Physics of the Ear and Hearing

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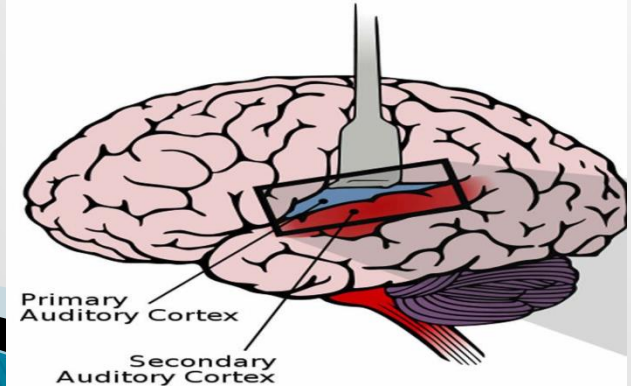
Physics of the Ear and Hearing

- **Speech and hearing are the most important means by which we communicate with our friends.**
- **The sense of hearing is in some ways more remarkable than the sense of vision.**
- **The ear can hear a range of sound intensities of over a 100 times grater than the range of light intensities the eye can handle or detected.**
- **The ear, also, can hear frequencies that vary by a factor of 1000, while the frequencies of light that the eye can detected vary by only a factor of 2**

The Sense of Hearing

The sense of hearing involves:

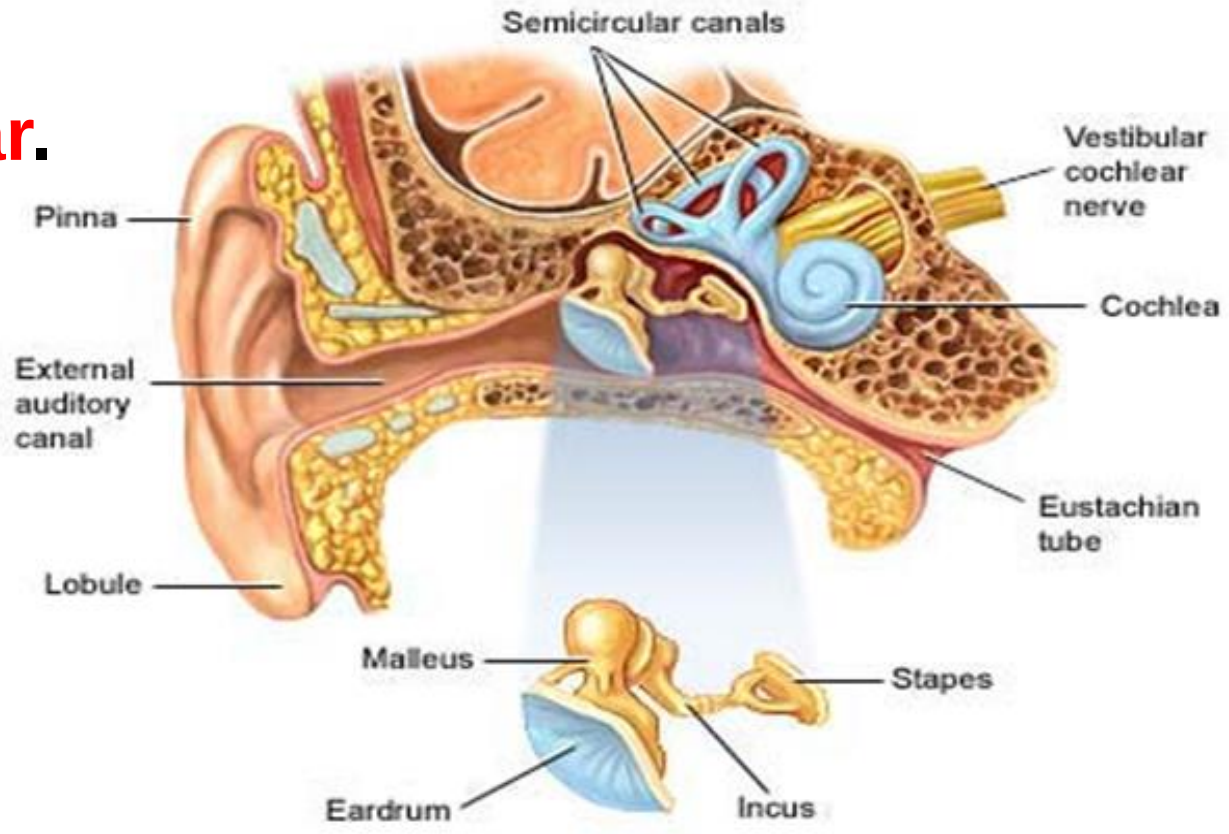
1. **The mechanical system that stimulates the hair cells in the cochlea**
2. **The sensors that produce the action potentials in the auditory nerves**
3. **The auditory cortex, the part of the brain that decodes and interprets the signals from the auditory nerves.**



The Sense of Hearing

- **The ear is cleverly designed converter of very weak mechanical waves in air into electrical pulses in the auditory nerve.**
- **The ear is usually divided into three areas :**

1) **The outer ear.**
2) **The middle ear.**
3) **The inner ear.**



1) The Outer Ear

The outer ear consists of the pinna and ear canal which terminates at the eardrum "tympanic membrane"(See Fig.)

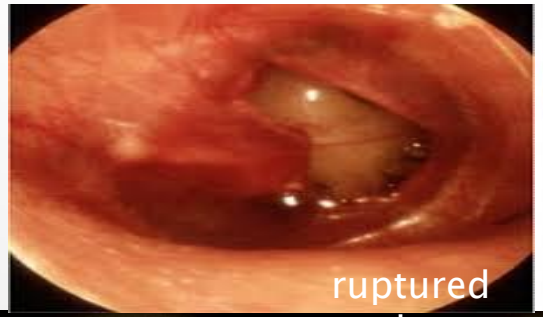
- **It is being a storage place for ear wax.**
- **The canal is about L=2.5 cm long and the diameter of a pencil.**
- **It is like an organ pipe closed at one end.**

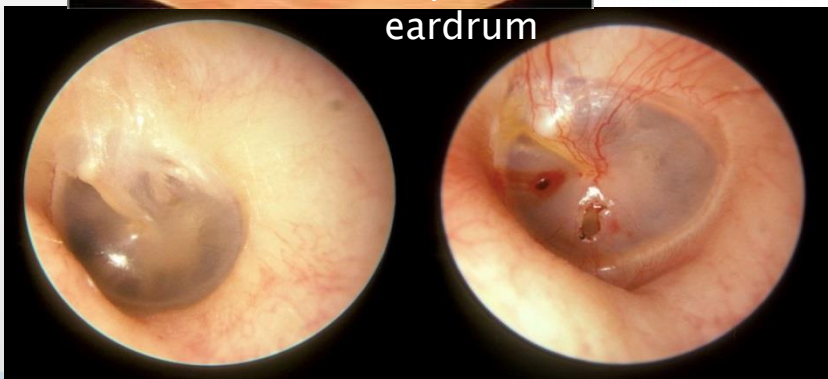
L= λ /4 , λ=4L , v = λf

v = 4L*f, f=v/4L this is the resonant frequency of about 3300Hz ,v= 330 m/s ⟶ (λ =10 cm). It s increase the ear s sensitivity in the region of 3000 to 4000 Hz .

The Eardrum

- It's called " tympanic membrane“ .
- It's about 0.1mm thick (paper thin).
- Has an area of about 65 mm^2.
- It couples the vibration in the air to the small bones in the middle ear.
- The actual movement of the eardrum is very small since it must be less than the movement of the air molecules in the sound wave.
- Sound pressure **above 160dB** rupture the eardrum
- A **ruptured eardrum** normally heals just as other living tissue does(see Fig.).

