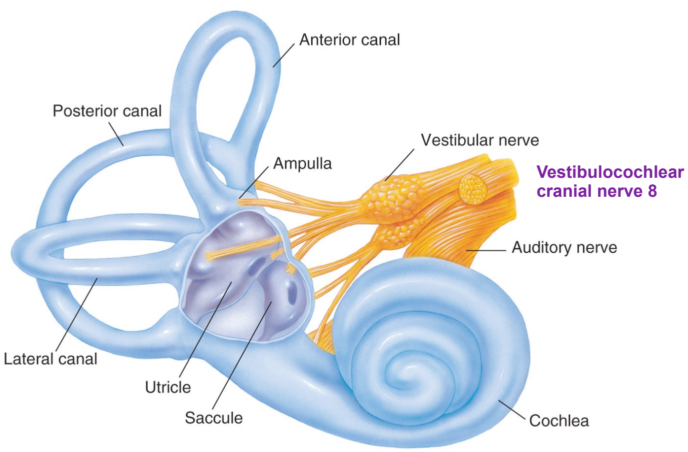
Anatomy of Inner Ear

Audition
Cochlea detects **sound** waves

Hair Cells
Receptor cells for audition and vestibular system.

Inner ear connected by ducts filled with **endolymph**, a high [K^+] fluid

Figure 10.12



Properties of Auditory System

1. Capture sound using outer ear (auricle, external auditory meatus) to the middle ear via **tympanic membrane** and **middle ear bones** (malleus, incus,stapes): transfer & amplify vibration to the **oval window**

2. Transmit to receptors: vibration of **basilar membrane** that runs length of cochlea. Response of basilar membrane varies across its length.

   Low frequency sound vibrates **apex** of cochlea.

   High frequency sound vibrates **base** of cochlea.

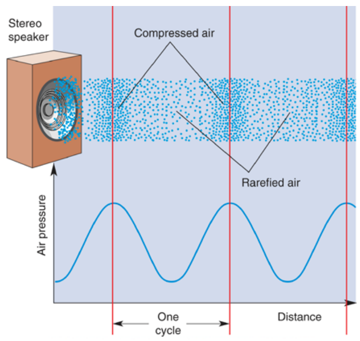
3. Transduction of sound frequency into spatial location (**tonotopy**) to stimulate auditory nerve fibers (Cranial Nerve 8: vestibulocochlear nerve).

4. Receptive Field of Auditory Neuron: tuned to **characteristic frequency**. Neuron's response (rate of action potentials) reflects intensity of sound at characteristic frequency.

5. Cranial Nerve 8 projects to cochlear nucleus in the brainstem.

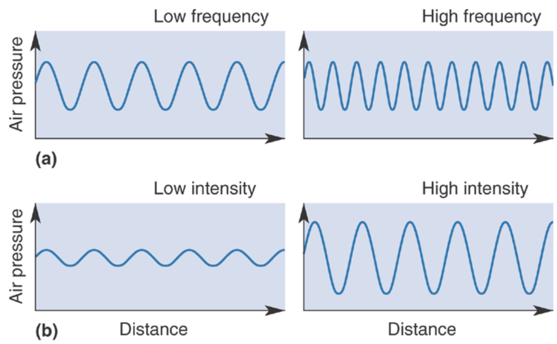
The Nature of Sound

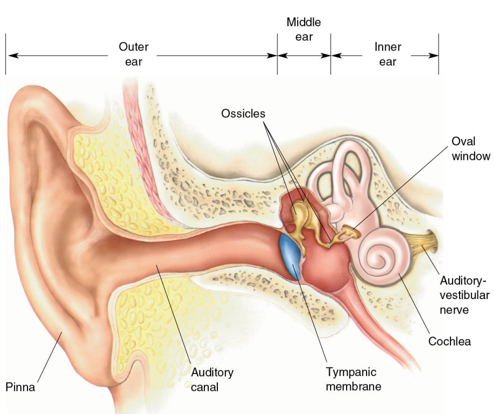
- **Audible variations in air pressure**
  - Sound frequency: Number of cycles per second expressed in units called hertz (Hz)
  - Cycle: Distance between successive compressed patches



The Nature of Sound

- Range: 20 Hz to 20,000 Hz
- Pitch: High pitch = high frequency; low frequency = low pitch
- Intensity: High intensity louder than low intensity





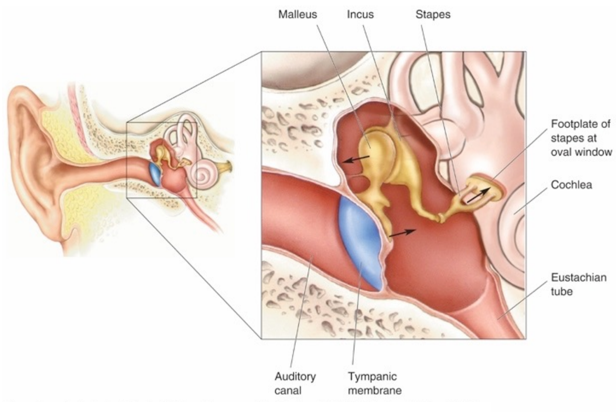
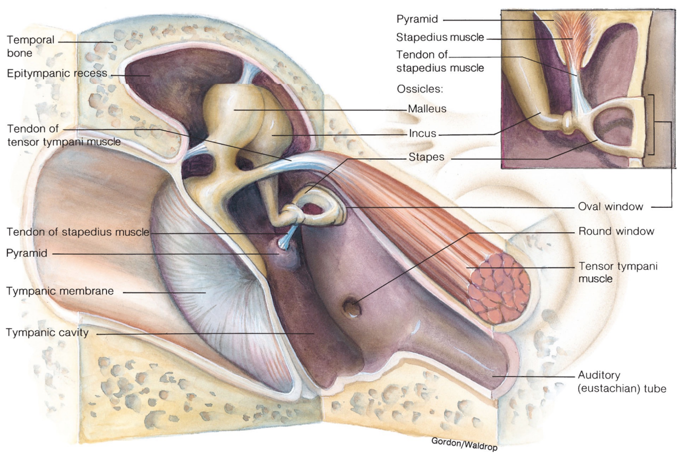


