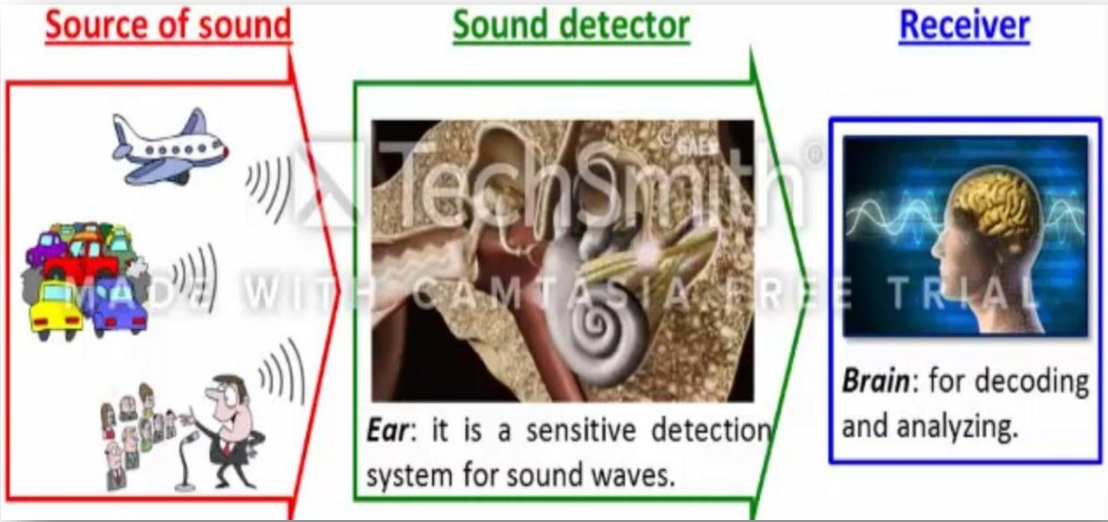
Physics of the Ear and Hearing

Topics of the Lecture

- Hearing system
- Parts of the ear.
  - Outer ear
  - Middle ear
  - Inner ear

Hearing System

- Any hearing system consists of:



Hearing: is the process where the ear transforms sound vibrations into nerve impulses that are interpreted by the brain as sounds.

The three parts of the ear are shown below

1. The outer ear

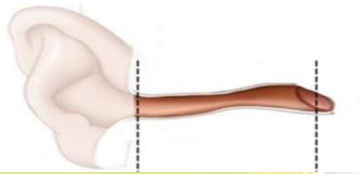
It is the outer visible portion of the ear that collects and directs sound waves toward the tympanic membrane by way of a canal. It consists of pinna, auditory canal and the tympanic (eardrum) membrane as following

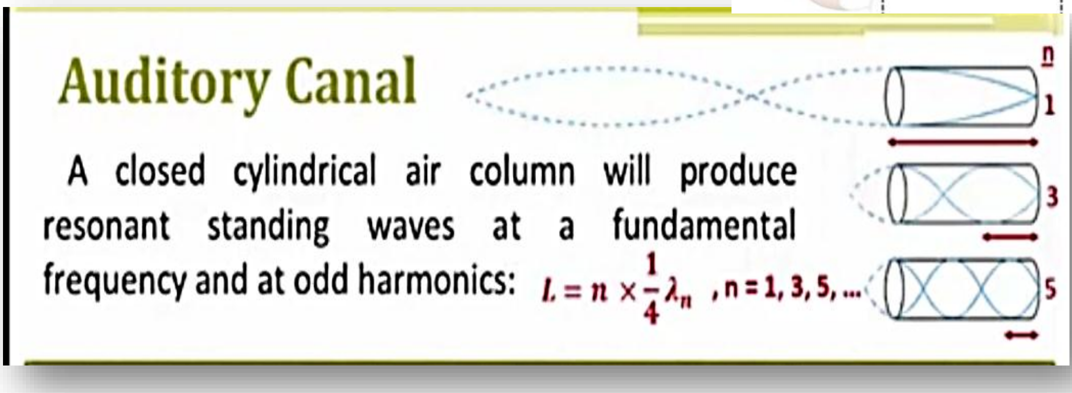
a) **Pinna:** The Pinna collects sound, acting as a funnel to amplify sound and directing sound toward the ear canal and adding directional information to the sound.

