Physics of Ear and Hearing

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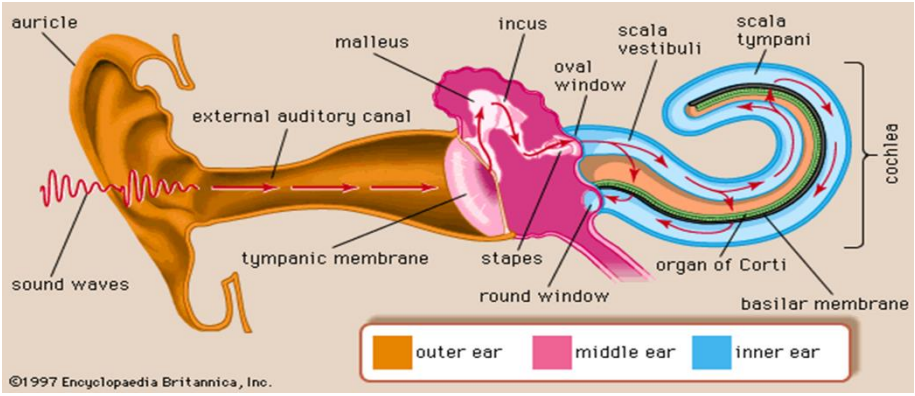
The sound : It is a mechanical disturbance in gas, liquid or solid that travels outward from the source with some definite velocity. It is spreads as a longitudinal wave that is, the wave in which pressure change is occur in the same direction as the wave travel.

The sound classification according to frequency:

- The audible sound range is usually defined as 20 Hz to 20 KHz.
- The infrasound refers to sound frequencies below the normal hearing range (< 20 Hz). It is produced by natural phenomena like (earthquake).
- Ultrasound refers to sound frequencies above the normal hearing range (>20 Hz).

The **ear** is a mechanical converter of very weak mechanical sound waves in air into electrical pulses in the auditory nerve. The ear consists of three parts.



<u>The outer ear</u> It consists of the following parts:

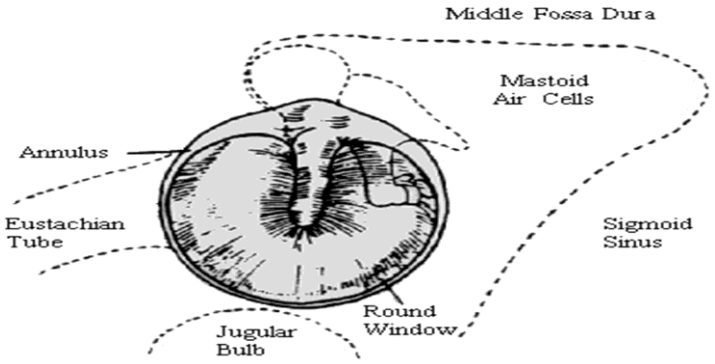
1- The outer structure (the auricle), which is the least important part of the hearing system.

2 -The external auditory canal which terminates at the eardrum (tympanic membrane). The canal is about 2.5 cm long and the diameter of a pencil.

3 -The external auditory canal is being a storage place for ear wax, serves to increase the ear's sensitivity in the region of 3000 to 4000 Hz.

4- The external auditory canal can be thought as an organ pipe closed at one end with a resonant frequency of about 3300 Hz, where is the sensitivity of the ear is the best in this region.

The eardrum (tympanic membrane): It is about 0.1 mm thick (paper thin). It has an area of about 65 mm^2 The eardrum does not vibrate symmetrically, its actual movement exceedingly small. This movement at a threshold of hearing at 3000 Hz is about 10^{-9} cm.

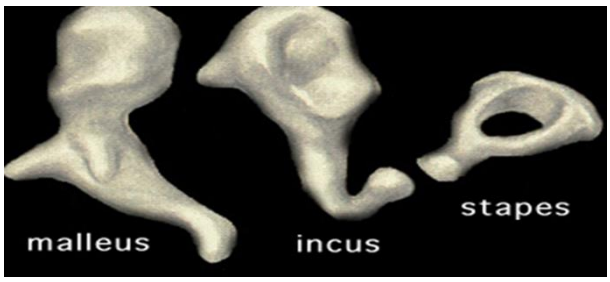


At the threshold of hearing at the lowest frequency that we can hear (20 Hz), the motion of the eardrum may be as large as 10-5 cm. It is possible for sound pressures above 160 dB to rapture the eardrum.

