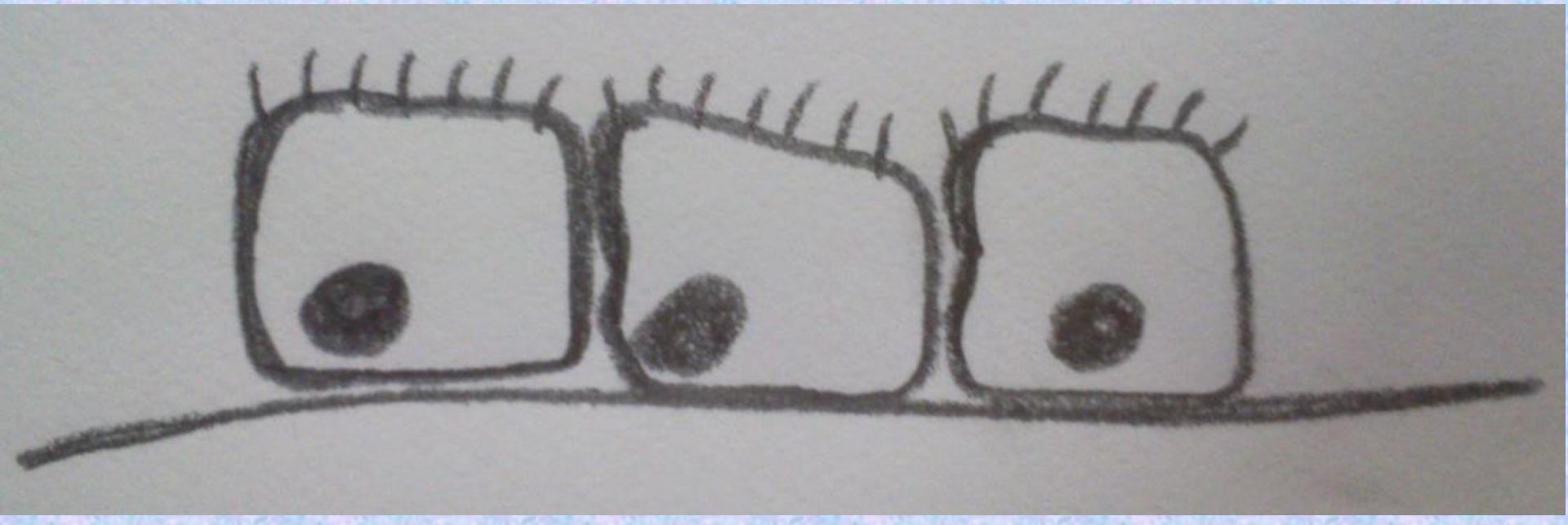
Receptors



Localisation: in membrame, in cytosol, in nuclei, in mitochondria

Receptor transform information from our sense to biological signals = electrical Action Potential

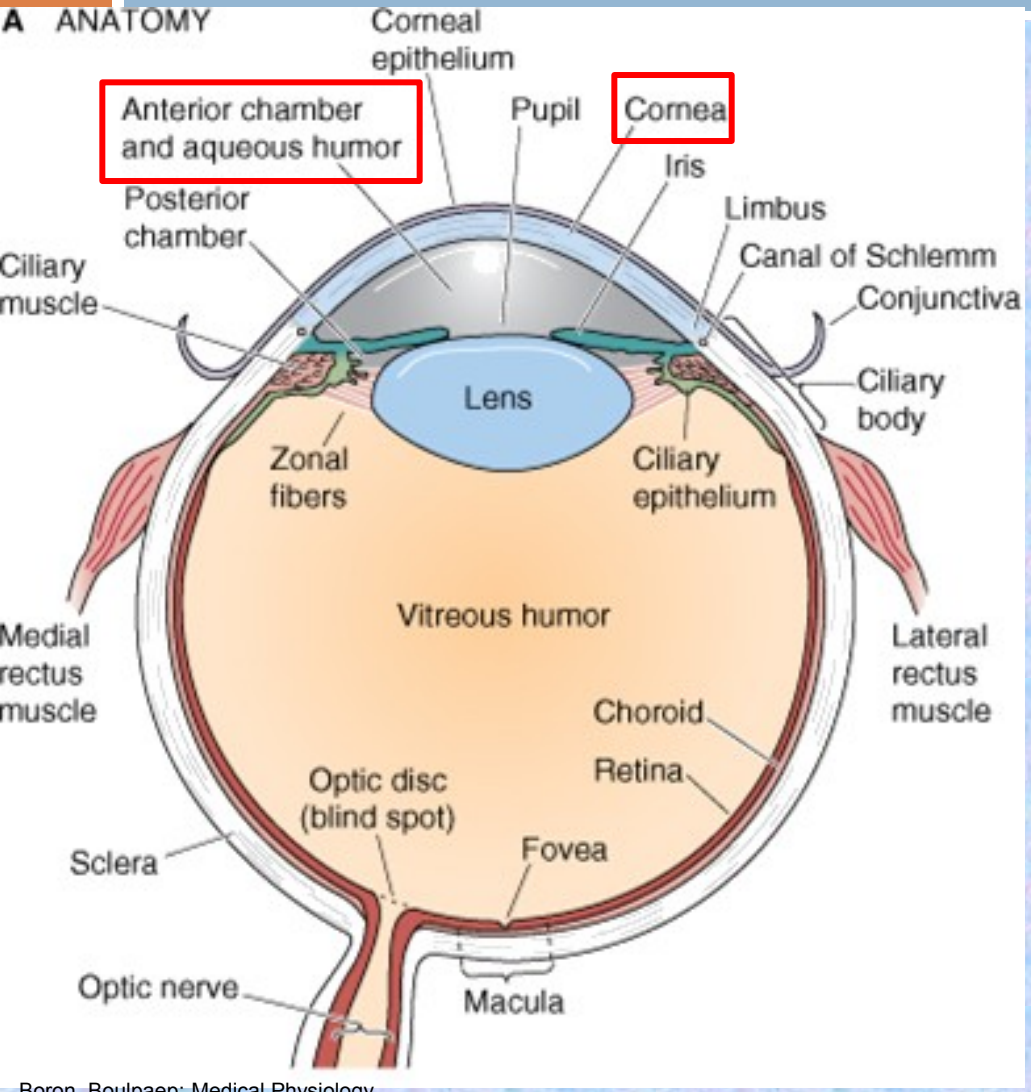
Type of receptors for senses

- Photoreceptors (rod and cone)
- Mechanoreceptors (touch on the skin, sound wave detection, wave detection in inner ear)
- Chemoreceptors (detection of molecules in food)
- Termoreceptors
  - Cold 23-28
  - Warm 38-43
    - Fast chang…0.1 gradius
    - Slow change….bigger difference

Physiology of vision

- Functional anatomy of the eye
  - Optical
  - Neural
- Photoreceptors
  - Rods
  - Cones
- Phototransduction
  - Mechanism
  - Termination
  - Light adaptation
- Colour Vision

Optical anatomy of the eye

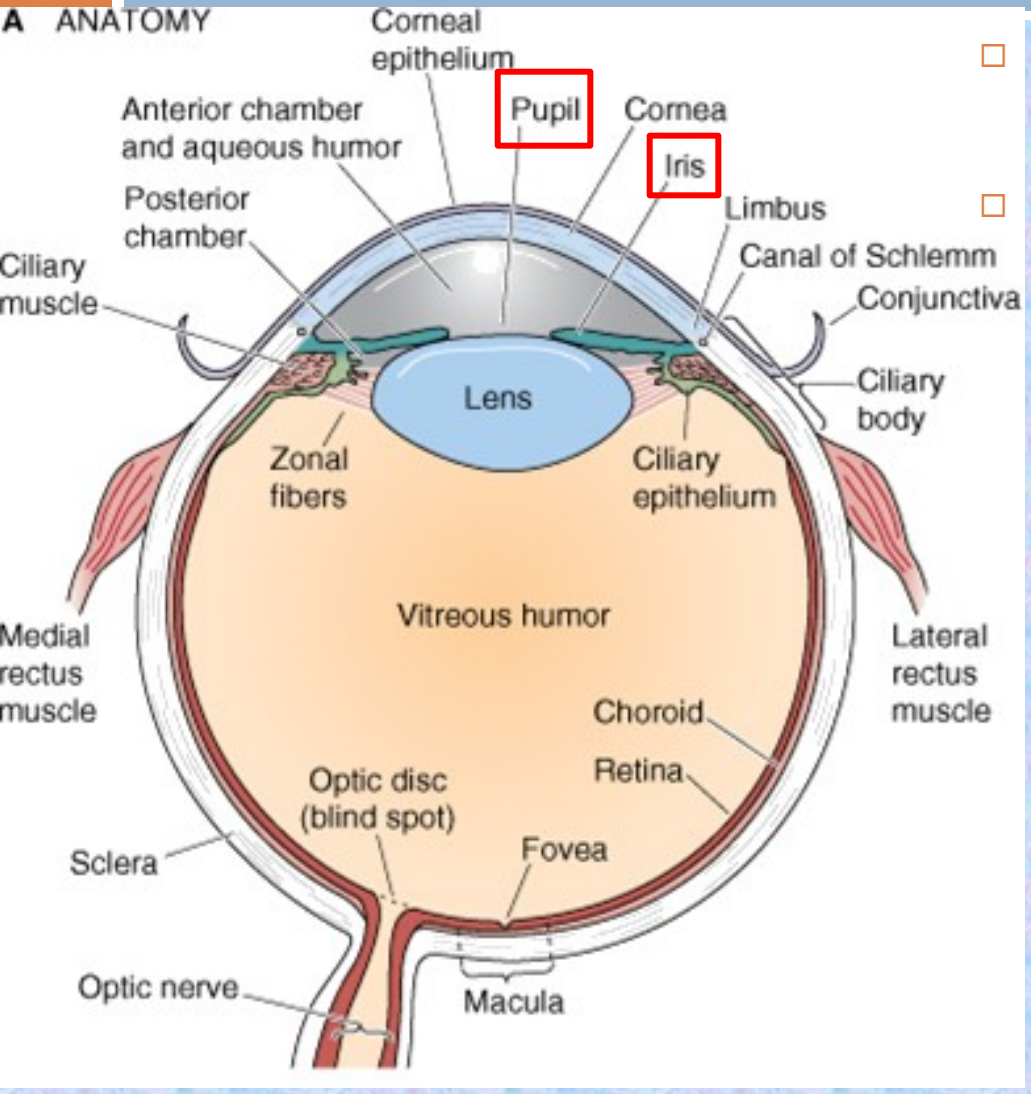


Boron, Boulpaep: Medical Physiology, 2003

Optical portion of eye focuses light thru cornea and lens onto the fovea.

- Cornea
  - Thin, transparent epithelium devoid of blood vessels
  - Receives nutrients by diffusion from tear fluid
  - Major refraktory portion of the eya, has unmyelinated nerve endings sensitive to touch and pressure
  - Aqueous humor
  - Produced by ciliary epithelial cells. Protein free watery liquid that supplies nutrients to cornea and lens
  - Maintains intraocular pressure and gives shape to anterior portion of eye

Optical anatomy of the eye

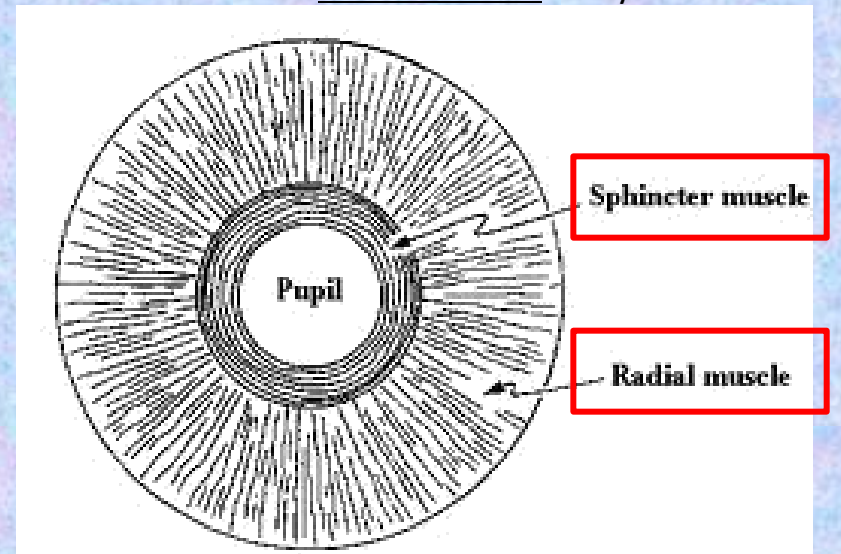


Pupil

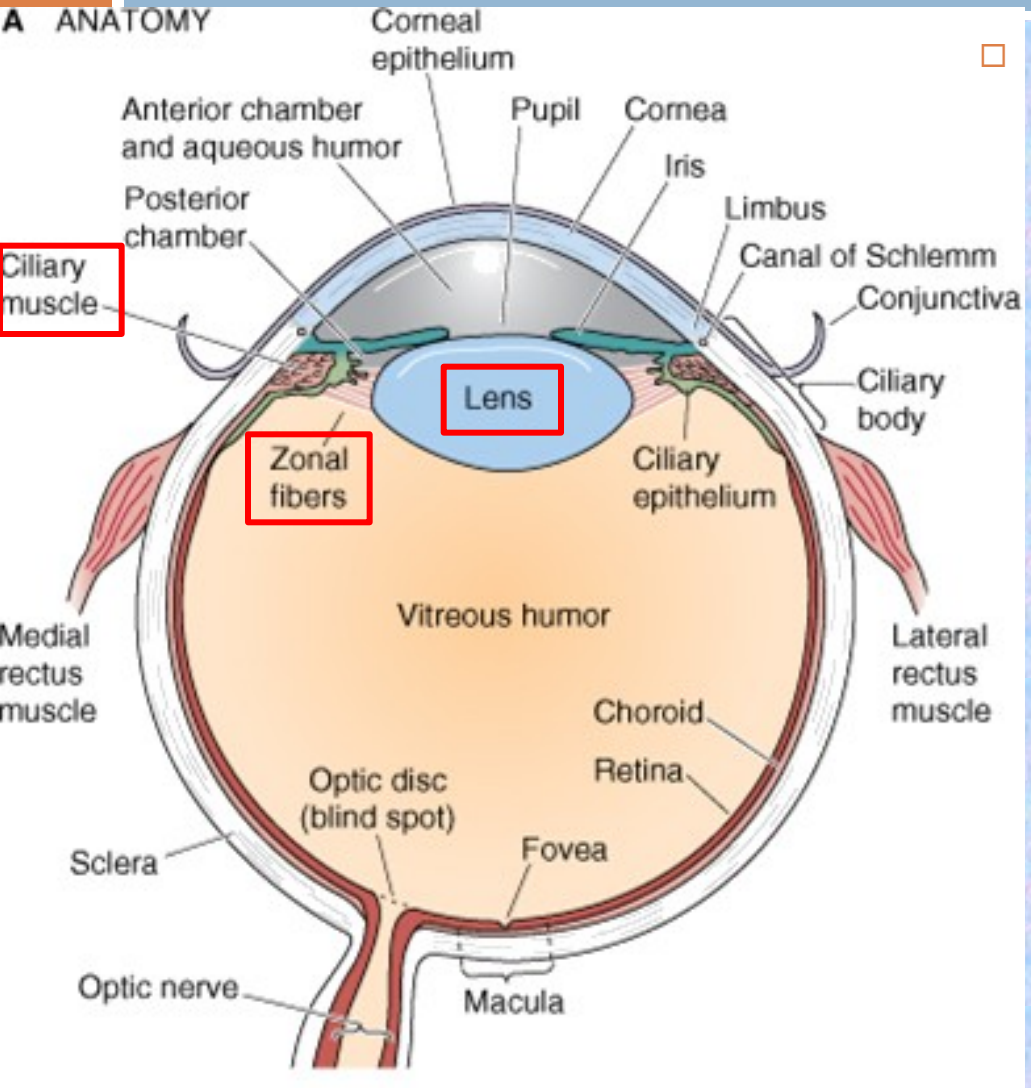
- Aperture of the eye

Iris

- is the colored portion of the eye, than can be seen through the cornea
- contains two sets of muscles
- Controls diameter of pupil
  - Contraction of sphincter muscles → miosis
  - Contraction of radial muscles → mydriasis



