横浜市立大学大学院

ナノシステム科学専攻

物理博士　ミケレット・ルジェロ

知覚情報科学

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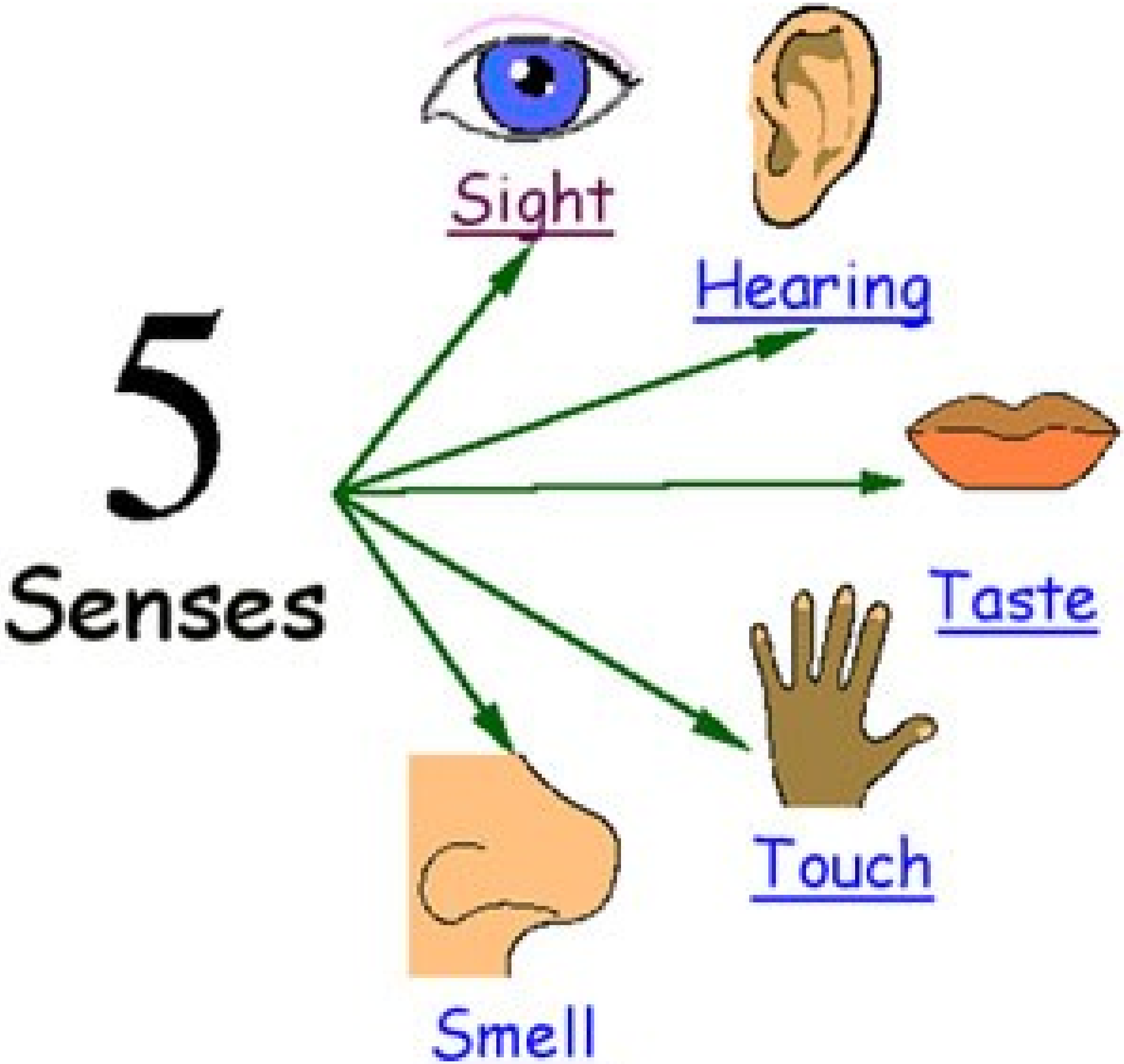
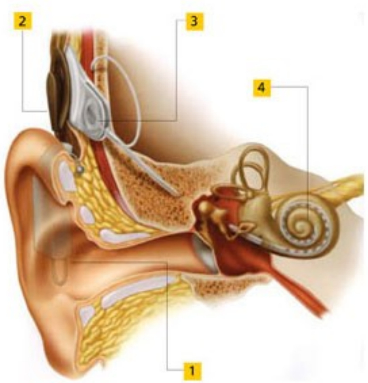
(4)

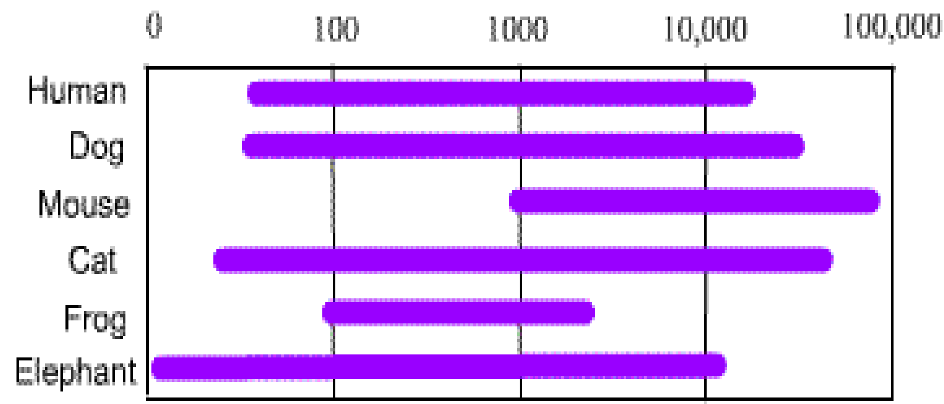
後期２０１０年

THE EAR: the HEARING sense （聴覚、ちょうかく）


5
Senses
Sight
Hearing
Taste
Touch
Smell



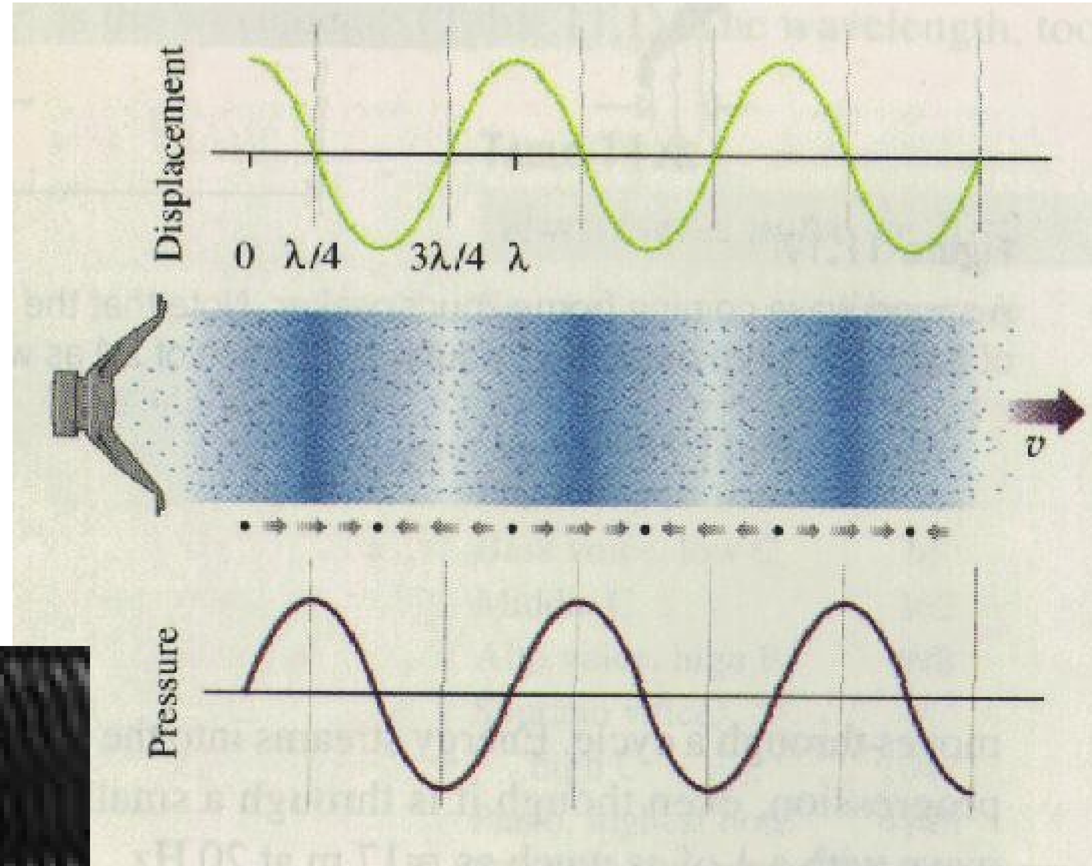
Frequency

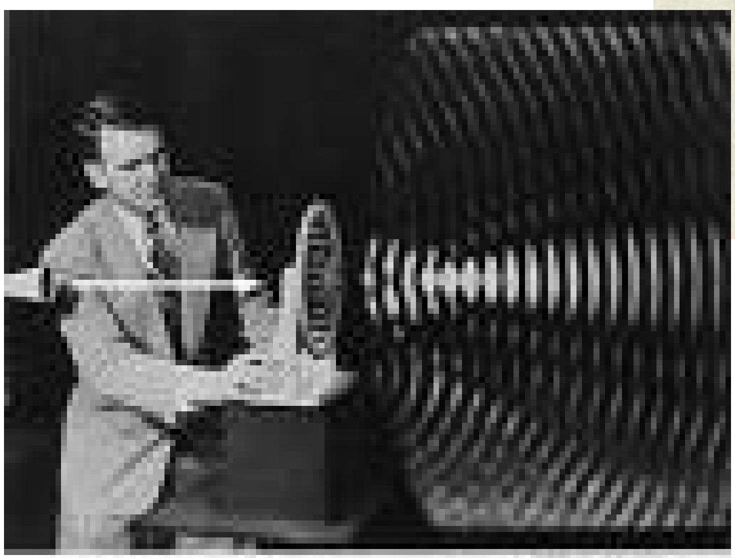


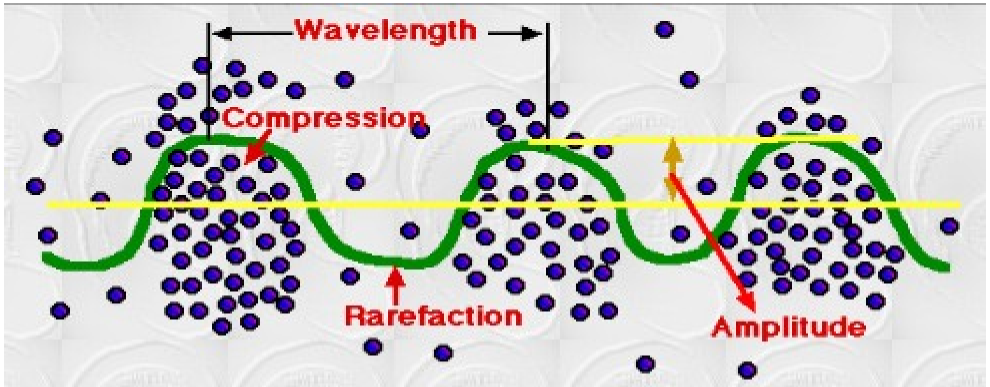
Noise	Decibels
Whisper	20
Normal Talking	50-60
Car Traffic	70
Alarm Clock	80
Lawn Mower	95
Rock Concert	100
Jackhammer	115
Jet Engine	130
Gun Shot	140

