Sensory receptors
Vision, Hearing

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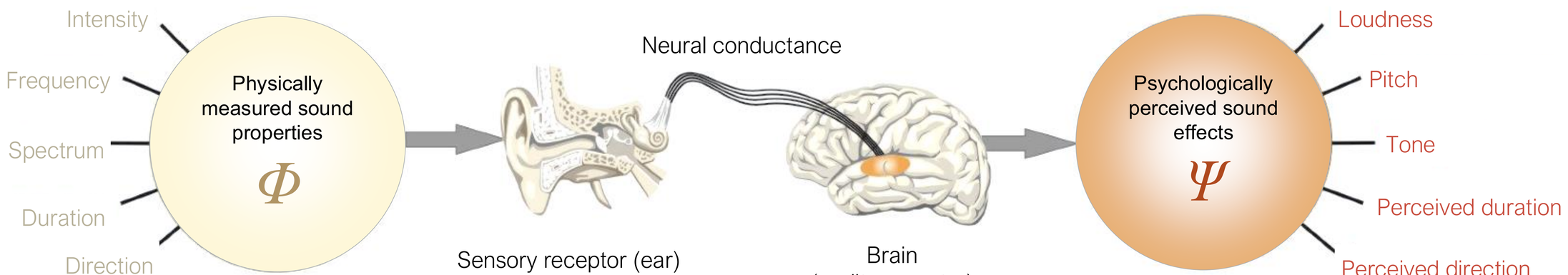
SEMMELWEIS
EGYETEM 1769

Sensing: process through which stimulus is converted to sensation

Stimulus:

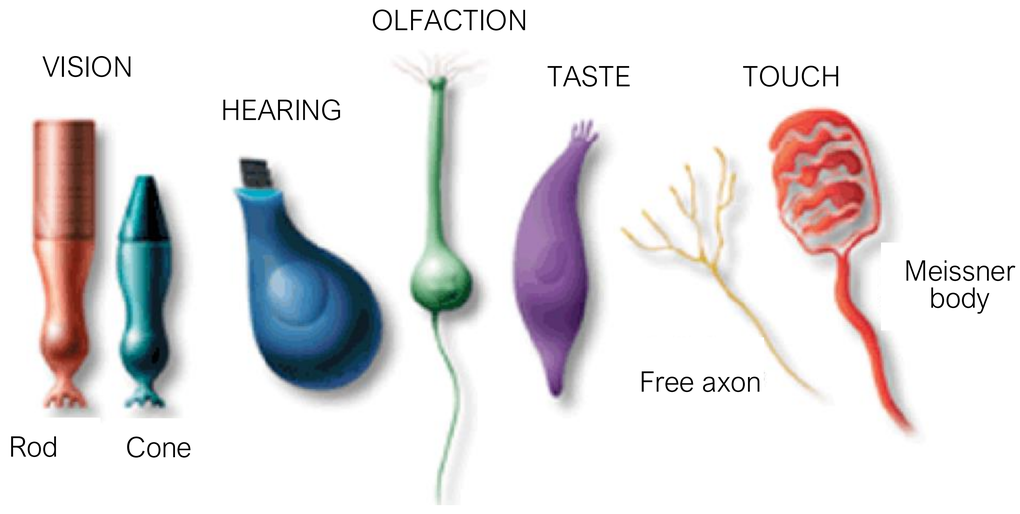
Change (signal, external, internal) that evokes a reaction (sensation at the highest level)

Sensation



Sensory receptor:

Specialized sensory cell, which responds to a given stimulus (e.g., light, sound, chemicals) and relays the information to the central nervous system.



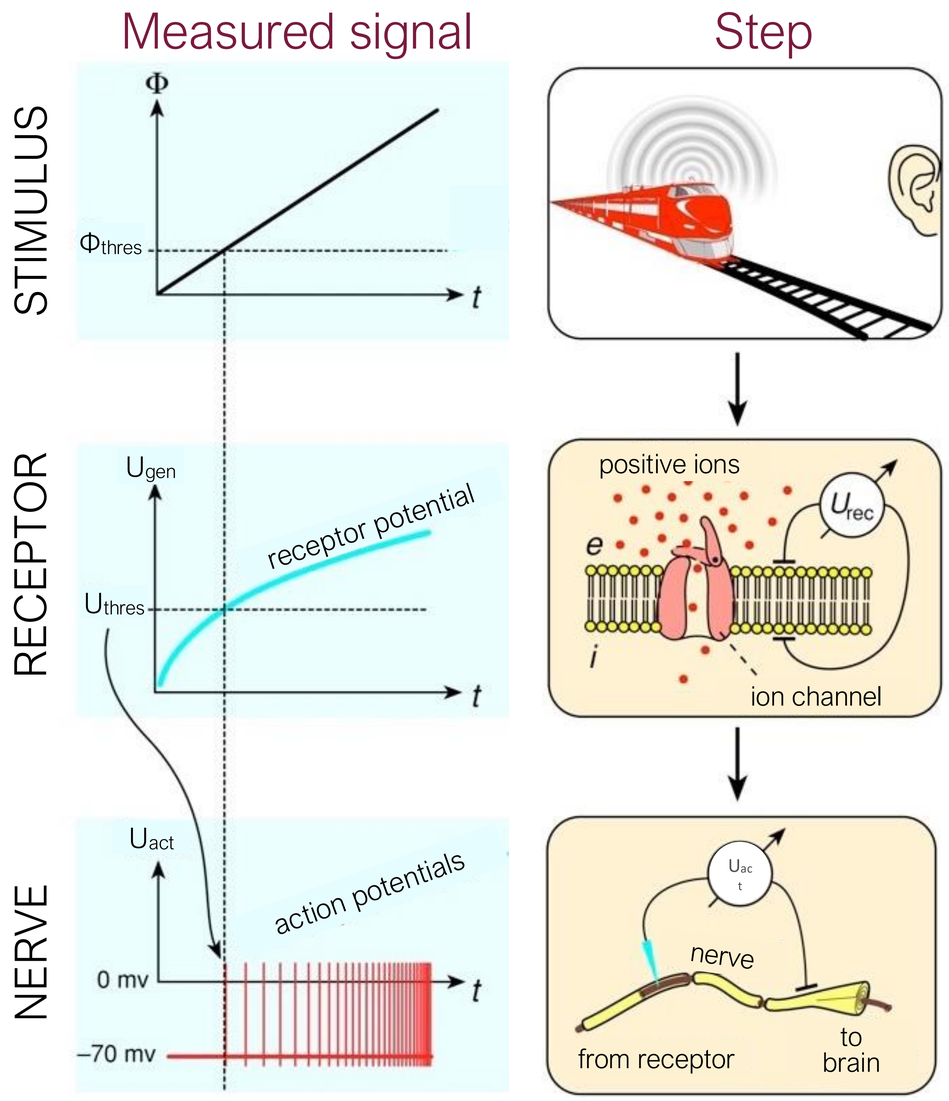
Sensitivity of sensory receptors:

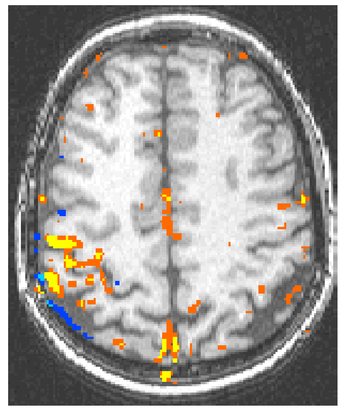
eV-size stimulus is sufficient for evoking action potential:

- sound receptors: thermal motion of the molecules of air
- light receptors: 1-2 photons

Steps of signal transduction

- Amplitude coding
- Adaptation
- Frequency coding





fMRI recording during sensomotoric function

Action potential codes the…

- modality (type)
- intensity (strength)
- duration
- localization

…of the stimulus

1. Modality

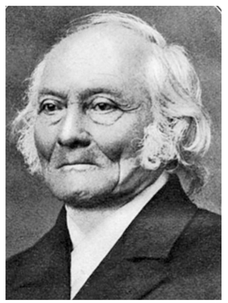
Sensory modality refers to the way information is encoded. Thus, it corresponds to the physical and chemical characteristic of the stimulus.

Adequate stimulus: type of energy for which the receptor is most sensitive (e.g., light for the eye).

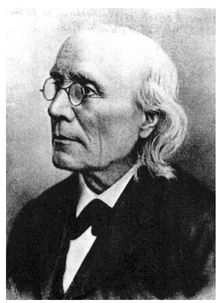
2. Stimulus intensity and perception strength

Weber-Fechner psychophysical law

$$\psi = const \cdot \lg \frac{\phi}{\phi_0}$$



Ernst Weber
(1795-1878)



Gustav Fechner
(1801-1887)

Stevens' power law

$$\psi = const \cdot \left(\frac{\phi}{\phi_0} \right)^n$$

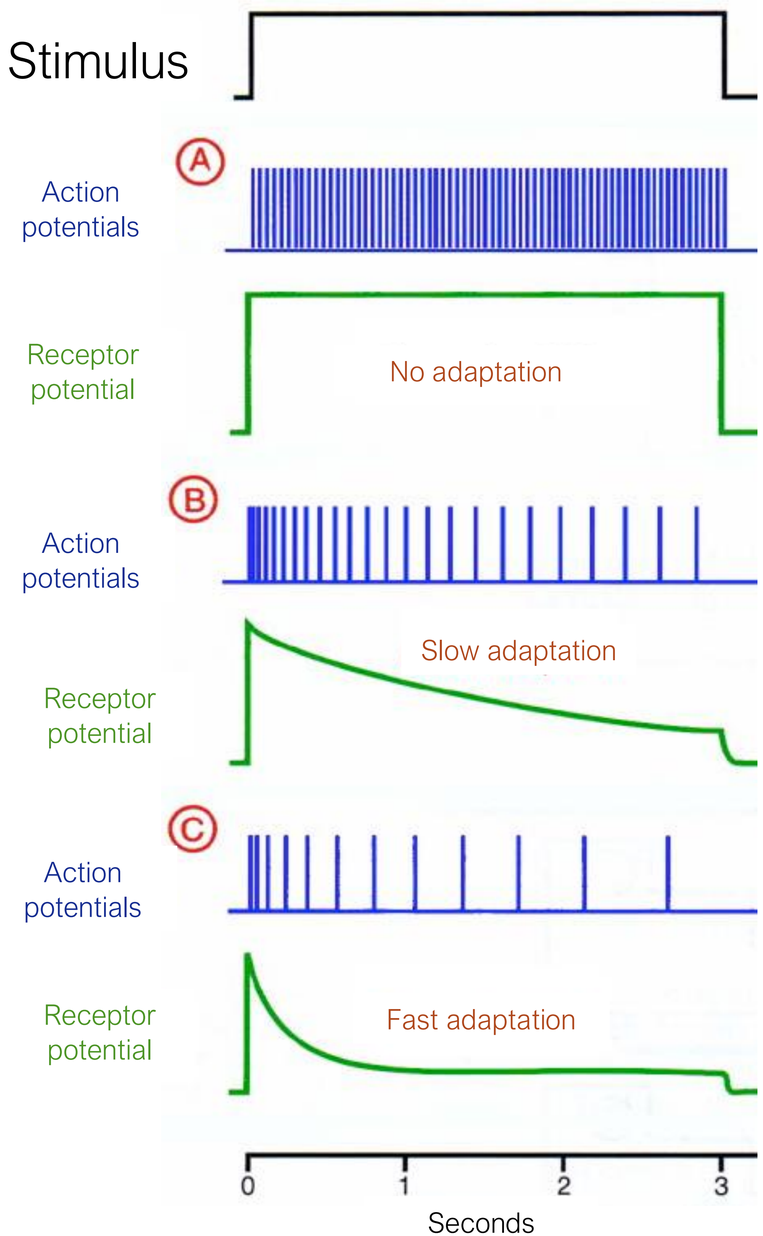
Stanley Smith Stevens
(1906-1973)

