Intensity of sound

OBJECTIVES

- Property named pitch and its relationship to frequency.
- Quality of sound and its relationship to the waveform.
- Loudness and its relationship to the amplitude.
- Relationship between the intensity of sound and the amplitude of sound wave.
- Threshold of hearing.
- Threshold of pain.
- Intensity levels of sound (decibel).
- Uses of ultrasonic waves.
- Uses of infrasonic waves.
- Applications of ultrasonic and infrasonic.

Characteristics of Sound

A sound can be characterized by the following three quantities:

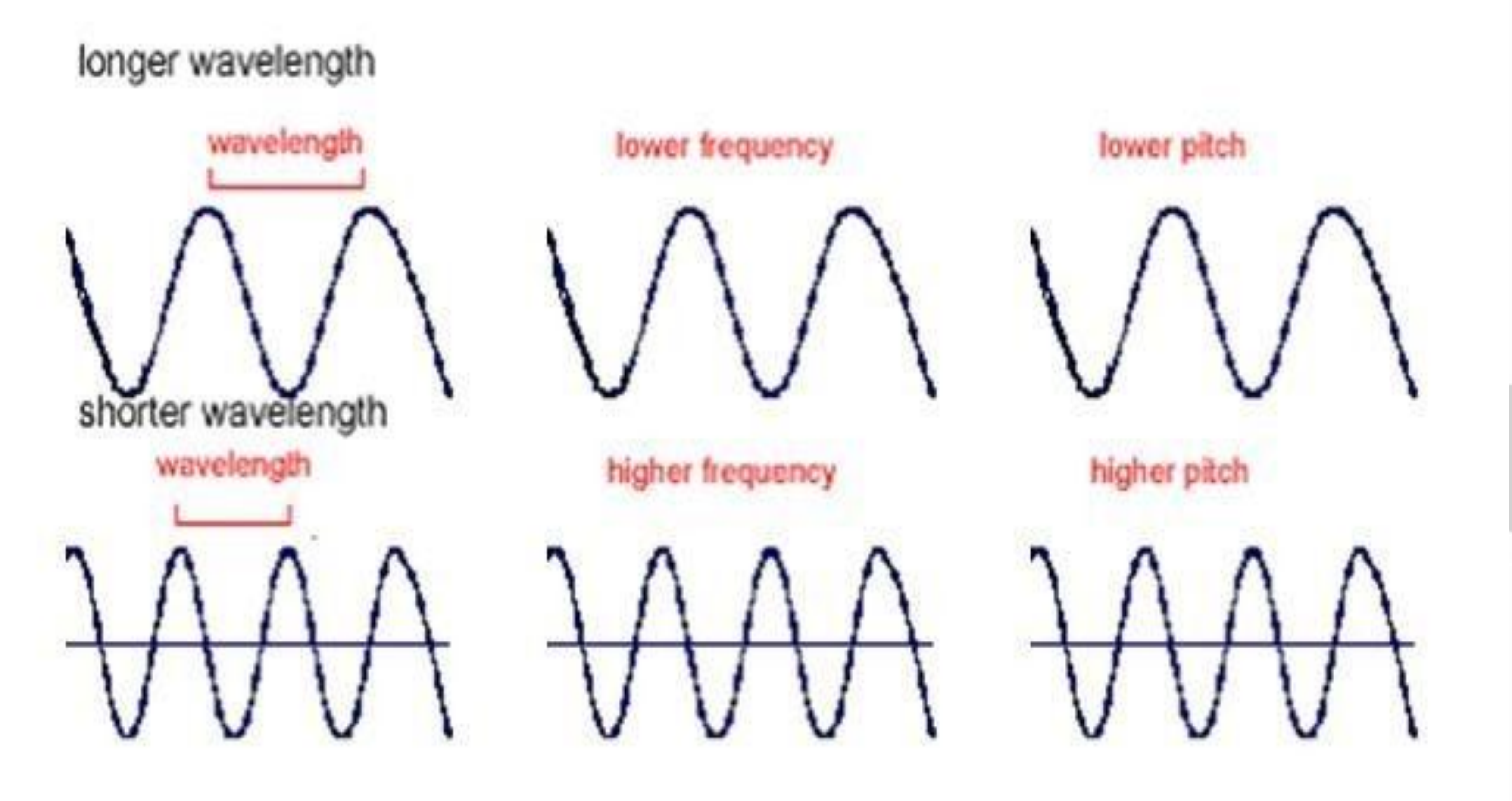
(i) Pitch.

(ii) Quality.

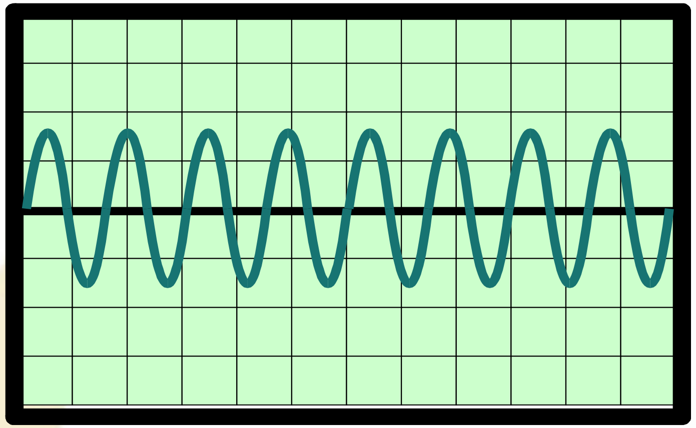
(iii) Loudness.

- What is the relationship between pitch and frequency?

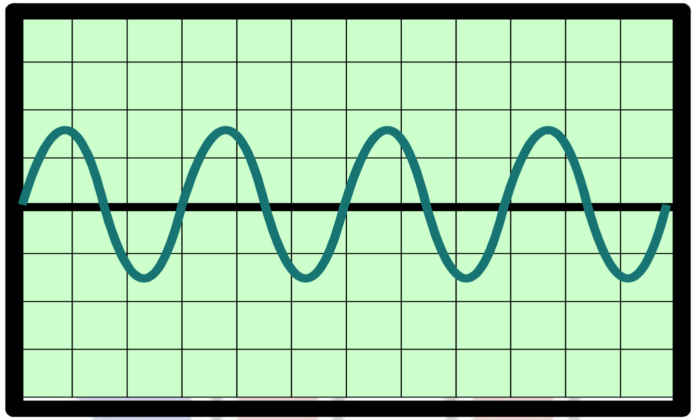
- Pitch is the frequency of a sound as perceived by human ear. A high frequency gives rise to a high pitch note and a low frequency produces a low pitch note.



Pitch (or frequency)



A high pitch sound



A low pitch sound.

The shorter the wavelength of the wave on the trace; the higher the frequency of the sound.

The more waves you can see, the higher the pitch/frequency.

The Origin of Sound

- Produced by the vibration of material objects

- <u>Pitch:</u> Our impression of the frequency of a sound

    - The greater the frequency of sound wave, the higher the pitch of sound wave produced

- Pitch is how high or how low a sound seems to be.

- High frequency means more vibrations hitting the ear.

- Healthy people hear pitches with frequencies ranging from 20 Hz to 20,000 Hz

Infrasonic: Sound waves with frequencies below 20 Hz

Ultrasonic: Sound waves with frequencies above 20,000 Hz

- We are most sensitive from 440 Hz to 7,000 Hz.

