بسم الله الرحمن الرحيم

Sound

What are waves?

A wave is a disturbance that propagates through space.

The wave itself moves in one direction but the particles that create the wave do not share in this motion. The particles oscillate back and forth about their equilibrium positions.

Types of Waves:

There are three types of waves:

- *Longitudinal Waves*
- *Transverse Waves*
- *Water Waves*

Longitudinal Wave **- A fixed point will move parallel with the wave motion.**
It has two areas:

1-Compression-
an area of high molecular density and pressure

2-Rarefaction -
an area of low molecular density and pressure

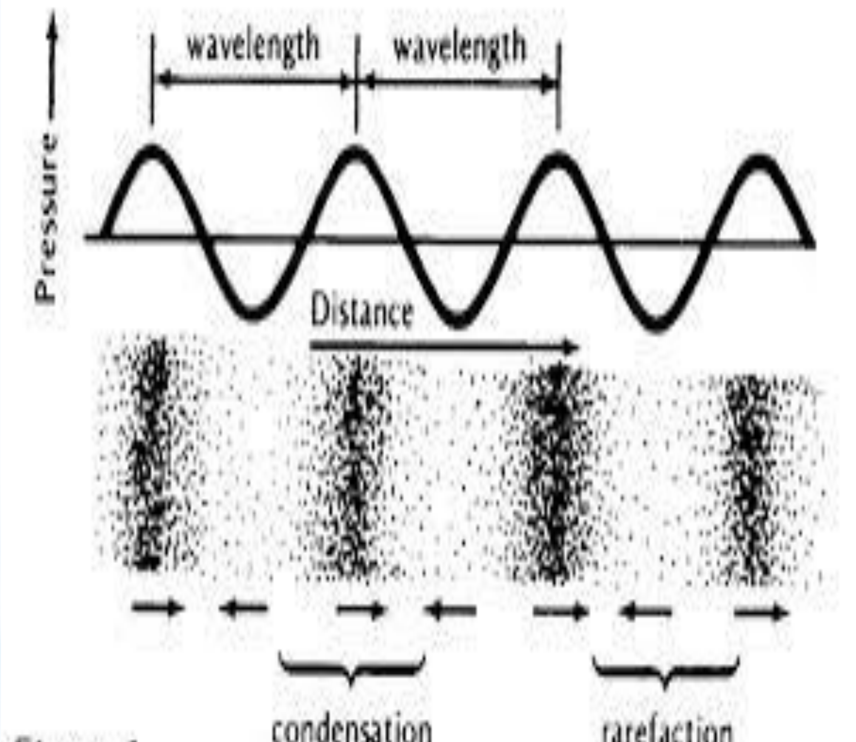


Figure 1

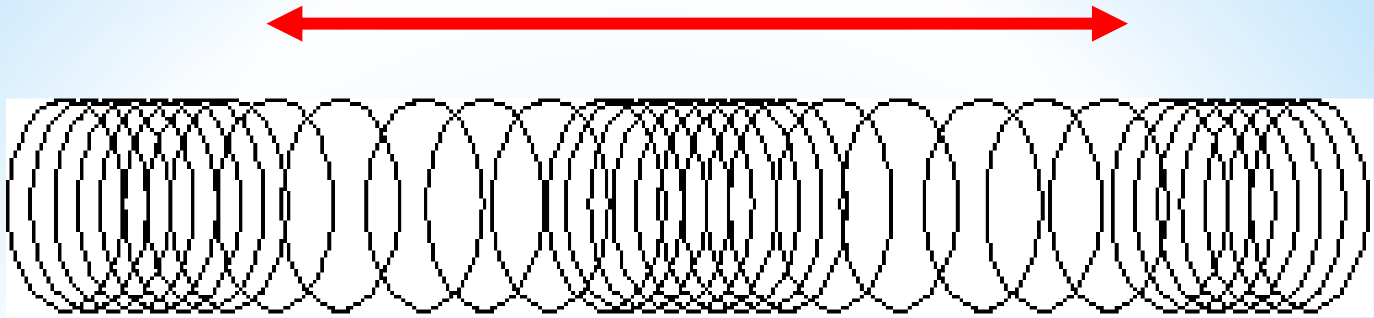
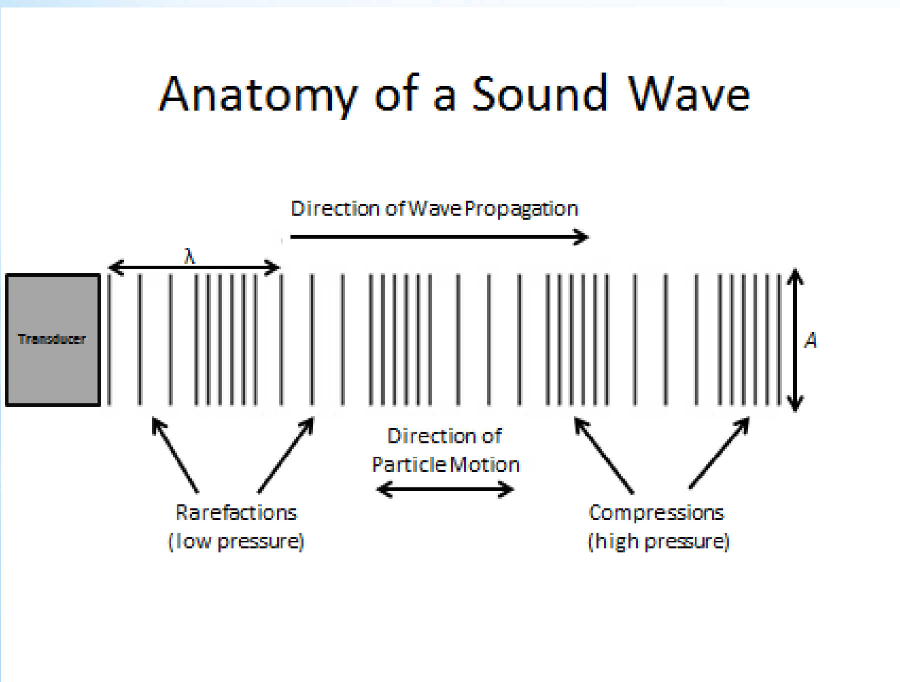
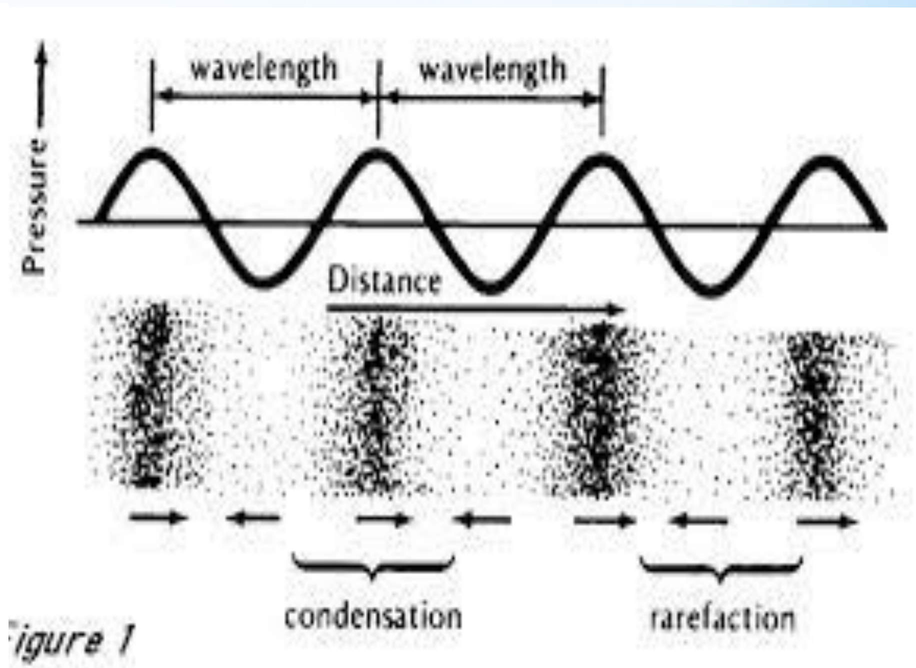


Fig.1 A longitudinal wave consists of a series of compressions and rarefactions.