Optical anatomy of the eye



- Lens
  - Dense, high protein structure that adjusts optical focus
  - Focus adjusted by process called accommodation
    - At rest, zonal fibers suspend lens and keep it flat
      - Focus on objects far away
    - Contraction of ciliary muscles releases tension in zonal fibers
      - Lens becomes rounder
      - Focus on near objects

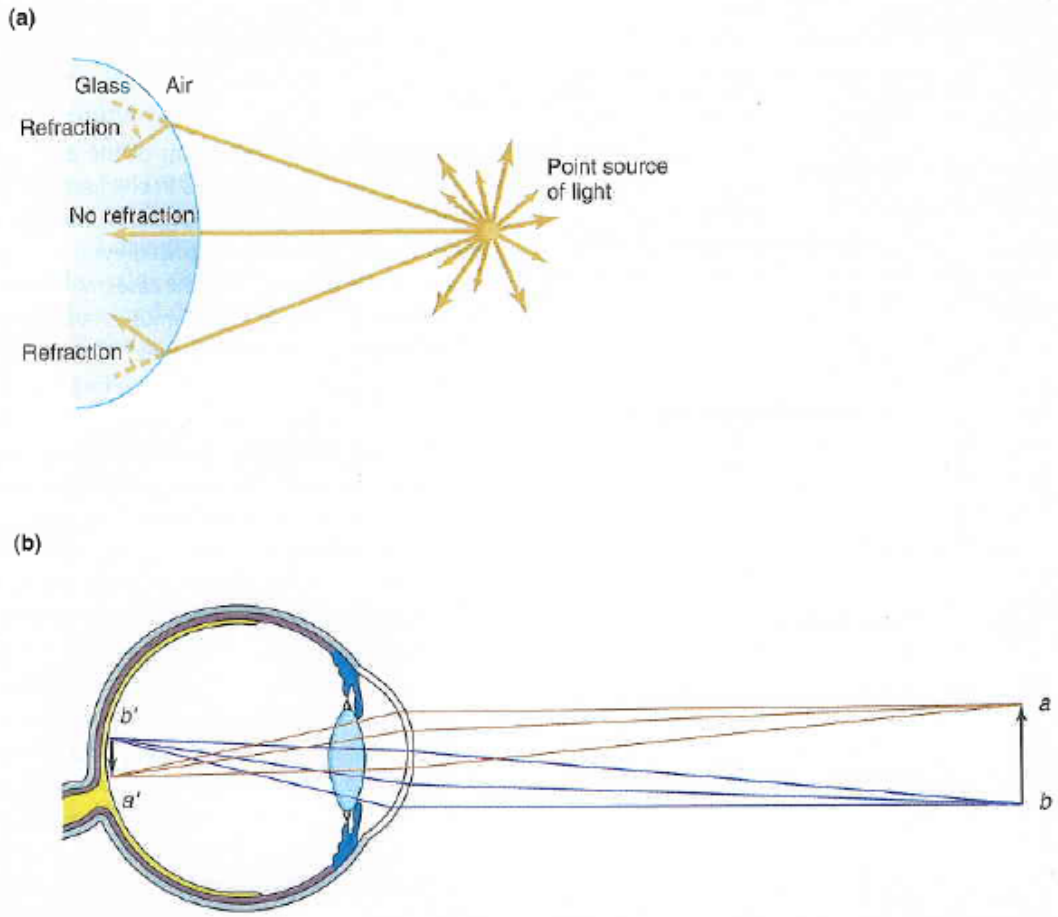


FIGURE 12–8 **Focusing point sources of light. (a)** When diverging light rays enter a dense medium at an angle to its convex surface, refraction bends them inward. **(b)** Refraction of light by the lens system. For simplicity, refraction is shown only at the corneal surface (site of greatest refraction) although it also occurs in the lens and elsewhere. Incoming light from *a* (above) and *b* (below) is bent in opposite directions, resulting in *b'* being above *a'* on the retina. (From Widmaier EP, Raff H, Strang KT: *Vander's Human Physiology*, 11th ed. McGraw-Hill, 2008.)

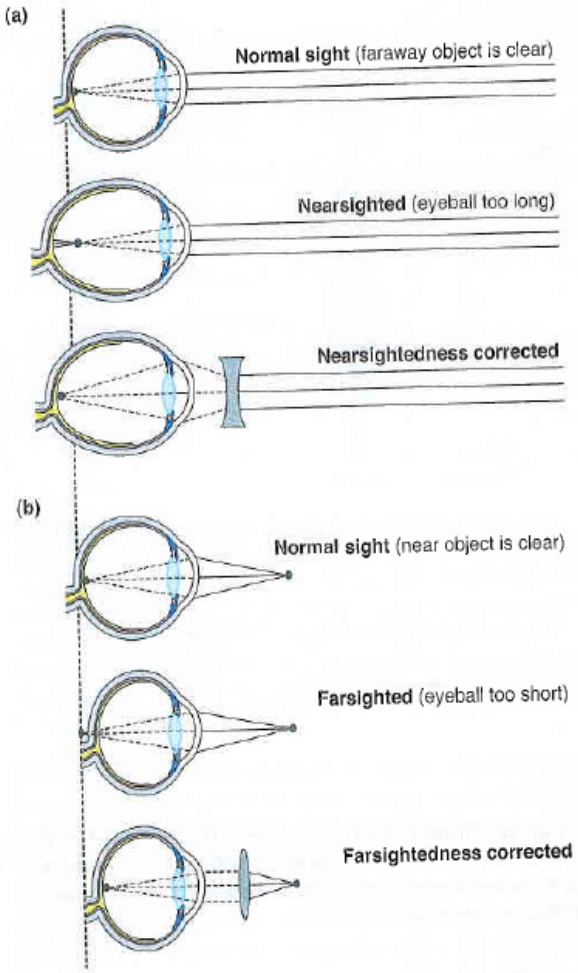
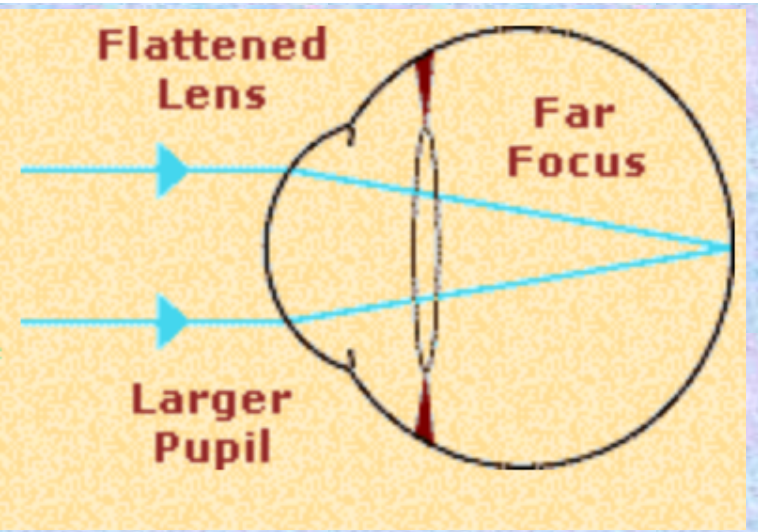
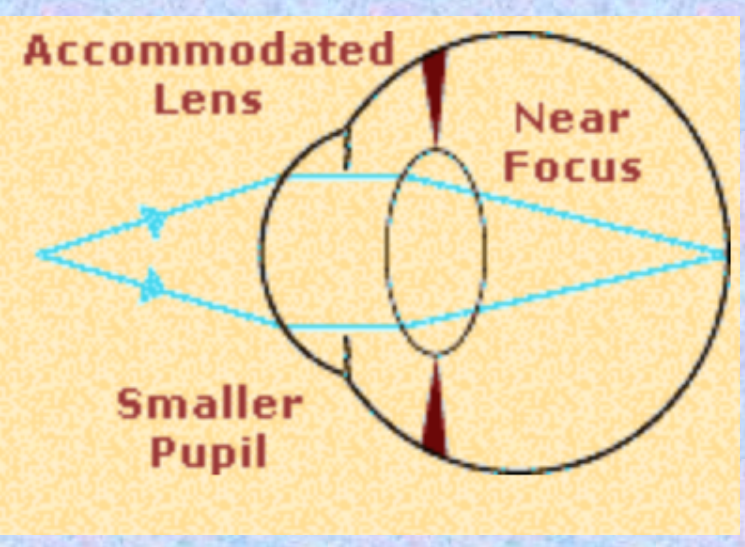


FIGURE 12–9 Common defects of the optical system of the eye. In hyperopia (farsightedness), the eyeball is too short and light rays come to a focus behind the retina. A biconvex lens corrects this by adding to the refractive power of the lens of the eye. In myopia (nearsightedness), the eyeball is too long and light rays focus in front of the retina. Placing a biconcave lens in front of the eye causes the light rays to diverge slightly before striking the eye, so that they are brought to a focus on the retina. (From Widmaier EP, Raff H, Strang KT: *Vander's Human*

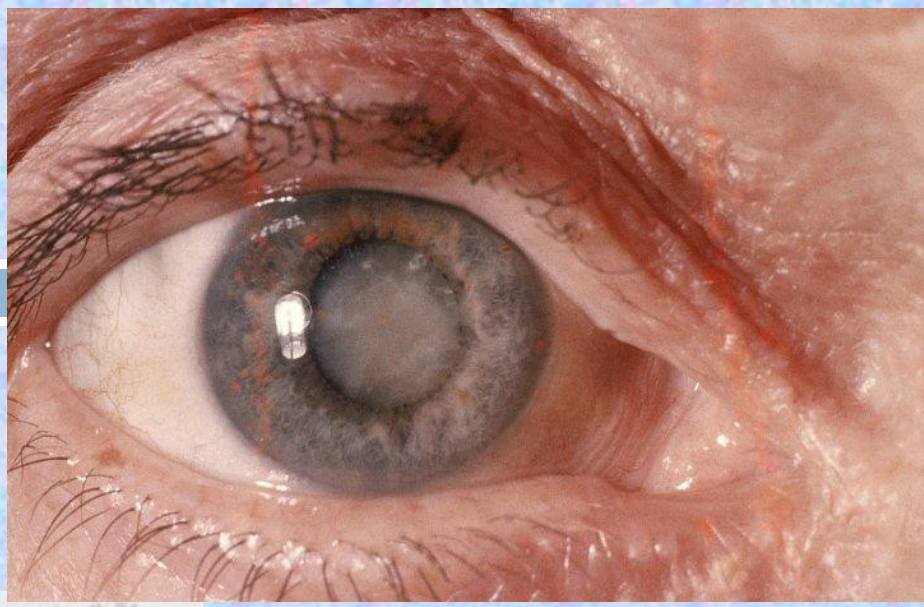
Accommodation and associated disorders



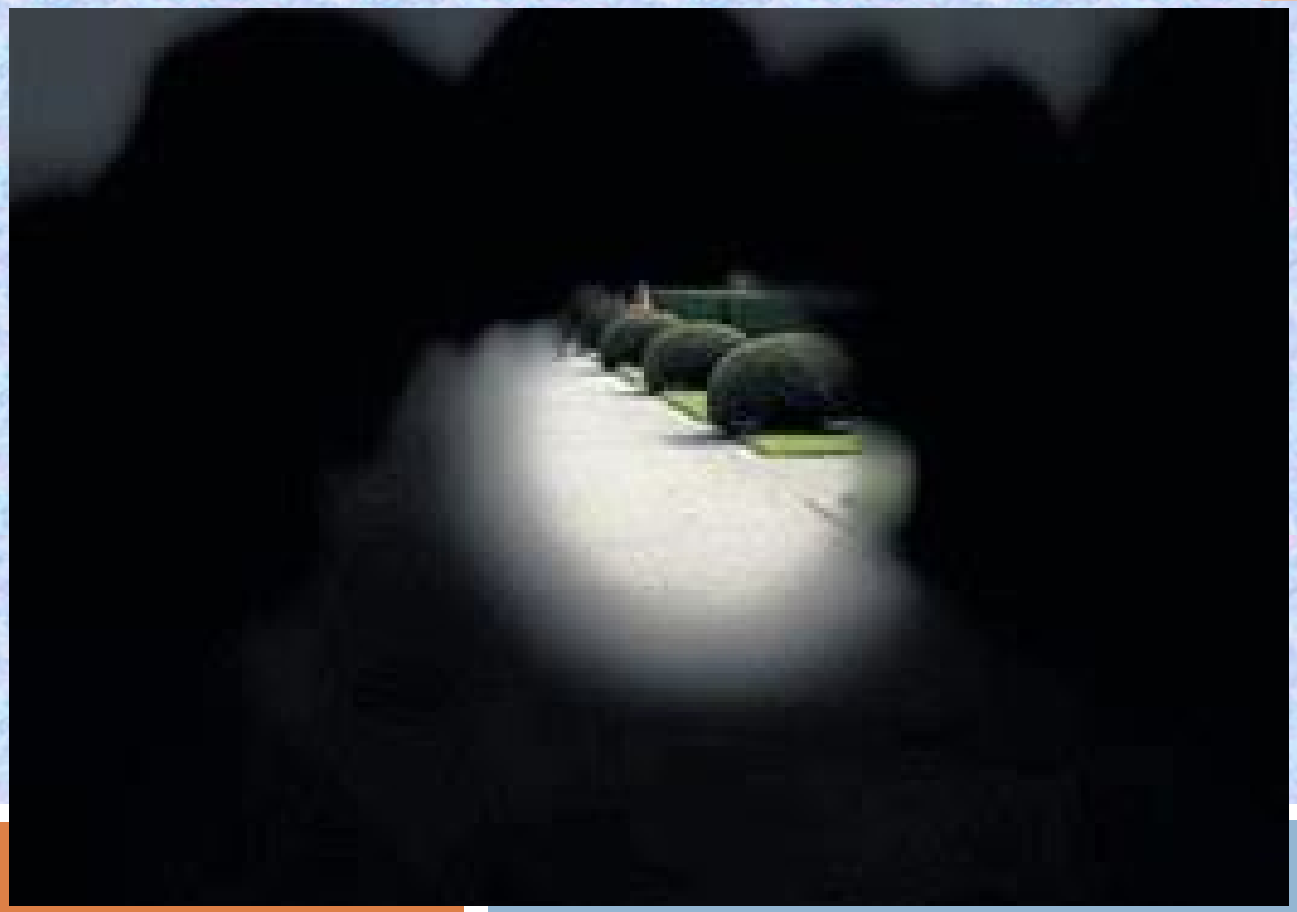


- Accommodation of the lens is limited and age dependent
  - With age, lens becomes stiffer and less compliant.
    - Age related loss of accommodation called **presbyopia**
- Accommodation accompanied by adaptive changes in size of pupil

