Hearing

Sound is conducted in 3 ways in ear

i) Ossicular conduction- normal conversation

ii) Air conduction- through air in middle ear (if ossicular chain fails to conduct)

iii) Bone conduction- only on very loud sound or when vibrating tuning fork is placed on skull.

Why hearing sensation is important for life?

1) It is important for communication

2) To make us alert from danger (survival & protective value)

3) Speech development

Anatomy of ear- ear include

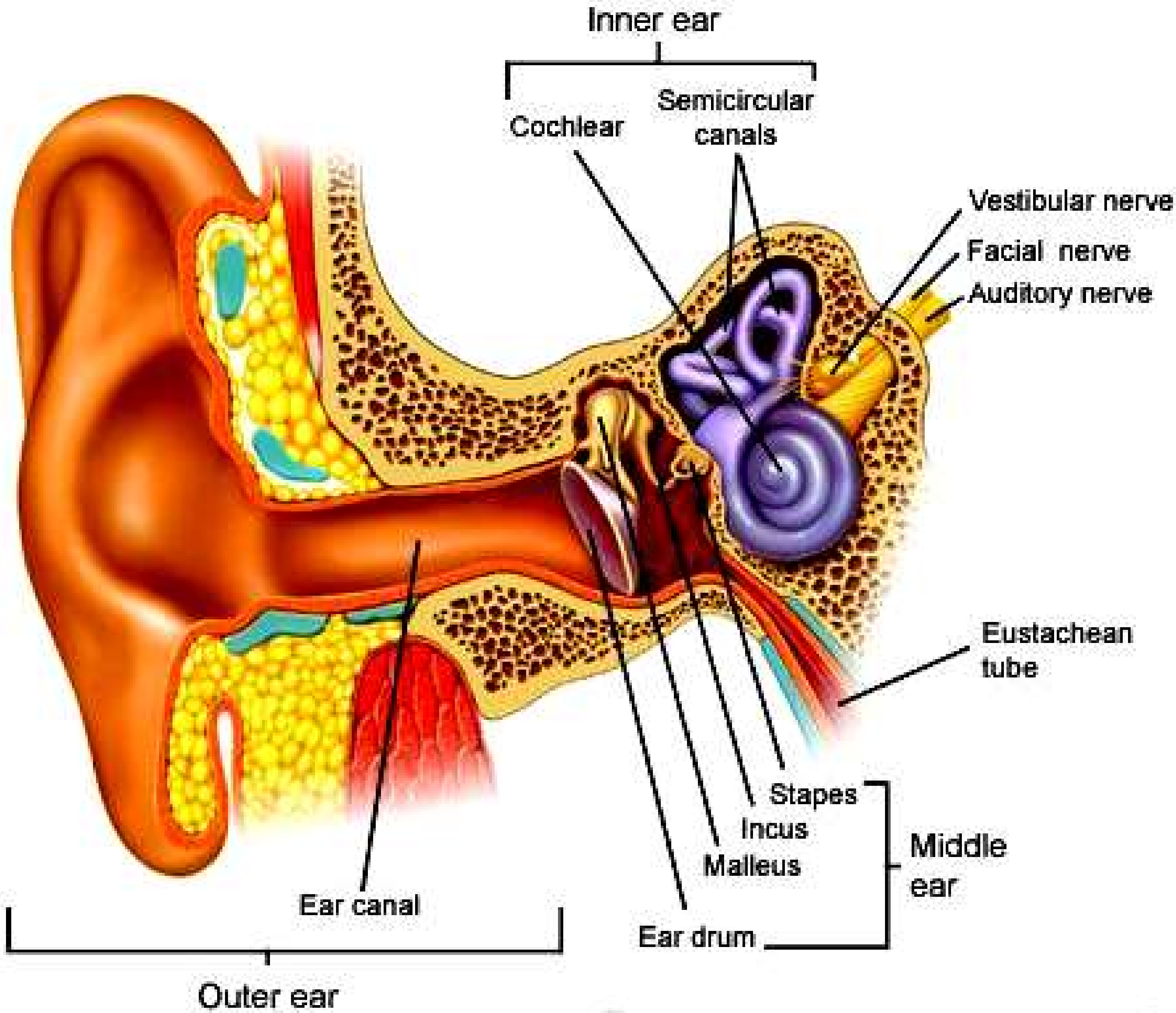
i) External ear

ii) Middle ear

iii) Internal ear(cochlea of vestibulocochlear apparatus)

Function of ear-

Ear helps in receiving, amplifying, transduction & transmission of sound waves


Inner ear
Cochlear
Semicircular canals
Vestibular nerve
Facial nerve
Auditory nerve
Eustachean tube
Stapes
Incus
Malleus
Middle ear
Ear drum
Ear canal
Outer ear

i) External ear-

- Made of Pinna & External auditory canal / meatus

Pinna-

- made of skin, cartilage and muscles (muscle vestigial in humans)

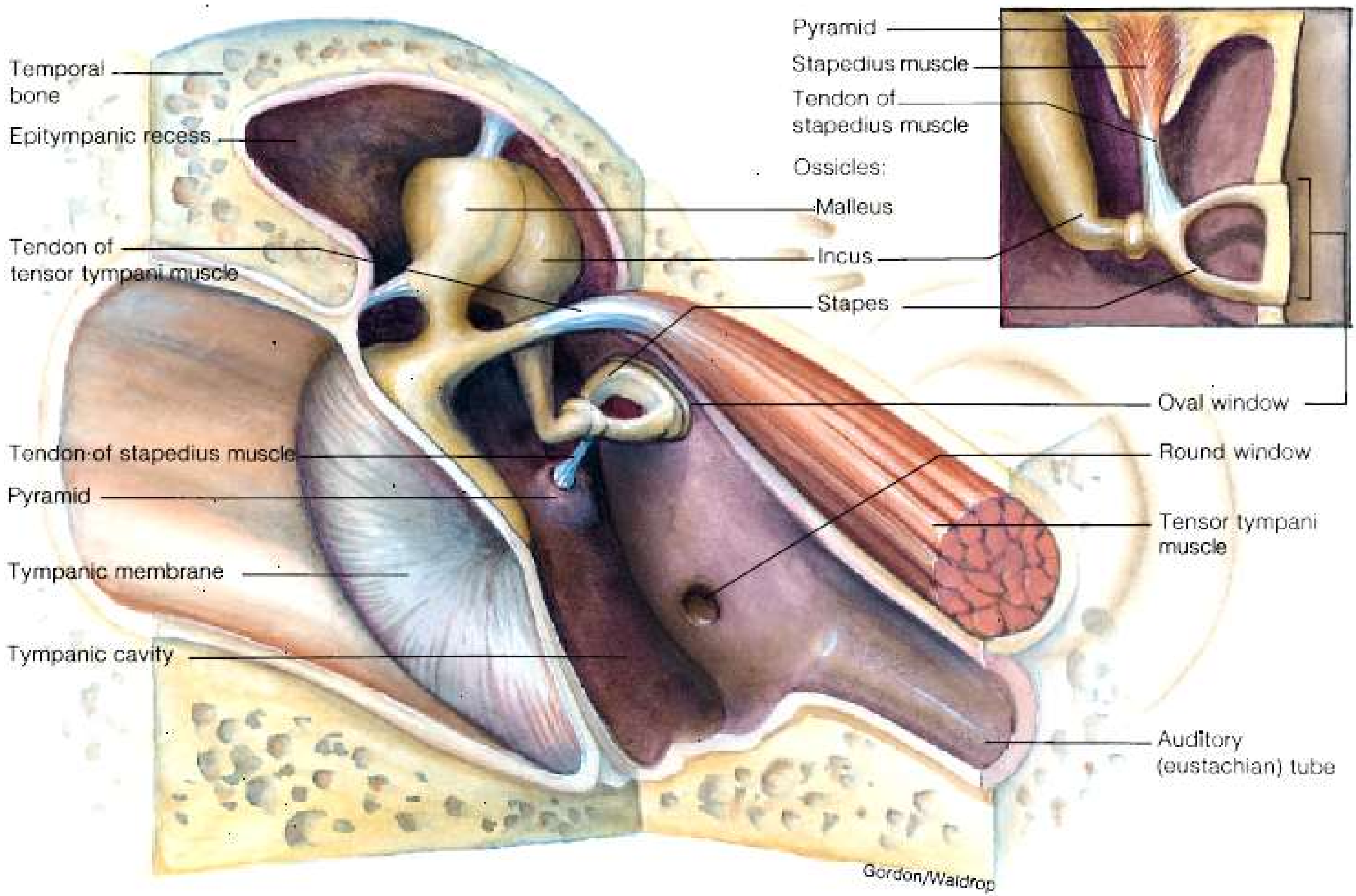
- Functions- collects & reflects the sound waves into the external auditory canal, help localizing the sounds

External auditory meatus or canal-

- it is 2.5 cm tortuous canal , which conducts the sound waves to the tympanic membrane (ear drum).

- Its tortuosity maintain optimum temp. & humidity for the function of ear drum as well as save it from mechanical injuries.

- It has hairs, sweat glands & ceruminous glands (which secrete protective ear wax)


Temporal bone
Epitympanic recess
Tendon of tensor tympani muscle
Tendon of stapedius muscle
Pyramid
Tympanic membrane
Tympanic cavity
Pyramid
Stapedius muscle
Tendon of stapedius muscle
Ossicles:
Malleus
Incus
Stapes
Oval window
Round window
Tensor tympani muscle
Auditory (eustachian) tube
Gordon/Waldrop

ii) Middle ear-

- Air filled cavity , lateral wall by tympanic membrane(ear drum) & medial wall by oval window (above) & round window (below),

- 1 Opening of auditory tube or eustachian tube or pharyngotympanic tube which connect it to naso-pharynx.

- 2 muscles- Tensor tympani (supplied by V nerve) & Stapedius (supplied by VII nerve)

- 3 ossicles- maleus, incus and stapes

Functions of middle ear-

1) transmit sound waves from external ear to internal ear (by ossicular & air conduction)

2) Ossicles- Amplify the sound (impedance matching)

3) Muscles- Protects internal ear from damage by loud sound (tympanic reflex)

4) Auditory tube helps equalize pressure between middle ear & external environment

5) Tensor tympani keep tympanic membrane tense for its optimum vibration.

- <u>Attenuation reflex or tympanic reflex (S.N.)-</u>
Is a protective reflex against loud sound.

- It is reflex contraction of tensor tympani & stapedius (main) muscles together in response to loud sound.

- this makes the ossicular chain rigid & so it moves less & transmission of sound are decreased.

Significance- i) Protection of organ of corti against loud sound

ii) Specially masks sound below 1000Hz, so background noise is blocked & we can concentrate on conversation sounds (above 1000Hz.)

iii) It reduces ones ability to hear own sound while speaking or chewing

Limitations- Reaction time is 40-160 msecs so fails to protect from brief intense stimulation eg. gun shot sound.

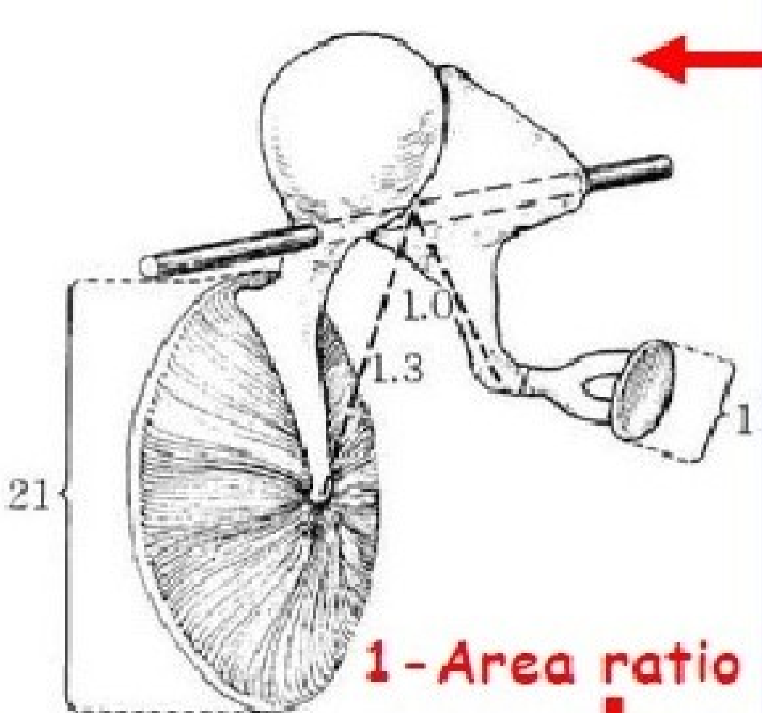
Impedance matching (S.N.)-

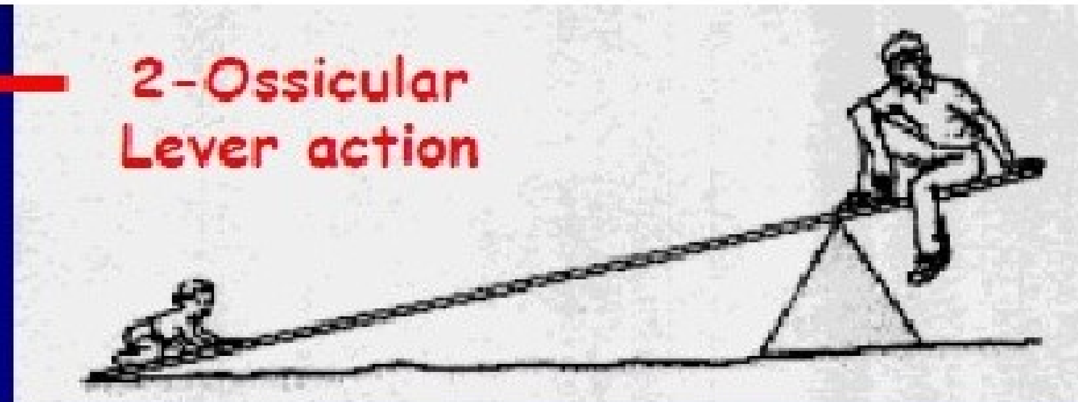
- is required as inertia of the fluid is more than air, so sound energy is likely to lost while travelling from air to the perilymph of the internal ear

- Is achieved by 22 times increase or amplification in the force or pressure on unit area of oval window in compare to tympanic membrane.

FUNCTIONS OF MIDDLE EAR:

1.IMPEDANCE MATCHING





Malleus and Incus behave as **1st degree lever**

$$\frac{\text{Diameter of TM}}{\text{Diameter of OW}} = \text{Area ratio } 21:1$$

- 17 times increase in the force is due to relatively large surface area of tympanic membrane (55 mm2) compare to oval window (3.2 mm2).

- 1.3 times increase in force per unit area is because ossicular chain act like a lever system, so total there is

- 17 X 1.3 = 22 times increase & this results-

- 60 % impedance matching for the sound b/t 300 to 3000 Hzs.

- What is the cause of ear pain during the attack of common cold & during flight?

- In common cold, pharyngeal end of auditory tube get blocked due to congestion and fail to open during swallowing. Eventually air in middle air get absorbed that results ear pain & hearing loss.

- Because at high altitude, air in middle ear expands (due to low pressure). So repeated swallowing should be encouraged (like inducing salivation by lemon candies) to open the A. Tube.

- Cochlea is a coiled bony tube, like shell of a snail, lying in the cavity of petrous part of the temporal bone.

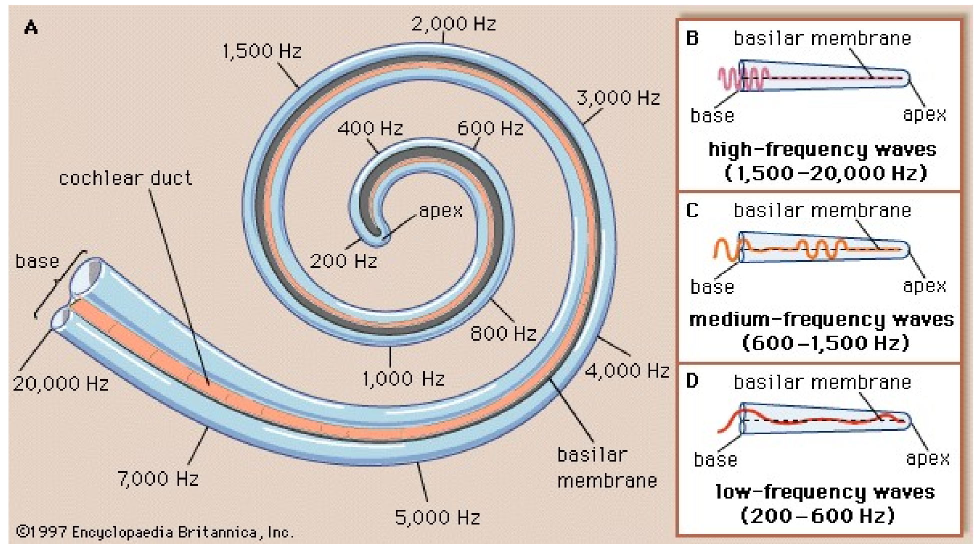
- There is a central bony pillar called modiolus which has internal auditory canal containing auditory nerve.

