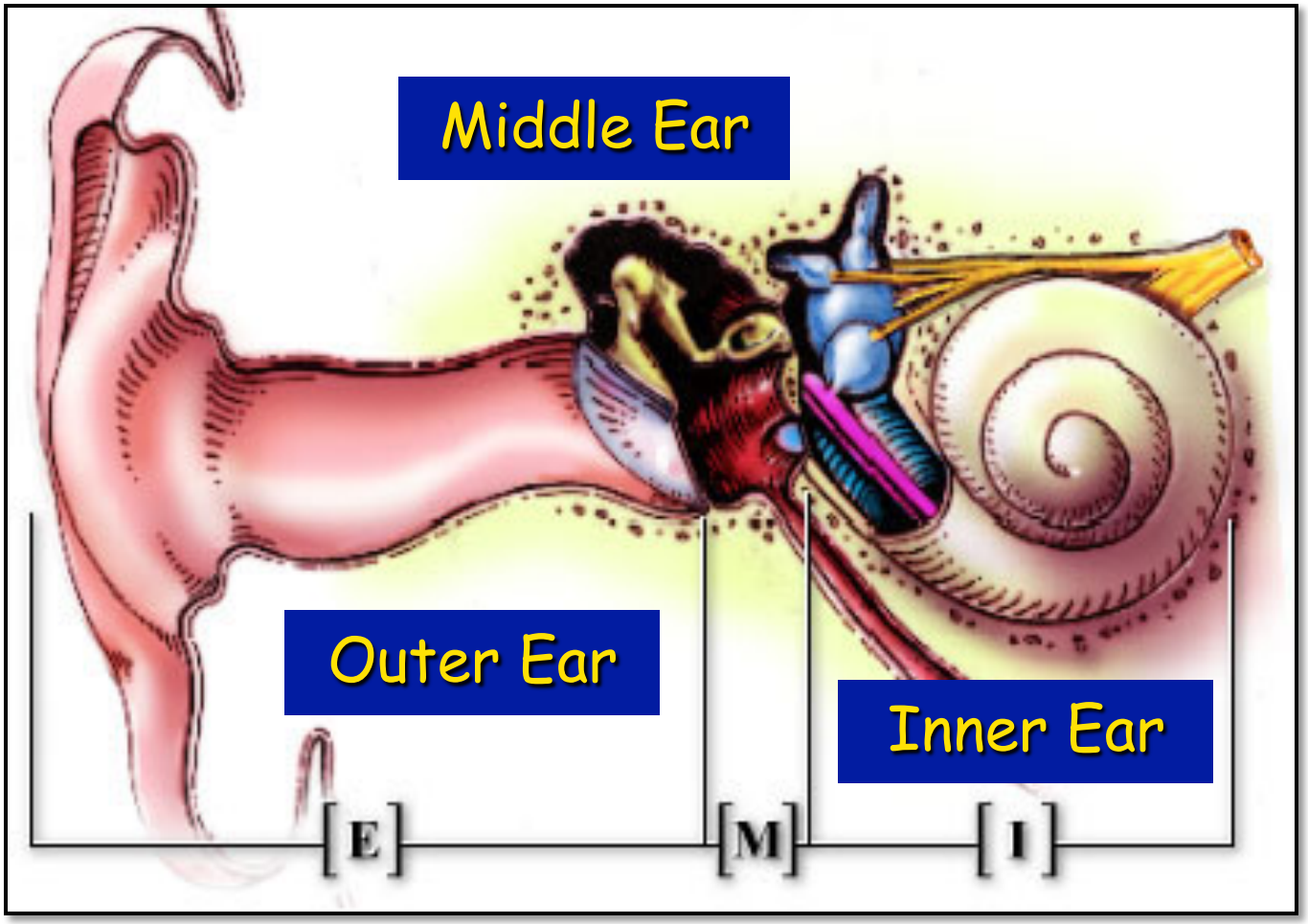
Musical Acoustics

Lecture 11

The Human Ear - I

Anatomy of Ear

The human ear is a highly sensitive sound receptor in which pressure fluctuations in the outer ear are transformed into vibrations of small bones (the ossicles) in the middle ear that are ultimately communicated to the cochlea located in the inner ear, where the vibrations are further transformed by stereocilia (hair cells) into neural impulses distributed by frequency.

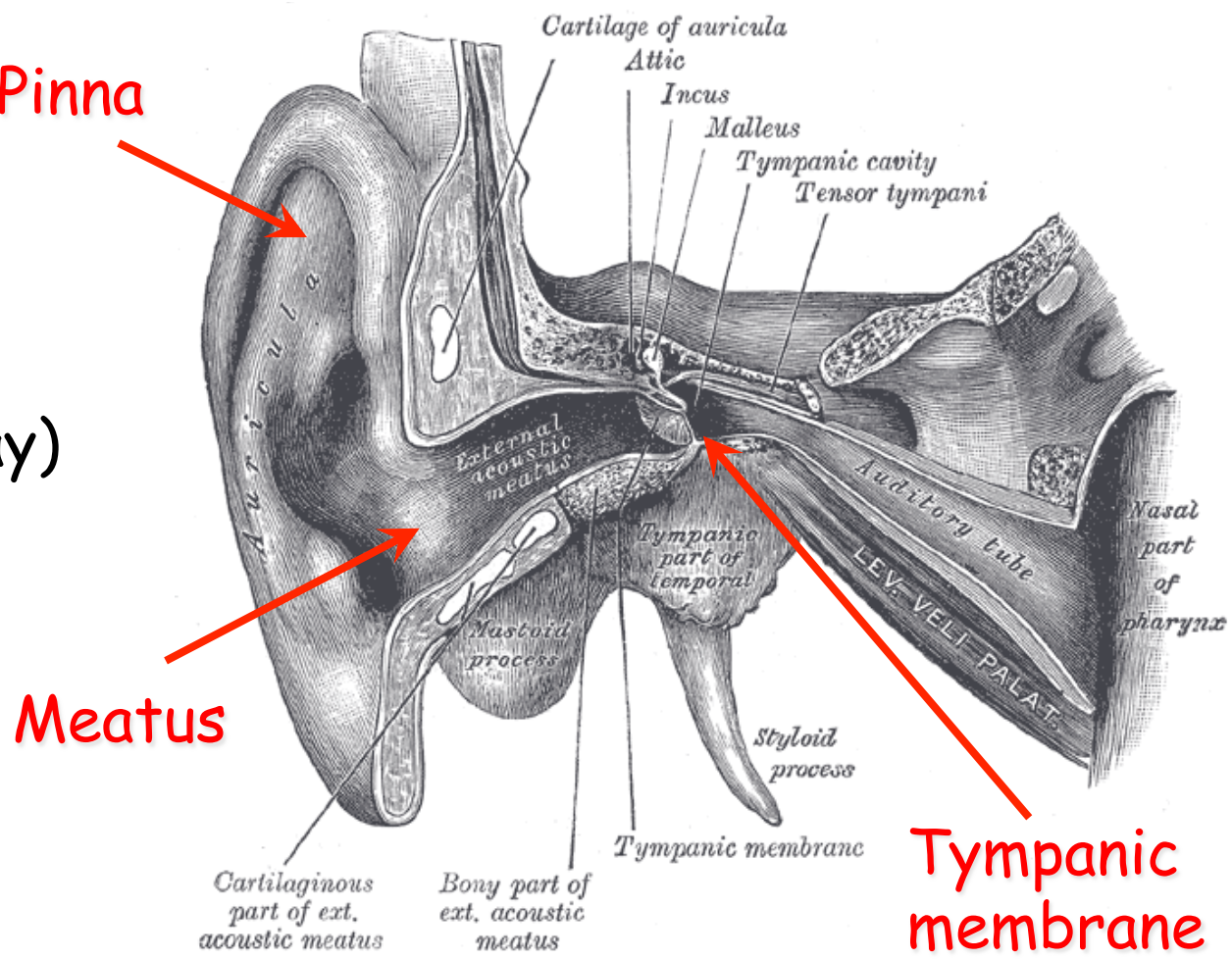


Outer ear

Pinna – (the feather) matches ear canal to outside world.

Meatus – (the passageway) conducts sound into head.

Tympanum – (the drum) transforms pressure fluctuations into displacement.