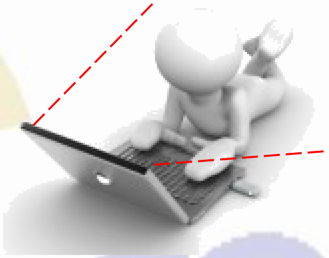
Ultrasound

Uses

1. Industrial cleaning – eg. of circuit boards and teeth.

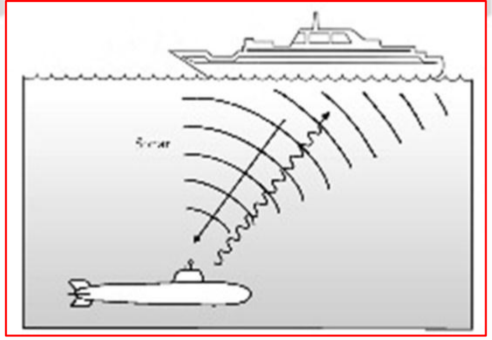
2. Breaking down kidney stones.

3. Industrial quality control.- eg. Detecting cracks in a metal.



Ultrasound is any sound above the range of human hearing (i.e. above 20,000Hz)

4. Pre-natal scanning of a foetus



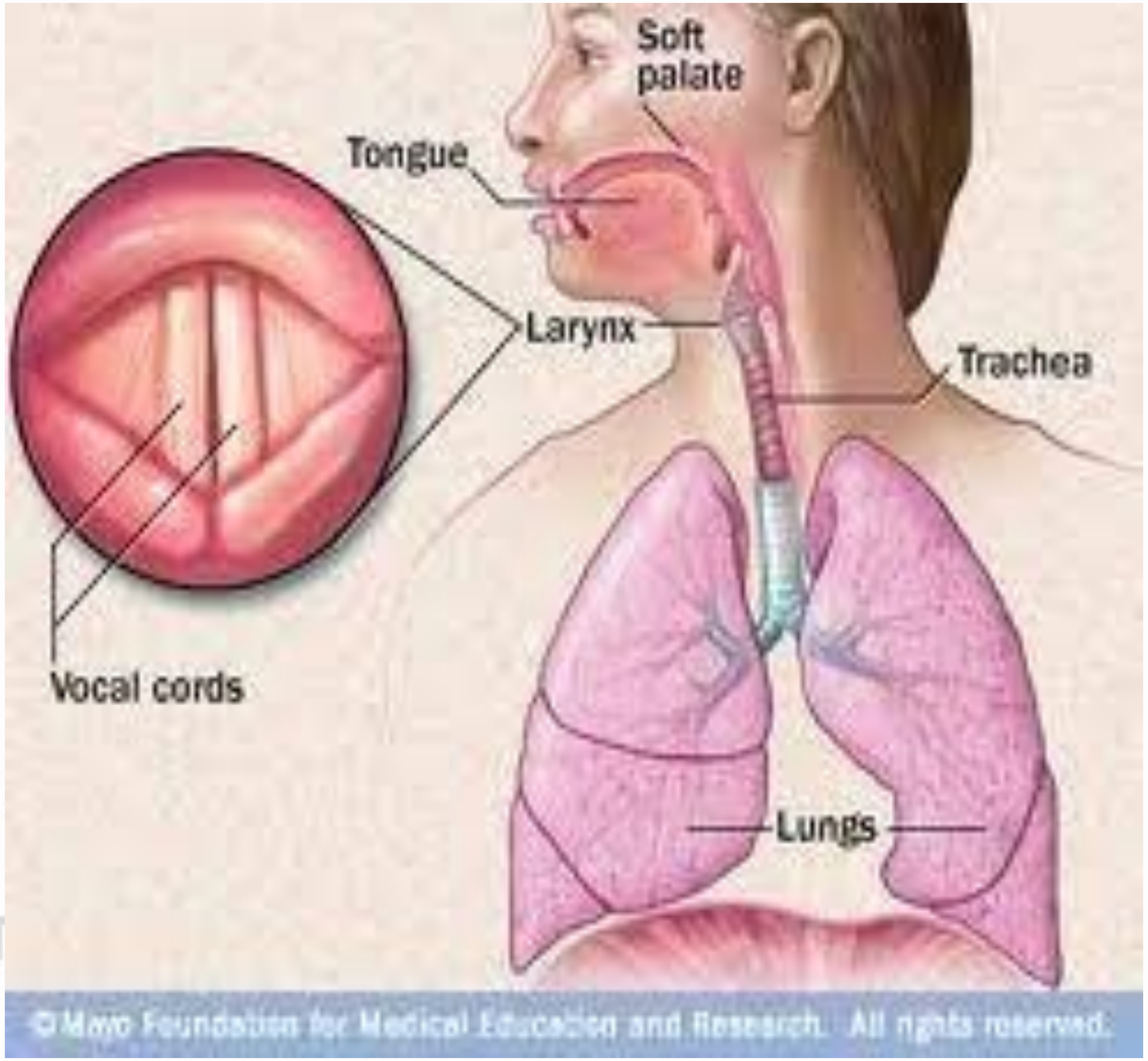
5. Range and direction finding - SONAR

Pitch

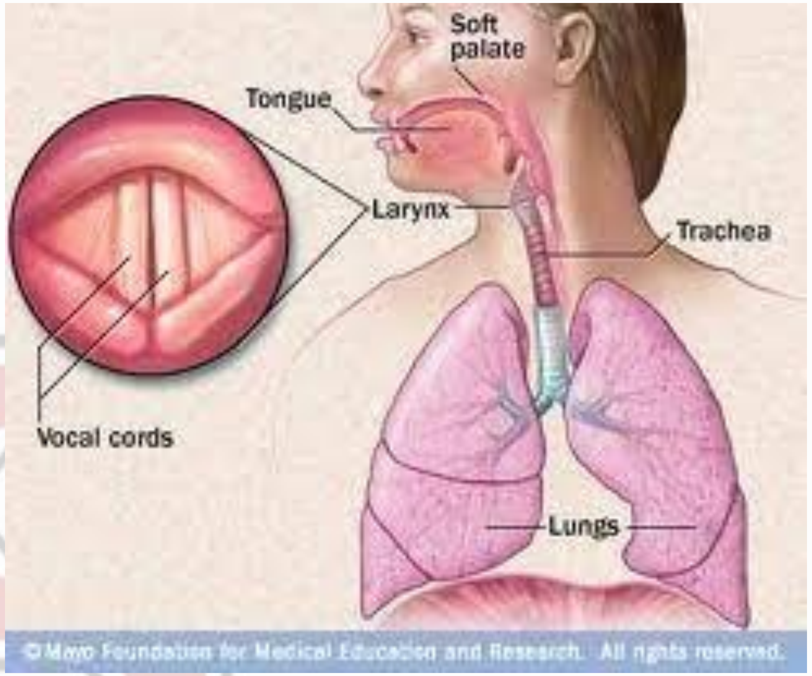
- Pitch is related mainly, although not completely, to the frequency of the sound
- Pitch is not a physical property of the sound
- Frequency is the stimulus and pitch is the response
  - It is a psychological reaction that allows humans to place the sound on a scale

Changing Pitch

A man’s vocal chords are normally longer and more massive than a female’s voice. Hence, a male’s voice is low pitched compared to the female’s voice.



