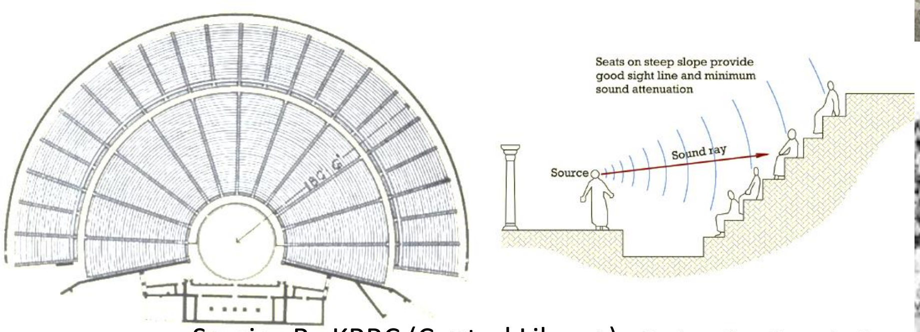
ἀκουστικός

Faculty: Momin Md. Zaki I Semester-5 I Building Services I Acoustics I 2017-18

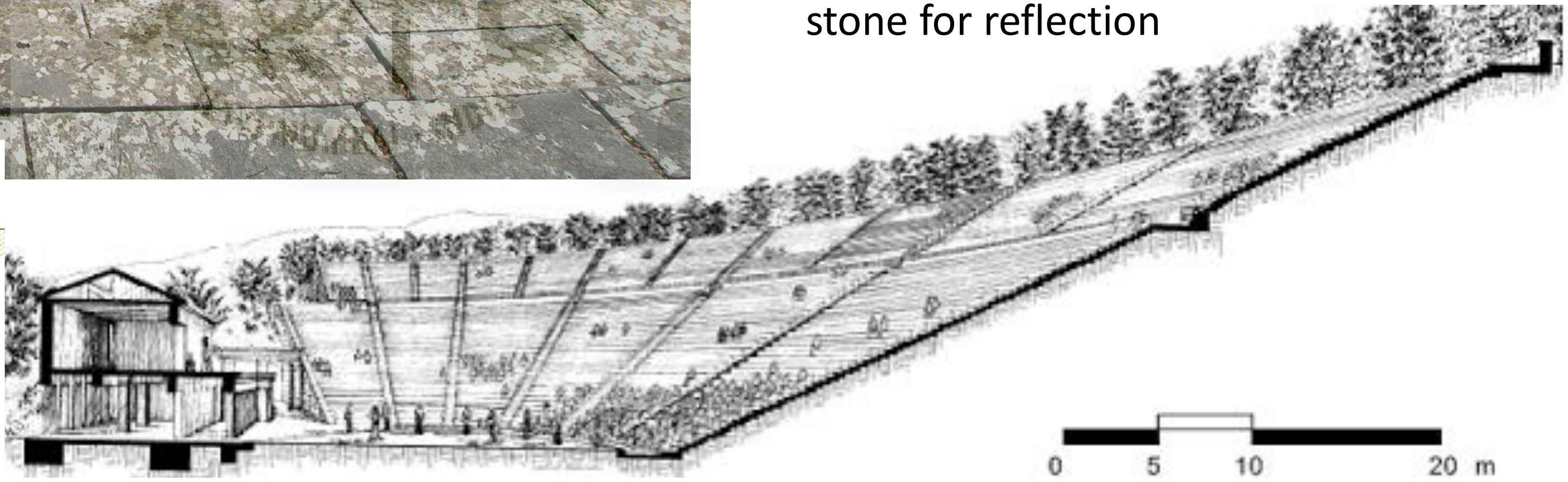
GREEK

Epidaurus 330BC

- Seating plan: segmented circle, more than 180°, mostly on hill-sides facing the sea
- Directional nature of human voice: Wind carrying sound
- Seating arrangements were made in concentric in front of speakers for best audibility and steep raked seats to lower background noise and lime stone for reflection



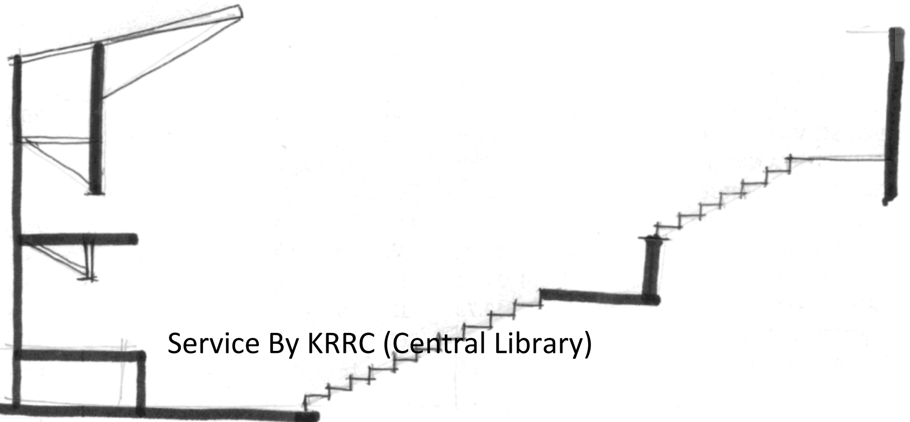
Plan and section: during Greek period



ROMAN (EARLY)
Aspendius Roman theatre, Turkey

Seating arc limited to 180°.

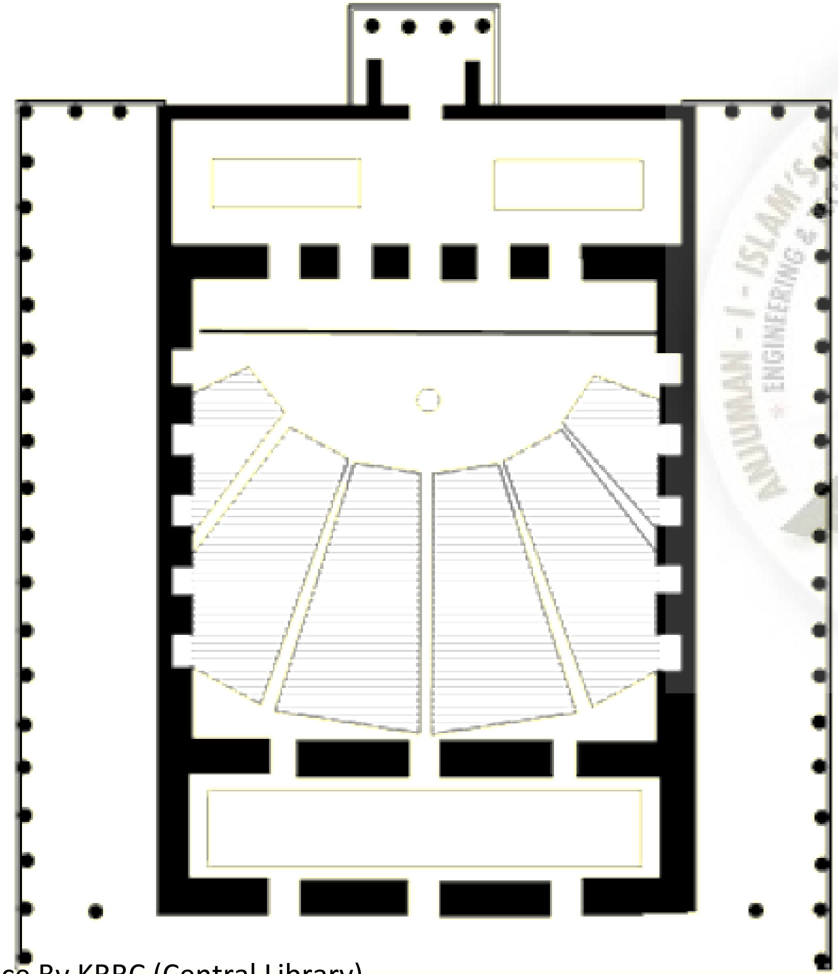
- Used arch features instead of hill slopes
- Added a stage house (*skiene*) behind the actors, a raised seating area (*proskenion*), hung awnings (*valeria*) to shade the patrons.