ψ=perception strength
φ=actual intensity
φ_0=absolute threshold intensity
n=constant specific for the type of sensation

n<1: compressive function (hearing, vision)

n>1: expansive function (pressure, taste)

3. Duration, adaptation



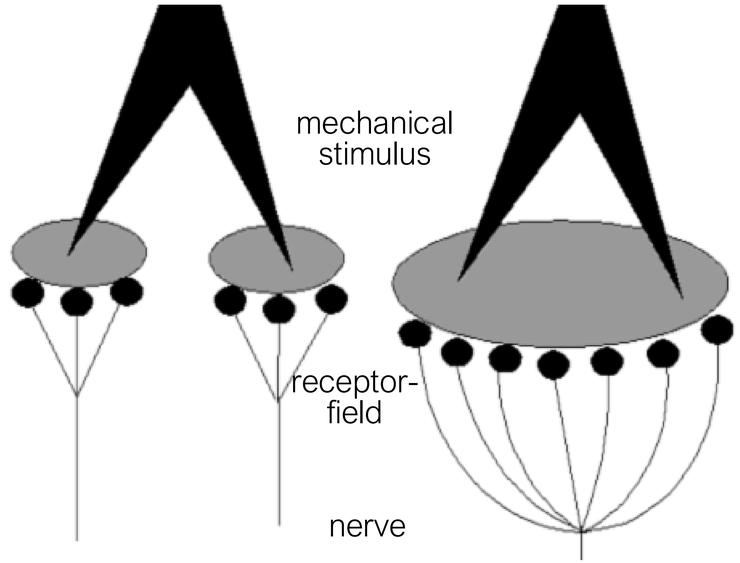
Adaptation: during constant stimulus the frequency of action potentials gradually decreases.

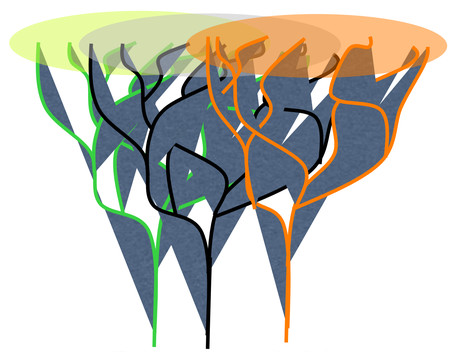
Rapidly adapting (phasic) receptors: pressure, smell, heat

Slowly and partially adapting (tonic) receptors: cold, pain (dental pain)

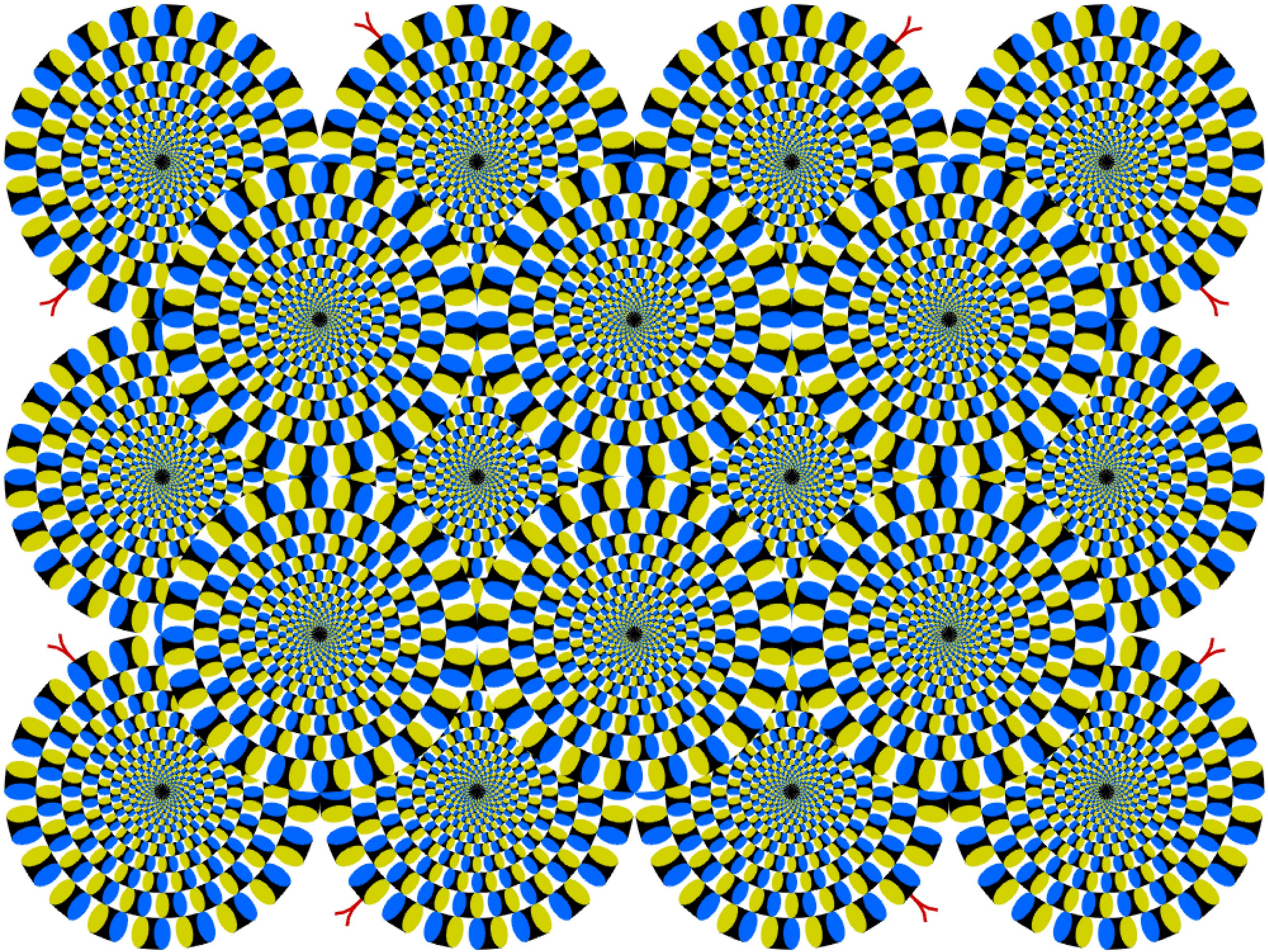
4. Localization

Branched nerve endings define receptor fields (convergence). Such can be found in the skin (touch) and in the peripheral retina (rods).