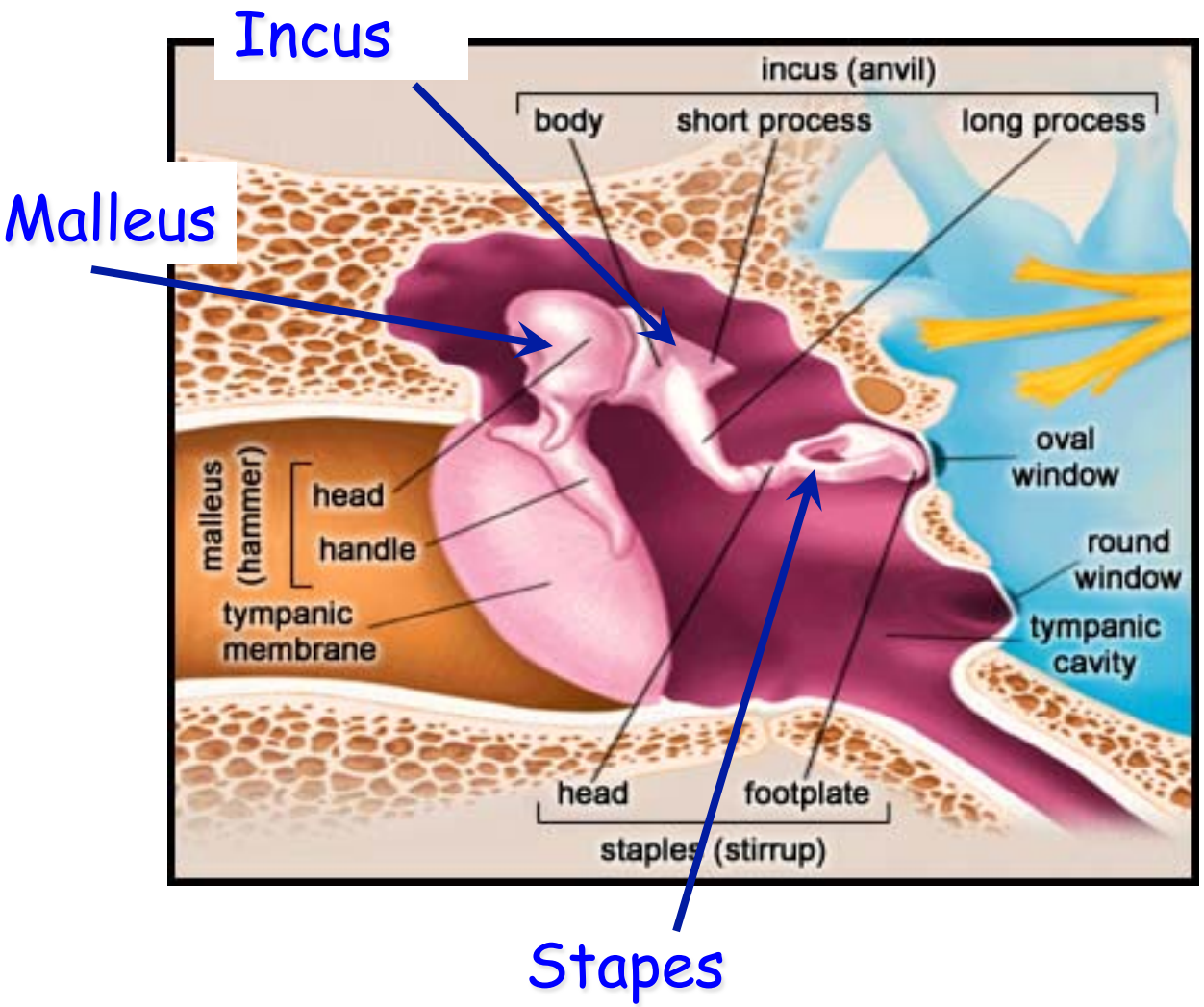


Middle ear – The ossicles (little bones)

Malleus — (the hammer) moved by Tympanum.

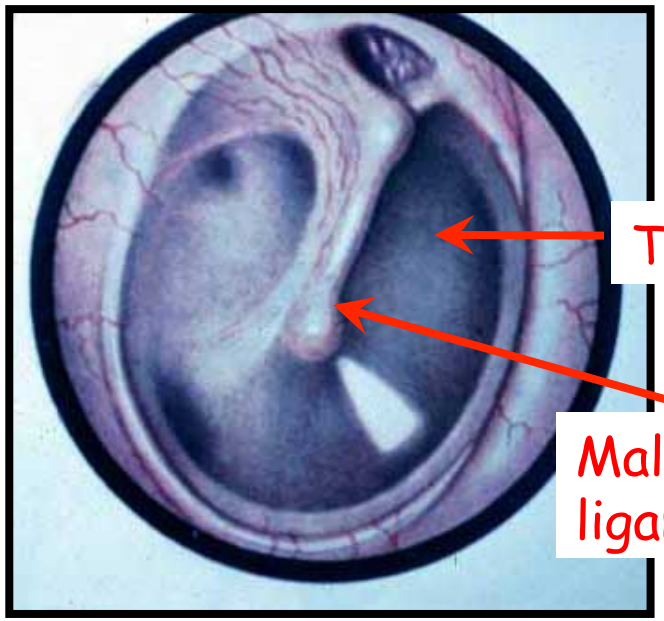
Incus — (the anvil) supported by ligaments that protect against loud percussion.

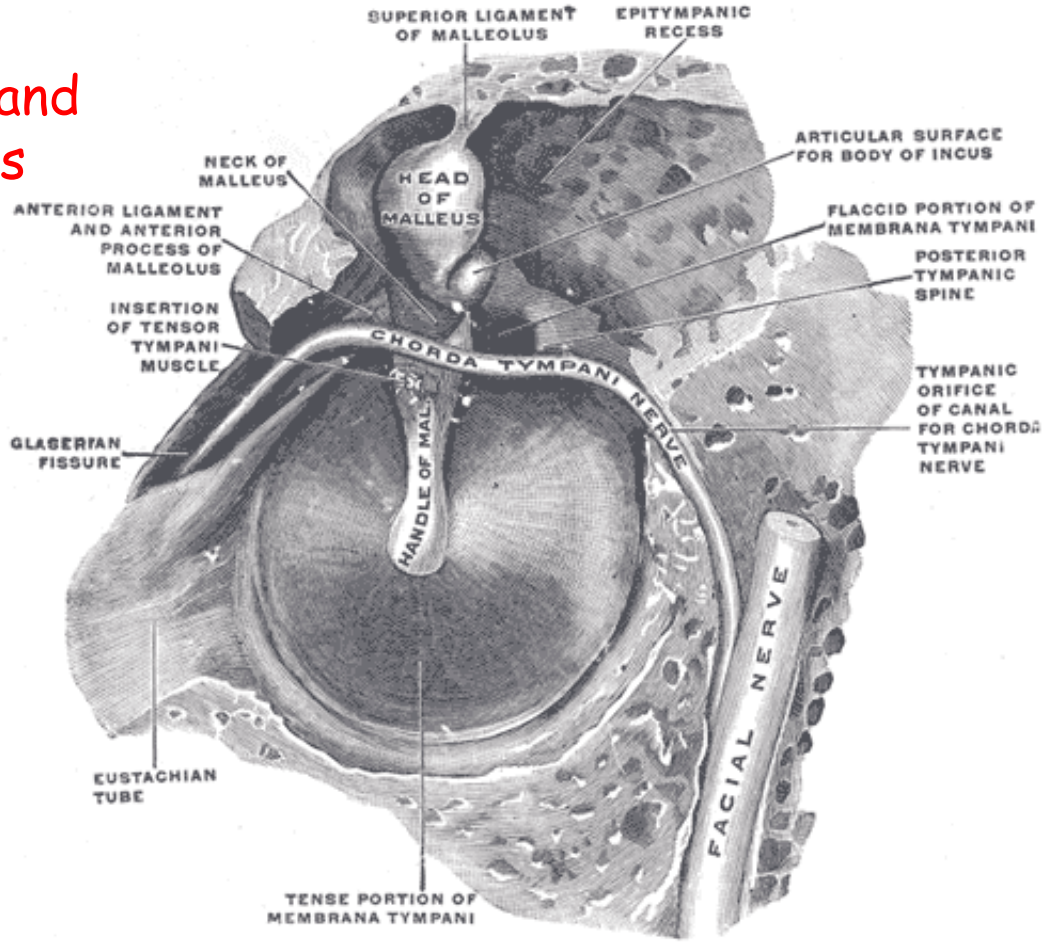
Stapes — (the stirrup) force multiplied by 1.3 because of lever action.



