Acoustics : # Lec 1

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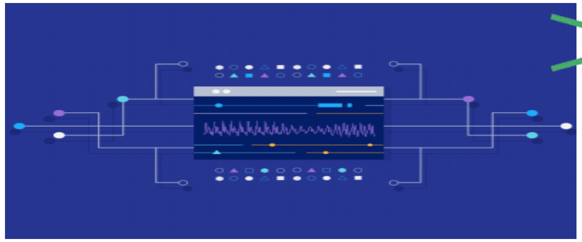
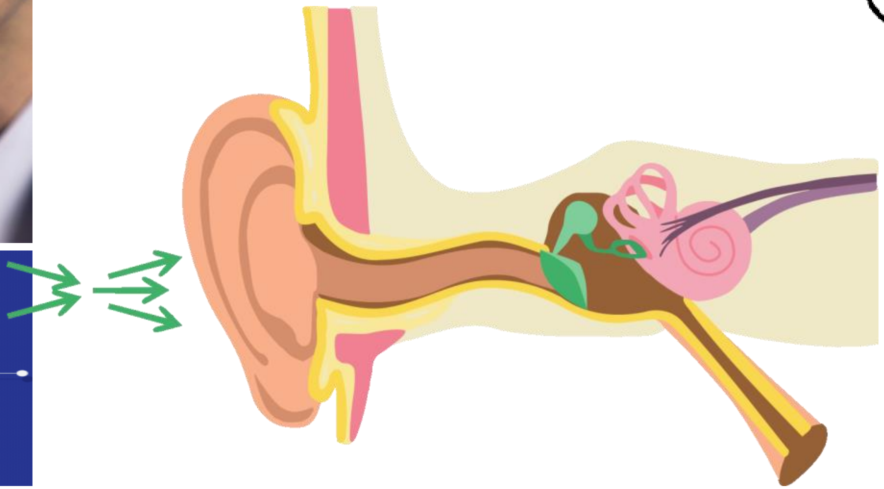
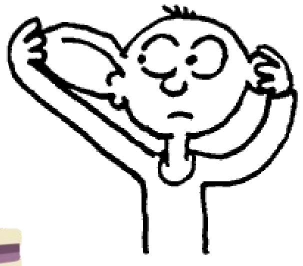
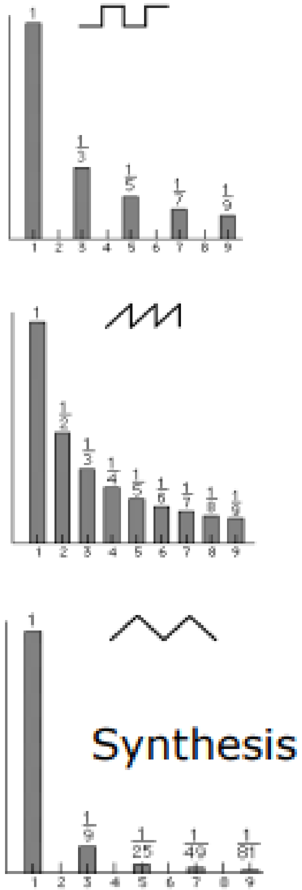
Topic I- Acoustics

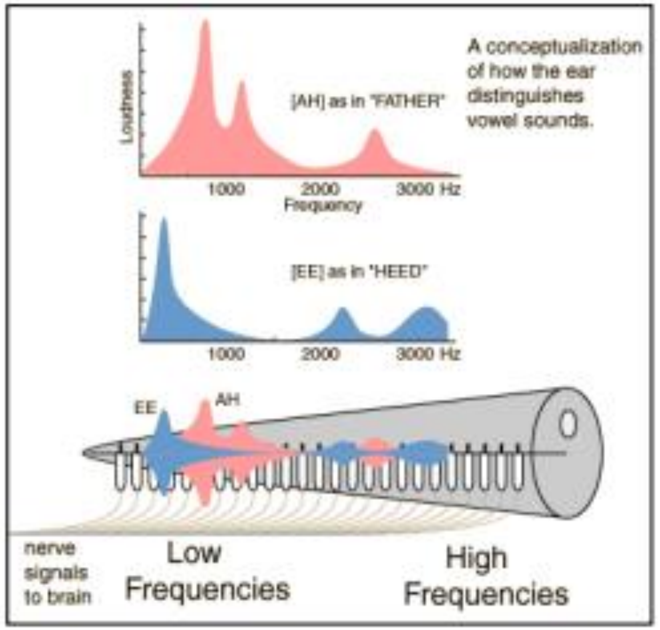
Cyber Crimes



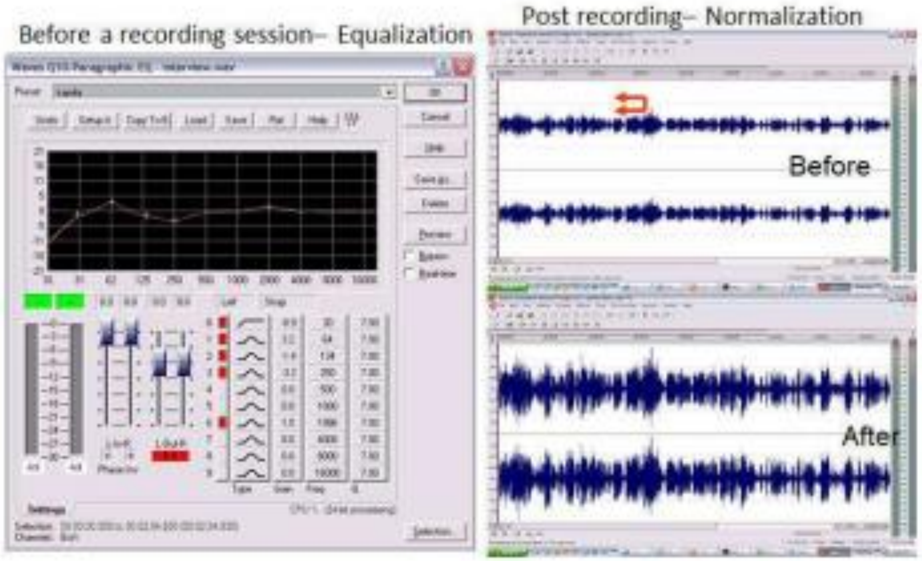








Understanding the perception of sound



- Pitch
- Intensity level (dB)
- Quality (timbre)

Topic I- Acoustics

How is clarity ensured for music and speech?

Roman Amphitheatre

Think, how did the ancient Greek/ Roman artist stage play without any amplifier

Deewan- E-aam

Think, how did the kings arrange courtyard so that everyone can hear without an amplifier

That’s where we need the knowledge of architectural acoustics

Syllabus

ACOUSTICS: 4

Classification- Music & Noise - Characteristics of Sound: Pitch/Frequency, Loudness/Intensity- decibel scale - Weber–Fechner law – Loudness Curves- Quality/Timbre

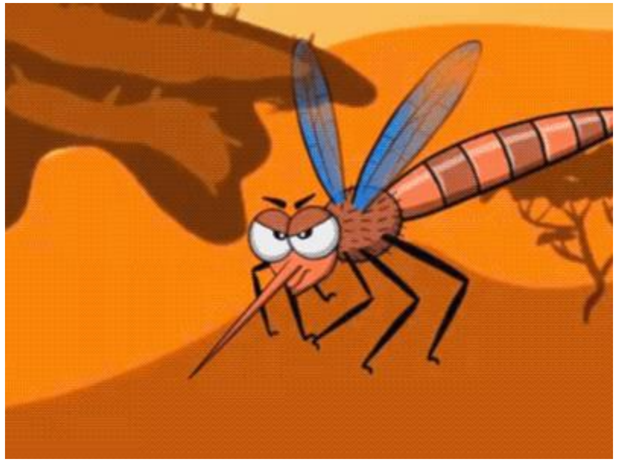
Today's Agenda

- Characteristics of musical sound
  - Relationships between quantitative perception and corresponding scientific metrics
    - (i) Pitch vs frequency
- The Weber-Fechner law
  - (ii) Loudness vs Intensity

Prerequisite knowledge:

Classification of sound
Acoustic wave properties

Acoustics



Acoustics and Ultrasonics: Introductory Lecture

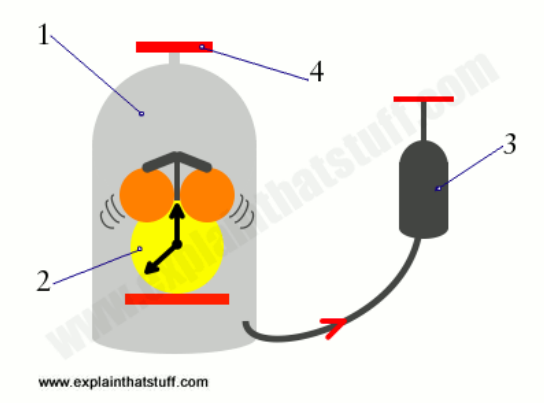
Acoustics

- “Acoustics” is originally a Greek word
- It means 'to hear’
- This relates the study of science of sound
- science of sound = generation, propagation and reception of sound

The term is derived from the Greek akoustos, meaning “heard.”