Figure 10.19



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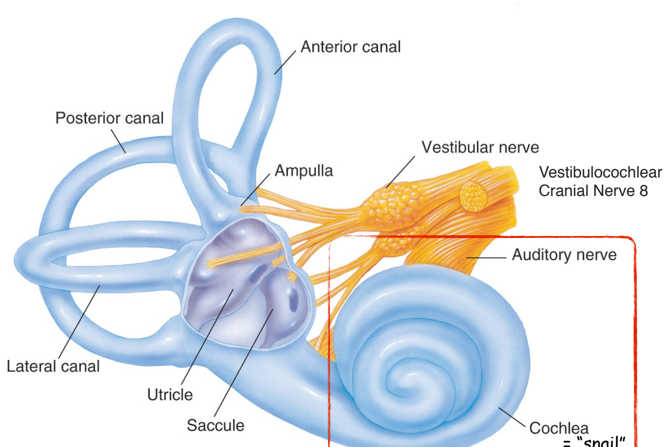
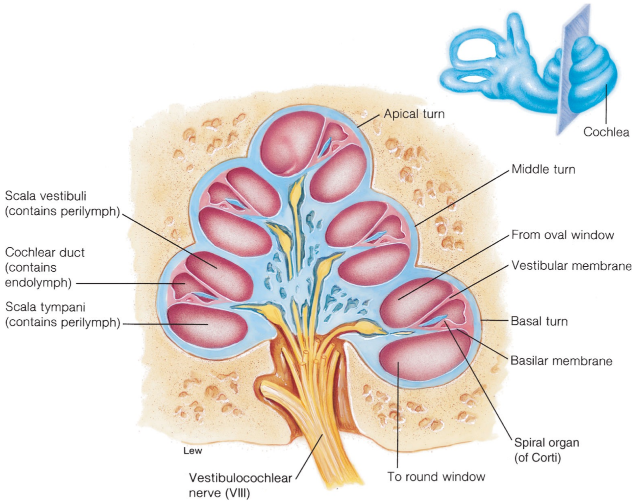
Cochlea & Sound Detection



Fox Figure 10.12

Figure



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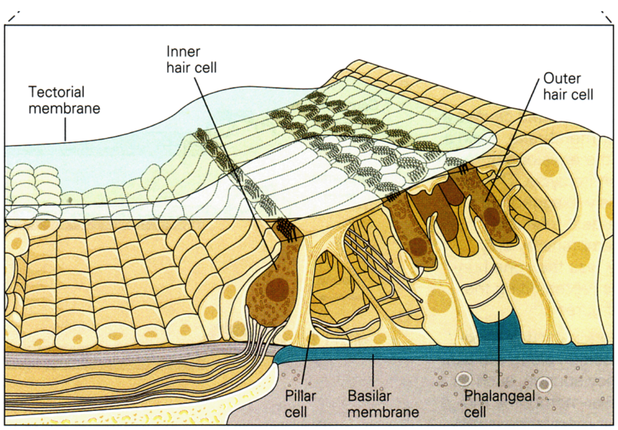
Basilar membrane to hair cells



Hair Cells of inner ear

Mechanoreceptors that detect vibration (audition), head acceleration (vestibular)

Stereocilia -- tufted projections that stick into endolymph and gelatinous tectoral membrane and bend with vibration.

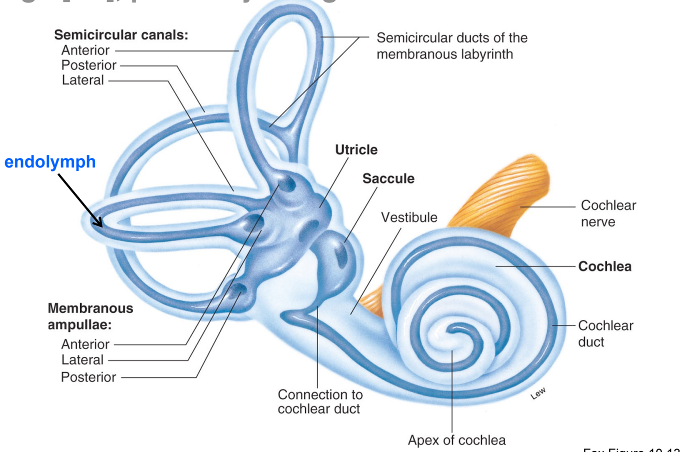
Bending of stereocilia causes change in membrane potential, and regulates release of neurotransmitter onto afferent nerve
- depolarization -> more transmitter release -> more Action Potentials
- hyperpolarization -> less transmitter release -> fewer Action Potentials

Bending of stereocilia opens **K+ channels**.

Because endolymph is high in K+, K+ rushes into hair cell to cause depolarization.