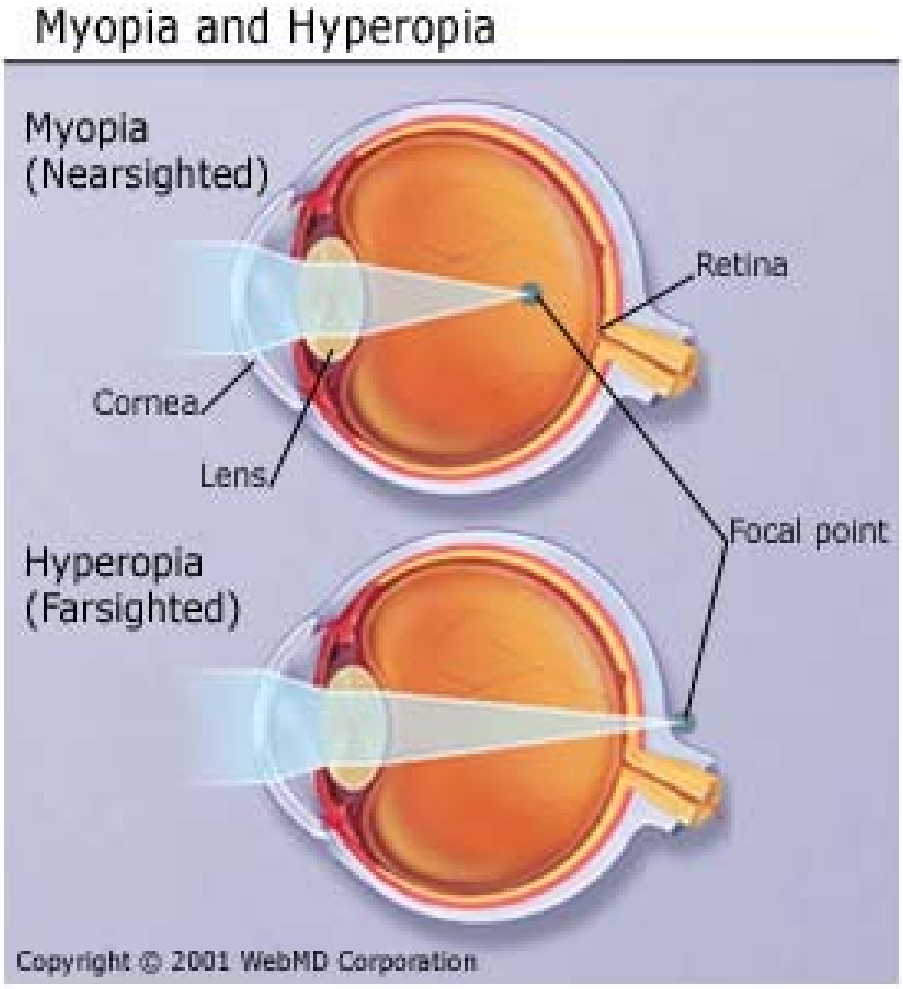
cataract



glaucoma



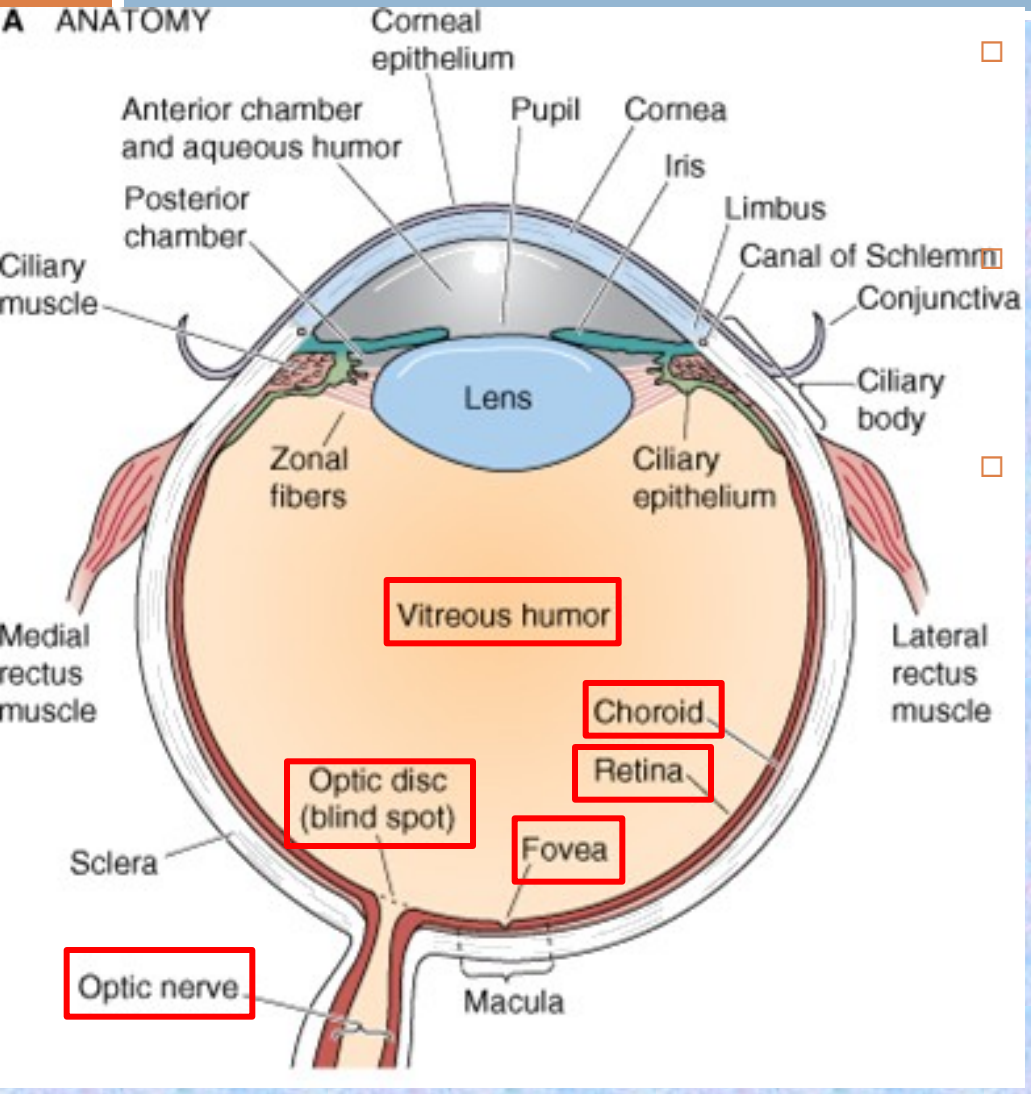
Accommodation and associated disorders



- Myopia
  - Image focused in front of retina
  - Far away objects appear blurry
- Hyperopia
  - Image focused behind retina
  - Close objects appear blurry

Each can be caused by abnormal shape of the eye as well.

Optical anatomy of the eye



- Vitreous humor
  - Gel of extracellular fluid containing collagen
- Choroid
  - rich in blood vessels and supports the retina
- Retina
  - Neural portion that transduces light into electrical signals that pass down the optic nerve
  - Optic nerve exits at optic disc. Devoid of photoreceptors: blind spot
  - Fovea is point on retina that has maximal visual acuity

RETINA

Its organized on layers
Visual receptors+4types of neurons.
Many different synaptic transmitters

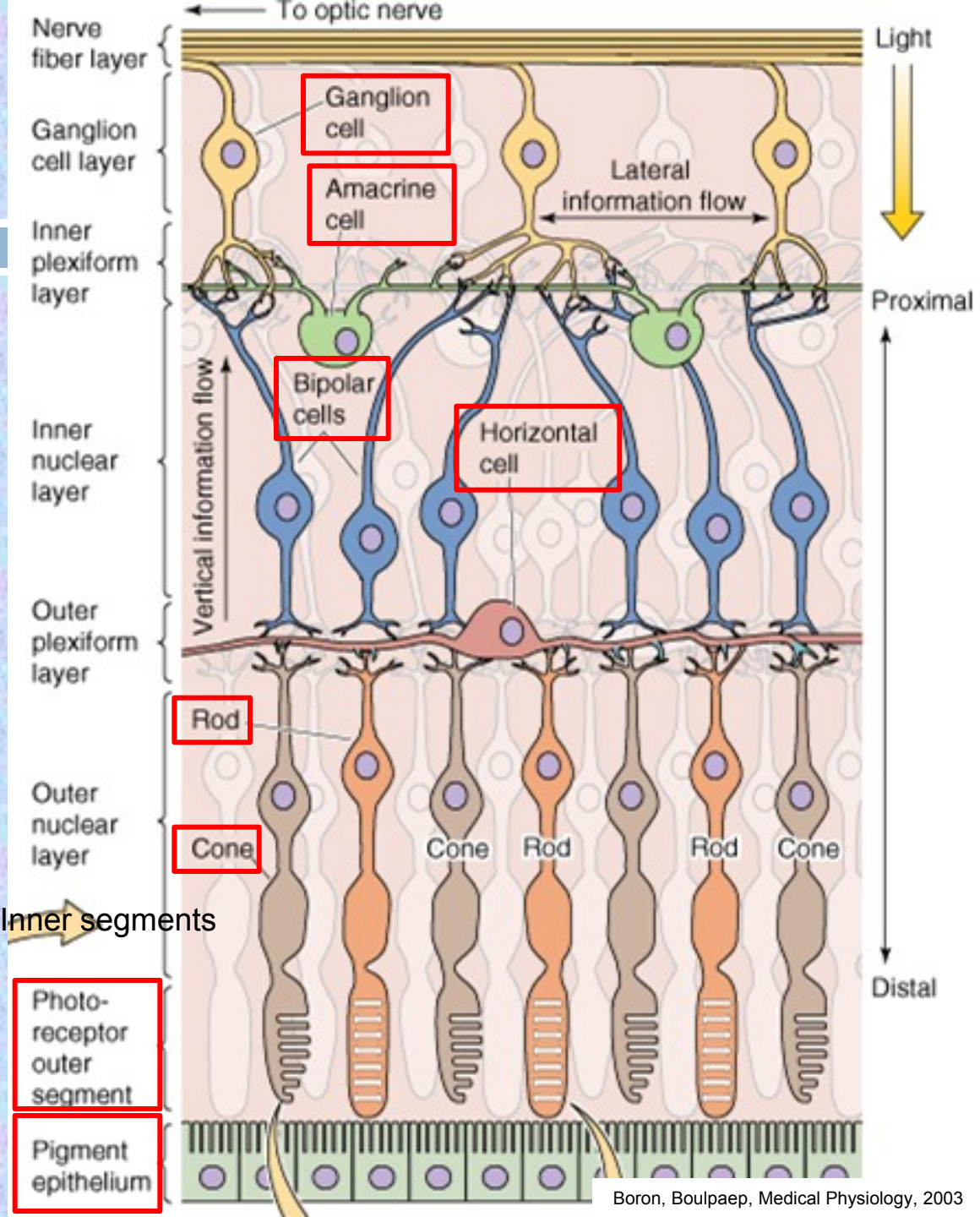
- Pigment epithelium
- Absorps light rays, prevention the reflection of rays back through the retina
  - Contains melanin to absorbs excess light
  - Stores Vitamin A
- Photoreceptors
  - Transduce light energy into electrical energy
  - Rods and cones
- **Ganglion cells**
  - Output cells of retina project via optic nerve

Bipolar cells – 12 different types occur

Horizontal cells

Amacrine cells - 29types have been described

  - The neural elements of retina are bound together by glial cells – Muller cells



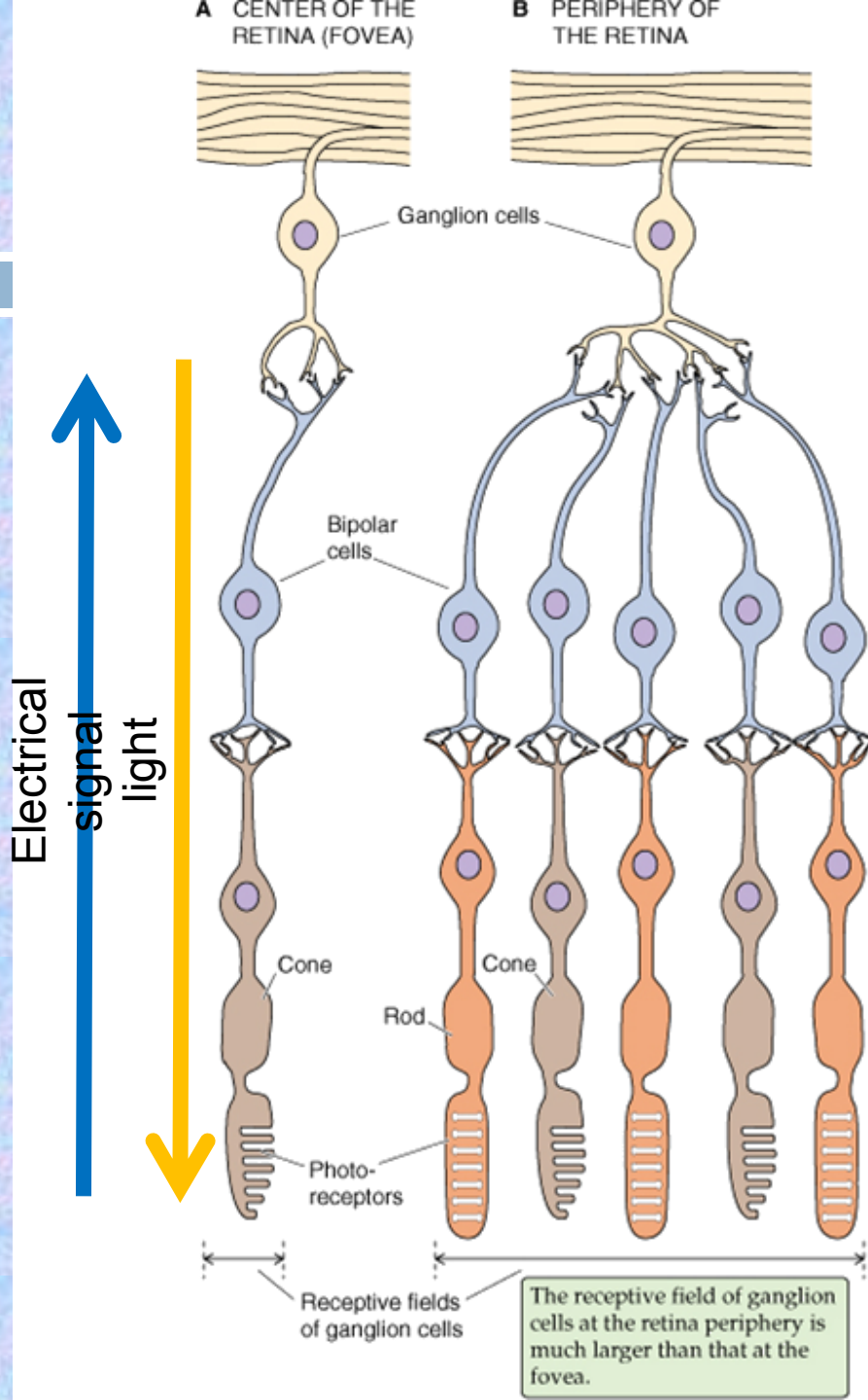
Boron, Boulpaep, Medical Physiology, 2003

Periphery of retina

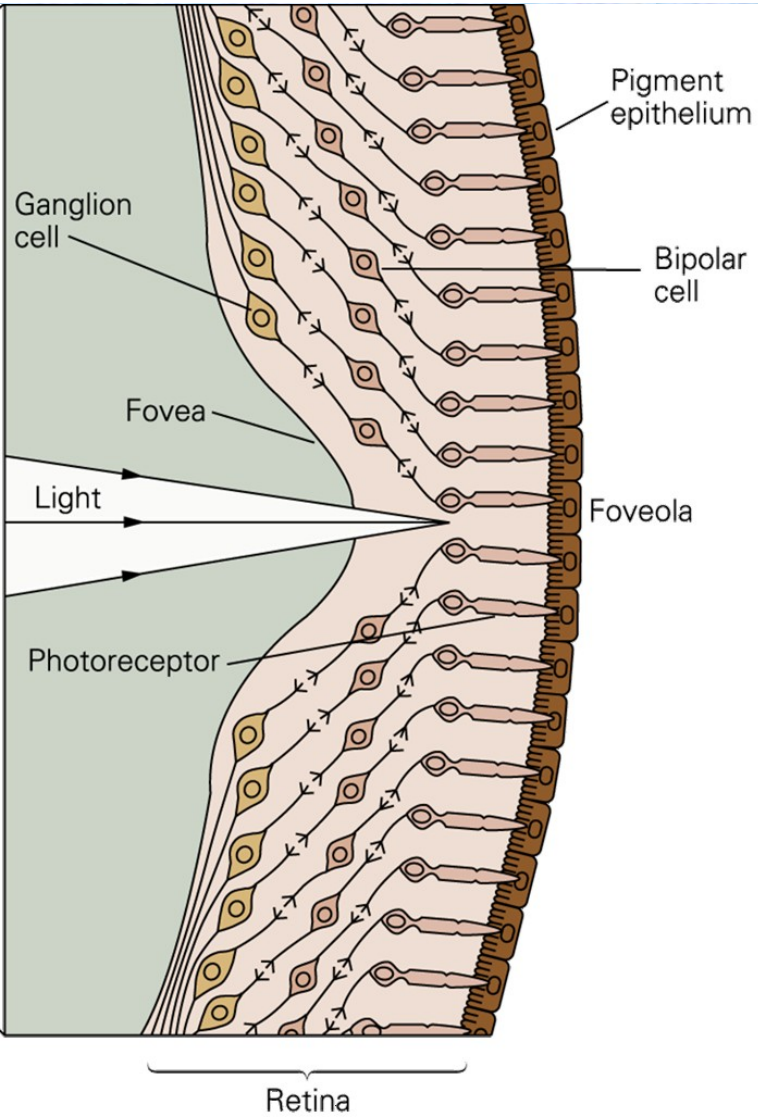
- High degree of convergence → large receptive field
- High sensitivity to light, low spatial resolution