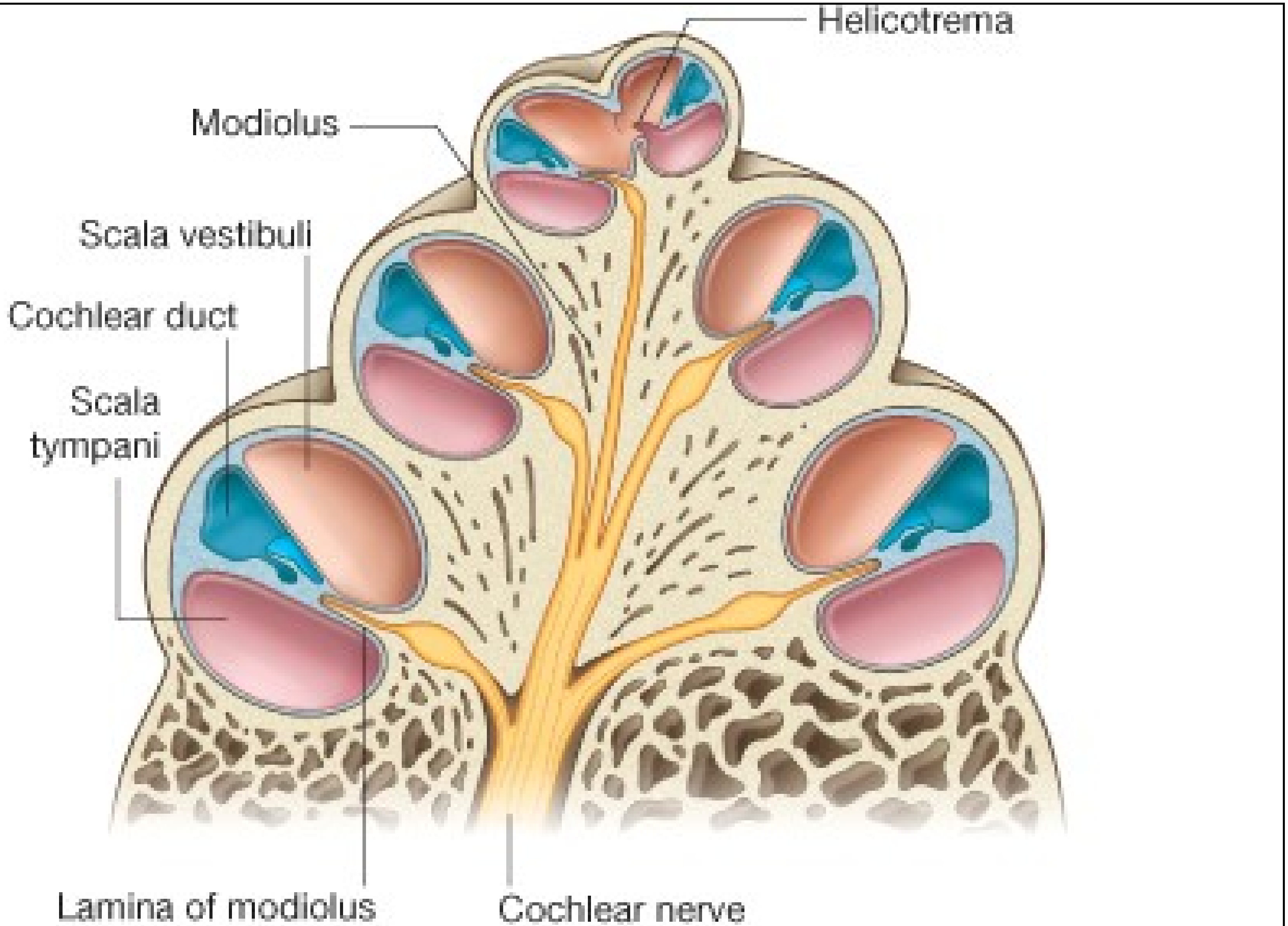
- Bony canal of cochlea winds round the modiolus for two and a half turns tapering from base to the apex.

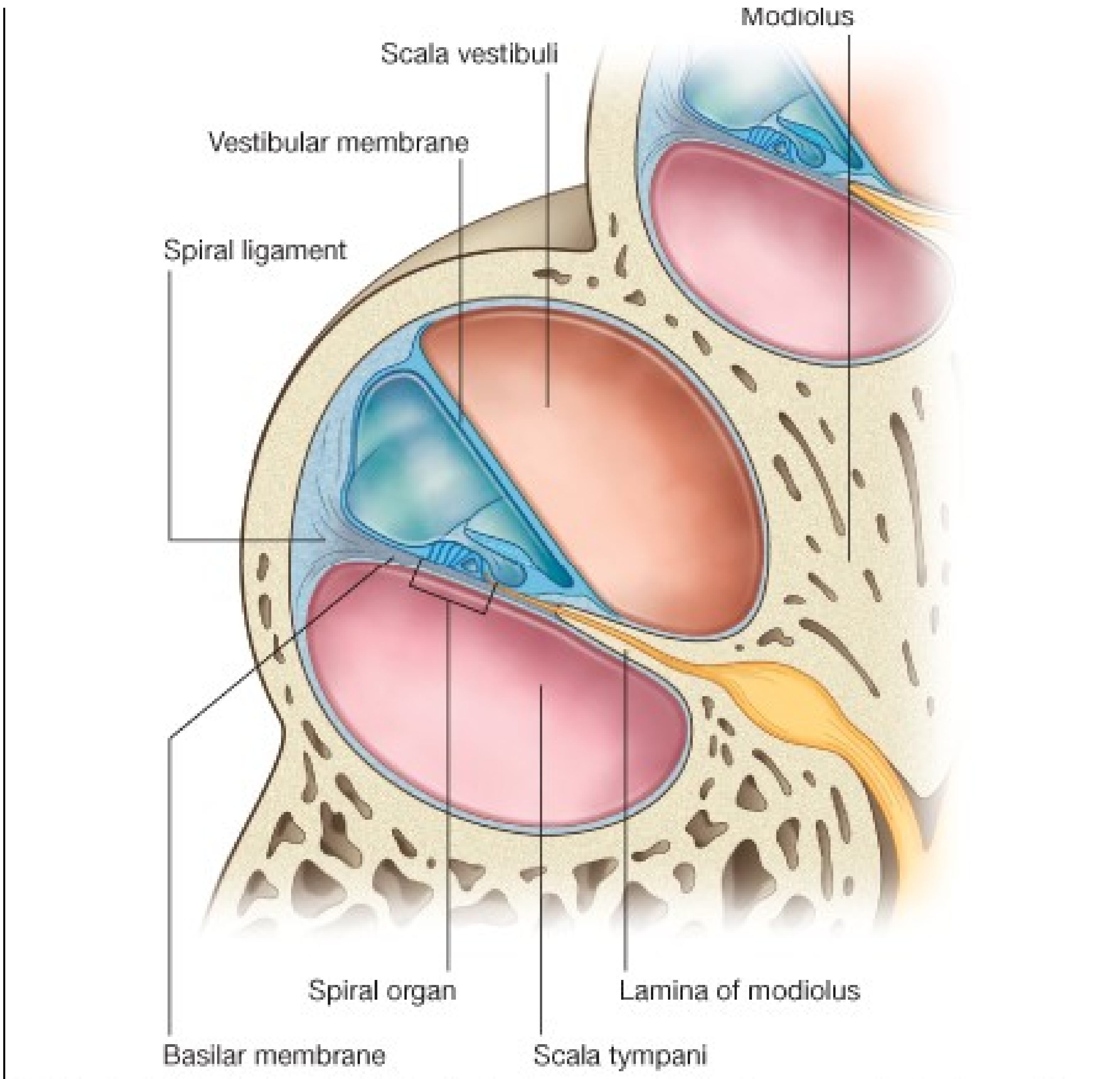
INNER EAR

Cochlea


SCIENCEphotoLIBRARY


A
2,000 Hz
1,500 Hz
3,000 Hz
400 Hz
600 Hz
cochlear duct
apex
base
200 Hz
800 Hz
20,000 Hz
1,000 Hz
4,000 Hz
7,000 Hz
basilar
membrane
5,000 Hz
©1997 Encyclopaedia Britannica, Inc.
B
basilar membrane
base
apex
high-frequency waves
(1,500–20,000 Hz)
C
basilar membrane
base
apex
medium-frequency waves
(600–1,500 Hz)
D
basilar membrane
base
apex
low-frequency waves
(200–600 Hz)


Helicotrema
Modiolus
Scala vestibuli
Cochlear duct
Scala tympani
Lamina of modiolus
Cochlear nerve


Modiolus
Scala vestibuli
Vestibular membrane
Spiral ligament
Spiral organ
Lamina of modiolus
Basilar membrane
Scala tympani

- A bony ledge osseous spiral lamina projects into the bony canal of cochlea.

- It winds round the modiolus like the thread of a screw. From the tip of osseous spiral lamina,

- basilar membrane arises which extends to the wall of cochlea.

- Another thin membrane called vestibular (Reissner's) membrane arises from upper surface of modiolus and extends up

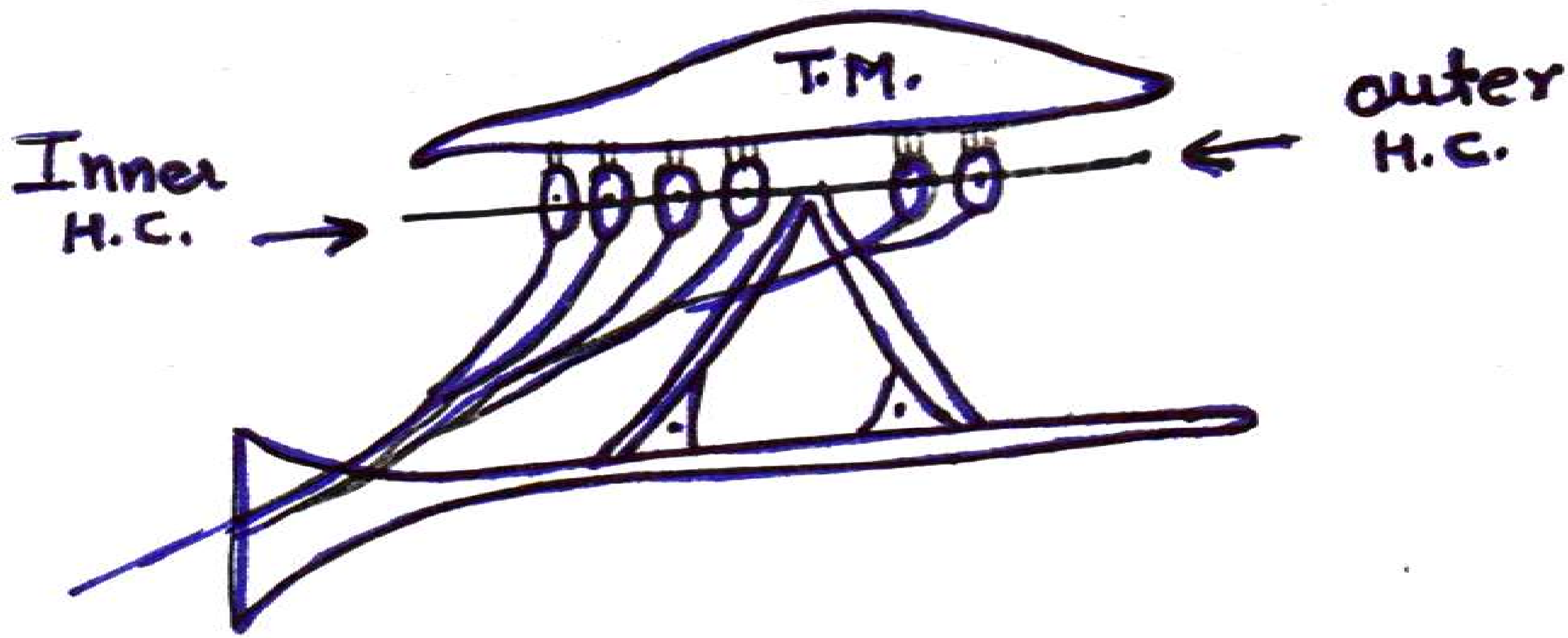
Structure of organ of Corti-

The main features of organ of Corti are the inner and outer rods of Corti forming a single row.

These are based on the basilar membrane. Their upper ends converge and join forming part of lamina reticularis

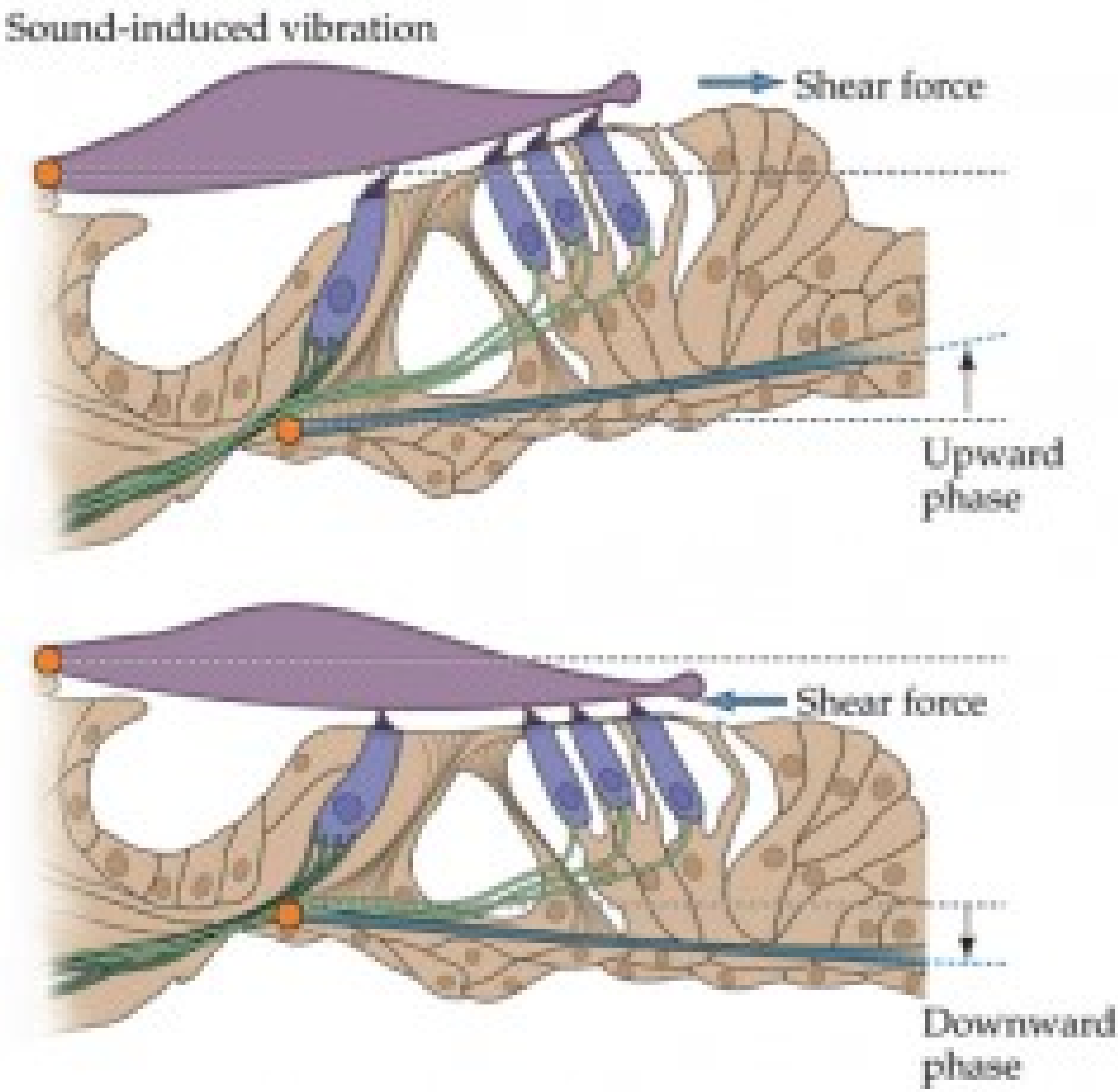
Receptor cells in the organ of Corti are inner and outer cells. Their bases lie on the basilar membrane and their upper ends are embedded in lamina reticularis.