- Lungs: Air From the lungs rushes up the trachea
- Vocal Cords: which are located in your voice box, or **larynx** vibrate as air rushes pass them
- Sound: Sound waves produced by the vibrating vocal cords come out through the mouth

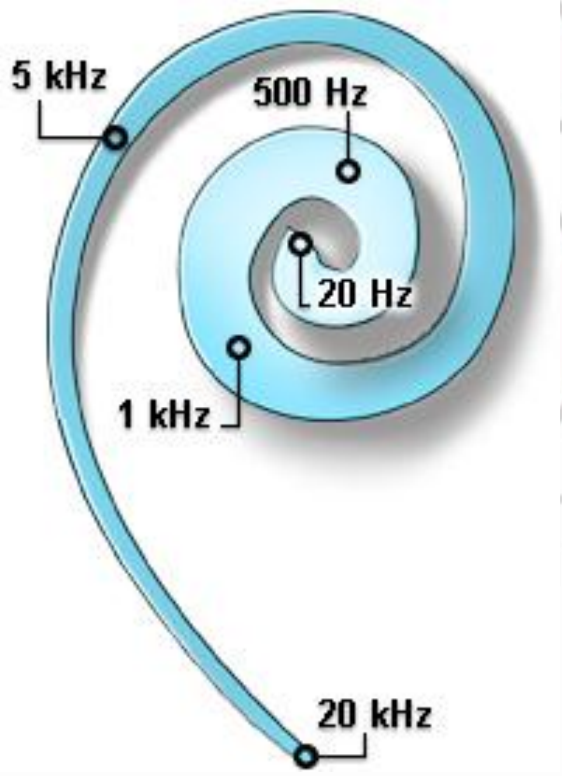


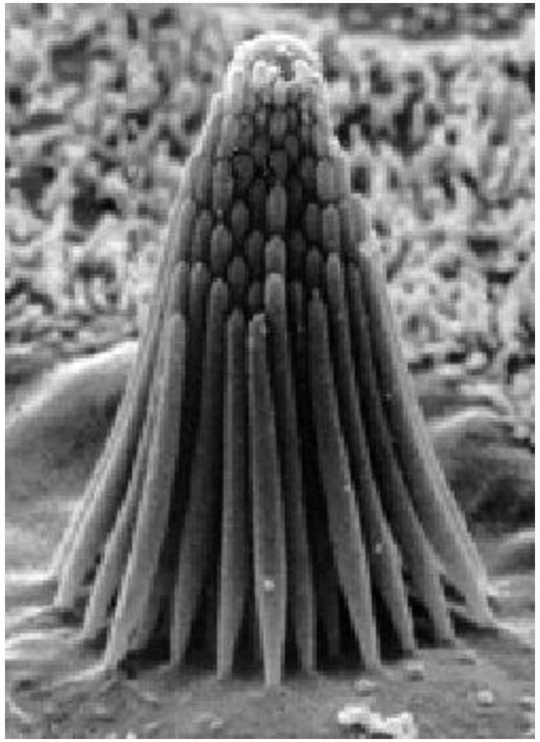
Sound Transmission

- Sounds can travel through solids, liquids, and gases
  - Sound travels faster and more efficiently through solids than liquids or gases
- The speed of sound is different in different materials
  - At room temperature (20^{o}C), the speed of sound is 340 m/s
- Sound <u>cannot</u> travel in a vacuum
  - No molecules to compress or expand

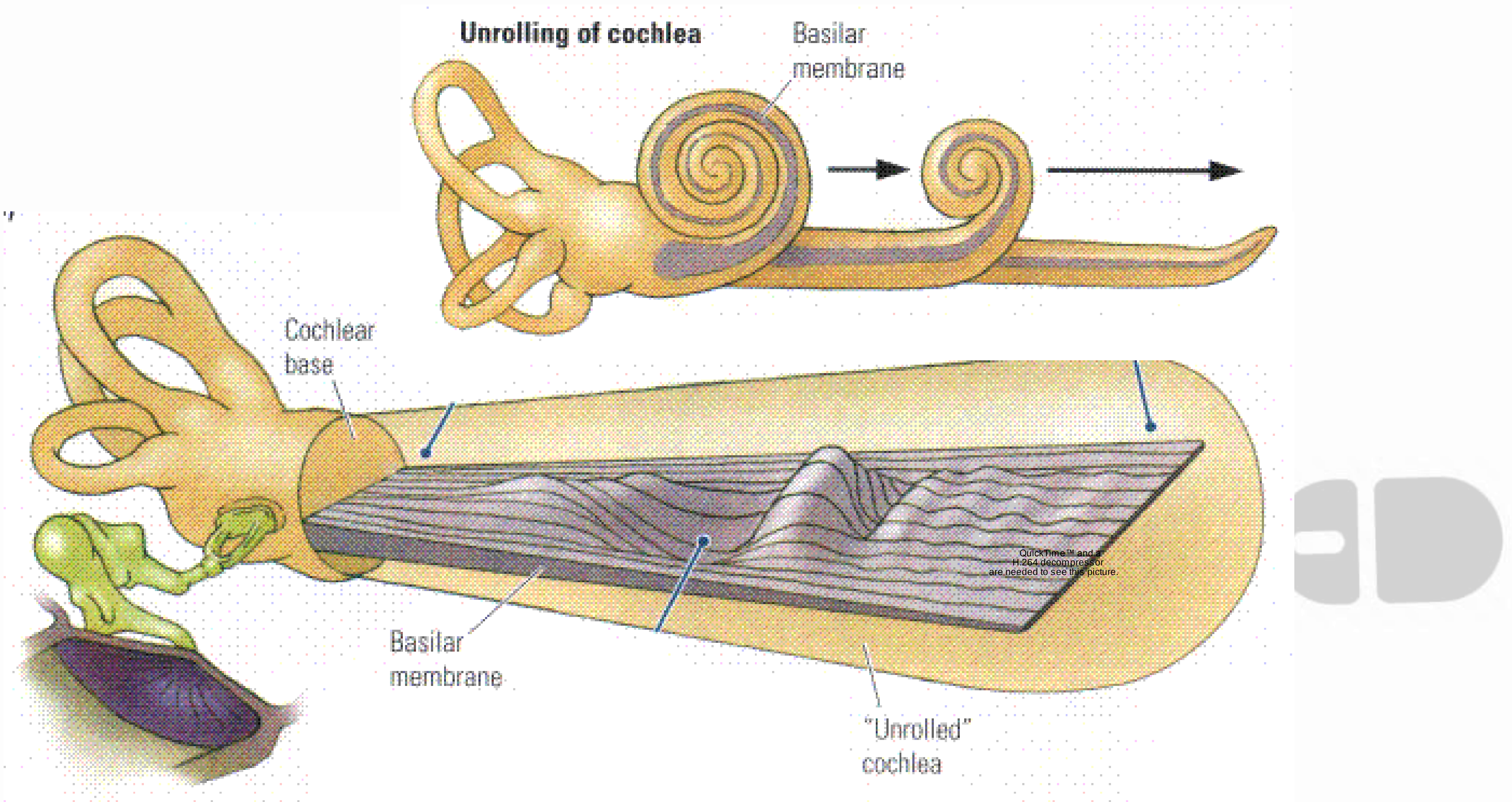
Discriminating pitch

- Your ear detects sound
- A mechanosensitive hair bundle in the cochlea of the ear. Each hair bundle is made up of 30-300 stereocilia (tiny hairs).
- Different locations host bundles that send different pitch signals.





Vibrations of the basilar membrane



The quality of sound -Timbre

QUALITY

- These difference in quality are due to the varying vibrations of the sound sources.
- In simple terms, timbre is what makes a particular musical sound different from another, even when they have the same pitch and loudness.
- For instance, it is the difference between a guitar and a piano playing the same note at the same loudness.