Fovea

- Low convergence → small receptive fields
- Lower sensitivity to light, high resolution (visual acuity)

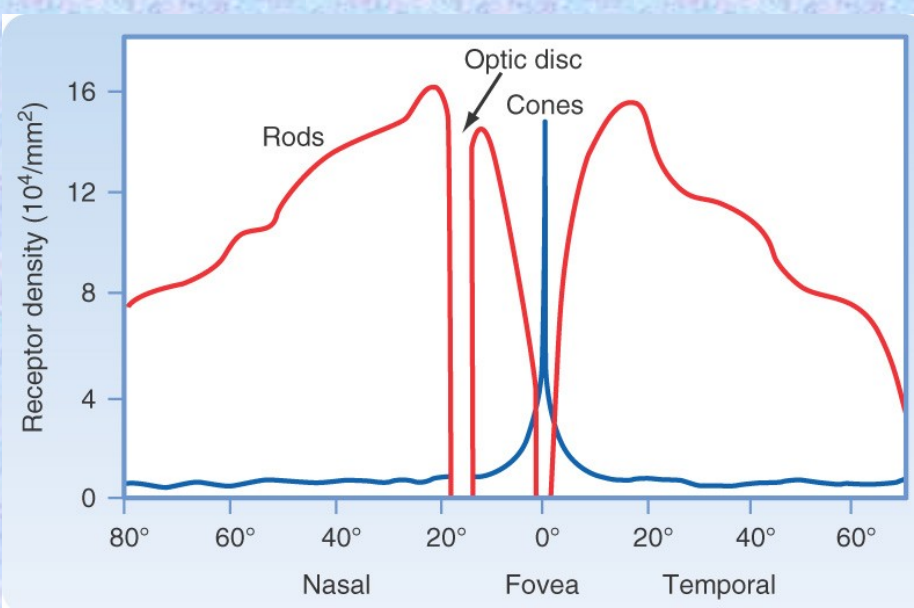


Fovea



Visual acuity of fovea enhanced by:

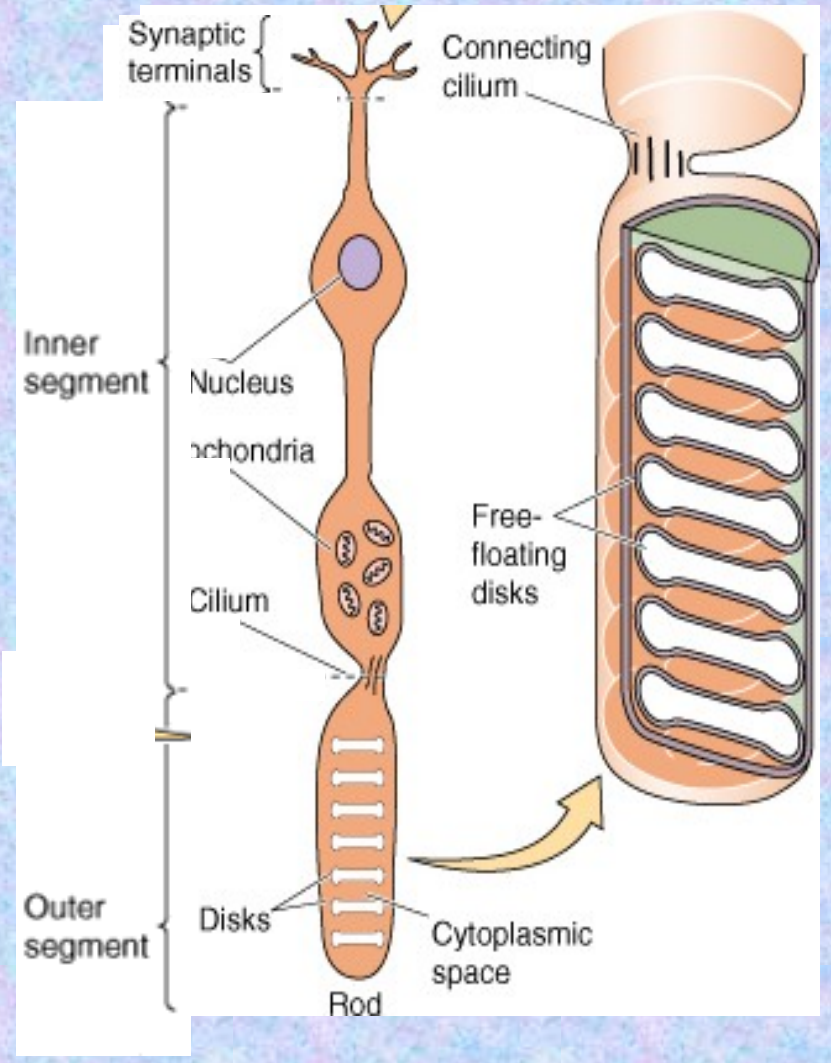
- One to one ratio of photoreceptor to ganglion cell
- Lateral displacement of neurons to minimize scattering of light
- High density of cones



Photoreceptors

Rods

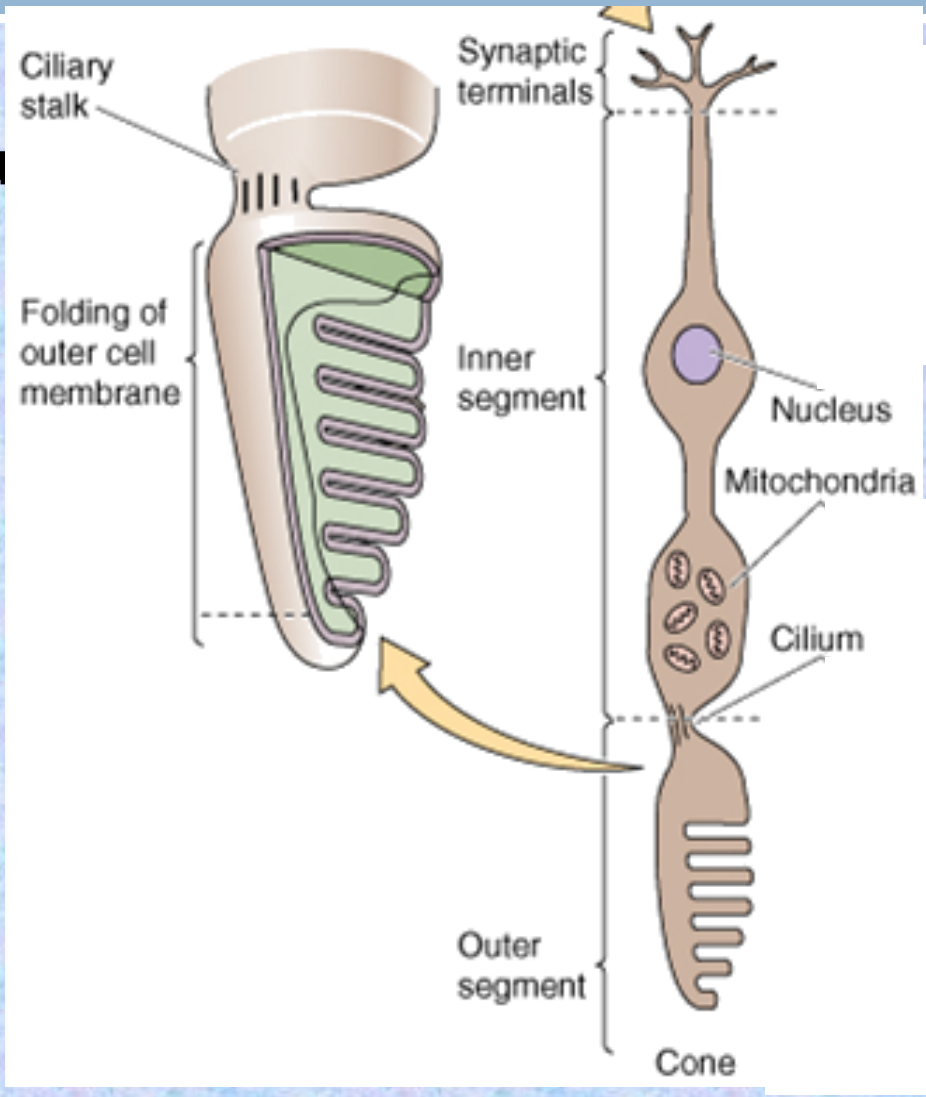
- Responsible for monochromatic, dark- adapted vision
- Inner segment contains nucleus and metabolic machinery
  - Produces photopigment
- Outer segments is transduction site
  - Consists of high density of stacks of disk membranes: flattened, membrane bound organelles
    - contain the photopigment rhodopsin



Photoreceptors

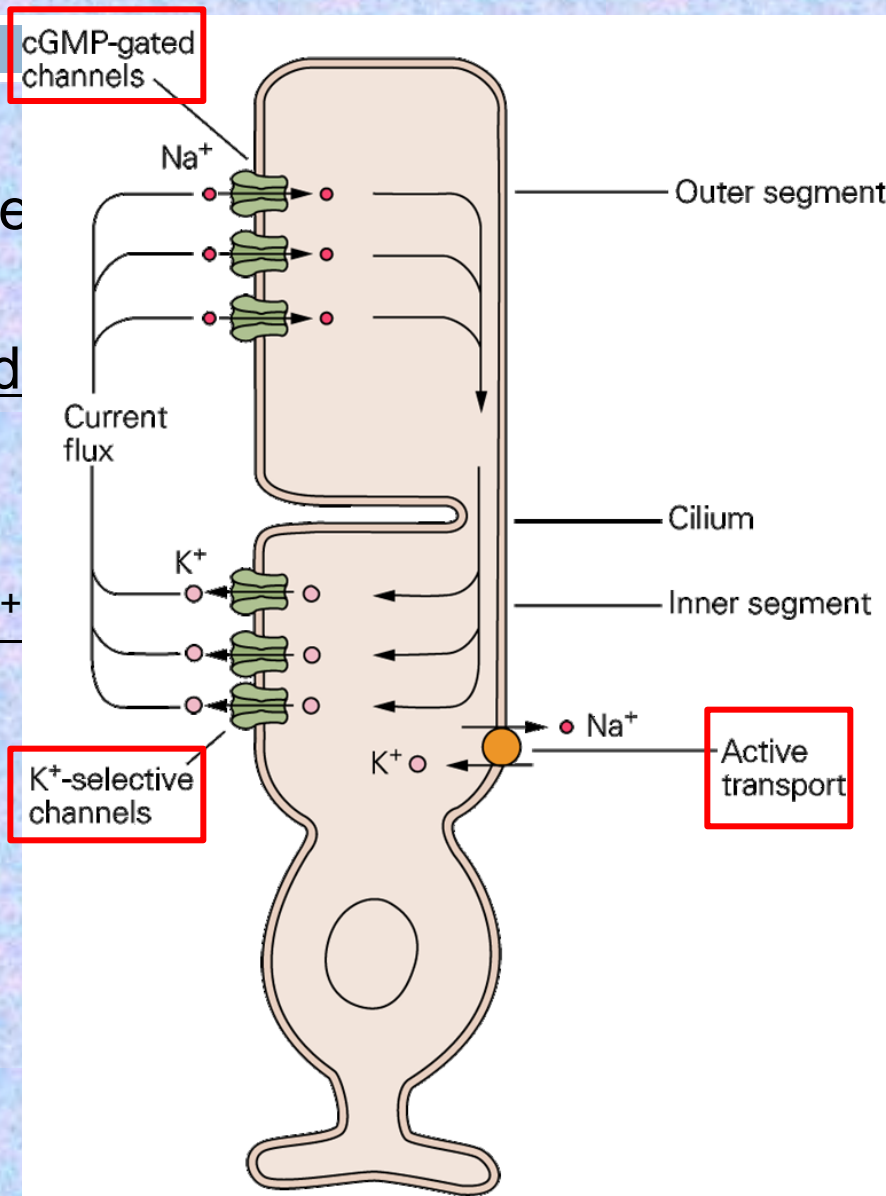
Cones

- 3 subtypes responsible for colou vision
- Inner segment produces photopigments similar to rhodopsin
- Outer segments is transduction site
  - consist of infolded stack membranes that are continuous with the outer membrane
    - vesicles containing pigment



Phototransduction: Dark current

- Partially active guanylyl cyclase keeps cytoplasmic [cGMP] high in the dark
- Outer segment contains cGMP-gated cation channels
  - Influx of Na^+ and Ca^{2+}
- Inner segment contains non-gated K^+ selective channels
  - K^+ efflux
- Resting, or dark V_m is -40 mV
- concentration gradients maintained by Na^+/K^+ pump and NCX



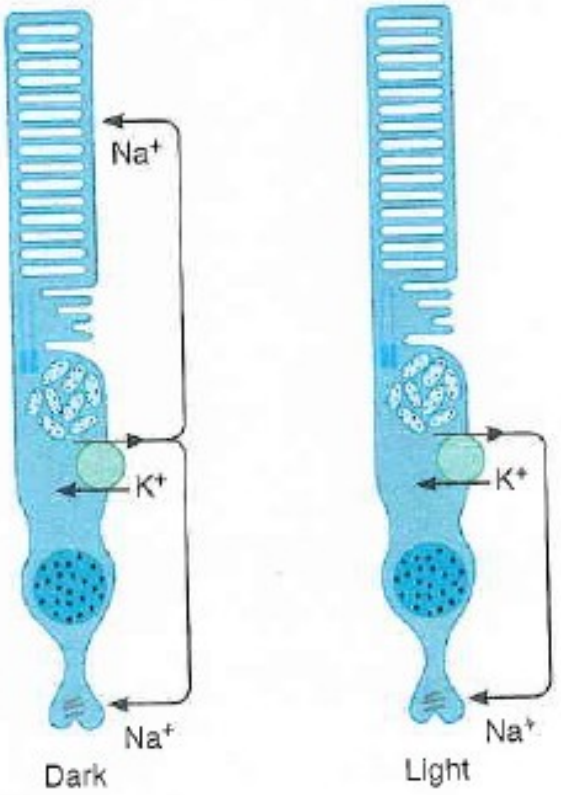


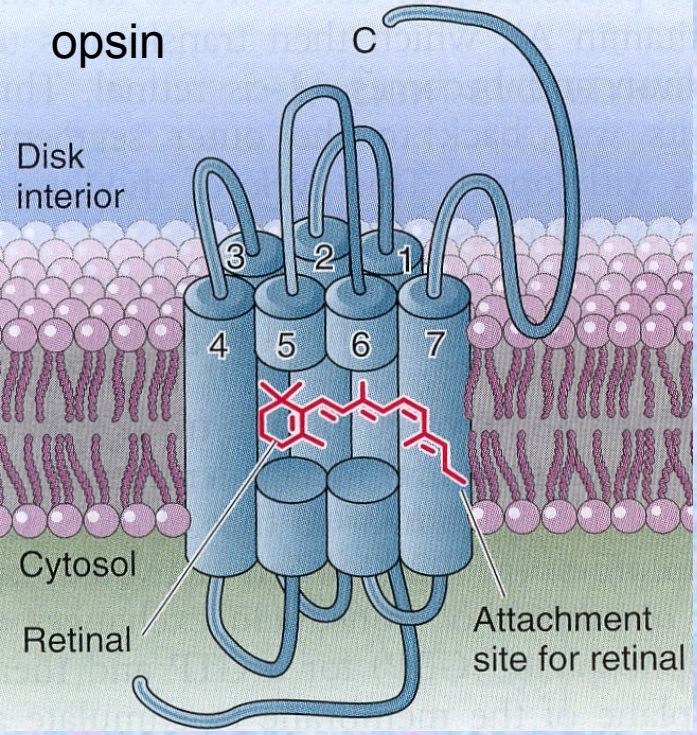
FIGURE 12–12 Effect of light on current flow in visual receptors. In the dark, Na^+ channels in the outer segment are held open by cGMP. Light leads to increased conversion of cGMP to 5'-GMP, and some of the channels close. This produces hyperpolarization of the synaptic terminal of the photoreceptor.