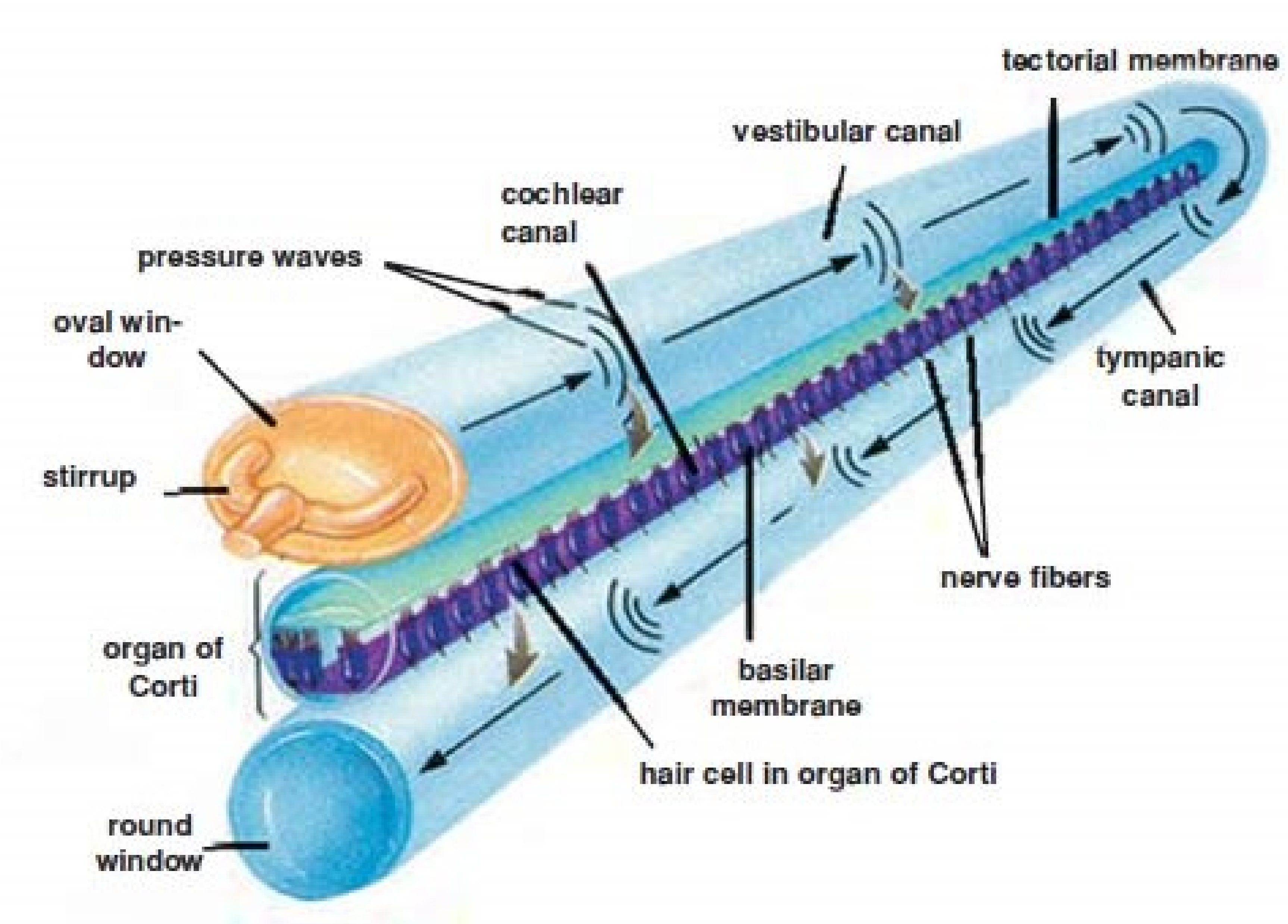
Structure of organ of Corti-

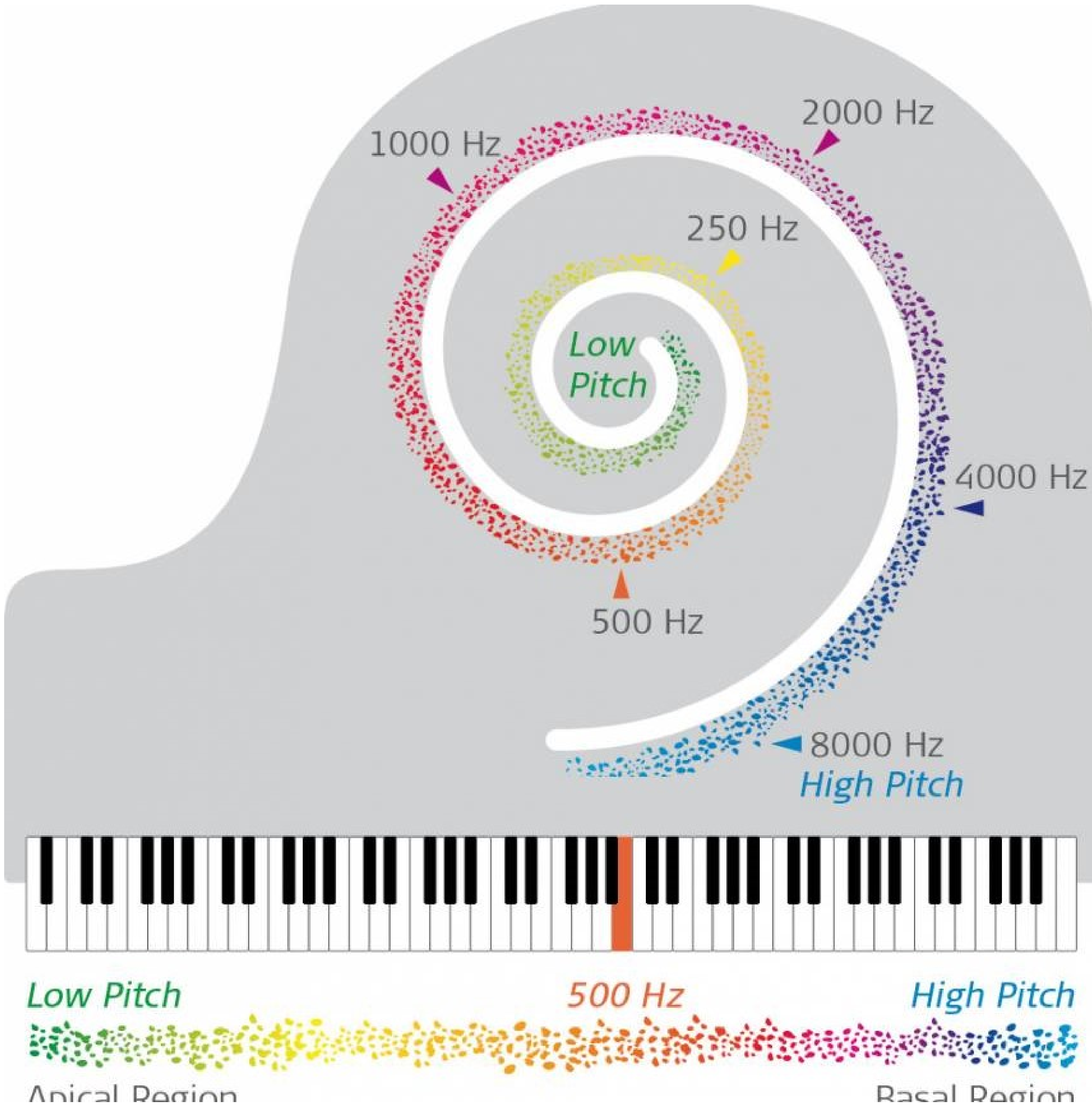


Inner hair cells- 3500, 1 row, 12 micron dia., 95 % nerve fibers

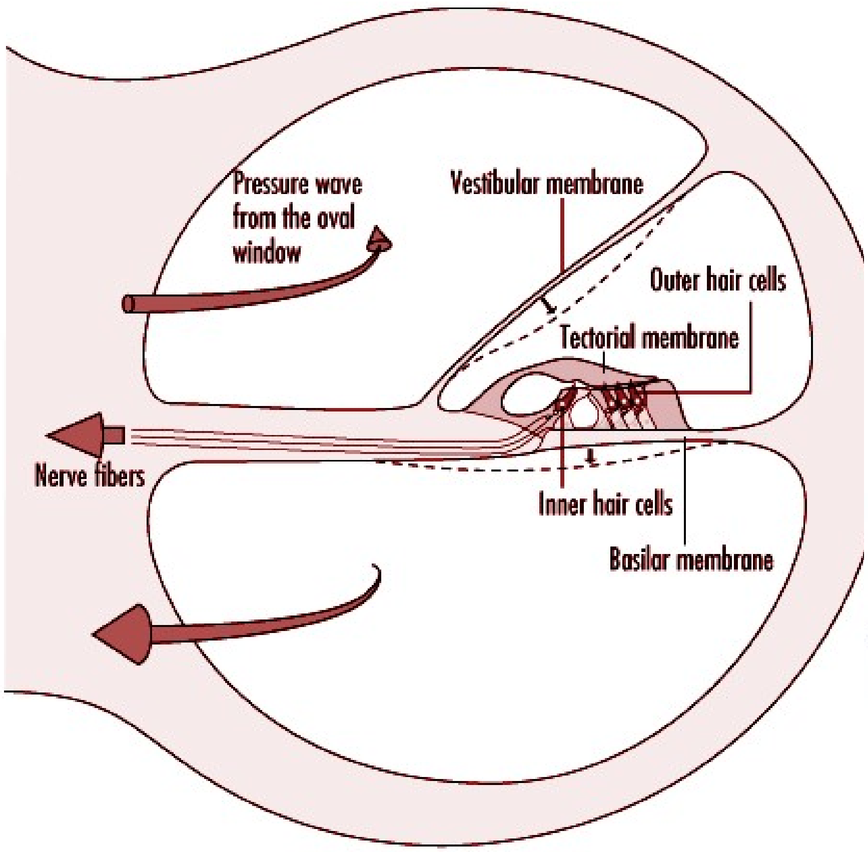
Outer hair cells- 12000, 3-4 rows, 8 micron, 5% nerve fibers


Sound-induced vibration
Shear force
Upward phase
Shear force
Downward phase

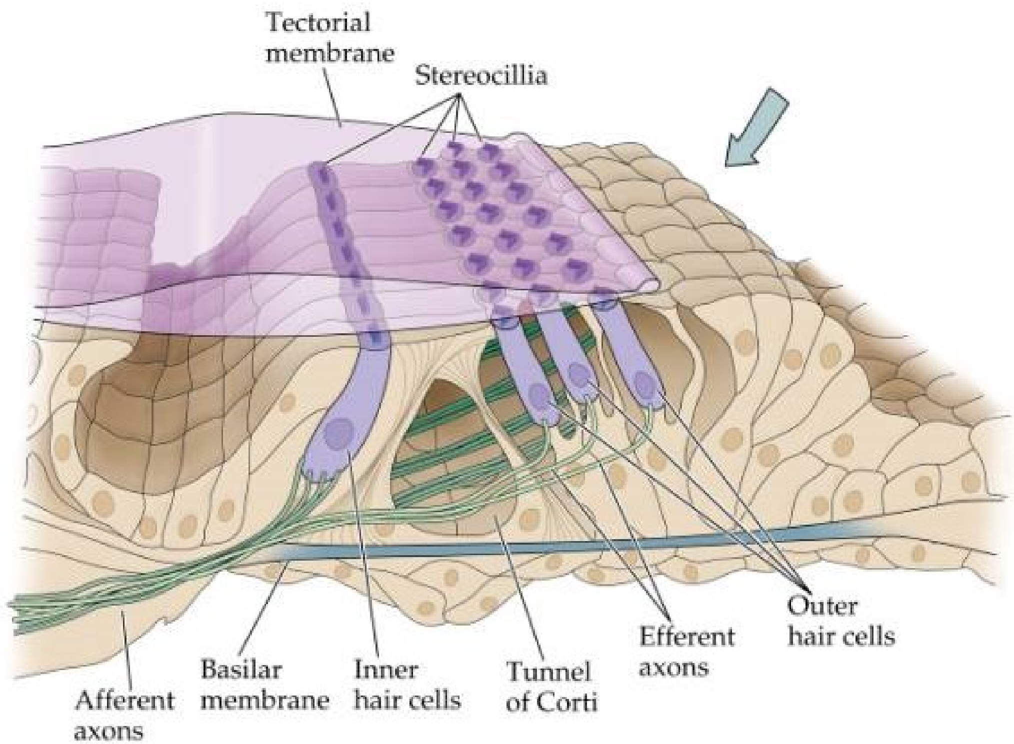

tectorial membrane
vestibular canal
cochlear
canal
pressure waves
oval win-
dow
stirrup
organ of
Corti
round
window
tympanic
canal
nerve fibers
basilar
membrane
hair cell in organ of Corti



2000 Hz
1000 Hz
250 Hz
Low Pitch
4000 Hz
500 Hz
8000 Hz
High Pitch
Low Pitch
500 Hz
High Pitch
Apical Region
Basal Region



Source: Hohmann and Schmuckli 1989.



Inner hair cells form a single row on the inner side of inner rod of Corti.

Outer hair cells form 3 to 4 rows on the outer side of outer rod of Corti. Hair coming out from upper end are covered by tectorial membrane.

These cells are supplied by network of cochlear nerve endings. They lead to spiral ganglion present in modiolus.

Basilar membrane.

Basilar membrane is a fibrous plate containing about 20,000 to 30,000 basilar fibres.

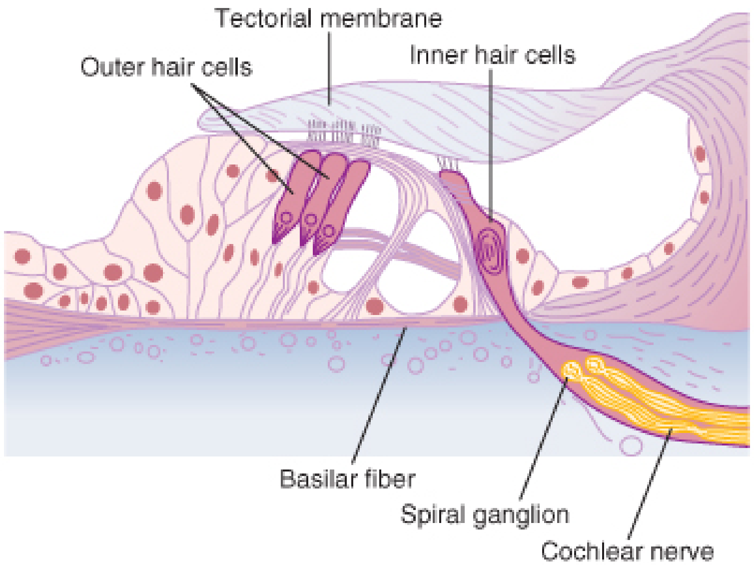
Each fibre projects from the tip of osseous spiral lamina to the wall of the cochlea.

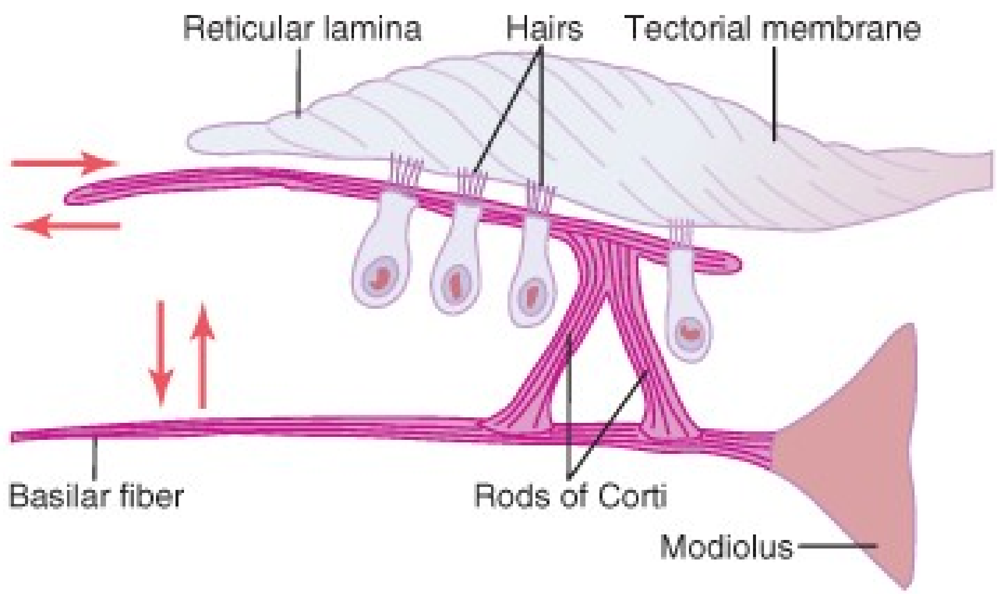
These fibers are stiff, elastic, and hair-like and are not fixed at their distal ends. Distal ends are embedded in the loose basilar membrane.

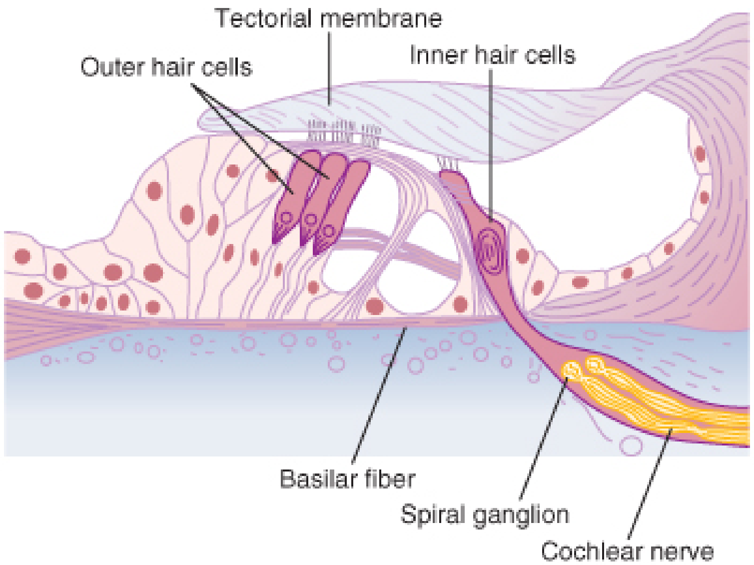
These fibres vibrate like reeds of harmonica. The length of basilar fibres increases progressively from base to apex of cochlea (from 0.04 to 0.5 mm).

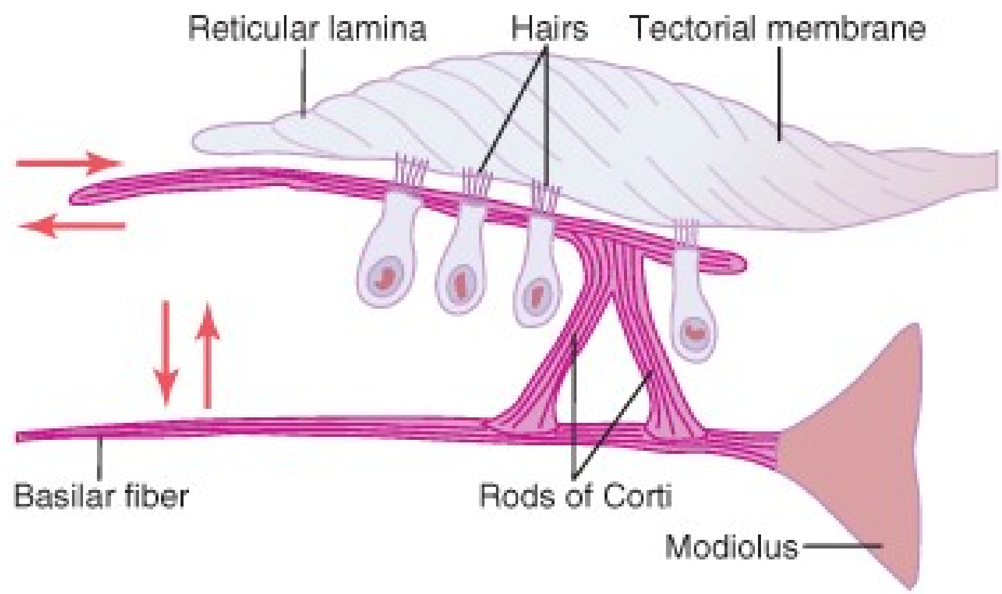
Thus there is twelvefold increase in length. Diameter of the fibres decrease from base to the apex of cochlea.