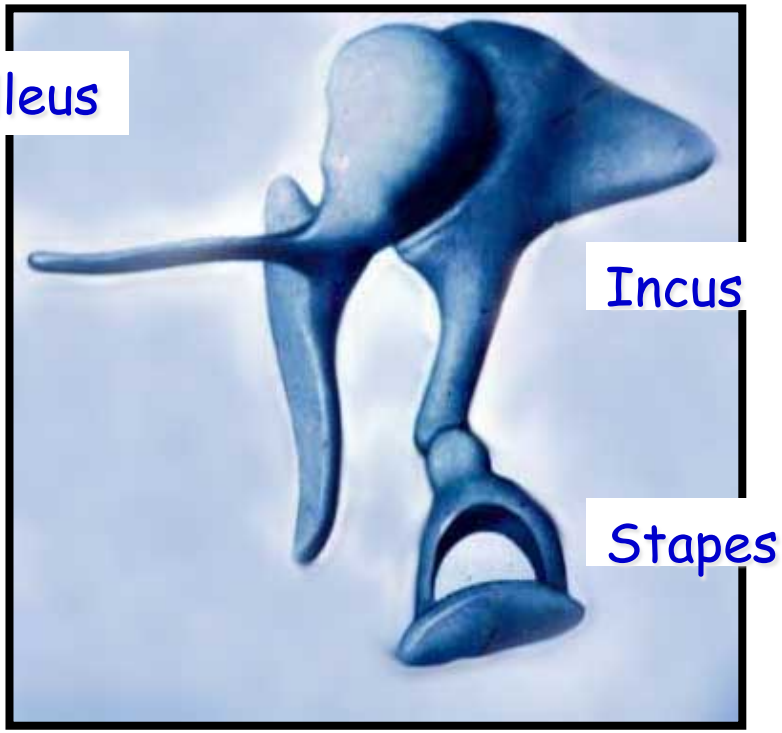
Tympanum (ear drum)

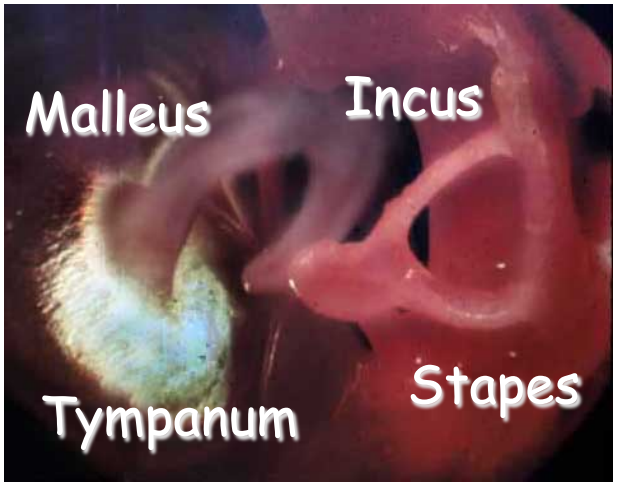
(view from inside)

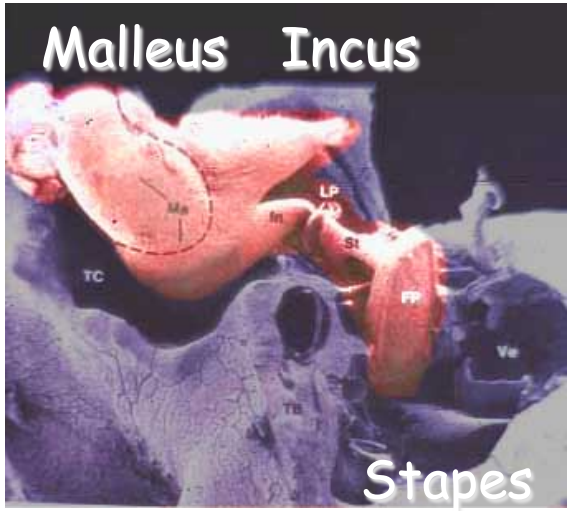




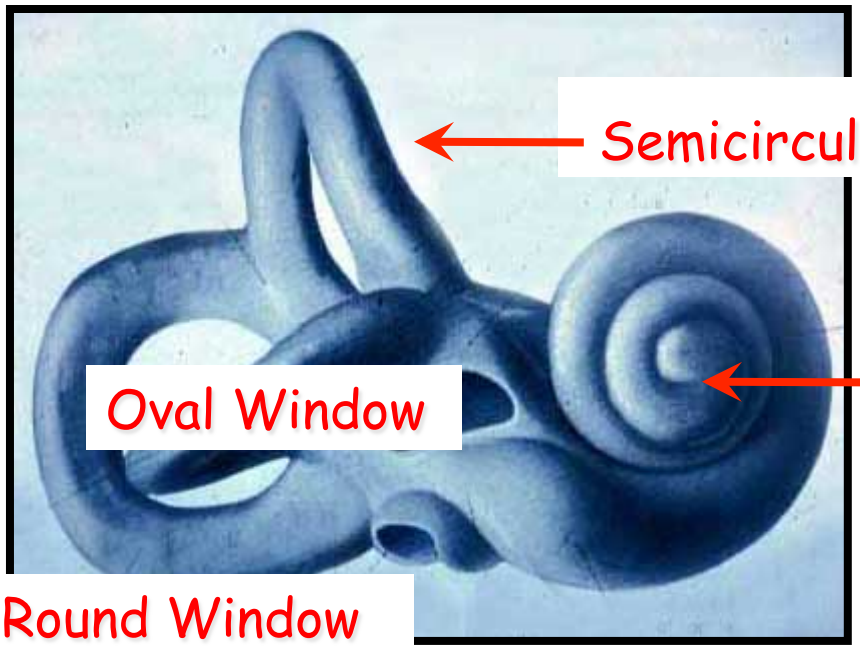
The Ossicles







Inner Ear



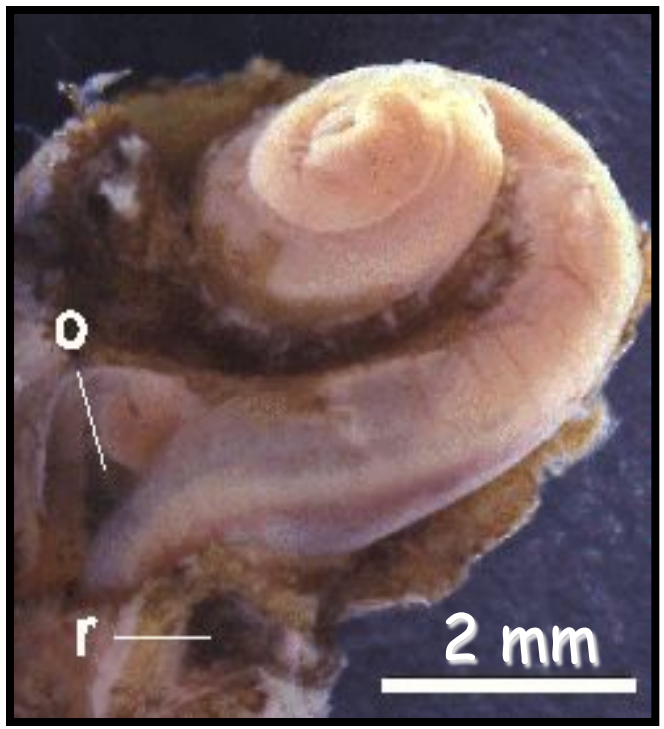
Cochlea – (the Snail) converts displacement into neural impulses.