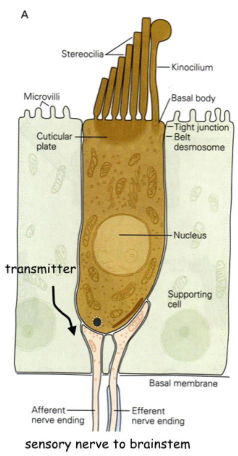
Endolymph of inner ear

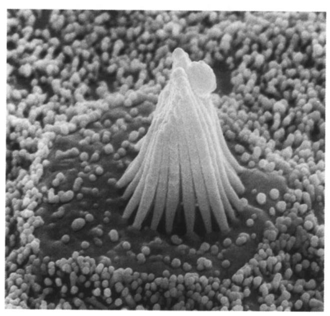
high [K+], positively charged fluid



Fox Figure 10.13

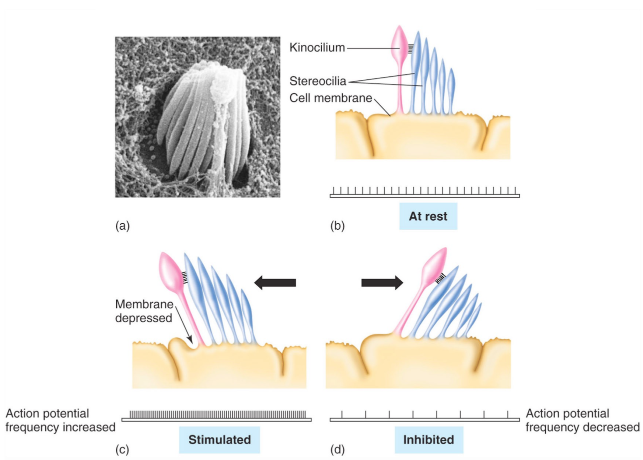
Hair cell



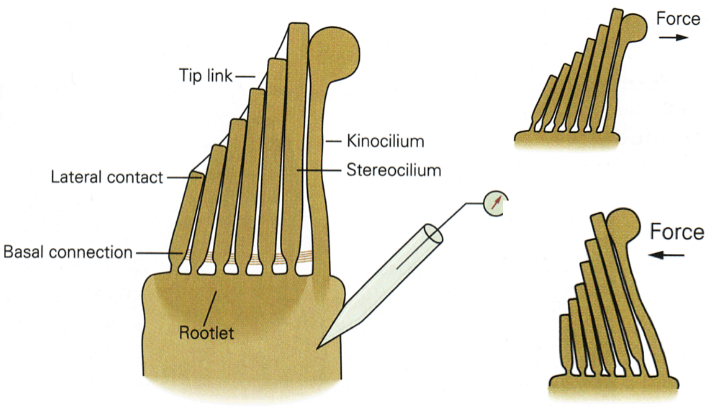


Stereocilia -- tufted projections that stick into gelatinous tectoral membrane and bend with vibration

Figure 10.14

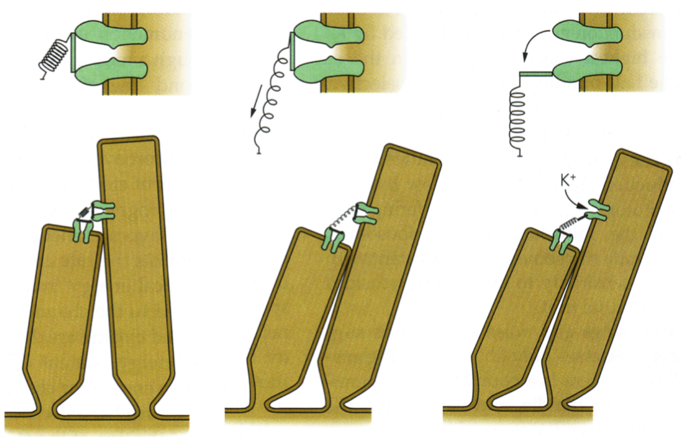


Vibration bends hair cells



Deflection of stereocilia opens K+ channels

K+ rushes into hair cell, causing depolarization

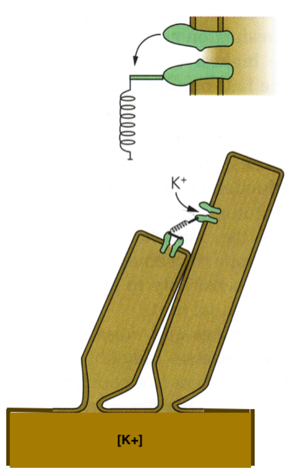


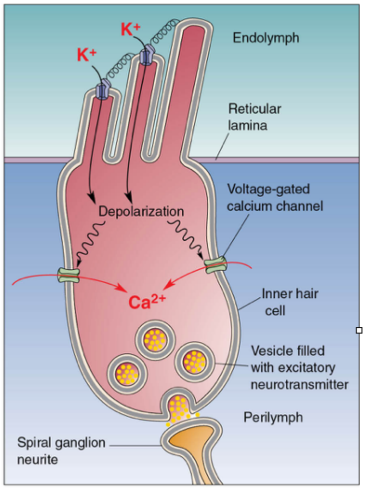
Endolymph of inner ear has high [K+]

K+ in hair cells works like Na+ in neurons

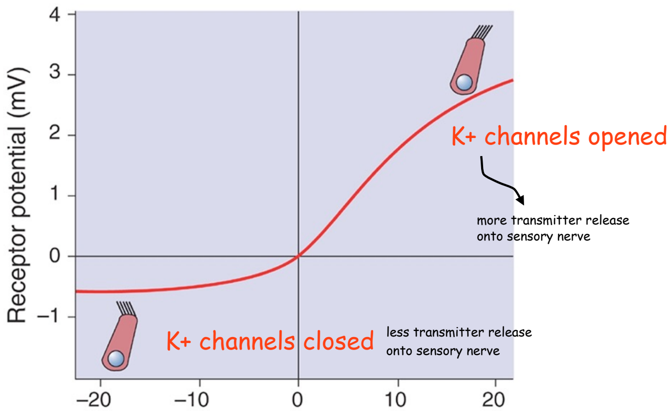
[K+] = 157 mM

[Na+] = 1.3 mM





Bending of stereocilia causes change in membrane potential



(a)

Vibration of Basilar Membrane

Vibrations of oval window -> vibrations in endolymph -> vibration of basilar membrane.