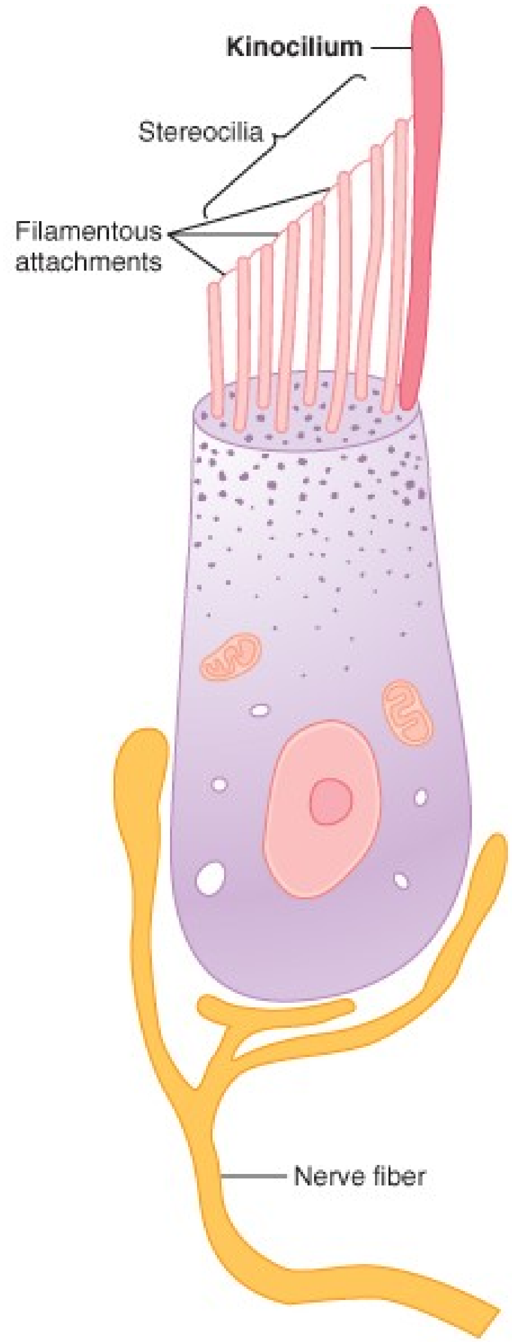
Therefore, there are stiff short fibres at the base which can vibrate with high frequency and thin long fibres at the tip which vibrate with low frequency.

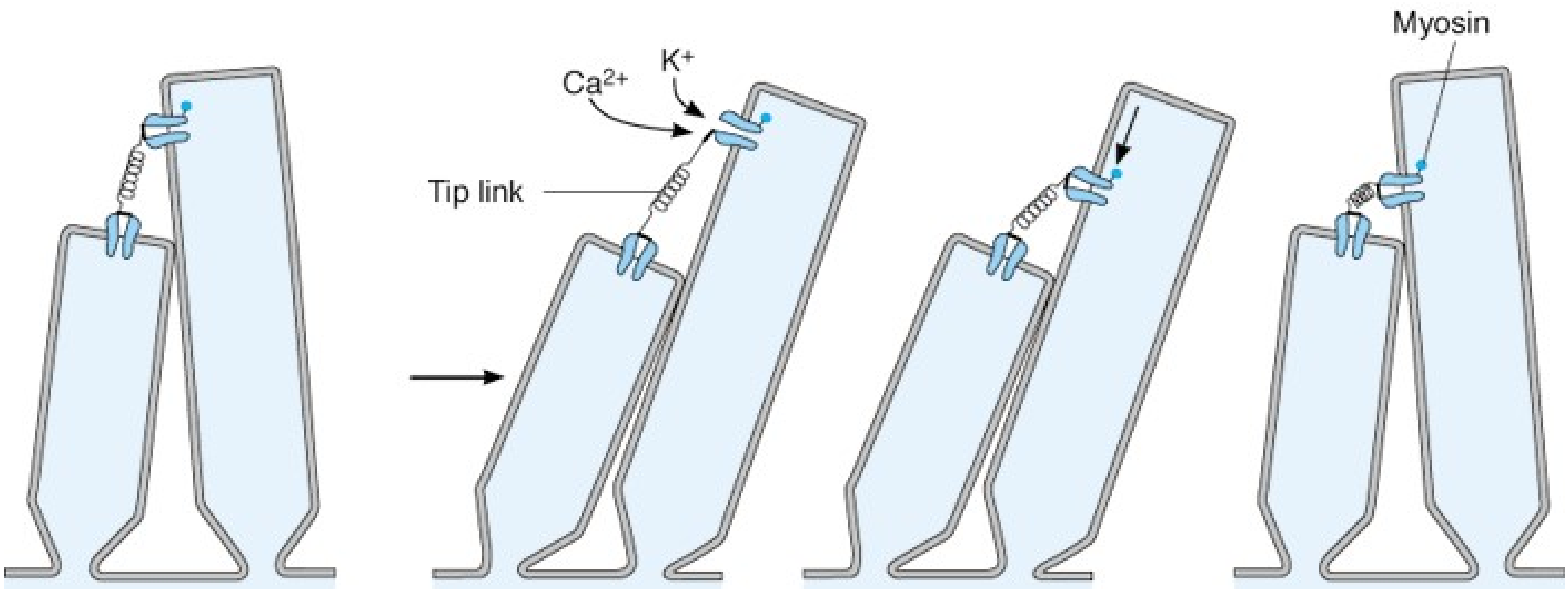

Tectorial membrane
Outer hair cells
Inner hair cells
Basilar fiber
Spiral ganglion
Cochlear nerve


Reticular lamina
Hairs
Tectorial membrane
Basilar fiber
Rods of Corti
Modiolus

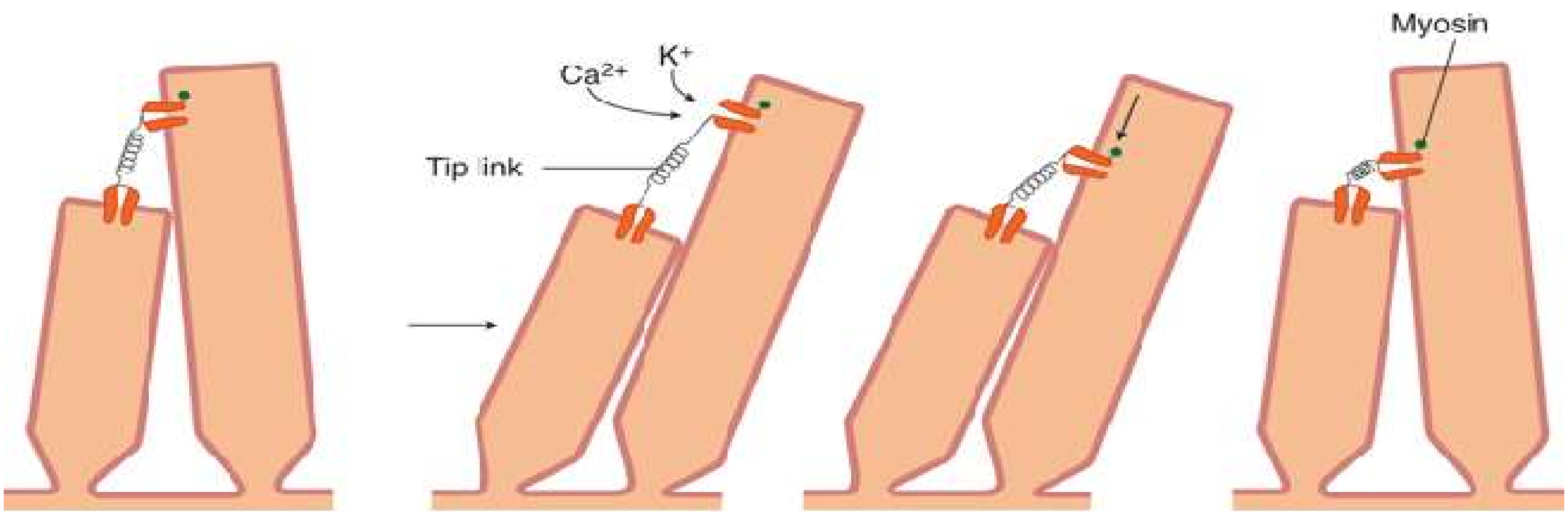

Tectorial membrane
Outer hair cells
Inner hair cells
Basilar fiber
Spiral ganglion
Cochlear nerve


Reticular lamina
Hairs
Tectorial membrane
Basilar fiber
Rods of Corti
Modiolus


Kinocilium
Stereocilia
Filamentous
attachments
Nerve fiber


Myosin
K+
Ca2+
Tip link

• When hairs move towards longer stereocilia causes mechanical transduction that opens 200-300 ca ion conducting channels which cause depolarisation. so hair cell receptor potential is generated.voltage gated ca channels open so ca dependant exocytosis of glutamate occur



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology, 23rd Edition*: http://www.accessmedicine.com

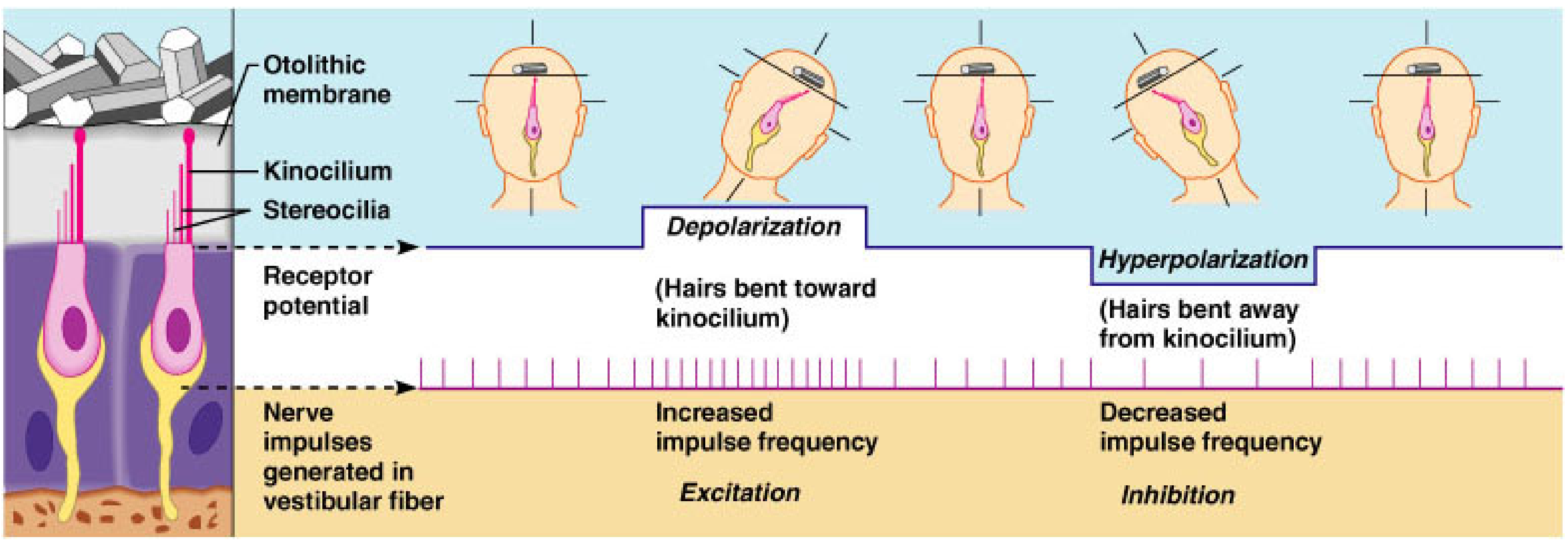
- If hair cells depolarise by entry of K then opens voltage gated Ca channels so exocytosis of neurotransmitter(glutamate)

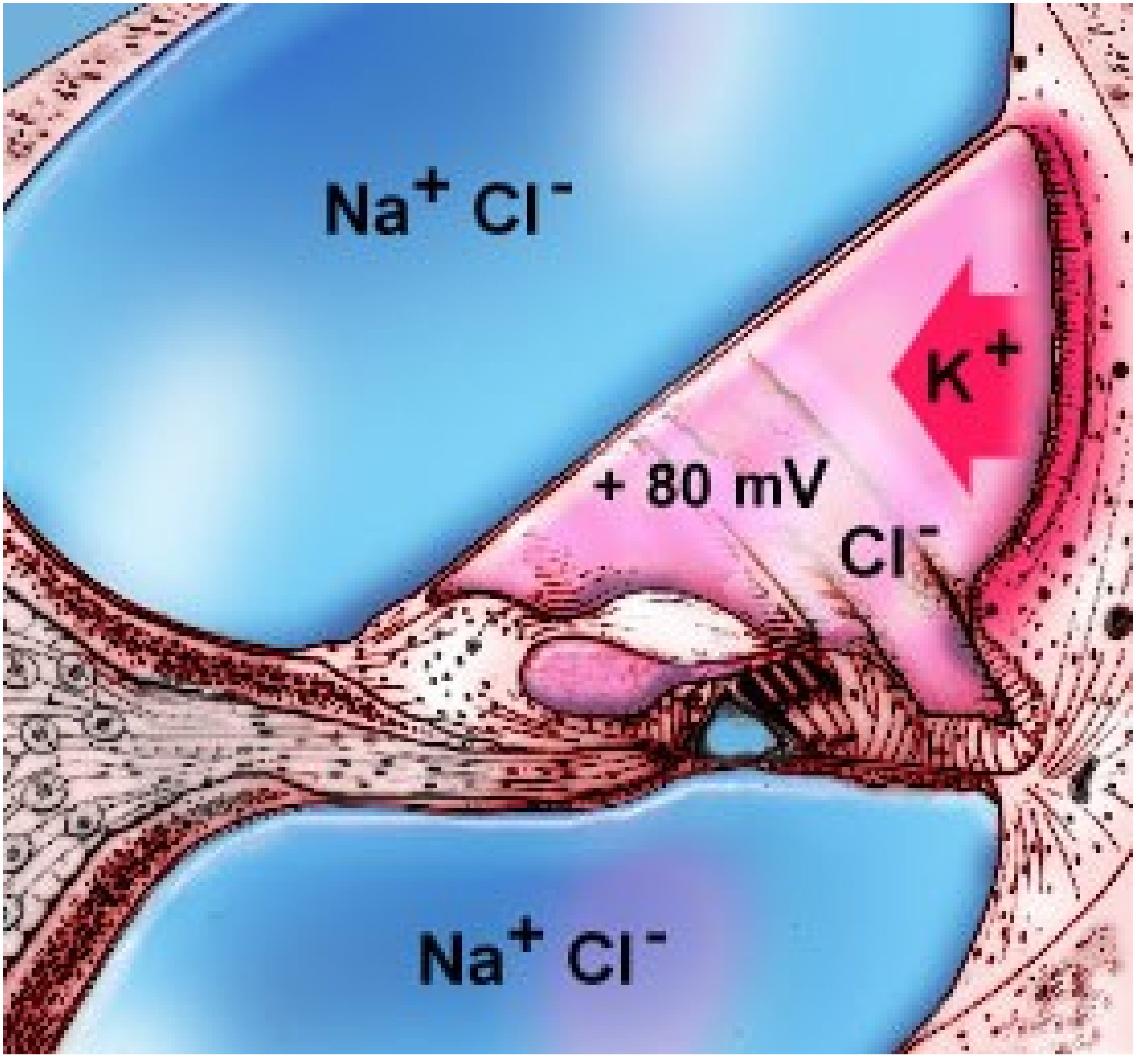
- If hyperpolarise then decrease glutamate

- Loud sound send more action potentials(frequency more) & also more no. of nerves stimulated

Electrophysiology of hearing

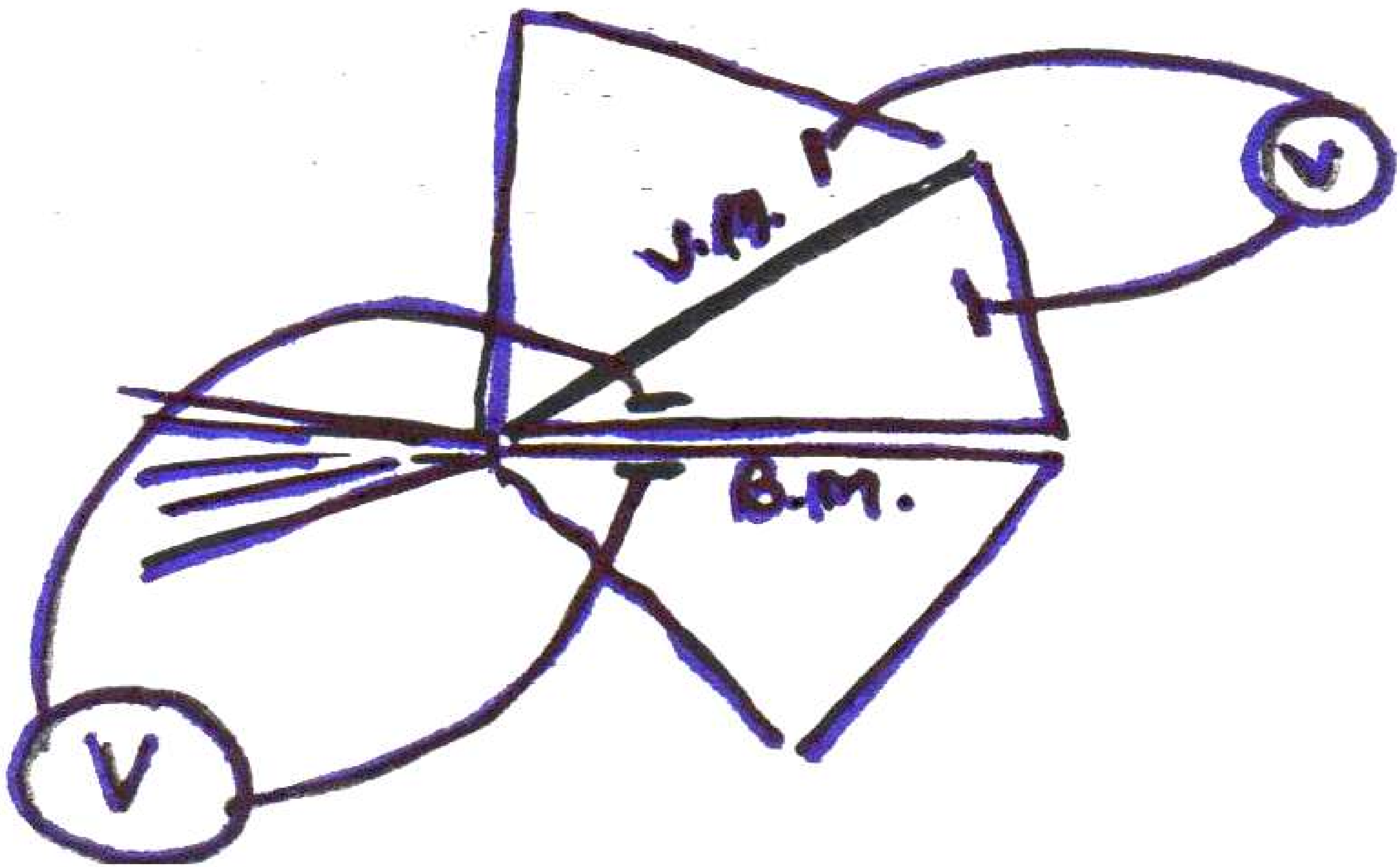
- Resting potential recorded are :- Endolymphatic potential or Endocochlear potential & Resting hair cell potential
- On stimulation recorded potentials are :- Cochlear microphonic potential & Action potential of 8^{th} nerve