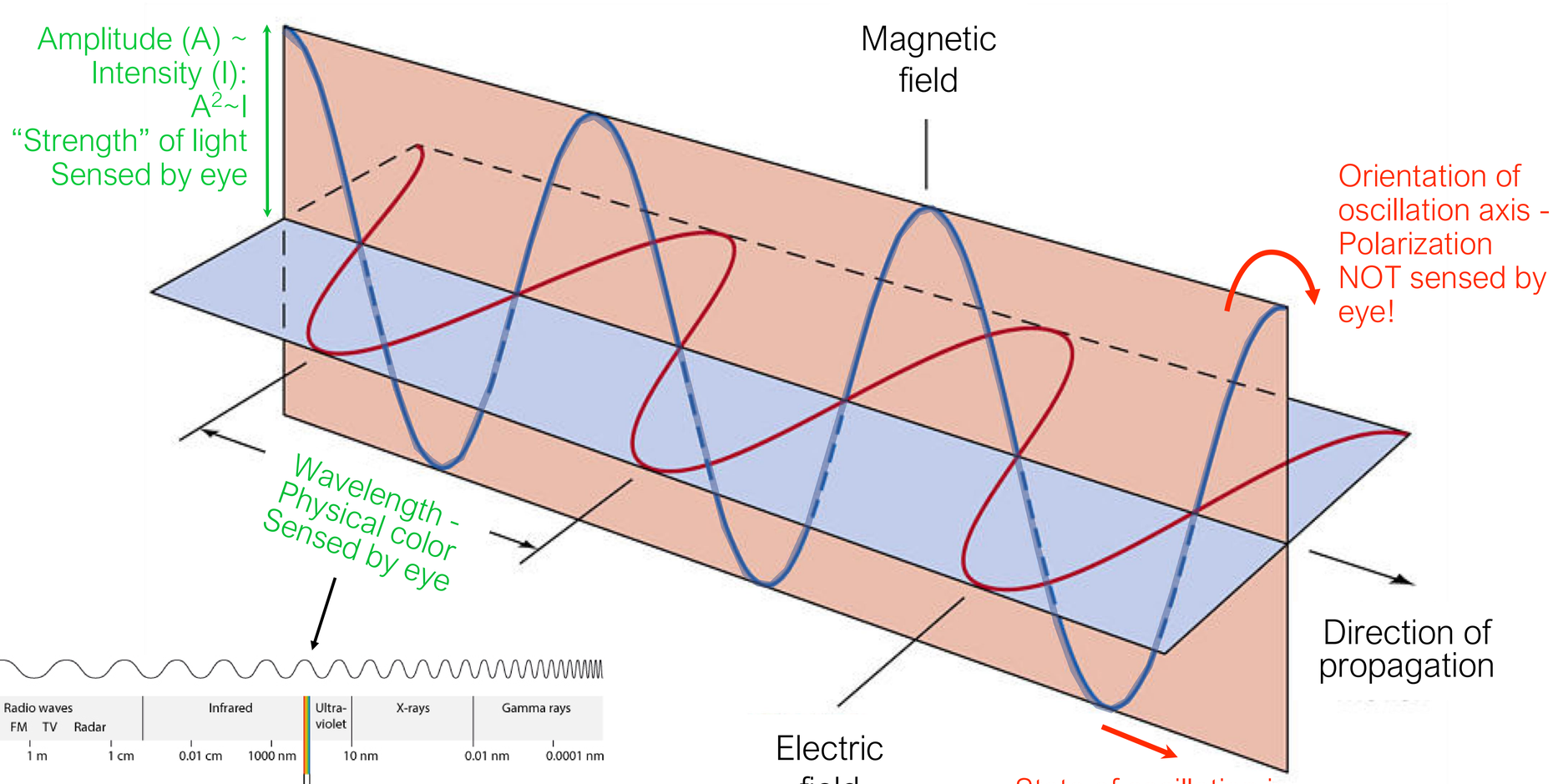


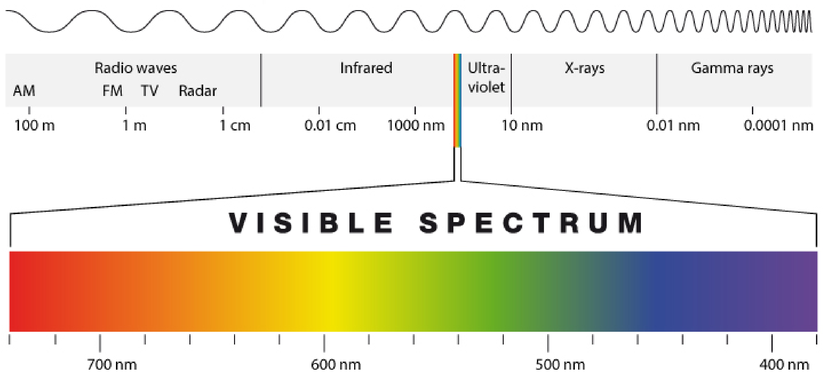
Receptor fields with overlap



Stimulus of vision: light

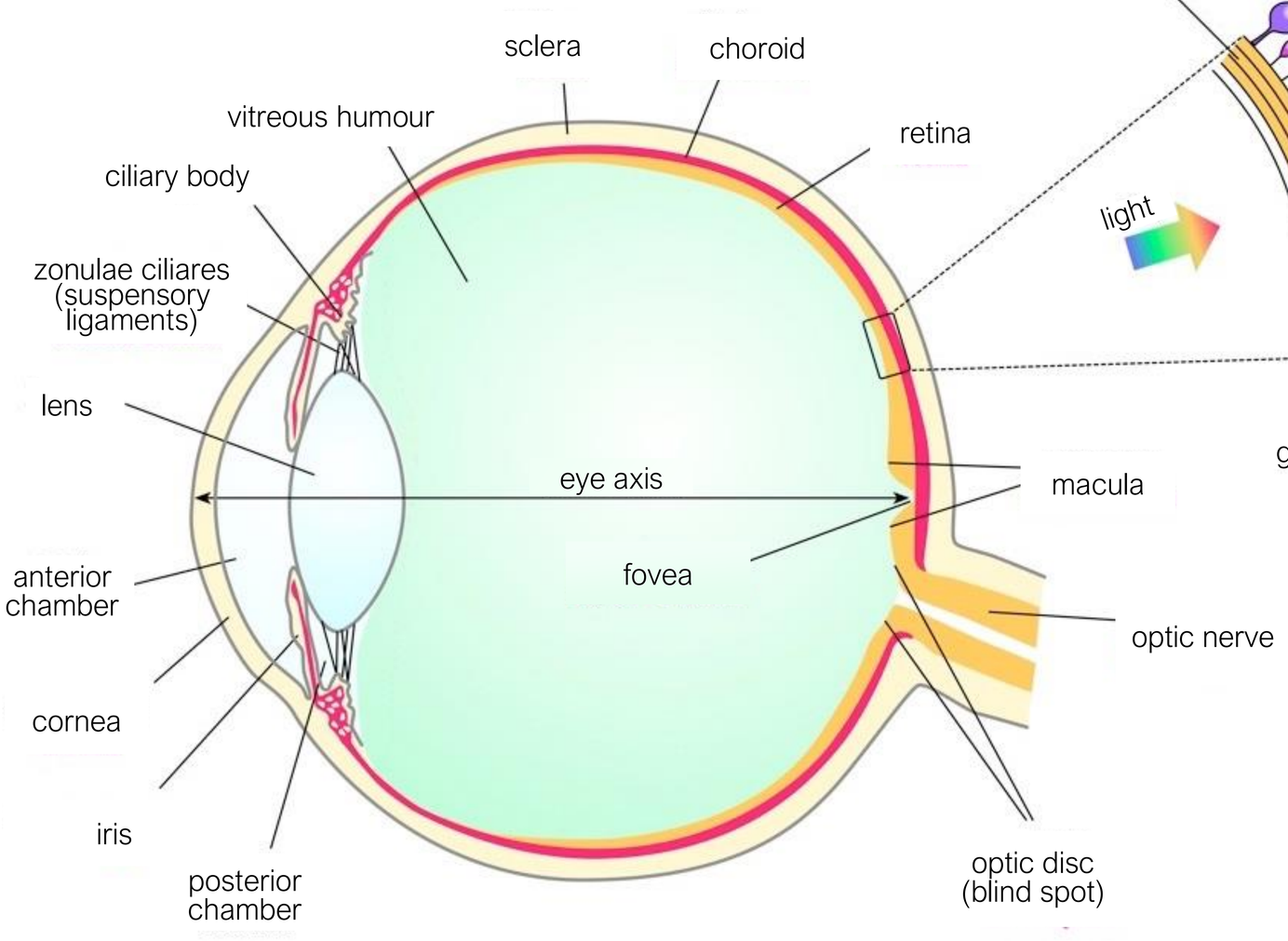
Electromagnetic (transverse) wave

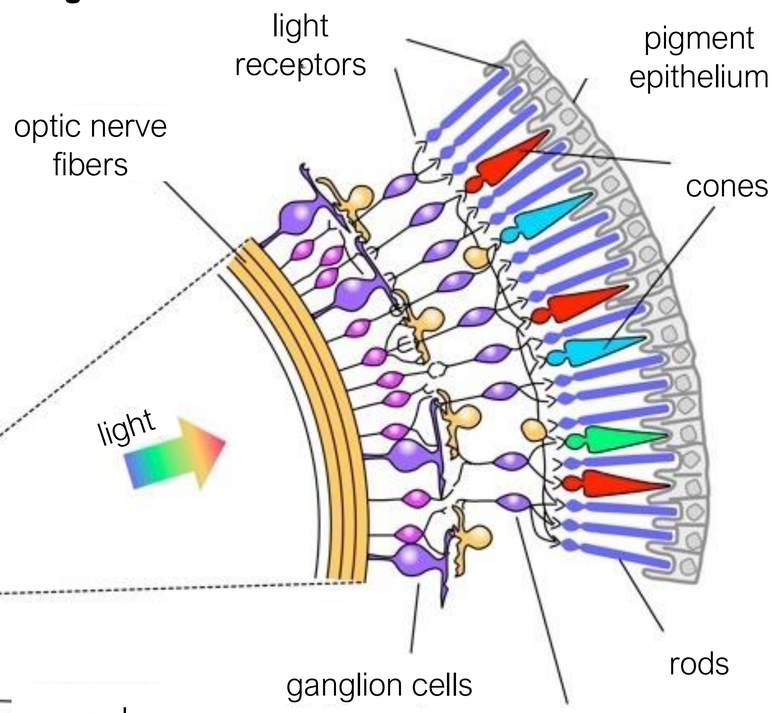


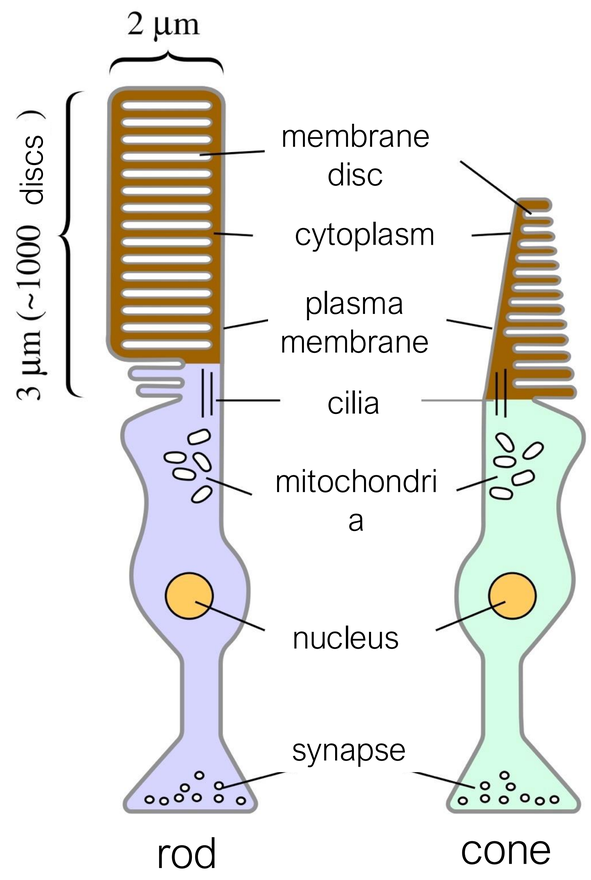


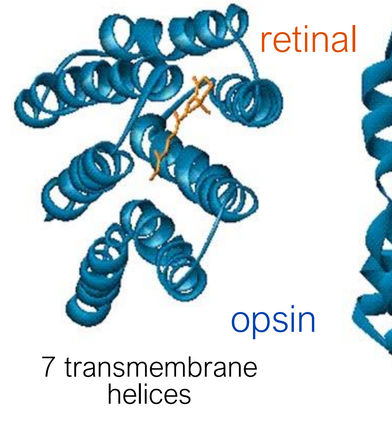
- Eye senses: wavelength and amplitude (~intensity)
- Eye is insensitive to: phase and polarization