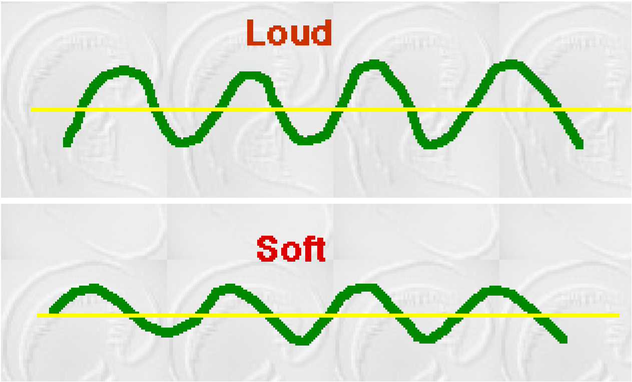
Amplitude

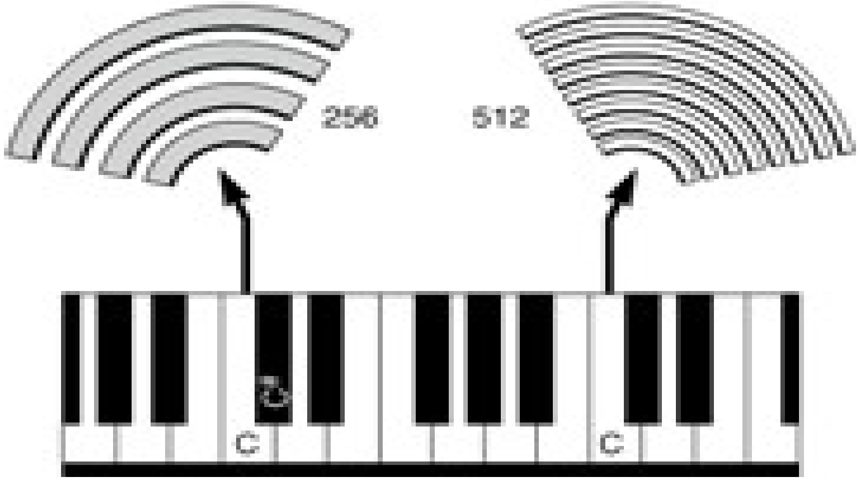
The sound it is a PRESSURE WAVE

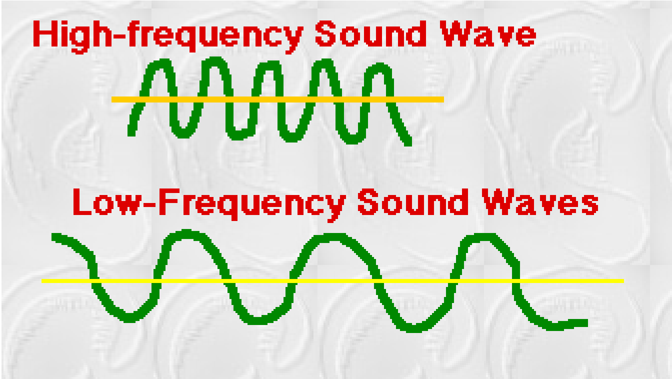





Wavelength
Compression
Rarefaction
Amplitude


Loud
Soft


256
512
C
C


High-frequency Sound Wave
Low-Frequency Sound Waves

The sound it is a PRESSURE WAVE

空気の圧力

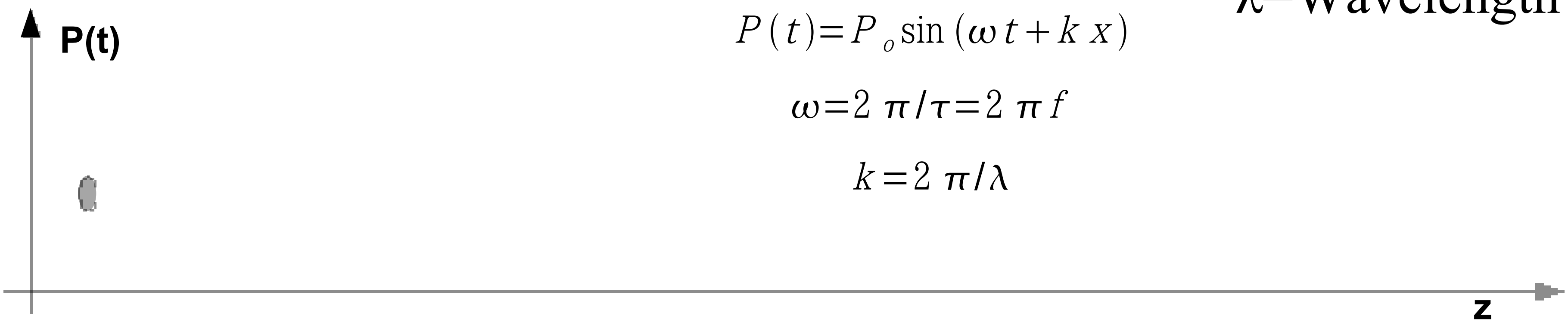
f=Frequency

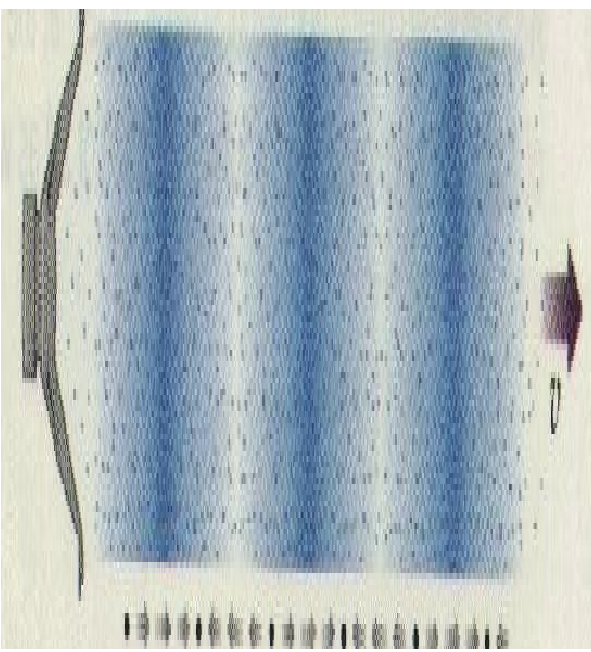
λ=Wavelength

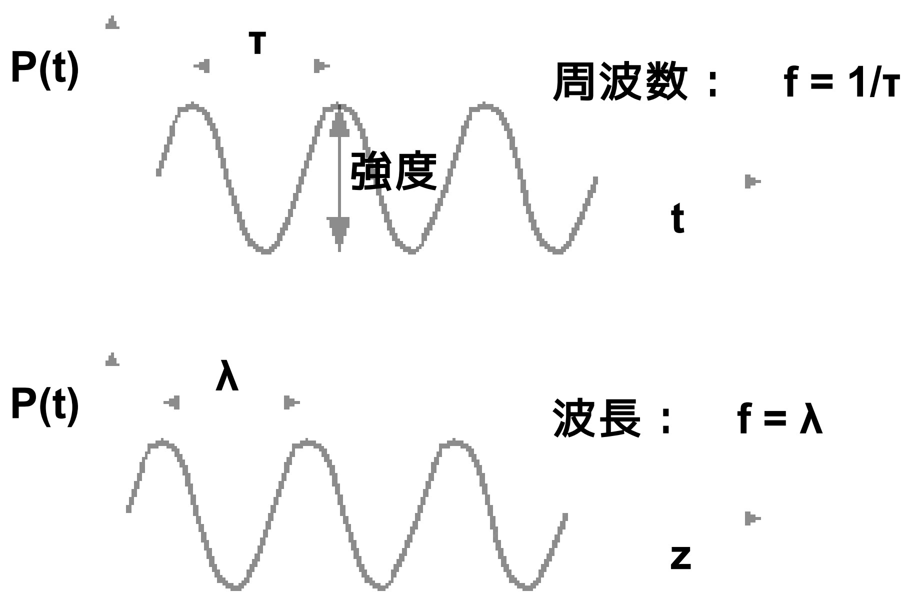
$$P(t)=P_o \sin(\omega t + k x)$$

$$\omega = 2\pi/\tau = 2\pi f$$

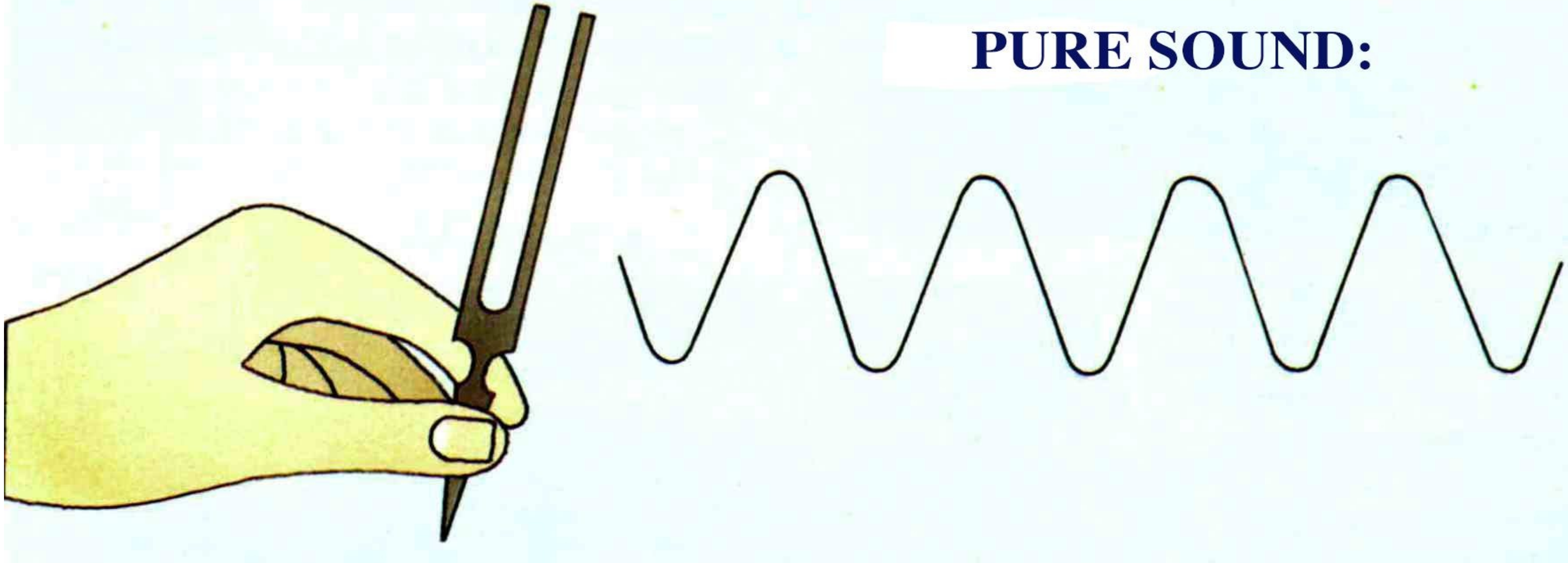
$$k = 2\pi/\lambda$$



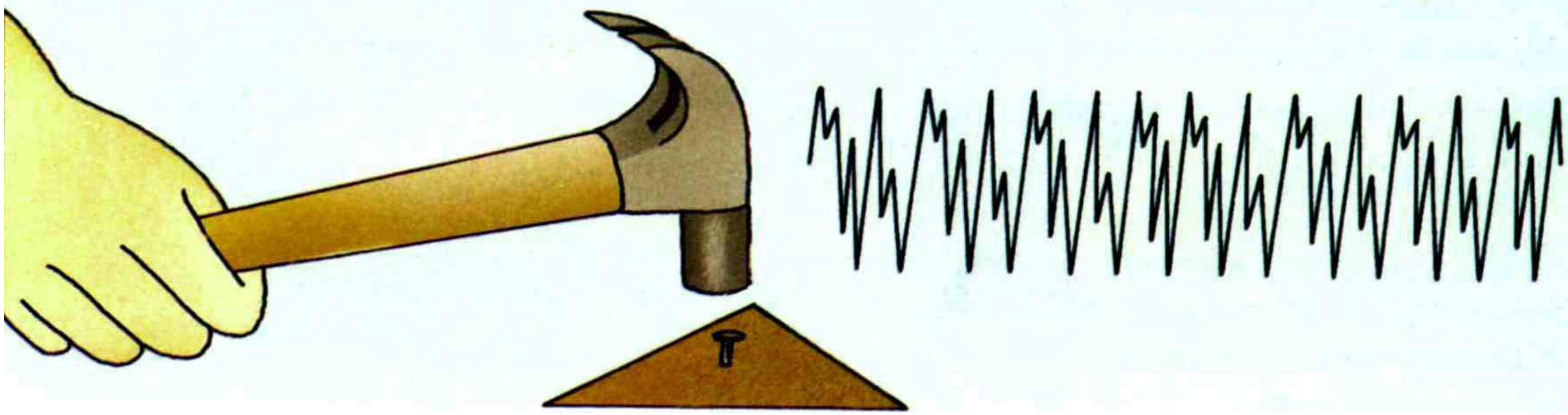




PURE SOUND:

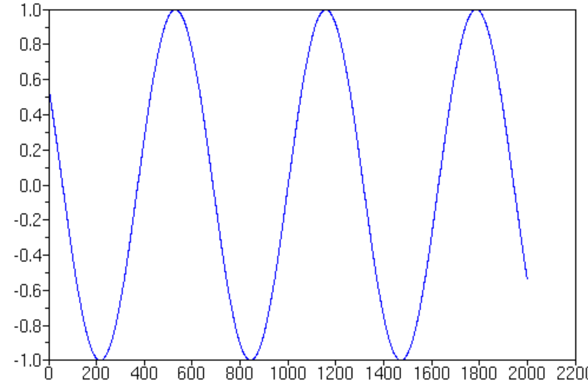


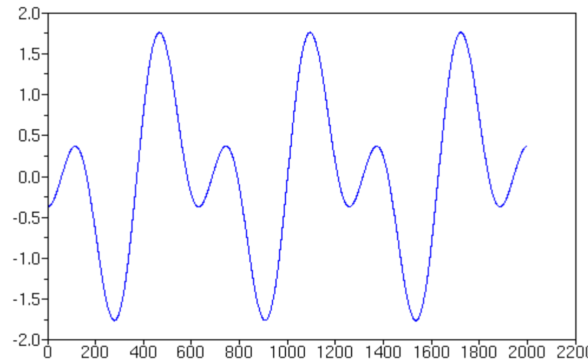
NOISE:

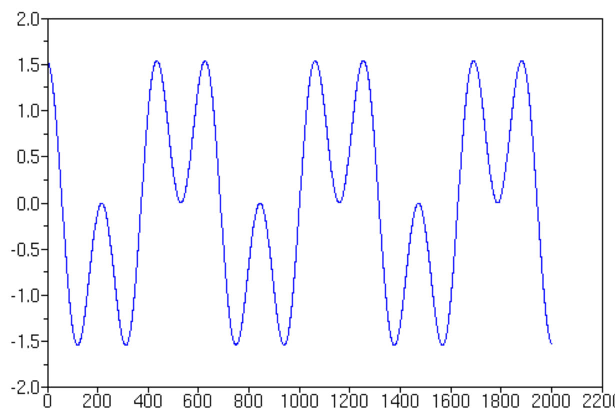


The sound SPECTRUM

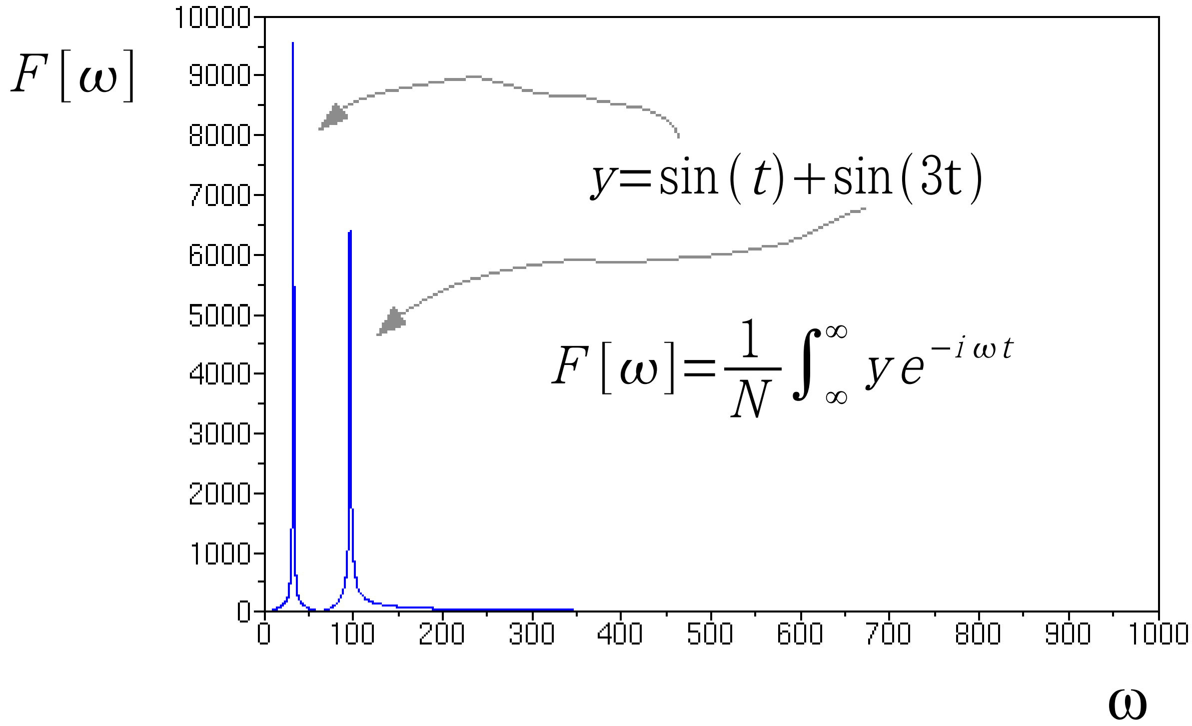
$$y = \sin(t)$$
$$y = \sin(t) + \sin(2t)$$
$$y = \sin(t) + \sin(3t)$$



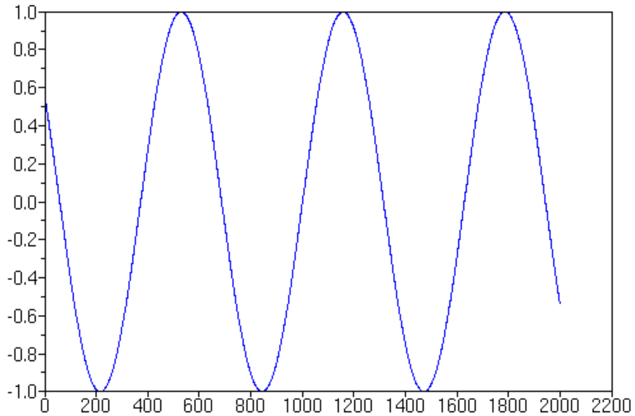




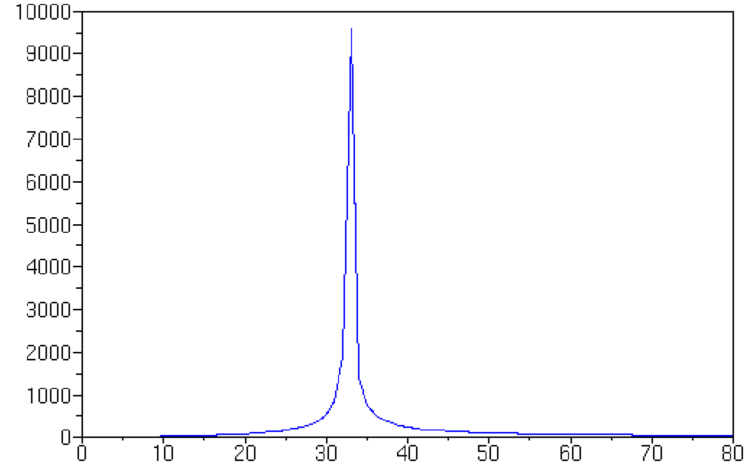
The FOURIER trasformation



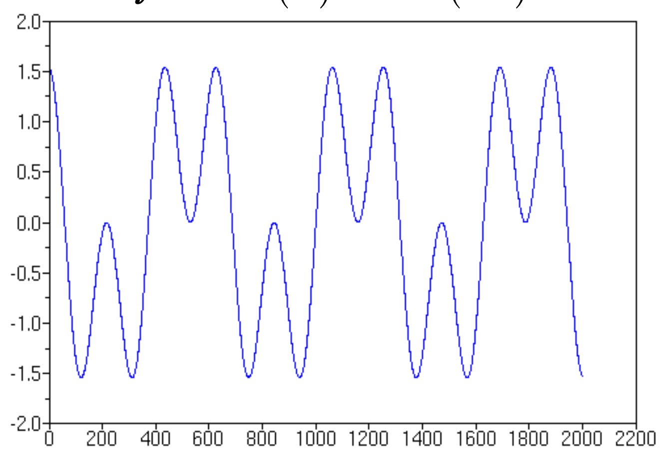
$$y = \sin(t)$$



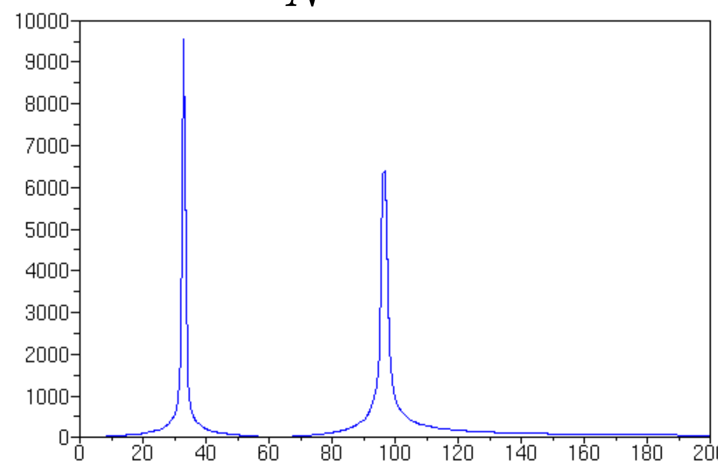
$$F[\omega] = \frac{1}{N}\int_{\infty}^{\infty} y e^{-i\omega t}$$