Na+ Cl-
K+
+ 80 mV
Cl-
Na+ Cl-

Electro-physiology of hearing

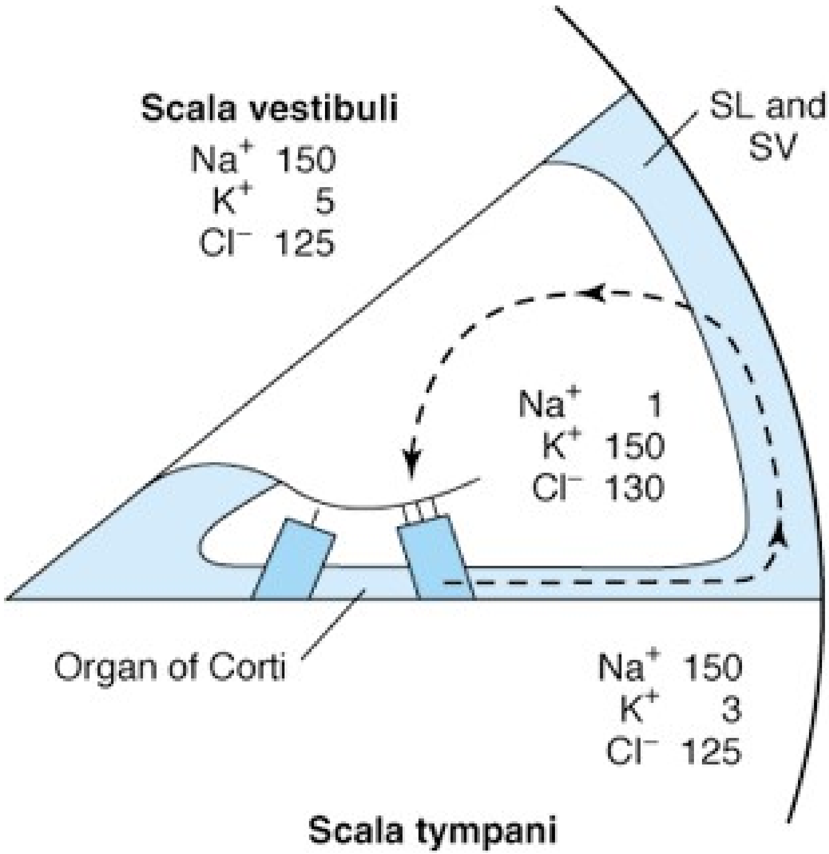


i) Endocochlear/endolymphatic Potent.

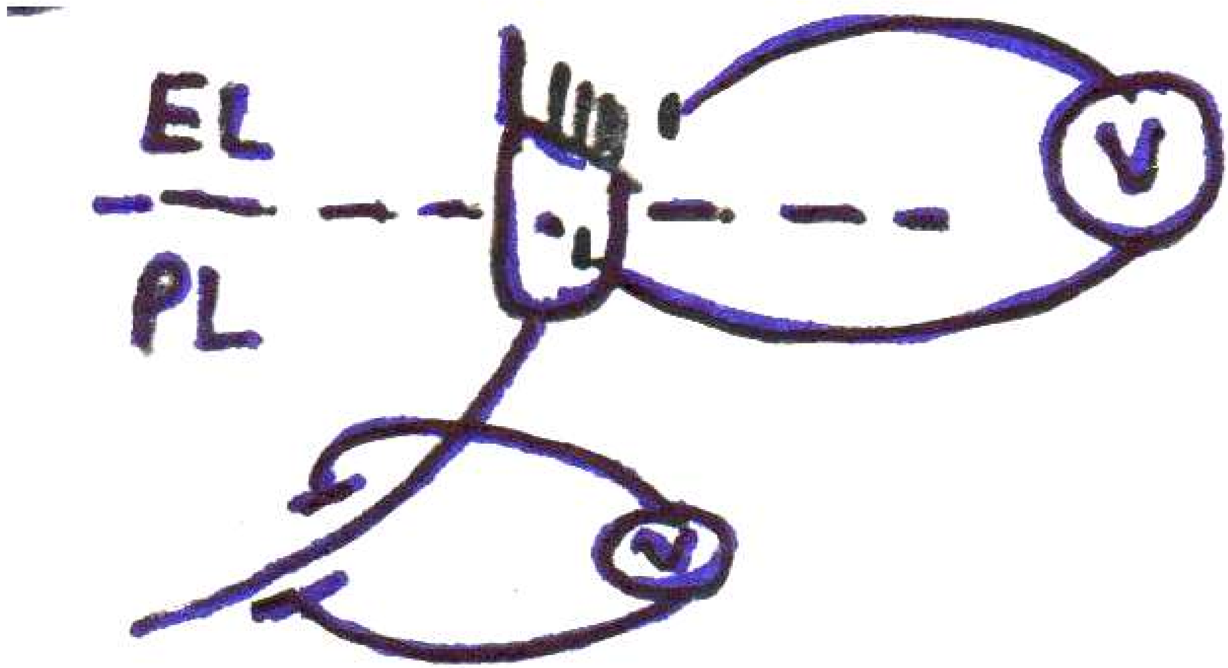
Is an electrical potential of about +80 mv. exists all the time between endolymph & perilymph, with positivity inside the scala media & negativity outside.
it is generated by continual secretion of + K ions into the scala media by the stria vascularis.

ii) RMP of hair cells-

Lower bodies of hair cells have a - intracellular potential of -70 mv with respect to the perilymph but



Scala vestibuli
Na+ 150
K+ 5
Cl− 125
SL and SV
Na+ 1
K+ 150
Cl− 130
Organ of Corti
Na+ 150
K+ 3
Cl− 125
Scala tympani



but -150 mv with respect to the endolymph at their upper surfaces where the hairs project through the reticular lamina & into the endolymph.

This -150 mv at stereocilia make hair cells extremely sensitive to slightest of sound.

iii) Cochlear microphonics potential-

- local potential developed at tip of inner hair cell at RL on stimulation

- when mechanical energy converted to electrical, like pizo-electric potential

- Discovered by wever & bray in 1930's

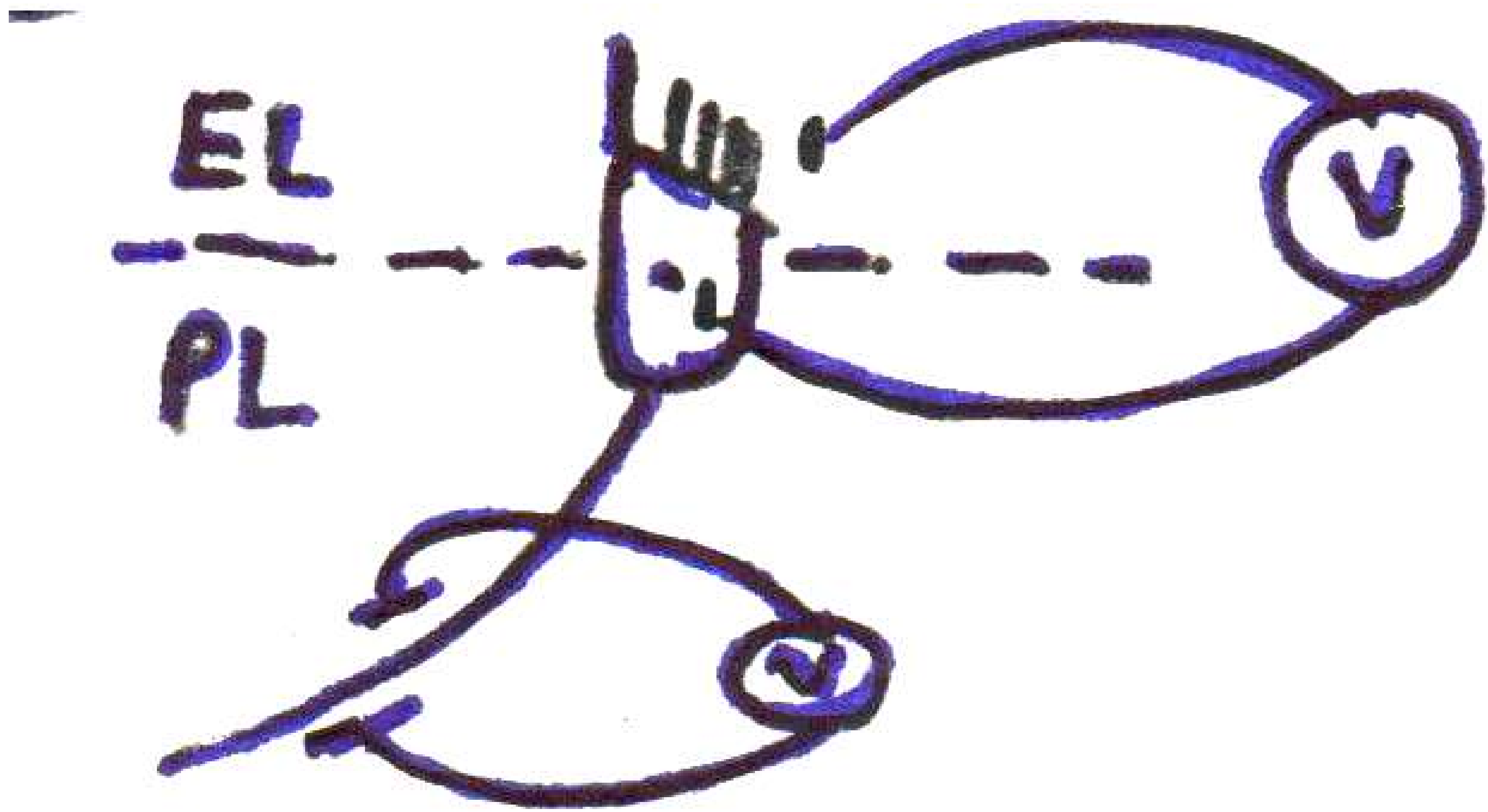
- recorded by placing one electrode in scala media and one electrode in scala tympani (both side of BM)

-Cause of development not very clear, may be due to vibration in basilar membrane & tension on the hairs of hair cells
-Leading to opening of K+ channels. Neurotransmitter is glutamate

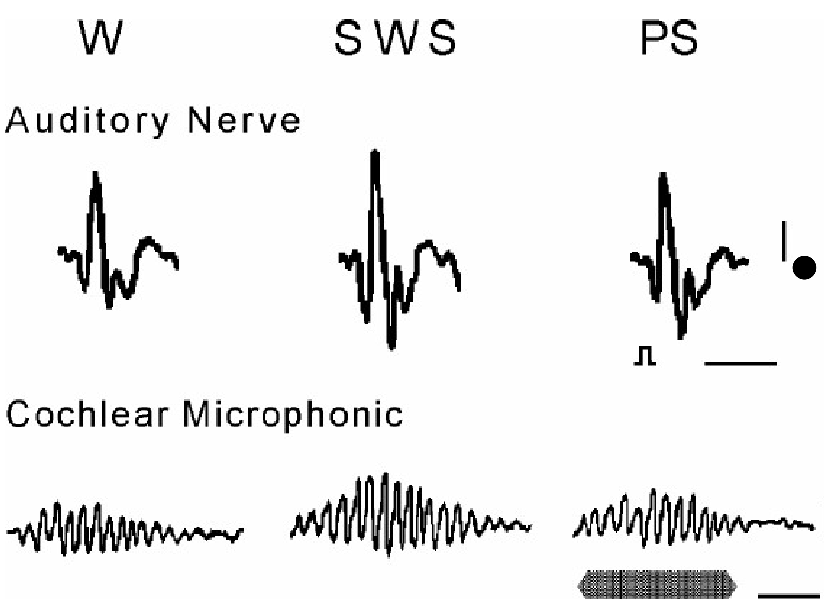
Characteristics of cochlear microphonics-

1. Resistant to ischemia or anesthesia
2. Do not show any latency or refractory period
3. Potentials recorded have the same form and polarity as that of the sound wave which is stimulating the ear.
4. It proceed AP.

iv) Action potential in 8 cranial nerve-

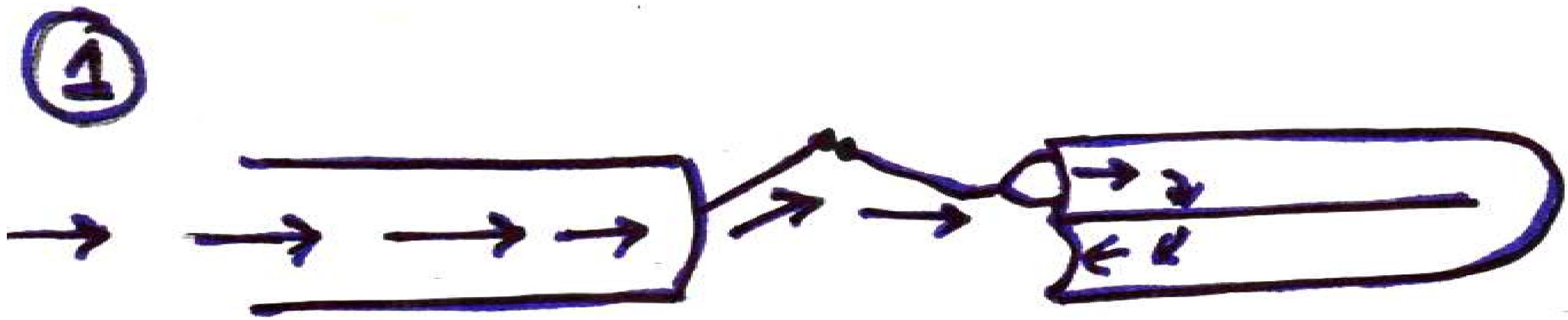


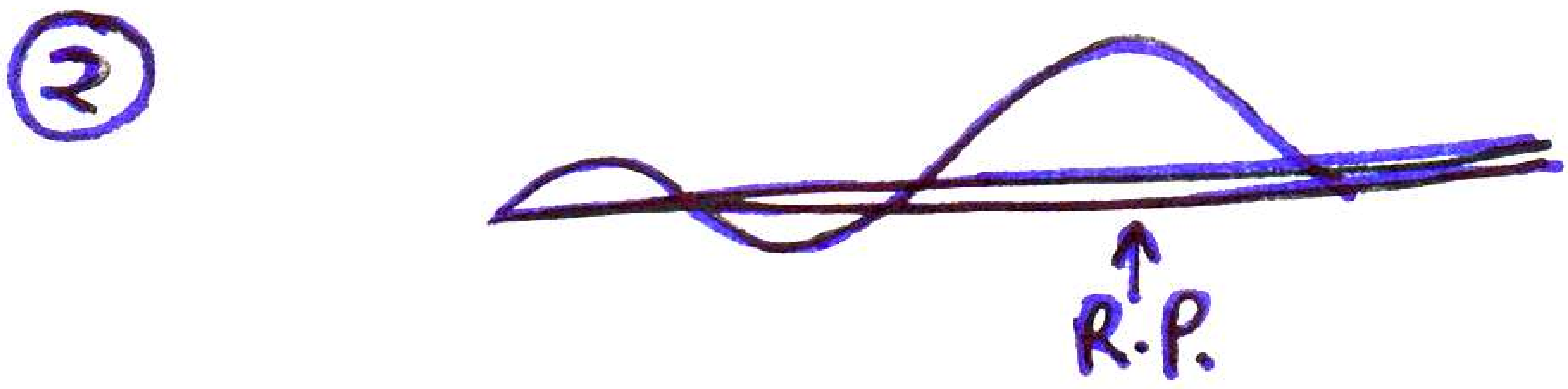
Action potential in 8th nerve fibers



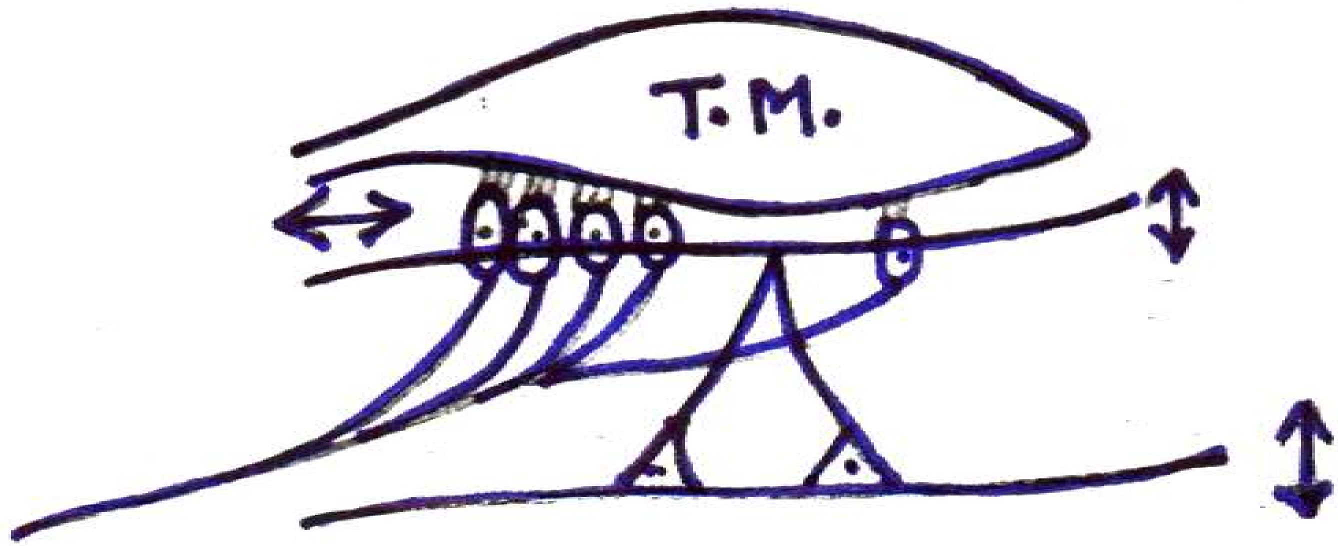
- **Compound action potential is recorded.**
- **Activity of large number of cochlear afferent fibers.**
- **Baseline impulses (8-10/sec) are continuously send to CNS**
- **When hair cells depolarise this impulses increase in number & when hyperpolarise then impulses decrease**