Acoustics

- ***Generation*** - Relates to the vibration of the sounding body.
- ***Propagation*** - Refers to transmission of sound energy throughthe medium



✓ **In gaseous and liquid media, they propagate as longitudinal waves.**

✓ **In solid media, they propagate as both transverse and longitudinal waves.**

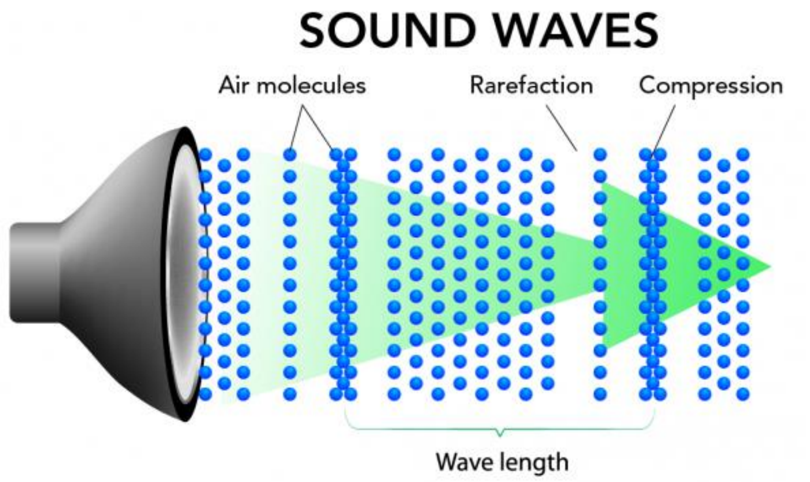
✓ **These result from disturbances in an elastic medium namely mechanical deformations.**

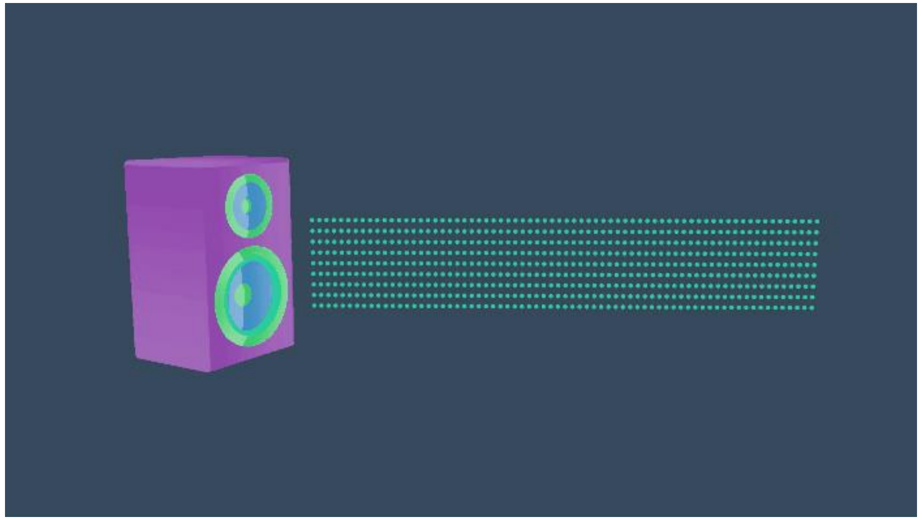
✓ **Thus, the elasticity and density of the medium are important factors that affect propagation sound.**

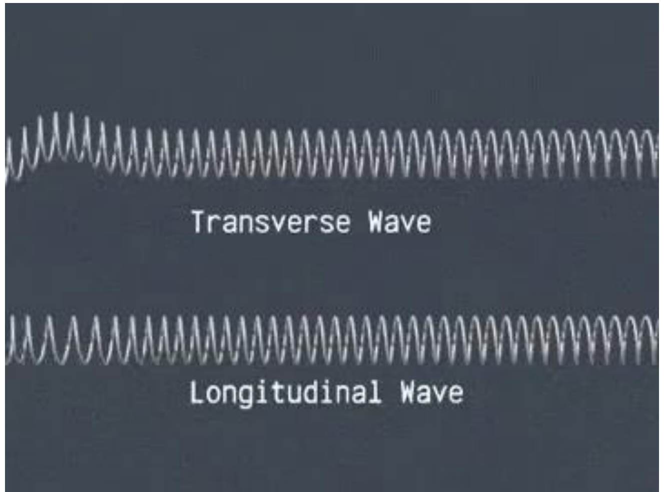
- ***Reception*** - Relates to the human ear receiving the transmitted sound which is in turn dependent on the sensitivity of human ear.

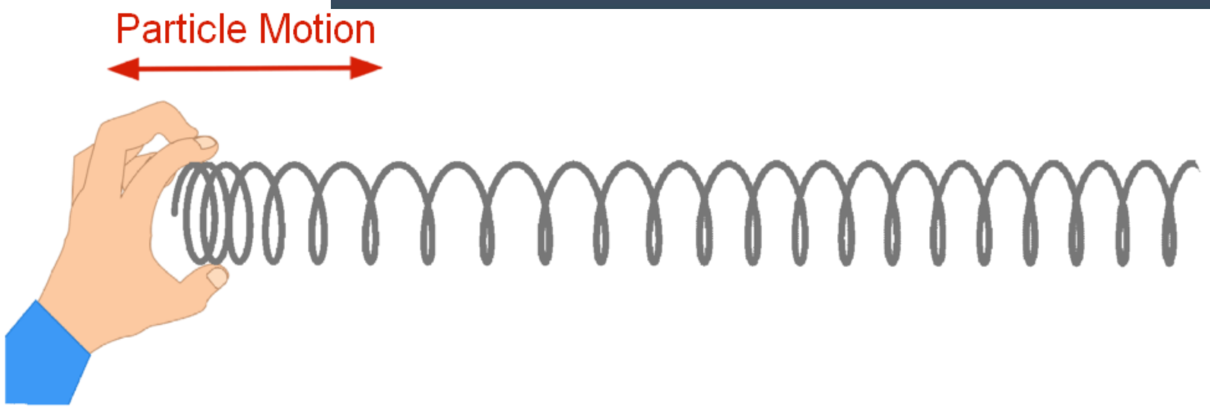
What is sound wave?- a kind of energy which creates the perception of hearing

Sound, a mechanical disturbance from a state of equilibrium that propagates through an elastic material medium.



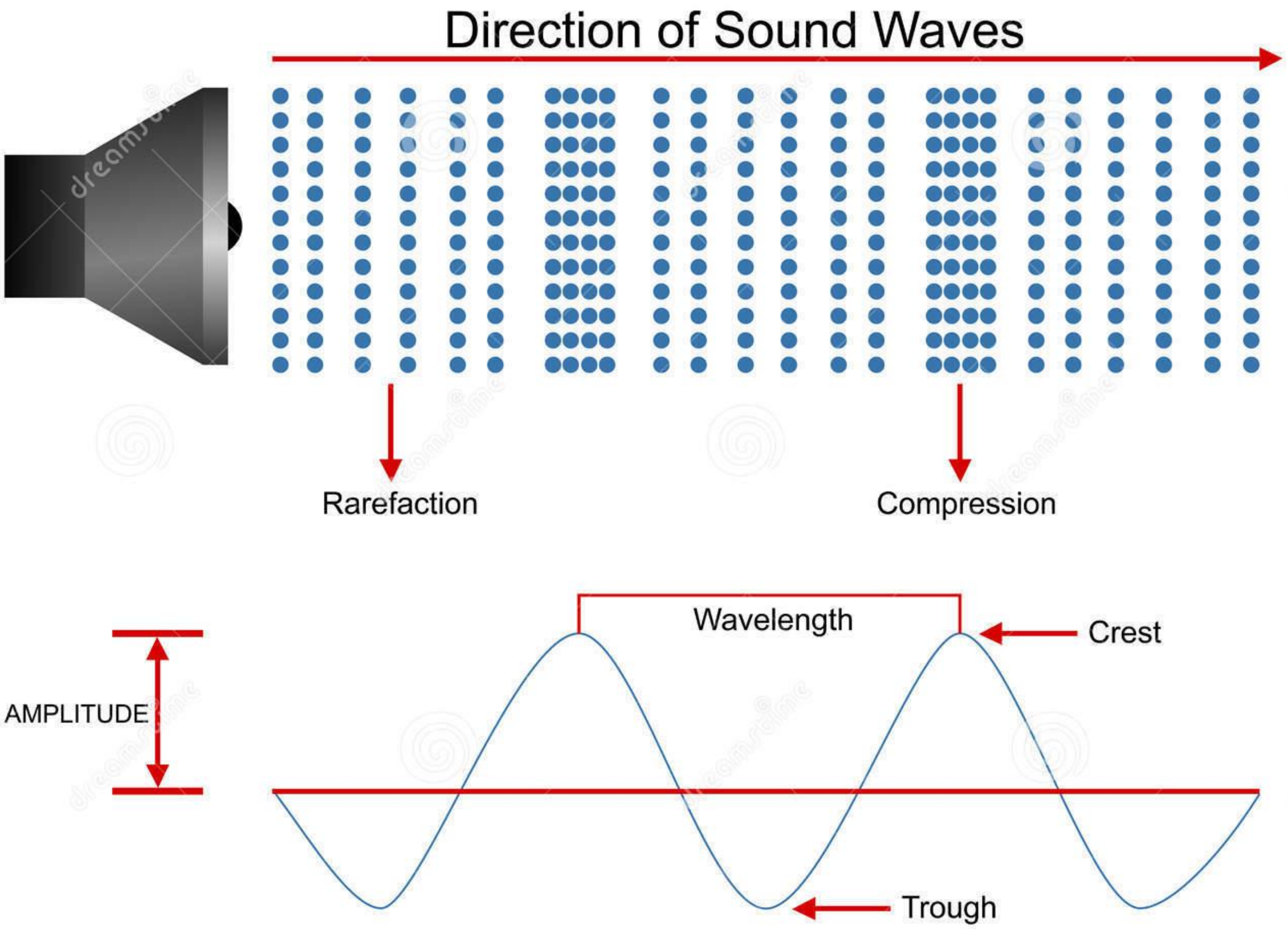






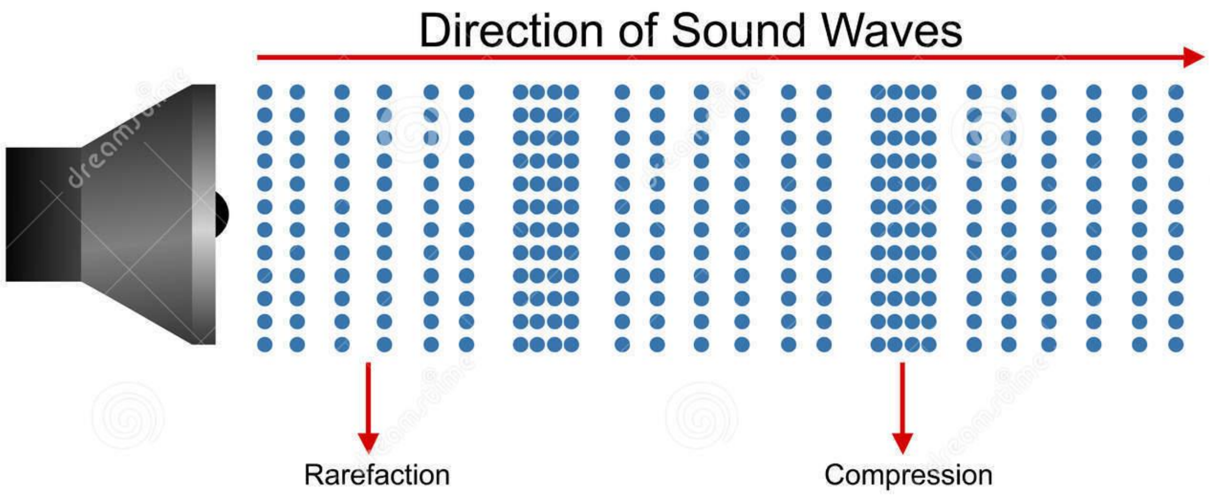
A wave is a disturbance in a medium that carries energy without a net movement of particles