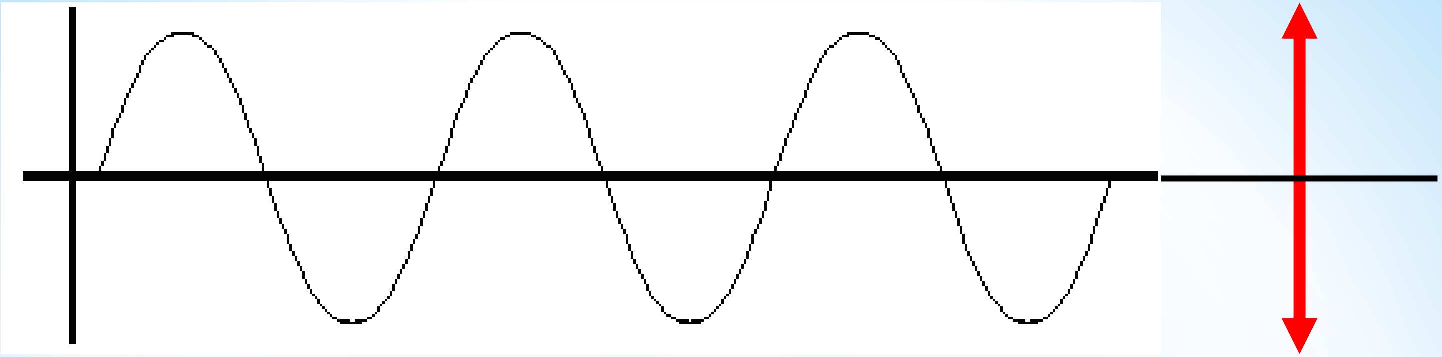


Fig. 2 A simple harmonic transverse wave.

Fig.3 Surface waves in water.

- In a sine wave, the points that correspond to maximum upward displacement are referred as **crests**; while points that correspond to maximum downward displacement are referred as **troughs**.
- The distance from one crest to the next or from one trough to the next is called the **wavelength** (λ) of the wave
- (λ the distance over which a wave repeats, Unit: m).

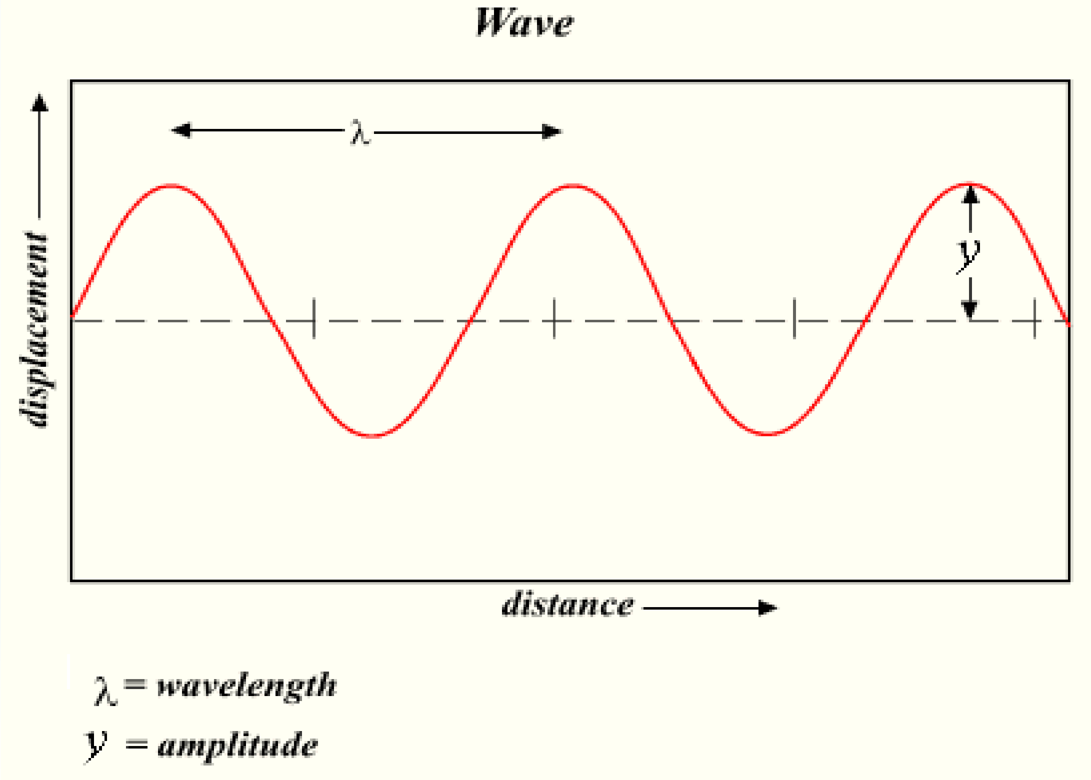


Fig.4 A wave with constant amplitude.