The function of the tympanic membrane is coupling the vibrations in the air to the small bones in the middle ear, because of the off-center attachment of the malleus with it.

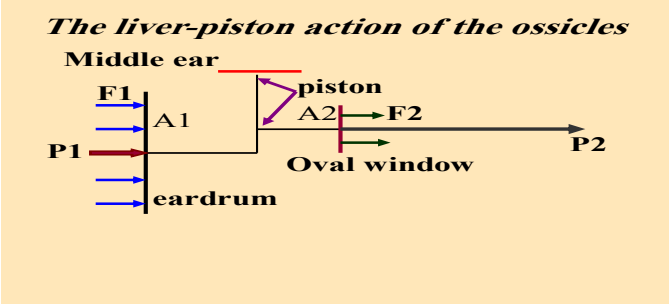
The middle ear It is a small air-filled cavity separated from the outer ear by the eardrum and houses the ossicles, which are full size bones before birth. The ossicles are:

The hammer (malleus).
The anvil (incus).
The stirup (stapes).



The ossicles play an important role they arranged so that they efficiently transmit vibrations from the eardrum to the inner ear, they transmit the poorly vibrations in the skull-even the large vibrations from the vocal cord, and they match the impedance of the sound waves at the eardrum to the liquid filled chambers of the inner ear. The ossicles amplify the pressure of the sound waves at the entrance to the inner ear.

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 malleus at the eardrum. Thus the lever action amplifies the force by a factor of 1.3.



The eardrum which act like a large piston is mechanically coupled to the stapes, which act as a small piston at the entrance of the inner ear. The ratio of the effectiveness area of the eardrum to that of the base of the stapes is about 15 to 1. This gain is combined with the piston gain result in a total gain in pressure of about 20.

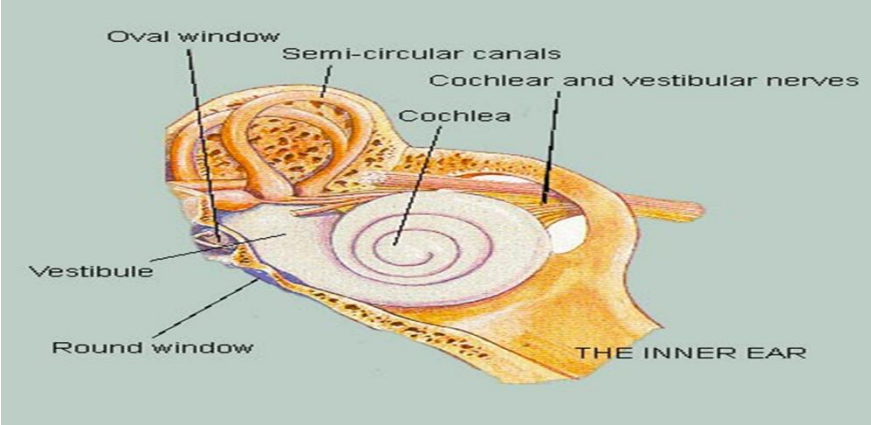
The functions of the ossicles extend to the protection of the ear from possible damage by loud sounds by rotating the stirup and puling it away from the oval window by the muscles which stiffens the eardrum as well, reducing the sound intensity reaching the eardrum. It takes 15 ms or longer for these muscles to react, and damage may be done in this brief period.

- **Austacian Tube:** It serves to equalize the pressure in the middle ear to the atmospheric pressure. Air in the middle ear is gradually absorbed into the tissue lowering the pressure on the inner side of the eardrum such is in chewing and swallowing causing a momentary opening of this canal. Pressure difference are usually noticed in situation in which the outside pressure changes rapidly in a short period of time such as in flying, riding an elevator of a tall building.
  The blockage of the Austacian tube by viscous fluid from a head cold and the swelling tissue around the entrance of the tube resulting in the failure of equaliztion system. Pressure difference reflects the eardrum inward and decrease the sensitivity of the ear. At about 60 mmHg across the eardrum, the pressure difference causes pain.