Auditory Nerve – neural impulses to brain

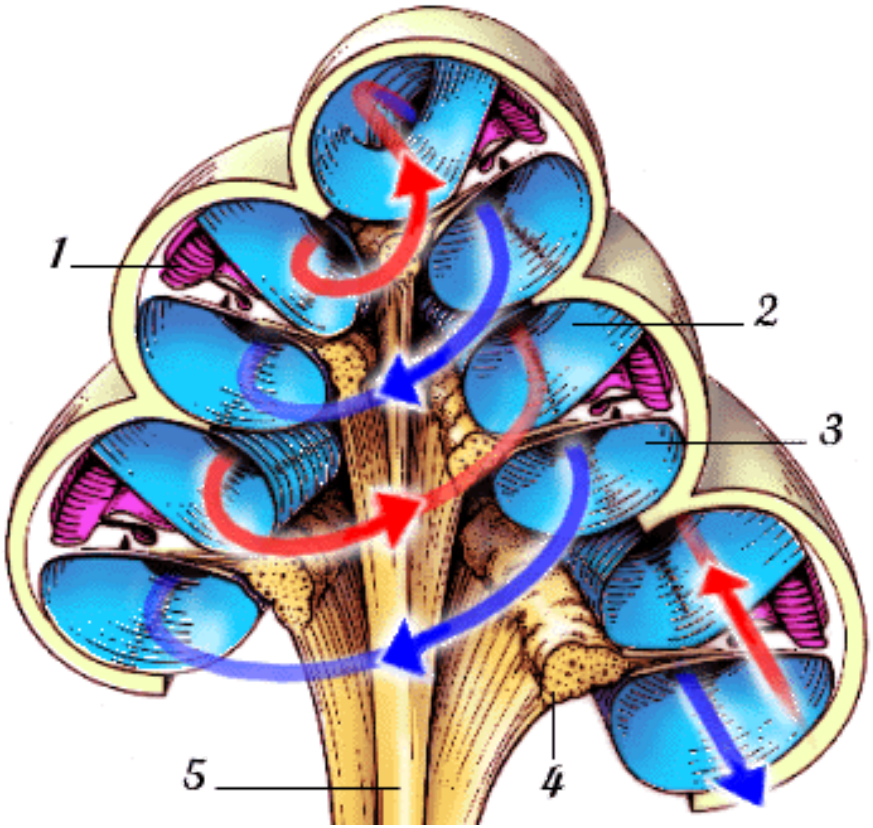
Semicircular canals – detect motion and orientation

Cochlea (micrograph)
"The Snail"

- o~ oval window
- r~ round window



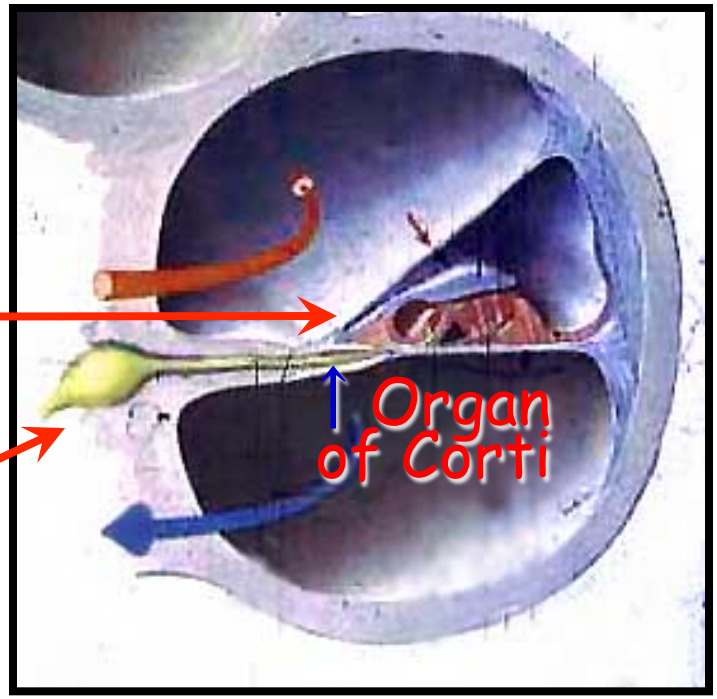
Structure of Cochlea



1. Spiral cone
2. Divided by Basilar Membrane
3. In on top half
4. Out on bottom
5. "Sloshing "

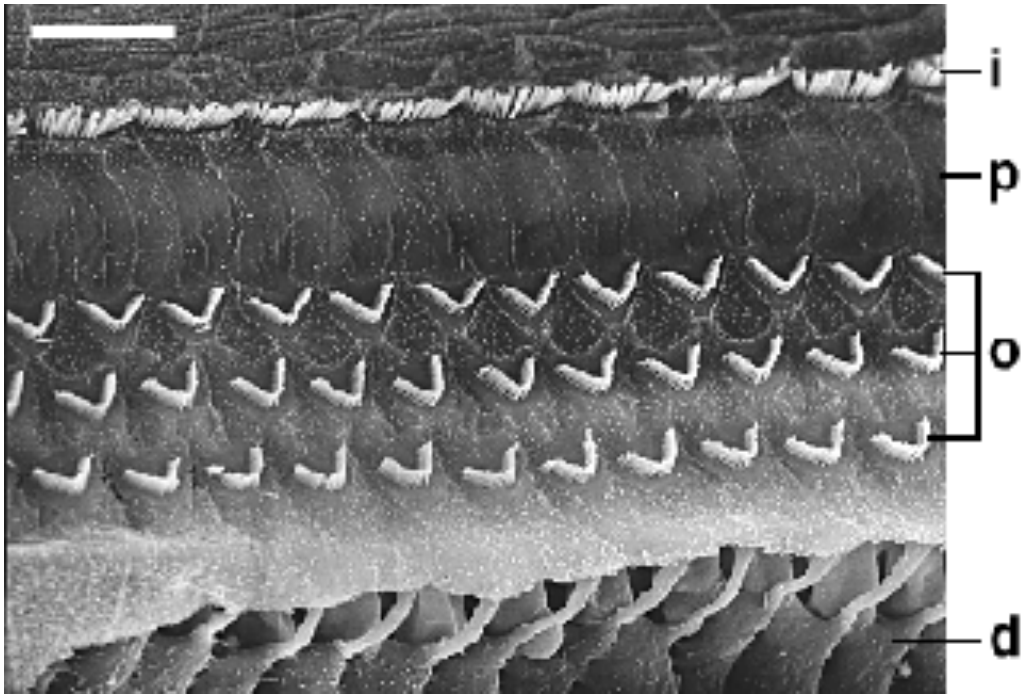
Basilar Membrane

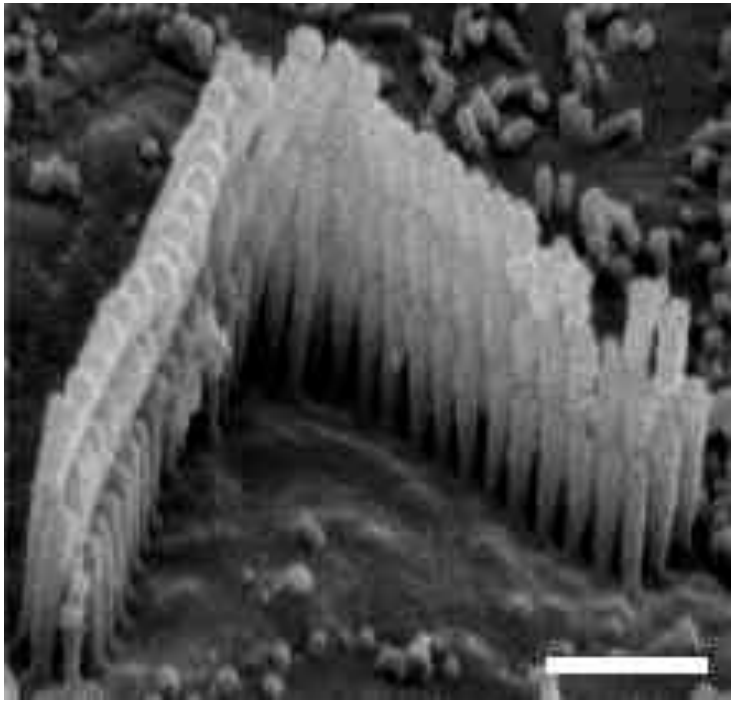
Auditory Nerve



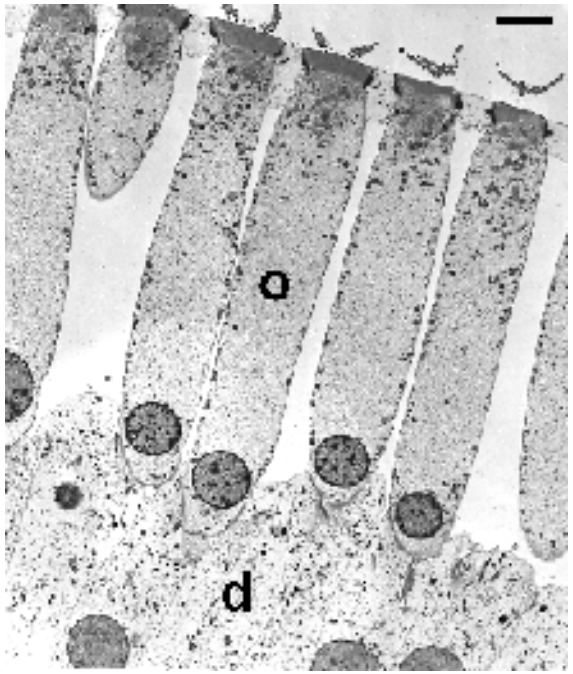
Structure of Cochlea

Stereocilia (Hair Cells)