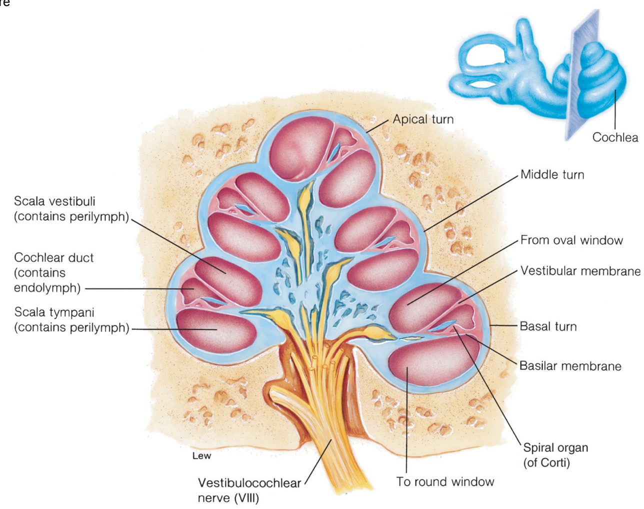
Response of basilar membrane varies across its length.

Low frequency sound vibrates **apex** of cochlea (basilar membrane **thicker**).

High frequency sound vibrates **base** of cochlea (basilar membrane **thinner**).

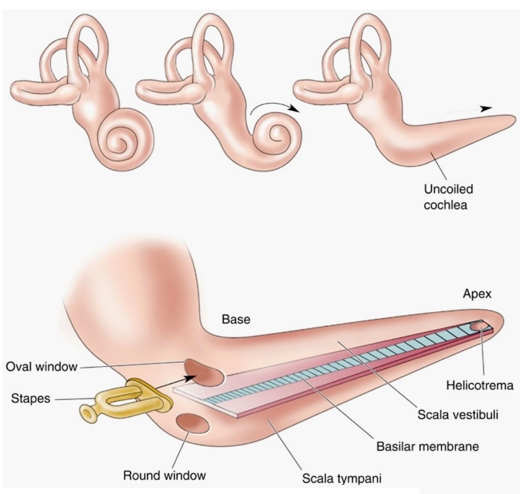
Transduce sound frequency into spatial location.

Figure

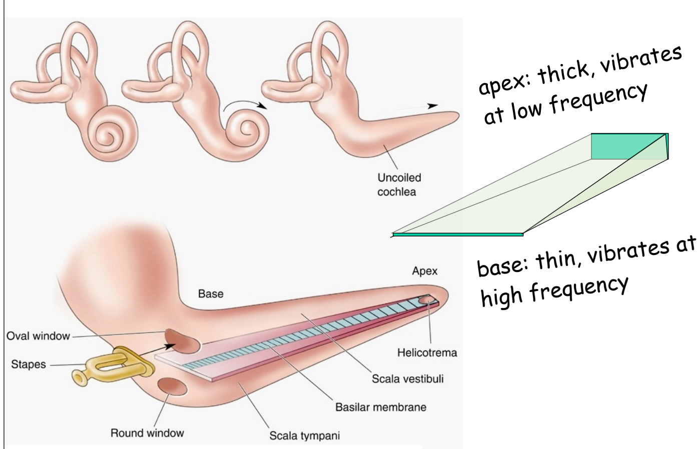


Apical turn
Cochlea
Middle turn
Scala vestibuli (contains perilymph)
Cochlear duct (contains endolymph)
Scala tympani (contains perilymph)
From oval window
Vestibular membrane
Basal turn
Basilar membrane
Spiral organ (of Corti)
Lew
Vestibulocochlear nerve (VIII)
To round window

22



Uncoiled cochlea
Apex
Base
Oval window
Stapes
Helicotrema
Scala vestibuli
Basilar membrane
Round window
Scala tympani



Uncoiled cochlea
Apex
Base
Oval window
Stapes
Helicotrema
Scala vestibuli
Basilar membrane
Round window
Scala tympani
apex: thick, vibrates at low frequency
base: thin, vibrates at high frequency