The Inner ear:

It is hidden deep within the temporal bone. It consists of a small spiral shaped filled with fluid called the cochlea. It is 2 and 3/4 turns over a length of 5 mm. It is communicated with the middle ear via the oval window.
The inner ear is divided into three chamber:
-The vestibular canal: it ends in the round window, it is filled with perilymph liquid.
- Tympanic canal: it ends In the round window it is filled with perilymph liquid. It is joined up with the vestibular canal at the apex of cochlea through a small opening called halicotrima.

- Cochlear duct: it is seperated from the vestibular canal by a thin membrane (Reisser's membrane) and from the tympanic canal by the basiler membrane.

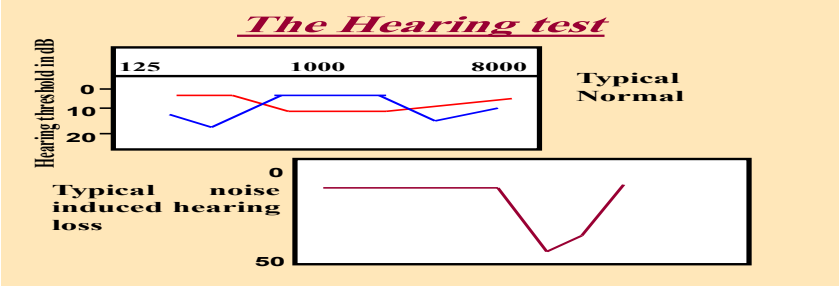


The cochlea is filled with endolymph liquid which is separated permanently from the perilymph. The basilar membrane supports the organ of Corti which contains (the ends of 30000 auditory nerves and occupying in area of 3 cm long by 0.3 mm wide. The organ of Corti is a gelatinous structure of about 7500 interrelated parts contain a mass of hairs fixed on both ends which stimulates the end of the auditory nerve.

The hearing mechanism:

The stapes transmit the pressure variation of the incoming sound waves to the cochlea. Inside the cochlea the original pressure wave in air has become a pressure wave in liquid, where its viscosity play the dominant role. This wave induces wave-like ripple in the basilar membrane that is stimulated depend on the frequency of the original sound wave. The organ of Corti converts the mechanical energy into electrical energy and send the information to the brain via the auditory nerves. The auditory nerve provides information on both the frequency and the intensity of he sounds we hear. The best sensitivity of the ears is in the region of 2 to 5 KHz. A good ear needs about 30 dB more intensity to detect a sound at 100 Hz. Sensitivity changes with age. The highest frequency you can hear will decrease as you get older. A person 45 years old typically cannot hear frequencies above 12 KHz and needs 10 dB more intensity than he did at age 20 to be able to hear a 4000 Hz. A 25 dB loss in sensitivity in the frequencies above 2000 Hz usually has occurred by age of 65. The loudness of the sound depends strongly on it is frequency. The range of sound intensities the ear responds is 10^{12}.

The Hearing test: 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. 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 chart may show a general loss in one or both ears.



Deafness and hearing loss: There two common cause of reduced hearing:

1-Conduction hearing loss: in which the sound vibrations don't reach the inner ear. It may be temporary due to a plug of wax blocking the eardrum or fluid in the middle ear. It may be due to the solidification of the small bones in the middle ear. It can be corrected by an operation in which the stapes, which pushes on the oval window, is replaced with a piece of plastic. If the conduction hearing loss is not corrected, a hearing aid can be used to transmit the sound through the bones of the skull to the inner ear.

2 -Nerve hearing loss: in which the sound reaches the inner ear but no nerve signals are sent to the brain. A nerve hearing loss may affect only a narrow band of frequencies or it may affect all frequencies, there is no known cure or aid for nerve hearing loss.

Hearing Aids: They catch the sound waves and concentrate the sound energy. They increases the sound level of the speech frequencies to above the hearing threshold. Electronic hearing aids are common use today. It consists of :

- A microphone: to detect the sound.
- An amplifier: to increase the energy, it is possible to obtain an amplification of 90 dB. Even thought deaf people may have a hearing threshold of 70 to 80 dB.
- A loudspeaker: to deliver the sound energy to the ear.