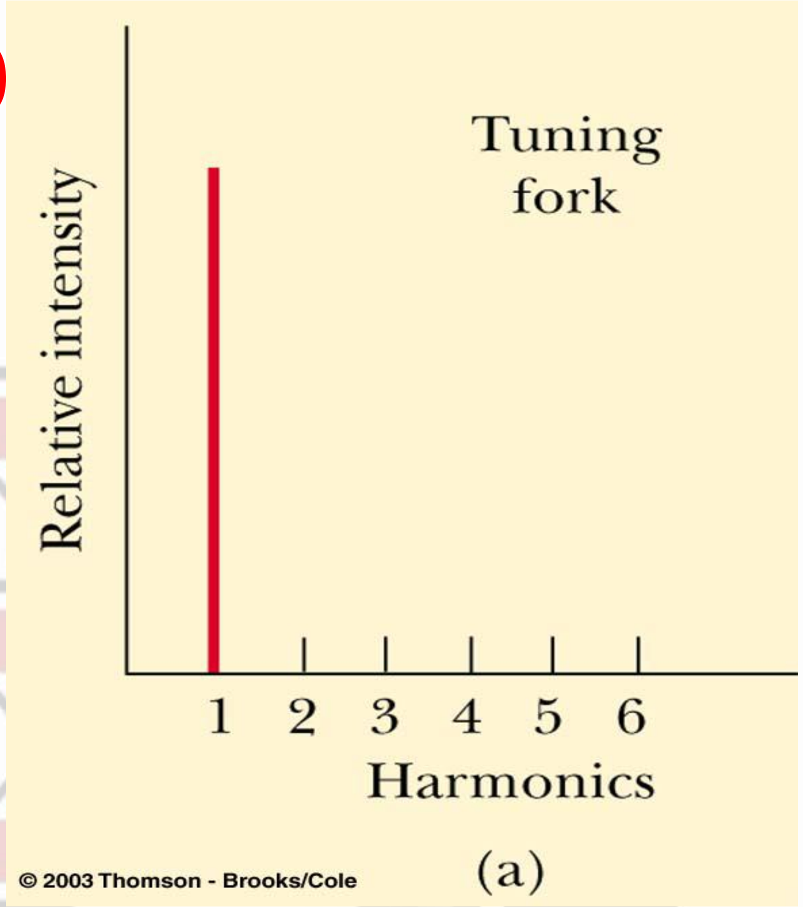
The quality of sound - Timbre

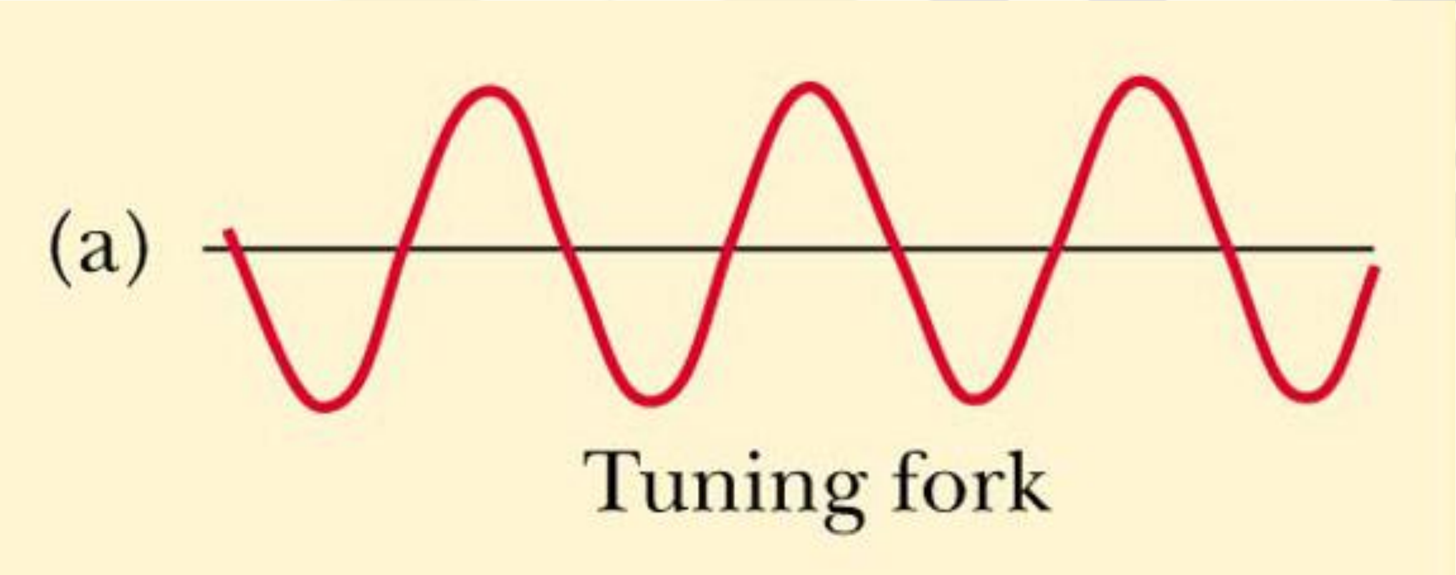
- In music, the characteristic sound of any instrument is referred to as the quality of sound, or the *timbre* of the sound.
- Not all sound is a pure tone. A pure tone is the sound of only one frequency, such as that given by a tuning fork or electronic signal generator.
- The fundamental note has the greatest amplitude and is heard predominantly because it has a larger intensity. The other frequencies such as 2fo, 3fo, 4fo, ... are called overtones or harmonics and they determine the quality of the sound.

- The quality depends on the mixture of ‘harmonics’ in the sound.
- This is a mixture of other frequencies with the original.
- Can completely describe the sound by only including overtones

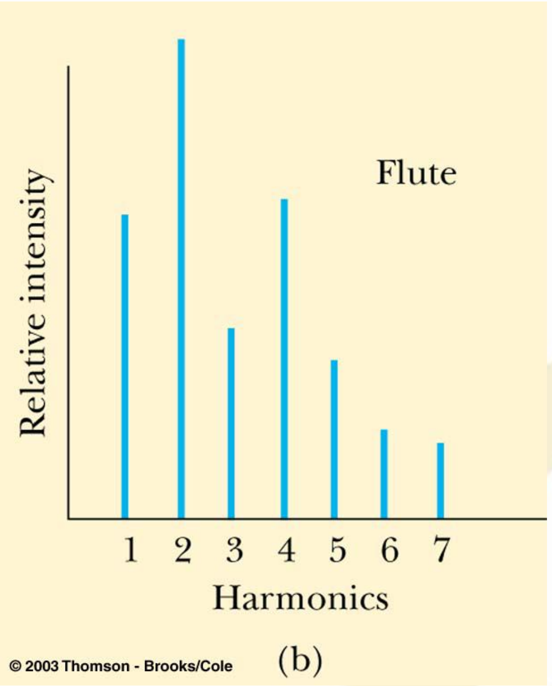
Quality of Sound – Tuning Fo

- Tuning fork produces only the fundamental frequency

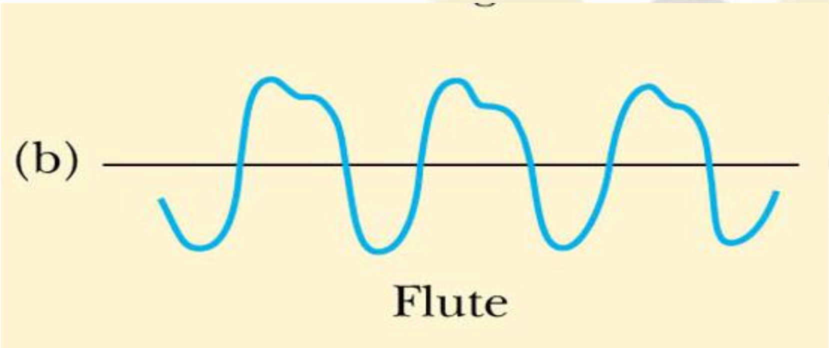




Quality of Sound – Flute



- The same note played on a flute sounds differently
- Not a pure tone



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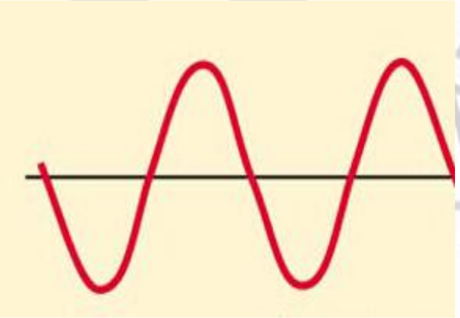