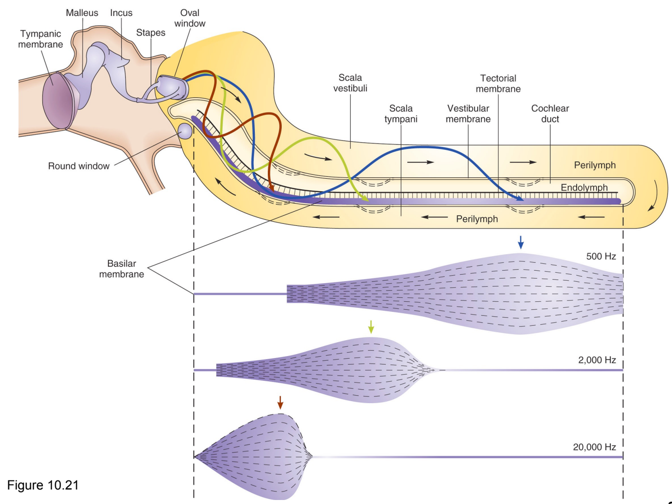


Figure 10.21

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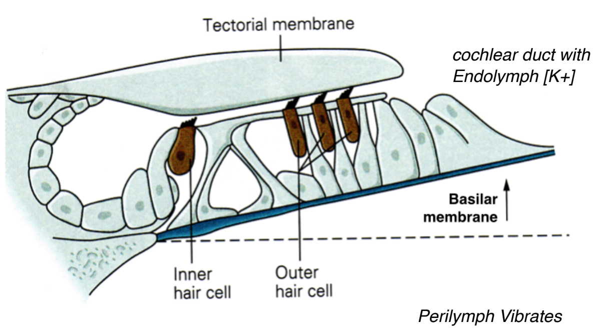
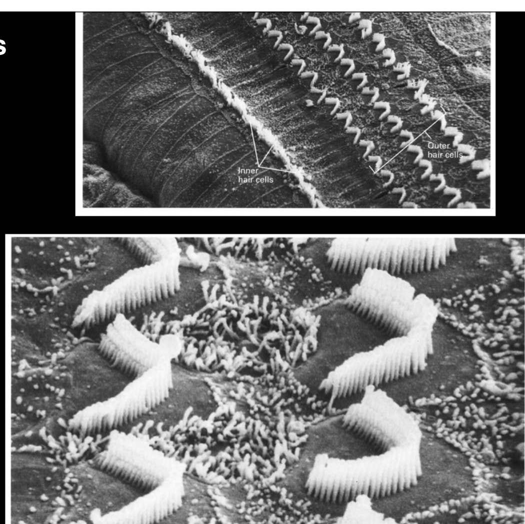
Basilar membrane vibration bends hair cells

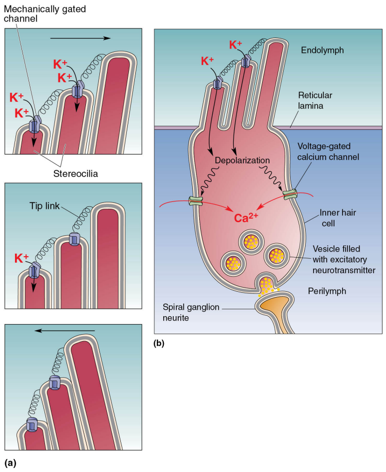


see Fox Figure 10.22

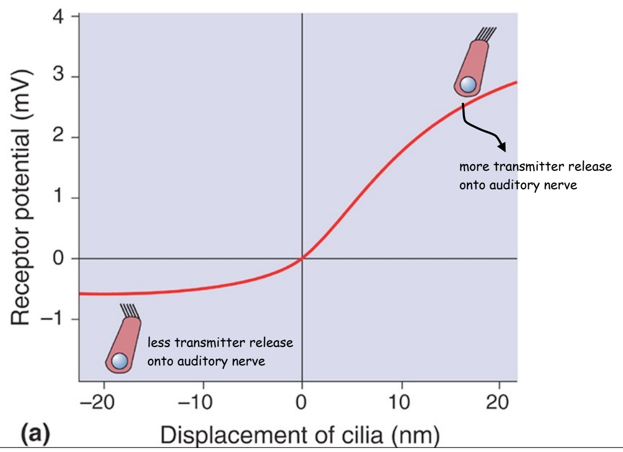
Hair cells



Deflection of stereocilia opens K+ channels

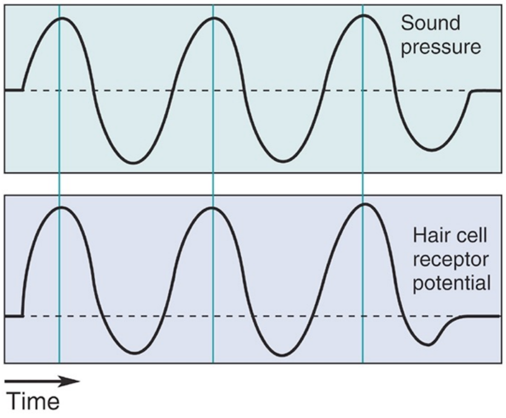


Bending of stereocilia causes change in membrane potential



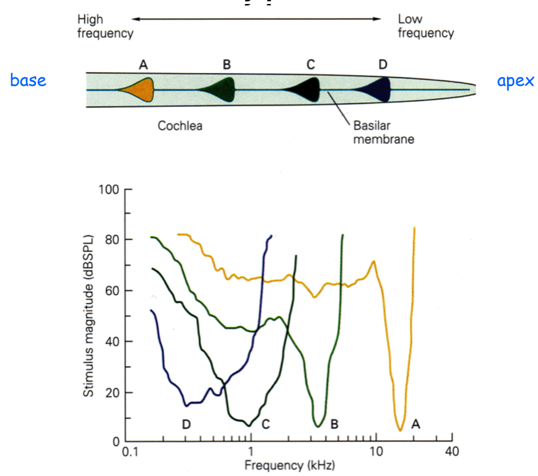
(a)