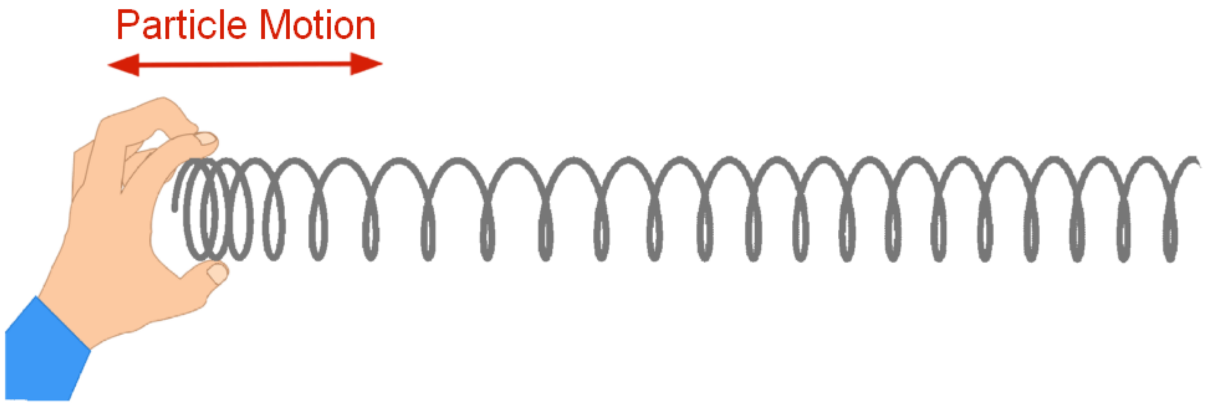
Acoustics

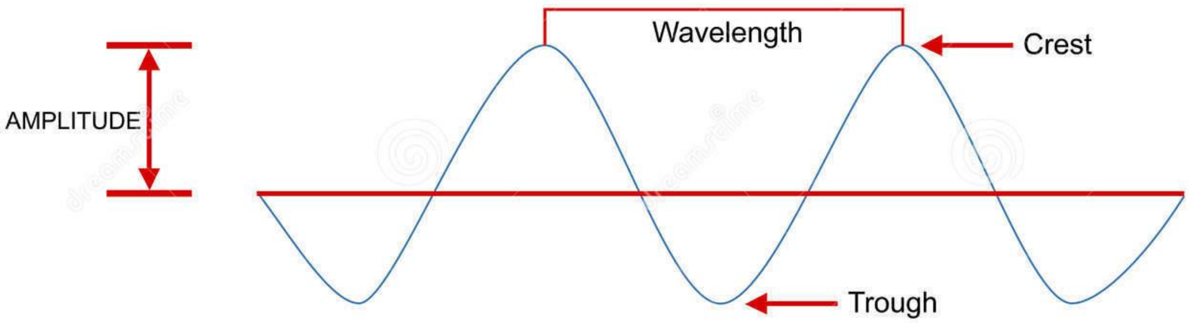

Direction of Sound Waves
Rarefaction
Compression
Wavelength
Crest
AMPLITUDE
Trough

1. Basics of Sound Waves

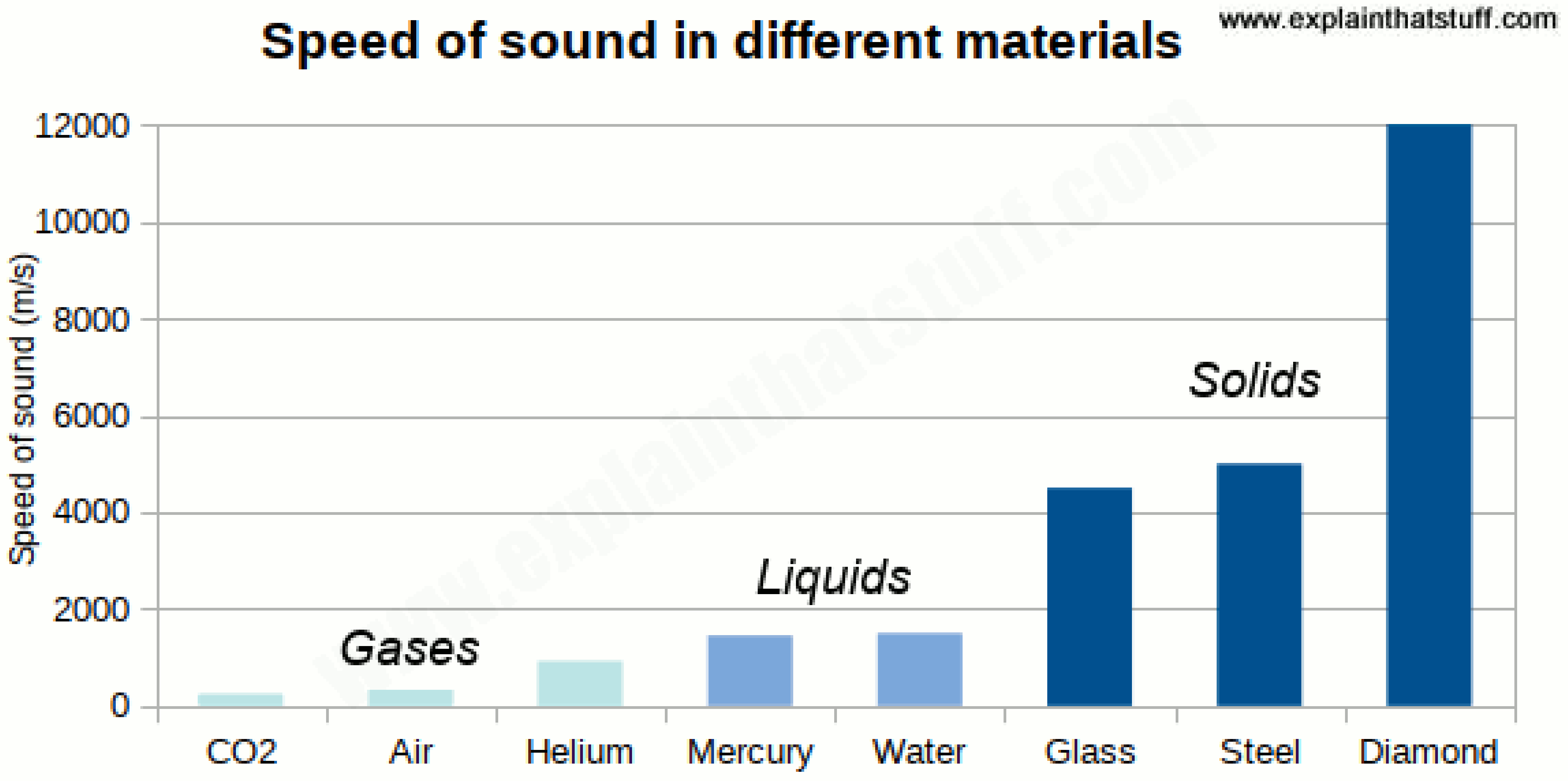
Sound, a mechanical disturbance from a state of equilibrium that propagates through an elastic material medium.