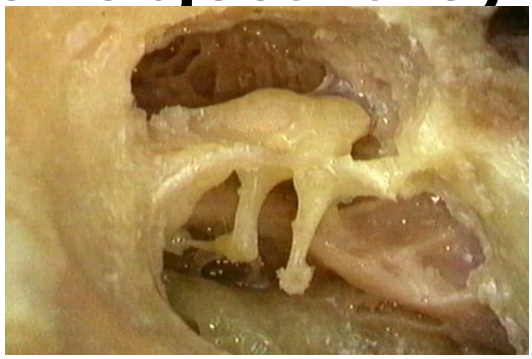




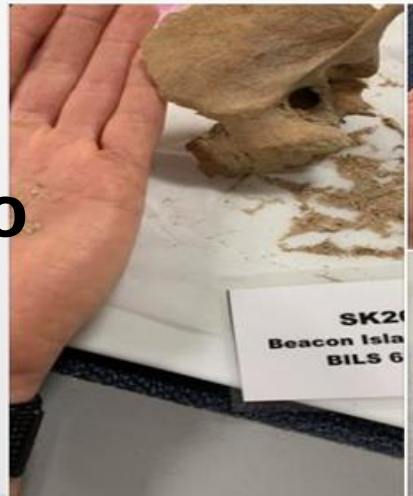
2) The Middle Ear

- The dominant features of the middle ear are the three small bones (ossicles) as shown in Fig.
- The ossicles are named after the object they resemble;

a) Malleus (hammer).
b) Incus (anvil).
c) Stapes (stirrup).



- The ossicles play an important role in matching the impedance of the sound waves at the eardrum to the liquid- filled chambers
- of the inner ear.
- They are arranged in a way to transmit vibrations from the eardrum to the inner ear.



The Middle Ear

- They amplify the pressure of the sound waves at the entrance to the inner ear by : lever action and piston action.
- The lever action of the ossicles is such that the motion of the plate of the stapes at the oval window of the inner ear is about 0.7 that of the malleus at the eardrum.
- The lever action amplifies the force by factor of 1.3 (lever gain)
- A much larger gain pressure is obtained by the piston action (see Fig)

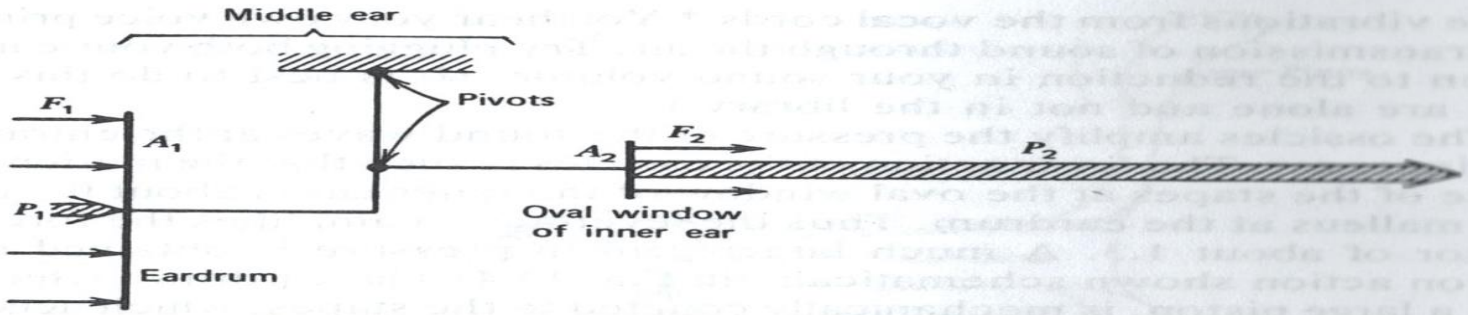


Figure 13.4. A schematic representation of the lever and piston action of the ear. The lever action of the ossicles increases the force by 30%. The ratio of the areas of the large eardrum and small oval window (A_1/A_2) increases the pressure by a factor of 15. These factors produce a pressure P_2 at the oval window that is about 20 times higher than the sound pressure P_1 at the eardrum.

The Middle Ear

- The eardrum acts like large piston is mechanically coupled to the stapes which acts like small piston at the entrance of the inner ear.
- The ratio of the area of large eardrum to that of small stapes (A_1/A_2)about 15 to 1.

$$A_1/A_2 = 65mm^2/4.3\ mm^2 = 15$$

- So total gain = lever gain X pressure (piston)gain. results in about (1.3X15)= 20 times.
- So the middle ear amplify the pressure of sound waves by 20 times.
- When a sound wave encounters a very different medium, most of the sound energy is reflected, that means, there is sound loss.
- The ear is designed to reduce this loss in sound energy by impedance matching.

The Middle Ear

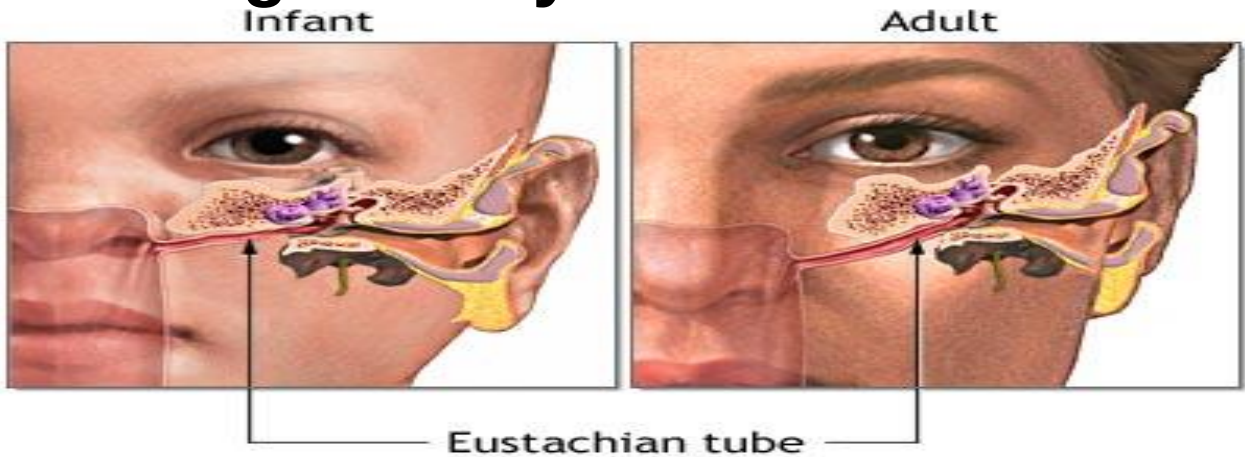
- **In the ear, the factors that affect the impedance are primarily the springiness of the eardrum and its mass.**
- **The impedance in the ear is fairly well matched from about 400 to 4000Hz, below 400 Hz the spring is too stiff and above 4000 Hz the mass of the eardrum is too great.**
- **The middle ear aids the impedance match by amplifying the pressure by the lever and piston action described before.**

The Middle Ear

- The ossicles and their sensory ligaments play an important role in protecting the ear against loud sounds.
- Aloud sound causes the muscles in the middle ear to pull sideways on the ossicles and reduce the sound intensity reaching the inner ear.
- Persons living or working in an environment of loud sounds permanently lose some of their hearing sensitivity.
- Noise pollution can result in permanent physiological damage to the hearing mechanism.

