🔊 Physiology of Hearing

اللهم إني أستودعك ما ستعلمه،
فافتح لي أبواب فهمك،
وارزقني علمًا نافعًا،
وذاكرةً قوية،
وتركيزًا دائمًا،
واجعل دراستي خالصةً لوجهك الكريم،
ووفقني لما تحب وترضى،
واصرف عني الكسل والتسويف،
واجعل لي من كل صعبٍ يسيرًا،
ومن كل همٍّ فرجًا.
اللهم بارك لي في وقتي وجهدي،
واجعل النجاح حليفي دائمًا.
آمين🤍✨

1️⃣ First: What is Sound?

Sound has 3 important properties:

- Frequency (Hz) → determines pitch
- Human range: 20 – 20,000 Hz
- Amplitude (dB) → determines loudness
- Wavelength → distance between two peaks

🧠 Standard sound = 1000 Hz at zero bel (does NOT mean no sound).

2️⃣ Big Picture: How Hearing Happens

Hearing happens in 5 major stages:

1. Collection of sound
2. Amplification
3. Fluid movement in cochlea
4. Hair cell activation
5. Transmission to brain

Now let's go step by step.

3️⃣ <u>Stage 1: External Ear (Collection Phase)</u>

The external ear:

- Pinna
- External auditory canal
- Tympanic membrane

What happens?

- Pinna collects sound and helps detect direction.
- External canal concentrates pressure on tympanic membrane.
- Tympanic membrane vibrates with sound waves.

👉 Important: The tympanic membrane converts air vibrations into mechanical vibrations.

4️⃣ Stage 2: Middle Ear (Amplification + Protection)

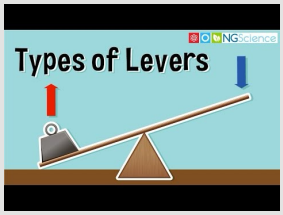
The middle ear:

- 3 ossicles (malleus → incus → stapes)
- Oval window
- Round window
- Tensor tympani & stapedius
- Eustachian tube

🔥 Amplification Mechanism (VERY IMPORTANT FOR EXAM)

There are 2 reasons for amplification:

1️⃣ Lever System



Ossicles act as a lever
→ Increase force 1.3 times

2️⃣ Surface Area Difference

Tympanic membrane area is much larger than oval window area
→ Pressure increases 17 times

Total amplification:

17 × 1.3 = 22 times

🧠 This is called impedance matching

It converts:

- Low density air vibration

→ Into

- High density fluid vibration (perilymph)

🔐 Protective Reflex (Acoustic Reflex)

- Tensor tympani → tightens tympanic membrane
- Stapedius → prevents excessive stapes movement

Protects cochlea from loud sounds.

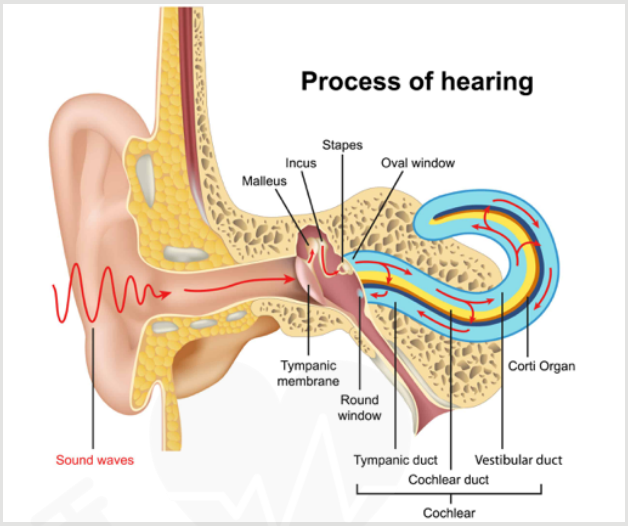
5️⃣ Stage 3: Inner Ear — Cochlear Fluid Movement

The cochlea has 3 chambers:

Fluid	Scala
Perilymph (↑Na^+)	Scala vestibuli
Endolymph (↑K^+)	Scala media
Perilymph (↑Na^+)	Scala tympani

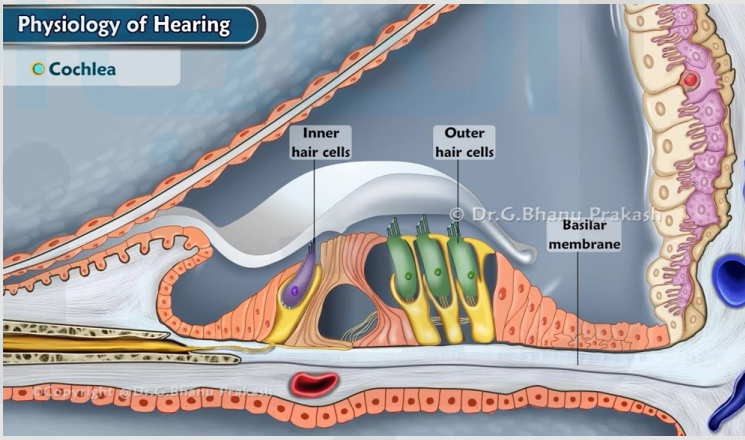
Sequence inside cochlea:

1. Stapes pushes oval window.
2. Perilymph in scala vestibuli moves.
3. Reissner's membrane vibrates.
4. Endolymph in scala media moves.
5. Basilar membrane vibrates.
6. Round window bulges outward to absorb pressure.