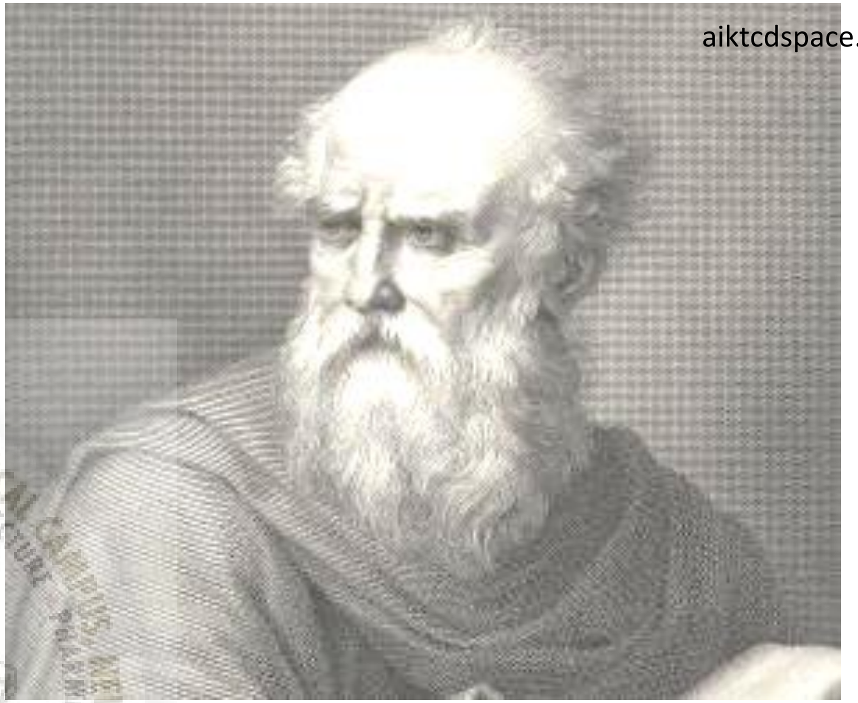


ROMAN

Smaller theatres (odea)-built for dramas / plays (dialogues)

Examples-Odeon of Agrippa,12BC





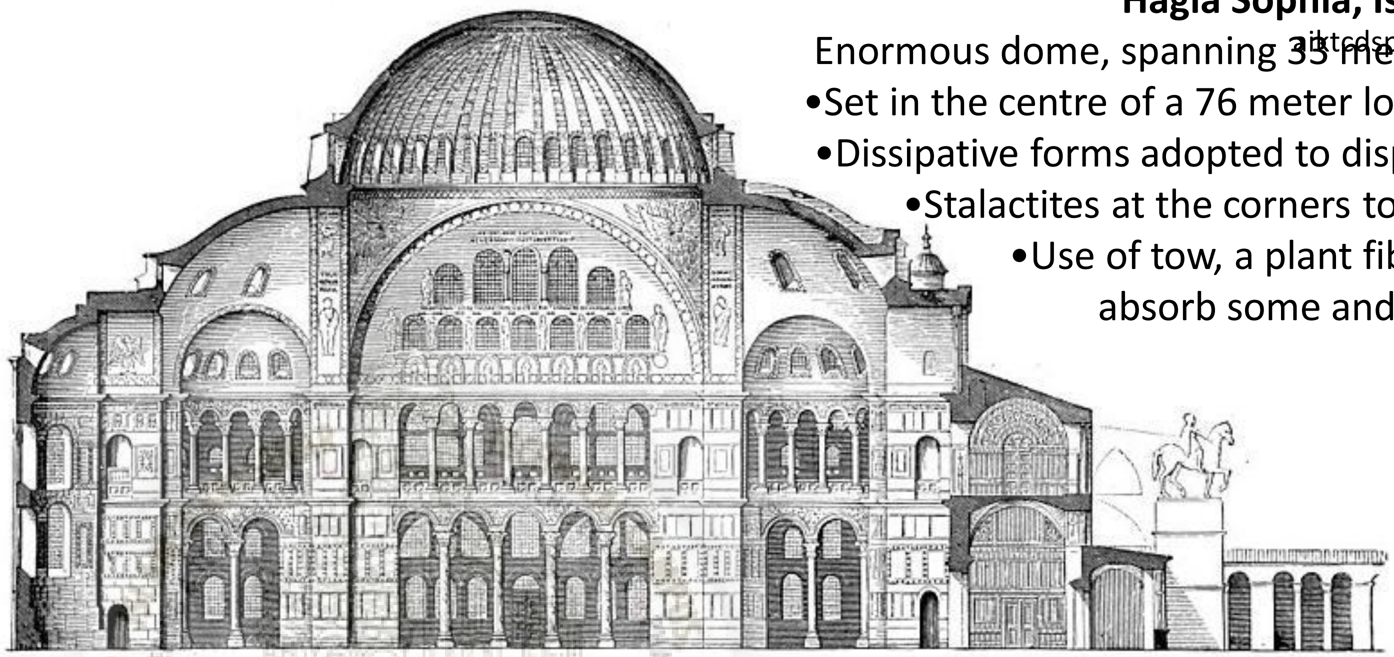
Book: De Architectura (27BC)

- Seating should not face South (audience should not be looking at the Sun)
- Unrestricted sight lines to be maintained
- Open mouths of Large sounding vases to be placed centred on cavities on wedges such that the mouth is exposed to the stage for improved sound quality

EARLY CHRISTIAN 400-800 AD

Basilican church of St.Peter, Rome,330AD.

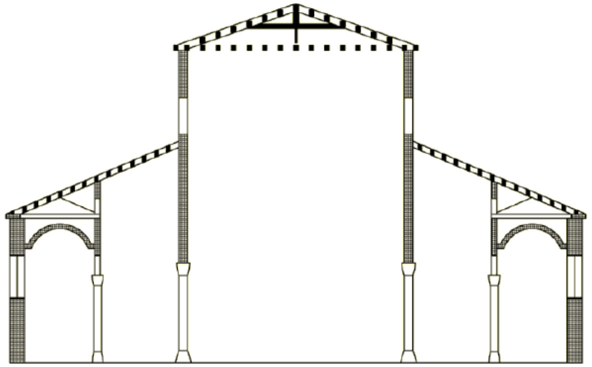
- •High central nave with two parallel aisle on either side.
- •Aisles separated by colonnade which supported upper walls.
- •Low pitched roof, ending in an apse.
- •Preceded by atrium. Model for later church construction.



Hagia Sophia, Istanbul (537AD)

Enormous dome, spanning 33 meters in diameter

- •Set in the centre of a 76 meter long central nave.
- •Dissipative forms adopted to disperse the sound
- •Stalactites at the corners to disperse sound
- •Use of tow, a plant fibre, in plaster to absorb some and rebound sound



Romanesque and Gothic Cathedrals (800 – 1100 AD) Plain chant was the music of the religious orders and was suited perfectly to the cathedrals.

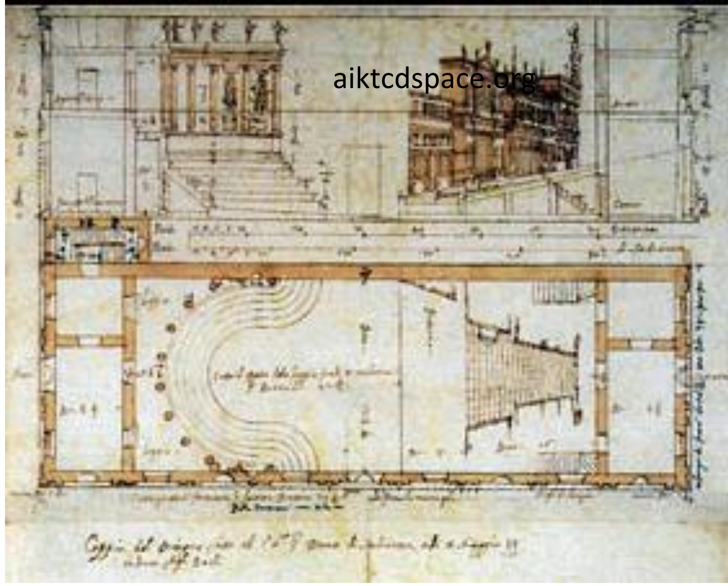
- art and engineering of working in stone
- vaulted naves, over 30 meters (100 feet) high
- lightened with windows and open colonnades

The Suleymaniye Mosque Istanbul (1558): The series of openings in the dome present for sound absorption

Renaissance (14th to 17th)

- Rise of towns and commerce, public entertainment became more secular less of religious in focus Plays and theatres
- Semi-elliptical seating plan of Romans was pushed back into a „U‟ shaped seating.
- Little acoustical support in halls