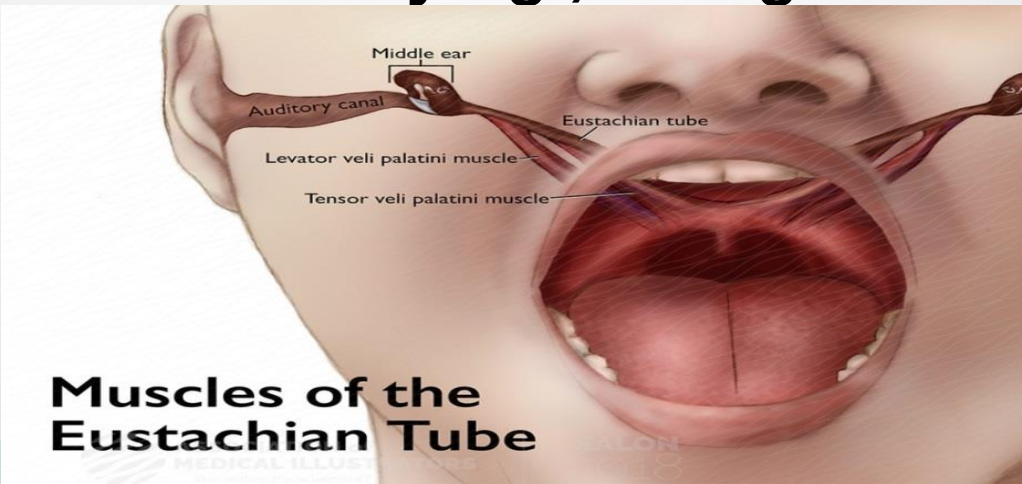
The Middle Ear

- Another structure in the middle ear plays a protective role –**the Eustachian tube**.
- The Eustachian tube is **normally closed** rather are open.
- The middle ear contains air, and it is important for the air pressures on both sides of the thin eardrum to be essentially the same, the Eustachian tube equalize this pressure.
- Air in the middle ear is gradually absorbed in to the tissues, lowering the pressure on the inner side of eardrum.



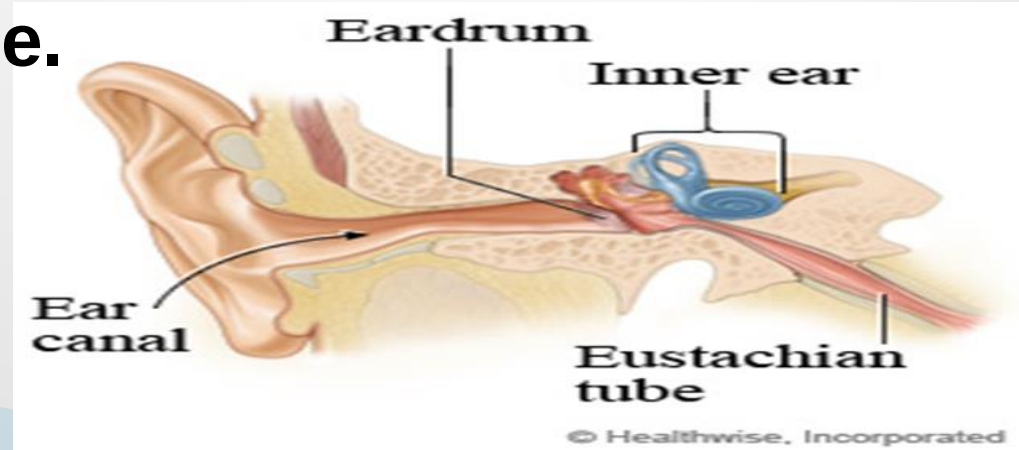
The Middle Ear

- **The movement of the muscles in the face during Swallowing, Yawning or Chewing, will usually cause a momentary opening of the Eustachian tube ,that equalizes the pressure in the middle ear with the atmospheric pressure.**
- **Pressure differences are usually noticed in situation in which the outside pressure changes rapidly in a short period of time, such as when flying , riding.**



The Middle Ear

- When for some reason the Eustachian tube does not open, the resulting pressure difference deflects the eardrum inward and decreases the sensitivity of the ear,
- At about 60 mmHg across the eardrum, the pressure difference causes pain.
- Common reasons for the failure of this equalizing system are the blockage of the Eustachian tube by the viscous fluid and swelling of tissues around the entrance to the tube.

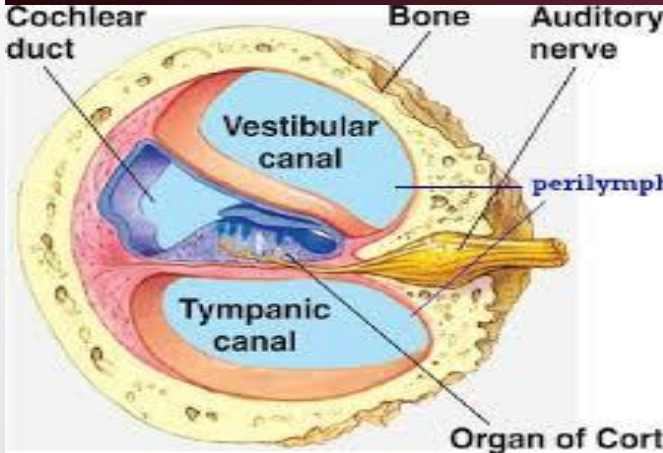


The Inner Ear

- **The inner ear is hidden deep within the hard bone of the skull (best protected sense organ).**
- **The inner ear consist of :**

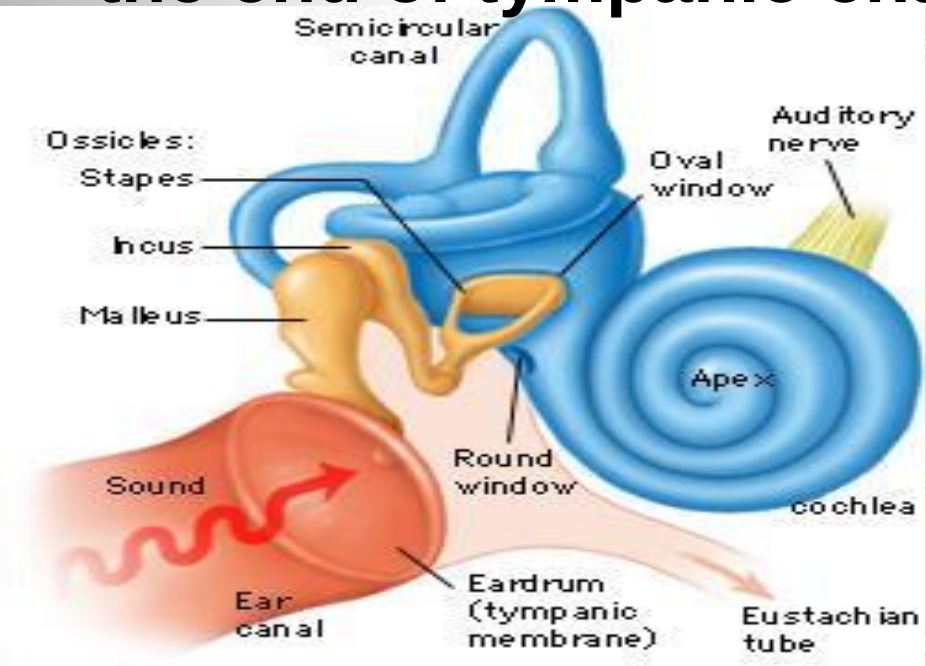
Cochlea ;is about the size of the tip of the little finger(3 cm length). It is divided into three small fluid –filled chambers that run its full length.