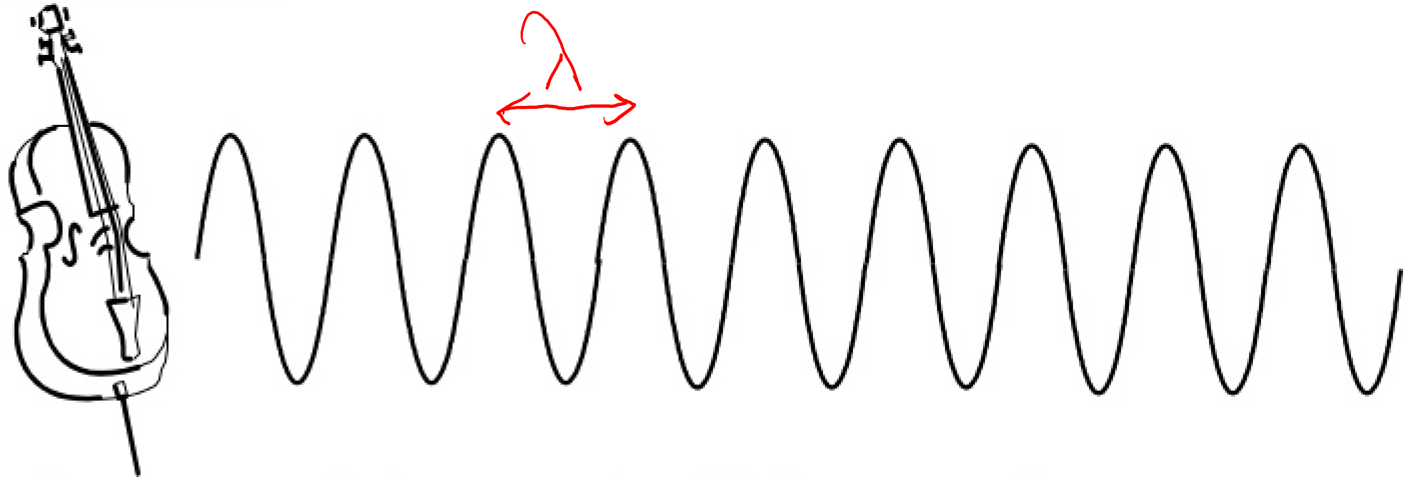
- **Periodic time** (τ) is the time required for one wavelength to pass a given point (Unit: sec).

- **Frequency** (f) of a wave is defined as the number of cycles or oscillations per second and it is the reverse of periodic time ($f = 1/\tau$) (Unit: sec^{-1} or Hz).

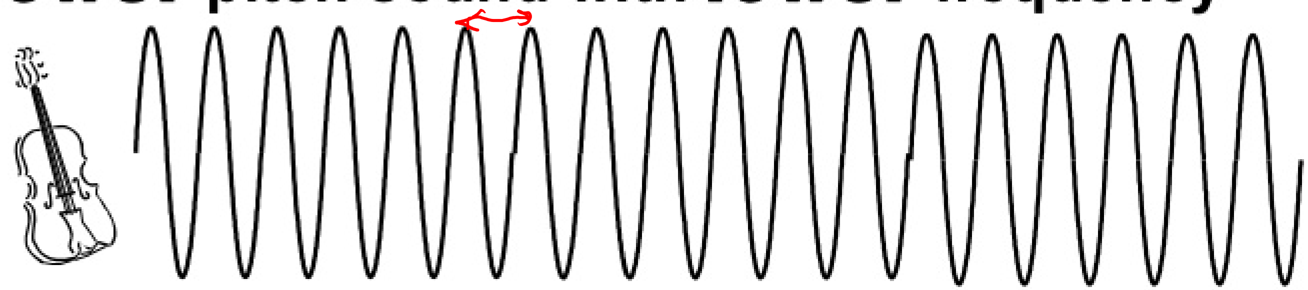
- So, the speed of the wave v can be determined by the equation:

$$v = \frac{\text{Distance}}{\text{Time}} = \frac{\lambda}{\tau} = \lambda . f \qquad (m/sec)$$

Compare the frequencies of sound with same loudness:



Lower pitch sound with **lower** frequency



Higher pitch sound with **higher** frequency

- **Sound waves** cannot travel through a vacuum and requires a medium (solid, liquid, or gas) to travel. Thus, a **sound wave** is **called a mechanical wave**.

- **Sound waves** in air (and any fluid medium) are **longitudinal waves** because particles of the medium through which the **sound** is transported vibrate parallel to the direction that the **sound wave** moves.

Comparing sound waves and light waves

Feature	Sound waves	Light waves
transfer energy	yes	yes
can travel through	solids, liquids and gases but need a medium	vacuum, gases, some solid and liquids, no medium needed
speed	330 m/s in air 1500 m/s in water 5 000 m/s in steel	3×10^8 m/s in air 2.2×10^8 m/s in water 2×10^8 m/s in glass
type of wave	longitudinal	transverse
typical frequency	1 kHz	5 x 10 Hz
typical wavelength	10 cm or 1 m	5000 nm = 5×10^{-7} m
part of the electromagnetic spectrum	no	yes

Types of sound:

- ***Infrasonic***

These are waves of too low frequency (less than 20Hz). These waves are too low for human ears to detect; that we can't hear.

Example: Natural phenomena such as earthquake waves and atmospheric pressure changes.