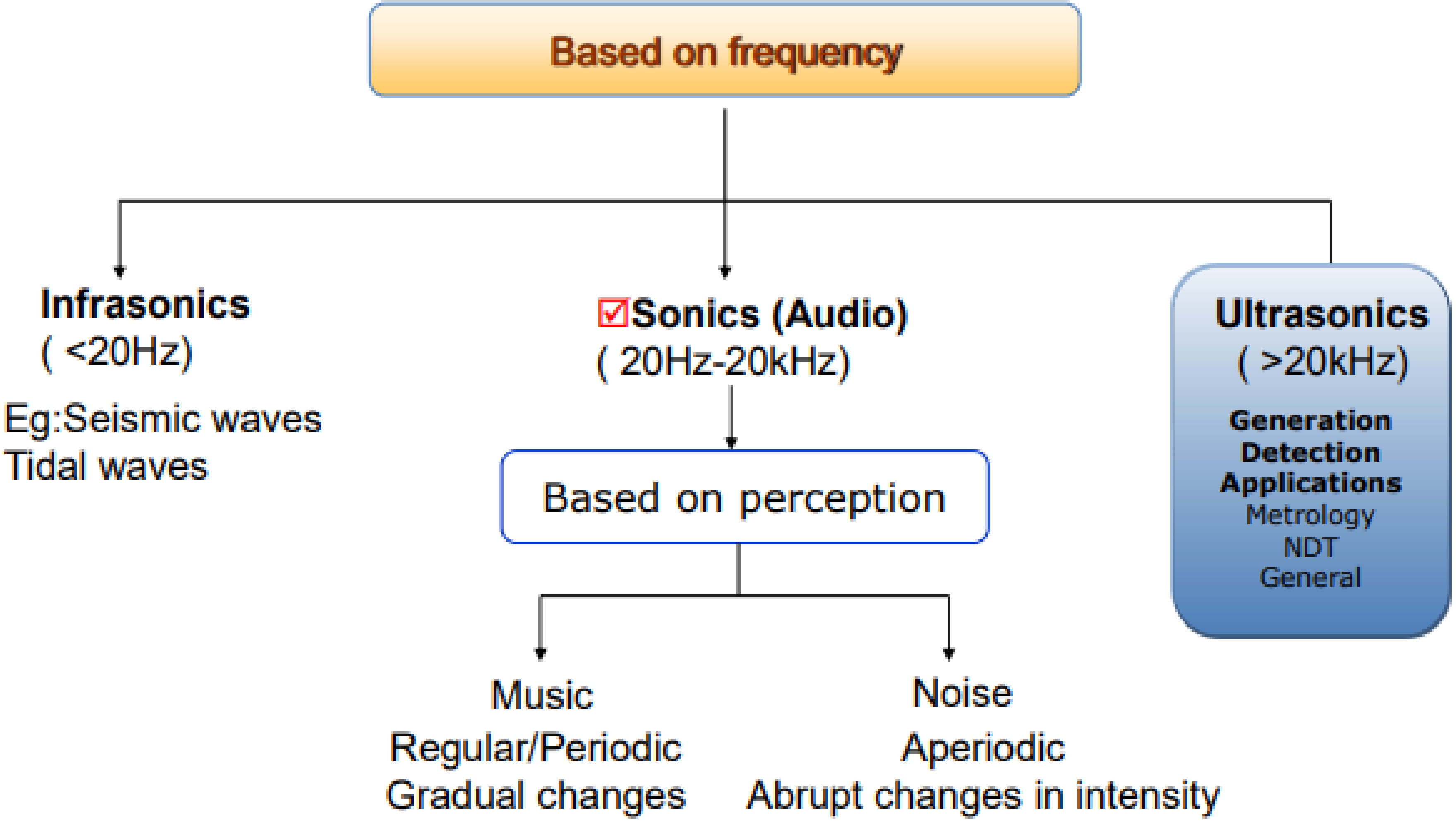




Materials- Speed of sound



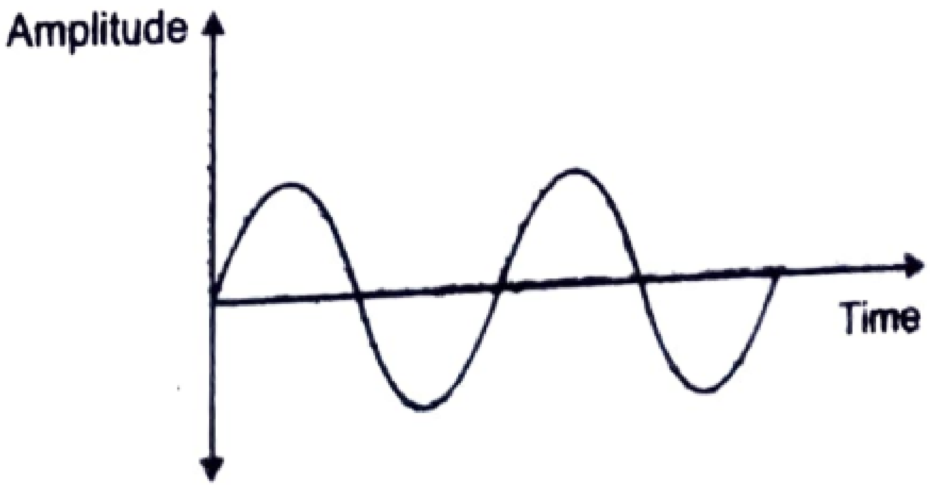
Classification of Sound



Characteristics of musical sound

1. Music

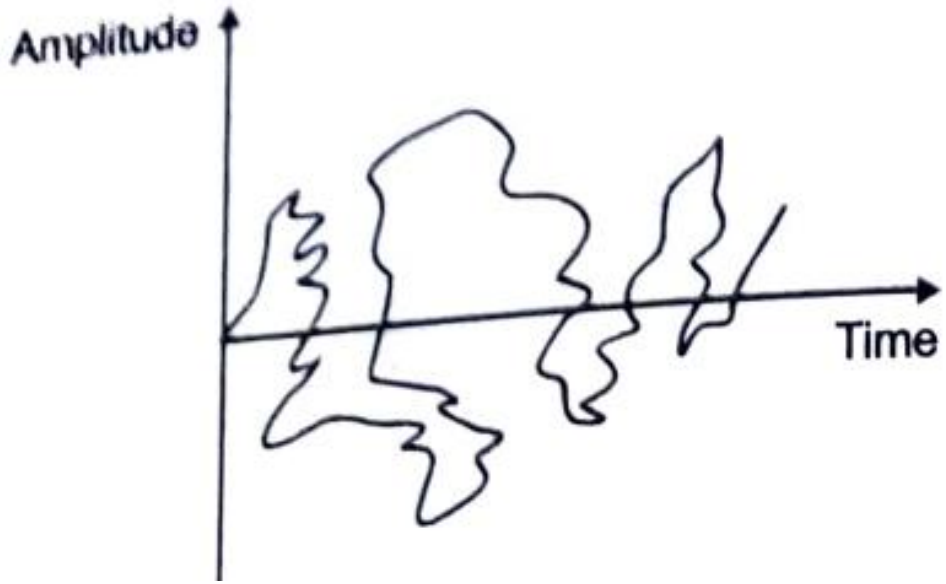
1. Produces a pleasing sensation to ear.
2. There is regularity in the shape of the curves.
3. There is a definite periodicity (i.e., definite frequency). (Fig. 3.3).
4. Sudden changes in intensities are absent.



Characteristics of musical sound

2. Noise

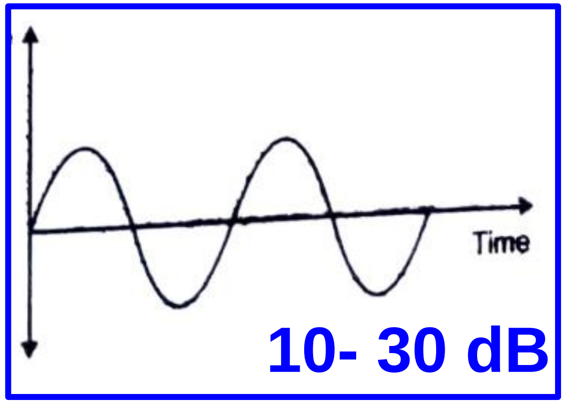
1. Unpleasant to the ears.
2. The curves have a irregular in shape.
3. No periodicity (no definite frequency)
4. There are sudden changes in intensities (that is amplitude)



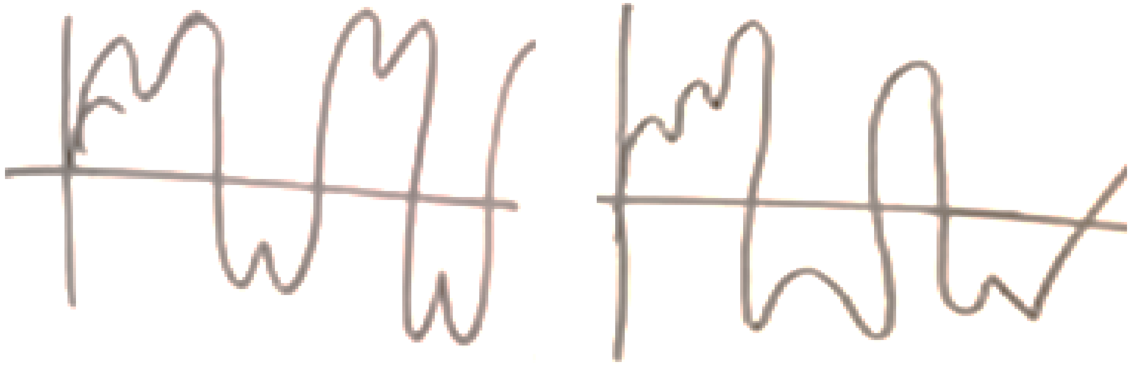
What we have learnt earlier

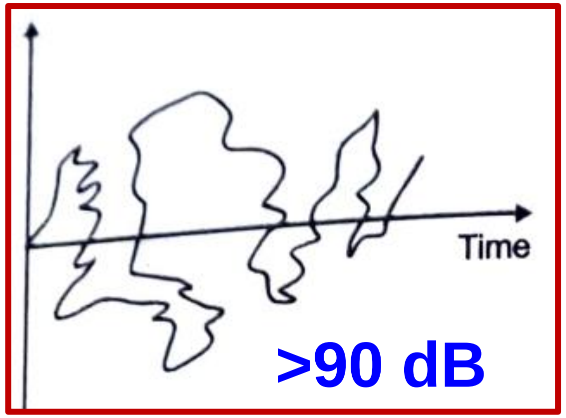
2. Music & Noise

Subjective



- Regular
- Smooth and pleasing
- Continuous
- Periodic





- Irregular
- harsh
- discontinuous
- Non-periodic

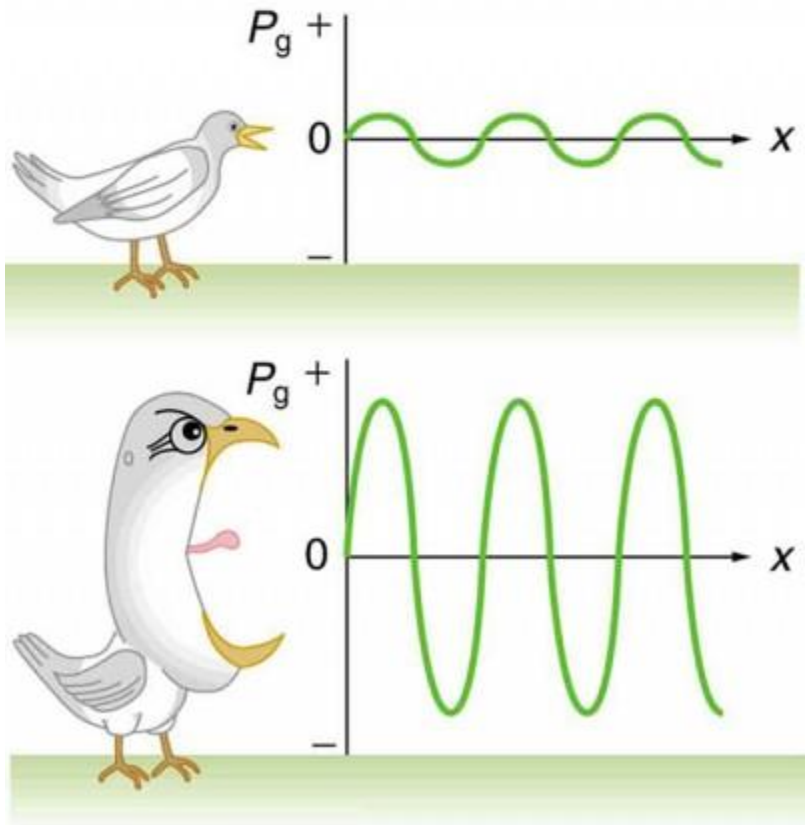
60- 70 dB

Characteristics of sound

2. a) **Loudness** is a physiological quantity.

   b) **Intensity** is a physical quantity and is measured in W/m^2.

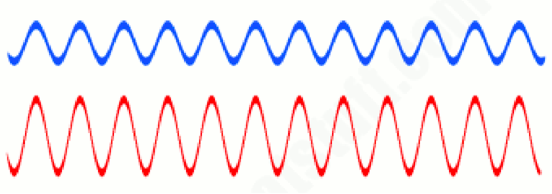
Audible sound can be divided further into **Music** and **Noise**.



1. Loudness α Amplitude^2
2. Loudness α $1/(\text{distance})^2$
3. Loudness increase density increase
4. Loudness increase with surface area
5. Presence of resonating body

What we have learnt earlier

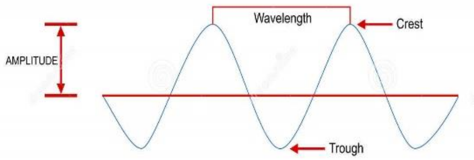
We can hear two sounds, can we differentiate?