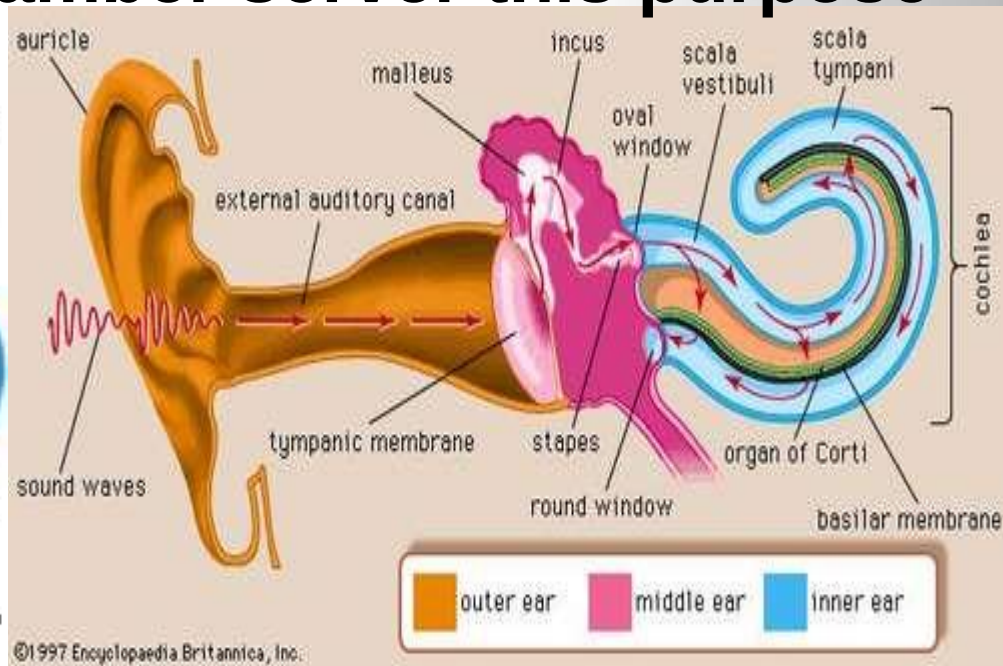
i. **The vestibular chamber.**
ii. **The middle chamber is the cochlear duct.**
iii. **The tympanic chamber, see fig.**



The Inner Ear

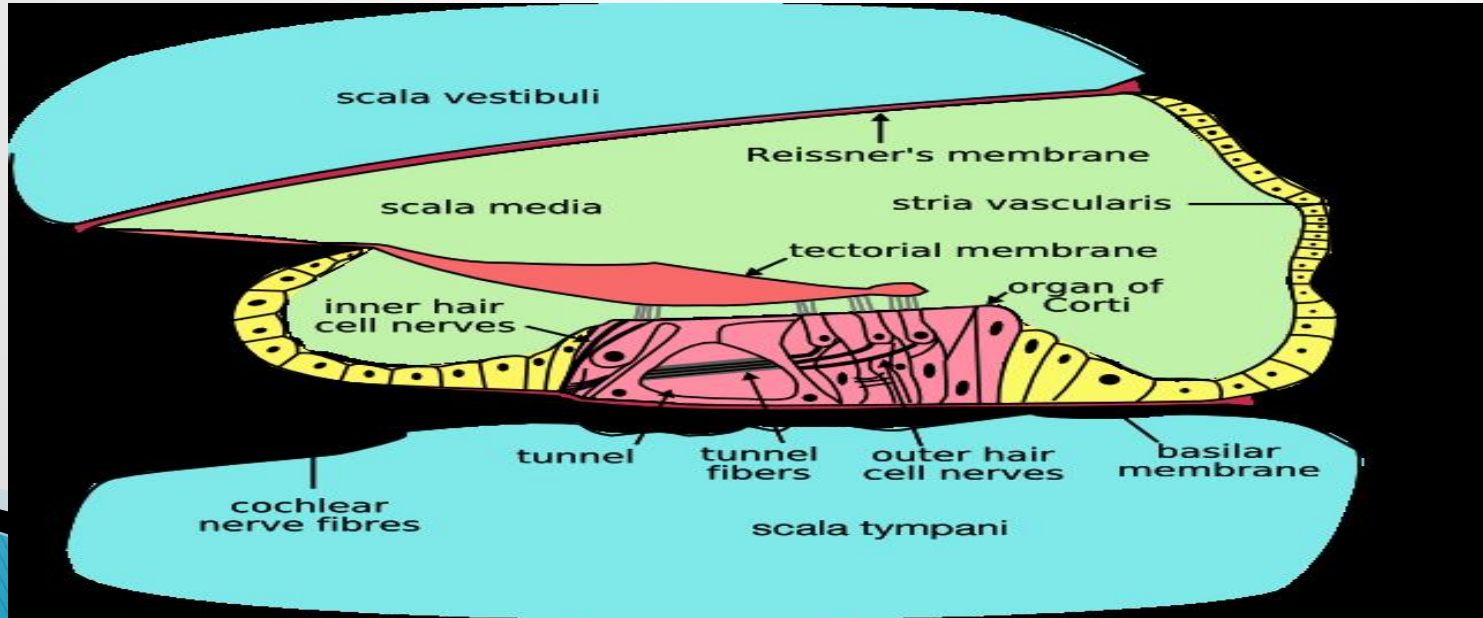
- **Pressure produced at the oval window by the stapes is transmitted via the vestibular chamber to the end of the spiral and then returns via the tympanic chamber.**
- **Because fluid is incompressible, the cochlea needs a relief valve, the flexible round window at the end of tympanic chamber server this purpose**