- ***Audible sound***

These are waves of frequency range from 20Hz to 20kHz.

Human ears can detect these waves.

- ***Ultrasonic***

These are waves of too high frequency (higher than 20 kHz).

These waves are too high for human ears to detect; that we can't hear.

(Audible sound)

Infrasonic* < 20Hz to 20kHz < *Ultrasonic

Spectrum of sound

Frequency range Hz	Description	Example
0 - 20	Infrasound	Earth quake
20 - 20.000	Audible sound	Speech, music
> 20.000	Ultrasound	Bat, Quartz crystal

AUDIBLE FREQUENCIES

- This range decreases as we get older and our ears lose their sensitivity to both high and low frequencies.
- Animals have different ranges of audible frequencies. Dogs and bats have a much higher upper audible limit. Bats can produce and detect very high ultrasonic sounds. This enables them to avoid obstacles, even when flying in the dark.

Intensity of the sound

The intensity is the amount of energy that passes through a given area perpendicular to direction of travel of the wave in a given time.

$$I = E_n / A.t = (E_n/t) / A = (J/sec.\ m^2)$$

The Power is the amount of energy that consumed in a given time.

Power = (E_n/t) (J/s) = Watt

$I = Power/A$ (W/m^2)

So, the Intensity of wave can define as the power per unit area (W/m^2)

For a plane wave, the intensity (**I**) is given by:

$$\mathbf{I} = \frac{1}{2}\ \rho\ v\ Y^2\ (2\pi f)^2 = \frac{1}{2}\rho\ v\ Y^2\ \omega^2 = \frac{1}{2} Z\ (Y\ \omega)^2$$

$$= \frac{(ZY\ \omega)2}{2Z} = \frac{P_o^{\ 2}}{2Z}$$

Where ρ is the density of the medium,

v is the velocity of sound in the medium,

Y is the amplitude of the wave or the maximum displacement of the molecules from the equilibrium position,

f is the frequency, **ω** is the angular frequency ($\omega = 2\pi f$)

Z is the acoustic impedance of the medium = **ρ v** **(kg/m2. s)**, and

P_o is the maximum acoustic pressure= Z Y ω.

Sound Intensity Level and Deci-Bel (dB)

Loudness is measure by the intensity level of a wave.

The intensity level (β) is the comparison of two sound waves (I_2/I_1); Which is given by the following equation

$$S.L = \beta = 10 \log_{10} (I / I_o) \text{ --------- (dB)}$$

Since, $I = P^2 / 2Z$, where **P** is the pressure and Z is the acoustic impedance

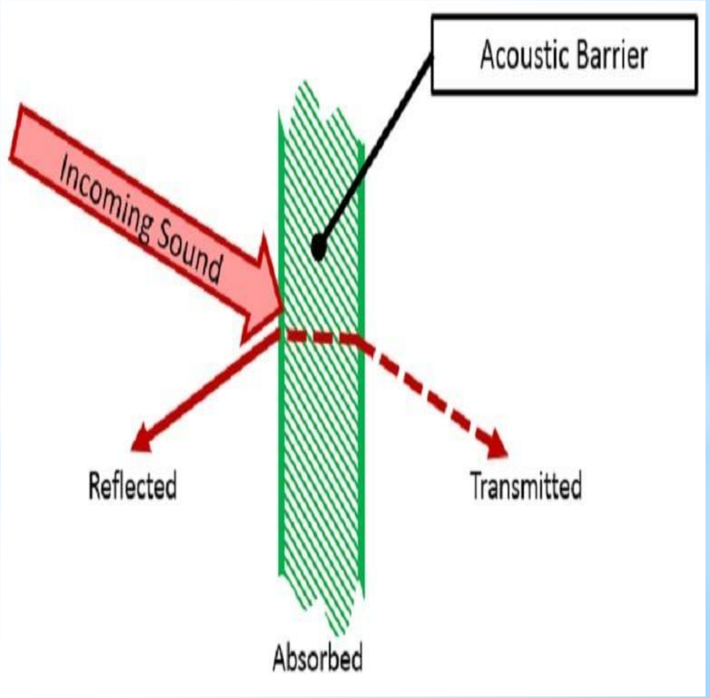
Sound Level $\beta = 10 \log_{10} (P/P_0)^2 = 20 \log_{10}(P/P_0)$

Example sound	Sound Intensity I (W/m^2)	Intensity Ratio (I/I_o)	Intensity Level (dB)
Loud rock concert	1	10^{12}	120
Underground train	10^{-2}	10^{10}	100
Shouting person	10^{-4}	10^{8}	80
Normal conversation	10^{-6}	10^{6}	60
Quiet room	10^{-8}	10^{4}	40
Rustling leaves	10^{-10}	10^{2}	20
Reference level (Io)	10^{-12}	1	0

