text{ref}} = 20 \, \mu\text{Pa} \), which is considered the threshold of human hearing at 1000 Hz.

- Sound pressure level (SPL) is a logarithmic measure of the effective sound pressure \( P \) of a sound relative to a reference value.

\[
\text{SPL (dB)} = 10 \log_{10} \left( \frac{P}{P_{\text{ref}}} \right)^2
\]

What kind of unit is dB?
The threshold of pain for sounds of 2000 Hz is at a sound pressure level of 50 Pa. If the threshold of hearing at that frequency is 10 μPa, then the threshold of pain in decibels (dB) is:

\[ SPL(dB) = 10 \log \left( \frac{P}{P_r} \right)^2 = 10 \log \left( \frac{50}{10 \times 10^{-6}} \right)^2 = 134 \text{ dB} \]

For different frequencies the thresholds of hearing and pain differ.

- Overexposure to excessively high decibels causes Hyperacusis (over-sensitivity to certain frequency and volume ranges of sound).
Sound Intensity

- The wave intensity at a distance $r$ from point source

\[
I = \frac{Power}{A} = \frac{Power}{4\pi r^2}
\]

Unit ?

- It is inconvenient to express sound intensity in terms of Pa units because of a wide range of sound intensity. Hence, intensity in the decibel scale is used:

\[
\text{Intensity (dB)} = 10 \log_{10} \left( \frac{I}{I_0} \right)
\]

$I$ = intensity of sound in watts/cm\(^2\)
$I_0$ = the threshold of hearing intensity

at 1000 Hz  $(10^{-16}$ watts/cm\(^2\))
**Example:** A point source emits sound waves with an average power of 80 watts, find its intensity level in dB at a distance of 3 m. (consider $I_o = 10^{-16}$ watts/cm$^2$)

$$I = \frac{\text{Power}}{4\pi r^2} = \frac{80}{4 \times \pi \times (3 \times 10^2)^2} = 7.074 \times 10^{-5} \text{ watts/cm}^2$$

$$I(dB) = 10 \log \left( \frac{I}{I_o} \right) = 10 \log \left( \frac{7.07 \times 10^{-5}}{10^{-16}} \right) = 118 \text{ dB}$$

**Find the Intensity of the sound that gives 40 dB**

$$I(dB) = 10 \log \left( \frac{I}{I_o} \right)$$

$$40 = 10 \log \left( \frac{I}{10^{-16}} \right) \quad \Rightarrow \quad 4 = \log \left( \frac{I}{10^{-16}} \right)$$

$$10^4 = \left( \frac{I}{10^{-16}} \right) \quad \Rightarrow \quad I = 10^{-12} \text{ watts/cm}^2$$

**Find the distance at which this sound reduces to this 40 dB**

$$I = \frac{\text{Power}}{4\pi r^2} \quad \Rightarrow \quad 10^{-12} = \frac{80}{4\pi r^2}$$

$$r = \sqrt{\frac{80}{10^{-12} \times 4 \times \pi}} = 2.52 \times 10^6 \text{ cm} = 2.52 \times 10^4 \text{ m}$$
Spherical Sound waves
A sound source generates sound waves of 350 watts. The intensity of the sound heard by an observer at 3 m away from the source is:

\[
I = \frac{\text{Power}}{A} = \frac{\text{Power}}{4\pi r^2} = \frac{350}{4\pi(3)^2} = 3.09 \text{ watts/m}^2 = 3.09 \times 10^{-4} \text{ watts/cm}^2
\]

\(I\) is independent of frequency
Loudness is a characteristic associated with the amplitude at a fixed frequency

\[I_0 = \text{the threshold of hearing intensity at 1000 Hz } (10^{-16} \text{ watts/cm}^2)\]

\[
\text{Intensity (dB)} = 10 \log_{10} \left( \frac{I}{I_0} \right) \\
\text{Intensity (dB)} = 10 \log_{10} \left( \frac{3.09 \times 10^{-4}}{10^{-16}} \right) = 124.9 \text{ dB}
\]
Loudness, Intensity, and Pitch

Intensity
An objective physical measurement independent of the frequency of the sound.

Loudness
Is a subjective measurement and depends upon the sensitivity of the ear to the particular frequencies of the sound.

1. Two sounds of the same intensity but different frequencies will not be perceived to have the same loudness.
2. At a constant frequency, an increase in intensity will increase the perceived loudness.

The pitch of a sound depends on frequency highness or lowness of a tone
Medical Uses of Sound Waves

Properties of sound waves

- Reflection
- Diffraction
- Refraction
- Interference
Piezoelectric Effect

Accumulation of charges due to the application of mechanical stress (e.g. quartz, PZT alloy)

- Current $\rightarrow$ pressure
  - Converse Piezoelectric Effect
- Poling Process
- Direct Piezoelectric Effect
  - Pressure $\rightarrow$ current
Hearing Aid Device

A device, amplifies the incoming sounds, when the sensitivity of the ear is low.
Lead zirconate titanate is an intermetallic inorganic crystal alloy.

Basic components of the Hearing aid device.
Assessing eardrum deformation by digital holography can indicate the degree of a patient's hearing loss

Laser Doppler vibrometry is used for displacement measurements due to various stimuli

Loudness determined by amplitude (pressure).

Pitch determined by frequency
1) Medical Ultrasonography
Processing reflected ultrasound waves with difference time differences

The human body tissue in which there is fastest sound propagation is the:
**Exercise 1:** A source emits sound waves with an average power of 90 watts, find the distance at which this sound reduces to an intensity level of 60 dB (consider $I_0 = 10^{-12}$ watts/m$^2$).

**Exercise 2:** An ambulance sounding a siren with frequency of 400 Hz moving away from an observer in a car moving in the same direction. Depending on the speed of the car, what are the properties of the sound heard by the observer?

Properties:

- Frequency
- Loudness
- Sound pitch