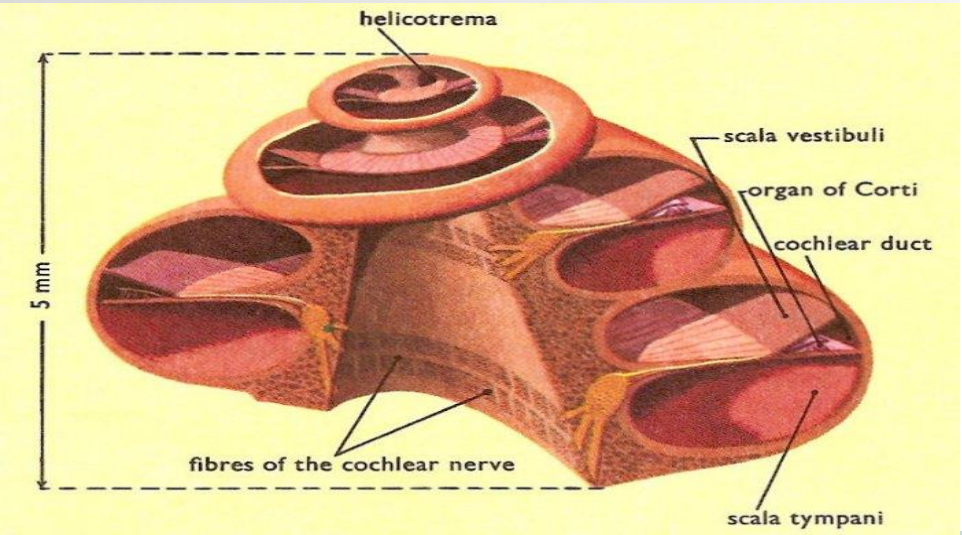
The Inner Ear

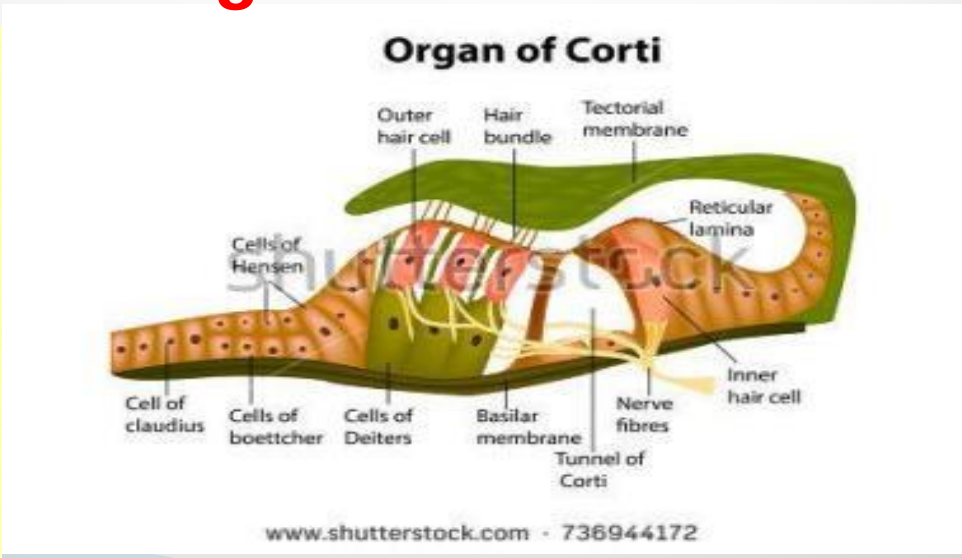
- A sound wave entering at the oval window produces a wave- like ripple in the basilar membrane of the cochlear duct, see Fig.
- Cochlear duct contains the sensors that convert the sound into nerve signals.
- The motions of the basilar membrane are about 10 times smaller in amplitude than the motions of the eardrum.



The Inner Ear

- **Stimulation of nerves in the cochlear duct near the oval window indicates high frequency sound.**
- **Low frequency sound cause large motions in the basilar membrane and stimulation of nerves in the cochlear duct near the tip of the spiral.**
- **The transducers that convert the mechanical vibration into electrical signals are located in the bases of the hair cell in the organ of Corti**





Sensitivity of the Ear

- The ear is **not uniformly** sensitive over the entire hearing range.
- Its best sensitivity is in the region of 2-5 kHz (Fig.).
- The lower curve in the Fig. (threshold) shows the value for a young person with good hearing .
- Notice that, even a good ear **needs about 30dB more intensity** to detect a sound at100 Hz than to detect one at 1000 Hz.
- The average line shows the levels at which half the people tested will detect the sound.

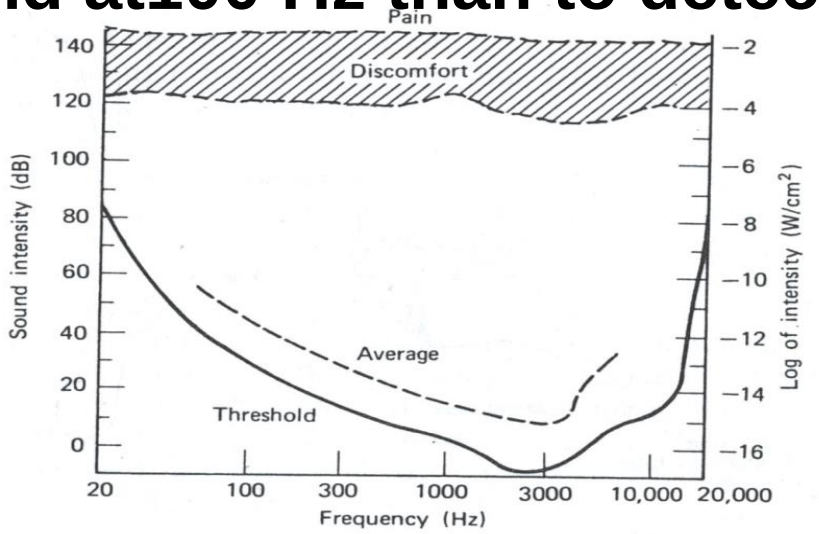
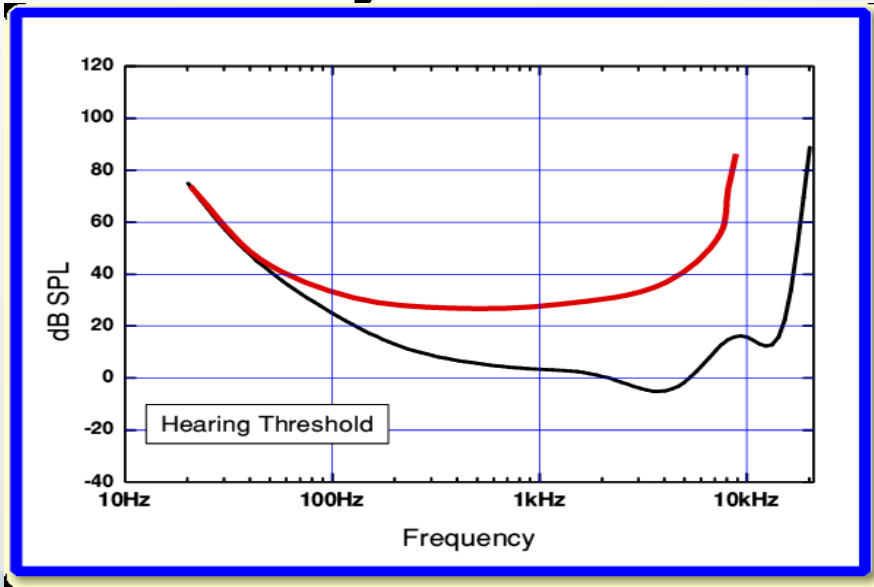


Figure 13.2. The sensitivity of the ear. The solid curve is the threshold of hearing for a young person with good hearing. Zero decibels occurs at 1000 Hz. The "average" curve is the average threshold for all people, young and old. Both axes—horizontal and vertical—are logarithmic scales.

Sensitivity of the Ear

- Sensitivity changes with age.
- The highest frequency you can hear will decrease as you get older and the level of sound will need to be greater for you to detect them.
- A person 45 years old typically cannot hear frequencies above 12kHz and needs about 10 dB more intensity than he did at age 20 to be able to hear a 4000Hz.
- At age 65 years ,25dB loos in sensitivity in the frequencies above 2000Hz.
- Hearing deteriorates more rapidly if the ear are subjected to continuous loud sounds (Noise pollution) like factory workers.



Sensitivity of the Ear

- The frequencies of most importance to us are those of the human voice.
- However, it is possible to have a hearing loss of 40dB and still hear most conversation.
- Sound are normally carried to the inner ear by air conduction.
- But sound energy may also be taken up and transmitted through the bones of skull by bone conduction.
- In general, a sound must be about 40dB more intense to be heard by bone conduction than to be heard by air conduction.

Testing of the hearing

- If one have a hearing problem and consult an "ear doctor"-an otologist, he or she may send you to an audiologist to have your hearing tested.
- If you have a hearing loss, the audiologist will be able to determine whether it is curable; if it is not, your ability to use a hearing aid will be assessed.
- The tests are normally done in a specially constructed soundproof testing room.
- Each ear is tested separately; test sounds can be sent to either ear through a comfortable headset.

Testing of the hearing

- The subject is asked to give a sign when he hears the test sound.
- Selected frequencies from 250 to 8000 Hz are used. At each frequency the operator raises and lowers the volume until a consistent hearing threshold is obtained.

- The hearing thresholds are then plotted on a chart and can be compared to normal hearing thresholds.
- The normal hearing threshold at each frequency is taken to be 0dB.
- The chart may show a general loss in one or both ears (see next Fig.). Usually a hearing loss is not uniform over all frequencies.