b) **Auditory canal**; is a tube running from the outer ear to the middle ear. It is about 2.5cm in length and 0.7cm in diameter. Functions of the auditory canal are:

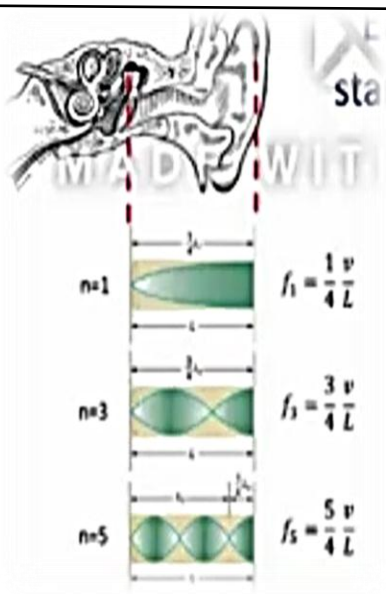
- Protects the eardrum from shocks.
- Preventing harmful items from entering the ear canal by the help of hair and wax.
- Amplification the sound by acting as a resonator.

By considered the auditory canal as an air-filled tube of length L with one end closed, the flow of air will produce a resonance (standing waves). The wavelength and frequency that will be resonated is given by $\lambda_n = \frac{4}{n} L$ and



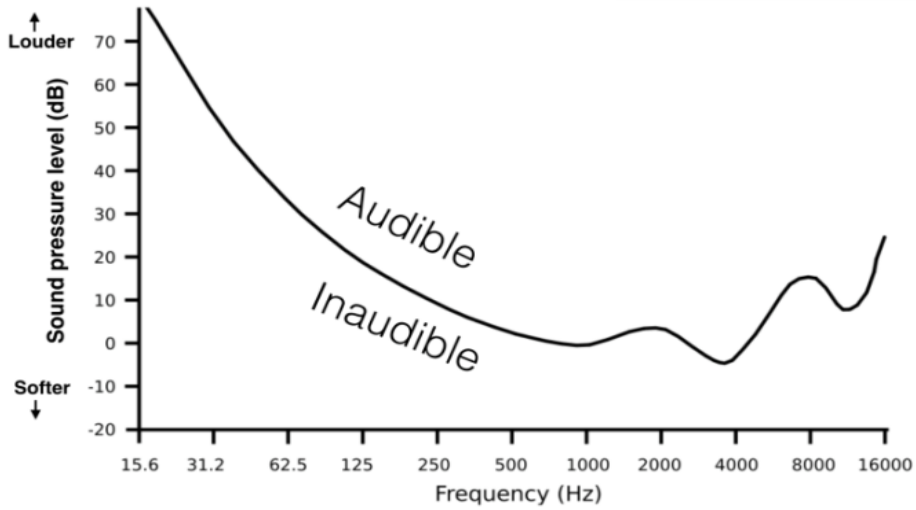


$$f = \frac{v}{\lambda_n} = n\frac{v}{4L}$$



So $f_1 = 3300\ Hz$,
$f_3 = \ =9900\ Hz = 3\ f_1$
Where, (v) velocity of sound in air = 330 m/s

This resonance will enhance the sensitivity of ear in the higher frequency range 2000-10000 Hz and the best sensitivity of the ear will be in the region 2000- 4000 Hz.



c) **Tympanic (eardrum) membrane;** it is a cone-shaped piece of skin about 10 mm in width, separates the outer ear from the middle ear. It is very sensitive, even the slightest pressure variation will cause it to vibrate. The main function of the tympanic membrane is transfer the sound that coming from the air into the ossicles of the middle ear

☒ Reflection and Transmission at the Tympanic Membrane

The acoustical signal travels along the ear canal and hits the eardrum. This causes partial reflection and transmission of the signal. To optimize the hearing sensitivity reflection should be minimized and transmission maximized.