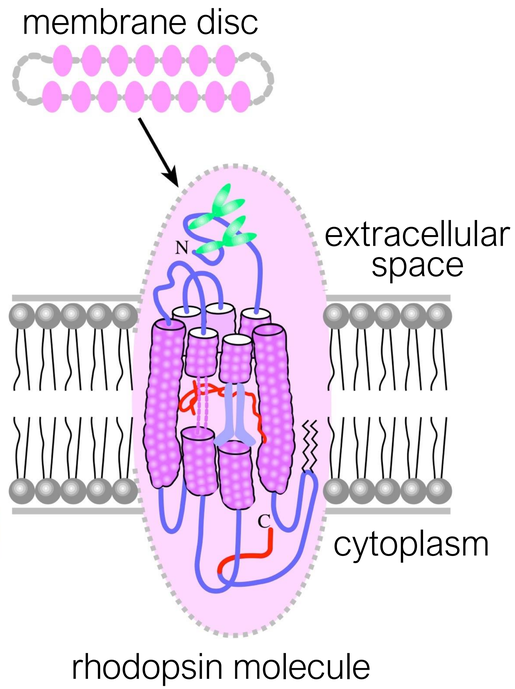
“Receptor-organ”: eye







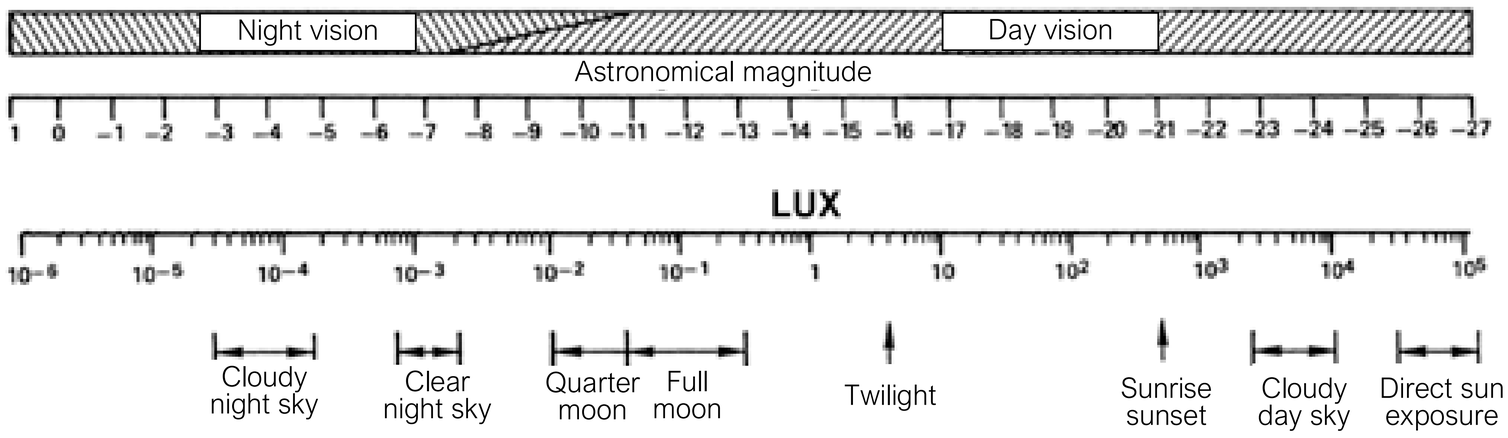




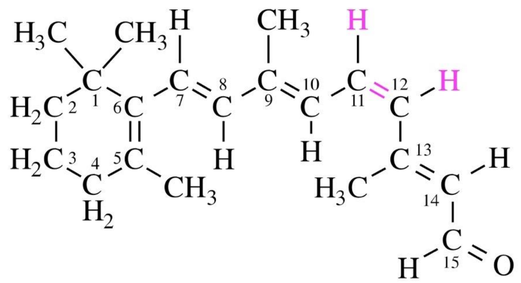
Properties of receptor cells

Rods	Cones
Stimulated by very small intensity (down to 1 photon!)	Smaller sensitivity, but is able to function at high intensities
Saturates at average intensities	No saturation
Found mainly in the peripheral retina	In the fovea, mainly the central fovea
Many rods per ganglion (convergence); greater sensitivity, smaller spatial resolution	Small convergence; greater spatial resolution
No color sensitivity	Sensitivity to colors
Large frequency sensitivity	Low frequency sensitivity (~20 hz)

Combined sensitivity of the receptors: 10^{-9} - 10^{5} lux!

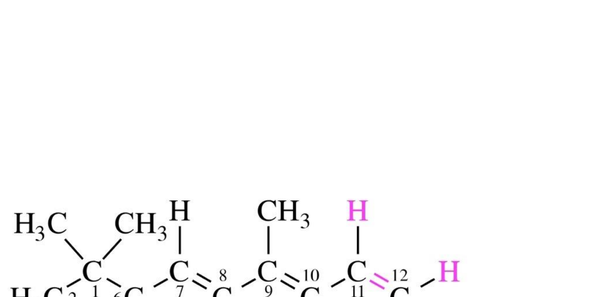


Basis of light sensing: photochemical reaction



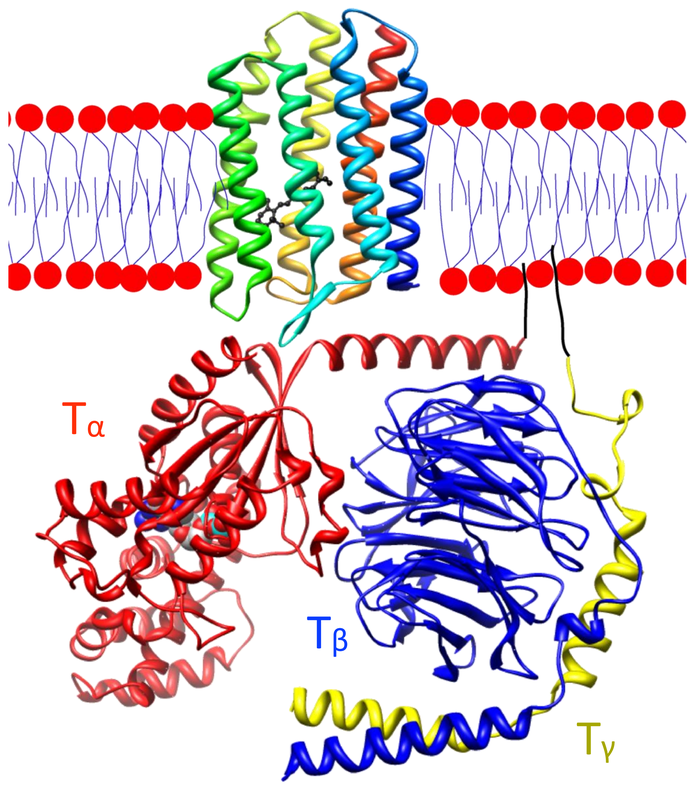
11-cis-retinal

optical excitation



all-trans-retinal

Rhodopsin



Transducin (T)

1 rhodopsin absorbs 1 photon
↓
metarhodopsin
↓
transducin molecule activated (T_α subunit dissociates from the $T_{\beta\gamma}$ subunit)
↓
500 phosphodiestherase molecules activated
↓
10^5 cGMP molecules hydrolyzed
↓
250 Na^+-channels closed
↓
Entrance of 10^6-10^7 Na^+ ions/s inhibited
↓
cell hyperpolarized (1 mV)
↓
transmitter release reduced (glutamate: inhibitory neurotransmitter).

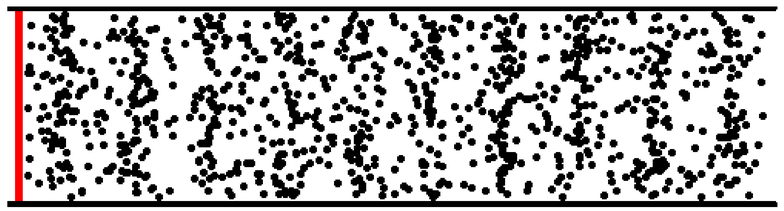
Amplification: (~10^4)

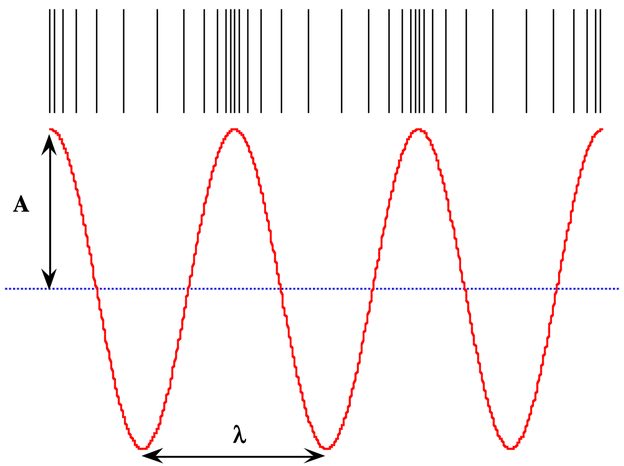
$$A = \frac{E_{ion}}{E_{photon}} = \frac{ne\Delta\varphi}{hf}$$

n: change in number of Na ions
e: elementary charge
$\Delta\varphi$: membrane potential
h: Planck's constant
f: frequency of light

Biophysics of hearing – adequate stimulus: sound

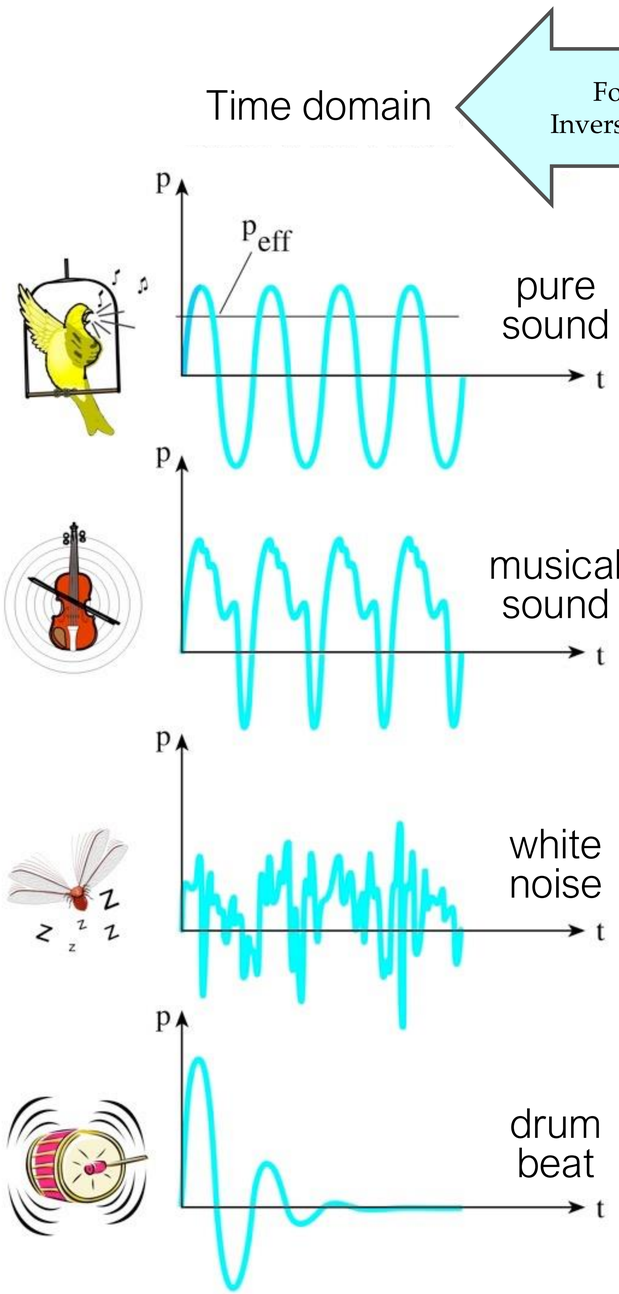
Longitudinal mechanical wave (pressure wave), propagates in elastic medium