Testing of the hearing

Hearing Test Chart

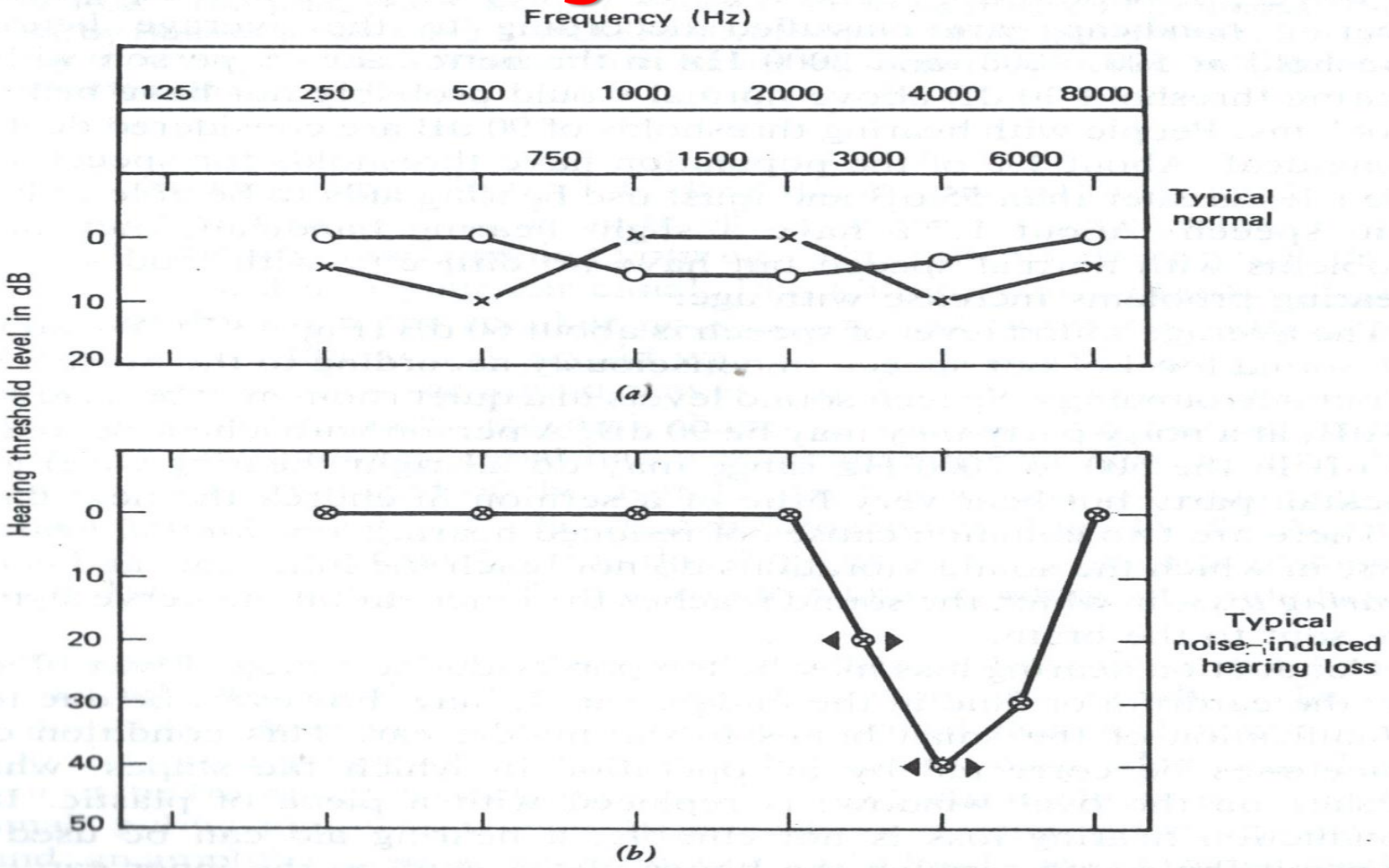
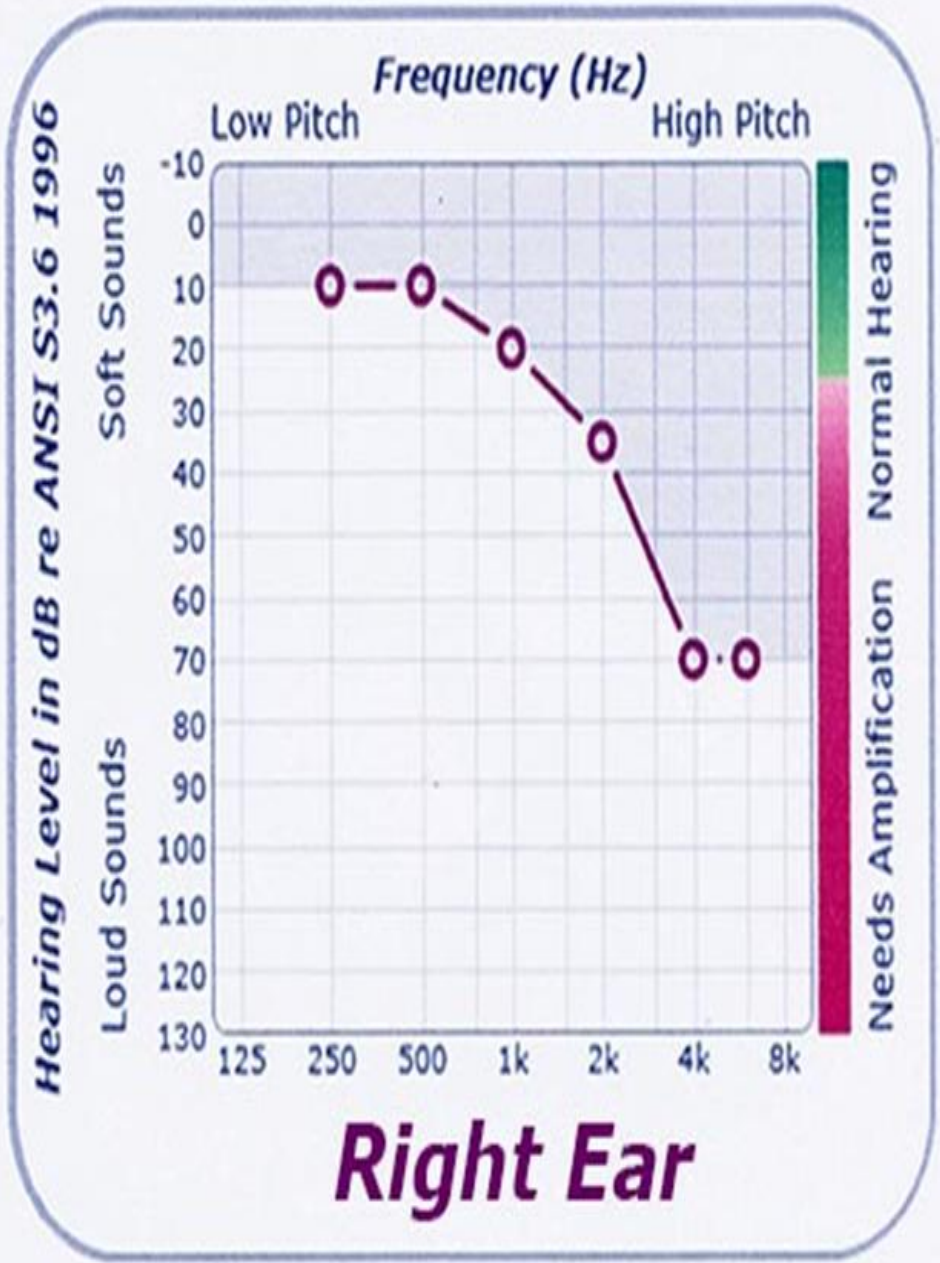
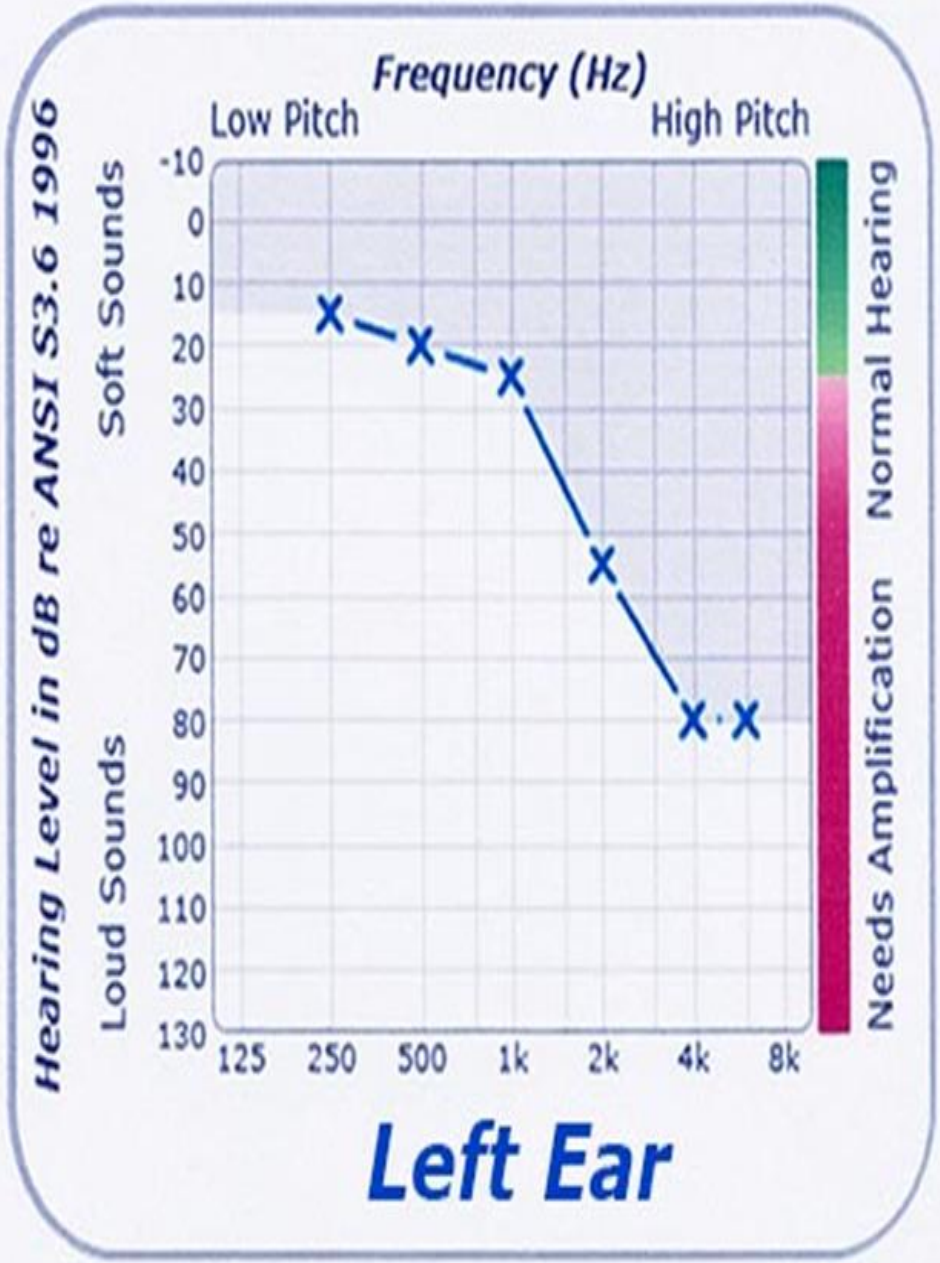