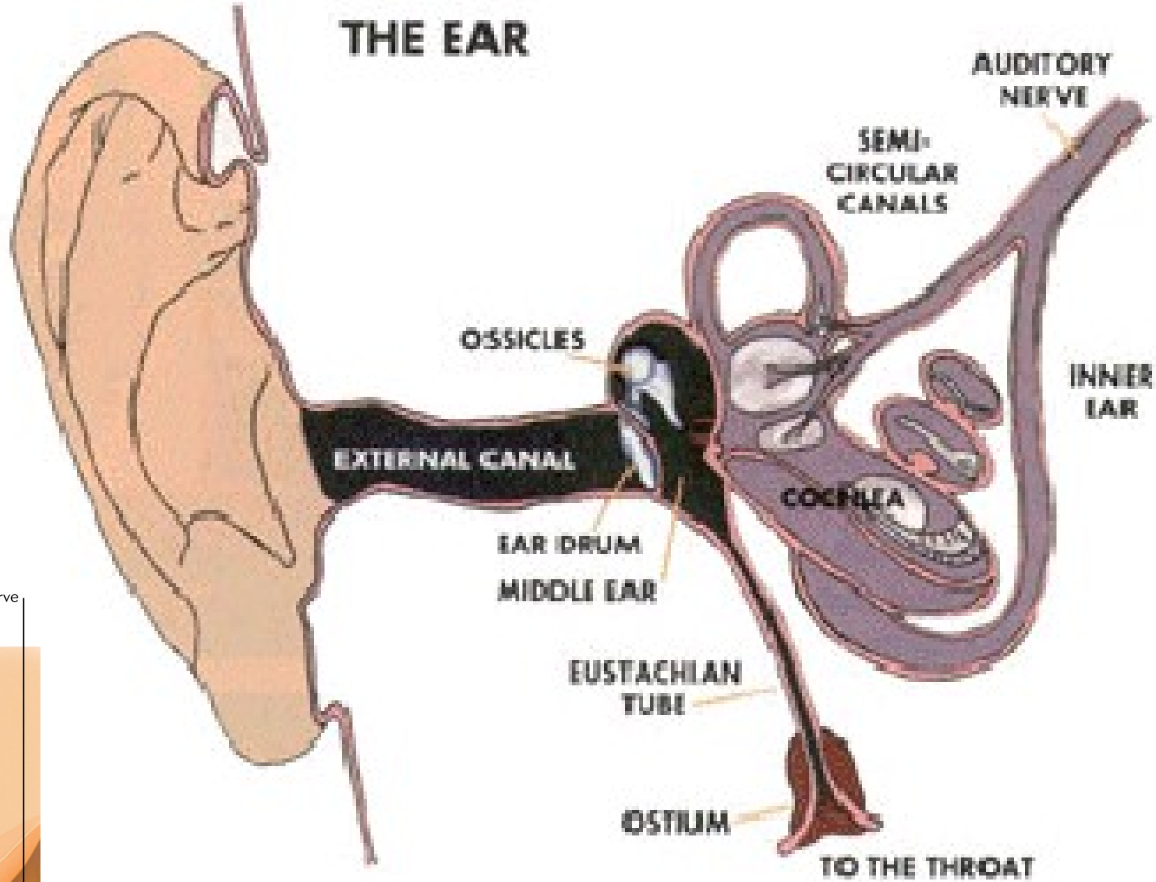
$$y = \sin(t) + \sin(3\mathrm{t})$$

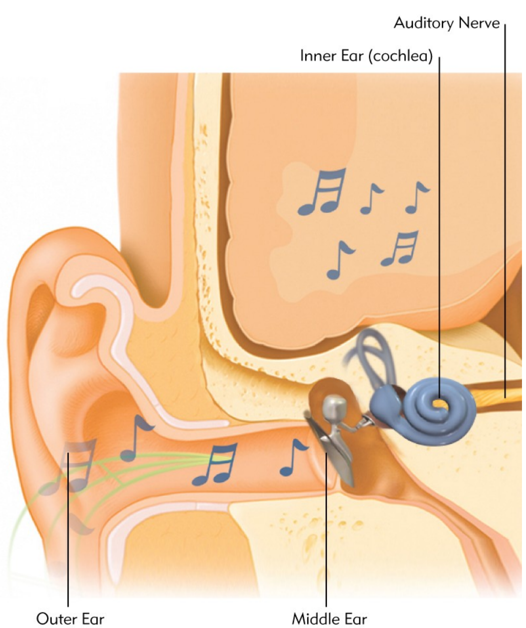


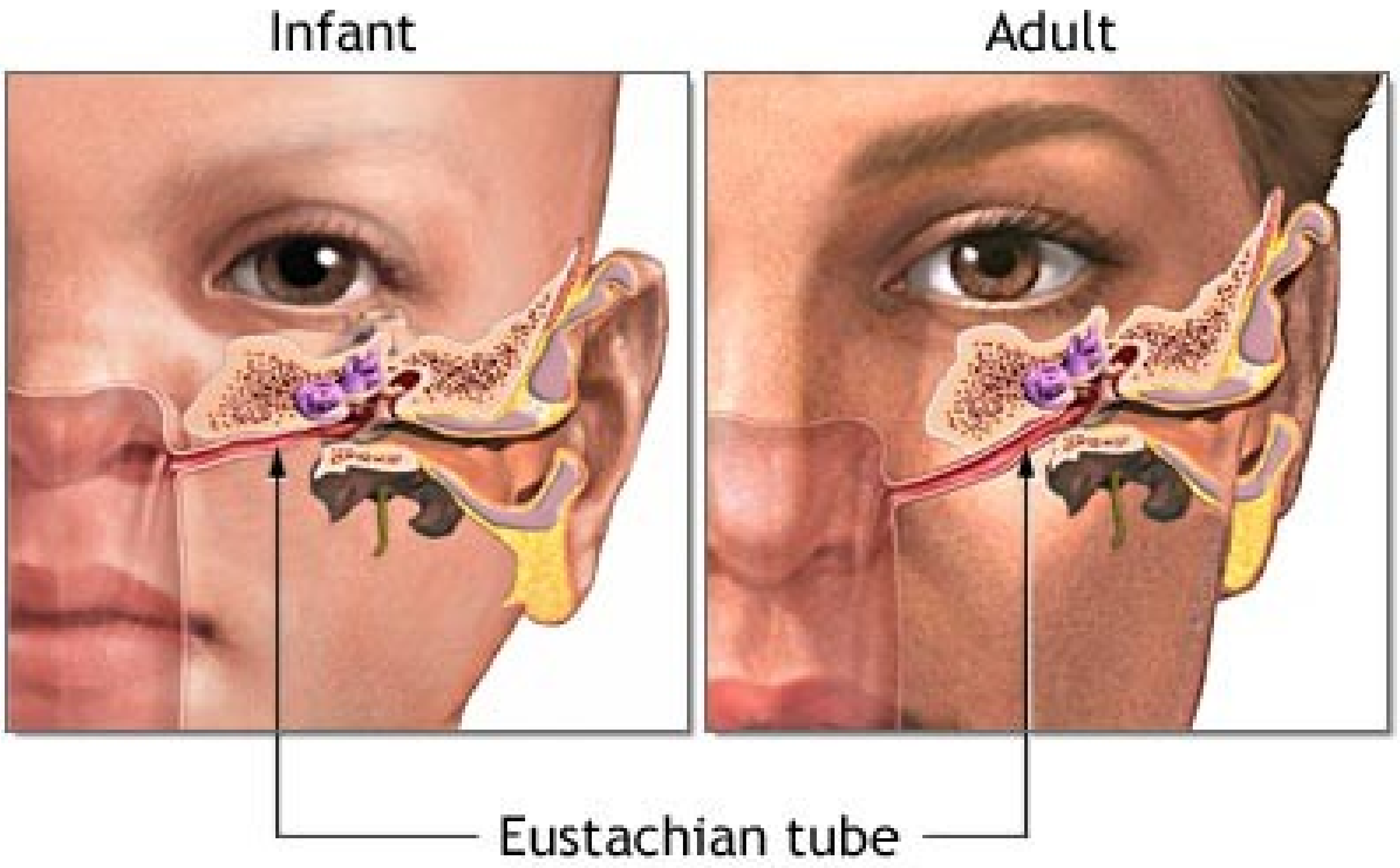
$$F[\omega] = \frac{1}{N}\int_{\infty}^{\infty} y e^{-i\omega t}$$

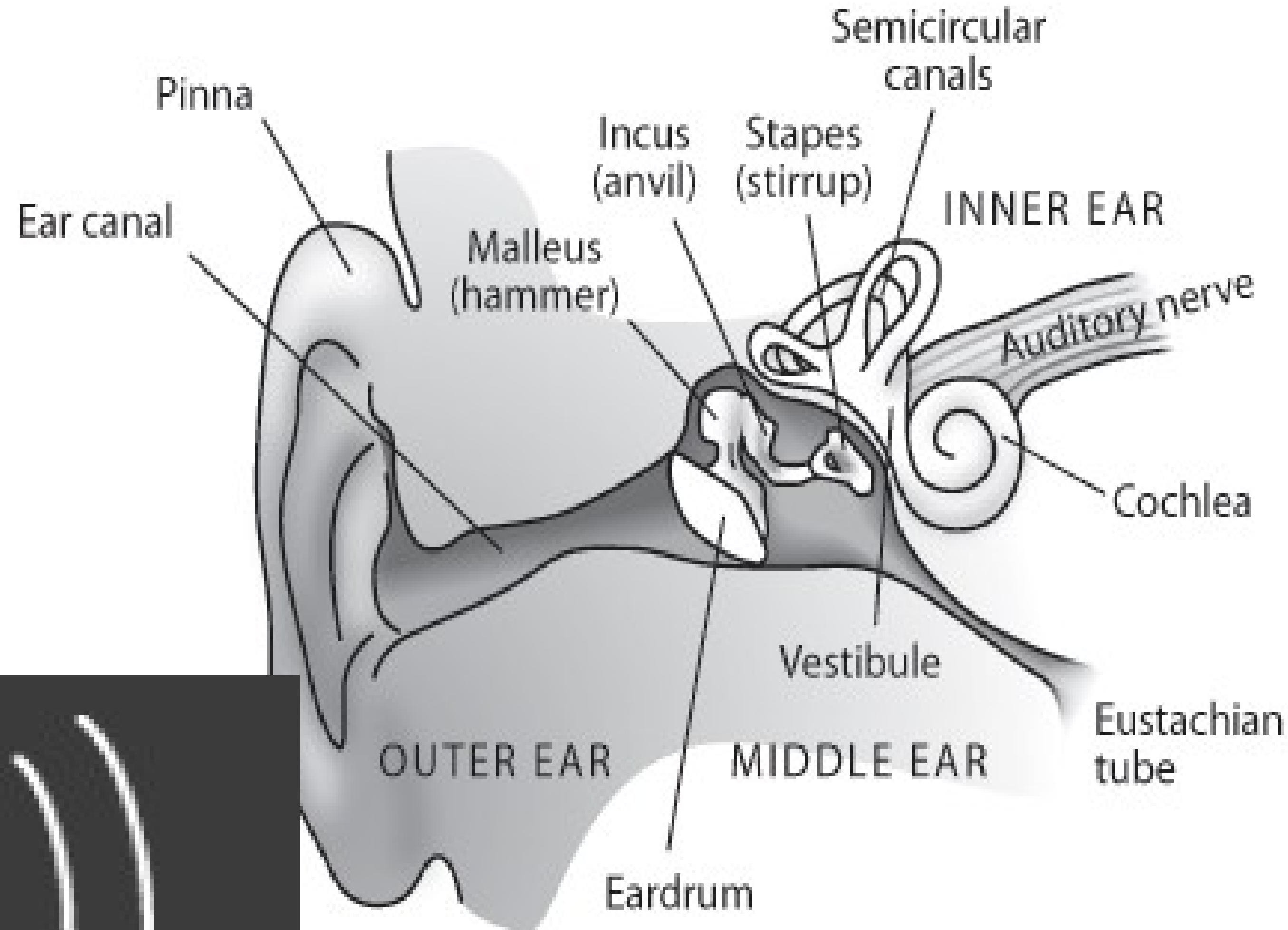


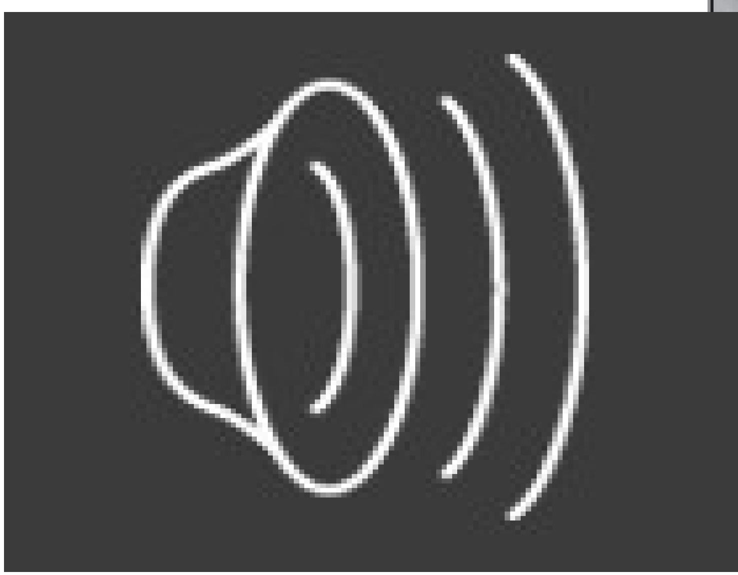
Inner Ear
Middle Ear
Outer Ear





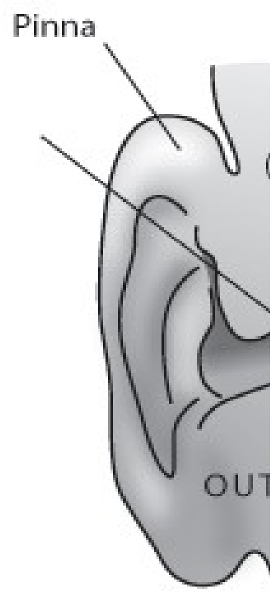

Infant
Adult
Eustachian tube


Semicircular canals
Pinna
Incus (anvil)
Stapes (stirrup)
INNER EAR
Ear canal
Malleus (hammer)
Auditory nerve
Cochlea
Vestibule
Eustachian tube
OUTER EAR
MIDDLE EAR
Eardrum