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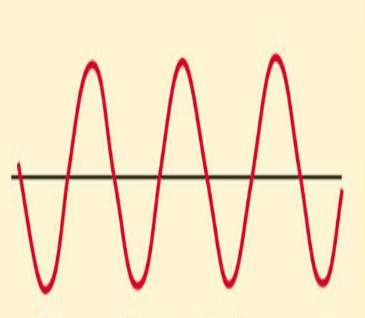

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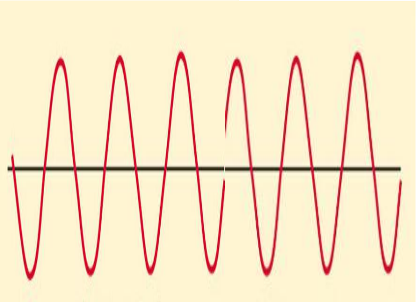


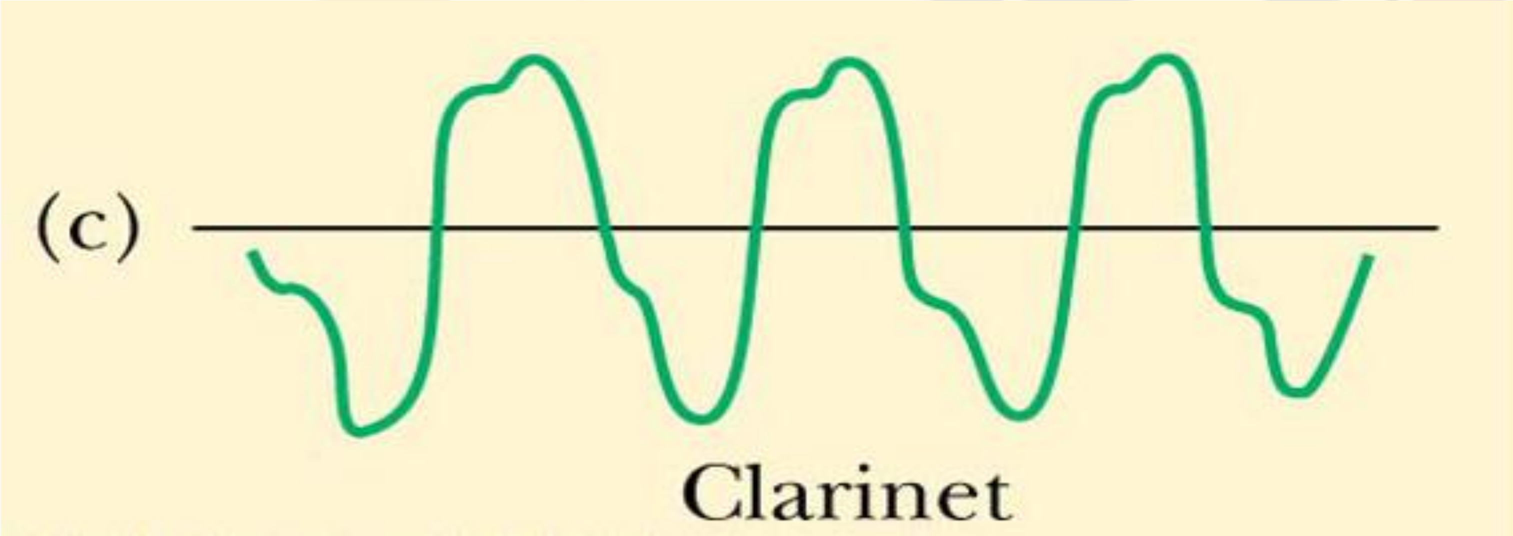
Fundamental, Freq. f

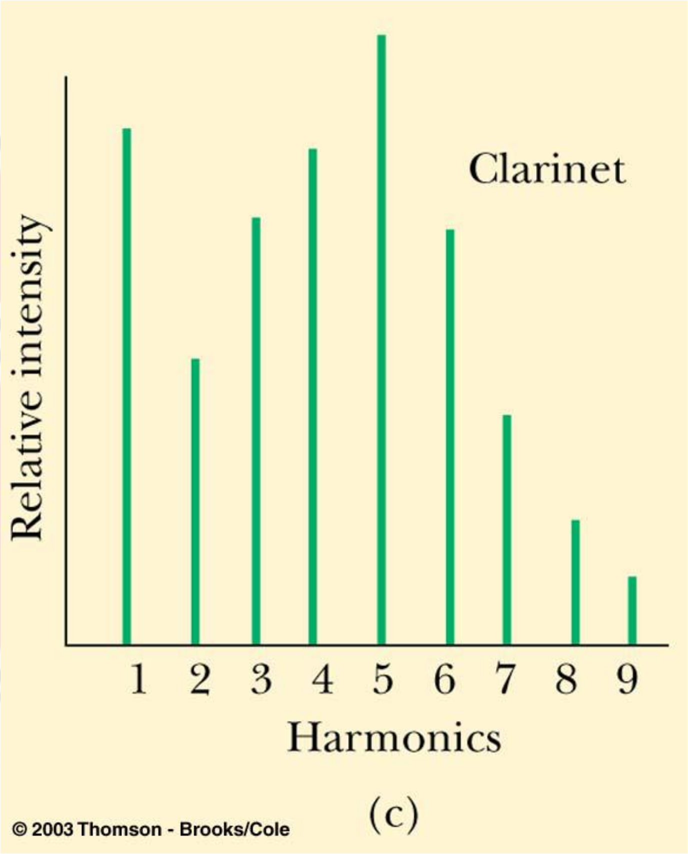
1st harmonic, Freq. 2f

2nd harmonic Freq. 3f

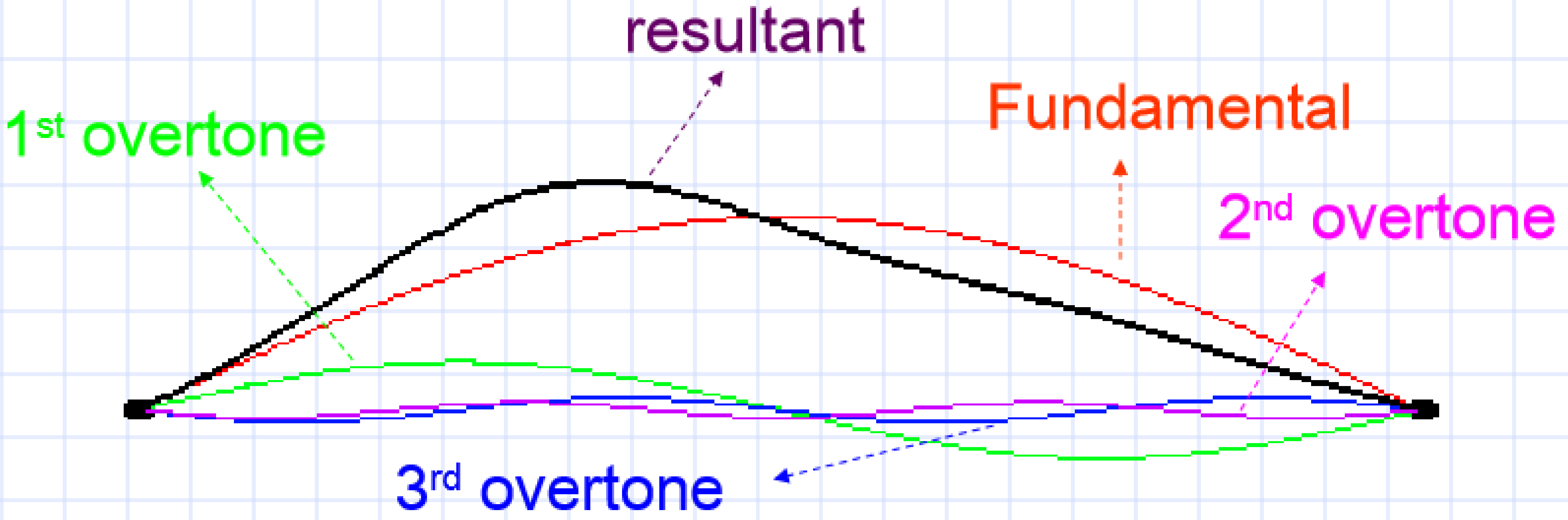
Quality of Sound – Clarinet

- The fifth harmonic is very strong
- The first and fourth harmonics are very similar, with the third being close to them