👉 Round window prevents pressure buildup.

6️⃣ Stage 4: Organ of Corti — The Critical Step

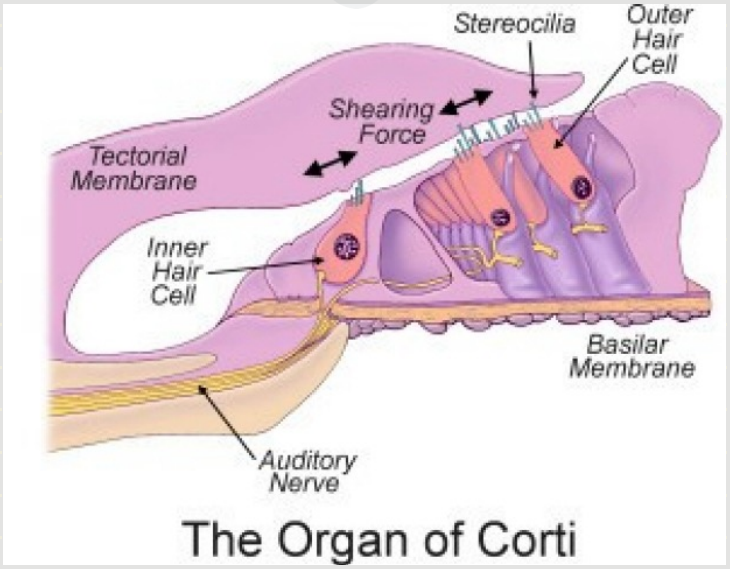


Located on basilar membrane.

Hair cells:

- 3 rows outer hair cells (20,000)
- 1 row inner hair cells (3,500)

Inner hair cells are the main sensory receptors.



🔬 Shearing Movement (KEY CONCEPT)

- Basilar membrane moves.
- Tectorial membrane stays relatively fixed.
- They slide over each other.
- This causes bending of stereocilia.

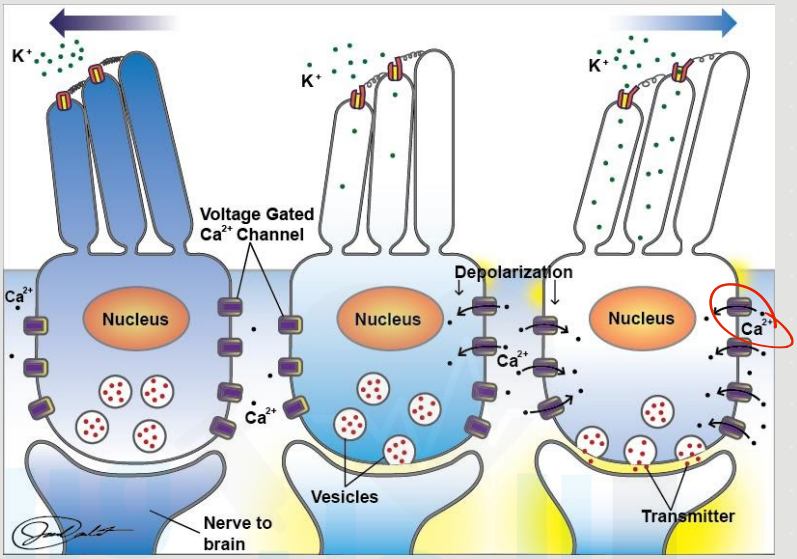
🔑 What Happens When Stereocilia Bend?

When they bend AWAY from modiolus:

- K^+ channels open.
- K^+ enters hair cell (because endolymph is rich in K^+).
- Cell depolarizes.

When they bend TOWARD modiolus:

- K^+ channels close.
- Cell hyperpolarizes.



⚡ Why is K^+ Entry So Important?