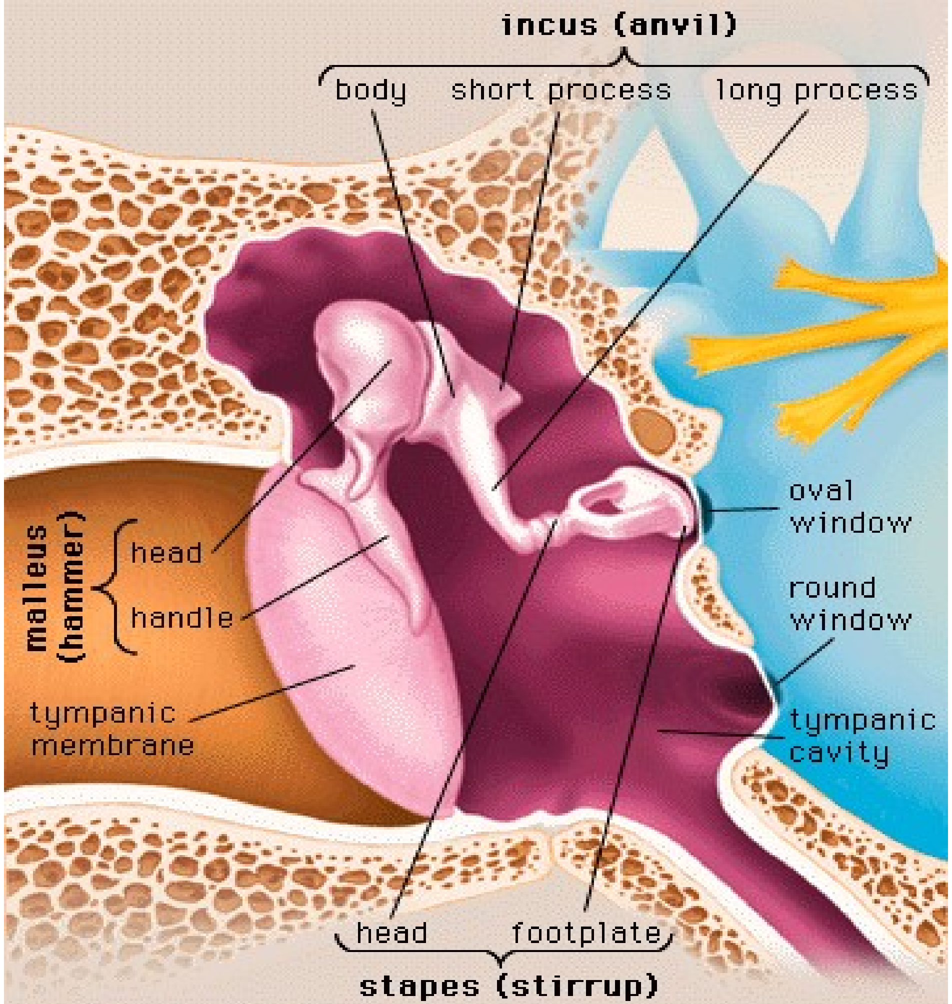


Outer Ear

- the “Pinna” is not frequency flat. Different frequencies are detected at different intensities.

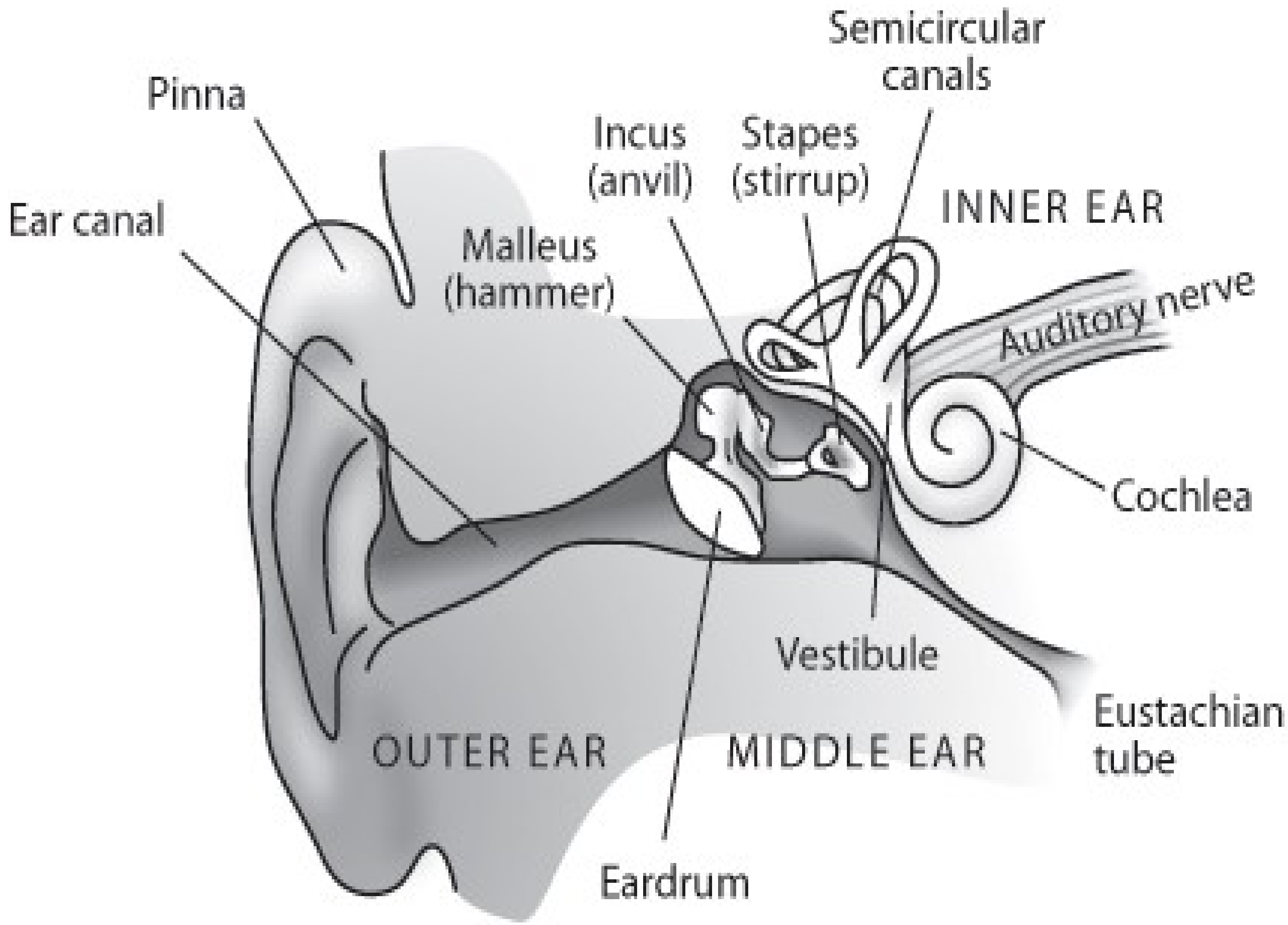


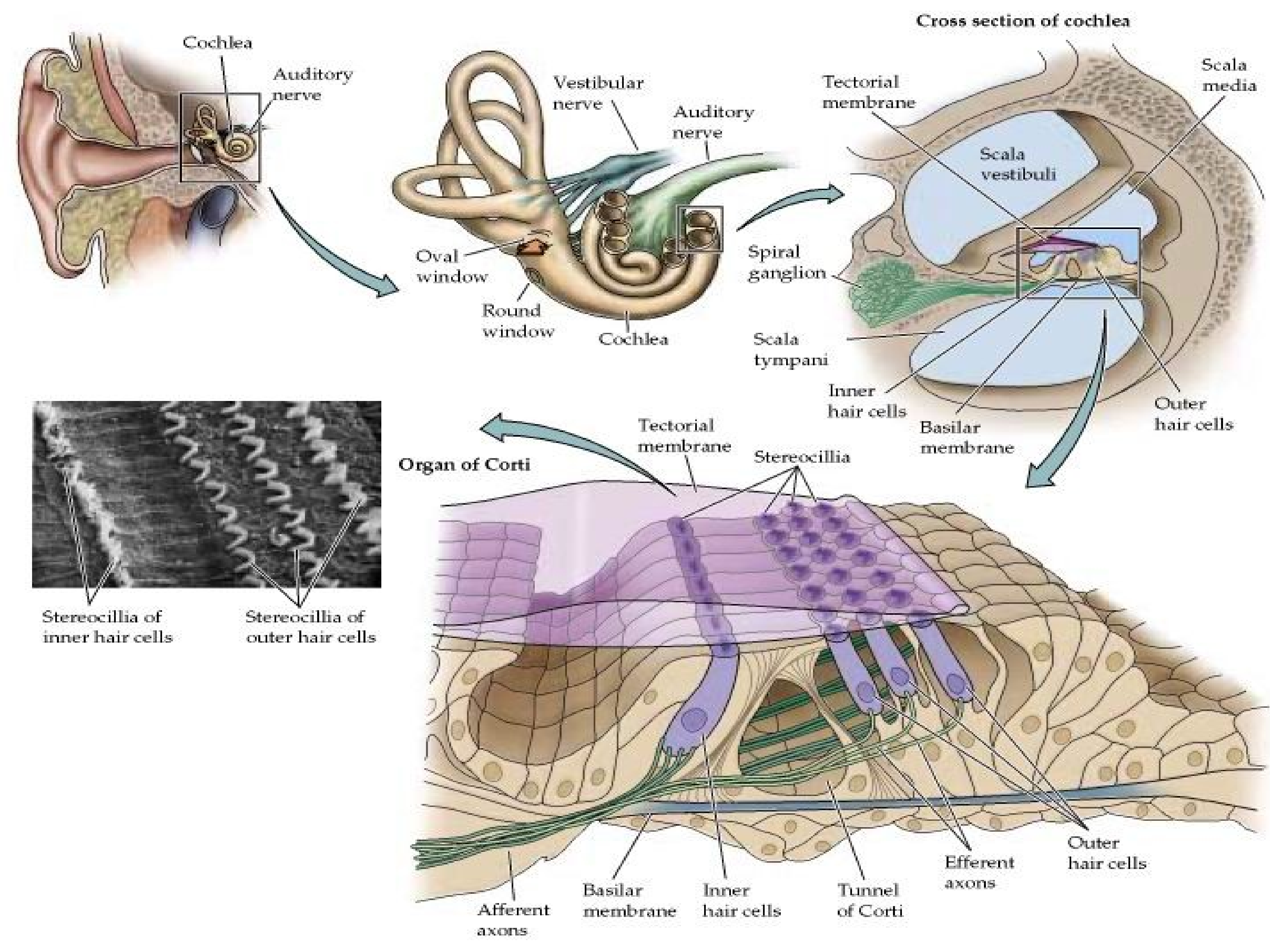
Middle Ear



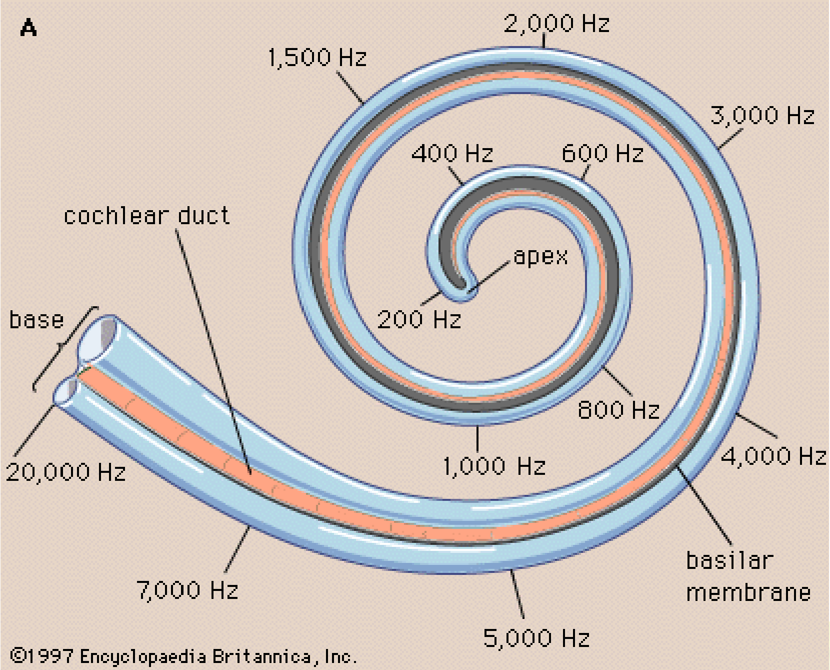
incus (anvil)
body
short process
long process
malleus (hammer)
head
handle
tympanic membrane
oval window
round window
tympanic cavity
head
footplate
stapes (stirrup)

Inner Ear


Semicircular canals
Pinna
Incus (anvil)
Stapes (stirrup)
INNER EAR
Ear canal
Malleus (hammer)
Auditory nerve
Cochlea
Vestibule
Eustachian tube
OUTER EAR
MIDDLE EAR
Eardrum



Cochlea
Auditory nerve
Vestibular nerve
Auditory nerve
Oval window
Round window
Cochlea
Cross section of cochlea
Tectorial membrane
Scala media
Scala vestibuli
Spiral ganglion
Scala tympani
Inner hair cells
Basilar membrane
Outer hair cells
Stereocillia of inner hair cells
Stereocillia of outer hair cells
Organ of Corti
Tectorial membrane
Stereocillia
Afferent axons
Basilar membrane
Inner hair cells
Tunnel of Corti
Efferent axons
Outer hair cells