Phototransduction

Photoreceptors hyperpolarize in response to light and release less neurotransmitter

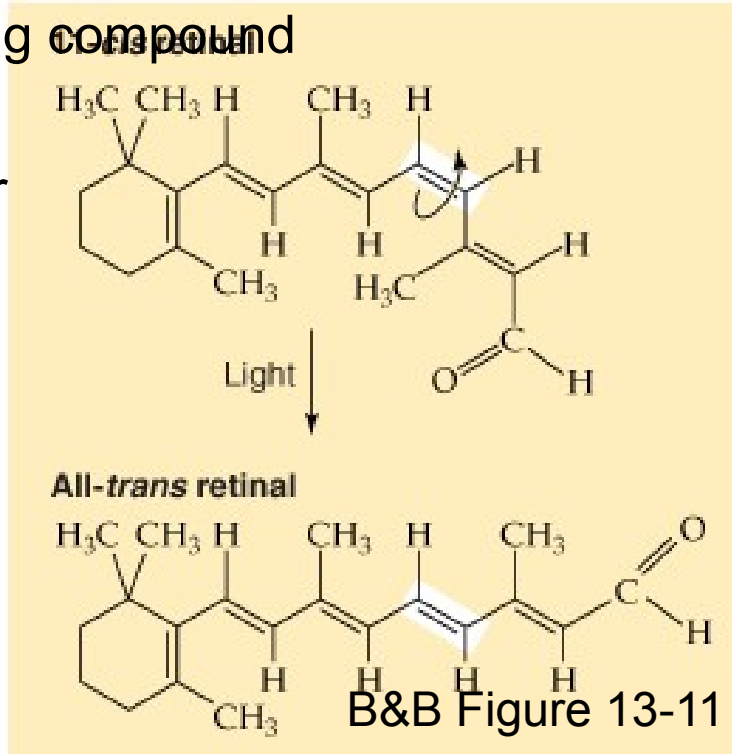
- In darkness, the V_m of -40 mV keeps CaV channels in the synaptic terminal **open**
  - photoreceptors continuously release neurotransmitter **glutamate**
- absorption of light by photopigment ⇩'s [cGMP]
  - cation channels close
  - K^+ efflux predominates, hyperpolarizes cell (-70mV)
  - CaV channels close, **decreased release** of glutamate

Phototransduction: mechanism



Photopigment rhodopsin is the light receptor in rods

- opsin
  - G-protein coupled membrane receptor
- Retinal= retinene1
  - Light absorbing compound
  - the aldehyde form of retinol or Vitamin A



- retinal changes conformation from 11-cis to all-trans after absorbing a photon
- isomerization of retinal activates opsin

B&B Figure 13-11

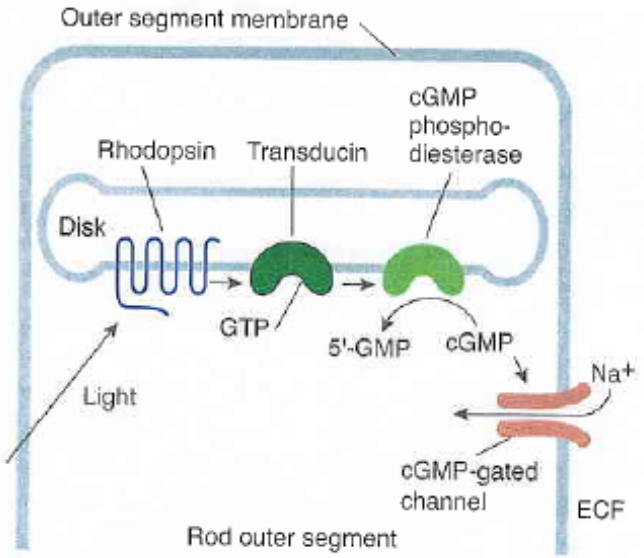


FIGURE 12–14 **Initial steps in phototransduction in rods.** Light activates rhodopsin, which activates transducin to bind GTP. This activates phosphodiesterase, which catalyzes the conversion of cGMP to 5'-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels to close.

darkness. The amount of rhodopsin in the receptors therefore varies inversely with the incident light level.

CONE PIGMENTS

Primates have three different kinds of cones. These receptors subserve color vision and respond maximally to light at wave-

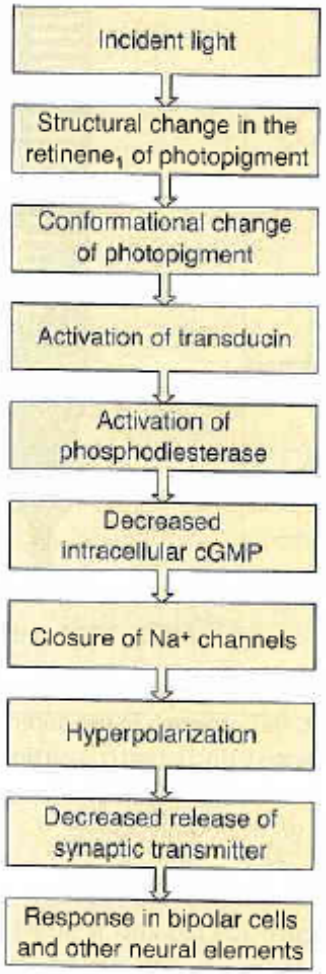
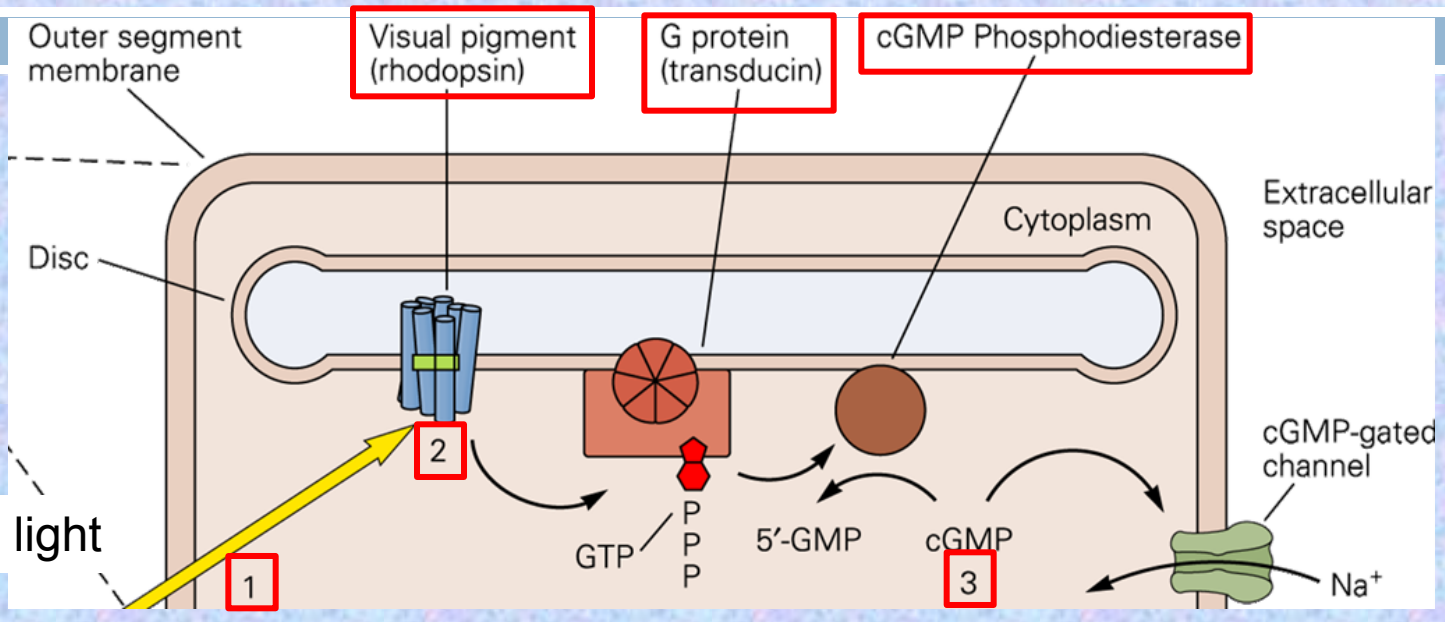


FIGURE 12–15 **Sequence of events involved in phototransduction in rods and cones.**

Phototransduction: mechanism



1. Absorption of a photon isomerizes retinal
   a) Converts opsin to metarhodopsin II
2. Metarodophsin II activates the G-protein transducin
   a) Activates cGMP phosphodiesterase (PDE)
3. PDE hydrolyzes cGMP to GMP
   a) Decreased [cGMP] closes cGMP gated cation channels
   b) Photoreceptor hyperpolarizes, less glutamate released

Phototransduction: termination

- Activated rhodopsin is a target for phosphorylation by rhodopsin kinase
  - Phosphorylated rhodopsin inactivated by cytosolic protein arrestin
- All-trans retinal transported to the pigment epithelium where it is converted back to 11-cis retinal, and recycled back to the rod
- Activated transducin inactivates itself by hydrolyzing GTP to GDP

Phototransduction: light adaptation

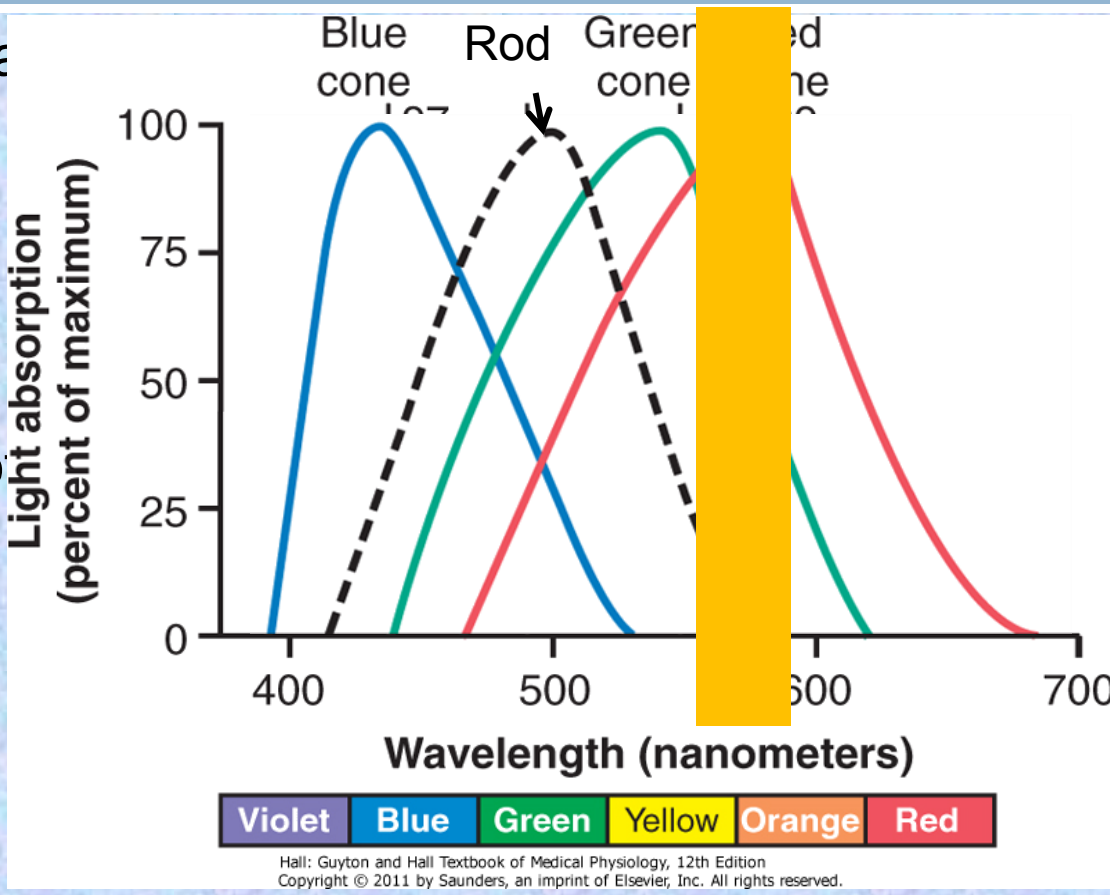
Eyes adapt to increased light intensity and remain sensitive to further changes in light

- Optic adaptation:
  - Constriction of pupils to allow in less light
- Photoreceptor adaptation:
  - The closure of cGMP gated channel reduces inward flux of Ca^{2+} →decreased $[Ca^{2+}]_i$
  - Ca^{2+} induced inhibition of guanylyl cyclase removed
    - More cGMP made → reopening of some cGMP gated channels → influx of cations → slight depolarization

Photoreceptor can once again be stimulated (hyperpolarized) by photons

Colour Vision

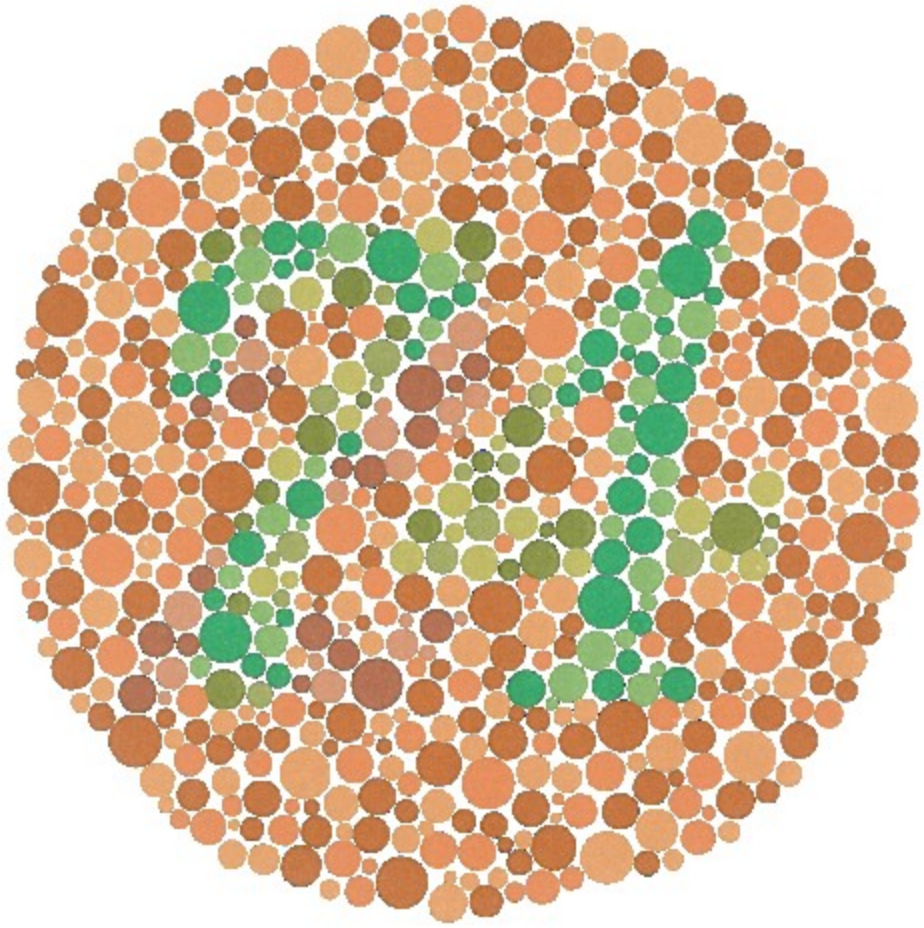
- 3 types of cones, each conta photopigment with different absorption spectra
  - 420 nm – blue
  - 530 nm – green
  - 560 nm - red
- Colour interpreted by ratio o cone stimulation
  - Orange (580nm) light stimulates:
    - Blue cone – 0%
    - Green cone – 42%
    - Red cone – 99%
  - 0:42:99 ratio of cone stimulation interpreted by brain as orange