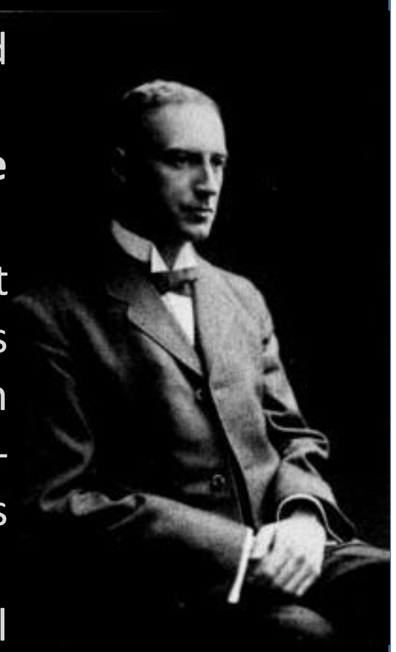
Theatres Italian Opera Houses Truncated elliptical seating



Baroque (17th–18th), Baroque era instrumental music, **Theatr-Farnese, Parma, Italy**

CLASSICAL PERIOD 18-19 CENT AD
A revival of visual and performing arts and music concerts (Haydn, Mozart & Bach, Beethoven)
Shoebox halls: high ceilings, multiple diffusing surfaces, and low seating capacity

Acoustical correction of Fogg Lecture Hall (1896)
Theoretical beginnings of architectural acoustics started by the young physics professor at Harvard College.
Father of Acoustical sciences: Wallace Clement Sabine (1868–1919)
Knowledge of the acoustical behaviour of rooms had not yet been set out in quantitative form. Successful halls were designed using incremental changes from previously constructed rooms. It was all experimental - termed as “bizarre science‟ by the Architect of Paris Opera House.
Key discovery was that the product of the total absorption and the reverberation time was a constant.

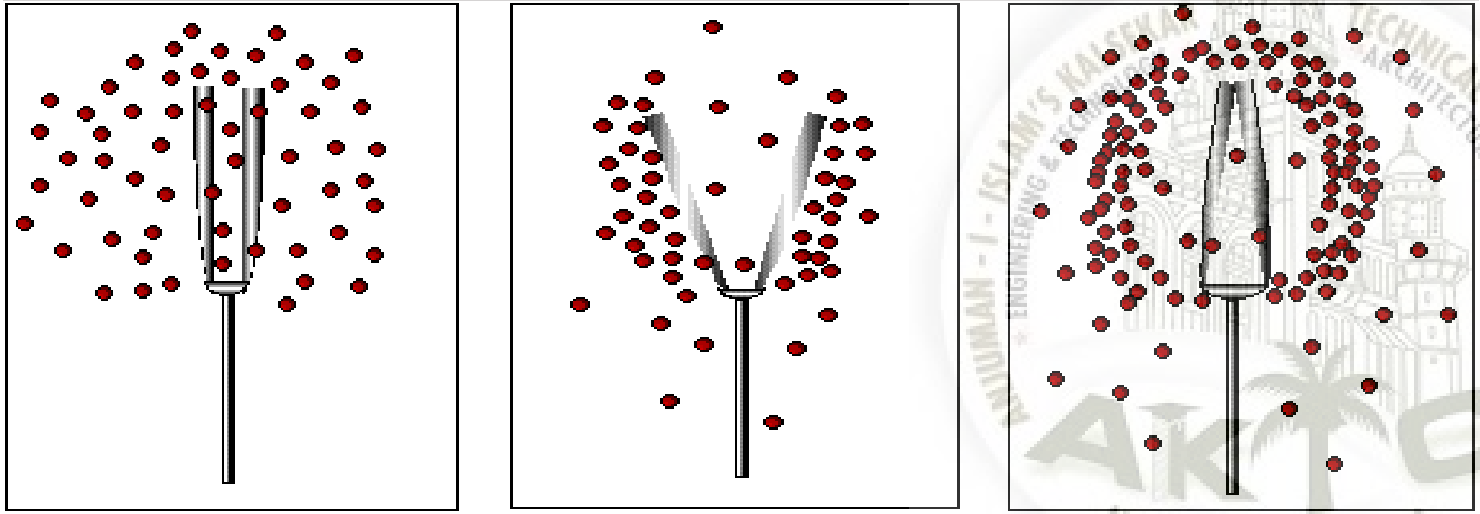


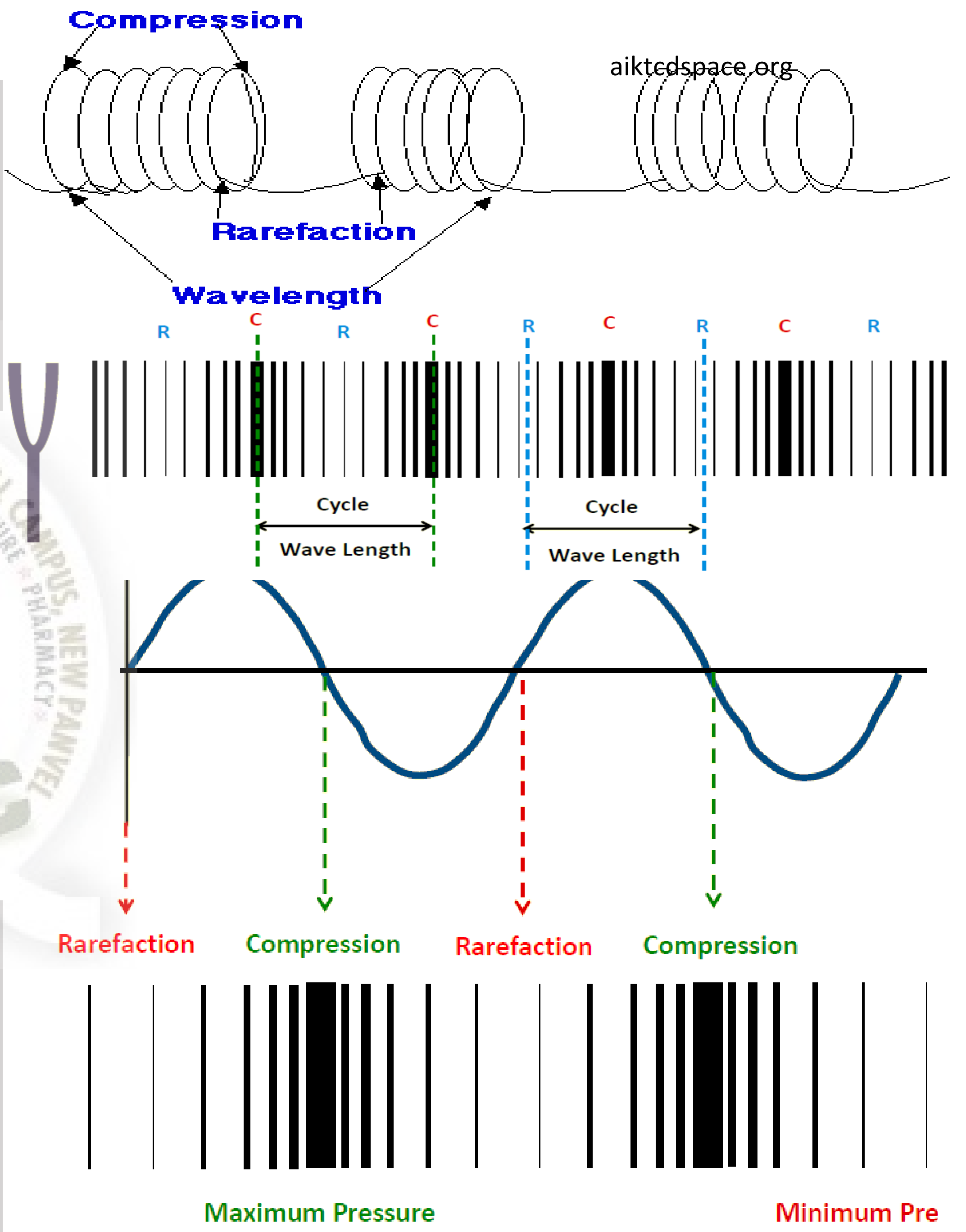
Acoustics

- **"Acoustics"**
- Greek word **ἀκουστικός** (akoustikos),
- meaning "of or for hearing, ready to hear"
- branch of physics deals with study of all kinds of mechanical waves in any medium.
- It was Aristotle who first established the relation that anything that vibrates can produce sound - dates back to (384–322 BC).
- **Architectural Acoustics**
- Architectural acoustics recognised as a science just over a century
- The scientific study to achieve a **good sound within a space** (building)
- Involves the study of speech **intelligibility**, speech **privacy**, music **quality**, noise control and **vibration reduction** within the built environment.

Acoustics: Science of Sound

Sound is a form of energy. It travels in waves through elastic media and causes fluctuation of pressure and particle displacement.
Sound is a mechanical wave that is an oscillation of pressure transmitted through a medium.
Sound is an auditory sensation produced by stimulation of the organ of hearing, evoked by physical fluctuation of pressure in media.