A
2,000 Hz
1,500 Hz
3,000 Hz
400 Hz
600 Hz
cochlear duct
apex
base
200 Hz
800 Hz
1,000 Hz
4,000 Hz
20,000 Hz
basilar membrane
7,000 Hz
5,000 Hz
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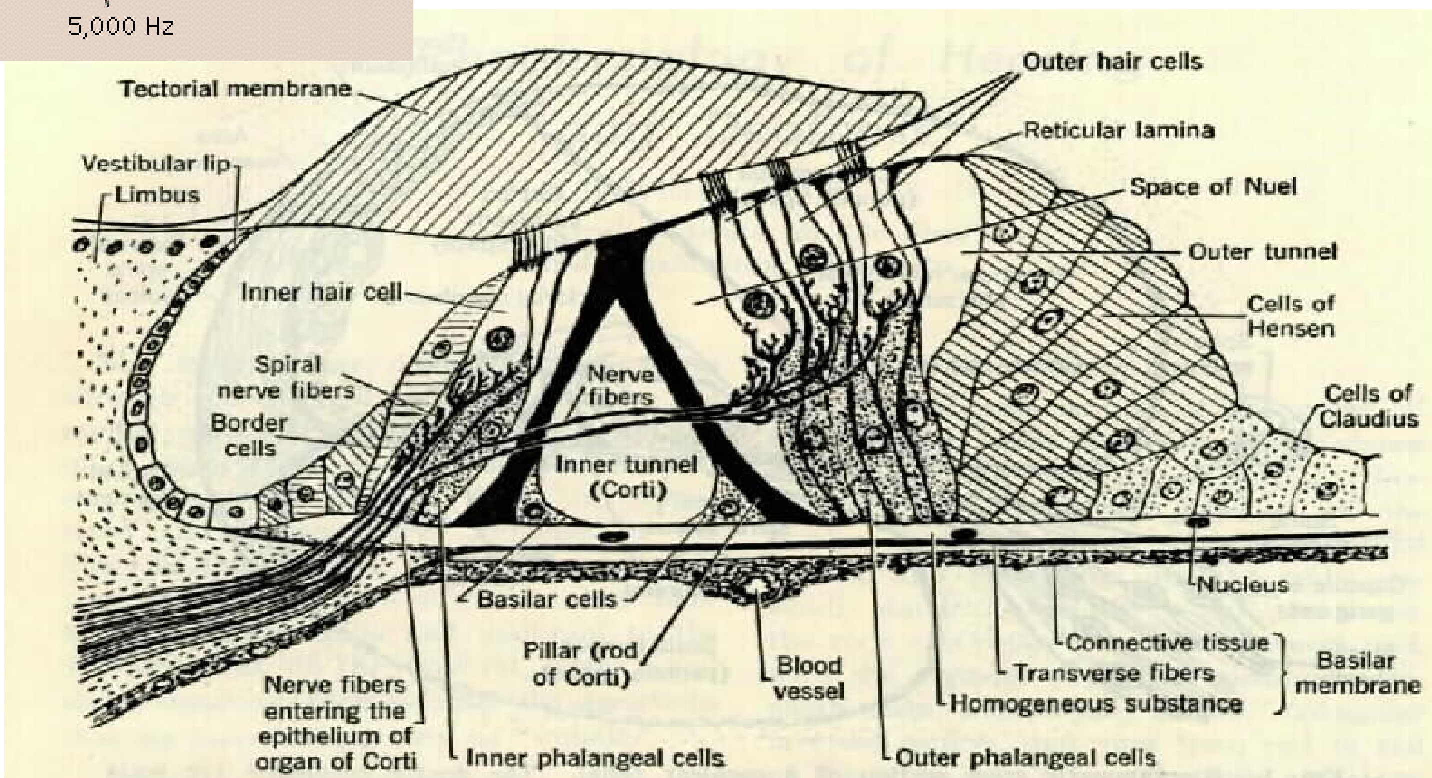
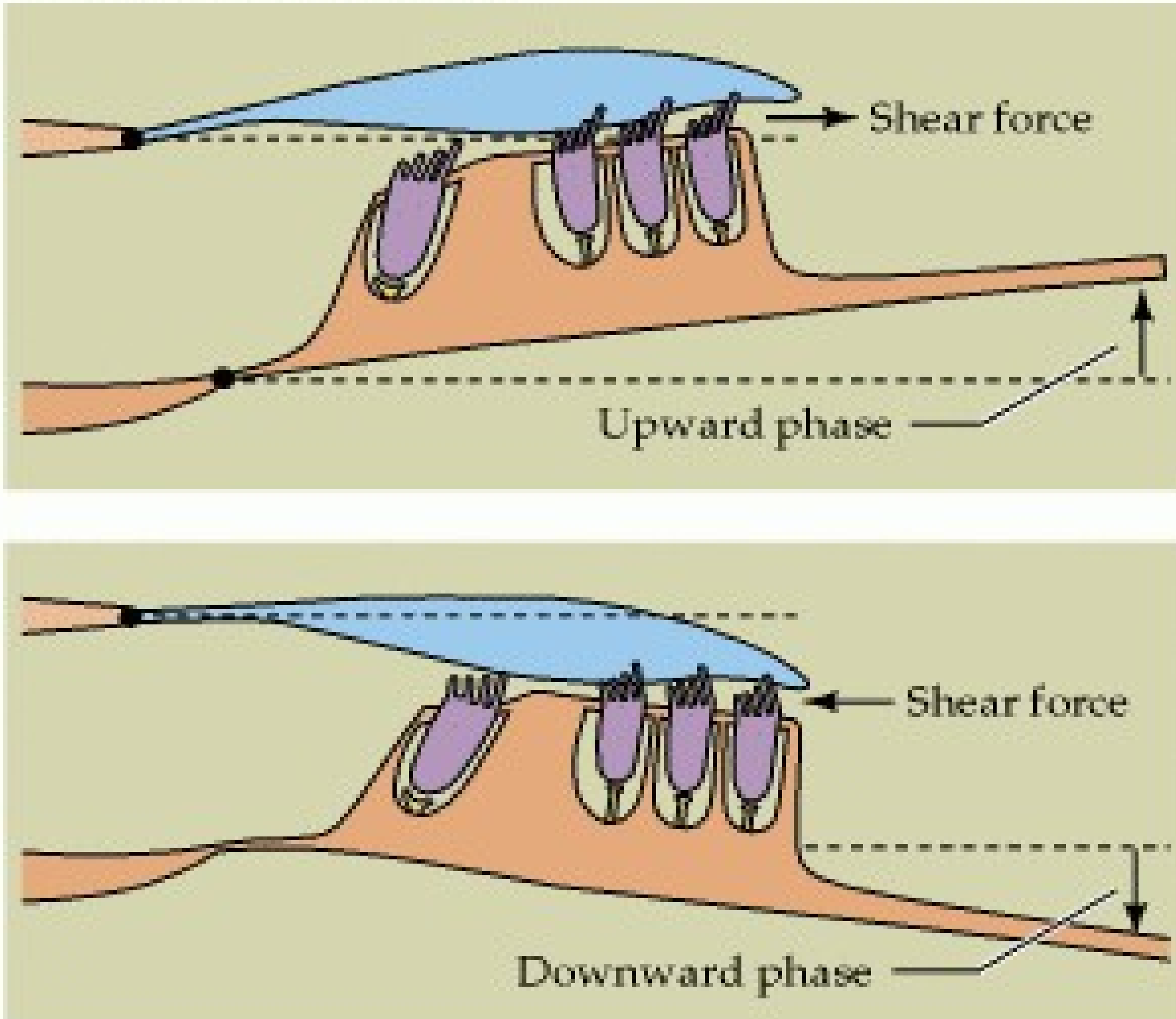
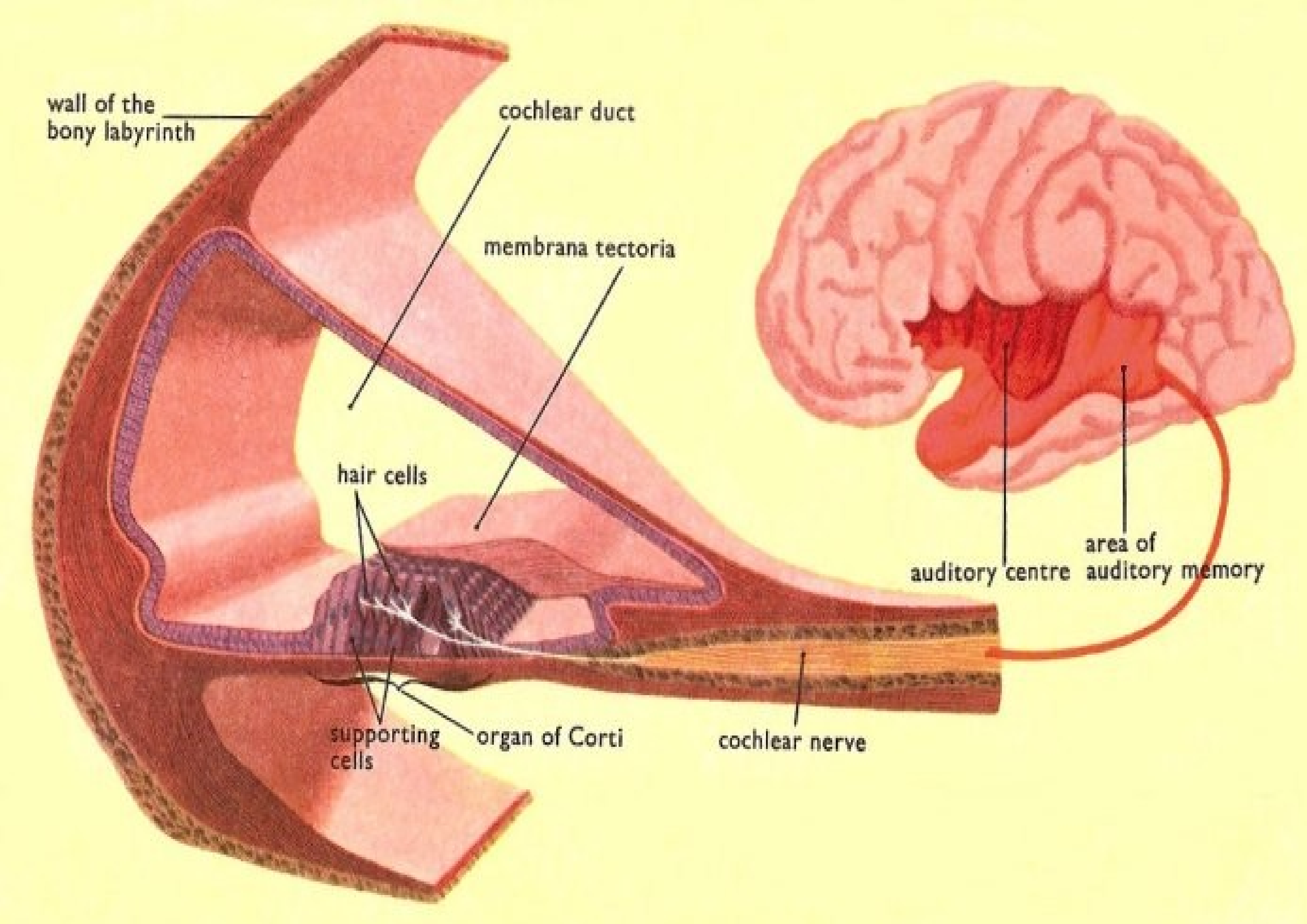
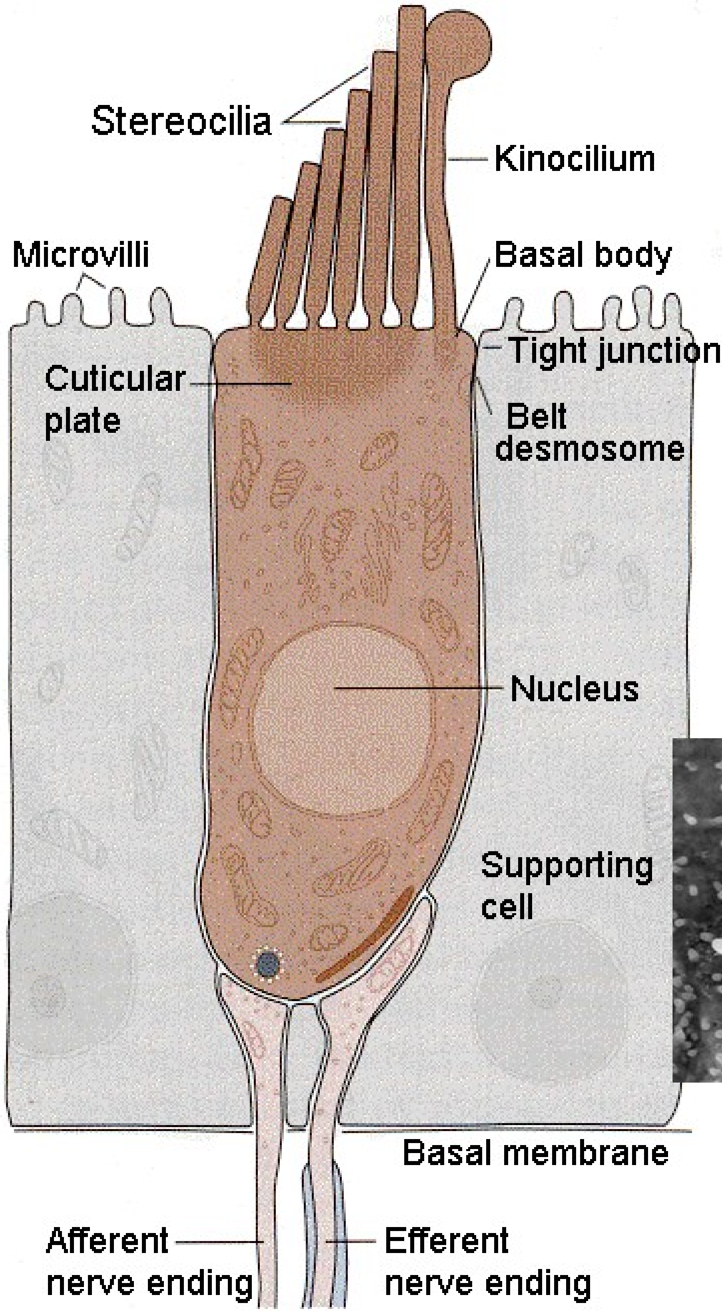
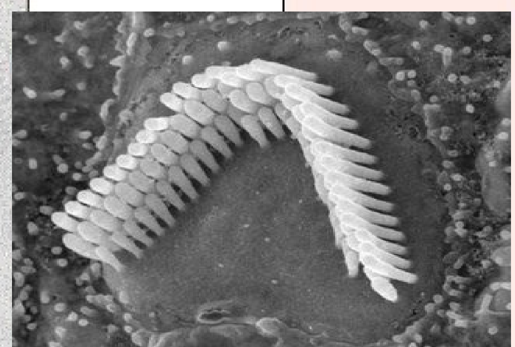

Outer hair cells
Tectorial membrane
Reticular lamina
Vestibular lip
Limbus
Space of Nuel
Outer tunnel
Inner hair cell
Cells of Hensen
Spiral nerve fibers
Nerve fibers
Cells of Claudius
Border cells
Inner tunnel (Corti)
Nucleus
Basilar cells
Connective tissue
Pillar (rod of Corti)
Blood vessel
Transverse fibers
Basilar membrane
Nerve fibers entering the epithelium of organ of Corti
Homogeneous substance
Inner phalangeal cells
Outer phalangeal cells