Bending of stereocilia causes change in membrane potential



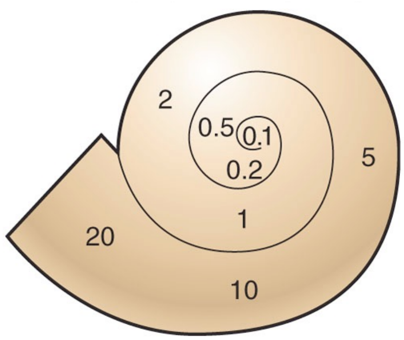
(b)

Hair cells are tuned by position in cochlea



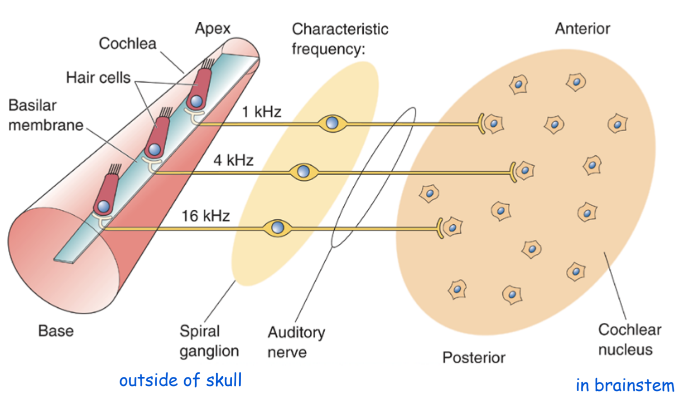
Frequencies Map on to Extent of Cochlea:

High frequencies at base, low frequencies at apex.

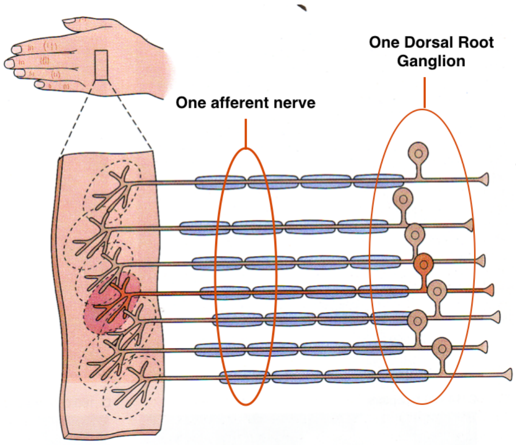


Fox Figure 10.23

- Stimulus Frequency
  - Tonotopic maps on the basilar membrane
  - 20 - 20,000 Hz range, 0.3% discrimination



Somatosensory receptive fields of spinal sensory nerves



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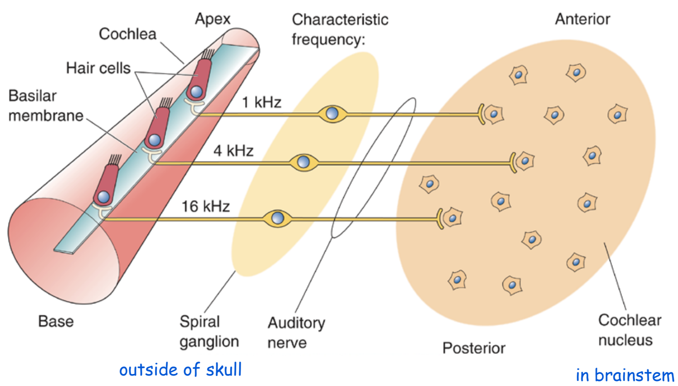
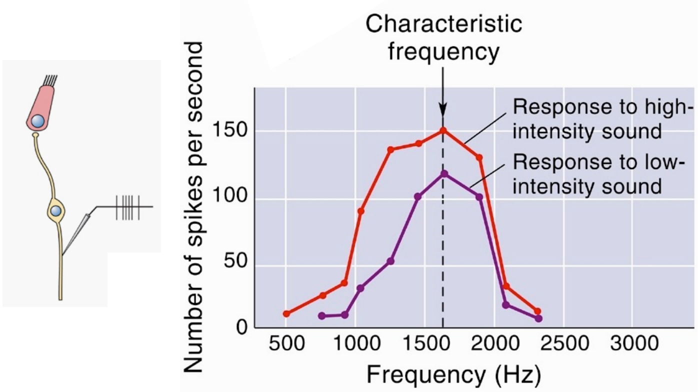
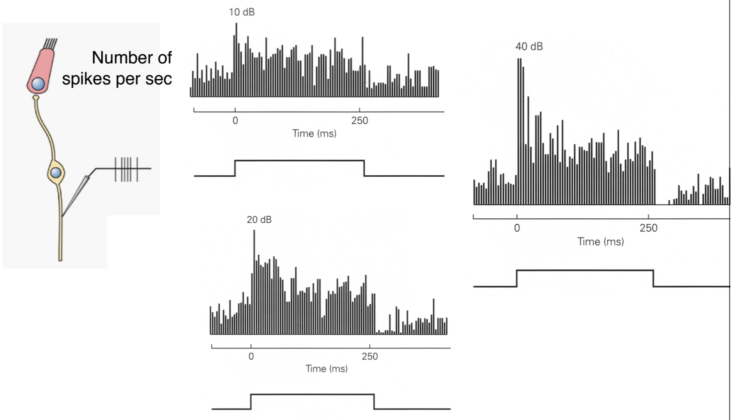


Each Auditory Neuron responds best to characteristic frequency
(position of hair cells in cochlea = receptive field of neuron)



Auditory Nerve encodes intensity of sound

(increased rate of action potentials = louder sound)