Mechanism of hearing-





3



4

Properties of Sound

- Sound is: a sensation produced by longitudinal vibrations of particles in any medium
  - A pressure disturbance (alternating areas of high and low pressure) originating from a vibrating object
  - Composed of areas of rarefaction and compression
  - Represented by a sine wave in wavelength, frequency, and amplitude(condensation as increase in pressure & rarefaction as decrease in pressure)

Properties of Sound

- Amplitude – intensity of a sound measured in decibels (dB).pressure difference in tympanic membrane surface
- Loudness – subjective interpretation of sound intensity
- Frequency and pitch:-no. of waves in 1 sec

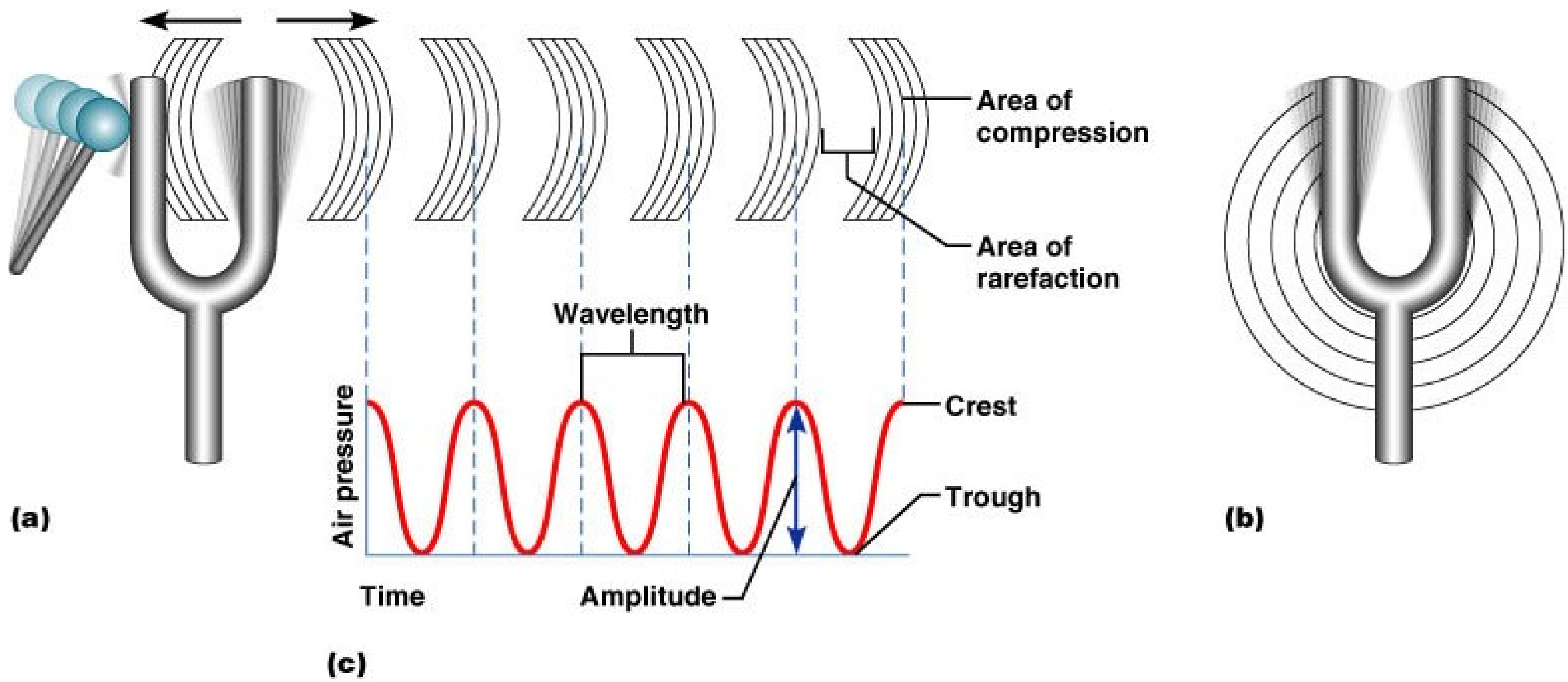
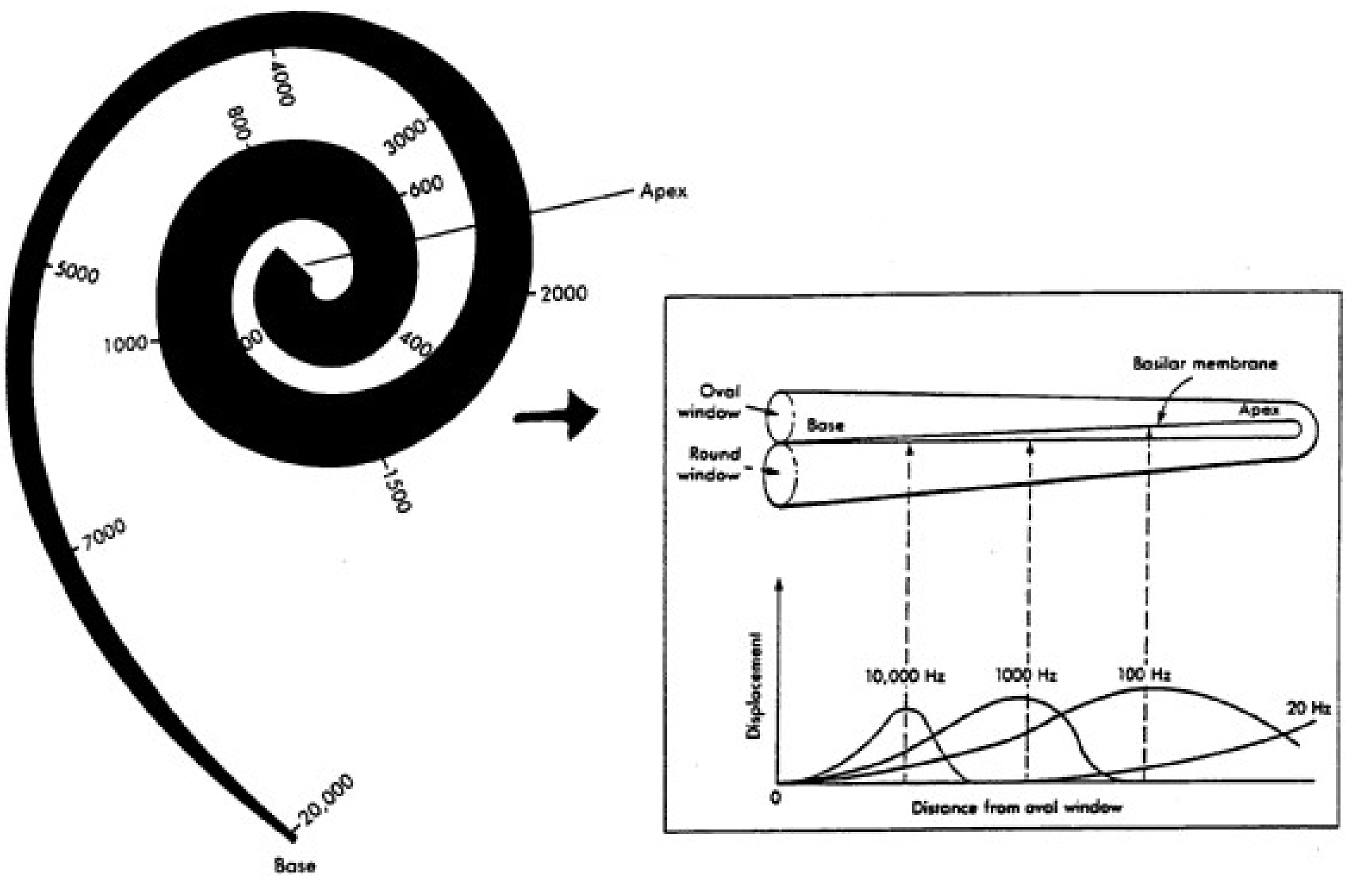


Figure 15.29

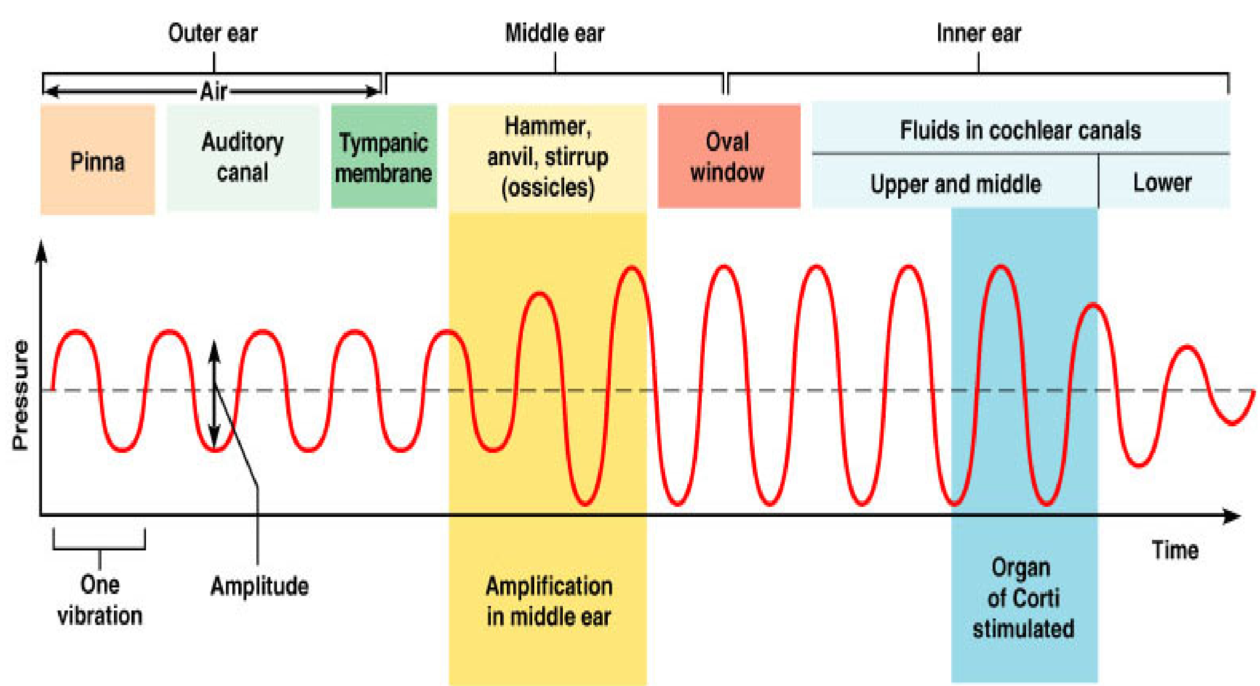
- Audible frequency for humans:- 20Hz - 20,000Hz
- Maximal sensitivity to pitch variations:-1000-3000 Hz(amplification of sound intensity by middle ear is greatest in this range)
- Higher the frequency ,pitch is high
- Lower frequency ,pitch low
- Louder sound has high amplitude

Basilar Membrane



Transmission of Sound to the Inner Ear

- The route of sound to the inner ear follows this pathway:
  - Outer ear :-pinna,external auditory canal,tympanic membrane
  - Middle ear – malleus, incus, and stapes to the oval window
  - Inner ear – scala vestibuli to the cochlear duct
    - Stimulation of the organ of Corti
    - Generation of impulses in the cochlear nerve



Transmission of Sound to the Inner Ear

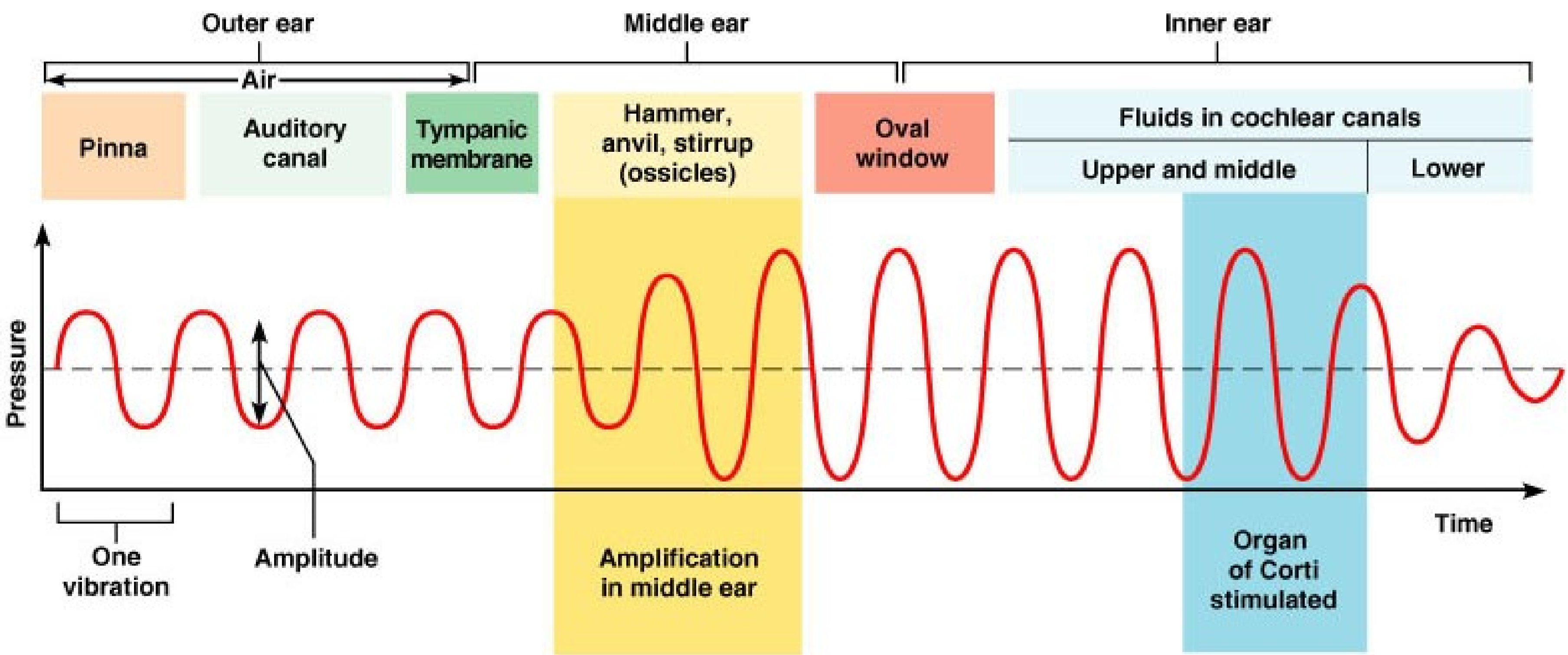
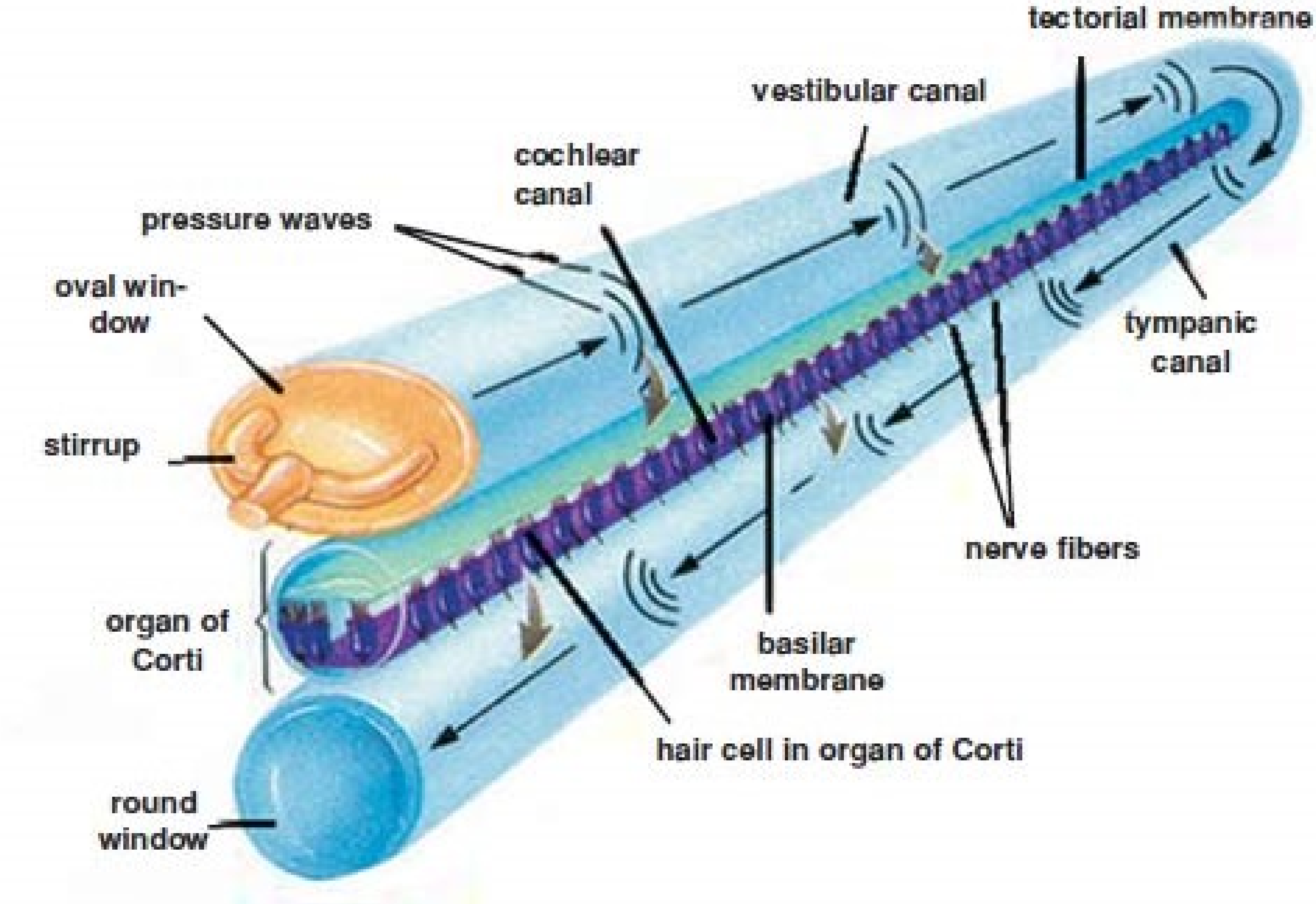