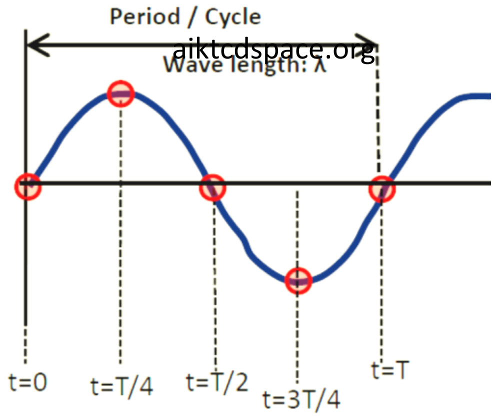


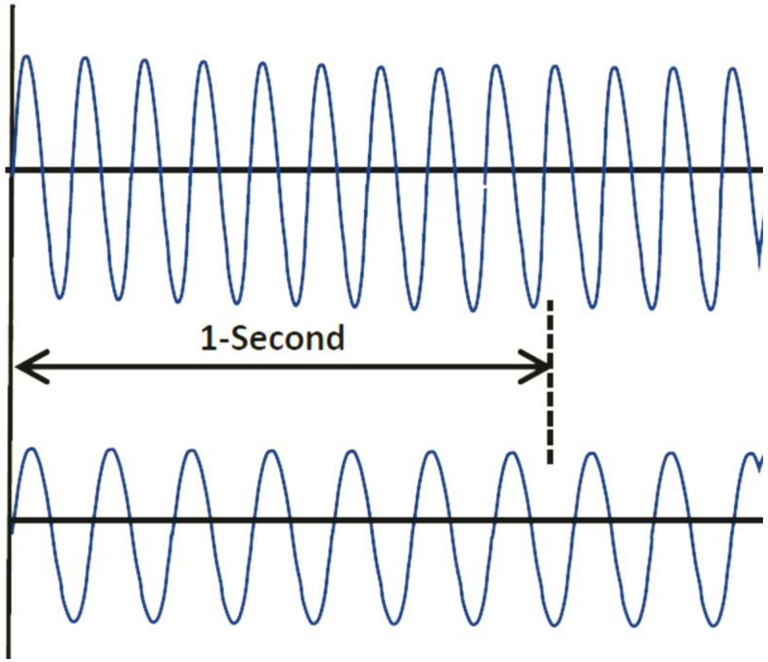


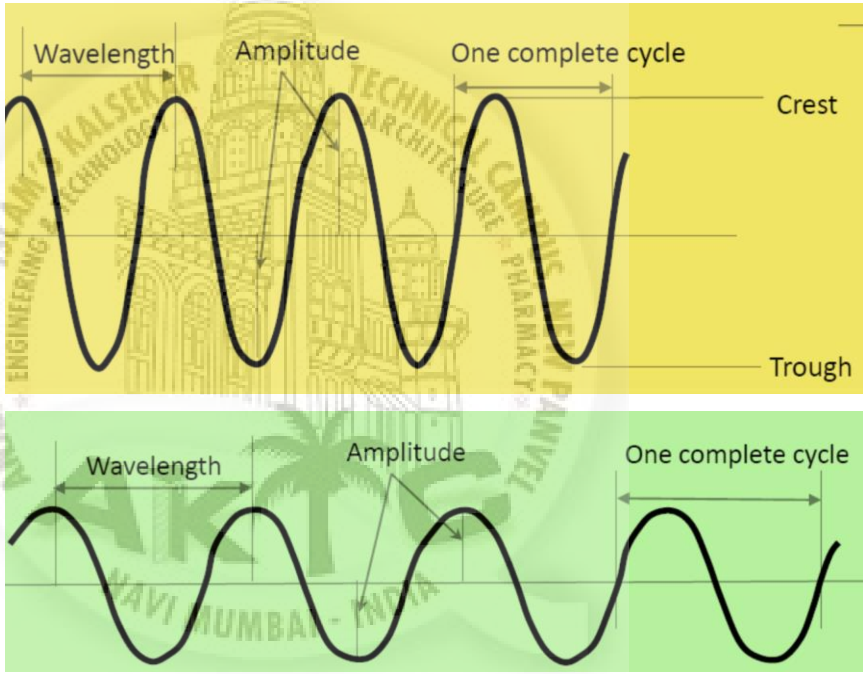
As a tuning fork vibrates, it causes molecules in the air to move.
The molecules bump into other molecules nearby, causing them to move.
This process continues from molecule to molecule.
The result is a series of compressions and rarefactions that make up sound waves.
And these compression and rarefactions sets the ear drum vibrating. The movements of ear drum are translated by the brain into sound sensation. So, *we really don't hear with our ears - we hear with our brains!*

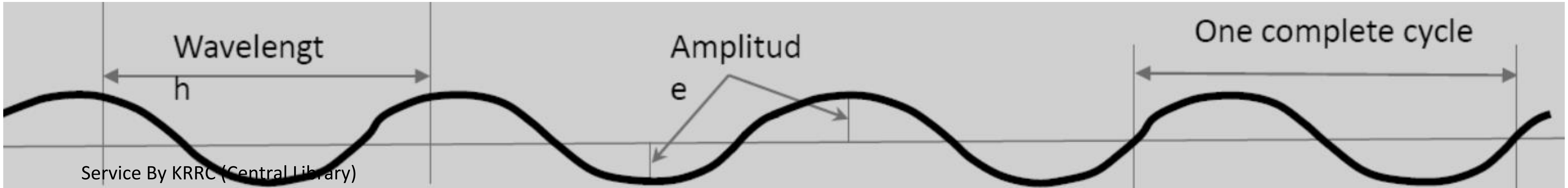
Frequency describes the number of complete wave cycle that pass a fixed point in unit time. Usually frequency is measured in cycles per second (CPS) or hertz unit, named in honor of the 19th-century German physicist Heinrich Rudolf Hertz.

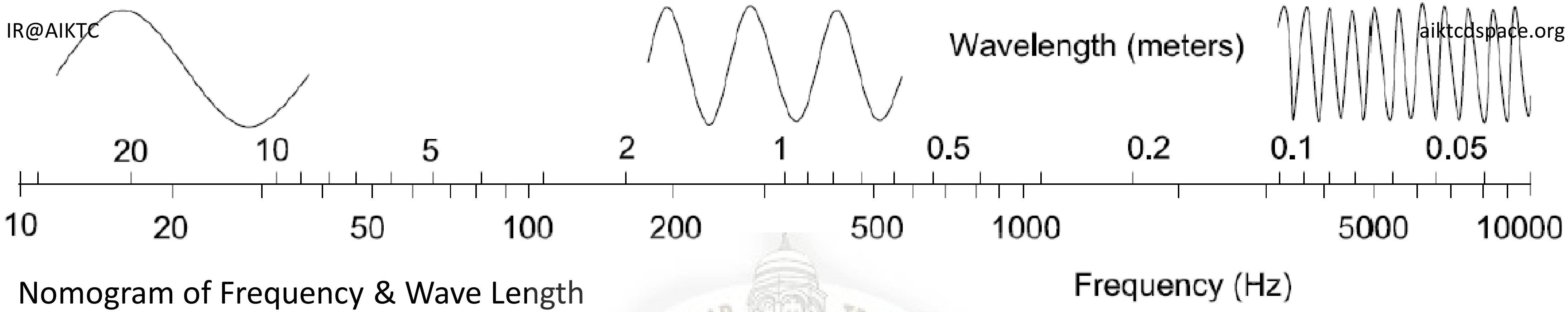
The distance between two successive crests or troughs, or the distance of a complete cycle of a wave propagation of in the direction of wave motion is called **Wavelength**.