From measuring the intensity ratios for reflected and transmitted acoustical waves at the eardrum, we can obtain the following (where, Z_{air} = 430 kg/m².s, Z_{muscle}= 1.48x10^6 kg/m².s):

$$\frac{I_{ref}}{I_{in}} = 0.99 \quad , \quad \frac{I_{trans}}{I_{in}} = 0.001$$

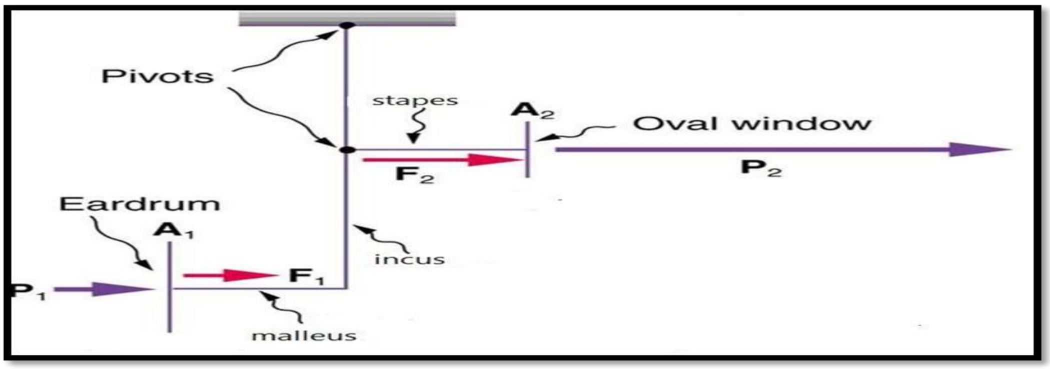
From the above values, one can observe that most of the incoming wave intensity is reflected (bad impedance matching) and therefore lost for hearing process. ***Good impedance matching is necessary for good signal transmission.***

2. Middle Ear

It consists of three small bones (hammer, anvil, and stirrup). They transmit the eardrum vibrations **to the oval window of the inner ear**.

The functions of the bones of the middle ear are:

a. act a lever system, in which amplify the pressure on the oval window by a factor of about 20, as shown in the following:



- The force on the oval window (f_o) is about 1.5 times the force on the eardrum (f_m).

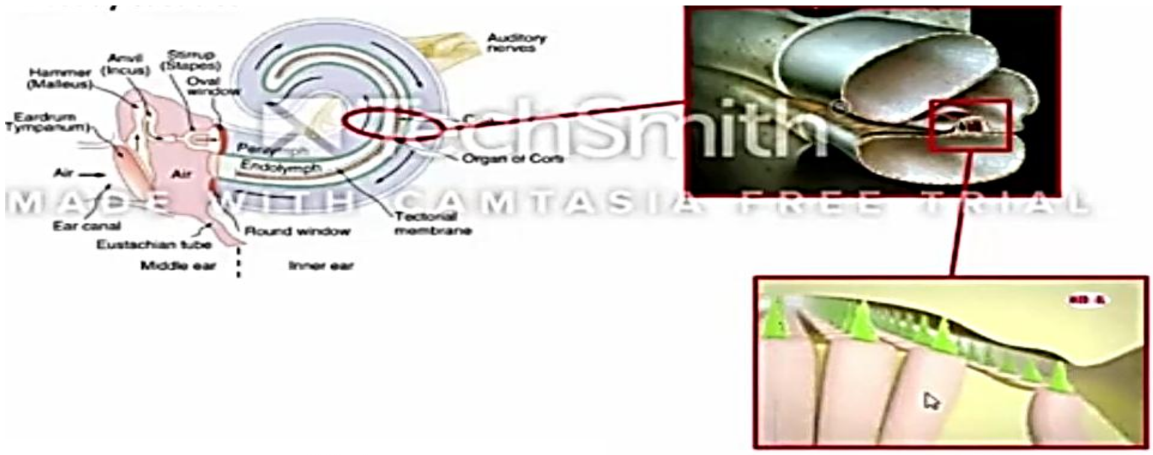
- The area of the oval window (A_o) is about 15 times smaller than the area of the eardrum (A_m).