$$y(t) = A\sin(ft + \varphi)$$

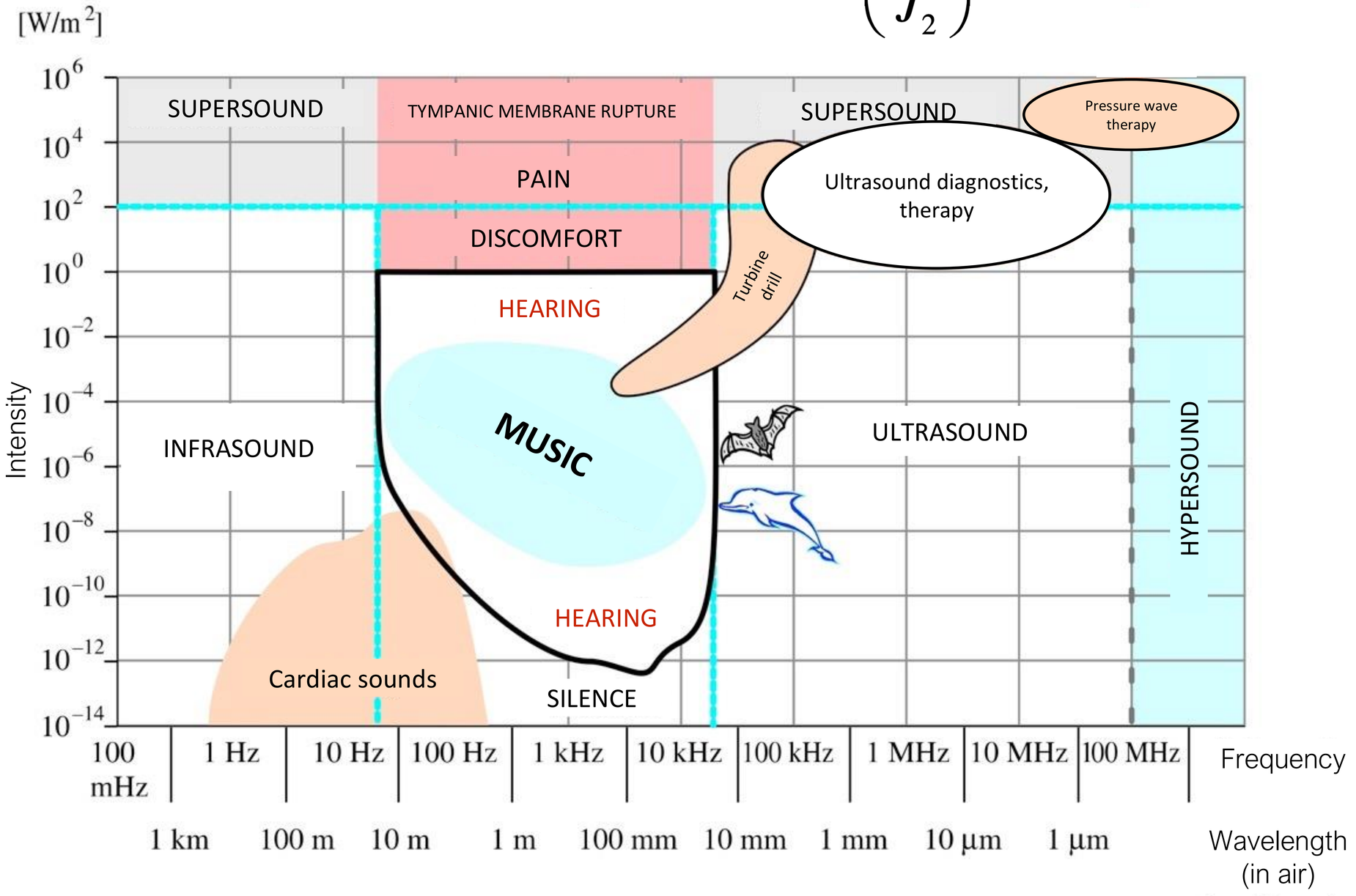
y=actual pressure; t=time
f=frequency (Hz); A=amplitude
φ=phase shift



Octave - frequency difference with a 2:1 ratio

Sound intensity and frequency

Intensity level: $n(dB) = 10 \lg\left(\frac{J_1}{J_2}\right)$



Receptor organ: ear

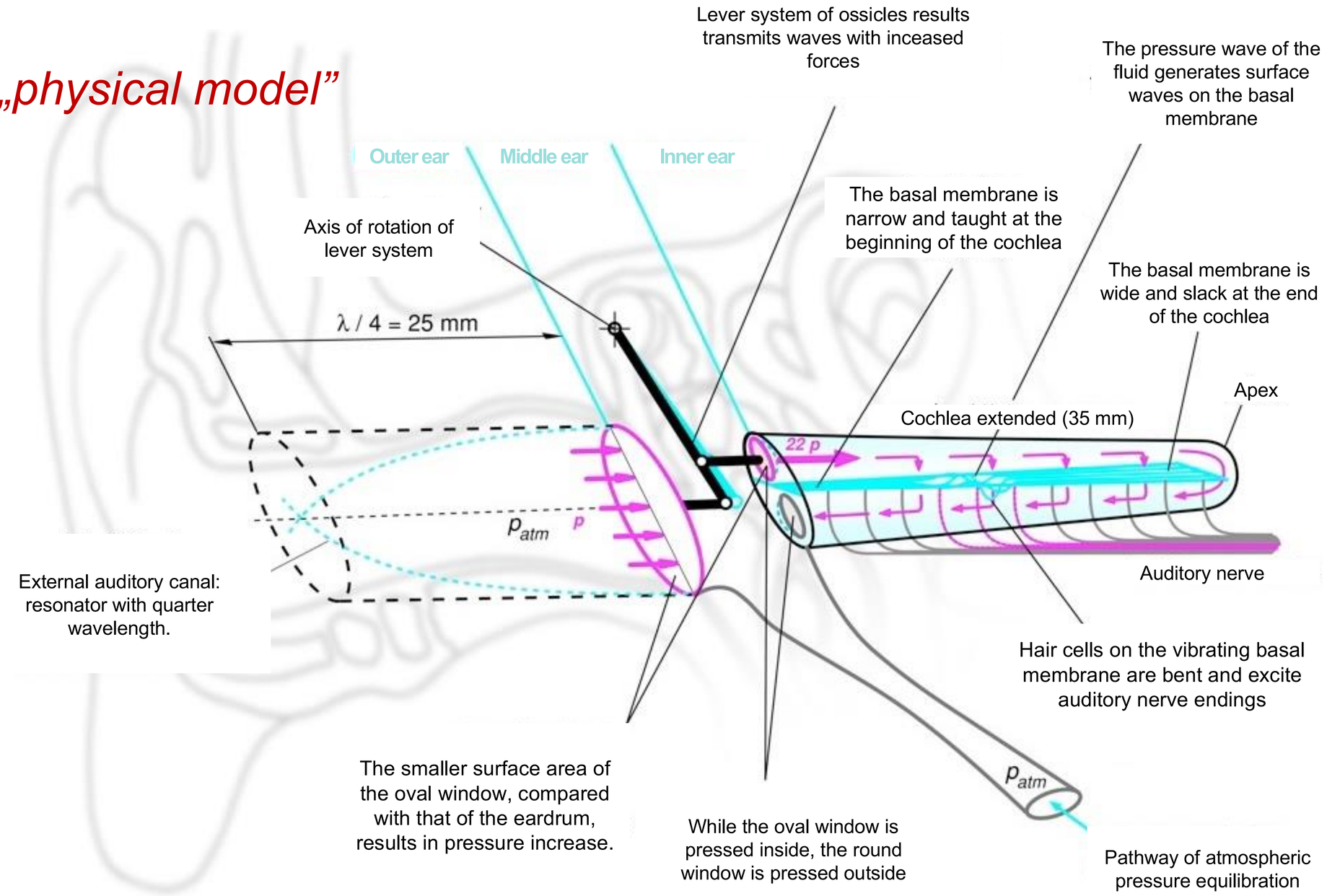
„physical model”

Outer ear:

1. Auricula
Sound is steered into the external auditory canal.

2. External auditory canal
Conducts pressure waves towards the eardrum. More efficient in certain freqency range
(2000-5000 Hz).

3. Eardrum
Brought into resonance by sound waves. Its oscillation amplitude at the stimulus threshold: 10^{-11} m (slightly exceeds that caused by thermal noise)!



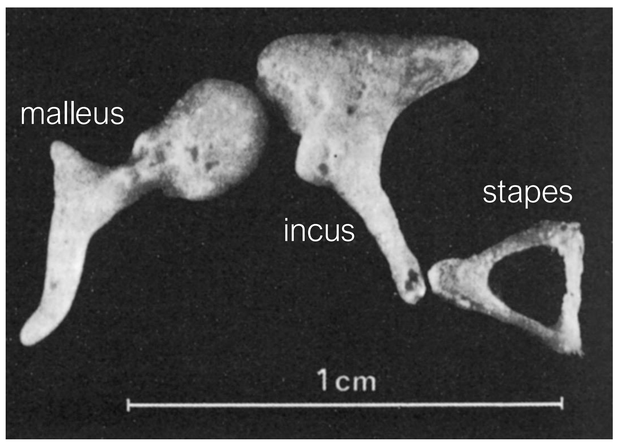
Middle ear: mechanical transmitter and amplifier

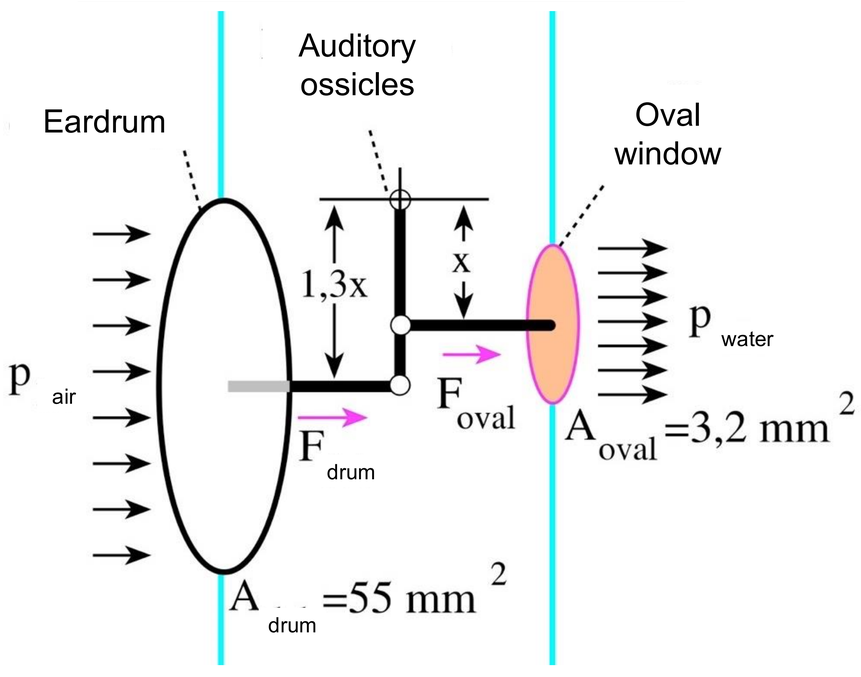
Auditory ossicles
(malleus, incus, stapes)

They **amplify** eardrum resonance and transmit it to the oval window. (N.B.: due to the difference in the acoustic impedance of air and water, total reflection would occur!)