Nomogram of Frequency & Wave Length

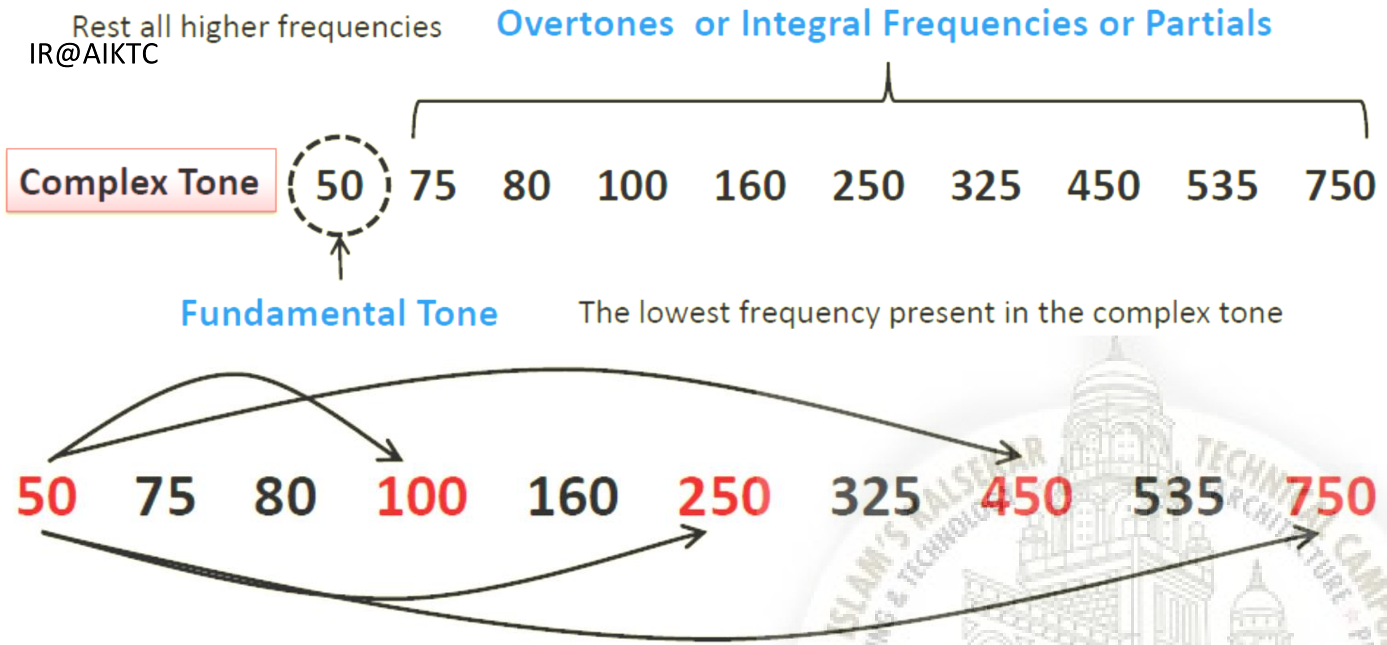
A normal human ear responds to sounds within the audio frequency range about **20 to 20000 Hz**

The speed of sound in air at room temperature is 340 m/s Velocity of Sound in Air (c) is depend upon:

- Atmospheric Pressure (p)
- Density of Air (ρ)
- Temperature of Air (t_a)

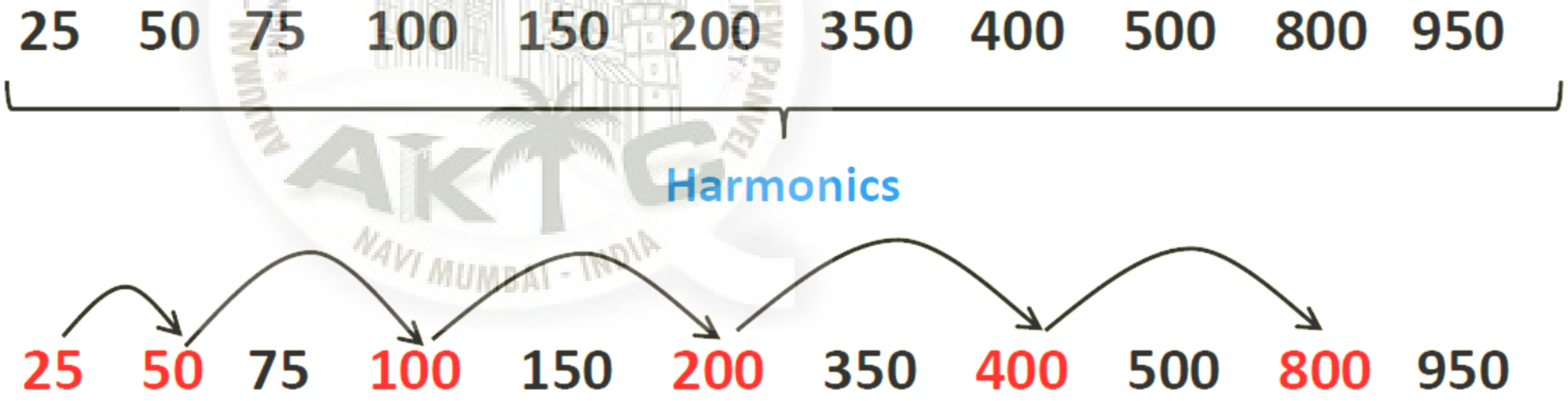
Tone — Sound Sensation

- **Pure Tone** — Sound Sensation consists of a Single Frequency — Striking a tuning fork, Vibration of string of a guitar
- **Complex Tone** — Sound Sensations consists of more than one frequency — Speech, Music, Road side noise



Harmonics

Numerical integer multiples of the fundamental (including the fundamental)



Octave

If a frequency is double of the another, then these two are called Octave

- Octave criteria gives an opportunity to logically select some specific frequencies out of many
- The octave band central frequencies provide the common platform for material testing and assess the acoustical data
- The logarithm of octave frequencies are separated by equal distance

One Third Octave Band

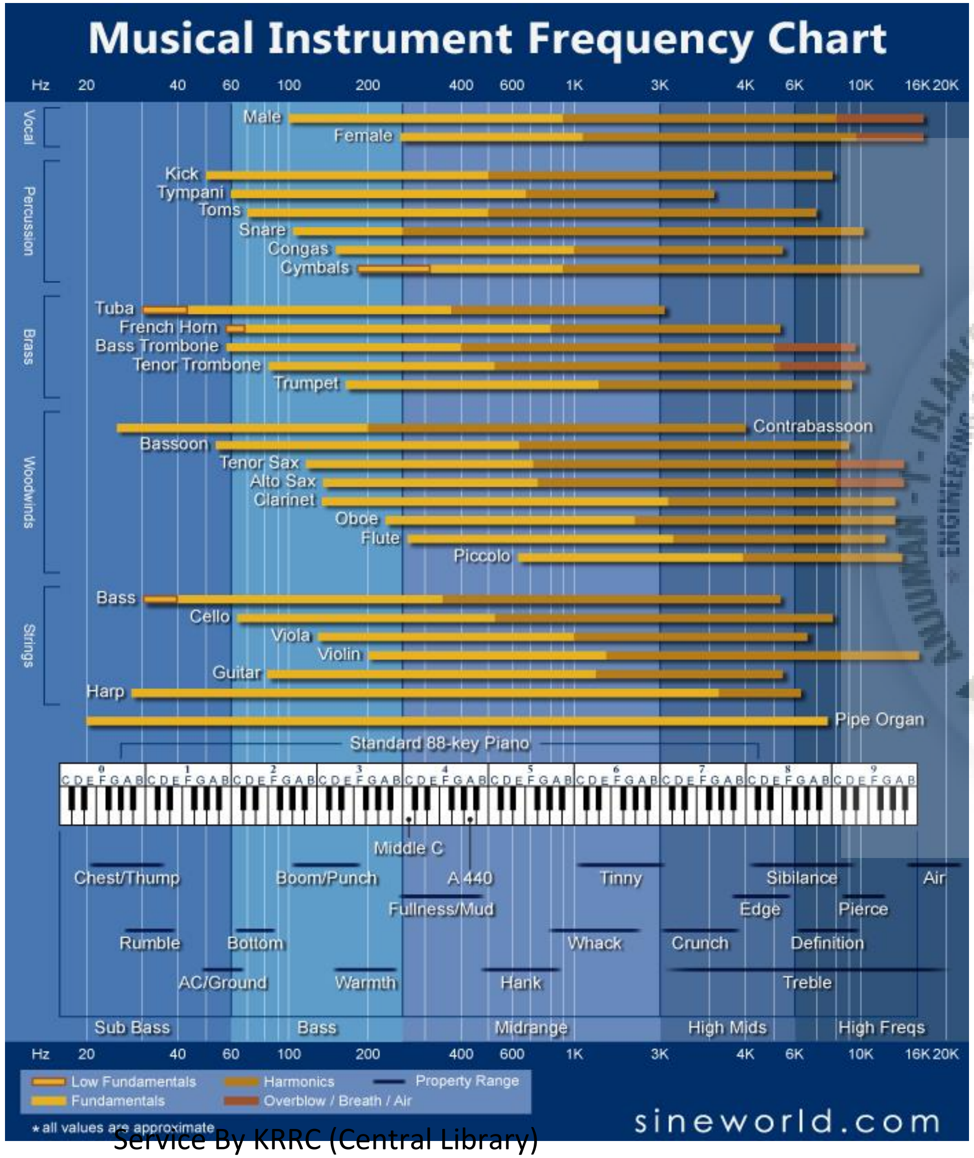
1/1 Octave Band	Band No		1/3 Octave Band
	14	→ Antilog 1.4 →	25
31.5	10 log(31.5) = 15		31.5
	16	→ Antilog 1.6 →	40
	17	→ Antilog 1.7 →	50
63	10 log(63.0) = 18		63
	19	→ Antilog 1.9 →	80