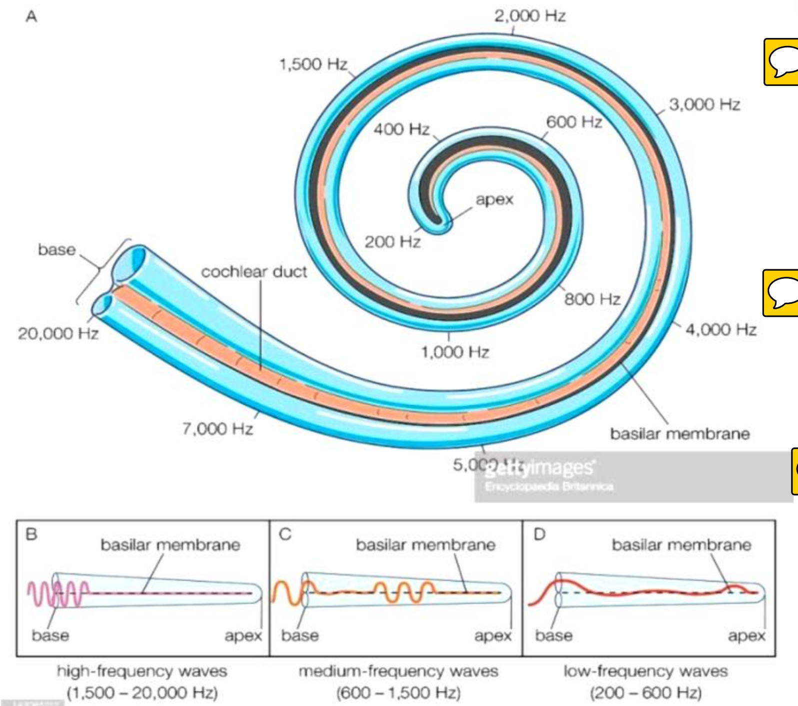
$$\frac{\textbf{pressure on the oval window } (P_O)}{\textbf{Pressure on the eardrumm } (P_m)}$$

$$= \frac{f_o}{A_o} \div \frac{f_m}{A_m} = \frac{f_o}{f_m} \times \frac{A_m}{(A_o)} = 1.5 \times 15 = 20$$

3. The inner ear

- ☒ The hearing portion of the inner ear is the cochlea, a snail shaped structure that is connected to the stirrup (or stape). As the stapes moves in and out, it produces fluid waves within the cochlea.
- ☒ These waves in turn cause movement of **tiny cells** within the cochlea called the hair cells. When hair cells vibrate, they send signals to the brain which can then be interpreted as sound.
- ☒ The basilar membrane has variable sensitivity to sound wave frequency along its length.





- ☒ *High frequency* sounds produce the greatest motion of the basilar membrane *near* the oval window.
- ☒ *Low frequency* sounds produce the greatest motion of the basilar membrane *farthest* from the oval window.
- ☒ This results in different nerve cells, distributed along the organ of Corti, producing electrical pulses depending on the frequency of the sound waves.

Hearing loss (Deafness)

In more general terms, hearing loss can be grouped into two main types:

1- **Conduction hearing loss**, in which the sound vibrations do not reach the inner ear, this is may be due:

- Plug of wax blocking the eardrum.
- Fluid in the middle ear.

The result is an overall lowering of volume and inability to hear faint sounds. This hearing loss is usually temporary and can sometimes be reduced or eliminated by medical intervention or surgery.

2- **Nerve hearing loss,** in which the sound vibrations reach the inner ear but no nerve signals are sent to the brain. In most cases, nerve hearing loss is permanent and usually affects both ears. This type of hearing loss is commonly treated through the fitting of hearing aids.