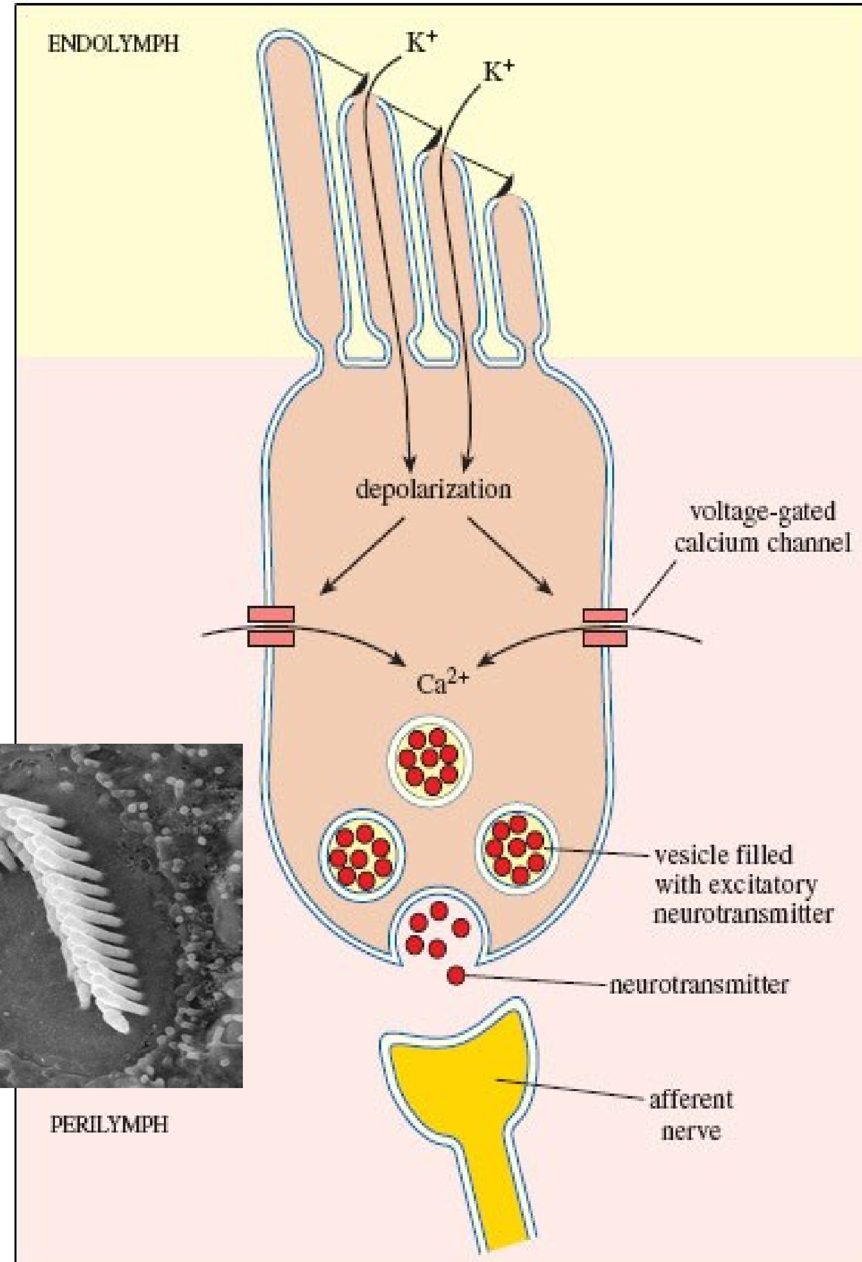
Sound-induced vibration

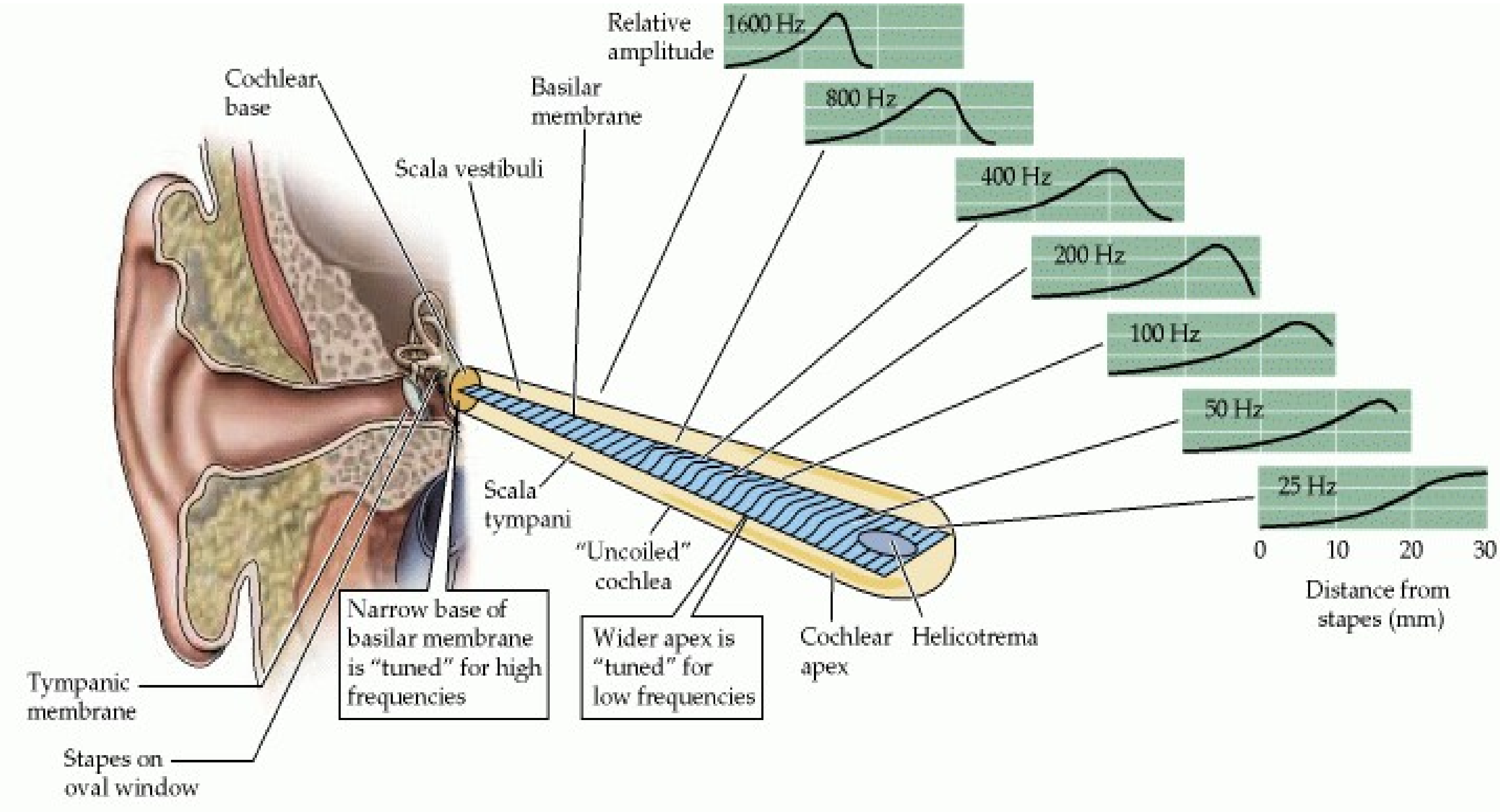



wall of the
bony labyrinth
cochlear duct
membrana tectoria
hair cells
supporting
cells
organ of Corti
cochlear nerve
auditory centre
area of
auditory memory


Stereocilia
Kinocilium
Microvilli
Basal body
Tight junction
Cuticular plate
Belt desmosome
Nucleus
Supporting cell
Basal membrane
Afferent nerve ending
Efferent nerve ending

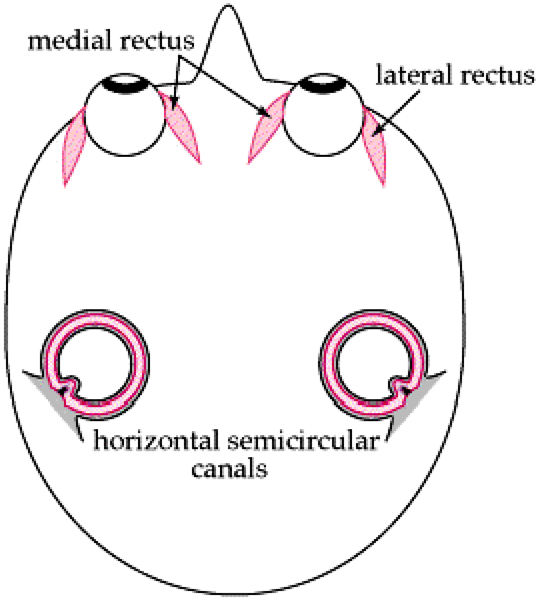


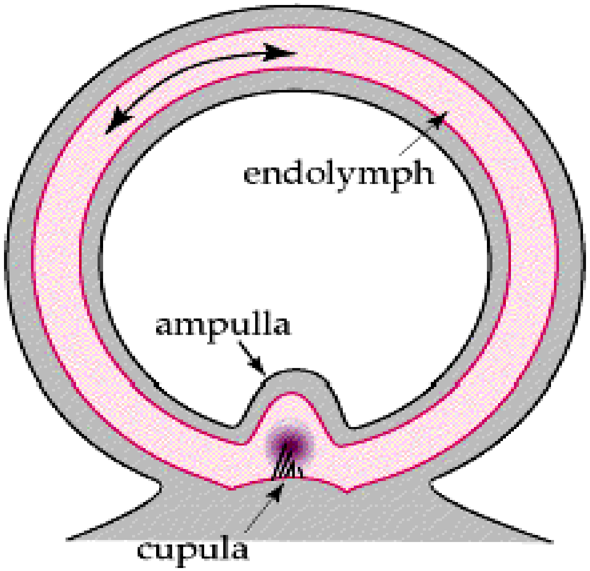

ENDOLYMPH
K+
K+
depolarization
voltage-gated calcium channel
Ca2+
vesicle filled with excitatory neurotransmitter
neurotransmitter
afferent nerve
PERILYMPH



Relative amplitude
1600 Hz
800 Hz
400 Hz
200 Hz
100 Hz
50 Hz
25 Hz
0
10
20
30
Distance from stapes (mm)
Cochlear base
Basilar membrane
Scala vestibuli
Scala tympani
"Uncoiled" cochlea
Cochlear apex
Helicotrema
Narrow base of basilar membrane is "tuned" for high frequencies
Wider apex is "tuned" for low frequencies
Tympanic membrane
Stapes on oval window

The semicircular canals detect angular acceleration. There are 3 canals, corresponding to the three dimensions in which you move, so that each canal detects motion in a single plane. Each canal is set up as shown below, as a continuous endolymph-filled hoop. The actual hair cells sit in a small swelling at the base called the ampula.



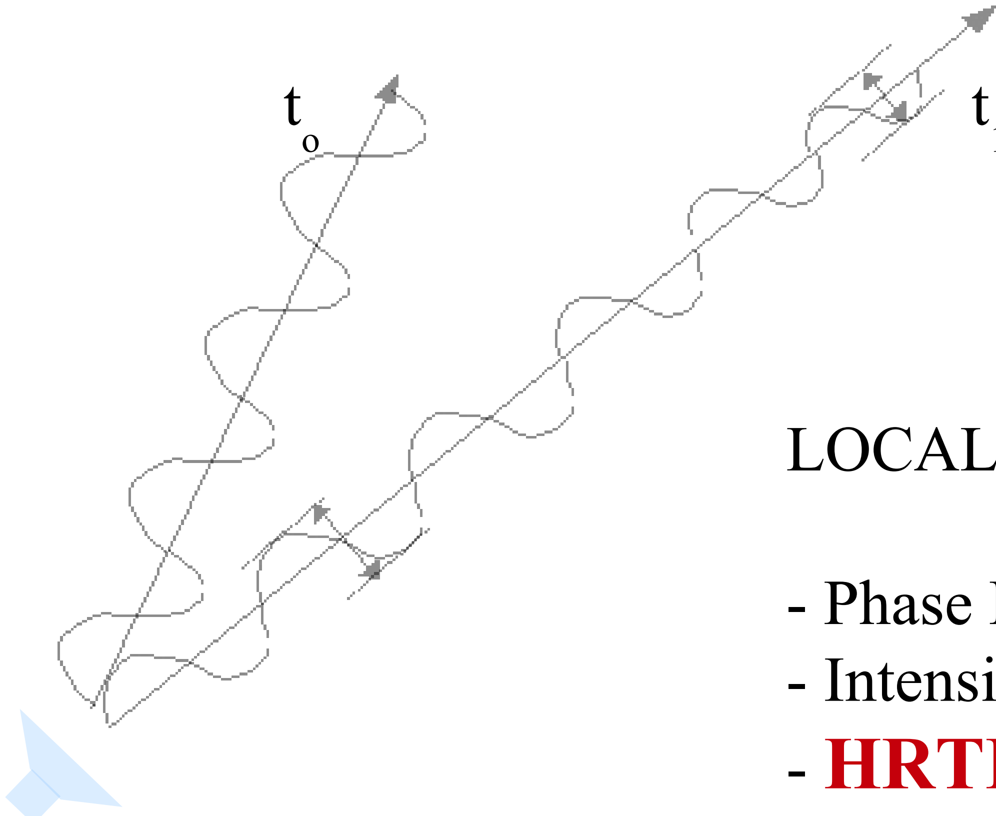


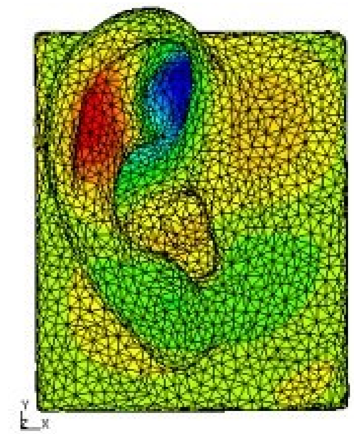
Localization of sound

The ability to estimate just where a sound is coming from, sound localization, is dependent on hearing ability of each of the two ears, and the exact quality of the sound. Since each ear lies on an opposite side of the head, a sound will reach the closest ear first, and its amplitude will be larger in that ear.

The shape of the pinna (outer ear) and of the head itself result in frequency-dependent variation in the amount of attenuation that a sound receives as it travels from the sound source to the ear. Furthermore, this variation depends not only on the **azimuthal angle** of the source, but also on its elevation. This variation is described as the head-related transfer function, or HRTF. As a result, humans can locate sound both in azimuth and altitude. Most of the brain's ability to localize sound depends on interaural (between ears) **intensity** differences and interaural **temporal**, or phase, differences. In addition, humans can also estimate the distance that a sound comes from, based primarily on how **reflections** in the environment modify the sound, for example, as in room reverberation.

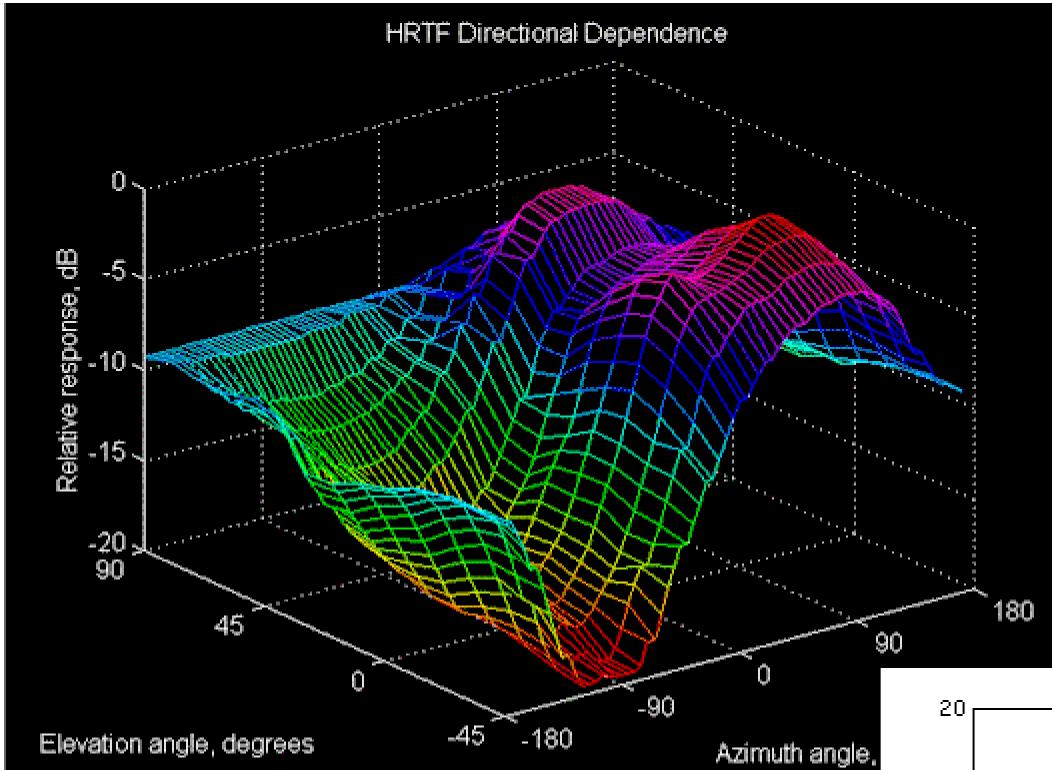
Human echolocation is a technique used by some blind humans to navigate within their environment by listening for echoes of clicking or tapping sounds that they emit.