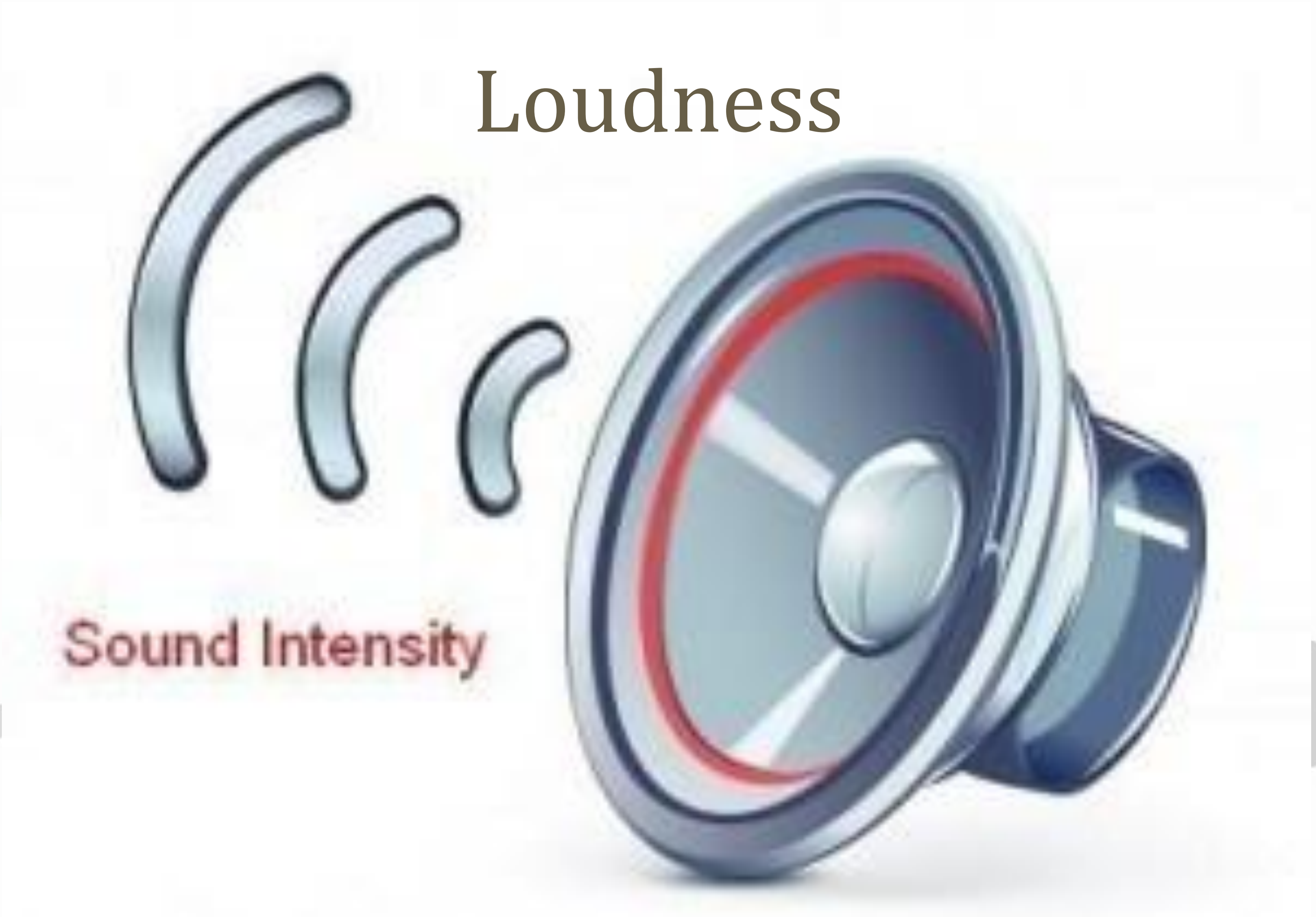




- The quality of sound is determined by the following factors:
  - The particular harmonics present in addition to the fundamental vibration,
  - The relative amplitude of each harmonic,
  - The transient sounds produced when the vibration is started.



Loudness



- Loudness is how our brain senses the sound.
  It describes the human perception of sound.

- Loudness of sound largely depends on the intensity of sound.
- A sound wave of higher Intensity is perceived as louder than a wave of lower intensity.

Intensity

- The amount of energy a sound wave carries per second through a unit area is its Intensity

- When you move away from the sound source, loudness decreases, because the intensity decreases.
- Loudness is measured using the unit called the Bel (B) in honor of Alexander Graham Bell. A bel is a rather large unit; the smaller unit is decibel (dB) is often used instead. ***1B = 10dB***
- Loudness and amplitude of sound is directly proportional to each other.
- The greater the amplitude (A), louder the sound produced
- (The greater the amplitude of the sound wave that reaches your eardrum, the greater the perceived loudness of the sound.) A can be measured by instruments such as an <u>oscilloscope.</u>

- The degree of loudness or faintness of a sound depends upon the different factors

1. Amount of energy of a sound
2. Distance from the source of sound
3. The state of the medium through which the sound is transmitted
4. The amount of the original vibrations
5. The frequency of the vibration
6. Area to which the sound is produced

Energy of a Sound Source

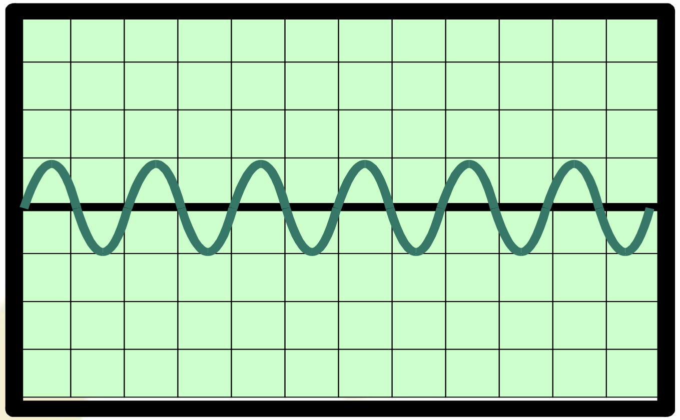
The greater the energy used to make a sound, the louder the sound

Example: Playing a guitar

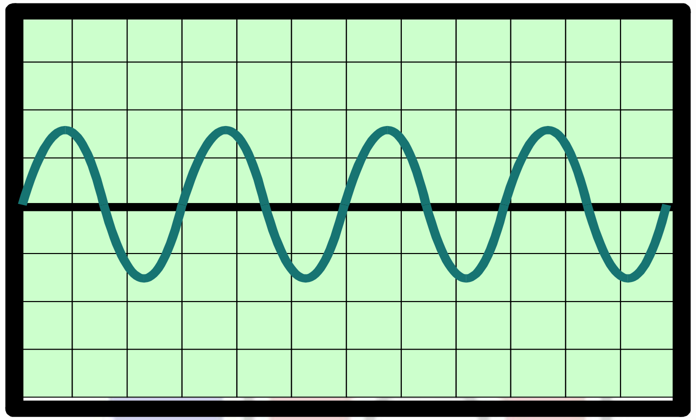
- When you use more energy to pull the strings of the guitar the louder the noise produced by the guitar is.

The more energy you use, the larger the amplitude
The larger the amplitude produces a louder sound.