Amplification:
due to area ratio: 17 ×
due to lever action: 1,3 ×

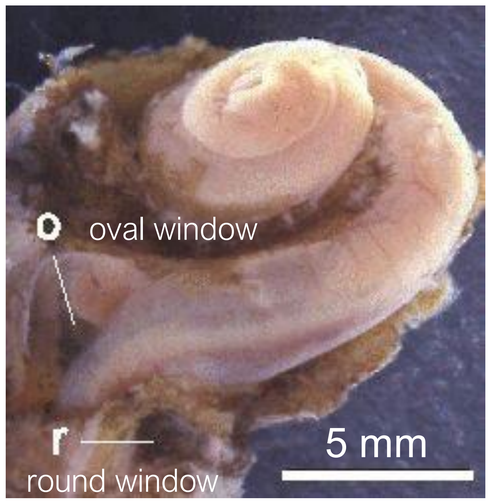
Total amplification: 22× (pressure increase)

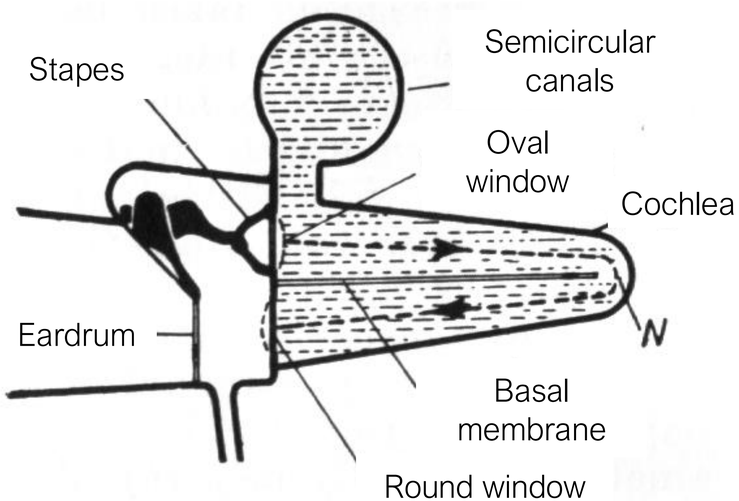




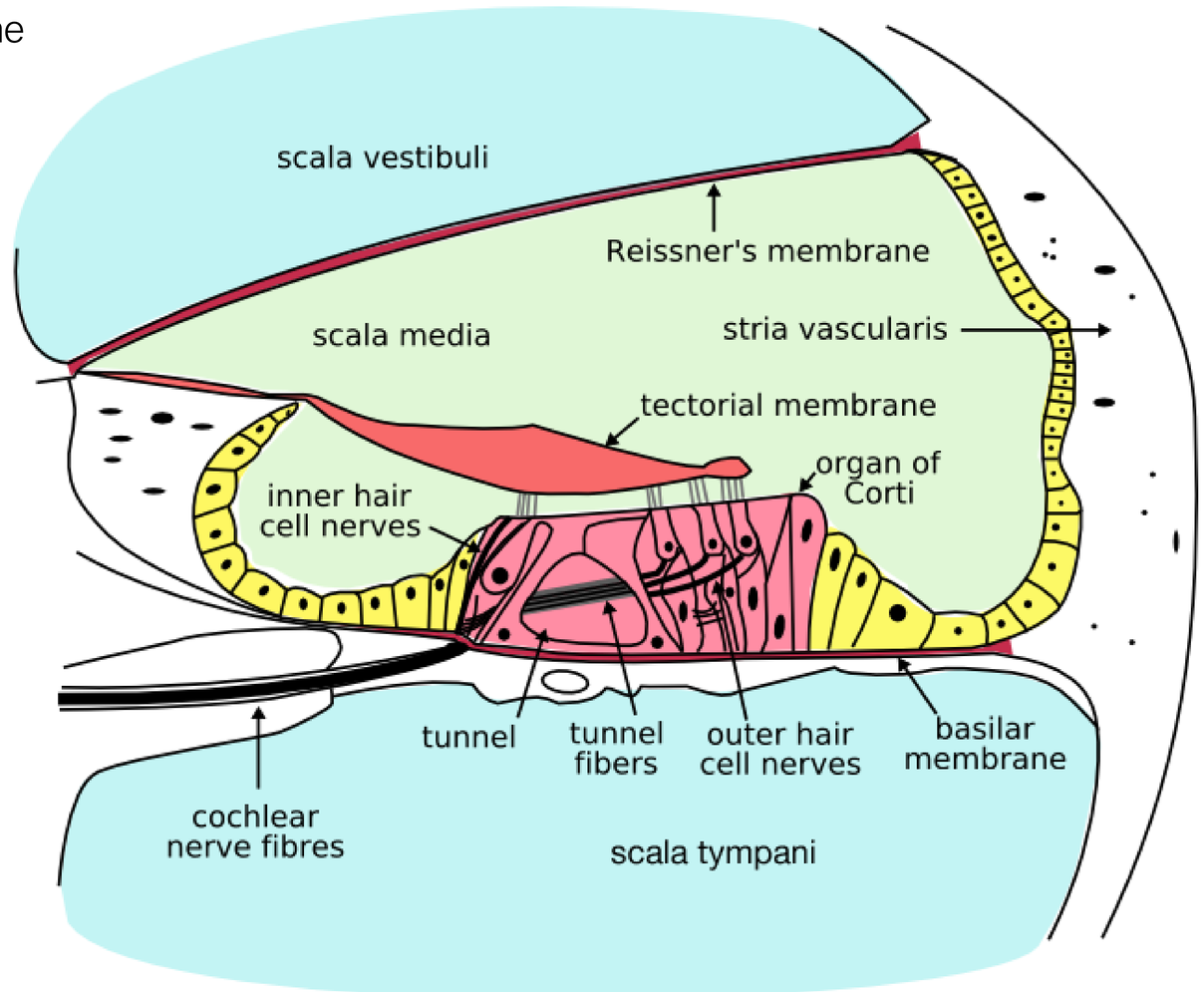
Ultrastructure of the inner ear

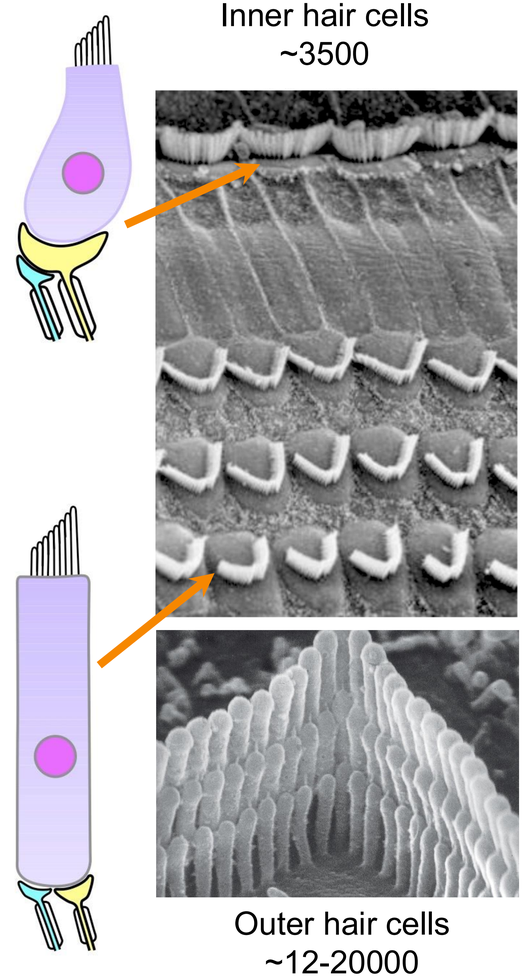
Vestibular organ: semicircular canals
Cochlea: 2.5-pitch, 35-mm-long fluid-filled channel. It is halved in length partly by an osseous, partly by a membranaeous wall, the basal membrane.