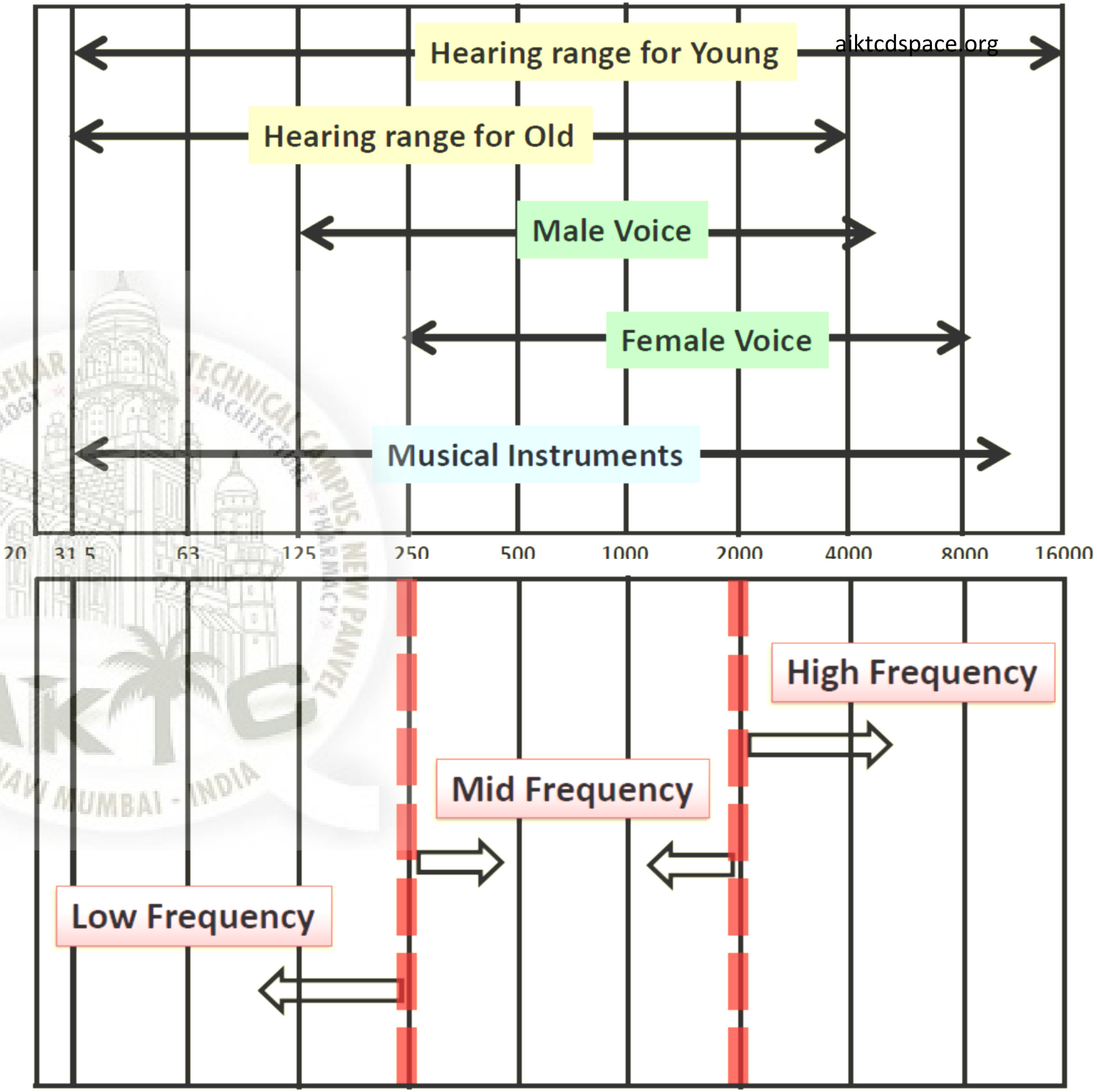
1/1 Octave band central frequencies

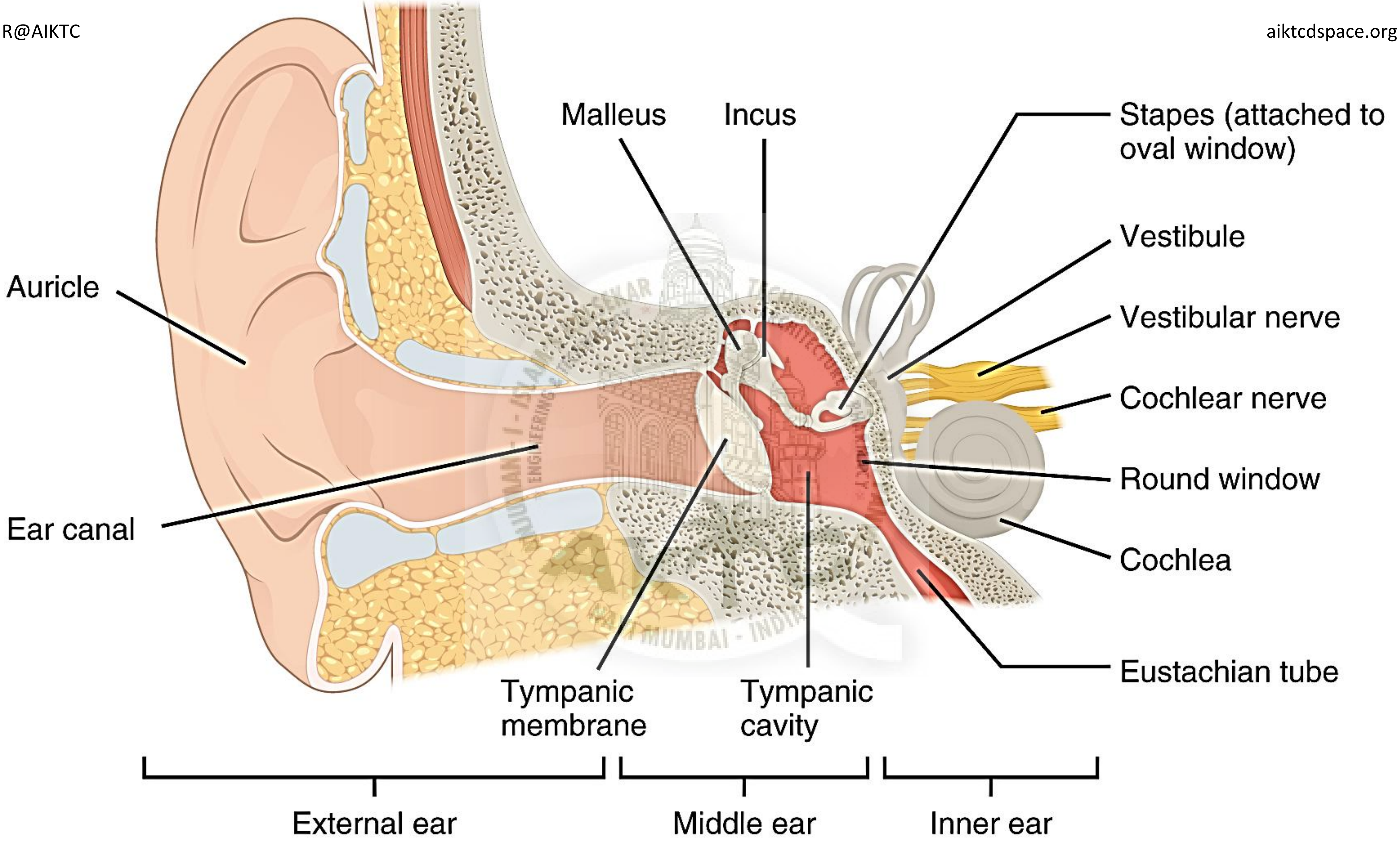
& 1/3 Octave band central frequencies

25 **31.5** 40 50 **63** 80 100 **125** 160 200 **250**
315 400 **500** 630 800 **1000** 1260 1600 **2000**
2500 3150 **4000** 5000 6300 **8000** 10000 12500 **16000** 20000