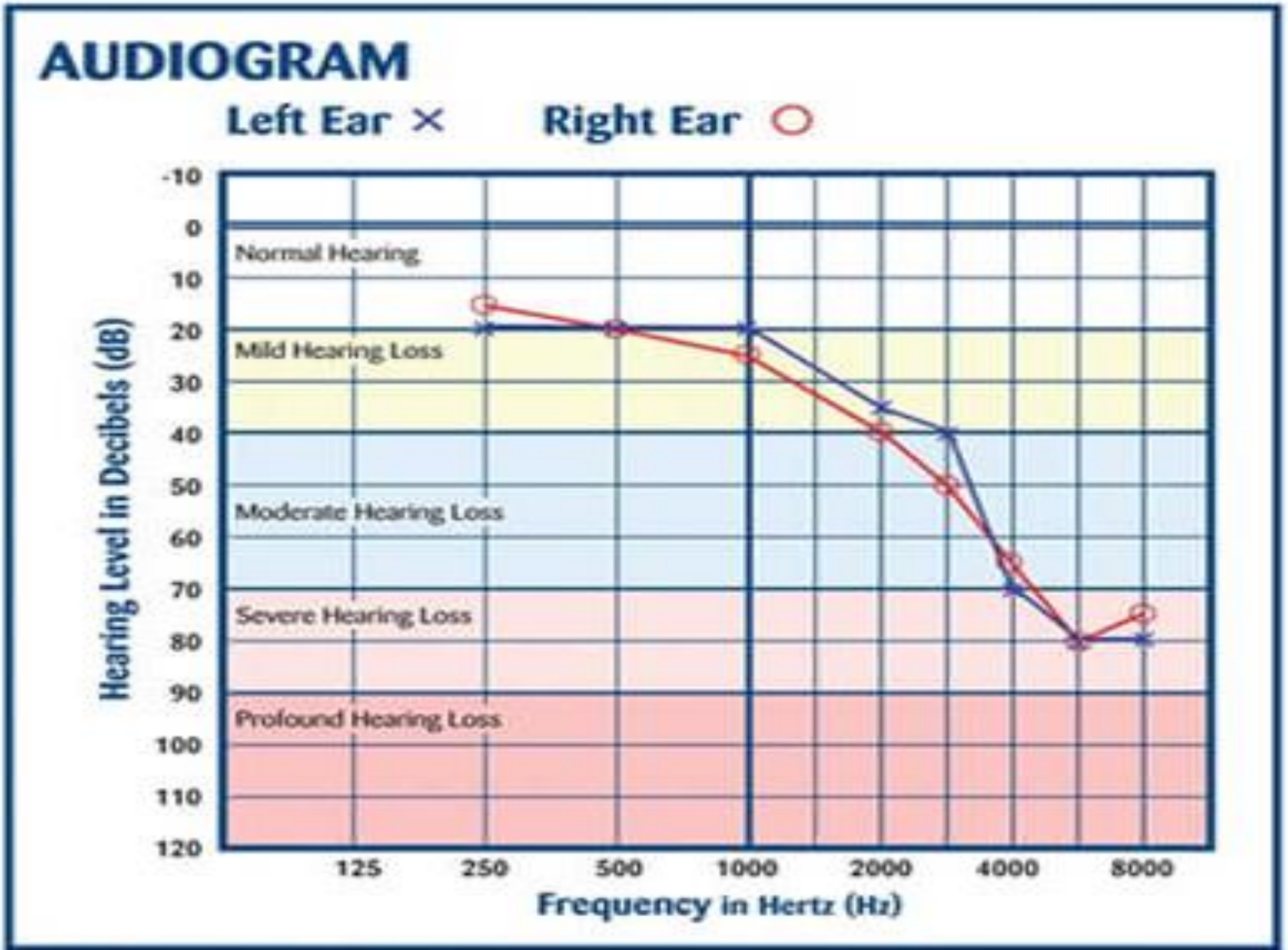
Figure 13.8. Hearing thresholds determined by a hearing test and plotted on a standard hearing chart. The Os represent the threshold for air conduction in the right ear; the Xs are for the left ear. (*a*) A typical response of a person with normal hearing. (*b*) A typical noise-induced hearing loss in the region of 4000 Hz. The black triangles indicate thresholds for bone conduction.