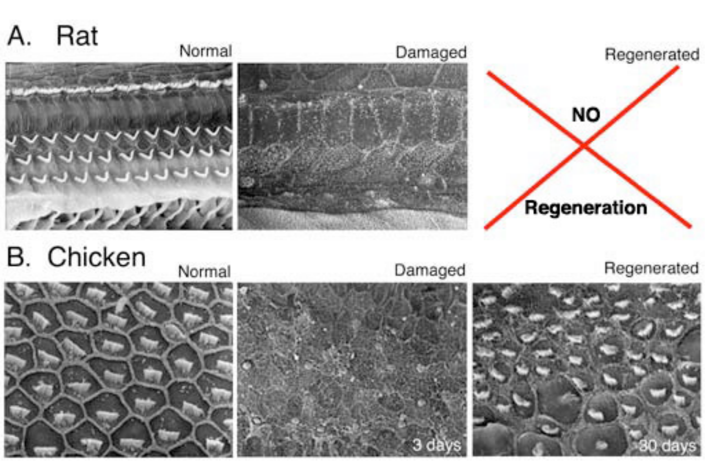
Damage to Inner Ear Hair Cells

In mammals, hair cells die with old age (e.g. hi frequency hair cells) or after damage due to high intensity noise.

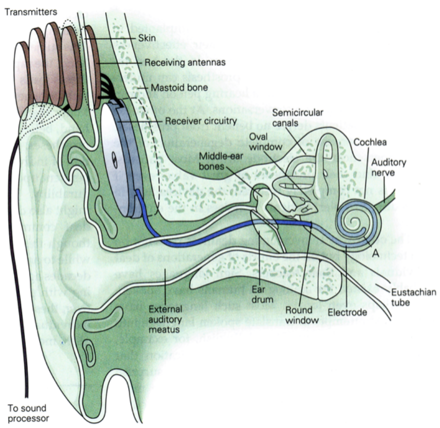
Hair cells do not regenerate (although they can regenerate in lower animals).

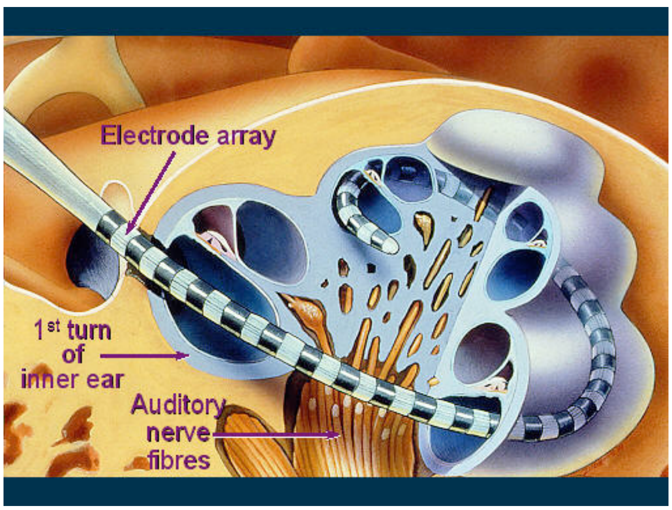
Cochlear Implants reproduce function of basilar membrane and hair cells: stimulate auditory nerve endings at appropriate point in cochlea to reproduce tonotopic mapping of missing hair cells.

Example: sound of voice, music if only a small number of frequencies are restored.



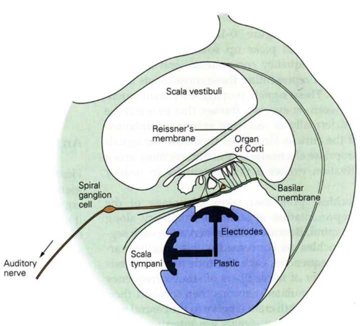
Map frequencies to electrode location in cochlea

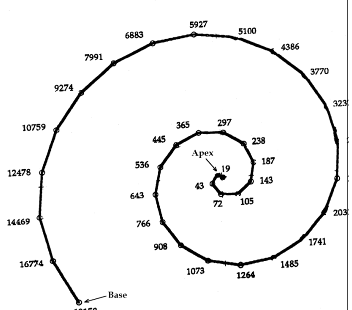




http://graemeclarkfoundation.org/bionic_ear/CI%20Function.htm

Cochlear implant to cure deafness by directly stimulating auditory nerves





cochlear implant -> 32 different frequencies
(normal inner ear -> 300+ different frequencies

http://graemeclarkfoundation.org/bionic_ear/CI%20Function.htm

Central Representation of Audition

Auditory input projects to mostly contralateral auditory cortex and some ipsilateral auditory cortex.

Tonotopy is preserved in auditory cortex: cortical neurons respond to characteristic frequencies, with mapping from low to high frequency across the auditory cortex.