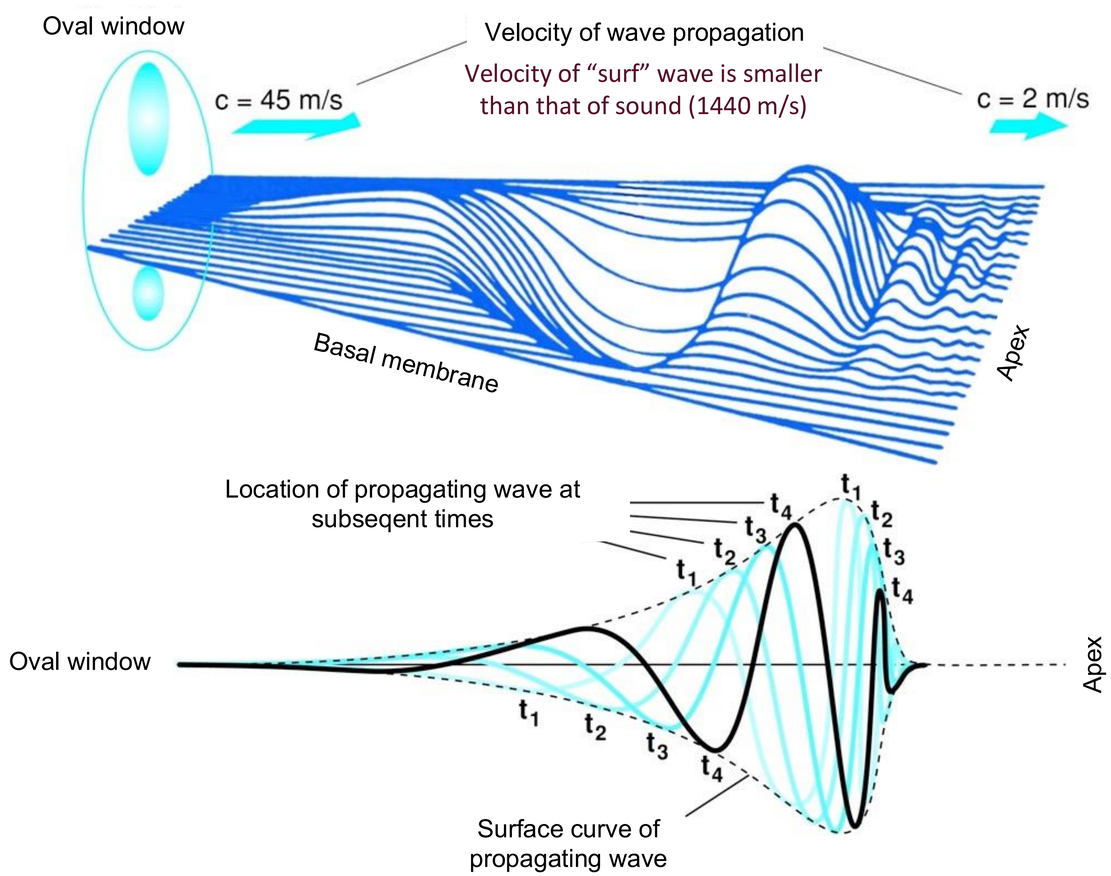


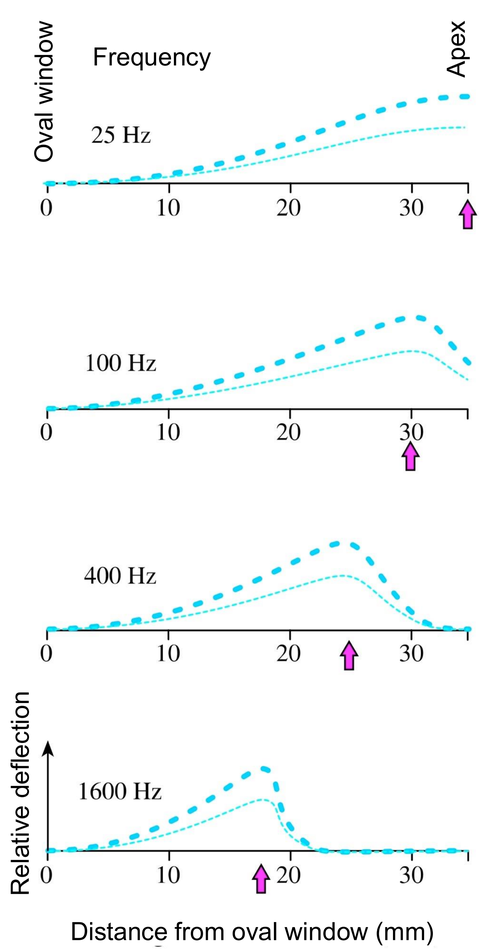
Cross-section of cochea





Békésy: propagating surface waves on basal membrane



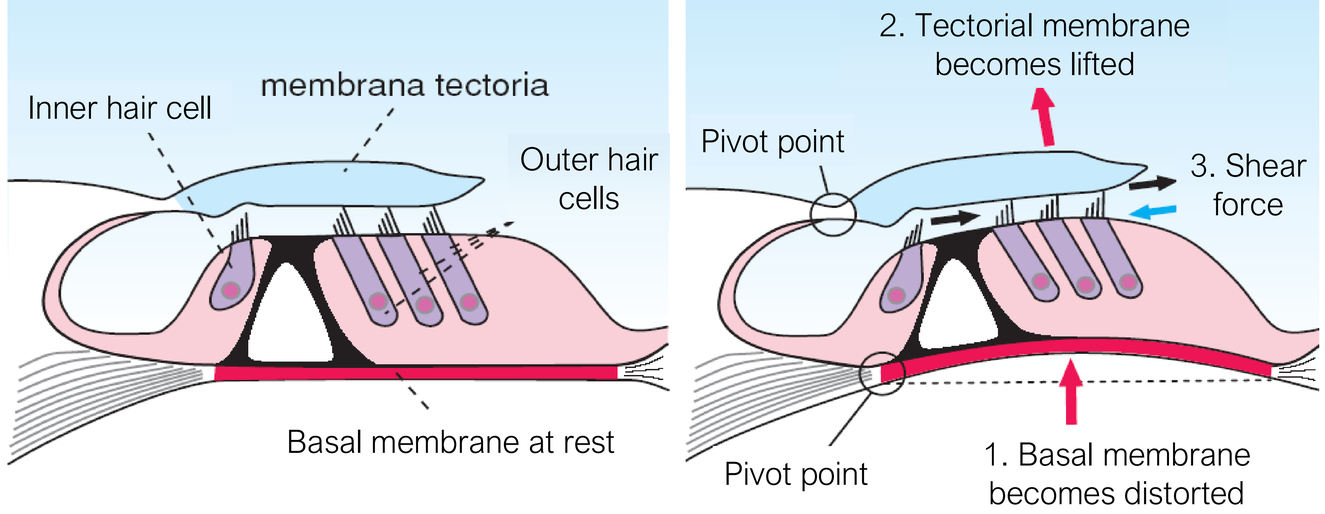


György Békésy
Nobel-prize 1961

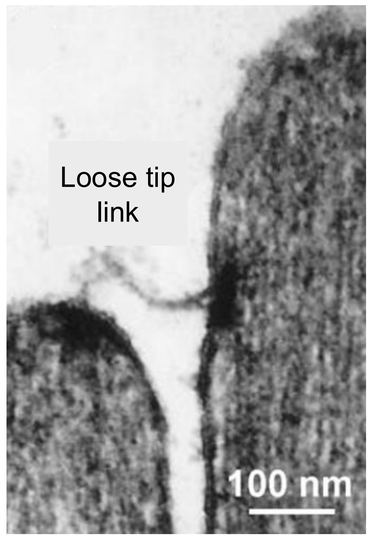
The frequency-dependence of the location of propagating wave maxima provide a rough frequency-discrimination.

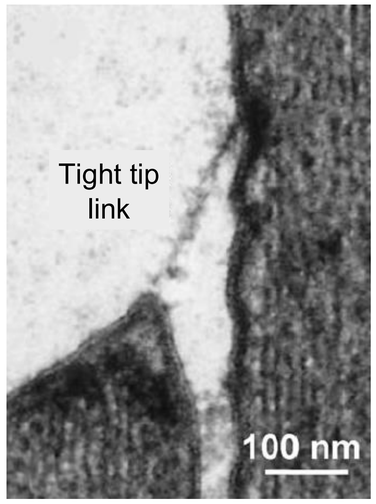
Function of the organ of Corti

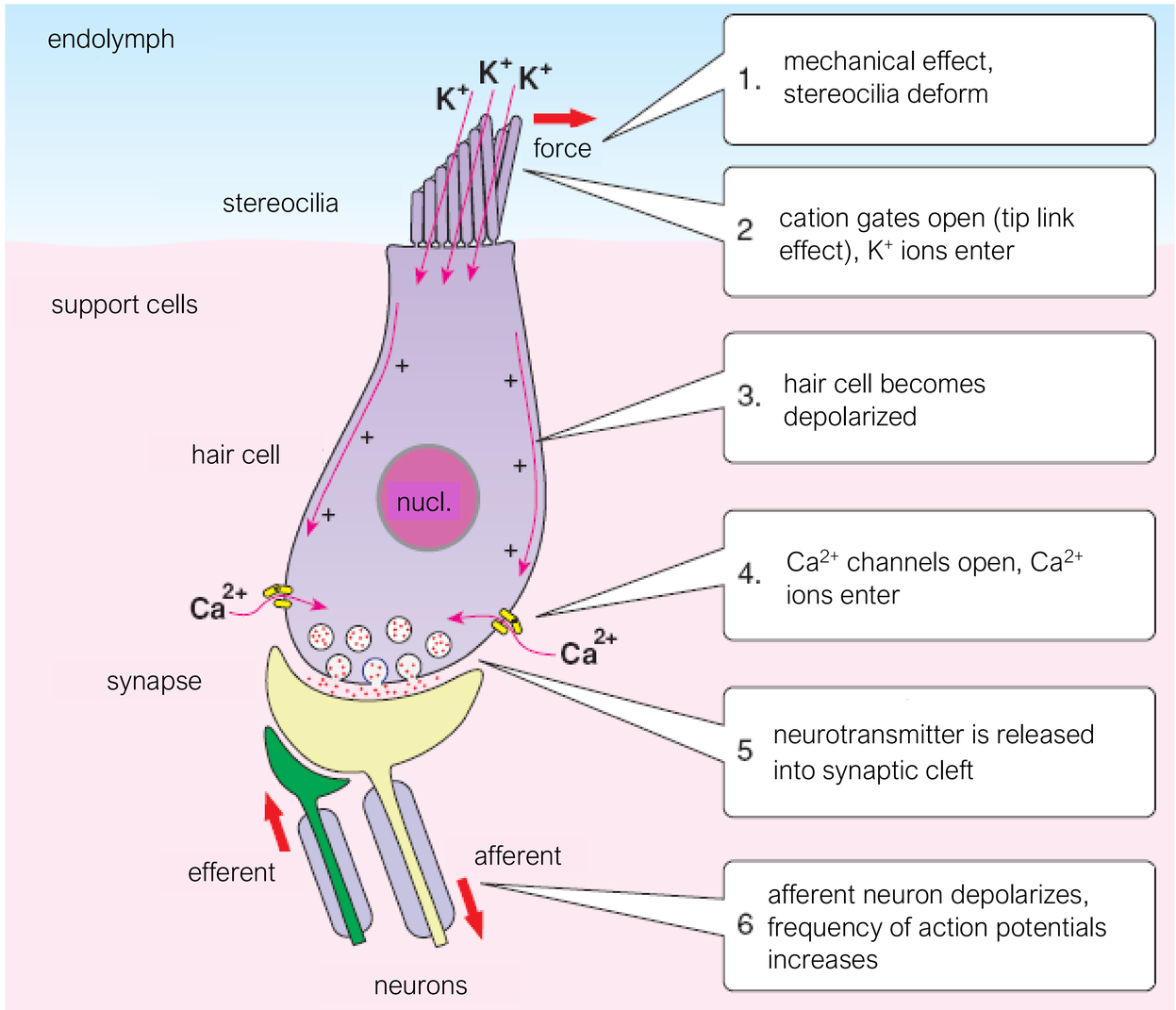
Due to the bending of the basal membrane, hair cells become tilted and depolarized.