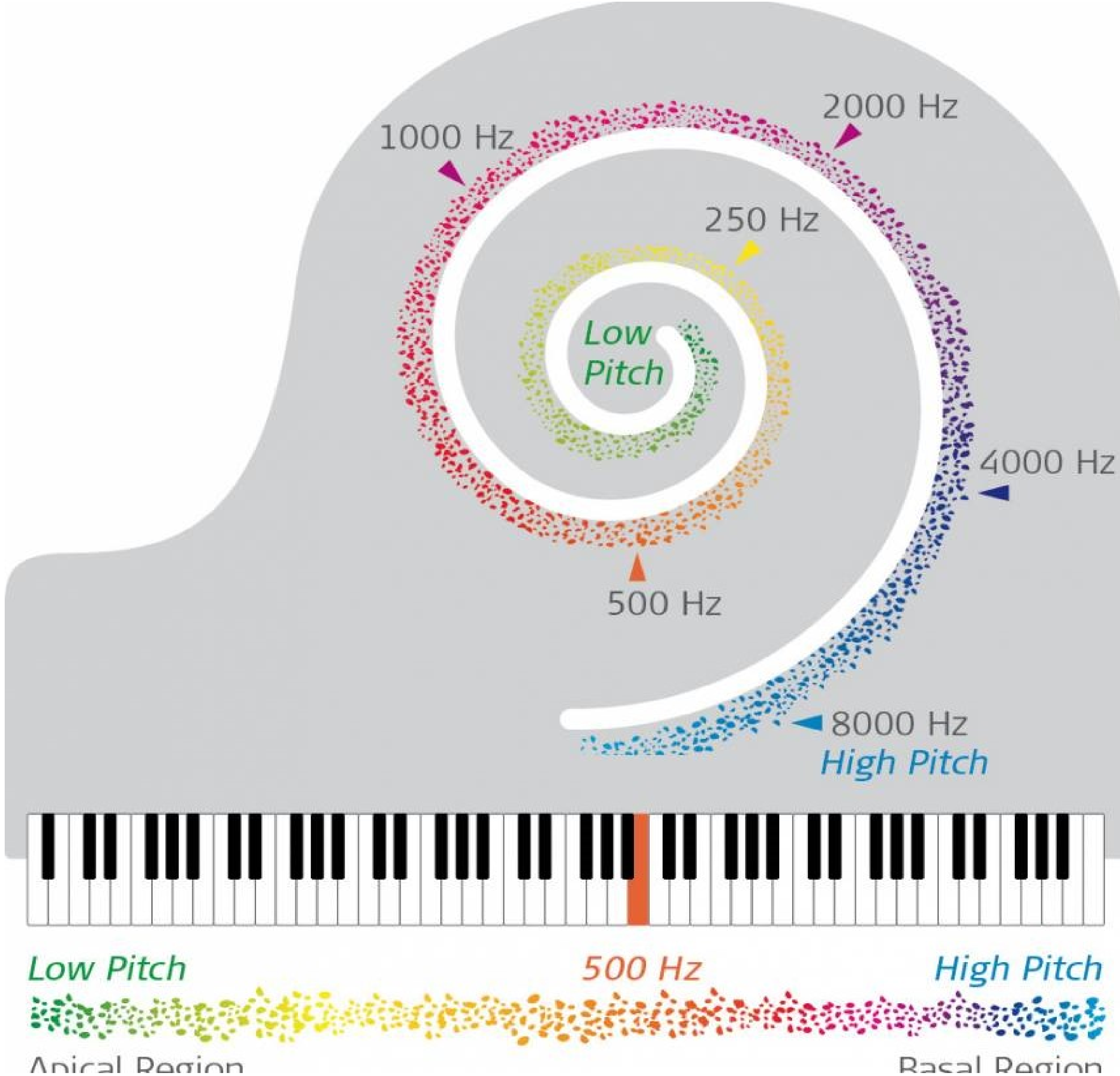
Figure 15.31

Intensity	1. By increasing - amplitude of vibration of basilar membrane 2. Recruitment of number of hair cells 3. Activation of nerve fibers + no. of APs/nerve fibres + stimulation Of outer hair cells.

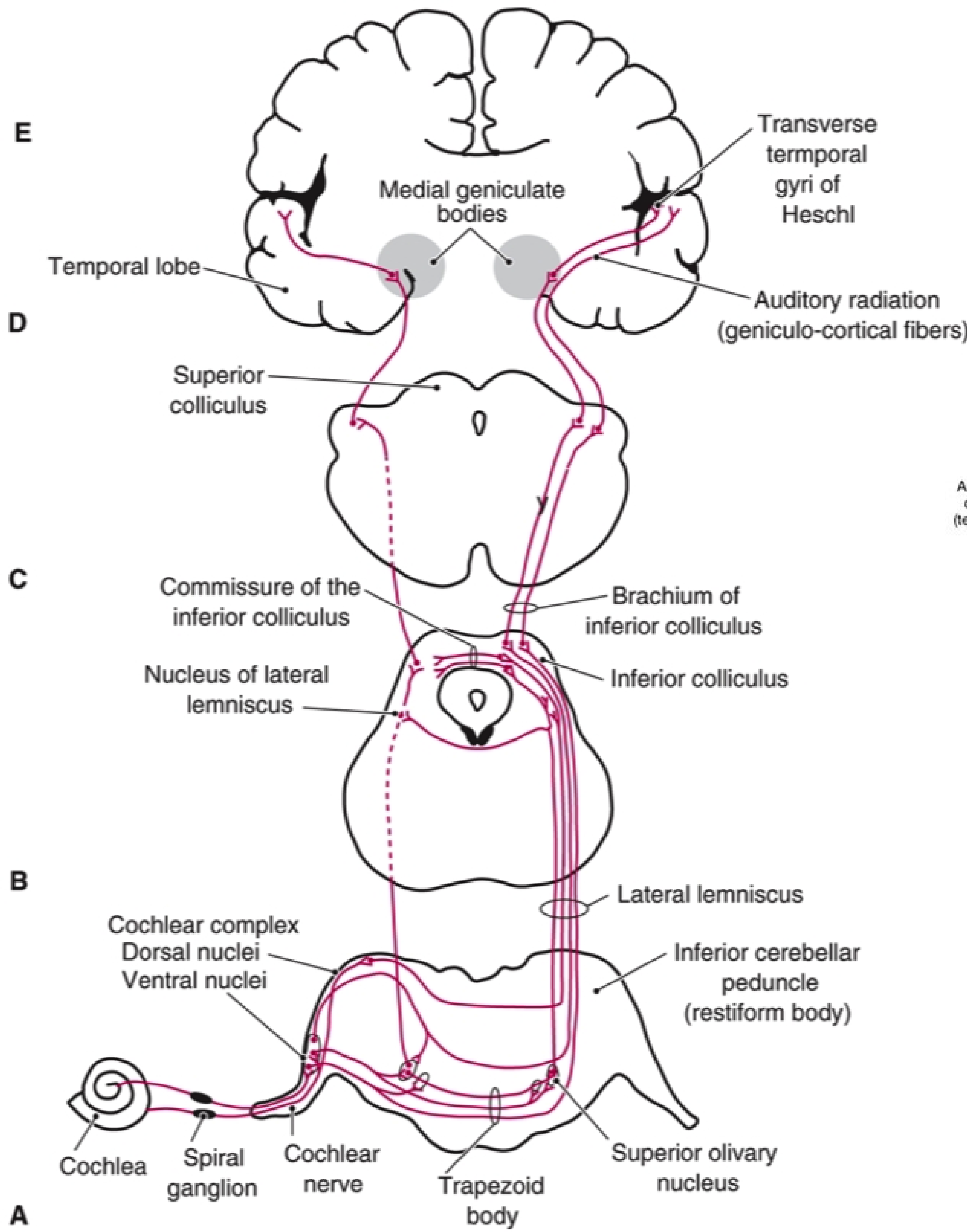
Frequency	**Bekesy travelling wave theory / Duplex theory** **Place principle:-** **High Freq.- maximum vibration of basilar membrane occurs at its base, for low frequency at its apex** **Volley's principle:-** **20- 200 Hz at the apex, freq. is synchronised with no. of APs / sec. of cochlea the number of action potentials in 8th nerve is same as frequency of sound.**

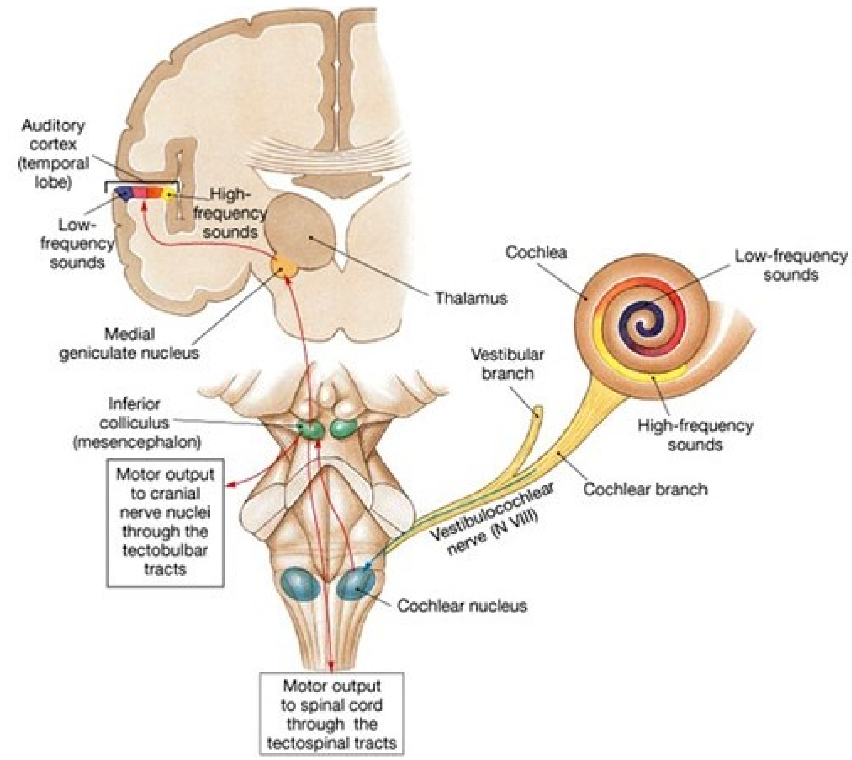
Direction	**Intensity lag principle-** **High frequency by lateral superior olivary nuclei** **Time lag principle-** **Low frequency by medial superior olivary nuclei** **+ Pinna help (for sound from front or behind)**

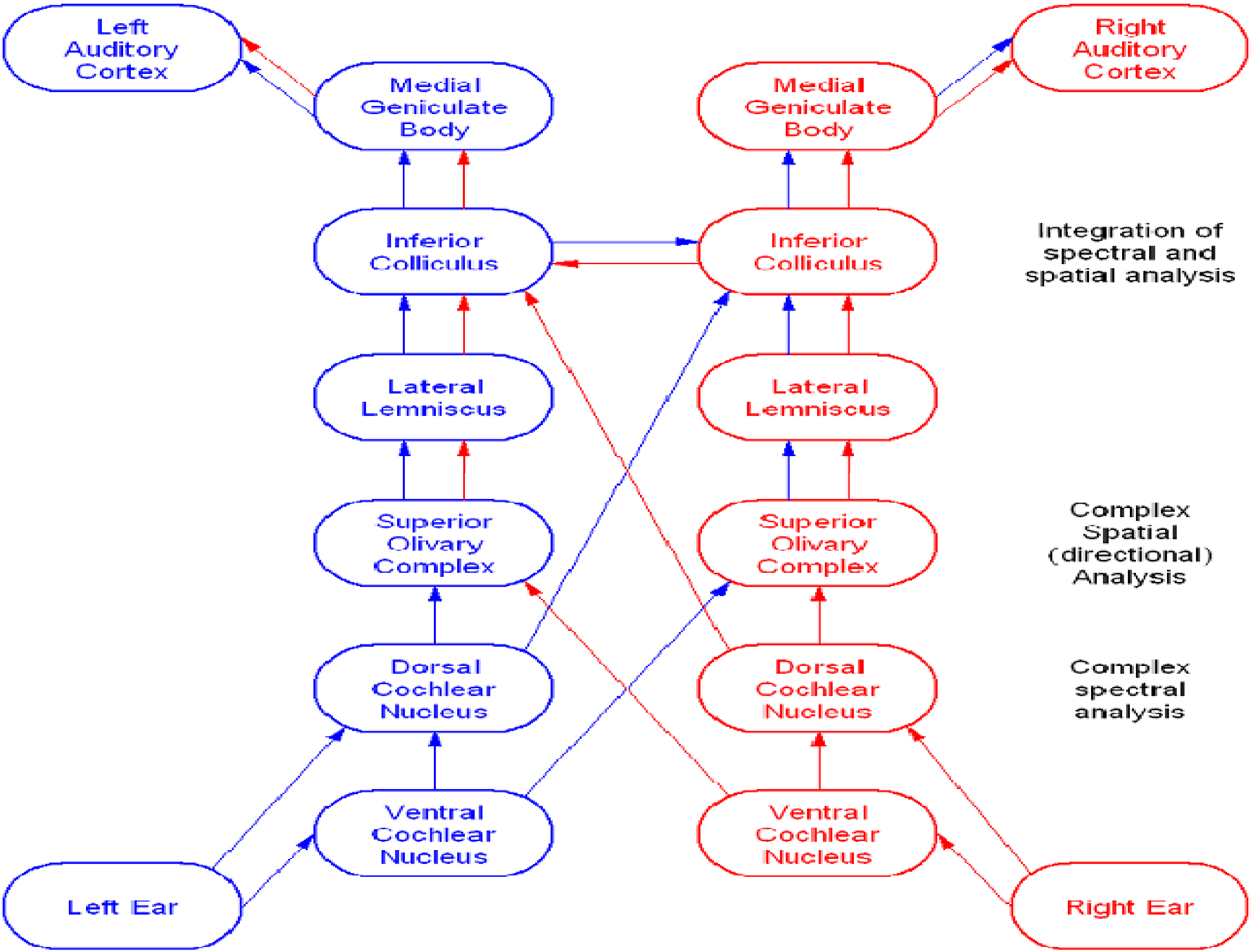

tectorial membrane
vestibular canal
cochlear
canal
pressure waves
oval win-
dow
stirrup
tympanic
canal
nerve fibers
organ of
Corti
basilar
membrane
hair cell in organ of Corti
round
window