Auditory cortex neurons send projections to higher levels of cortex that extract features from sound:

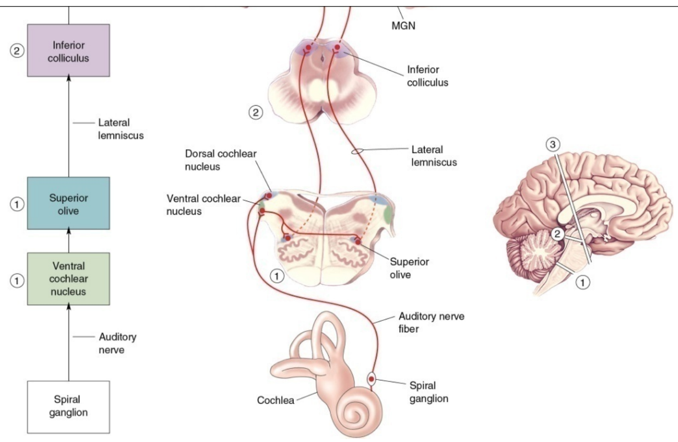
Wernicke's Area -- extracts meaning from words, integrate with vision

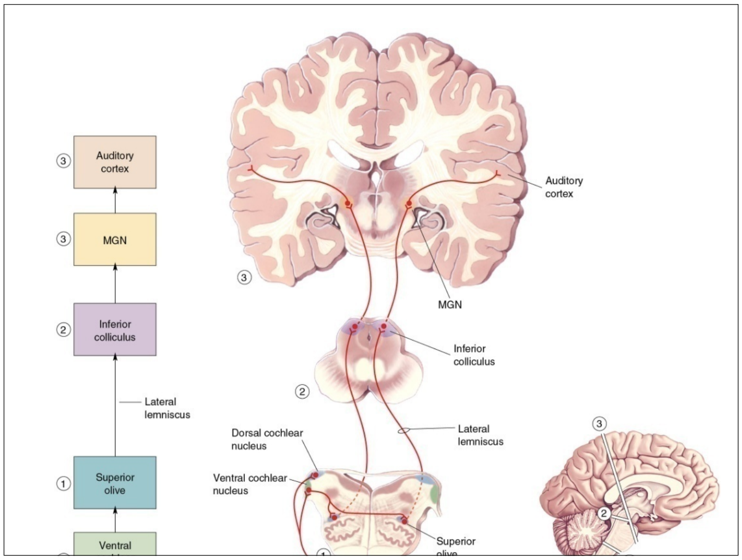
Broca's Area -- generates speech via projections to motor cortex (to move the tongue lips, & throat).

McGurk Effect: example of sound integration with visual information to change perception of syllable.

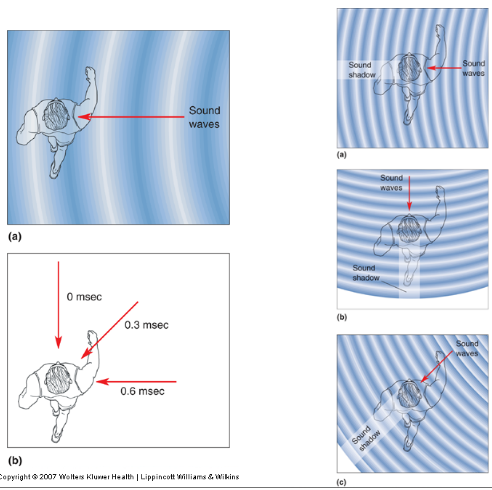
Mechanisms of Sound Localization

- Techniques for Sound Localization
  - Horizontal: Left-right, Vertical: Up-down
- Localization of Sound in Horizontal Plane
  - Interaural time delay: Time taken for sound to reach from ear to ear
  - Interaural intensity difference: Sound at high frequency from one side of ear
  - Duplex theory of sound localization:
    - Interaural time delay: 20-2000 Hz
    - Interaural intensity difference: 2000-20000 Hz

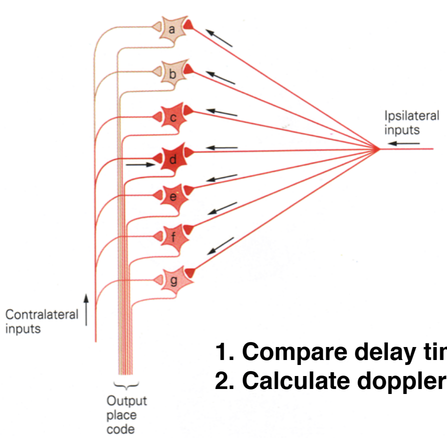




- Interaural time delay and interaural intensity difference



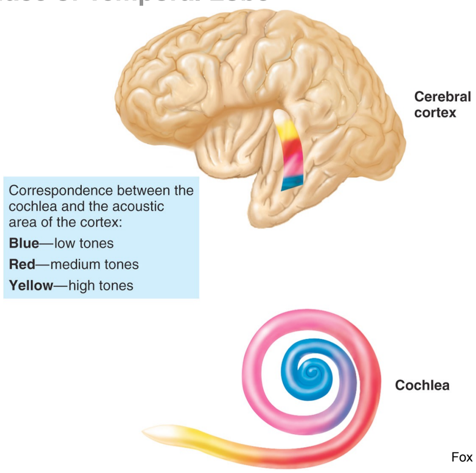
Auditory Localization



1. Compare delay times from each ear
2. Calculate doppler and echo (bats)

Auditory Cortex

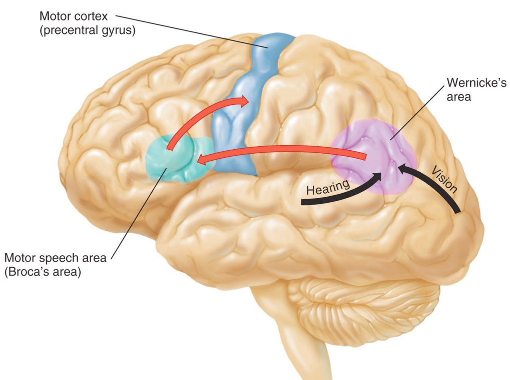
Inner surface of Temporal Lobe



Fox Figure 10.25

Feature Extraction and Integration of Auditory Input

Integration with vision, word extraction, speech generation



Fox Figure 8.14