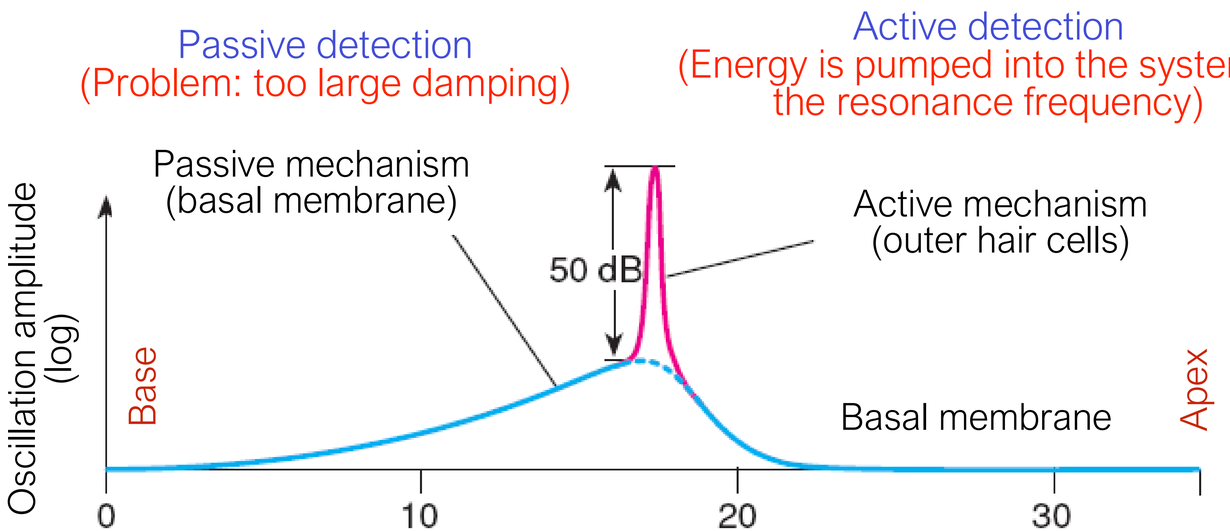
Inner hair cells: Mechanoelectric transduction







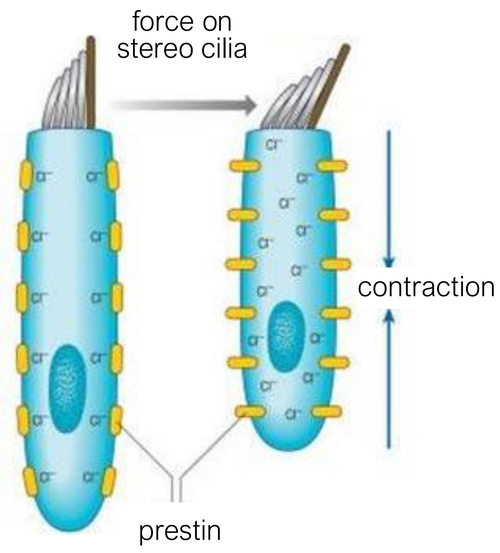
Outer hair cells: amplifiers



Amplification: sound-induced contraction in outer hair cells

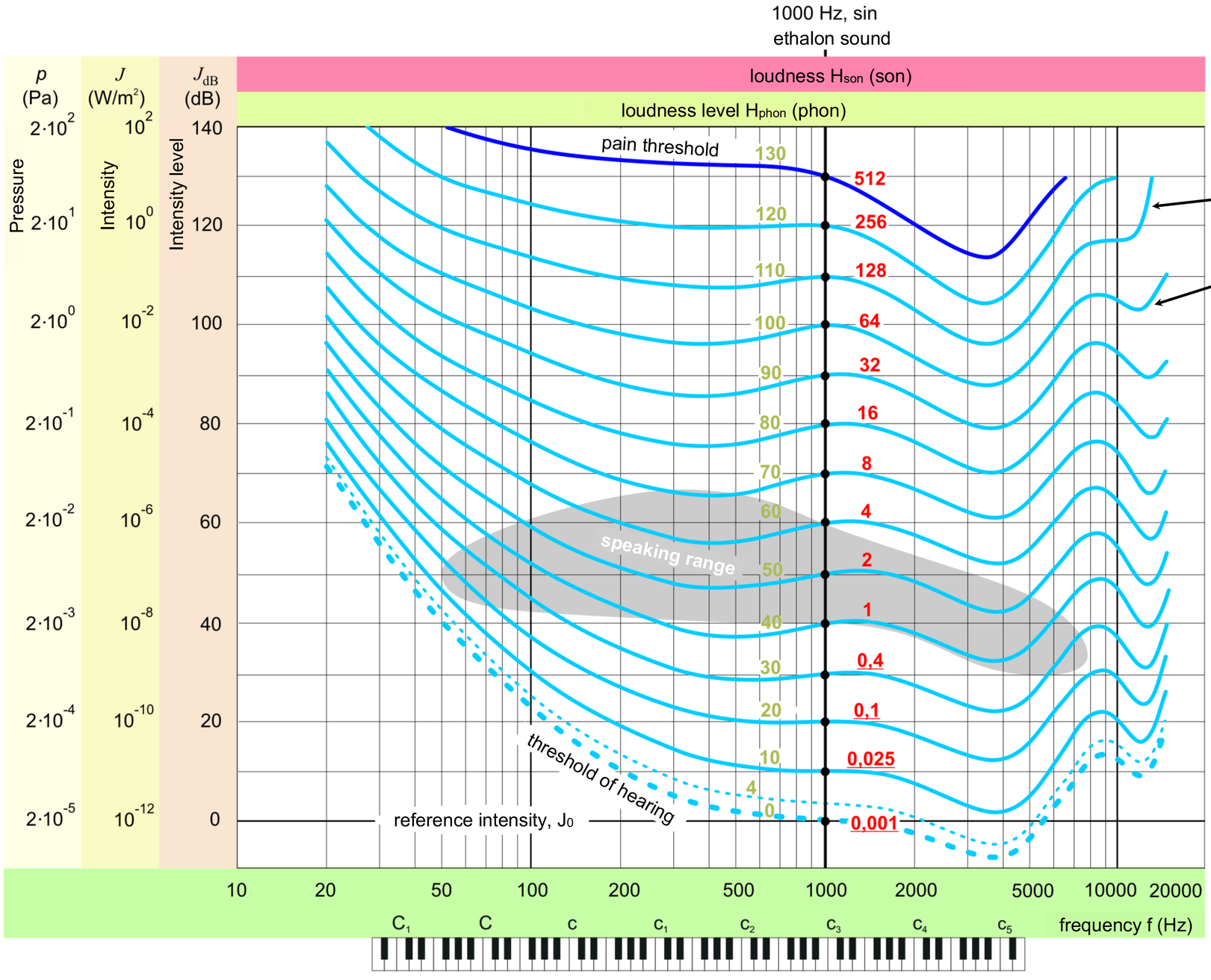
The inner ear is a regenerative amplifier

- **Positive feedback** mechanism
- Large amplification in narrow frequency range.
- Only the dissipated energy is regenerated (otherwise ringing occurs)
- The key molecule of the amplifier is prestin.



- **Prestin** - transmembrane motor protein (Péter Dallos, 2000). *Presto* – ”quickly”.
- Mechano-electric and electromechanical transduction

Stimulus intensity and sensing - psychoacoustics



Disco
120 phon

Street
noise
80 phon

Loud
speaking
60 phon

Whisper
30 phon

Isophon curves: connect points of identical loudness level Fletscher-Munson curves

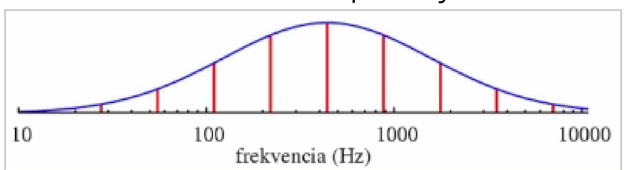
N.B.: The loudness level of a sound, in phon, is the dB value of a 1000 Hz sound with which we hear it identically loud.

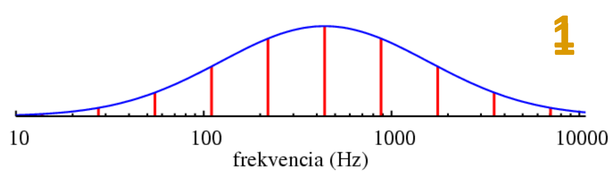
Subjective loudness (son scale):
10 dB increase in loudness level is perceived as doubling of loudness. (Stevens law)

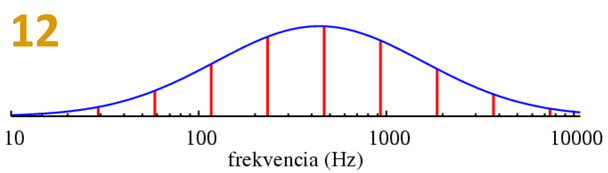
Is there acoustic illusion?

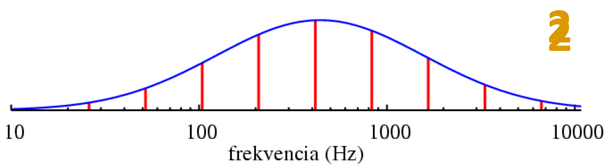
Shepard tone:
sine waves separated by octaves

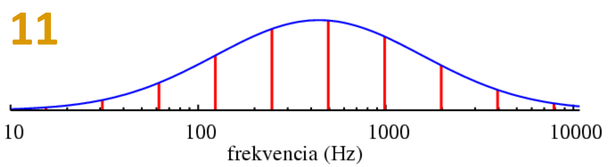
Shepard scale:
fundamental frequency moves

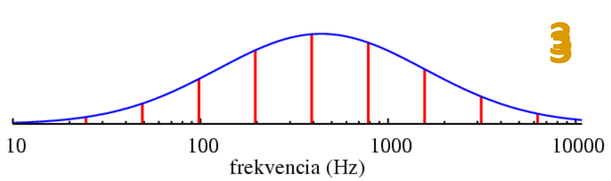


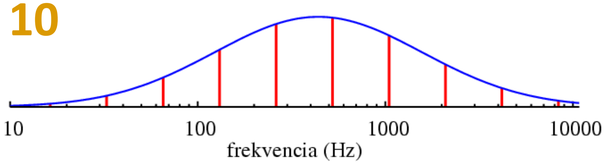


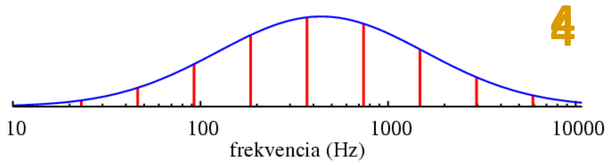


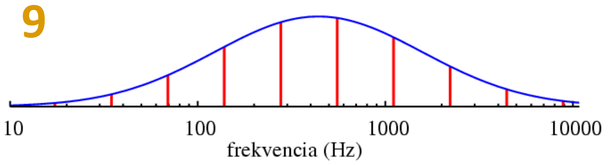


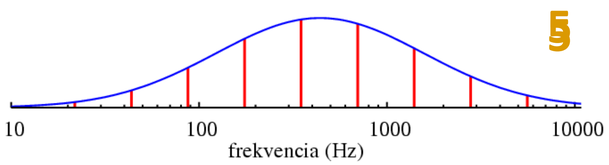


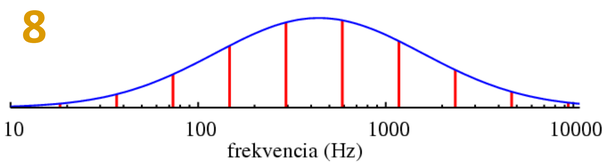


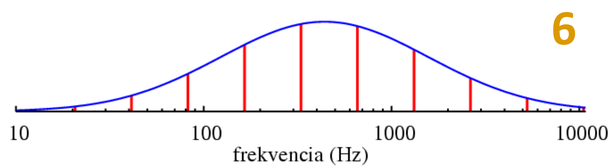


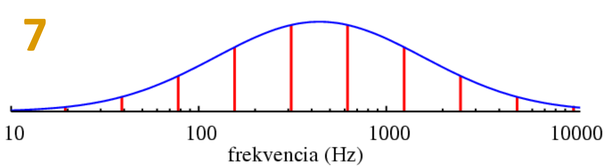












Feedback

https://feedback.semmelweis.hu/feedback/index.php?feedback-qr=RWAI1C8IENFH9W3E