Reflection of Sound Waves

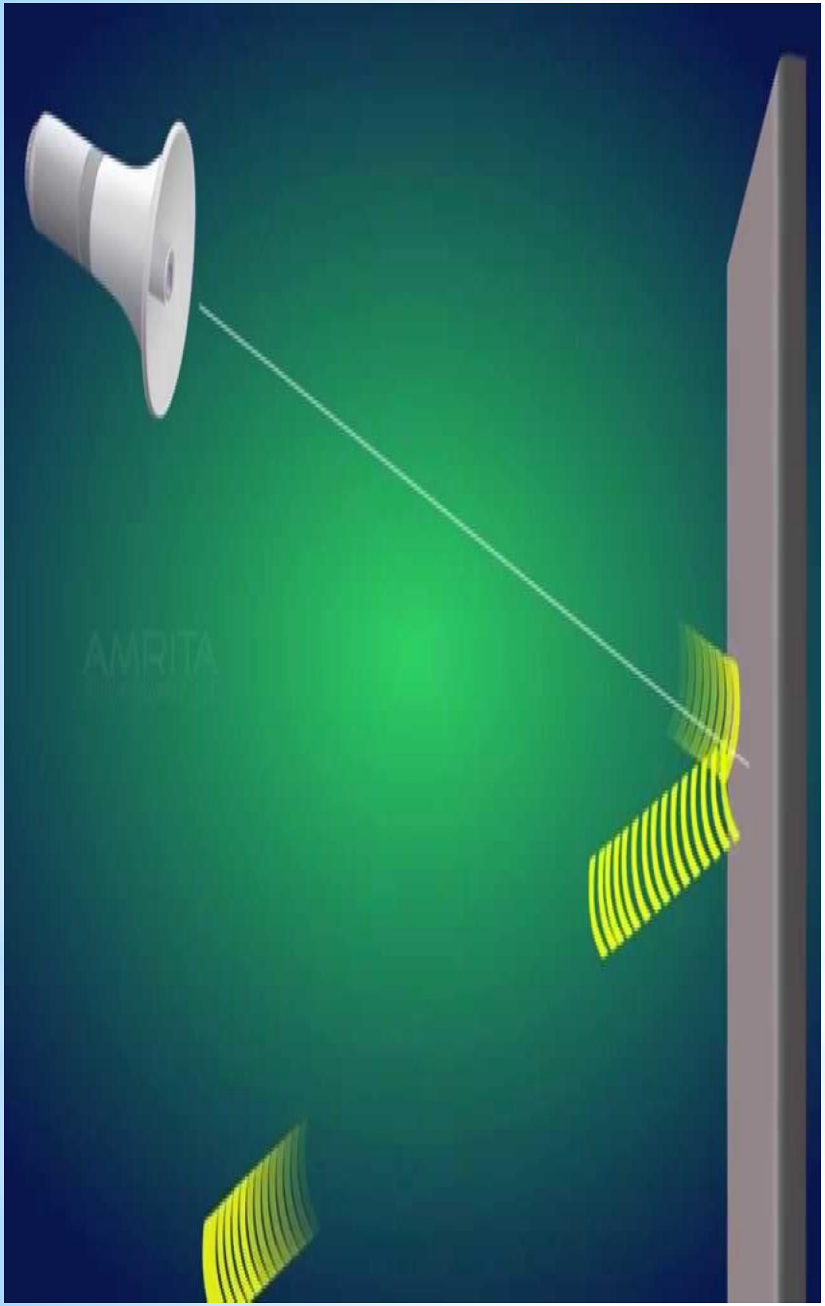
When a wave reaches the boundary between one medium and another medium, a portion of the wave undergoes reflection and a portion of the wave undergoes transmission across the boundary. The ratio of the reflected pressure amplitude (Pr) to the incident pressure amplitude (Pi) is given by:

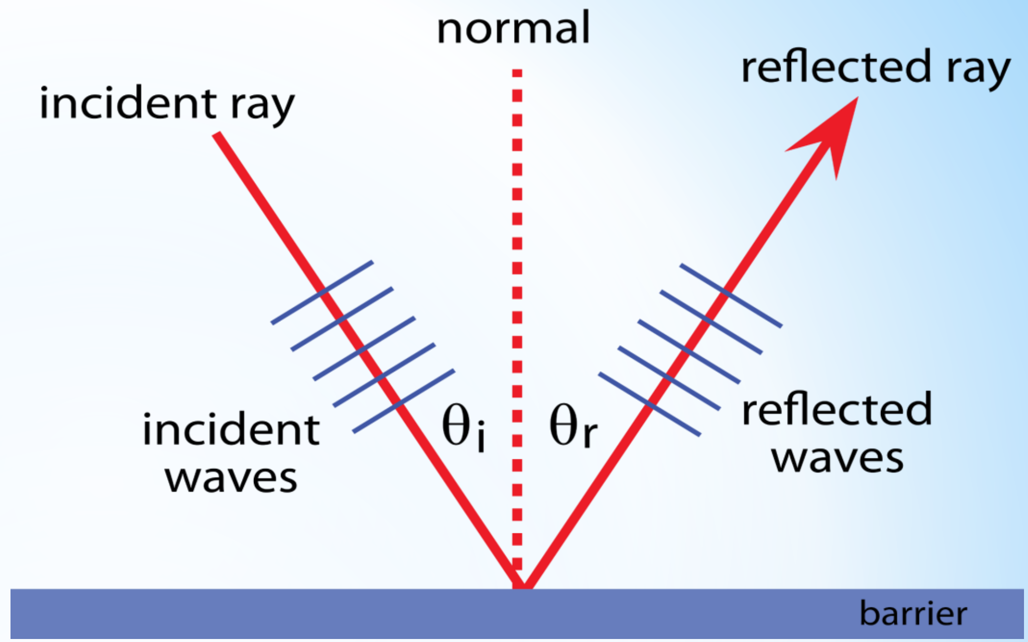
$$(P_r / P_i) = R = [(Z_2 - Z_1)/(Z_2 + Z_1)]^2$$

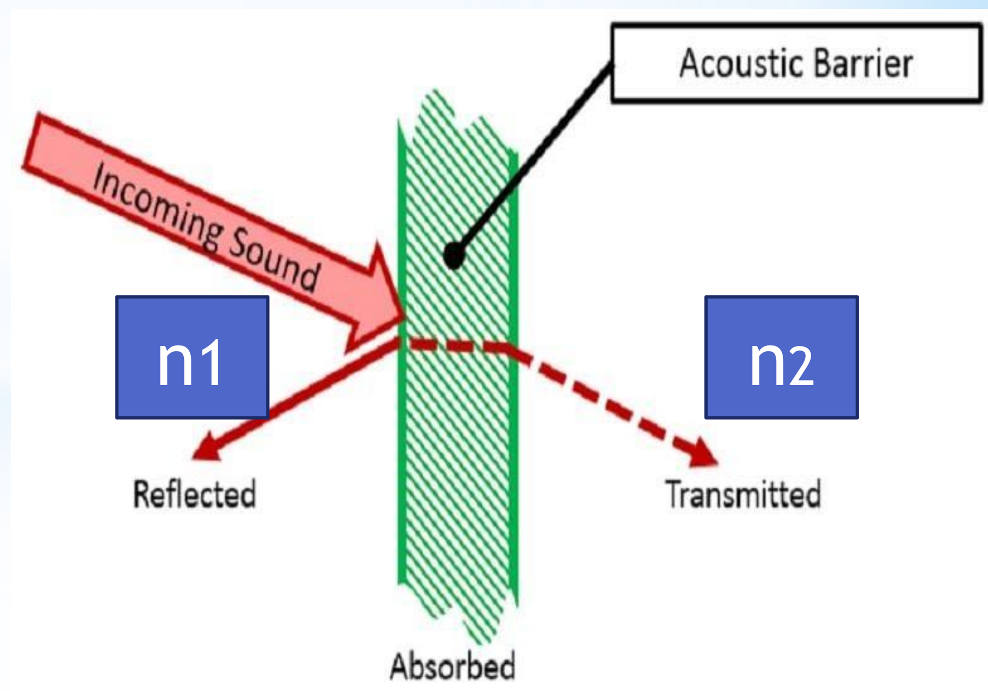


The ratio of the transmitted pressure amplitude (P_t) to the incident pressure amplitude (P_i) is given by:

$$(P_t / P_i) = T = 2Z_2 / (Z_1 + Z_2)$$




normal
incident ray
reflected ray
incident waves
θ_i
θ_r
reflected waves
barrier


Acoustic Barrier
Incoming Sound
n1
n2
Reflected
Transmitted
Absorbed

When a sound waves strike a boundary between two media at angle (θ), then the geometric laws involving **reflection** and **refraction** are: $\theta_i = \theta_r$ and

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}.$$

Where, θ_i and θ_r are the angle of incidence and the angle of reflection respectively.

θ_1 and θ_2 are the angle of incidence and the angle of refraction and v_1 , v_2 the velocities of sound in the medium 1 and 2. n_1 and n_2 are refractive indices of the two mediums.