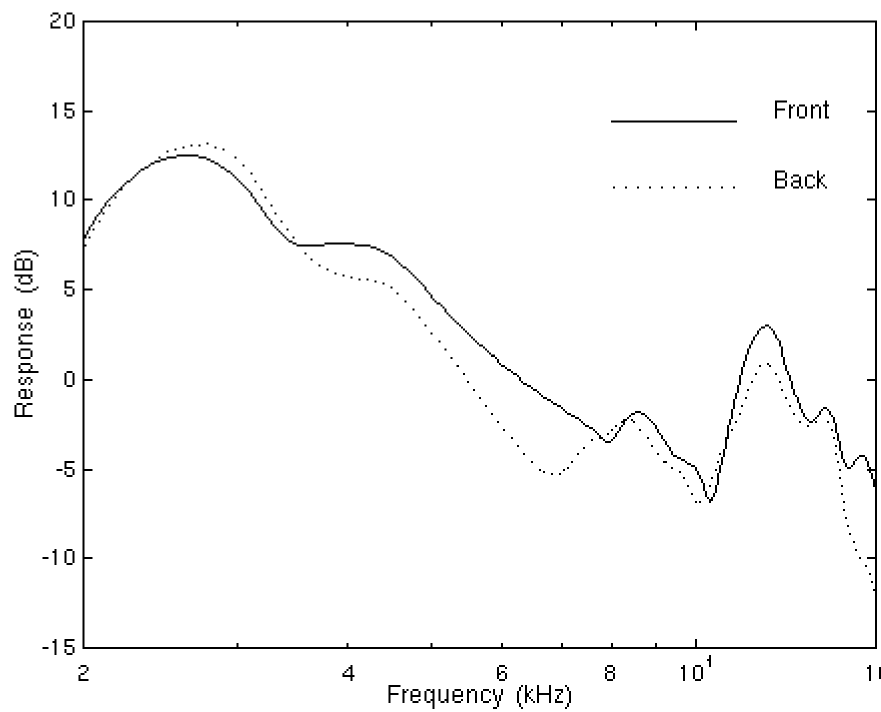



LOCALIZATION

- Phase Difference 位相
- Intensity Difference　強度
- **HRTF**

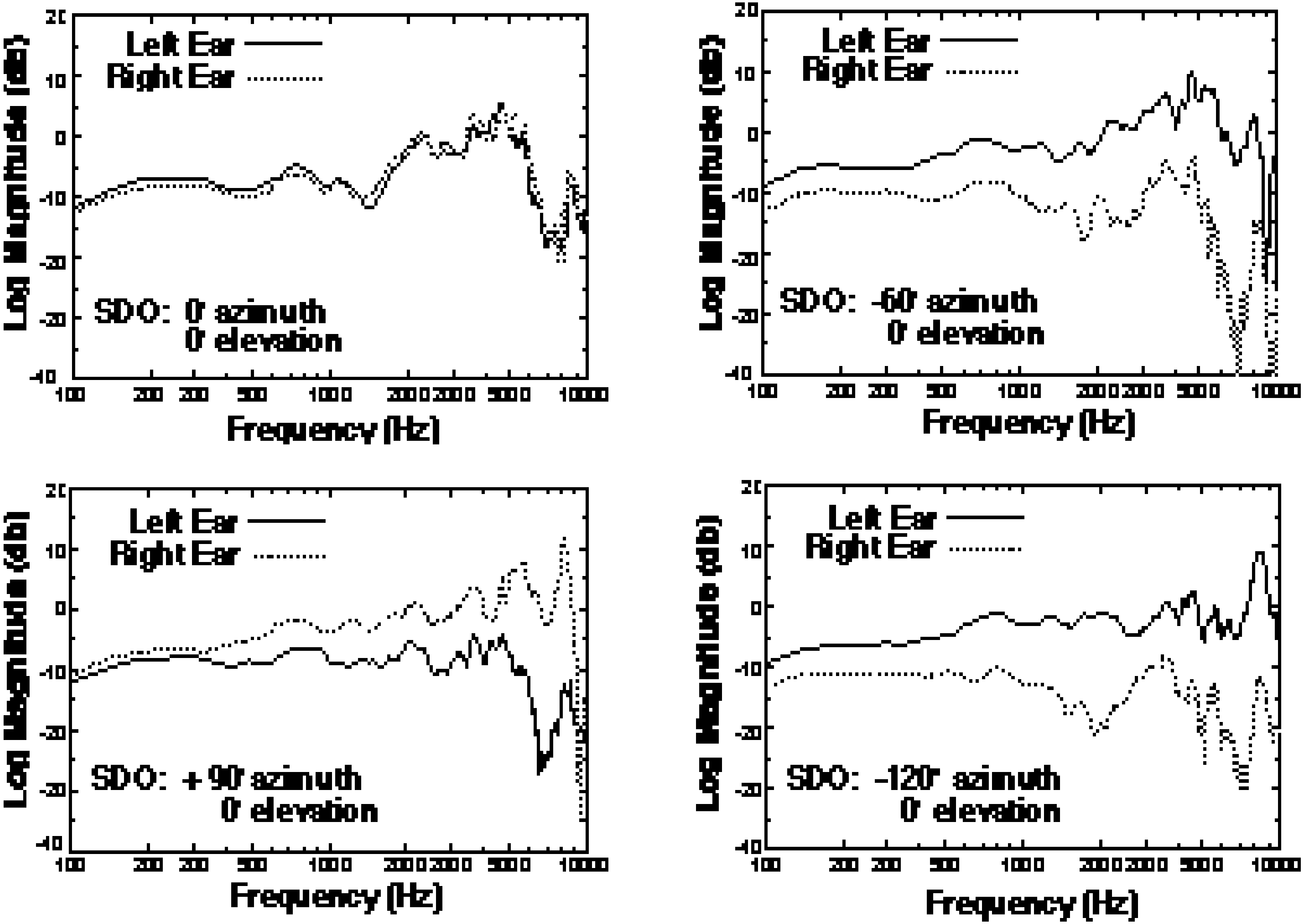


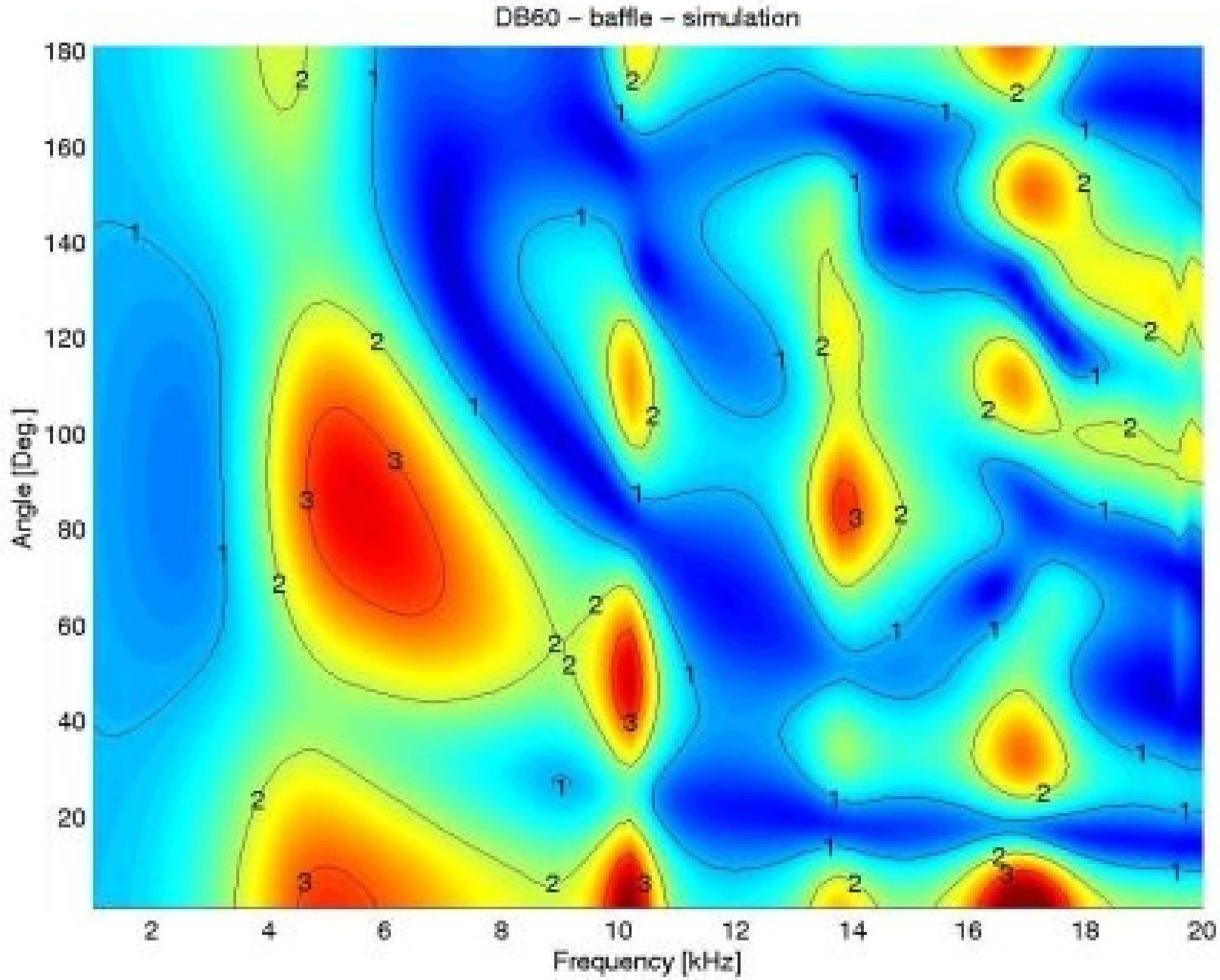
HRTF Directional Dependence
Relative response, dB
0
-5
-10
-15
-20
90
45
0
-45
Elevation angle, degrees
-180
-90
0
90
180
Azimuth angle,



Front
Back
Response (dB)
20
15
10
5
0
-5
-10
-15
2
4
6
8
10^1
16
Frequency (kHz)

Head-Related Transfer Functions (HRTFs)
Frequency Domain: Magnitude Spectra



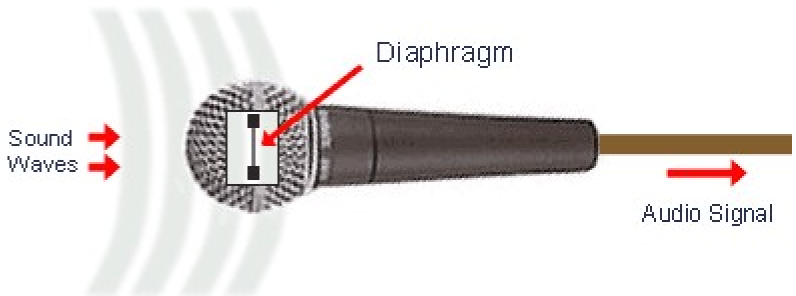


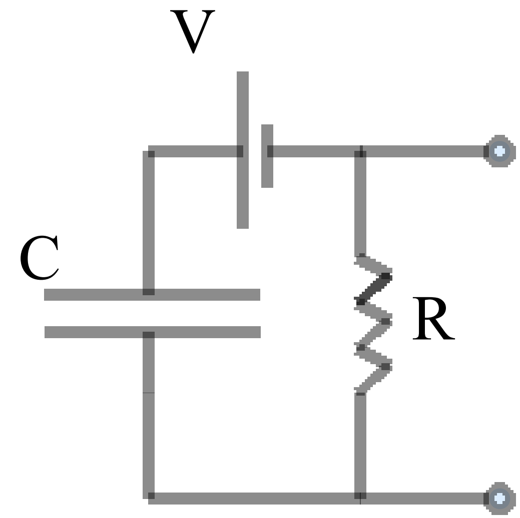
DB60 – baffle – simulation
Angle [Deg.]
Frequency [kHz]

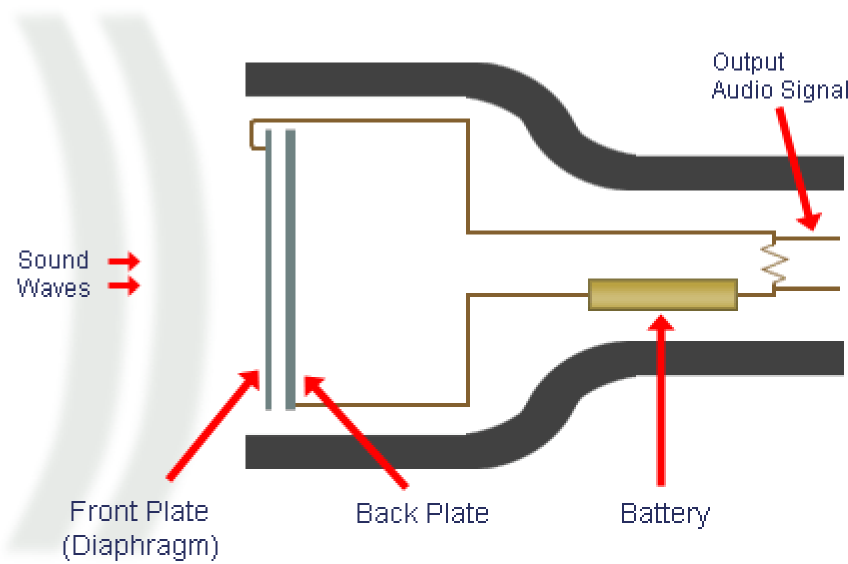
THE ARTIFICIAL EARS: (マイクロホン)

Frequency response
Dynamic Response

Condenser microphones



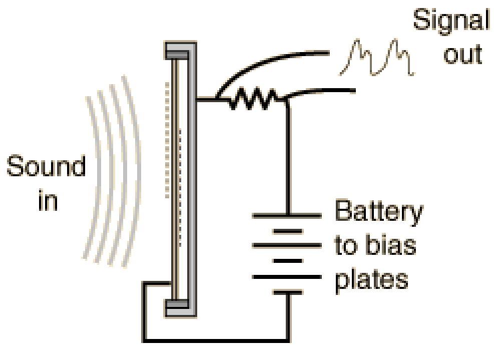




$$C = \epsilon \frac{S}{d}$$

$$V_C = \frac{Q}{C}$$

Condenser microphones have a flatter frequency response than dynamics



Condenser

$$Q=CV=\frac{\alpha(\text{Area of plate})(\text{voltage})}{(\text{plate spacing})}$$

Advantages:

Best overall frequency response makes this the microphone of choice for many recording applications.

Disadvantages:

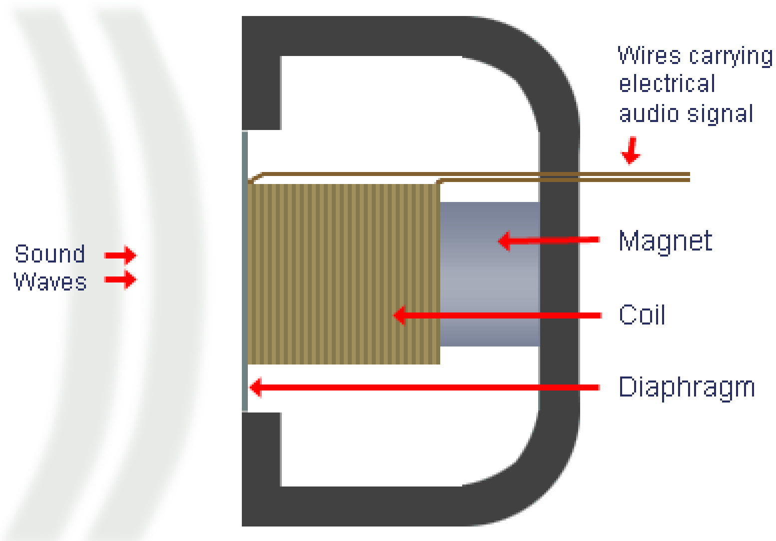
Expensive

May pop and crack when close miked

Requires a battery or external power supply to bias the plates.