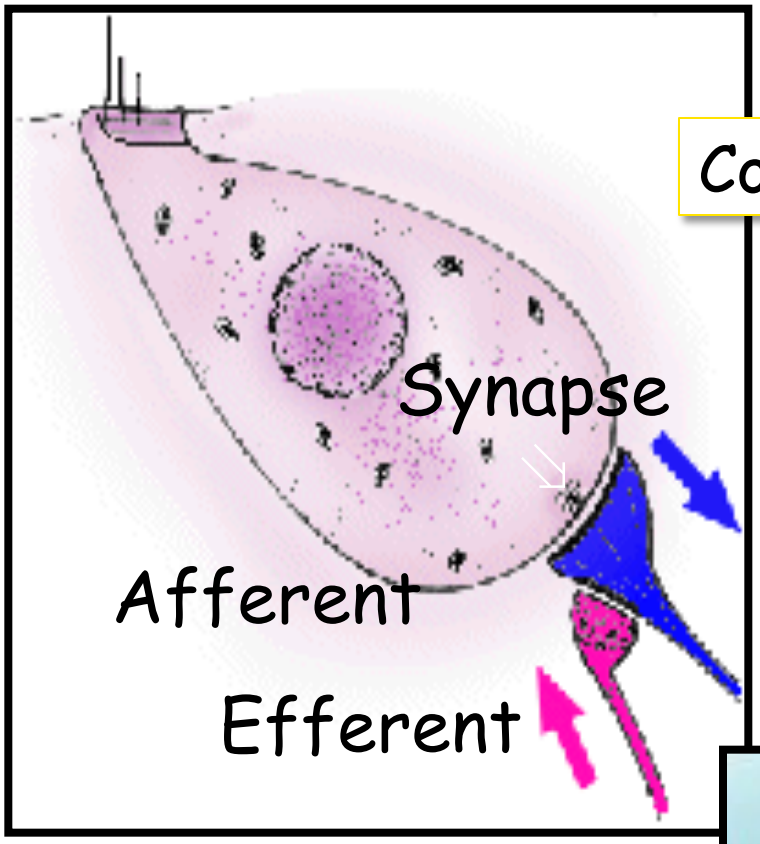


Outer Hair Cell

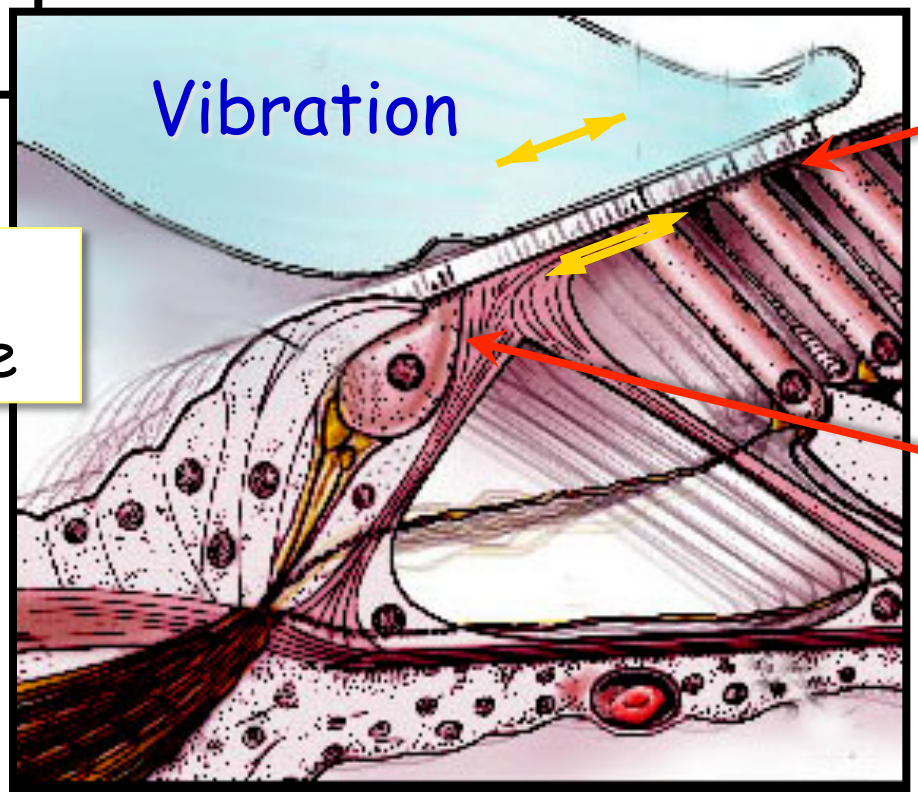


Structure of Cochlea

Connection to nerves

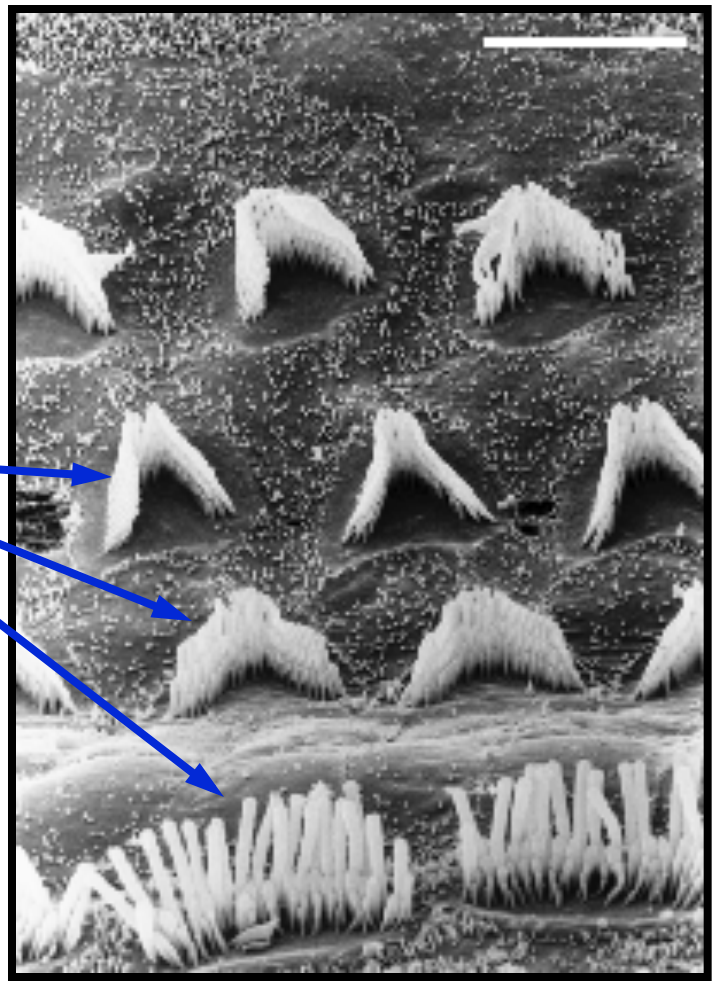


Organ of Corti and Basilar Membrane

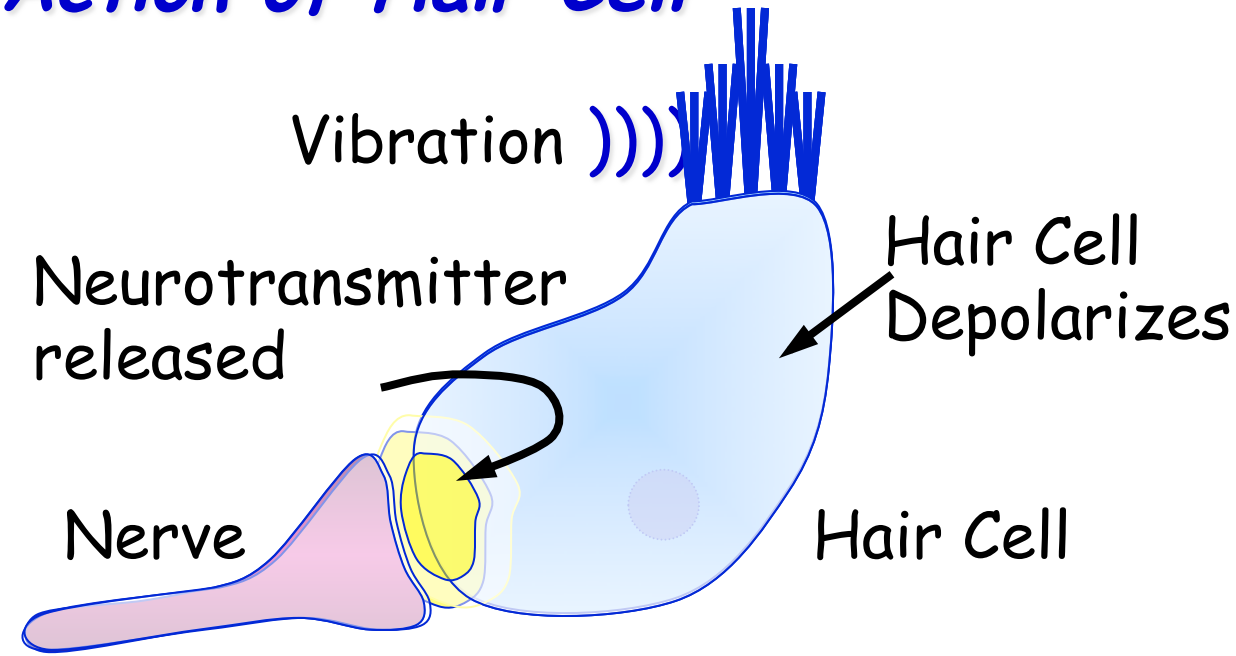


Detail of Hair Cell