3. Characteristics of Sound- Loudness

Two sounds from same instruments/ same source can be differentiated----- different level

1. Loudness α Amplitude^2



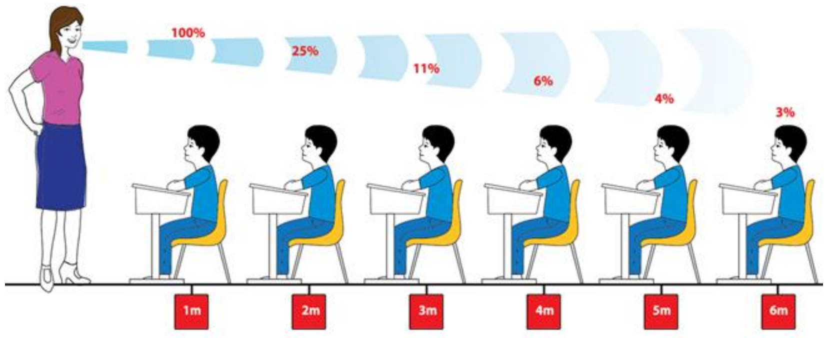
2. Loudness α 1/(distance)^2
3. Loudness increase density increase

4. Loudness increase with surface area

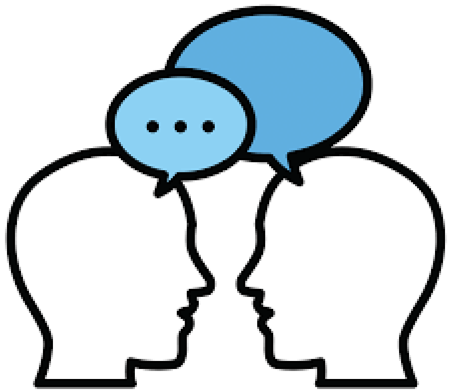
5. Presence of resonating body

Loudness is subjective

Loudness is subjective



30 dB

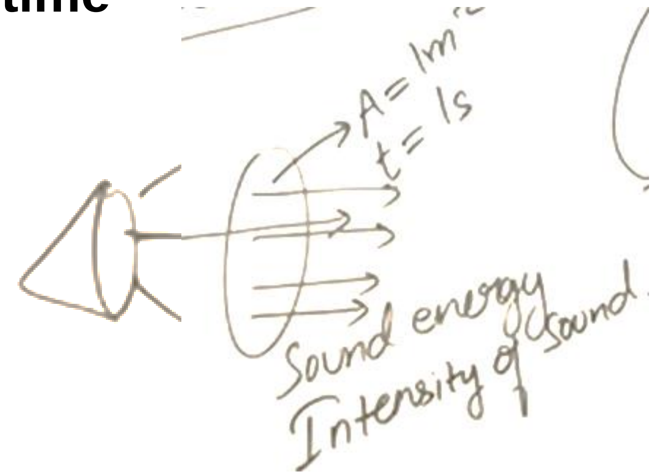


50 dB

Intensity is objective

Measurable quantity

Energy passed per unit area (perpendicular to the direction of the propagation of energy) in unit time



$$I = E/\ A{*}t \sim J/m^2 s \sim W/m^2$$

The minimum sound we can hear is 10^{-12} W/m^2

This level is called as pin drop silence

Loudness and Intensity

Loudness:

- ✓ Loudness signifies how far and to what extent, sound is audible.
- ✓ Loudness of sound is again a subjective perception.
- ✓ Because of the varying sensitivity of the ear, different people perceive the same sound differently.
- ✓ What is loud to one person may be soft for another.
- ✓ An objective measure of loudness is sound intensity, which is applicable equally to everyone.
- ✓ Loudness is found to vary with frequency also.

Loudness is basically the intensity corrected by the ear's response

Intensity:

The intensity of the sound wave is defined as the rate of flow of sound energy through a unit area normal to the direction of propagation.

Intensity of sound is a physical quantity and does not depend on the listener

Male- Low pitch	**Female- High pitch**
Bass	Treble
Woofer	Shrill
Grave	Acute

fɑ1/l

Characteristics of musical sound

1. a) **Pitch** is a physiological quantity (mental sensation).

   Example of high pitch : Humming of a bee

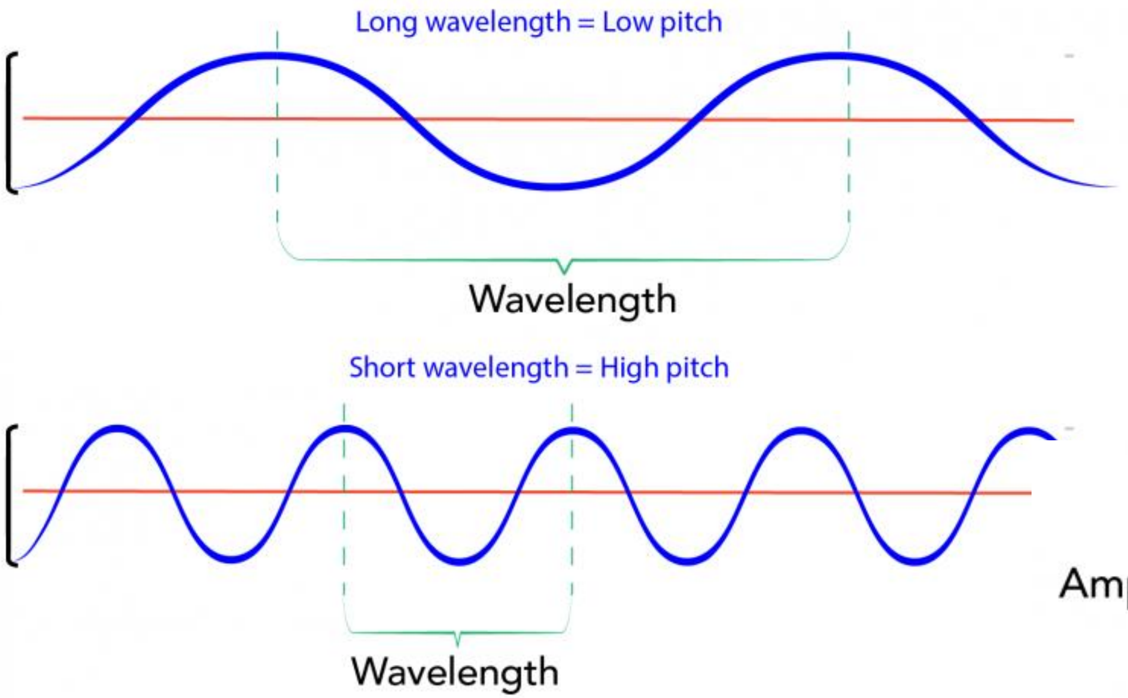
   Example of low pitch : Roaring of a lion

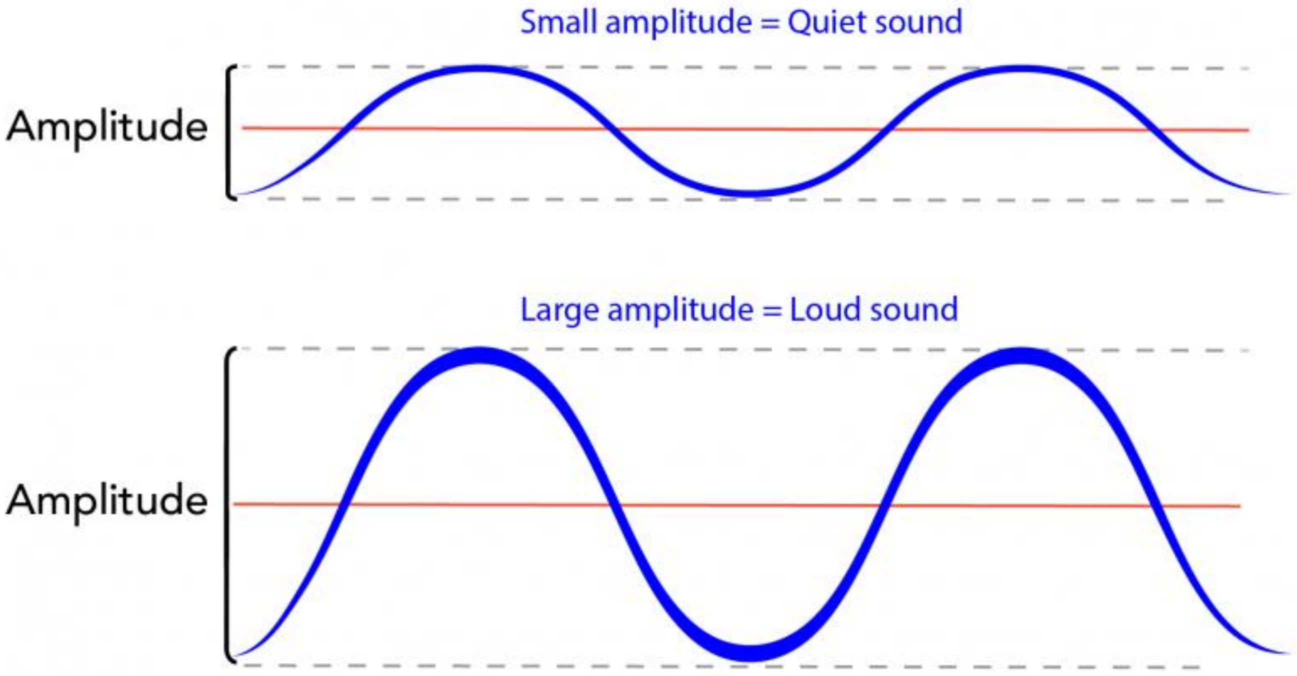
   b) **Frequency** is a physical quantity and is measurable.

   It refers to the number of vibrations/second.

   Unit : Cycles/second or Hz.

Characteristics of sound

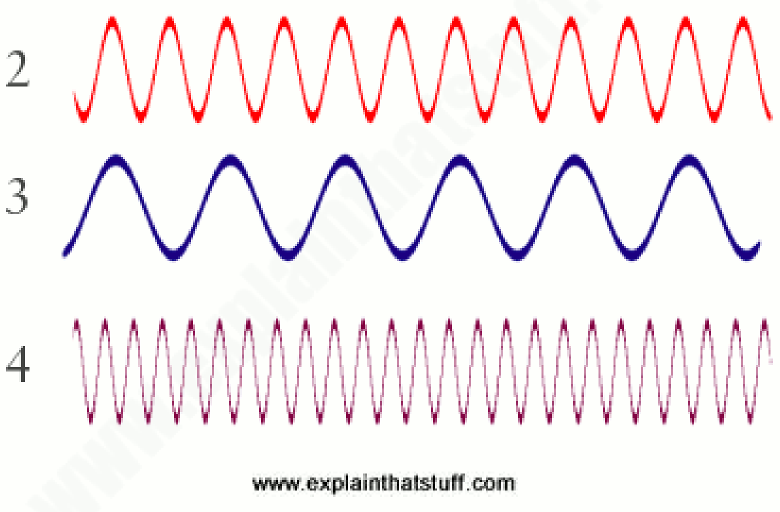




Intensity/ loudness same

Can the sound be different to us?