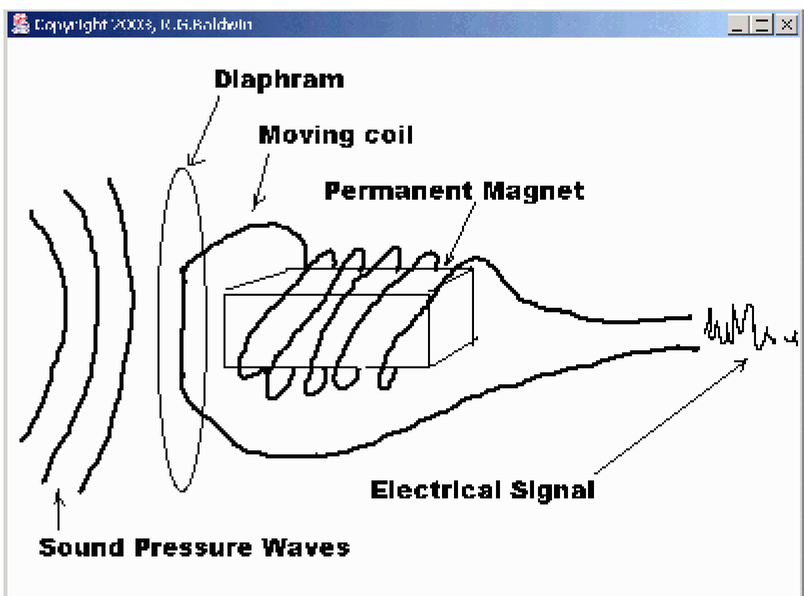
Dynamic microphones (Electromagnetic Microphones)

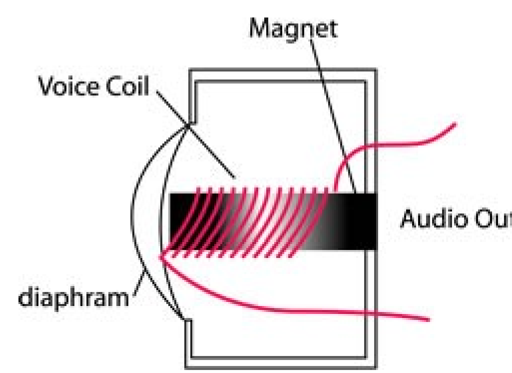
Cross-Section of Dynamic Microphone



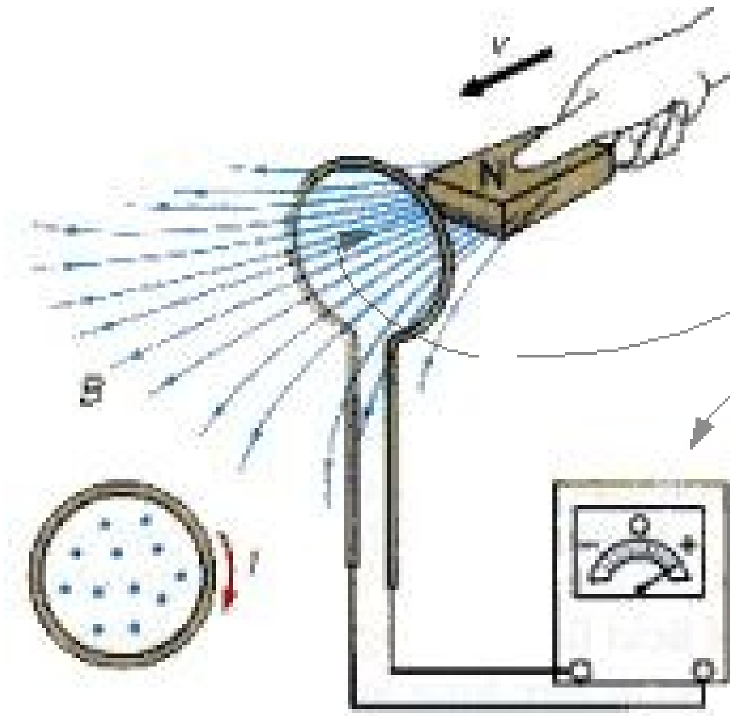
Dynamics do not usually have the same flat frequency response as condensers. Instead they tend to have tailored frequency responses for particular applications.

However they have a good Dynamic response.



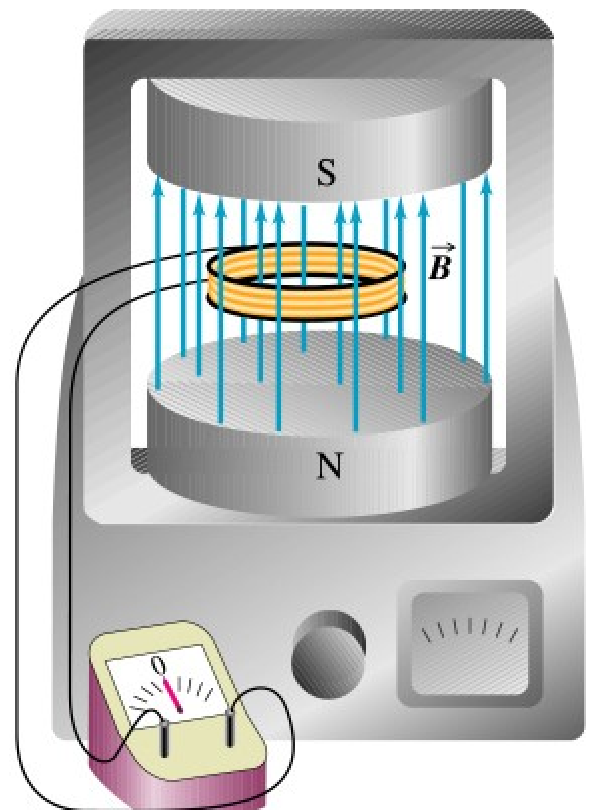


Dynamic Microphone

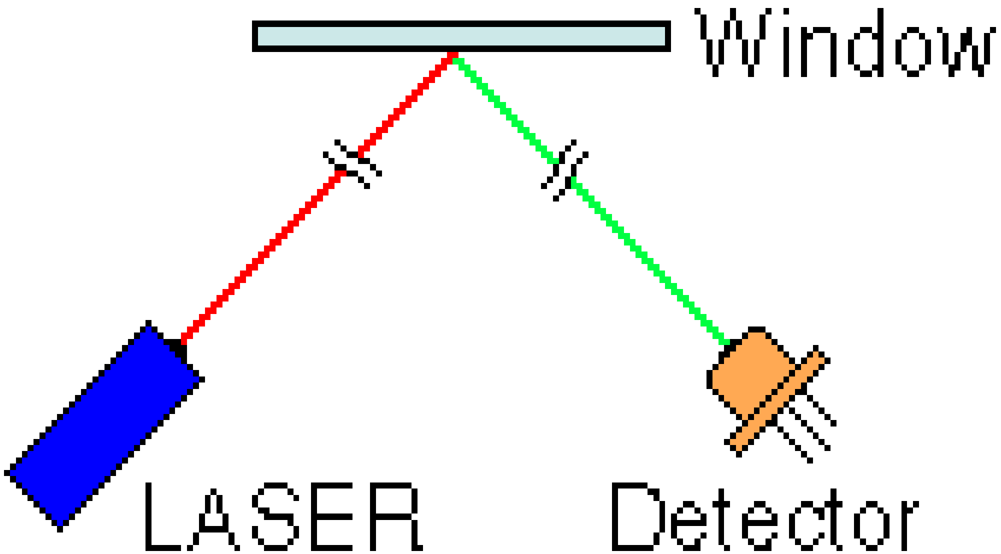


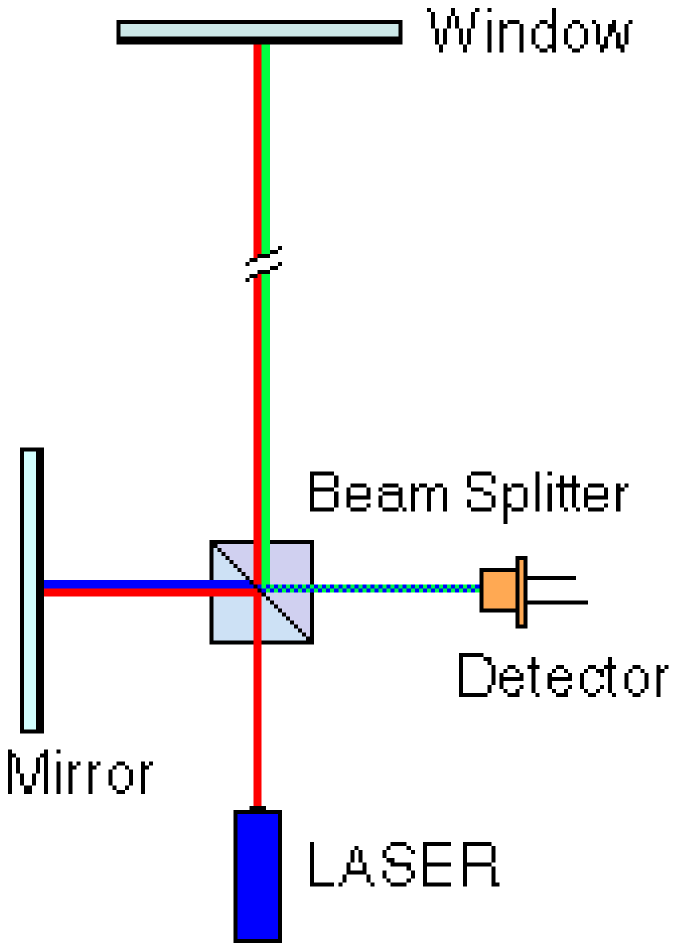
$$\phi = \oint B.dA$$

$$e = \frac{-d\,\phi}{dt}$$

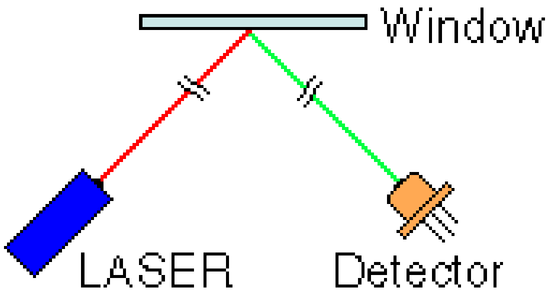


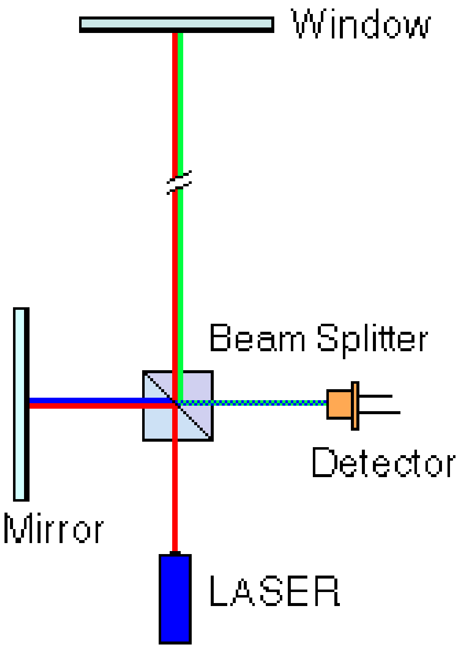
LASER microphone (Spy Microphone)

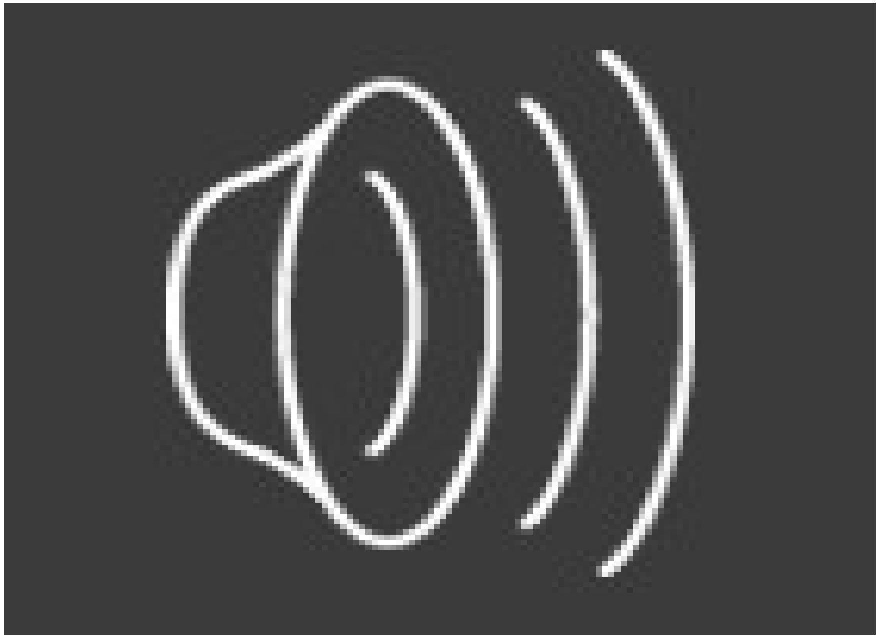


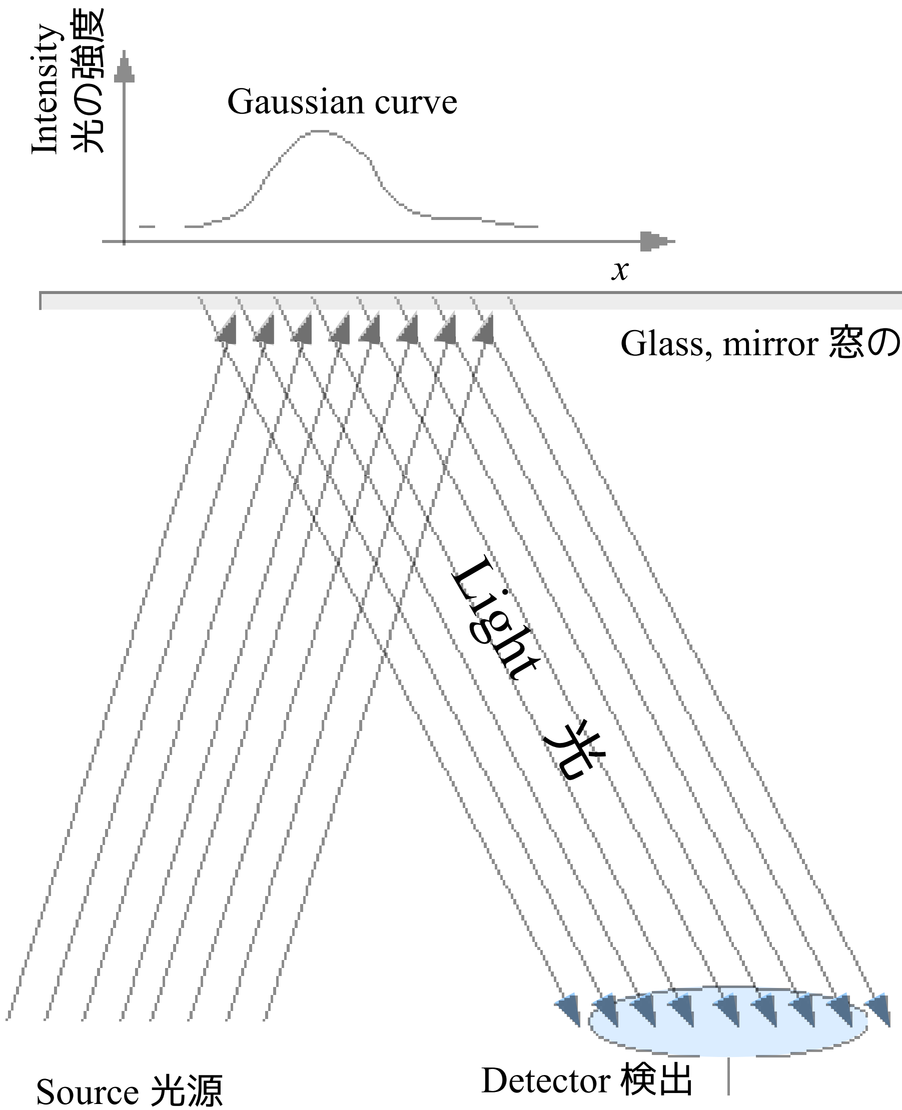


LASER microphone (Spy Microphone)

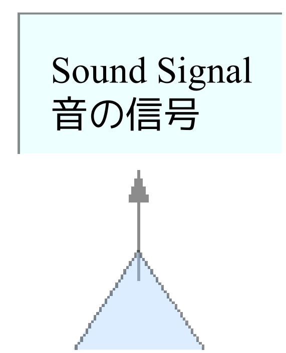








窓に反射するときに音の強度によって反射角度は少し変更します。角度変更によって、検出に得られた光の信号は同じように変更します。



The sound system, a summary: documentary