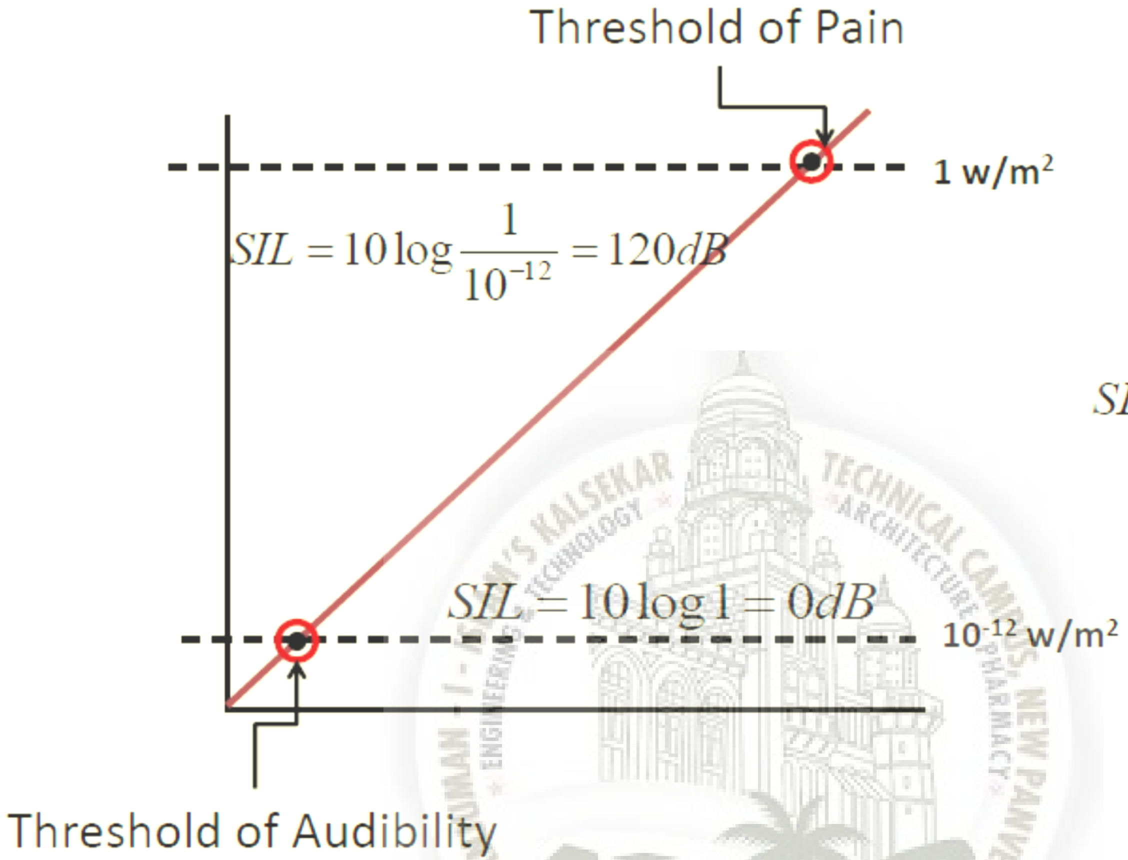
Bass is low frequency range, approximately 20Hz to 250Hz
Mid range is approximately 250Hz to 2000Hz
Treble is the high frequency range, above 2000Hz







https://philschatz.com/anatomy-book/resources/1404_The_Structures_of_the_Ear.jpg



SIL

$$\log a = x, \Rightarrow 10^x = a$$

$$(\log a) + (\log b) = \log(ab)$$

$$(\log a) - (\log b) = \log\left(\frac{a}{b}\right)$$

$$\log a^n = n \times \log a$$

$$\text{Intensity} \propto (\text{Pressure})^2$$

Sound Intensity Level

$$SIL = \log\frac{I}{I_{ref}} \text{ [bel]} \qquad SIL = 10\log\frac{I}{I_{ref}} \textit{ decibel}$$