Because of Endocochlear Potential:

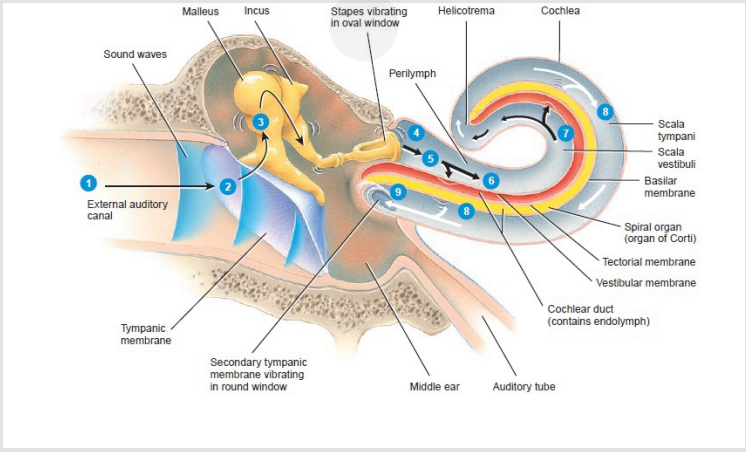
- Endolymph = +80 mV
- Hair cell interior = –70 mV

Total difference = 150 mV

This large difference causes strong K^+ influx.

After Depolarization

1. Ca^{2+} enters hair cell.
2. Neurotransmitter released.
3. Auditory nerve fibers stimulated.
4. Action potentials generated.



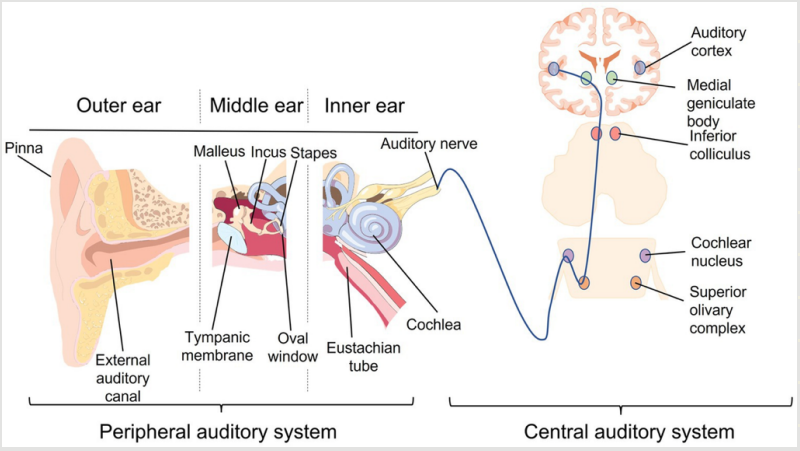
🔥 Important:

- Hair cell apical part in endolymph
- Base of hair cell in perilymph
- This ionic difference is essential.

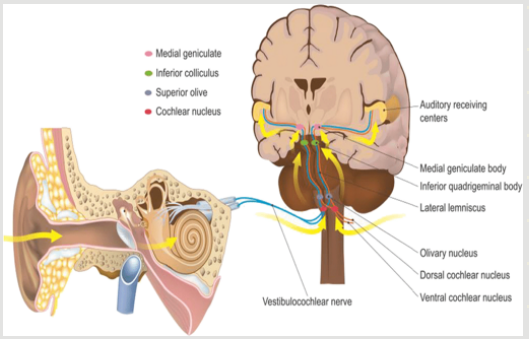
7 Stage 5: Auditory Pathway (To the Brain)

Now the signal travels in 5 neurons:

1. Spiral ganglion (1st order)
2. Cochlear nuclei (2nd order)
3. Superior olivary nucleus (3rd order)
4. Inferior colliculus → MGB (4th order)
5. Auditory cortex in temporal lobe (5th order)



Most fibers cross to opposite side.



8 How We Differentiate Sounds

🎵 1. Frequency (Pitch)

Two main theories:

A) Place Theory (Helmholtz)

- Base of cochlea → high frequency
- Apex of cochlea → low frequency

Because:

- Base fibers = short & tight
- Apex fibers = long & loose

B) Traveling Wave Theory (Von Bekesy)

Sound creates a traveling wave.
Maximum vibration occurs at specific location depending on frequency.

High frequency → peak near base
Low frequency → peak near apex

🔊 2. Loudness (Intensity)

Stronger sound →

- Larger area of basilar membrane vibrates
- More action potentials
- Brain interprets as louder

📍 3. Sound Localization

- Time difference between two ears
- Stronger in nearer ear

🎼 4. Sound Pattern

Ability to recognize:

- Sequence of tones
- Regular vs noise
- Cortical function

Two sounds separated by > 0.1 second can be detected separately.

🧠 Ultra-High Yield Exam Summary

Memorize this sequence:

Air vibration
→ Tympanic membrane
→ Ossicles (22× amplification)
→ Oval window
→ Perilymph movement
→ Reissner membrane
→ Endolymph movement
→ Basilar membrane
→ Hair cell bending
→ K^+ influx
→ Depolarization
→ Ca^{2+} entry
→ Neurotransmitter
→ Auditory nerve
→ Cortex