When a sound wave passes through tissue, there is some loss of energy due to frictional effect. The absorption of energy in the tissue causes a reduction in the amplitude and intensity of the incident sound wave.

$$Y = Y_o e^{-\alpha x}$$

Where, Y_o is the incident amplitude at zero depth (x = 0), Y is the amplitude at depth x and α is the absorption coefficient for the medium at a particular frequency.

Since the intensity is proportional to the square of the amplitude, so

$$I = I_o e^{-2\alpha x}$$

Where, I_o is the incident intensity at zero depth (x = 0), I is the intensity at depth x and 2α is the absorption coefficient for the medium at a particular frequency.

So, the intensity decreases more rapidly than the amplitude with depth.

Sound absorption coefficient is used to evaluate the sound absorption efficiency of materials. It is the ratio of absorbed energy to incident energy and is represented by **α**.

The sound absorption coefficient of materials is correlated with frequency, and it varies with different frequencies.

The half-value thickness (HVT) $X_{1/2}$

It is the thickness of the absorber (tissue) that is needed to (reduce) decrease the intensity value to its half ($I = I_o/2$).

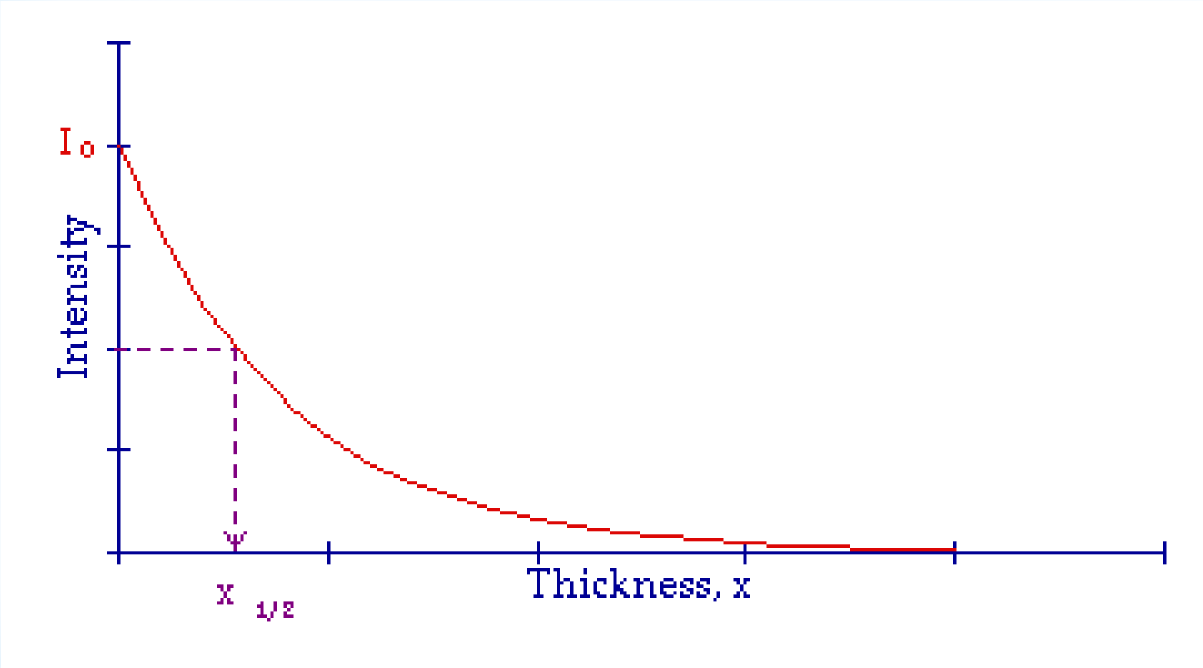


Fig.5 Half-value thickness.

$$HVT = X_{1/2} = \ln 2 /(2\alpha)$$

$$X_{1/10} = \ln 10/ 2\alpha$$

Absorption coefficient - α - for some common materials can be found in the table below:
the sound absorption coefficient varies with frequency.

Material	Sound Absorption Coefficient - α -
Acoustic belt, 12 mm	0.5
Brickwork, painted	0.01 - 0.02
Brickwork, unpainted	0.02 - 0.05
Carpe, heavy on foam rubber	0.5 - 0.7
Carpet, heavy on concrete	0.3 - 0.6
Concrete block, coarse	0.3 - 0.4
Concrete block, painted	0.05 - 0.07
Floor, concrete or terrazzo	0.02
Floor, wood	0.06 - 0.1
Glass, large panes heavy plate	0.03 - 0.05
Glass, ordinary windows	0.1 - 0.2
Gypsum board, 12 mm	0.04 - 0.07
Hardwood	0.3