I = Actual Sound Intensity in W/m^2

$I_{ref} = 10^{-12}\ W/m^2$

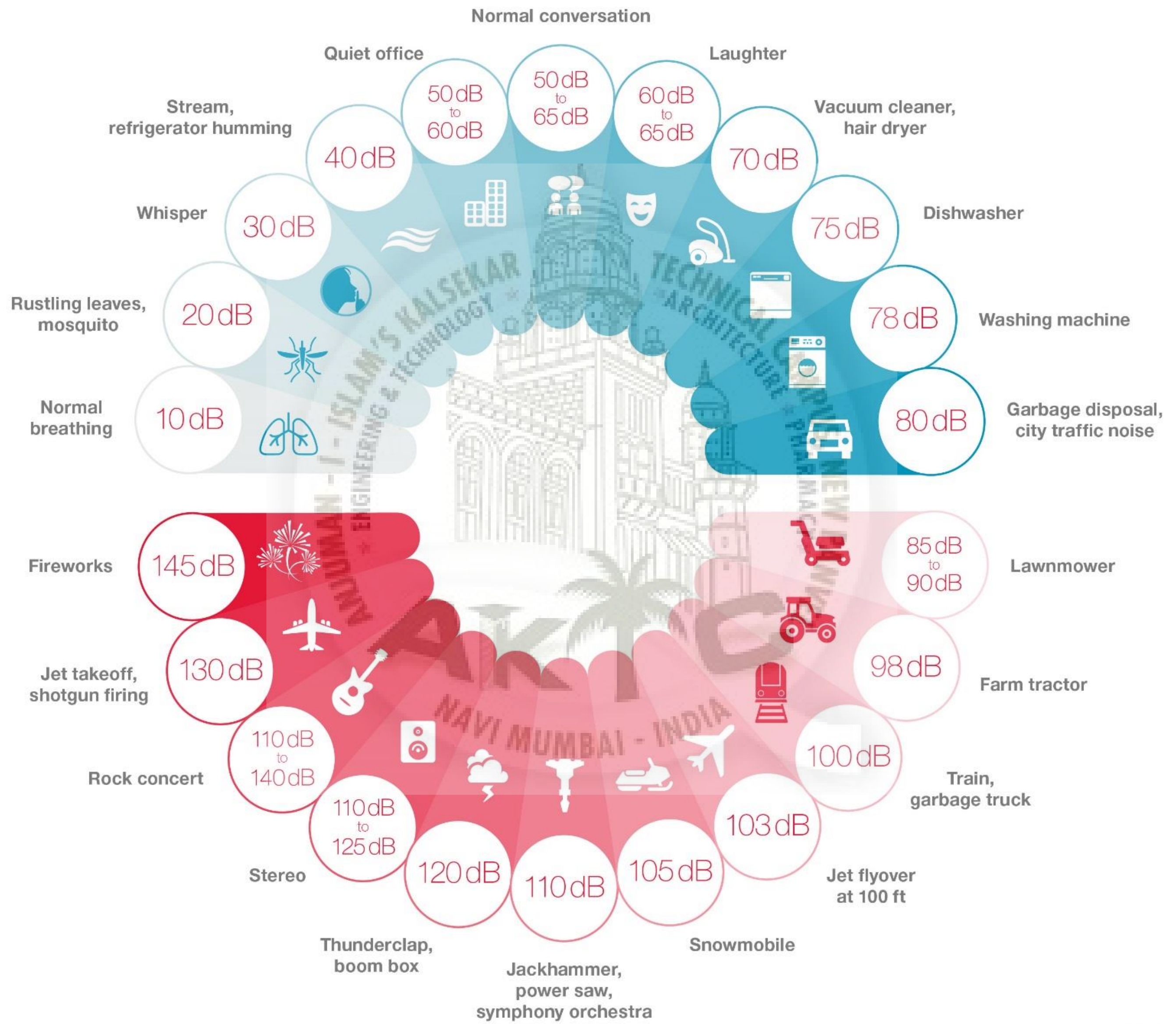
Sound Pressure Level

$$SPL = 20\log\frac{P}{P_{ref}}$$

P = Actual Sound Pressure in Pa

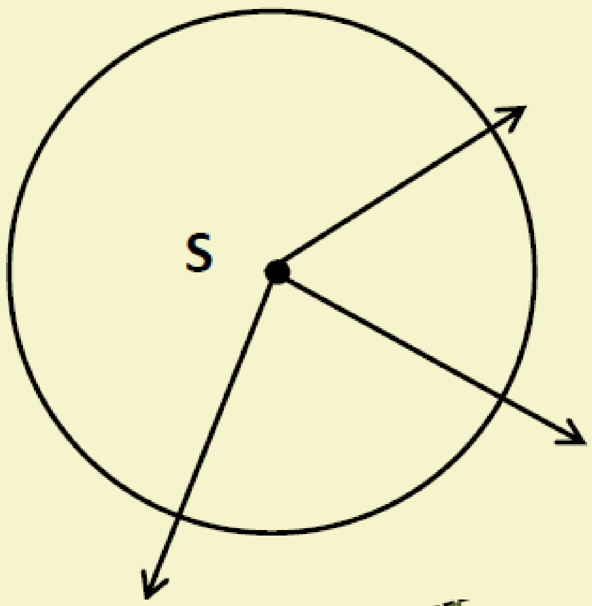
$P_{ref} = 2x10^{-5}$ Pa = 20μPa

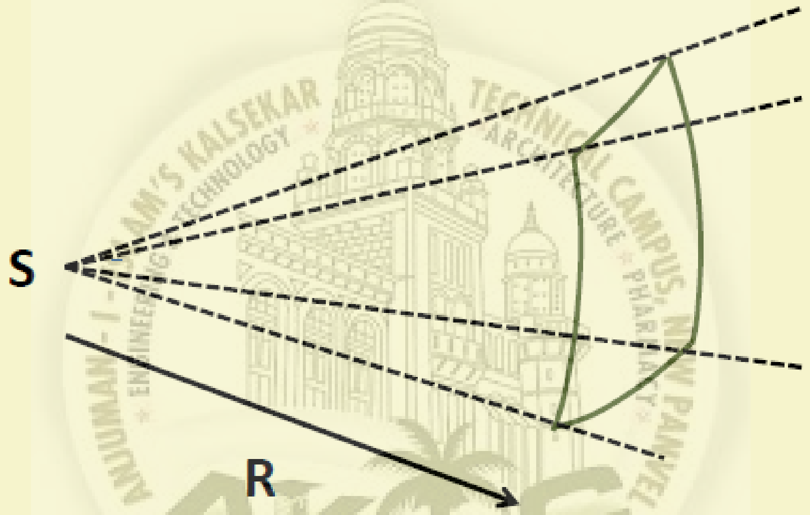
How loud is too loud?



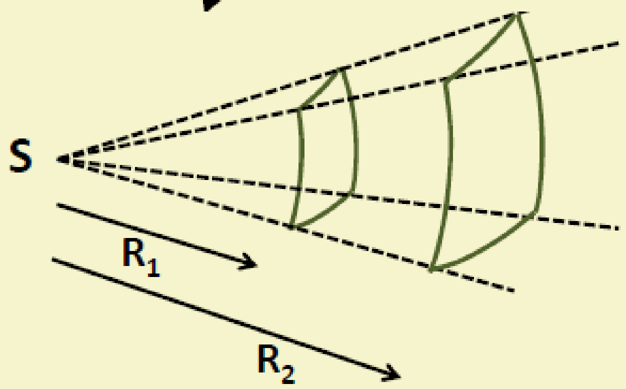
Point Source >>>>>>>> Spherical Propagation

$$\text{Intensity} = \frac{\text{Watt output}}{\text{Surface Area of the Sphere}}$$





$$\text{Intensity} = \frac{W}{4\pi R^2}$$



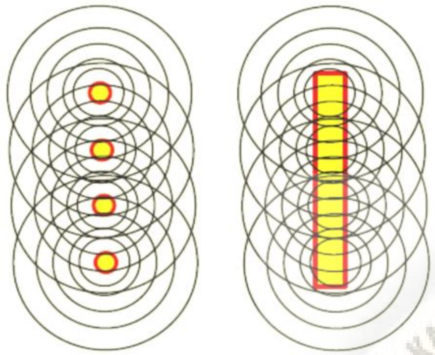
If, $R_2 = 2R_1$ $\quad SPL_1 - SPL_2 = 20\log\left(\frac{R_2}{R_1}\right) = 20\log(2) = 6dB$

Point Source

Spherical Propagation

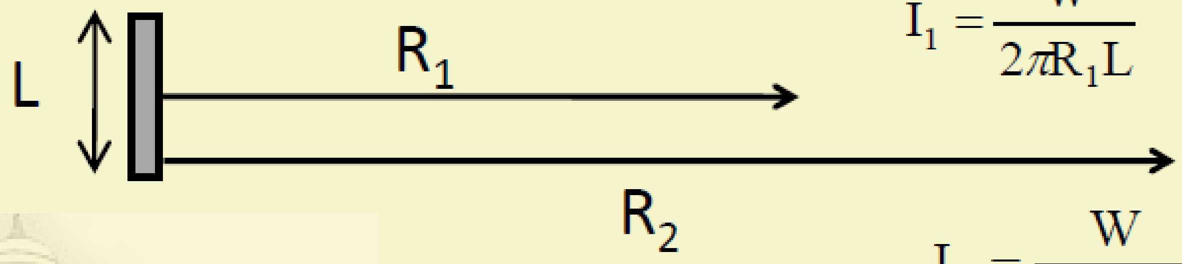
Single Loudspeaker
Human Voice
Noise from a Car

Multiple Point Source
Line Source



Cylindrical Propagation

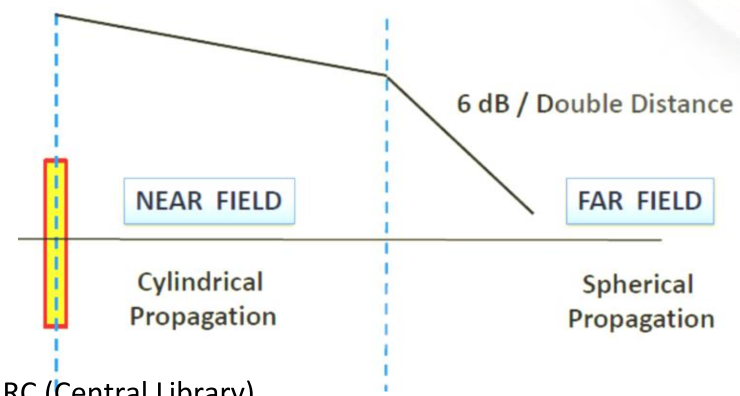
Road Traffic Noise
Railway
Array of Loudspeakers

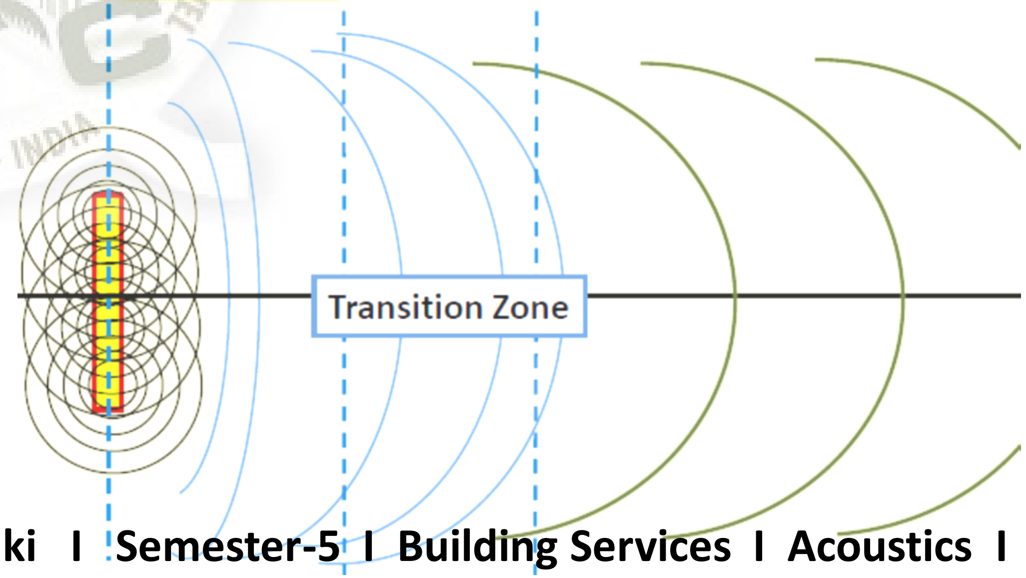


$$I_1 = \frac{W}{2\pi R_1 L}$$

$$I_2 = \frac{W}{2\pi R_2 L}$$

If, $R_2 = 2R_1$ $\quad SPL_1 - SPL_2 = 10\log\left(\frac{R_2}{R_1}\right) = 10\log(2) = 3dB$





Loudness

Sensation / Perception of sound measured in Phon

By definition, 1 Phon is equivalent to 1 dB at 1000 Hz