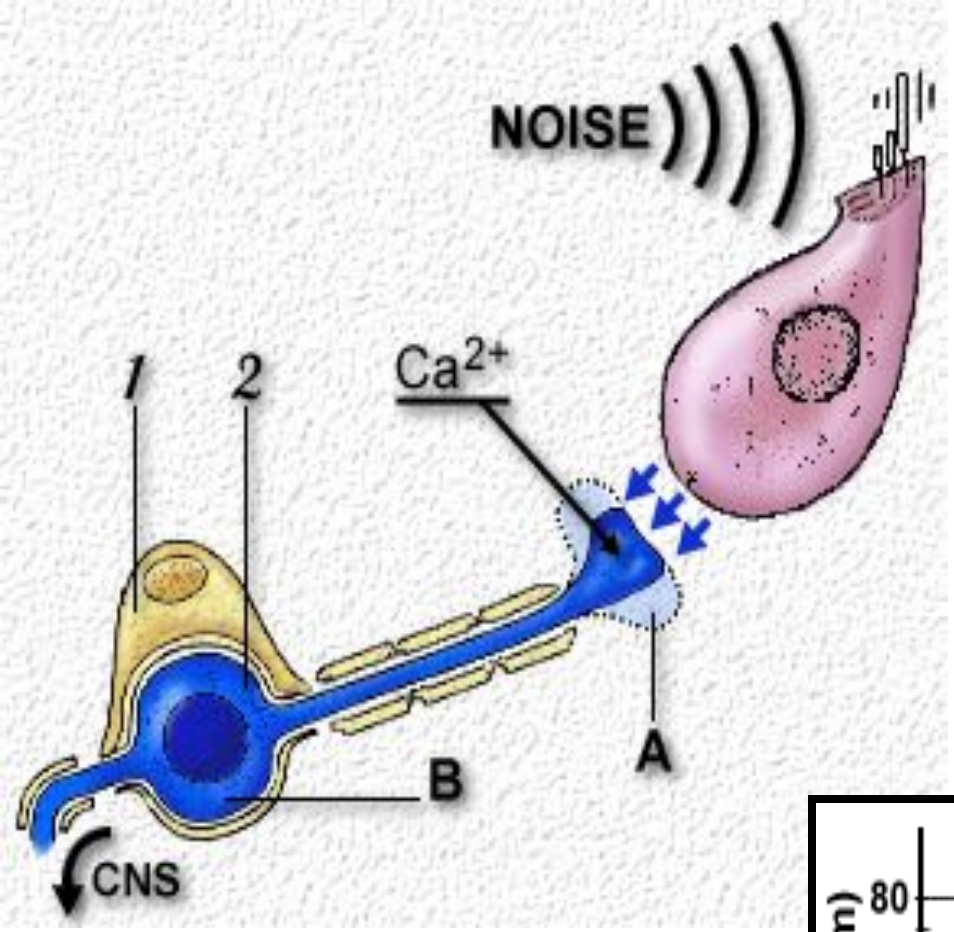
Hair cells have nothing to do with hair that grows in the skin. Hair cells are vibration sense organs



Action of Hair Cell

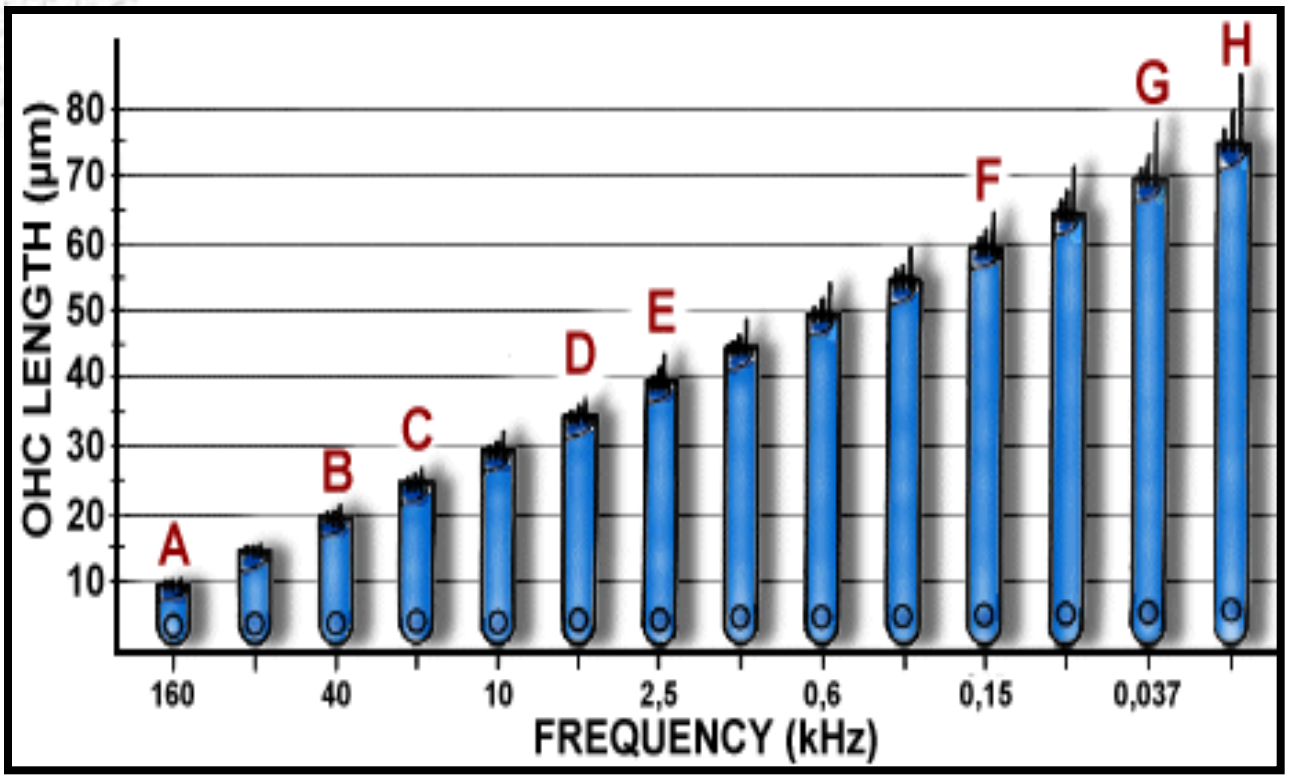


Function of Stereocilia



Stimulation in hair cells (HC) causes neuro-transmitter to stimulate neuron in auditory nerve