Loudness



A quiet sound



A loud sound

The larger the amplitude of the wave on the trace; the louder the sound.

The bigger the waves you can see, the louder the sound.

Source of Sound	Intensity level in dB	Intensity I (W/m2)
Threshold of hearing	O	1×10^{-12}
Rustle of Leaves	10	3.2×10^{-11}
Whisper	20	1×10^{-10}
Ordinary conversation	65	3.2×10^{-6}
Busy street traffic	70	1×10^{-5}
Auto interior moving at 90 kph	75	2.8×10^{-4}
Loud indoor rock concert	100	1×10^{-2}
Threshold of pain	120	1×10^{1}

Source of Sound	Level (dB)
Normal Breathing	10
Close Whisper	20
Library	40
Normal Speech	60
Busy Street Traffic	70
Subway Train	100
Loud Rock Music	115
Threshold of Pain	120
Jet Engine at 30 m	140

120 dB: The F/A-18 Hornet

As the tines of a tuning fork move back and forth through the air, they exert a force on a layer of air and cause i to move. In other words, the tines do work on the layer of air.

We define the **intensity, I,** of a wave to be the rate at which energy flows through a unit area, A, perpendicularly to the direction of travel of the wave.

$$I = \frac{1}{A}\frac{\Delta E}{\Delta t}$$

It can be written in an alternative form

$$I = \frac{\text{power}}{\text{area}} = \frac{P}{A}$$

where P is the sound power passing through A. The intensity has units of watts per square meter.

The fintest sounds the human ear can detect at a frequency of 1000 Hz have intensity of about 10^{-12} W/m^2. This intensity is called the **threshold of hearing**. The laudest sounds the ear can tolerate have an intensity of about 1 W/m^2, which is called the **threshold of pain**.

Sound Intensity (E≈I≈A^2)

- Sound intensity is the sound power as it passes through a given area
- $I = P$ / Area… (W/m^2)
- So... $I = P / 4\Pi r^2$… for a sphere

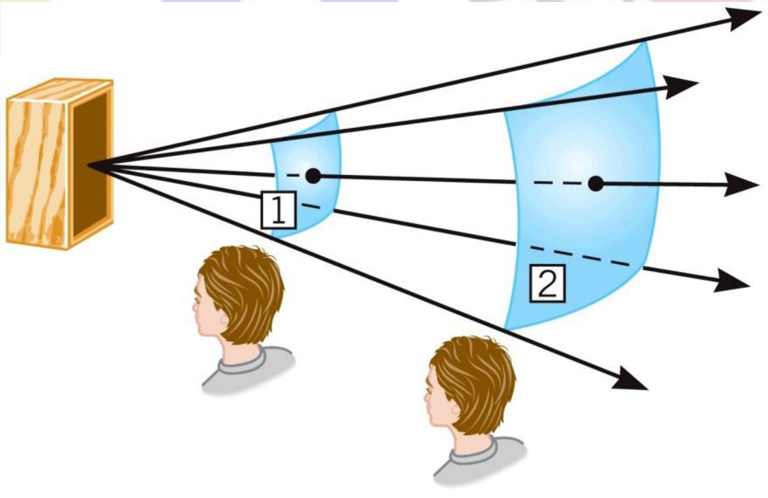


Figure 16.21

The human ear can detect a wide range of intensities, with the loudest tolerable sounds having intensities about 10^{12} times greater than those of the faintest detectable sounds. However, the most intense sound is not perceived as being 10^{12} times louder than the faintest sound.

The relative intensity of a sound is called the **intensity level, β,** and is defined as

$$\beta = 10 \log \left(\frac{I}{I_0} \right)$$

where $I_0 = 10^{-12}\ \mathrm{W/m^2}$ is the reference intensity, and I is any intensity. β is measured in decibels (dB).

On this scale, the threshold of pain corresponds to an intensity level of $\beta = 120$ dB. Nearby jet airplanes can create intensity levels of 150 dB. The electronically amplified sound heard at rock concerts can be at levels of up to 120 dB, the threshold of pain. Recent evidence suggests that noice pollution may be contributing factor to high blood pressure, anxiety, and nervousness.

The unit of the sound level is “decibels” (*dB*).

A sound of intensity I_0 has a Intensity level of 0 *dB*.

The sound at the upper range of human hearing, called the threshold of pain has an intensity of $1 w/m^2$ and a Intensity level of 120 dB.

Qn Spherical sound waves are emitted uniformly in all directions from a point source, the radiated power P being 25 w. What are the intensity and the sound level of the sound wave at a distance r=2.5m from the source?

Solution:

$$I = \frac{P}{4\pi r^2} = \frac{25w}{4\pi(2.5m)^2} = 0.32w/m^2$$

$$SL = 10\log\frac{I}{I_0} = 10\log\frac{0.32w/m^2}{10^{-12}w/m^2} = 115dB$$

- Determine the intensity level of a sound wave with an intensity of $5 \cdot 10^{-7}\ \mathrm{W/m^2}$.

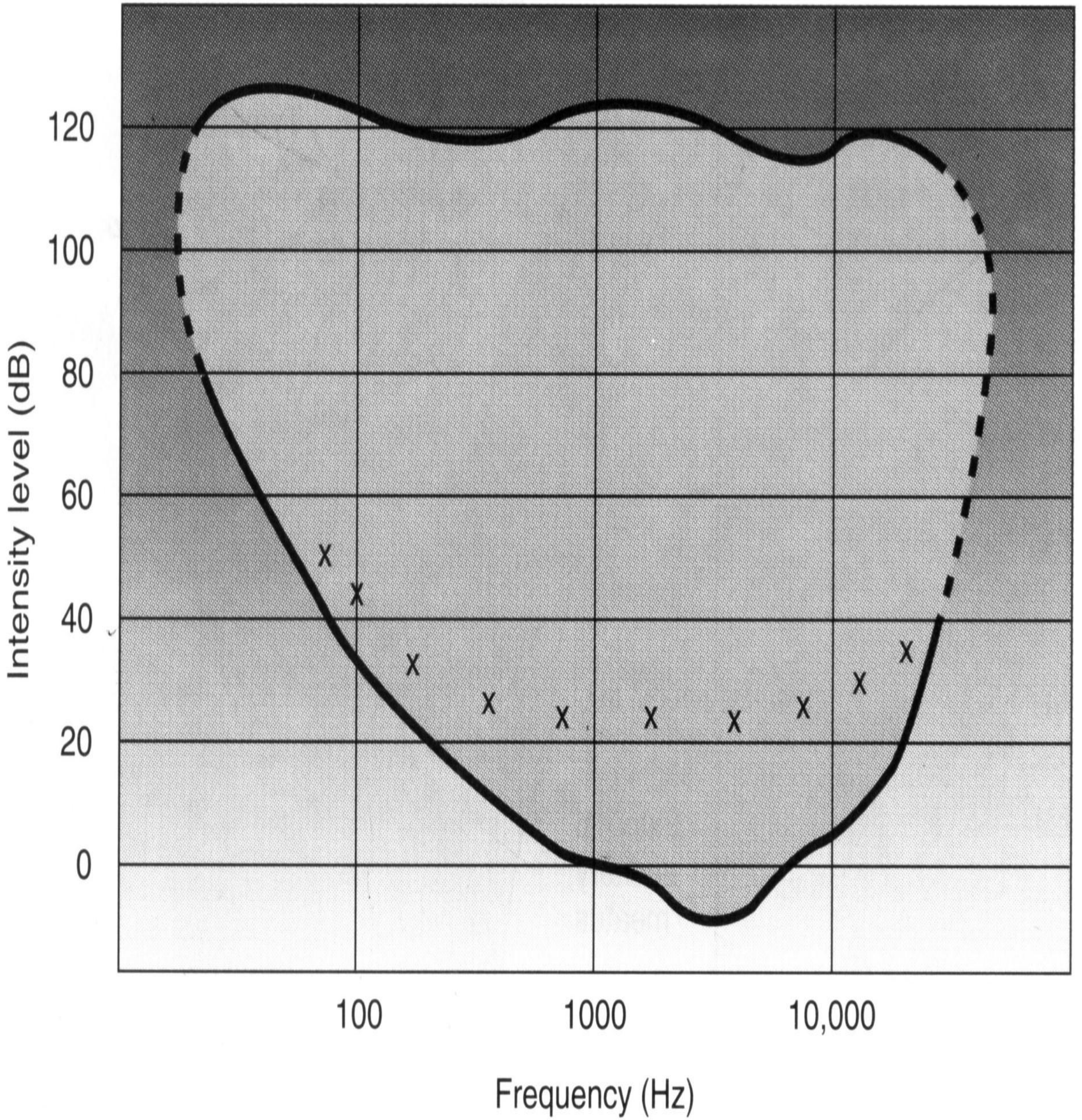
$$\begin{aligned}\beta &= 10\log\left(\frac{I}{I_0}\right)\\ &= 10\log\left(\frac{5\cdot 10^{-7}\ \mathrm{W/m^2}}{10^{-12}\ \mathrm{W/m^2}}\right) = 57\ \mathrm{dB}\end{aligned}$$