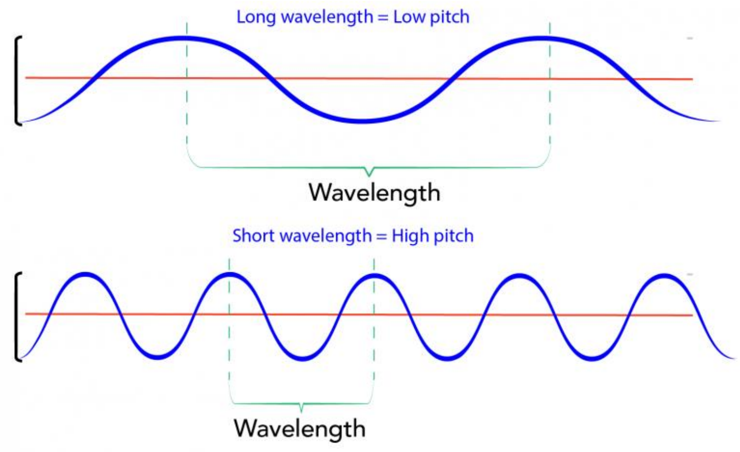
May be the instrument is also same



4. Characteristics of Sound- Pitch

We can distinguish two sounds from of same loudness

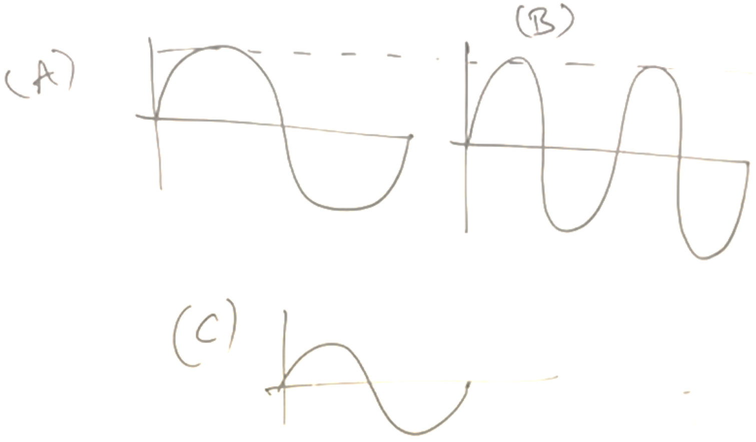
Frequency----- Objetive



BASS

Number of waves emitted per second

SHRILL



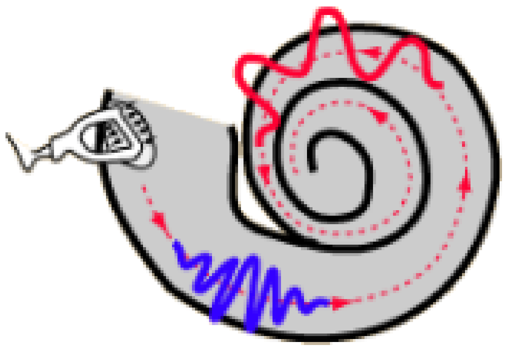
Characteristics of sound

Pitch (P) - The perception of sound that correlates to frequency of sound waves . Pitch increases with the frequency of sound waves

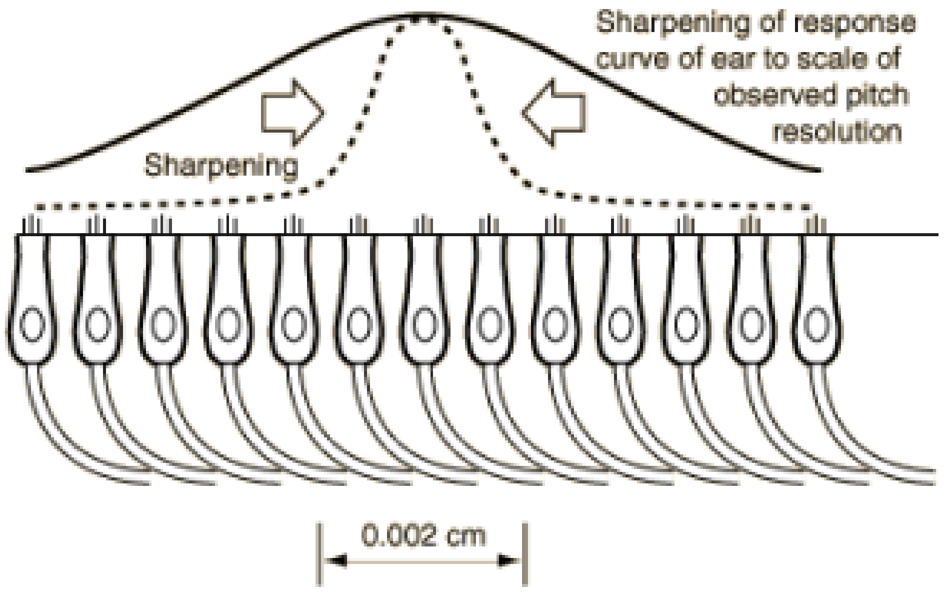
$P \propto \nu$

$= \text{const} * \nu$, where the constant is found to be $\sqrt[12]{2}$ (attributed to Pythagorus)

Our ear identifies frequency with a resolution of 2Hz.

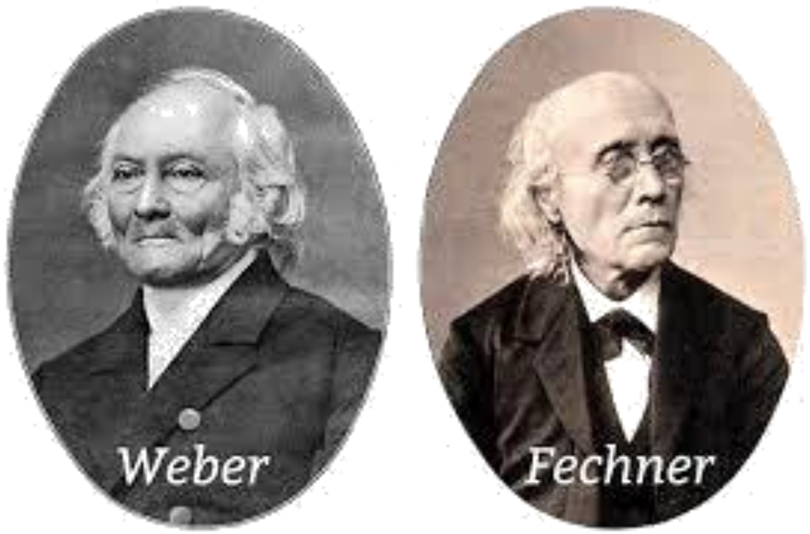


Spatial distribution of freq. sensitive celia



Weber-Fechner Law

✓ **How can we represent loudness?**



- Relates human perception to any physical stimulus Eg –equally applicable to brightness, to sound etc
- Quantitative verification by Ernst Heinrich Weber (1795-1878), consolidation of results by Fechner

Experimental observation:

Instantaneous change in perception **dP α dS** (change in stimulus)

α 1/S

$\therefore$ **dP α dS/S**

dP = k dS/S

Weber-Fechner Law

$$\Rightarrow \int dP = k\int \frac{dS}{S}$$

$$\boxed{P = k \ln S + C}$$

when perception is 0, $P = 0$,

$$\Rightarrow \boxed{0 = k \ln S_0 + C}$$

(Assuming perception is 0 for a stimulus S_0)

$$\Rightarrow \boxed{C = -k \ln S_0}$$

$$\Rightarrow P = k \ln S - k \ln S_0$$

$$= k \ln \left(\frac{S}{S_0}\right)$$

$$\Rightarrow \boxed{P = K \log \frac{S}{S_0}}$$

(where $2.303\, k = K$)

We have loudness as perception and the intensity as the stimulus. Hence, we may write loudness as

$$\boxed{L = K \log \frac{I}{I_0}}$$

This law is referred to as the Weber Fechner Law

Weber- Fechner law as applied to sound

States that loudness of sound is proportional to the logarithm of relative intensity of sound.

Intensity level of sound

- The range of intensity of sound that an ear can hear ranges from 10^{-12} W/m^2 to about 1 W/m^2.
- The lowest intensity of sound at 1 kHz to which a normal human ear can respond is $I_0 = 10^{-12}$ W/m^2.
- This is known as the threshold of hearing and is chosen as the “zero” or “standard” intensity.
- Intensity of a sound is measured with reference to this standard frequency.
- The logarithmic ratio of the intensity of sound wave to the threshold intensity of hearing is defined as the intensity level of sound

$$\boxed{L = K \log \frac{I}{I_0}}$$

Summary

- ✓ **Idea about loudness and Intensity**
- ✓ **The lowest intensity of sound at 1 kHz to which a normal human ear can respond is $I_0 = 10^{-12}$ W/m^2.**
- ✓ **Idea about pitch and frequency**
- ✓ **Derivation of Weber Fechner Law**

How you can quantify loudness?

What we have learnt earlier

How can we distinguish two voices/ sounds?

Loudness and Pitch

Can we quantify loudness?

Weber Fechner Law

$$\boxed{L = K \log \frac{I}{I_0}}$$

Intensity level of sound

- ✓ The range of intensity of sound that an ear can hear ranges from 10^{-12} W/m^2 to about 1 W/m^2.
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- ✓ The logarithmic ratio of the intensity of sound wave to the threshold intensity of hearing is defined as the intensity level of sound

$$\boxed{L = K \log \frac{I}{I_0}}$$

Intensity level and decibel scale

The intensity level of any sound (audible) can be measured with respect to the standard intensity I_o.