Guyton Figure 50-8

Colour Vision: Disorders

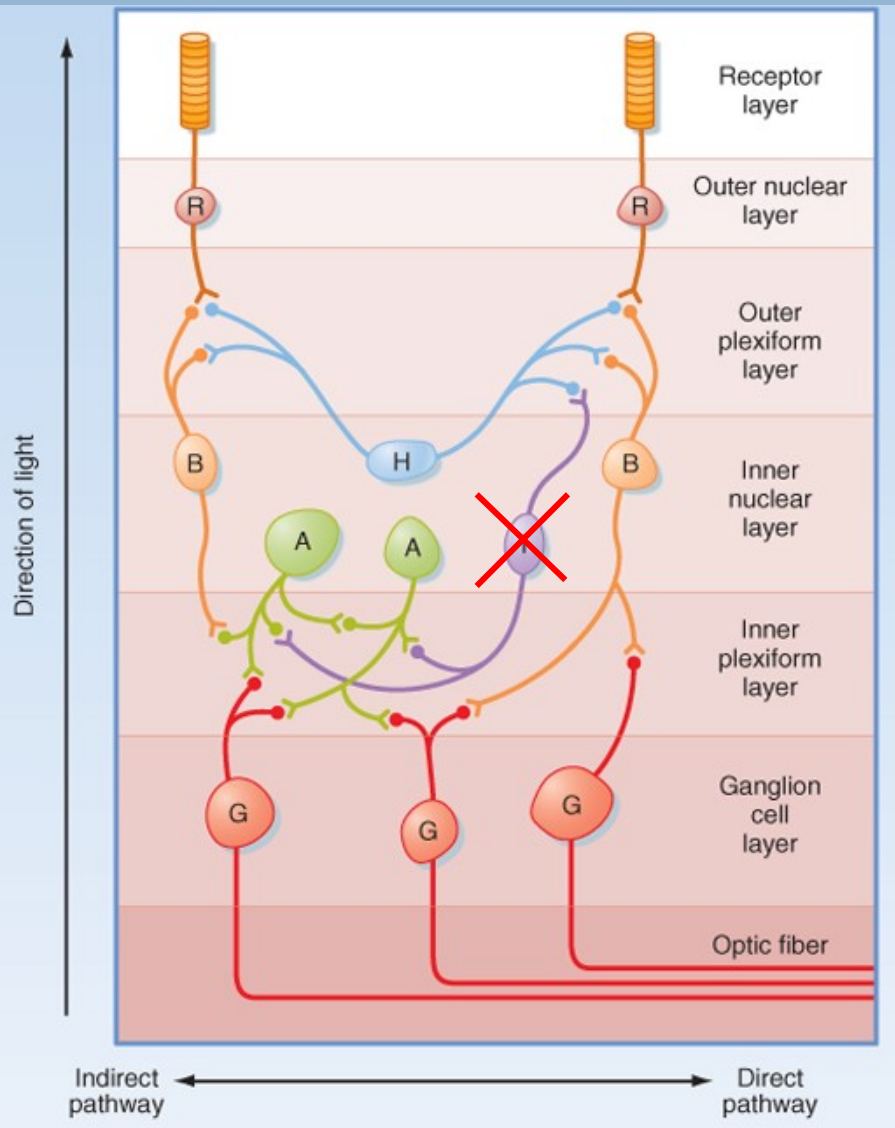
- Malfunction of one group cones leads to colour blindness
- Most common form is red green colour blindness
  - Either red or green con are missing
  - Difficulty distinguishing from green because the colour spectra overlap (of cone stimulation is affected → impaired ne interpretation of colours




NORMAL VISION
DEUTERANOMALY
PROTANOPIA
TRITANOPIA

Retinal circuitry: review of cell types

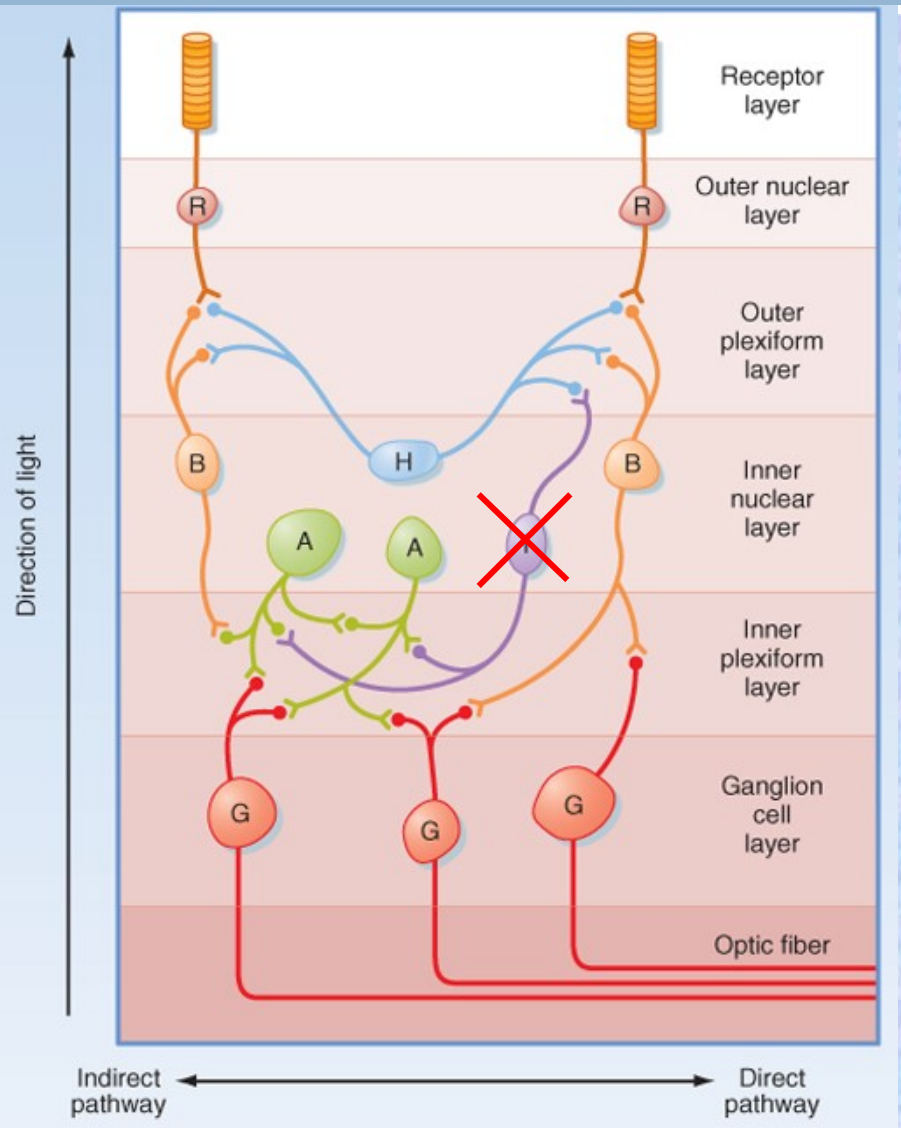
- **rods and cones** synapse on bipolar cells and horizontal cells
- **horizontal cells** make lateral inhibitory synapses with surrounding bipolar cells or photoreceptors
- **bipolar cells** make synaptic connections with ganglion cells and amacrine cells
- **amacrine cells** transmit signals from bipolar cells to ganglion cells or to other amacrine cells
- **ganglion cells** transmit action potentials to the brain via the optic nerve



B&L Figure 8-7

Retinal circuitry: key features

- 2 types of bipolar cells
  - On center: hyperpolarized by glutamate
  - Off center: depolarized by glutamate
- Bipolar and horizontal cells play a role in lateral inhibition
  - Important for increasing visual contrast
  - Set up "surround" arrangement of ganglion cell receptive fields



B&L Figure 8-7

Receptive fields

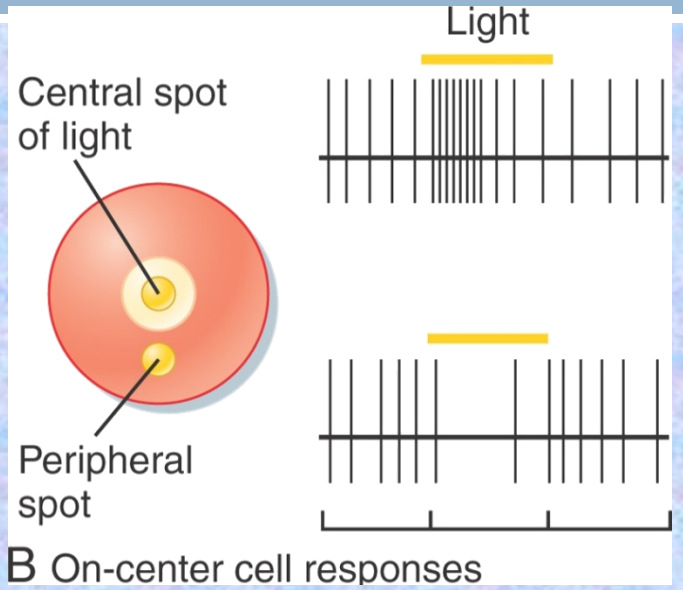
- **Photoreceptor** receptive fields include retinal area that, when stimulated by light, results in hyperpolarization of individual photoreceptor
  - Small and circular
- **Ganglion cell** receptive field *size* determined by
  - ganglion cell type
  - degree of convergence of photoreceptors and bipolar cells

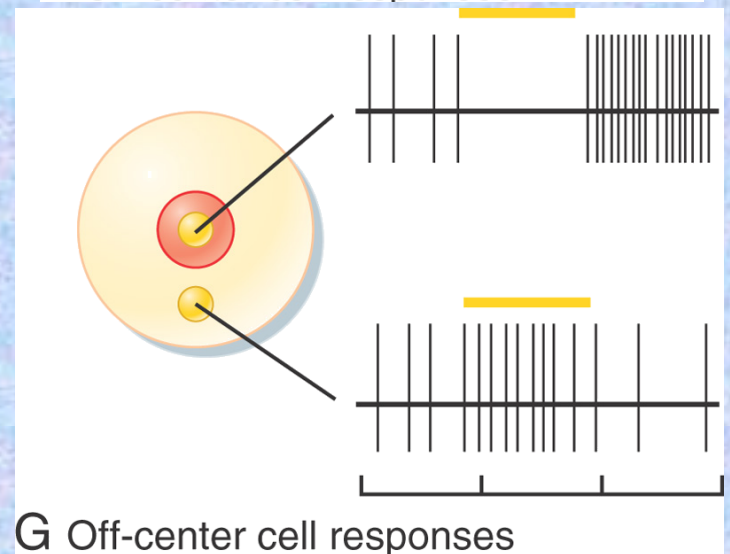
  and field *type* by retinal circuitry (lateral inhibition)
    - On-center/off-surround
    - Off-center/on-surround

Where in the retina is there is there a high degree of convergence?

Receptive fields

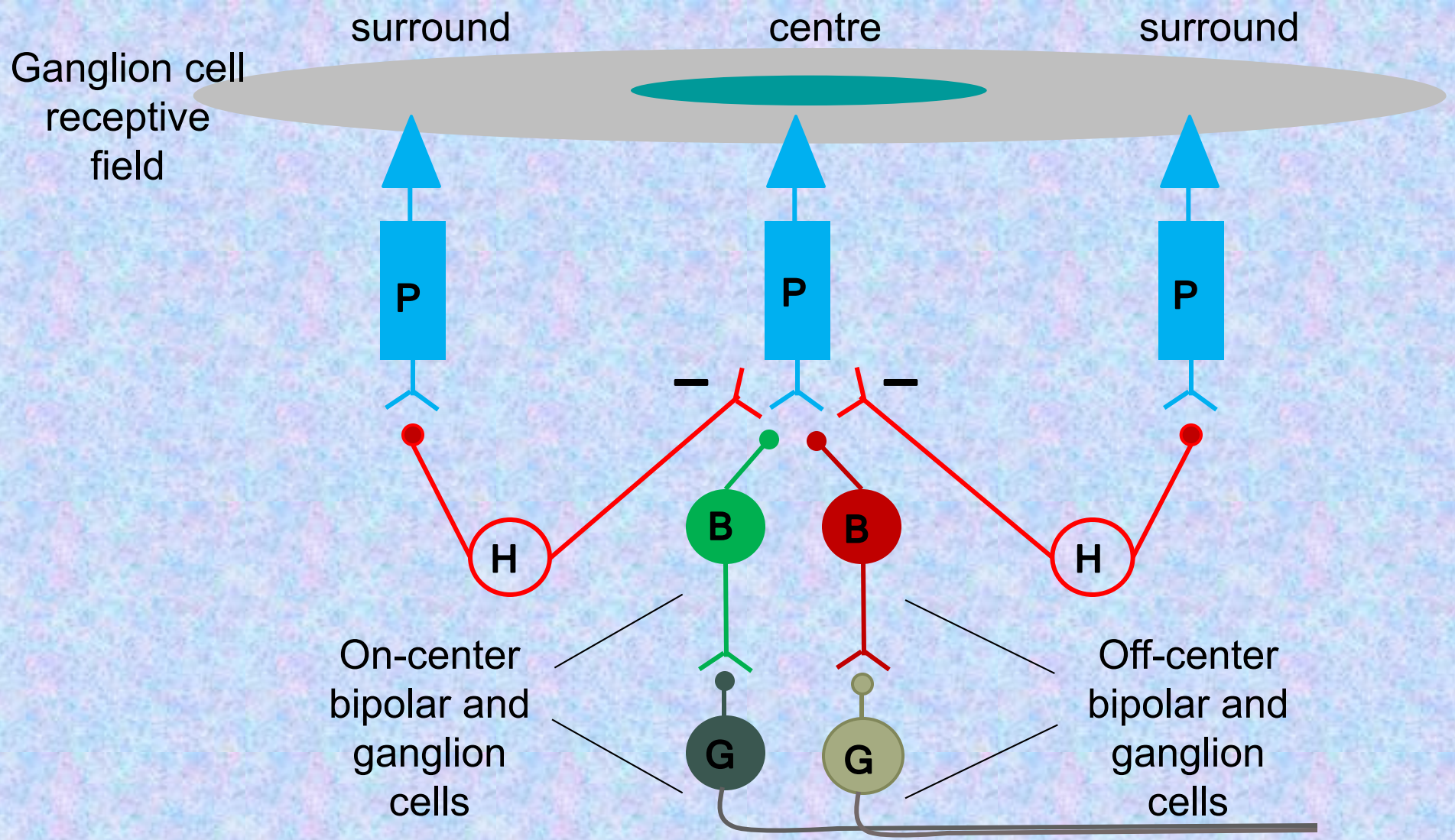
- On-center/off-surround
  - Light shines on center of ganglion cell receptive field → ganglion cell increases AP firing
  - Light on surround region → decreased AP firing
- Off-center/on-surround
  - Light on center → decreased AP firing
  - Light on surround → increased AP firing