1000 Hz
2000 Hz
250 Hz
Low
Pitch
4000 Hz
500 Hz
8000 Hz
High Pitch
Low Pitch
500 Hz
High Pitch

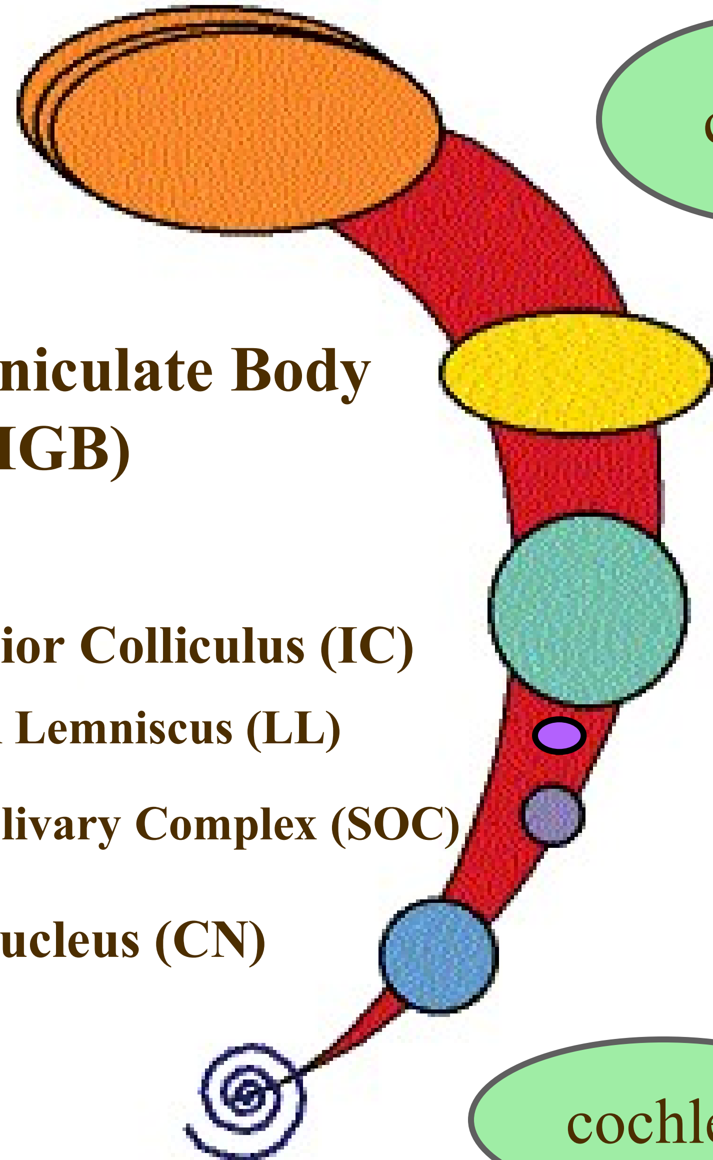
Auditory Pathway


E
Transverse
termporal
gyri of
Heschl
Medial geniculate
bodies
Temporal lobe
Auditory radiation
(geniculo-cortical fibers)
D
Superior
colliculus
C
Commissure of the
inferior colliculus
Brachium of
inferior colliculus
Nucleus of lateral
lemniscus
Inferior colliculus
B
Lateral lemniscus
Cochlear complex
Dorsal nuclei
Ventral nuclei
Inferior cerebellar
peduncle
(restiform body)
Cochlea
Spiral
ganglion
Cochlear
nerve
Trapezoid
body
Superior olivary
nucleus
A


Auditory
cortex
(temporal
lobe)
High-
frequency
sounds
Low-
frequency
sounds
Thalamus
Medial
geniculate nucleus
Cochlea
Low-frequency
sounds
Vestibular
branch
High-frequency
sounds
Inferior
colliculus
(mesencephalon)
Motor output
to cranial
nerve nuclei
through the
tectobulbar
tracts
Cochlear branch
Vestibulocochlear
nerve (N VIII)
Cochlear nucleus
Motor output
to spinal cord
through the
tectospinal tracts


Left Auditory Cortex
Medial Geniculate Body
Medial Geniculate Body
Right Auditory Cortex
Inferior Colliculus
Inferior Colliculus
Integration of spectral and spatial analysis
Lateral Lemniscus
Lateral Lemniscus
Superior Olivary Complex
Superior Olivary Complex
Complex Spatial (directional) Analysis
Dorsal Cochlear Nucleus
Dorsal Cochlear Nucleus
Complex spectral analysis
Ventral Cochlear Nucleus
Ventral Cochlear Nucleus
Left Ear
Right Ear

Anatomy of the Auditory Pathway: 2



Medial Geniculate Body (MGB)

Inferior Colliculus (IC)

Lateral Lemniscus (LL)

Superior Olivary Complex (SOC)

Cochlear Nucleus (CN)

cortex

thalamus

brain stem

cochlea

Characteristics of Auditory pathway

1. Six order neuron pathway
2. Bilaterally represented, although contra lateral is dominant.
3. Cross over occurs three times:

   Trapezoid body

   Commissure at lateral leminiscus

   Commissure at inferior colliculi

Characteristics of Auditory pathway

4. Collaterals are sent to reticular activating system and cerebellum.
5. high degree spatial orientation is maintained for frequency discrimination.
6. Corticofugal fibres/ descending pathway: cortex to outer hair cells
7. Plasticity of auditory pathways: visually impaired or musicians

AUDITORY DEFECTS

- Auditory defects are of two types:

1. Conduction deafness
2. Nerve deafness
3. Central deafness (damage to auditory cortex)

CONDUCTION DEAFNESS

- Conduction deafness is the type of deafness that occurs due to impairment in transmission of sound waves in the external ear or middle ear.

Causes for Conduction Deafness

1. Obstruction of external auditory meatus with dry wax or foreign bodies
2. Thickening of tympanic membrane due to repeated middle ear infection
3. Perforation of tympanic membrane due to inequality of pressure on either side

4. Otitis media (inflammation of middle ear)
5. Otosclerosis (fixation of footplate of stapes against oval window) due to ankylosis

NERVE DEAFNESS

- Nerve deafness is the deafness caused by damage of any structure in cochlea, such as hair cell, organ of Corti, basilar membrane or cochlear duct or the lesion in the auditory pathway.

Causes for Nerve Deafness

1. Degeneration of hair cells due to some antibiotics like streptomycin and gentamicin
2. Damage of cochlea by prolonged exposure to loud noise
3. Tumor affecting VIII cranial nerve

TESTS FOR HEARING

Whispering Test

- The examiner stands about 60 cm away from the subject at his side and whispers some words.
- If the subject is not able to hear the whisper, then hearing deficit is suspected.

Tickling of Watch Test

- Wrist watch with tickling sound is kept near the ear of the subject
- The subject suffering from hearing defects cannot hear the tickling sound of watch.

RINNE TEST

- Base of a vibrating tuning fork is placed on mastoid process, until the subject cannot feel the vibration and cannot hear the sound
- When the subject does not hear the sound any more, the tuning fork is held in air in front of the ear of same side
- Normal person hears vibration in air but in conduction deafness, the vibrations in air are not heard after cessation of bone conduction
- In conduction deafness, the bone conduction is better than air conduction

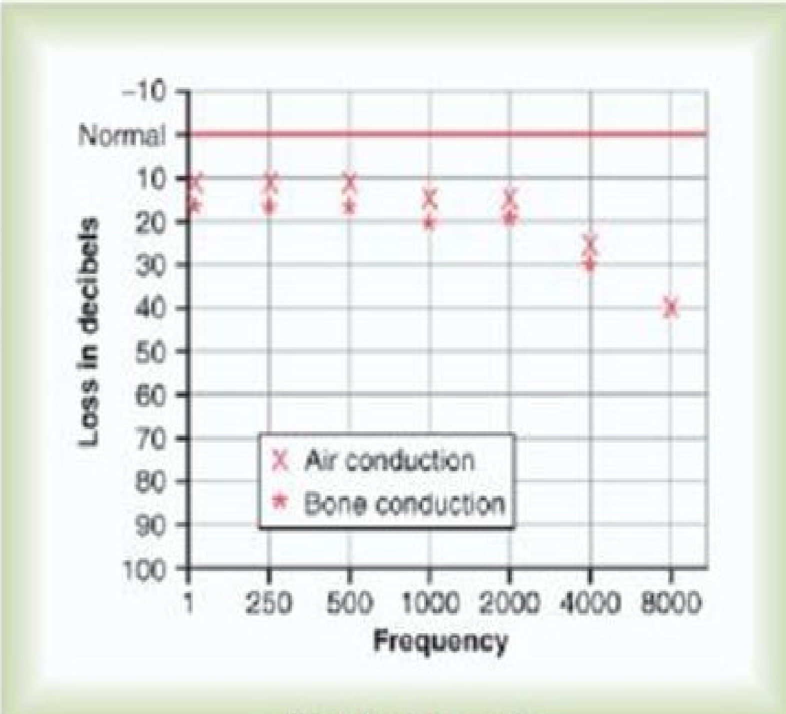
WEBER TEST

- Base of a vibrating tuning fork is placed on the vertex of skull or the middle of forehead.
- Normal person hears the sound equally on both sides
- In unilateral conduction deafness (deafness in one ear), the sound is heard louder in diseased ear
- In affected side, the sound is louder due to the absence of masking effect of environmental noise
- During unilateral nerve deafness, sound is heard louder in the normal ear.

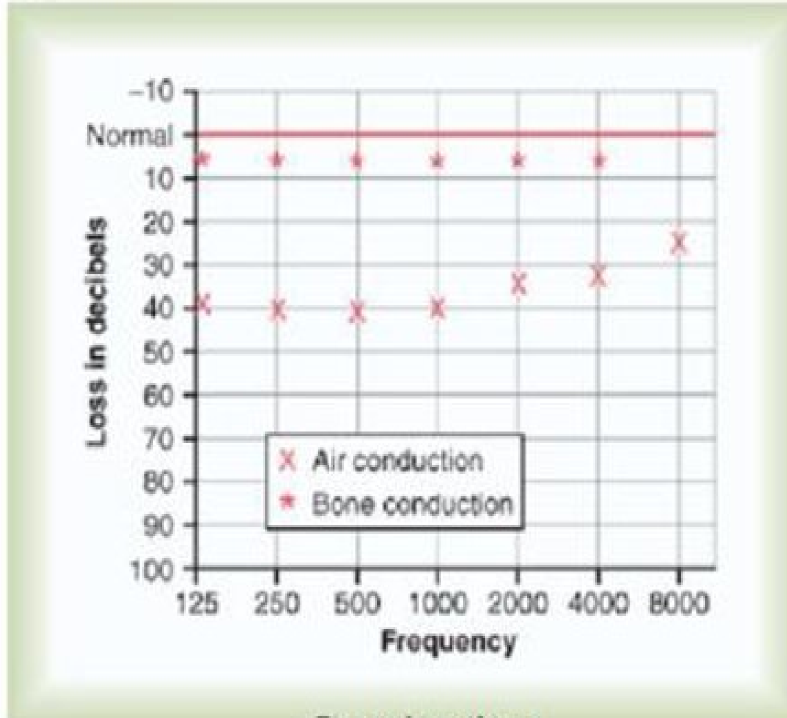
AUDIOMETRY

- Audiometry is the technique used to determine the nature and the severity of auditory defect
- An instrument called **audiometer** is used
- This instrument is capable of generating sound waves of different frequencies from lowest to highest

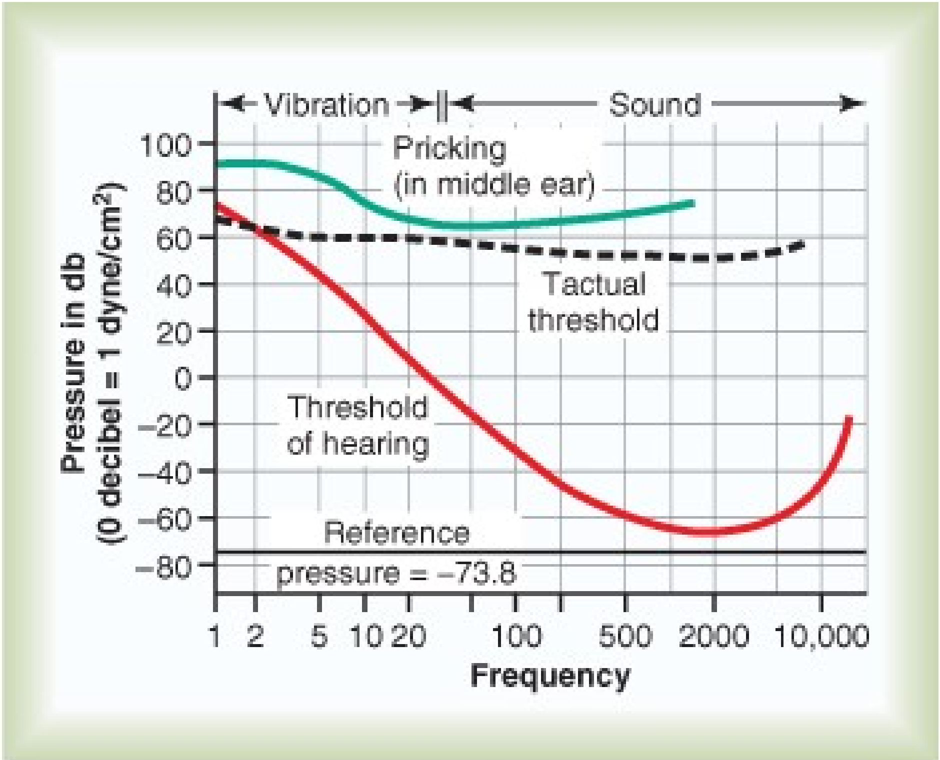
Audiogram



Partial Nerve
Deafness



Conduction
Deafness
(involving middle
ear)

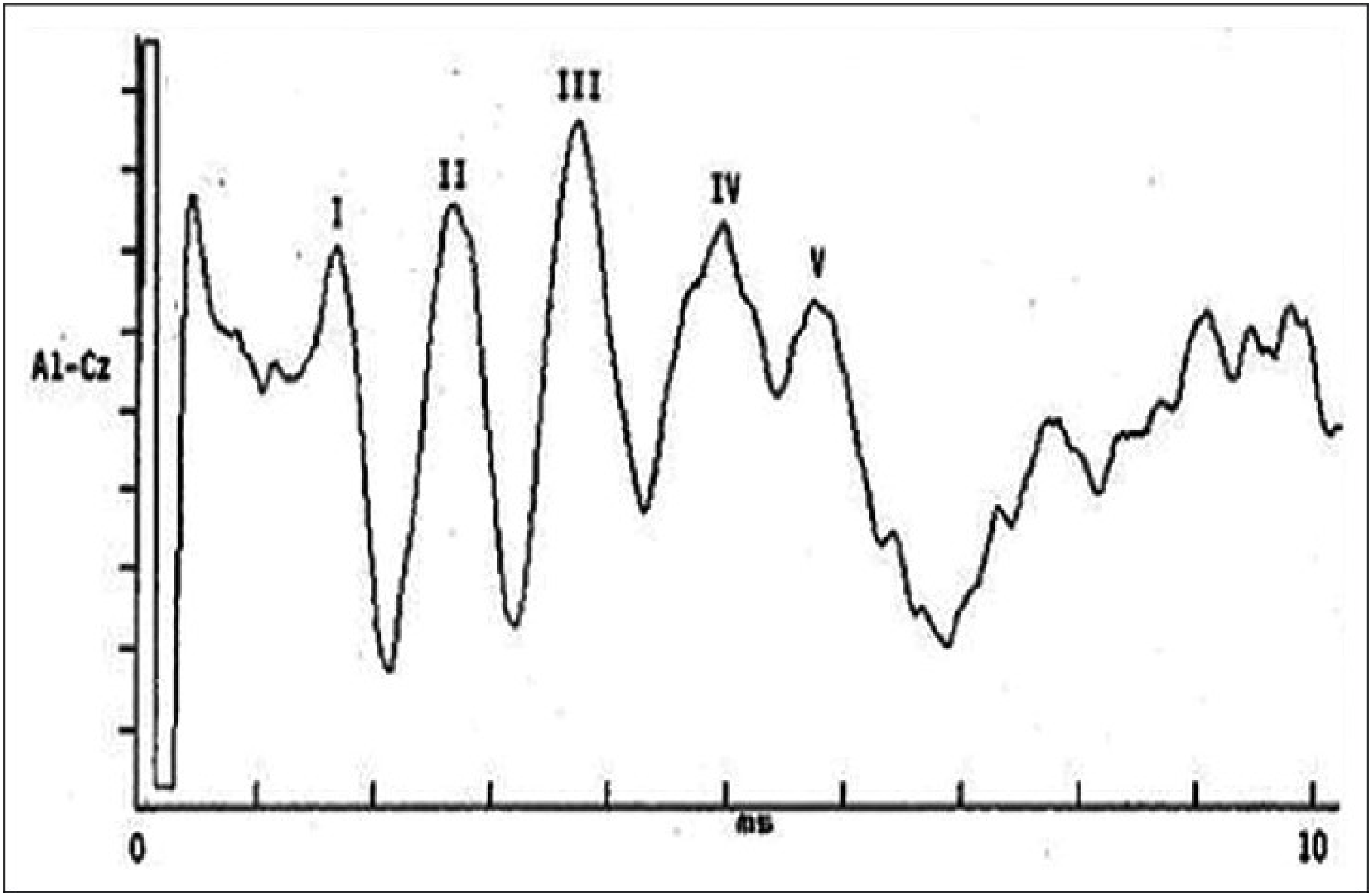

Vibration
Sound
Pricking
(in middle ear)
Tactual
threshold
Threshold
of hearing
Reference
pressure = –73.8
Pressure in db
(0 decibel = 1 dyne/cm²)
100
80
60
40
20
0
–20
–40
–60
–80
1 2 5 10 20 100 500 2000 10,000
Frequency

BRAIN EVOKED RESPONSE AUDIOMETRY (BERA)

Objective test to understand the transmission of electrical waves from the VIIIth cranial nerve to the brainstem, in response to click sounds given through the ear

- The waveforms of impulses are produced at the brainstem in response to the sound stimulus.
- These waveforms are recorded by the electrodes that are placed over the scalp at various places.
- The generated waveforms are amplified through various electrical procedures easy recording of waveforms.
- The peaks of the waveform are labelled as Wave I to Wave VII.
- The time interval between the waveform and the click stimulus is usually within 10 milliseconds.

- The waves I to VII are believed to arise from parts of the brainstem which are listed below:
- Cochlear nerves – Wave I and Wave II
- Cochlear nucleus (Brainstem) – Wave III
- Superior olivary complex – Wave IV
- Lateral lemniscus – Wave V
- Inferior colliculus (Midbrain) – Waves VI and VII



A1-Cz
I
II
III
IV
V
ms
0
10