We define relative intensity as $\left(\frac{I}{I_o}\right)$. But we have seen that the intesity varies from $10^{-12}\ W/m^2$ to $1\ W/m^2$. This is a broad scale. In order to compress this scale, logrithmic scale is chosen.

bel and decibel scale

The Bel and *dB* Scale

If $\frac{I}{I_o} = 10^x$, the intensity level is said to be 'x' bels.

$$\text{i.e., } \log\left(\frac{I}{I_o}\right) = \log 10^x = x \log 10$$

$$= x \text{ bels} \quad \text{.. (10)}$$

bel again is a large unit and hence the decibel (dB) scale is used

$$1 \text{ dB} = \frac{1}{10} \, bel \Rightarrow 1 \text{ bel} = 10 \; dB \quad \text{.. (11)}$$

$$\therefore \text{ Intensity level} = \log\left(\frac{I}{I_o}\right) bels$$

$$\boxed{\text{Intensity level in } dB = 10 \log\left(\frac{I}{I_o}\right) dB} \quad \text{.. (12)}$$

Meaning of 1 decibel

$$1\ dB = 10 \log\left(\frac{I}{I_o}\right)$$

$$\log\left(\frac{I}{I_o}\right) = 0.1$$

$$\frac{I}{I_o} = 10^{0.1} = 1.26$$

$$\boxed{I = 1.26\ I_o}$$

i.e., if the intensity increases by 26 % the intensity level is 1 dB. This is with reference to the standard intensity I_o. If there are 2 intensities (I_1 and I_2), 1 dB would be either 26 % increase or 26% decrease in intensity depending on which intensity we take as our initial condition. Thus in a more general fashion 1 dB intensity level implies a 26% change in intensity.

In general, 1dB intensity level implies a 26% change in intensity

bel and decibel scale

For $10^{-12}\ W/m^2$,

Pin drop silence

$$\text{Intensity level} = 10 \log \frac{10^{-12}}{10^{-12}}$$

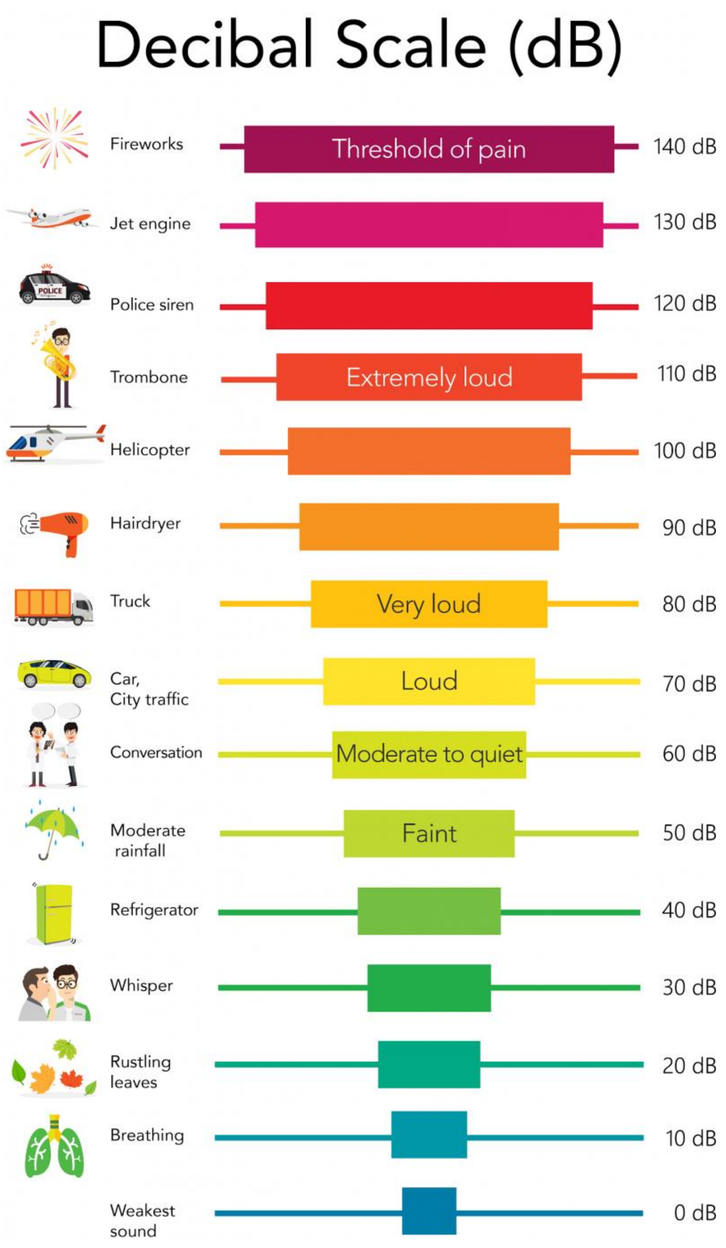
$$= 10 \log 1 = 0\ dB$$

For $1\ W/m^2$,

$$\text{Intensity level} = 10 \log \frac{1}{10^{-12}}$$

$$= 10 \log 10^{12} = 120\ dB$$

Dynamic range of ear



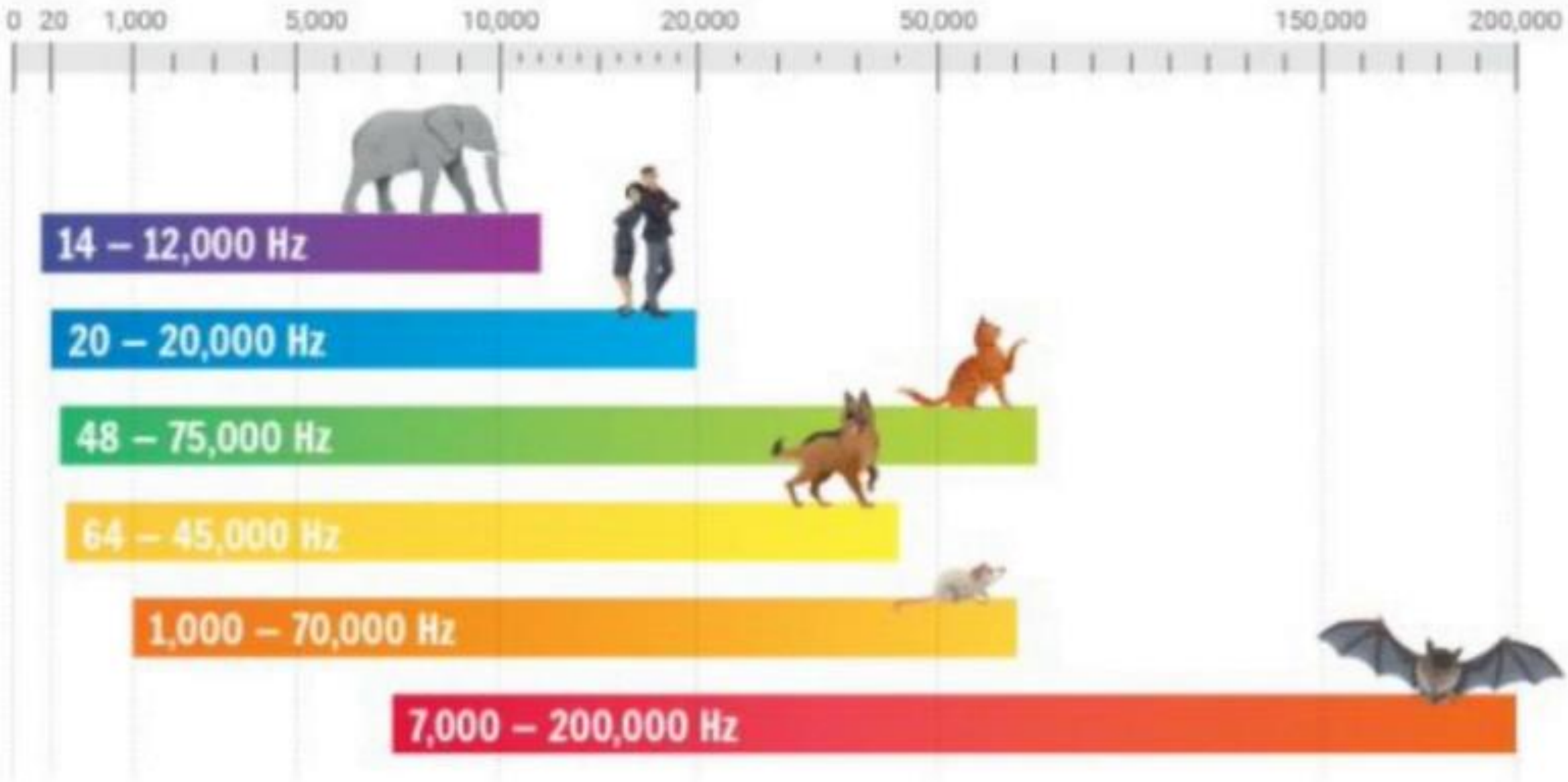
The upper limit of intensity that the ear can actually tolerate represents the threshold of pain - where the sound is so loud it actually hurts the ear and can cause physical damage.

Threshold of pain =120dB

	Min	Max
Frequency:	20 Hz	20,000 Hz
Intensity:	10^{-12}	10 W/m²
Pressure:	20 μPa	200 Pa

@1kHz

The threshold values (both threshold of hearing and pain) change over the lifespan of the person based on aging and misuse


0
20
1,000
5,000
10,000
20,000
50,000
150,000
200,000
14 – 12,000 Hz
20 – 20,000 Hz
48 – 75,000 Hz
64 – 45,000 Hz
1,000 – 70,000 Hz
7,000 – 200,000 Hz

decibel scale

What does log scale imply?
Ear converts multiplicative factor into additive factor (i.e a G.P into an A.P)
For example if Intensity x is doubled, what is the increase in Intensity level (I.L)?

Original I.L $= 10 \log (x / I_o)$ dB

New I.L $= 10 \log (2x / I_o)$ dB

New I.L - Old I.L $= 10\log (2x / I_o) - 10 \log (x / I_o)$
$= 10 \log (2) = 3.010$ dB

Therefore I.L increases by 3.010 dB
i.e new I.L = (old I.L +3.010) dB

Be careful while handling log units.
Remember log (A.B) = log A + log B
log (A/B) = log A - log B

What does 0 dB mean?

A mosquito produces a sound intensity level of 0dB. If 100 mosquitoes are present what will be the intensity level?

A machine produces a sound intensity level of 70 dB. If it is operating in a room with a sound level of 80dB, what is the total intensity level within the room?