- A noise grinding machine in a factory produces a sound intensity of $1 \cdot 10^{-5}\ \mathrm{W/m^2}$. Find the intensity level of this machine, and calculate the new intensity level when a second, identical machine is added to the factory.

$$\begin{aligned}\beta_1 &= 10\log\left(\frac{I}{I_0}\right) = 10\log\left(\frac{1\cdot 10^{-5}\ \mathrm{W/m^2}}{10^{-12}\ \mathrm{W/m^2}}\right) = 70\ \mathrm{dB}\\ \beta_2 &= 10\log\left(\frac{2I}{I_0}\right) = 10\log\left(\frac{2\cdot 10^{-5}\ \mathrm{W/m^2}}{10^{-12}\ \mathrm{W/m^2}}\right) = 73\ \mathrm{dB}\end{aligned}$$

- The human ear is responsive to a large range of frequencies and intensities. A typical response curve is shown in Figure . The intensity level of sound is plotted against the frequency of the sound. The continuous curved line at the bottom represents the response curve of a normal ear. The lowest region on the curve occurs from about 1000 Hz to about 4000 Hz. These frequencies can be heard by the normal ear at very low intensity level. On the other hand, to hear a frequency of 100 Hz the intensity level would have to be increased to about 35 dB. And for a normal ear to hear a frequency of about 20,000 Hz the intensity level would have to be increased to about 40 dB. At an intensity of 20 dB a frequency of 1000 Hz can easily be heard, but a frequency of 100 Hz could not be heard at all.

Graph of intensity level of sound versus the frequency of the sound for a human ear.



- With age the frequencies that the human ear can hear decreases. Many people resort to a hearing aid to overcome this hearing deficiency? A test is made of the person's ability to hear a sound of known intensity level and frequency. The person is placed in a soundproof booth and earphones are placed over his or her ears. The examiner then plays pure sounds at a known frequency. He or she starts at a low intensity level and increases the intensity in small steps until the individual hears that particular frequency

- . When the individual hears the sound, he or she presses a button to let the examiner know that he or she has heard the sound. The examiner then marks an x on the graph of the frequency and intensity level of the normal ear shown in the figure. The x’s represent the actual frequencies heard at a particular intensity level. By knowing the frequencies that the person can no longer hear very well, a hearing aid, which is essentially a miniature electronic amplifier, is designed to amplify those frequencies, and thus bring the sound of that frequency up to a normal intensity level for that individual.

- For example the x’s in the figure indicate that the individual’s hearing response has deteriorated. In particular, the hearing response in the midrange frequency is much worse than at the low end or the high end of the spectrum. (The x’s in the midrange are farther away from the normal curve). Thus a hearing aid that amplifies the frequencies in the middle range of the audio spectrum would be useful for the individual. We would certainly not want to amplify the entire audio spectrum,
- for then we would be amplifying some of the frequencies that the person already hears reasonably well.

- It is interesting to note that not only humans use sounds to communicate but animals do also. Some animals communicate at a higher frequency than can be heard by humans. These sounds are called ultrasonic and occur at frequencies above 20,000 Hz. Birds and dogs can hear these ultrasounds and bats even use them for navigation in a kind of sound radar. Ultrasound is used in sonar systems to detect submarines. It is also used in a variety of medical applications, including diagnosis and treatment. For example, chiropractors and physical therapists routinely use ultrasound for relief of lower back pain.

Frequency Response Curves

- Bottom curve is the threshold of hearing
    - Threshold of hearing is strongly dependent on frequency
    - Easiest frequency to hear is about 3000 Hz
- When the sound is loud (top curve, threshold of pain) all frequencies can be heard equally well

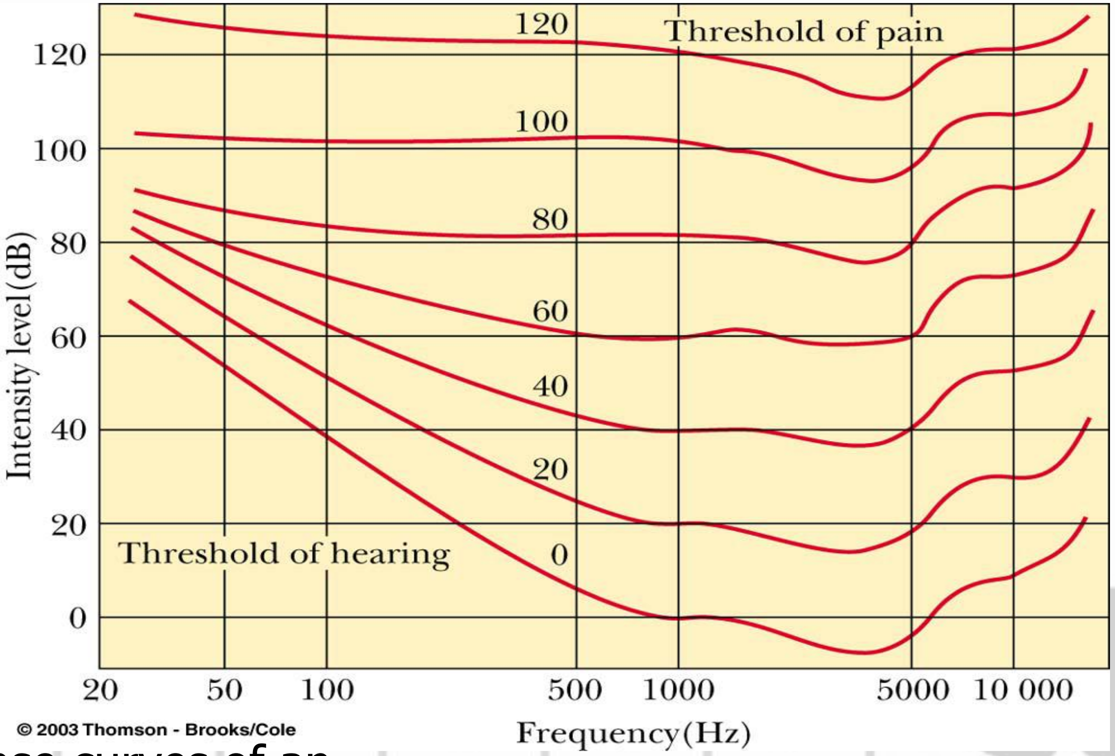


Figure shows the frequency response curves of an average human ear for sounds of equal loudness, ranging from 0 to 120 dB. To interpret this series of graphs, take the bottom curve as the threshold of hearing. The easiest frequencies to hear are around 3300 Hz.