B&L Figure 8-8

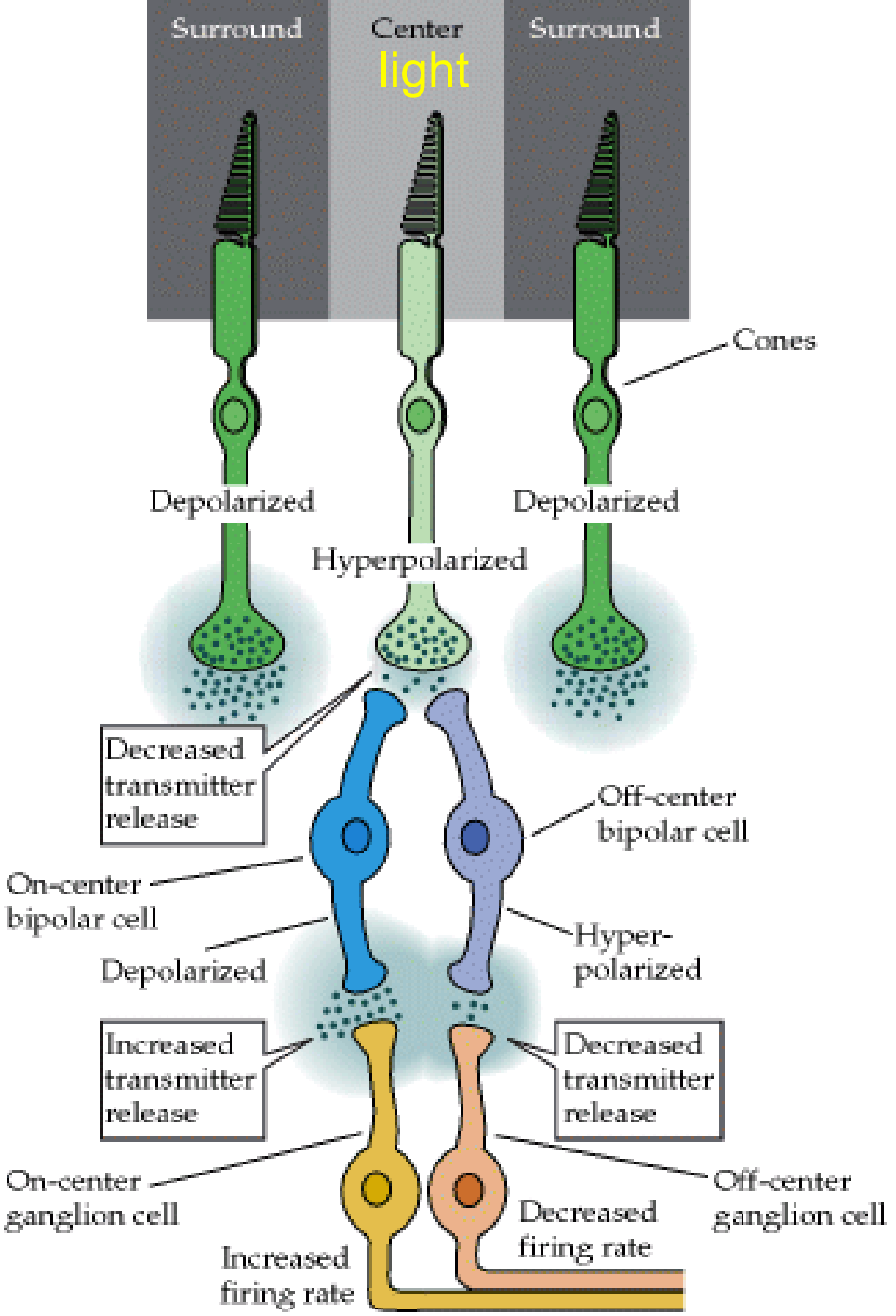
Neural circuits of retinal receptive fields



Neural Circuits of R Receptive Fields

Light stimulus on center:

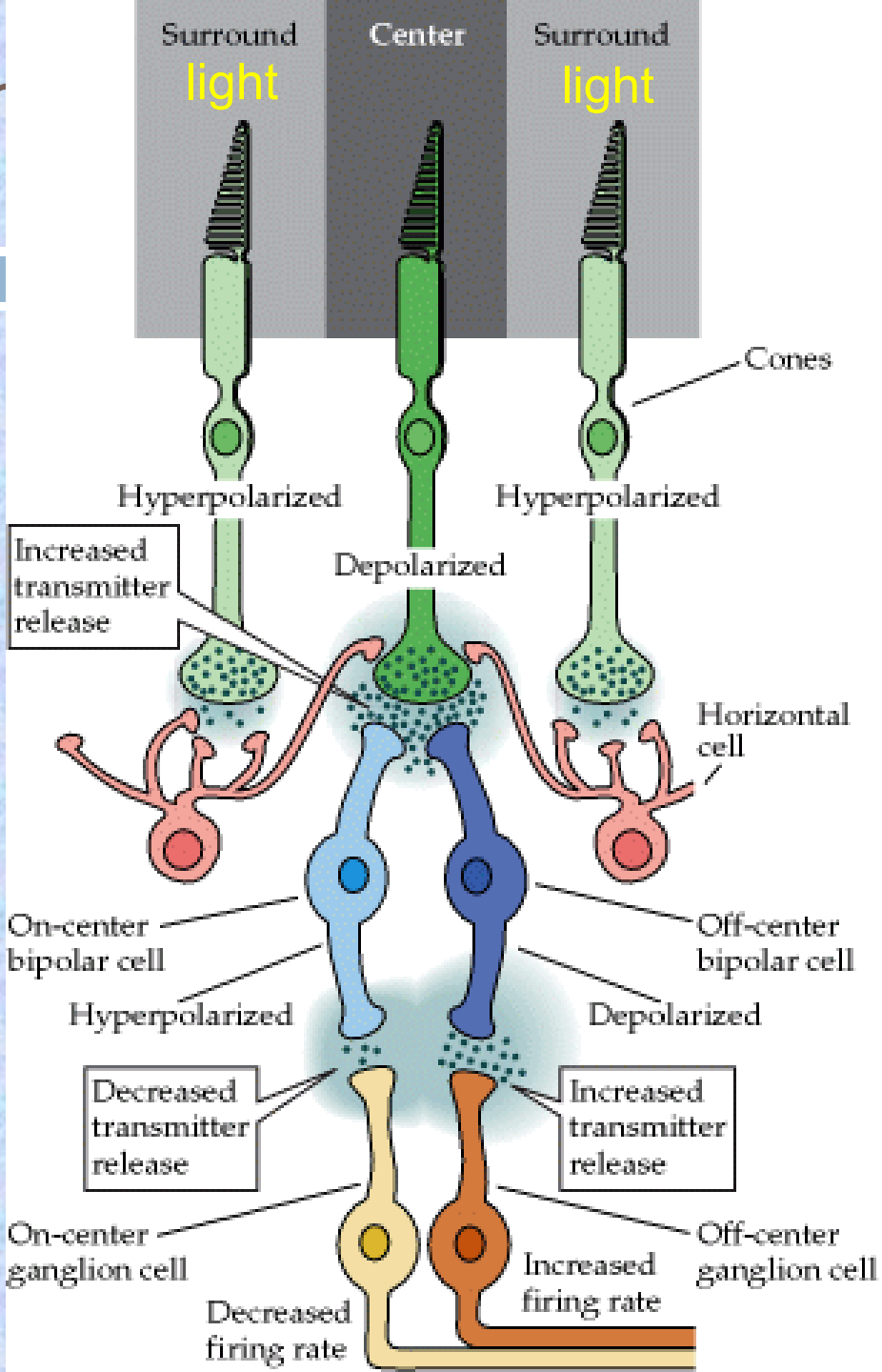
- ↓ glu release from central photoreceptor
  - ↓ inhibition of on-center bipolar cell → depolarization
    - ↑ NT release → <u>on-center ganglion cell excited</u>
  - less glu available to excite off-centre bipolar cell → hyperpolarization
    - ↓NT release→ <u>off-center ganglion cell inhibited</u>



Neural Circuits of Retir Receptive Fields

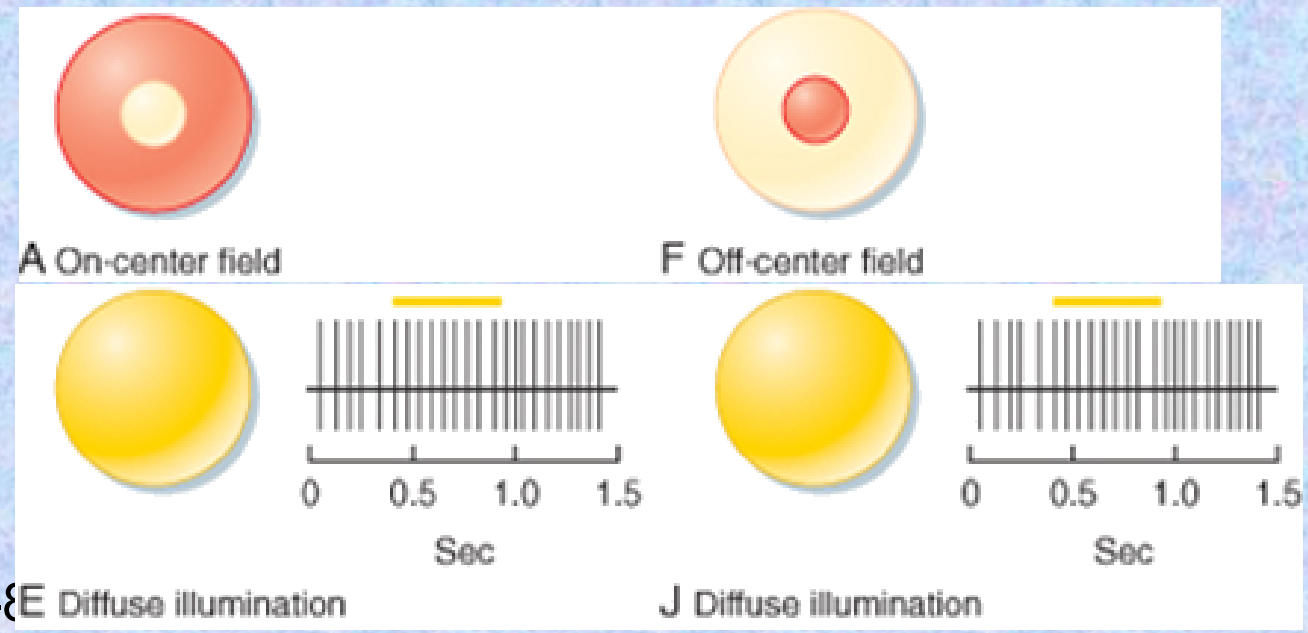
Light stimulus on surround:

- ↓ glu release from surround photoreceptor
  - ↓ excitation of horizontal cells → ↓ inhibitory NT released
    - ↓ inhibition of central photoreceptor → ↑ glu released
    - ↑ glu hyperpolarizes on-center bipolar cell and depolarizes off-center bipolar cell
    - <u>On-center ganglion cell inhibited</u>, <u>off-center ganglion cell excited</u>



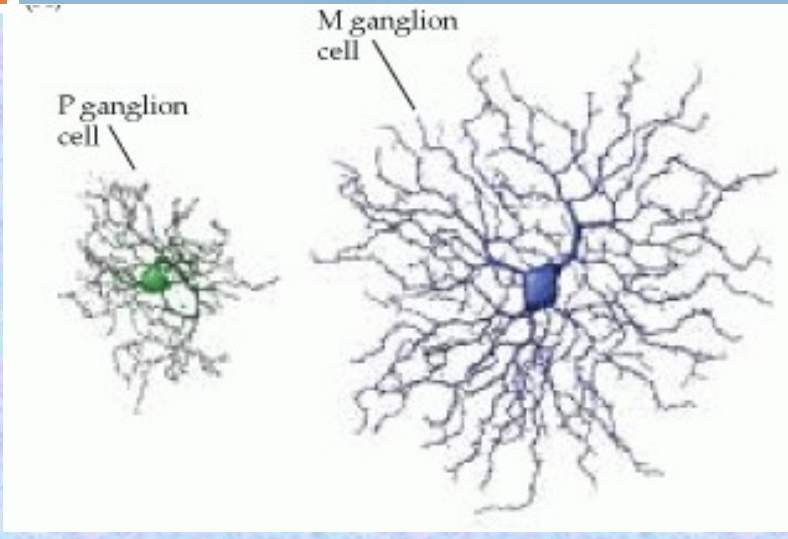
Retinal receptive fields: outcome

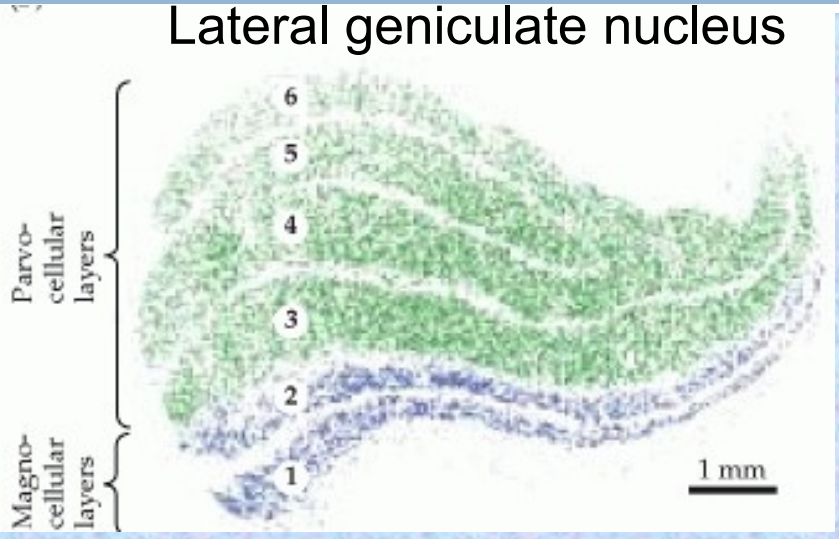
- Surround arrangement and lateral inhibition allows ganglion cells to respond best to contrast borders in a visual scene
  - Ex. Reading dark letters against a white background
  - Respond only weakly to diffuse illumination



B&L Figure 8-8

Ganglion cell types and projections





- **P cells**
  - Project to parvocellular layer of LGN
  - Tonic firing, small surround receptive fields,
  - Important for colour detection, form and detail of visual image
- **M cells**
  - Project to magnocellular layer of LGN
  - Transient activity, large surround receptive fields
  - Convey information about illumination and movement
- **W cells**
  - Resemble M cells, large diffuse receptive fields
  - Function is less clear

Visual pathway

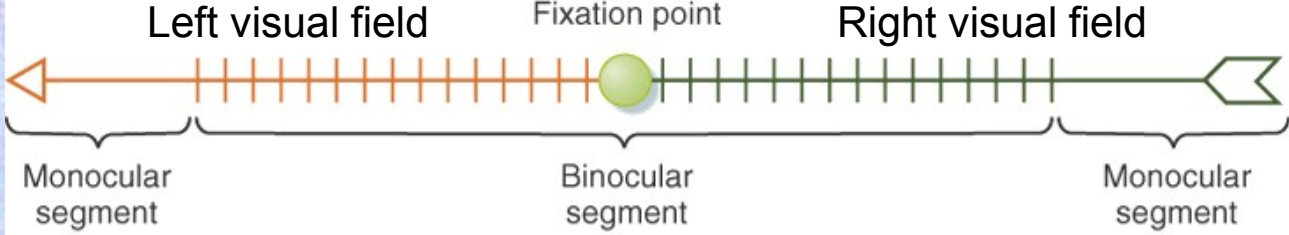
- Light from **binocular zone** strikes retina in both eyes
- **Monocular zone** only strikes retina on same side as light