A machine produces a sound intensity level of 70 dB. If it is operating in a room with a sound level of 80dB, what is the total intensity level within the room?

$$IL_1 = 70dB, \qquad IL_2 = 80dB$$

$$IL_1 = 10\log\frac{I_1}{I_0} = 70, \qquad IL_2 = 10\log\frac{I_1}{I_0} = 80$$

10^8

$$IL_1 = 10\log\frac{I_1}{I_0} = 70, \qquad IL_2 = 10\log\frac{I_1}{I_0} = 80$$

$$\log\frac{I_1}{I_0} = 7, \qquad \log\frac{I_1}{I_0} = 8$$

$$\frac{I_1}{I_0} = 10^7, \qquad \frac{I_2}{I_0} = 10^8$$

$$What \quad is \quad IL_{total} = 10\log\frac{I_1 + I_2}{I_0}$$

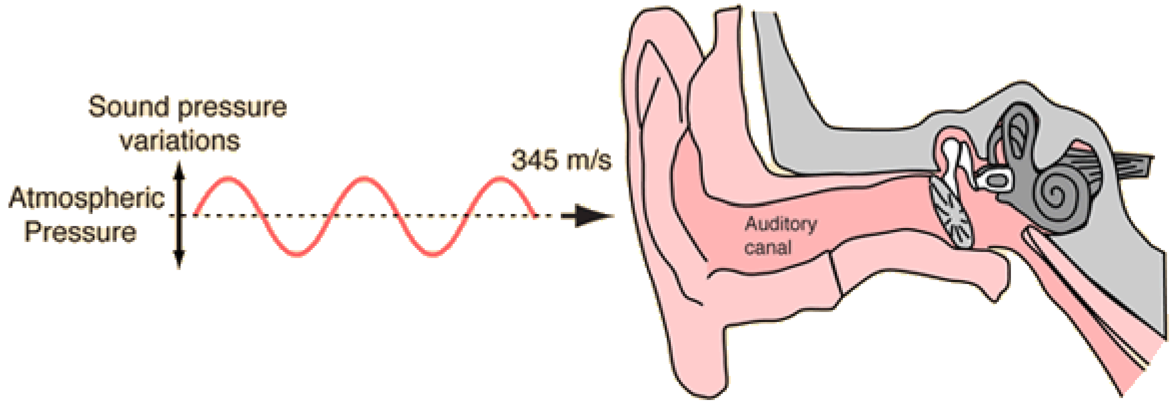
$$\frac{I_1}{I_0} + \frac{I_2}{I_0} = \frac{I_1 + I_2}{I_0} = 10^7 + 10^8$$

$$\frac{I_1 + I_2}{I_0} = 10^8(1 + 0.1) = 1.1\,x\,10^8$$

$$IL_{total} = 10\log\left(\frac{I_1 + I_2}{I_0}\right) = 80.41dB$$

Sensitivity of human ear

The human ear can respond to minute pressure variations in the air if they are in the audible frequency range, roughly 20 Hz - 20 kHz.



It is capable of detecting pressure variations of less than one billionth of atmospheric pressure.

The threshold of hearing corresponds to air vibrations on the order of a tenth of an atomic diameter.

This incredible sensitivity is enhanced by an effective amplification of the sound signal by the outer and middle ear structures.

Contributing to the wide dynamic range of human hearing are protective mechanisms that reduce the ear's response to very loud sounds.

The ear has incredible sensitivity

Threshold of hearing I_0 less than one billionth of atmospheric pressure.

and an incredible power range of operation!

Threshold of pain $10^{13} I_0 = 10{,}000{,}000{,}000{,}000 I_0$

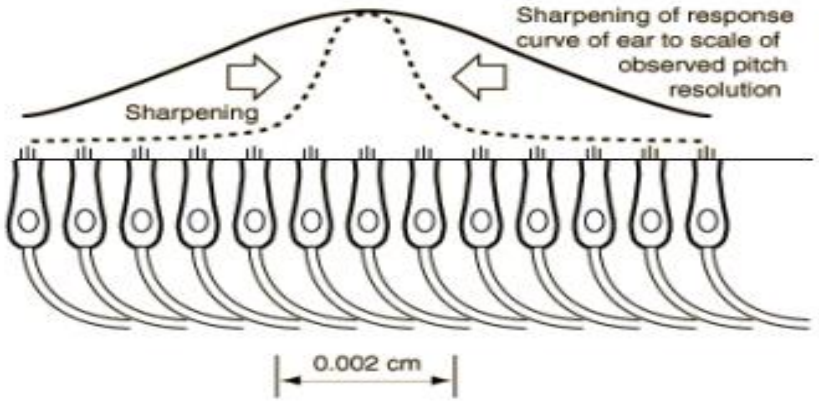
Pitch Resolution

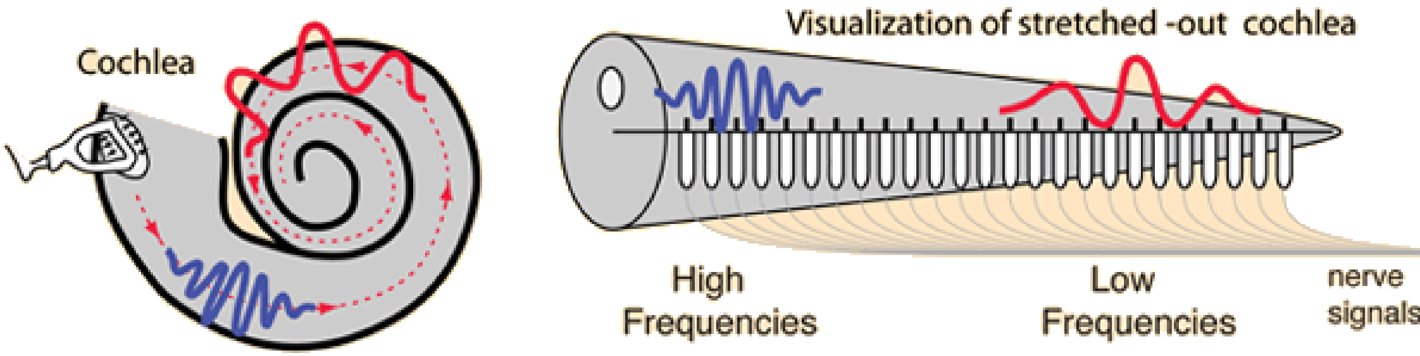
The extremely small size of the cochlea and the extremely high resolution of human pitch perception cast doubt on the sufficiency of the place theory to completely account for the human ear's pitch resolution. Some typical data

Cochlea:	$2\frac{3}{4}$ turns, about 3.2 cm length. Resolves about 1500 separate pitches with 16,000-20,000 hair cells.

This would require a separate detectable pitch for every 0.002 cm, which is physically unreasonable for a simple peaking action on the membrane.

The normal human ear can detect the difference between 440 Hz and 442 Hz. It is hard to believe it could attain such resolution from selective peaking of the membrane vibrations. Some pitch sharpening mechanism must be operating.





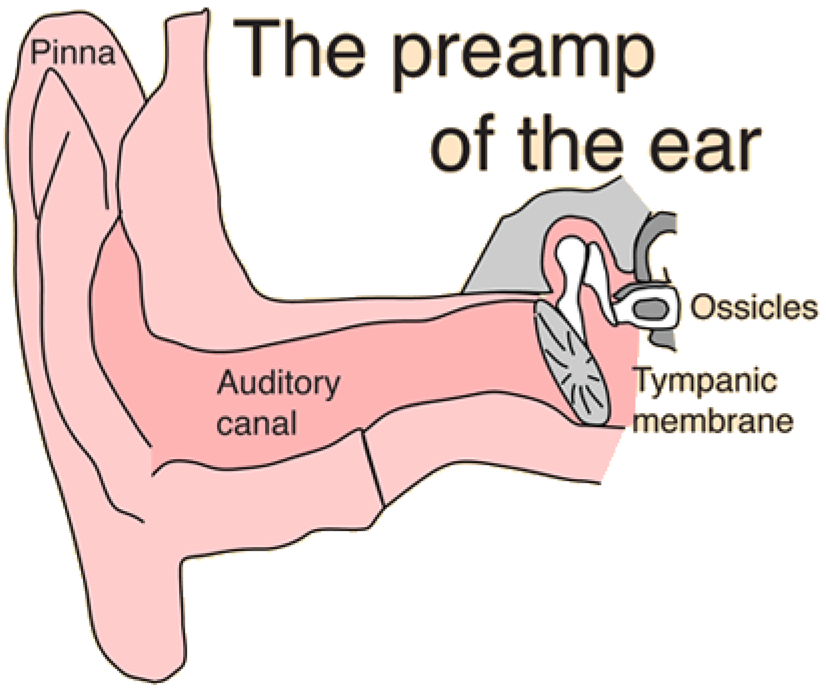
Preamp of the ear

The structures of the outer and middle ear contribute to both the remarkable sensitivity and the wide dynamic range of human hearing. They can be considered to be both a pre-amplifier and a limiter for the human hearing process.

The outer ear (pinna) collects more sound energy than the ear canal would receive without it and thus contributes some area amplification.

The numbers here are just representative ... not precise data.

The outer and middle ears contribute something like a factor of 100 or about 20 decibels of amplification under optimum conditions.



Closed tube resonance of the auditory canal enhances 2000-5000 Hz	Tympanic membrane (eardrum) has some 15x area of oval window contributing an area amplification.	Ossicles (hammer, anvil and stirrup) contribute a lever-type amplification when listening to soft sounds.
Outer ear 2x	Tympanic membrane 15x	Ossicles 3x

Sound characteristics

Prolonged exposure to any noise above 90 dB can cause gradual hearing loss

Decibel Level	Source
84 dB	Diesel truck
70-90 dB	Recreational vehicle
88 dB	Subway, motorcycle
85-90 dB	Lawnmower
100 dB	Train, garbage truck
97 dB	Newspaper press
98 dB	Farm tractor

Regular exposure of more than 1 minute risks permanent hearing loss.

Decibel Level	Source
103 dB	Jet flyover at 100 feet
105 dB	Snowmobile
110 dB	Jackhammer, power saw, symphony orchestra
120 dB	Thunderclap, discotheque/boom box
110-125 dB	Stereo
110-140 dB	Rock concerts
130 dB	Jet takeoff, shotgun firing
145 dB	Boom cars

Sound Pressure Level (SPL)

$$I \propto P^2$$

Intensity level $= 10 \log \dfrac{I}{I_0}$ decibels (dB)

In acoustical problems, sound levels are generally dealt in terms of pressure rather than intensity. In fact, sound measuring devices respond to pressure exerted by sound. Equ.(11.5) shows that the sound intensity is proportional to the square of its pressure. Using equ.(11.5) into equ.(11.9), an expression for the SPL may be obtained as follows.

$$\text{SPL} = 10 \log \frac{I}{I_0} = 10 \log \left(\frac{P}{P_0} \right)^2 = 20 \log \frac{P}{P_0} \quad \text{decibels} \qquad (11.10)$$

The reference pressure P_0 is usually taken as $P_0 = 2 \times 10^{-5}$ N/m^2.

The SPL can be directly measured on a sound level meter.