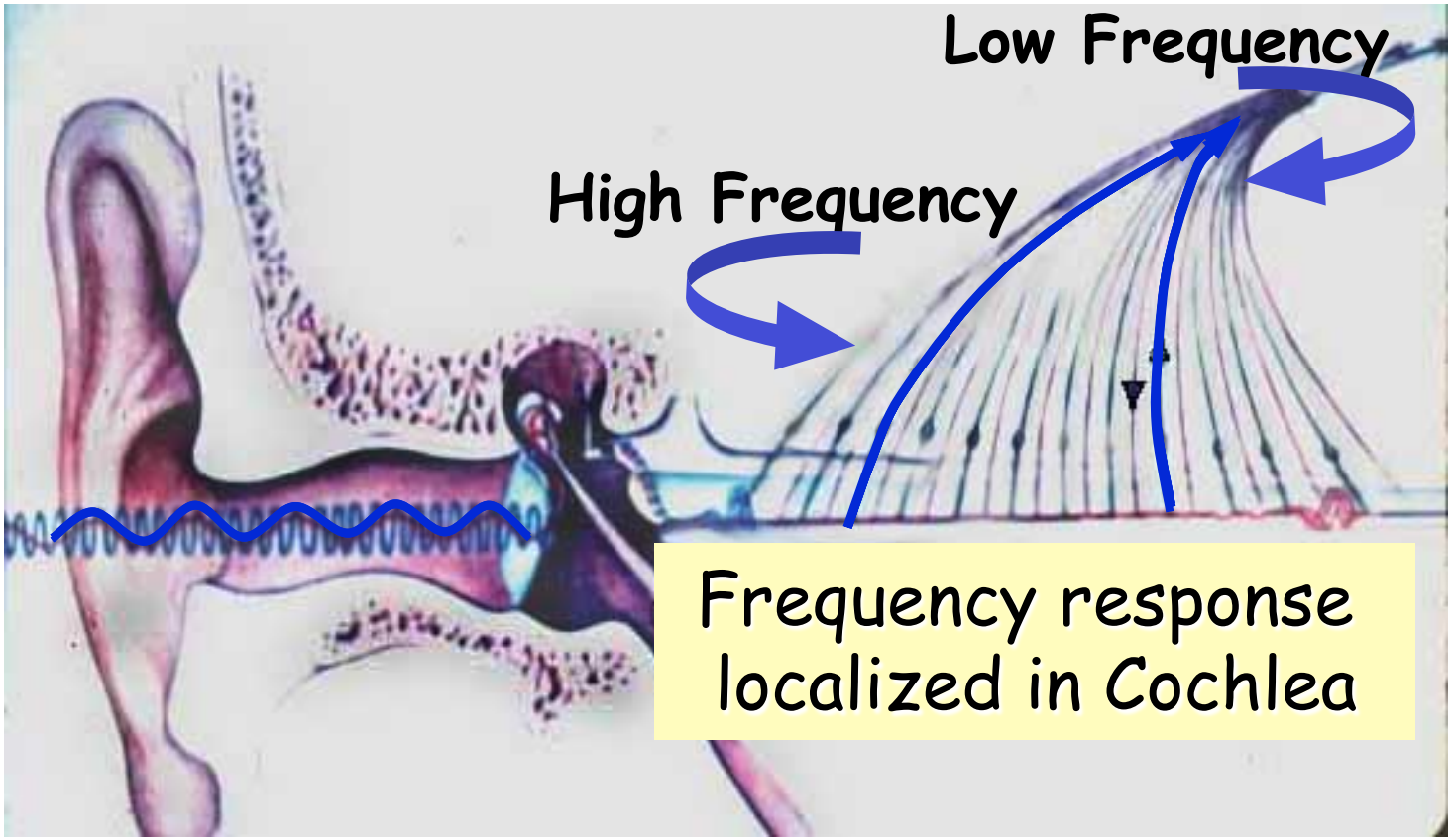
Frequency Response of Hair Cells



Frequency Discrimination in Cochlea

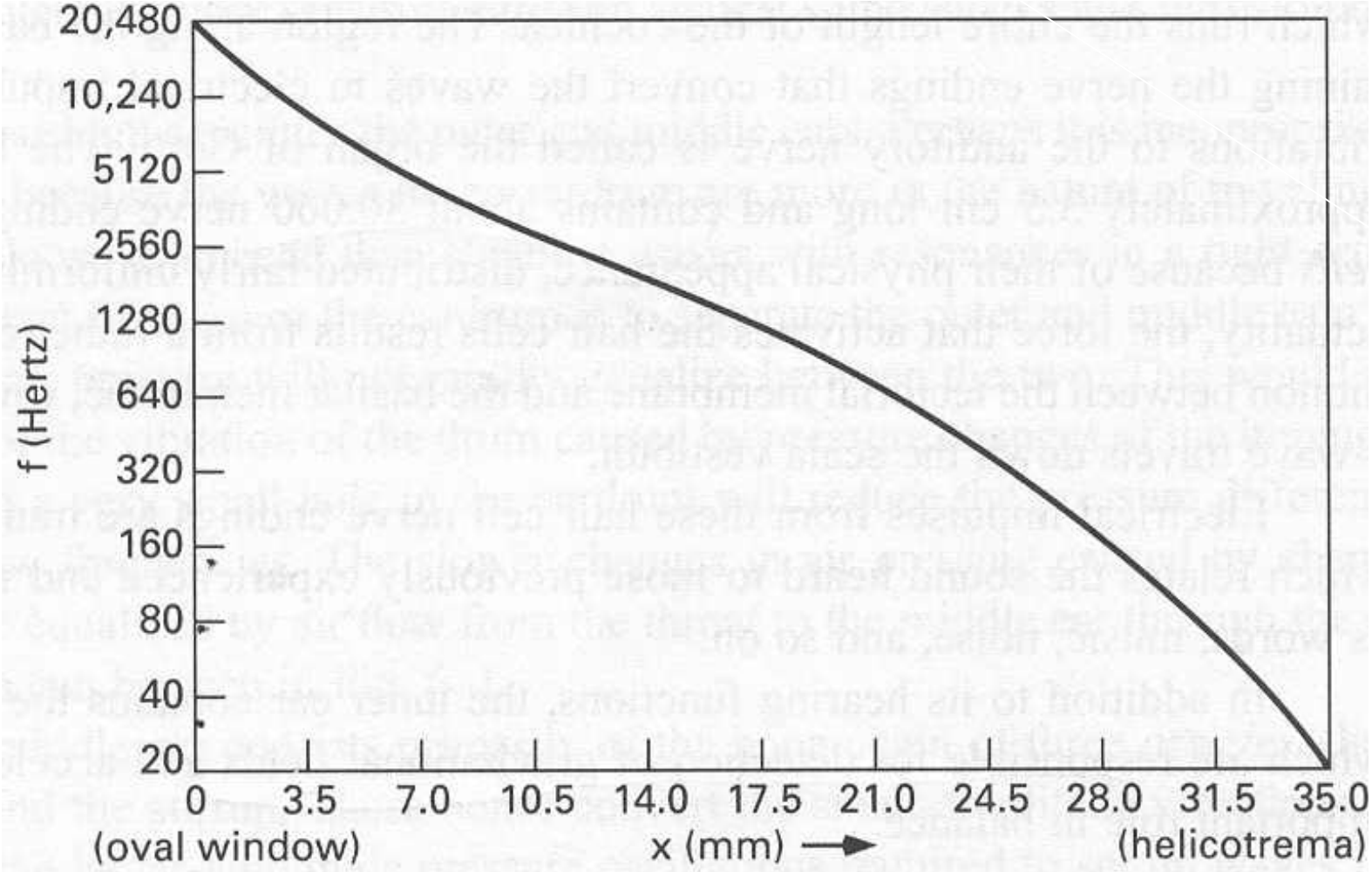
- 20 Hz to 20 kHz (typical in Humans)
- Resonances in basilar membrane and in HC cause spatial separation by frequency.
- Differential movement of membranes stimulate HC.
- Minimum stimulation required for response. Inhibition of neighbors causes non-linear response.

Neuronal Decoding of Sound (Schematic)



Localization of Vibration on Basilar Membrane

- Each octave is an ≈ equal shift of ≈ 3.5 mm
- Each pure tone is localized to a Critical Band of ≈ 1.2 mm.
- Each pure tone excites ≈ 1300 hair cells covering a 15% frequency range (< minor third).



Neuronal Response to Sound

- **Frequency** → Where? The location where in the Cochlea the stereocilia are stimulated.