Hearing Test Chart (Audiogram)





Hearing Test Chart Rang (Audiogram)



Deafness and hearing aids

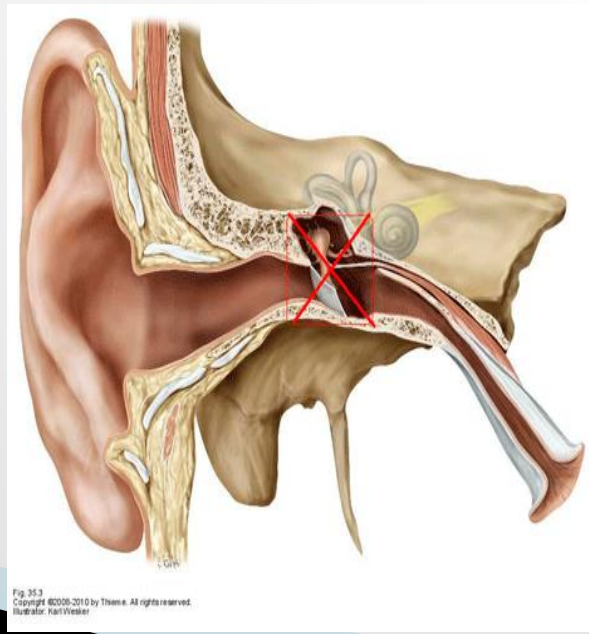
- The frequency range most important for understanding conversational speech is from about 300 to 3000 Hz.
- A person who is "deaf" above 4000Hz but who has normal hearing in the speech frequencies is not considered deaf or even hard of hearing.
- Hearing handicaps are classified according to the average hearing threshold at 500, 1000, 2000 Hz in the better ear.
- A person with a hearing threshold 30dB above normal would probably not have hearing problems.
- People with hearing thresholds of 90dB are considered deaf or stone deaf.

Hearing impairment

Deafness and hearing aids

- Hearing problems are increase with age.
- There are two common causes of reduced hearing: –

1. Conduction hearing loss, in which the sound vibrations do not reach the inner ear.
2. 2. Nerve hearing loss, in which the sound reaches the inner ear but no nerve signals are sent to the brain.



Deafness and hearing aids

- **Conduction hearing loss may be temporary due to a plug of wax blocking the eardrum or fluid in the middle ear.**

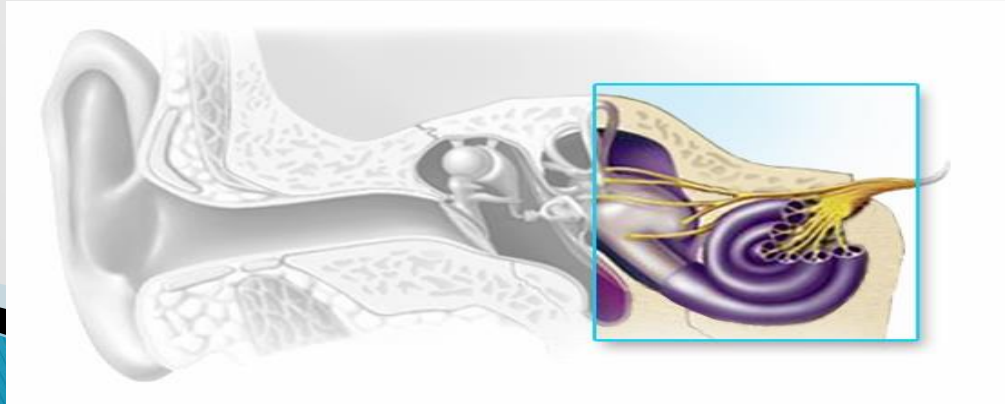
- **It may, however, be due to a solidification of the small bones in the middle ear. This condition can sometimes be corrected by an operation in which the stapes, which pushes on the oval window, is replaced with a piece of plastic.**

Deafness and hearing aids

- **If a conduction hearing loss is not curable, a hearing aid can be used to transmit the sound through the bones of the skull to the inner ear**

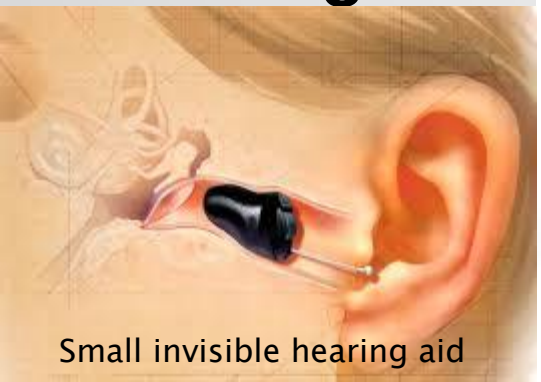



- **Nerve hearing loss may affect only a narrow band of frequencies or it may affect all frequencies.**

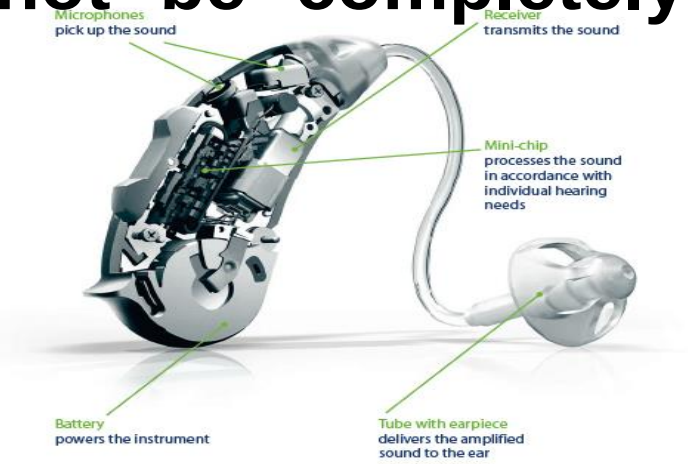


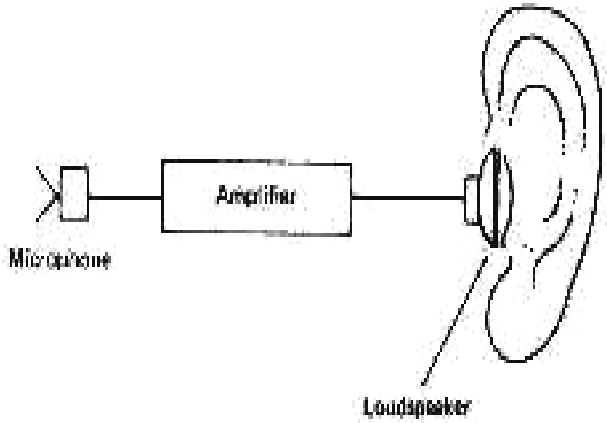
Deafness and hearing aids

- Electronic hearing aids are in common use today.
- It consists of a microphone to detect sound, an amplifier to increase its energy, and a loudspeaker to deliver the increased energy to the ear (see Fig.).
- Hearing aids cannot return hearing to normal. They can only help compensate for the hearing loss. For example, an abrupt hearing loss above 3000Hz cannot be completely corrected with a hearing aid.



Small invisible hearing aid





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