- **Intensity** → How many? The number of HC that are stimulated by the sound determines the perceived loudness.

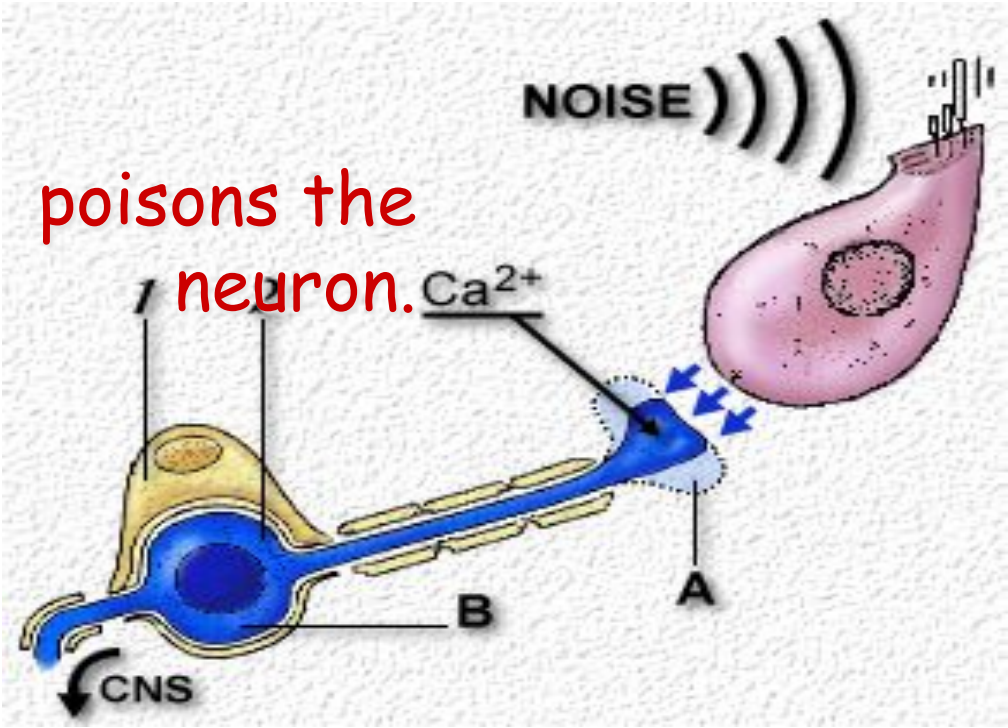
- *Repeated acoustic trauma can cause permanent and profound hearing loss or deafness.*

- *If you have experienced temporary hearing loss due to loud sounds you have had a warning.*

- *Stereocilia do regenerate daily.*

Hearing loss

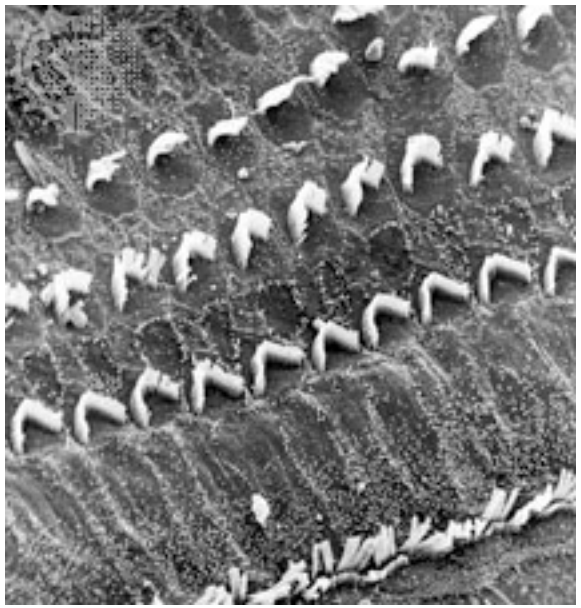
Too much Ca^{2+} poisons the neuron.



Hearing loss due to over stimulation causes excitotoxicity

Extreme acoustic trauma

Guinea Pig Stereocilia damage (120 dB sound)



not exposed

after exposure

Hearing Loss

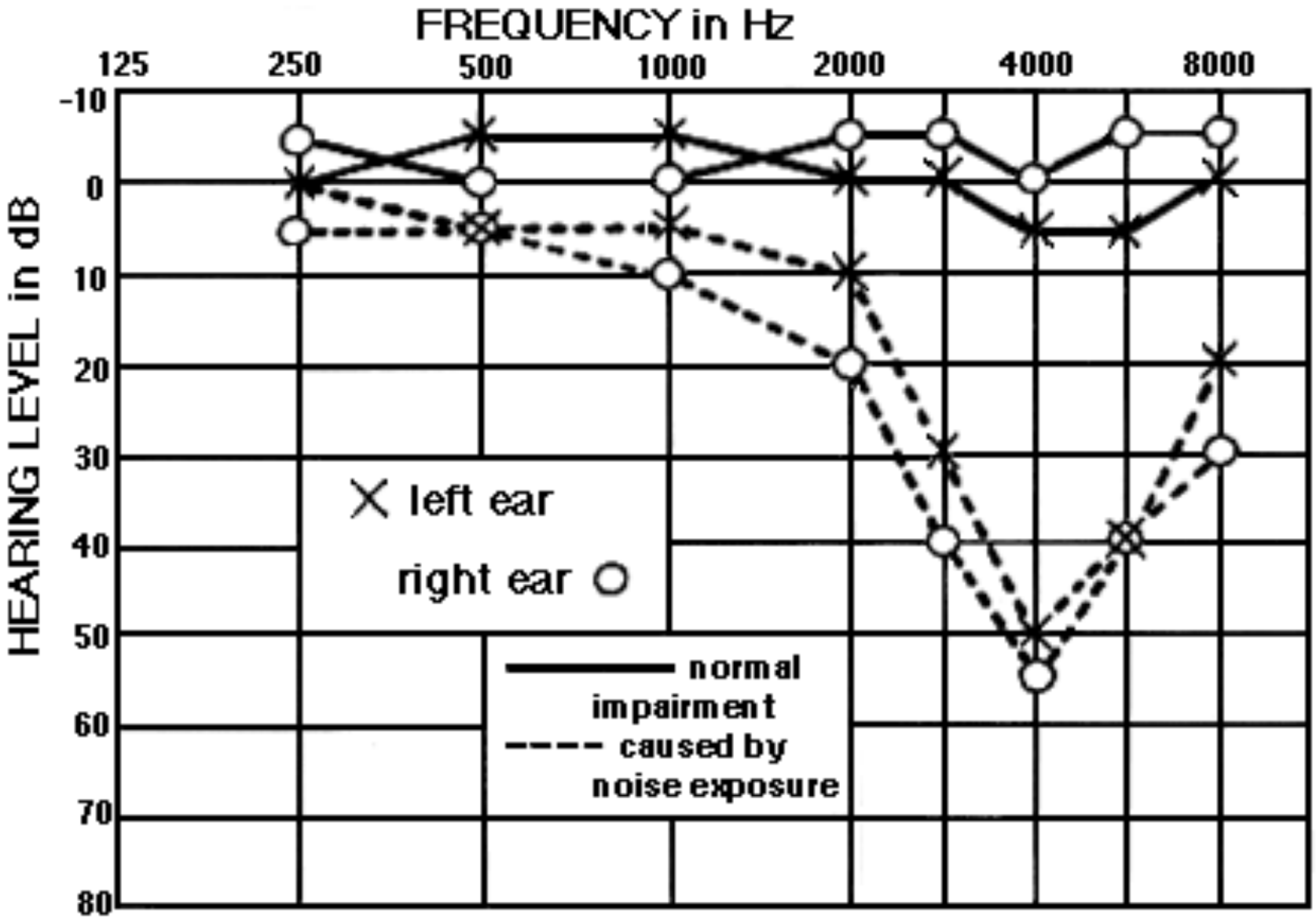
Causes

1. Temporary threshold shifts: exposure to noise, reaction to drugs
2. Permanent hearing loss: noise or drug exposure, natural aging (presbycusis), rubella during pregnancy
3. Tinnitus or ringing in ear (permanent or temporary): noise or drug exposure

Treatments

1. Diagnosis using **audiogram**
2. Surgery for outer and middle ear
3. No correction for central auditory system problems
4. Hearing aid corrects threshold problems
5. Cochlear Implants

Hearing loss - Audiograms



Cochlear Implant