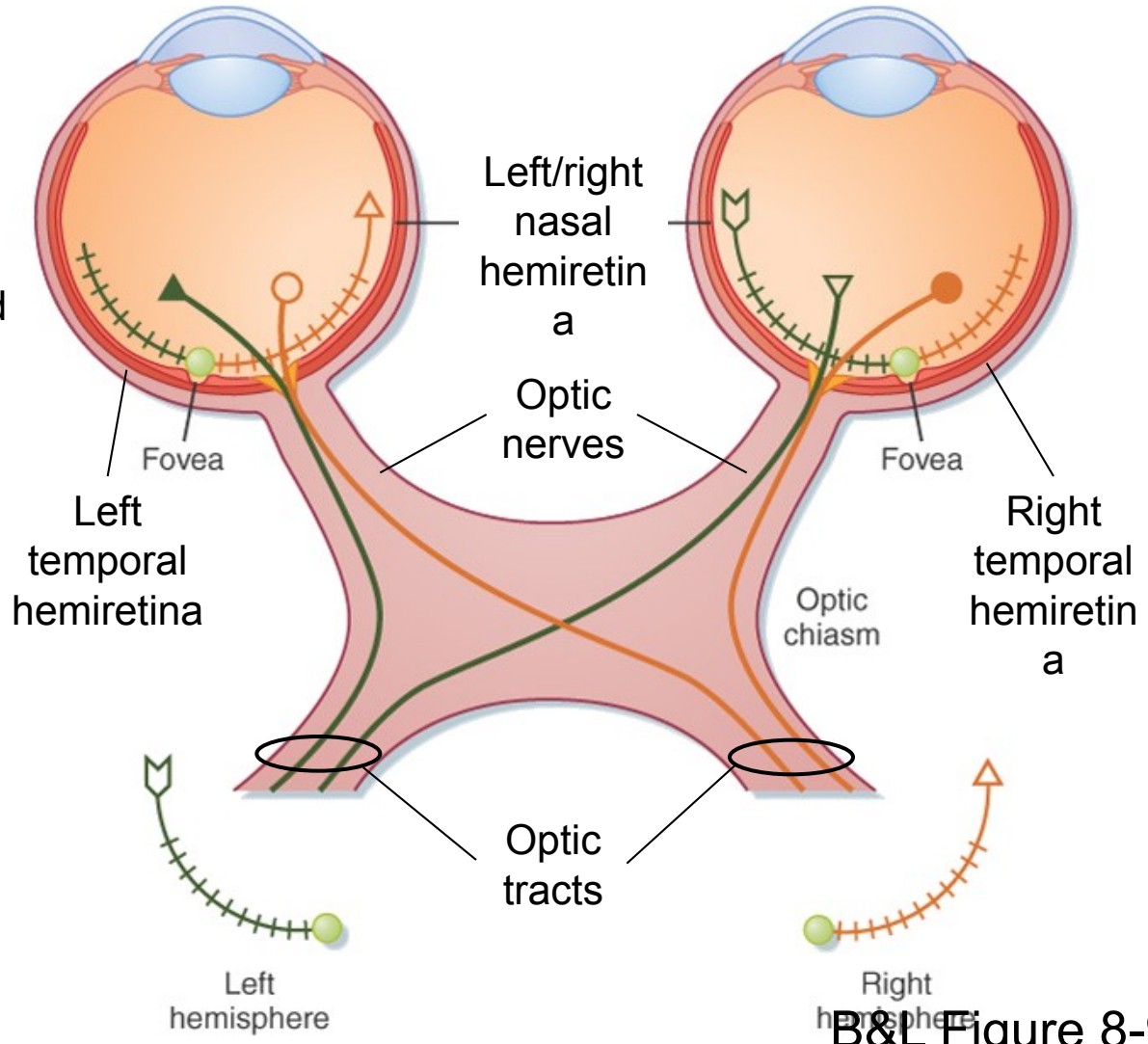
The right visual field is projected to the _____ and _____ hemiretina

The **optic nerves** segregate and carry information from _____

Each _____ crosses at the **optic chiasm**

The **optic tracts** carry information from _____ to the brain





B&L Figure 8-9

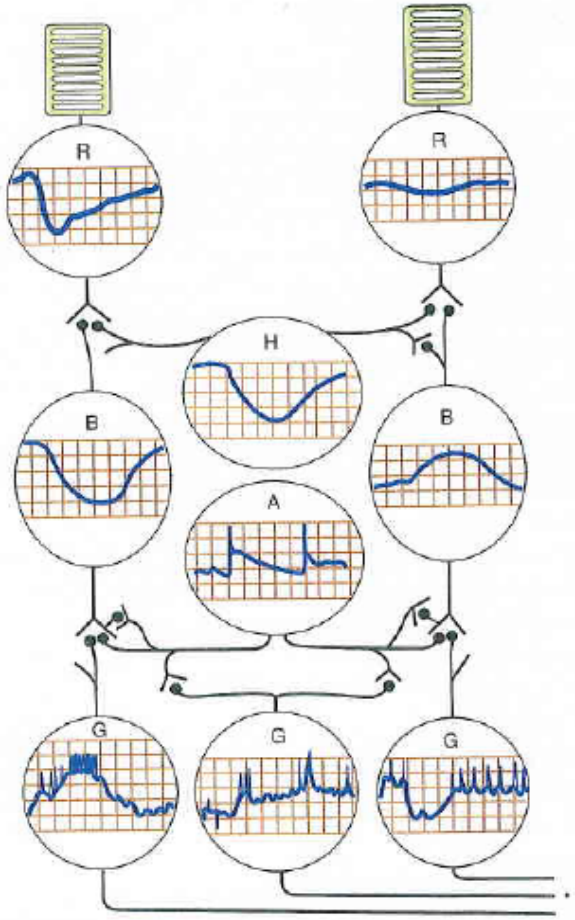
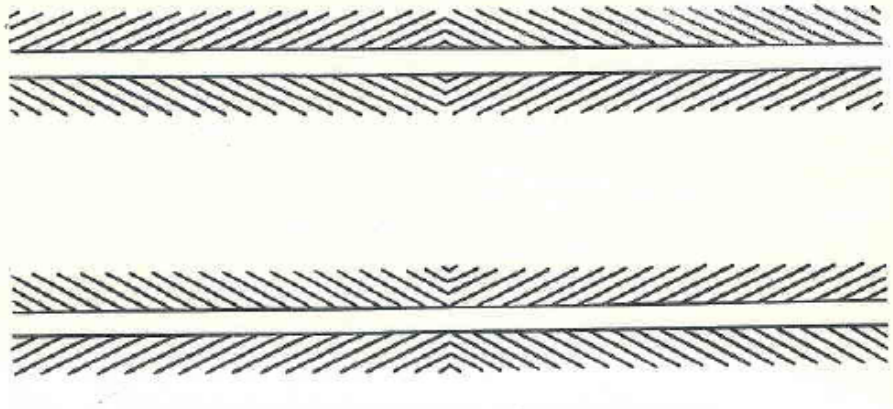
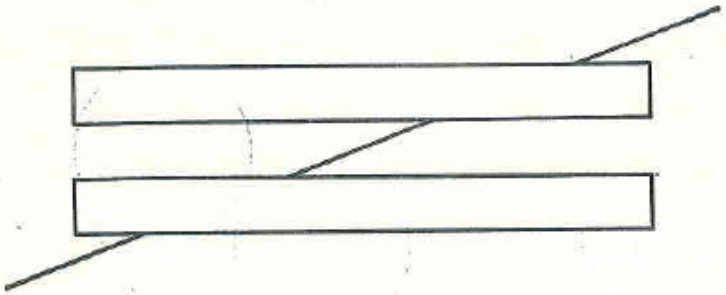


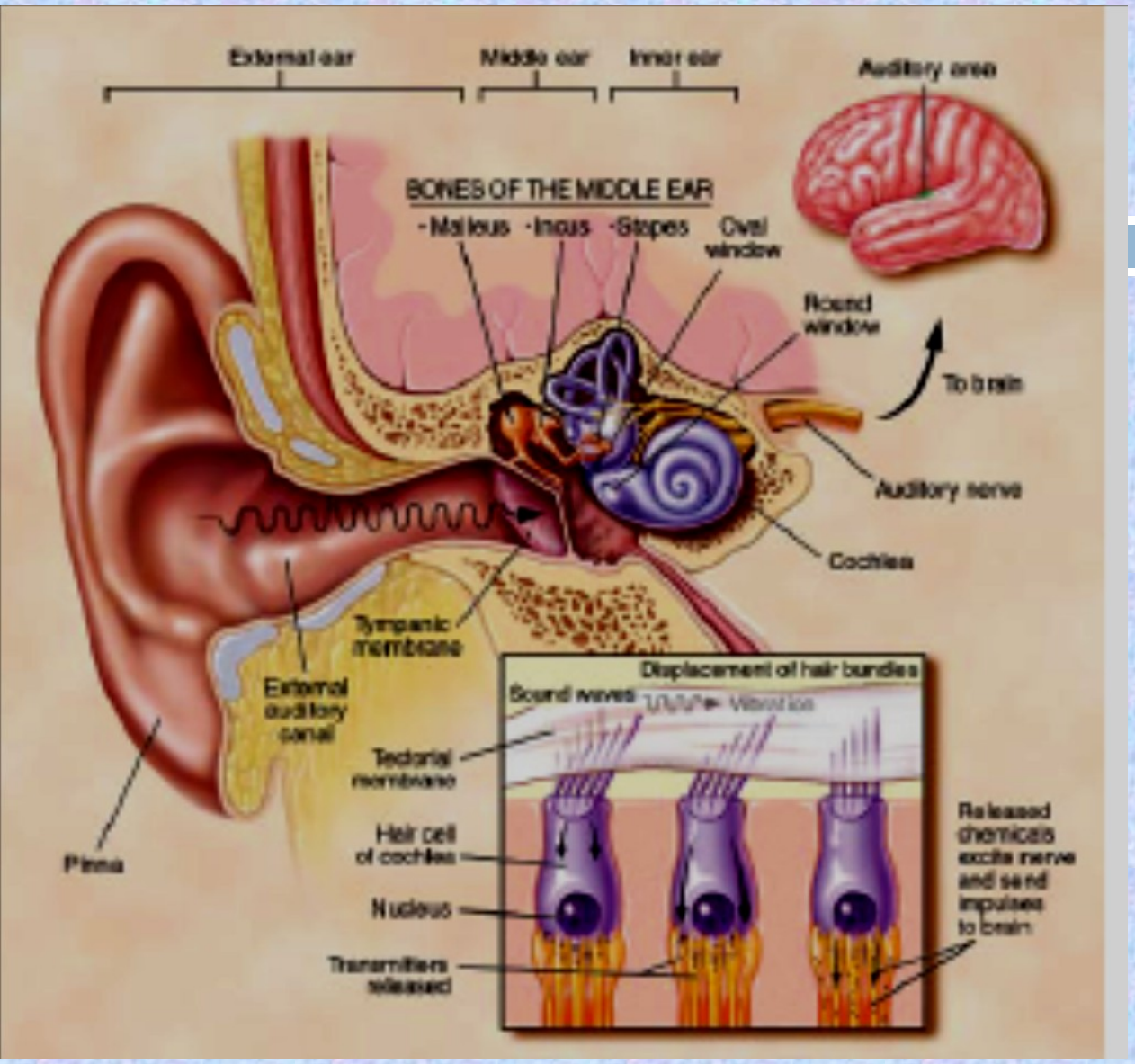
FIGURE 12–11 **Intracellularly recorded responses of cells in the retina to light.** The synaptic connections of the cells are also indicated. The eye is unique in that the receptor potentials of the photoreceptors and the electrical responses of most of the other neural elements in the retina are local, graded potentials. The rod (R) on the left is receiving a light flash, whereas the rod on the right is receiving steady, low-intensity illumination. The responses of rods and horizontal cells (H) are hyperpolarizing, responses of bipolar cells (B) are either hyperpolarizing or depolarizing, and amacrine (A) cells produce depolarizing potentials and spikes that may act as generator potentials for propagated spikes of ganglion cells (G). (Reproduced with permission from

Optical illusion



Obr. 712. Heringova modifikace Zöllnerovy figury.
Dlouhé rovnoběžky se zdají sbíhat ke středu nebo k okraji. Tento klam je podmíněn drobnými pohyby očí, které jsou strhovány šikmými úsečkami.

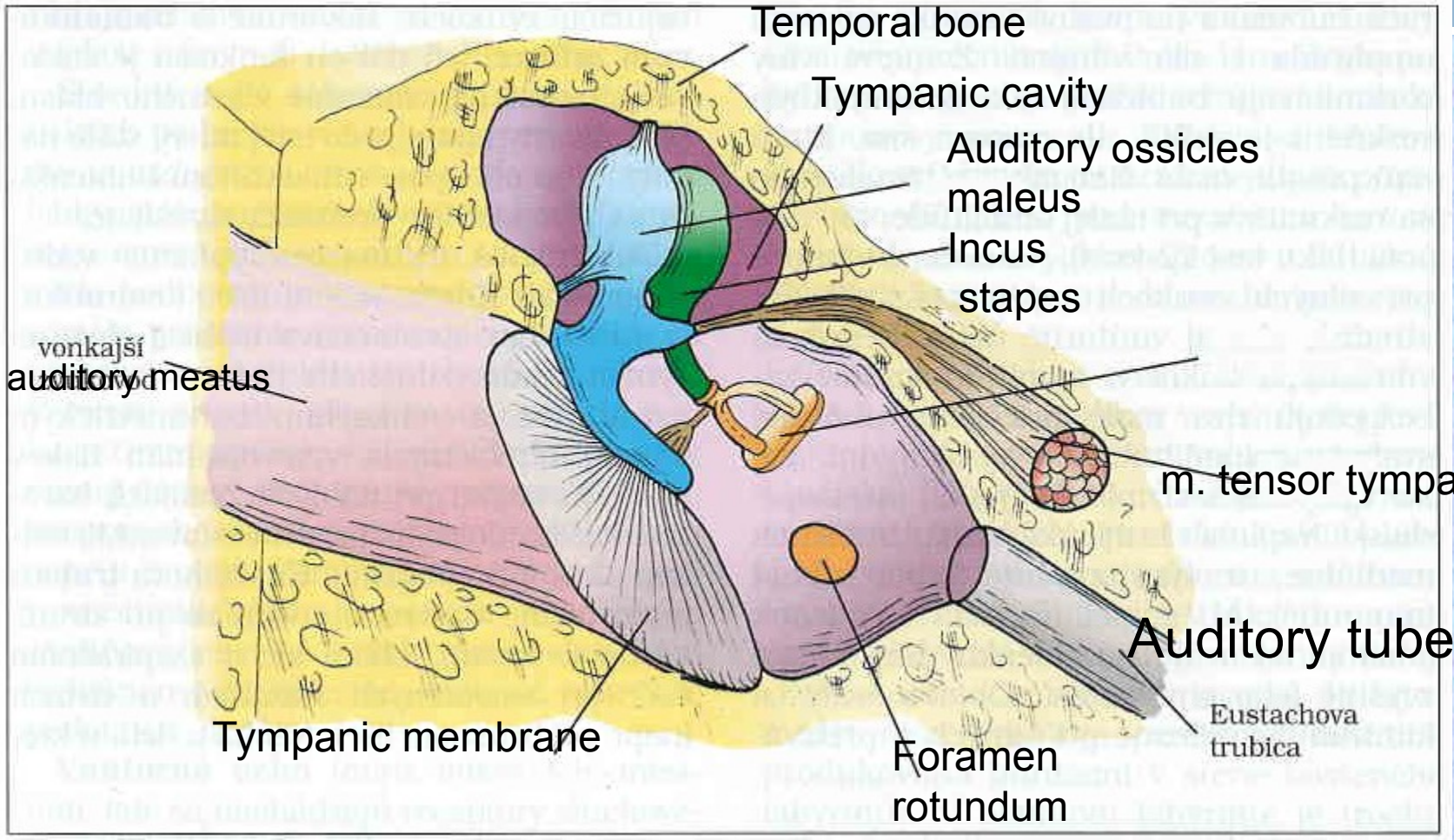




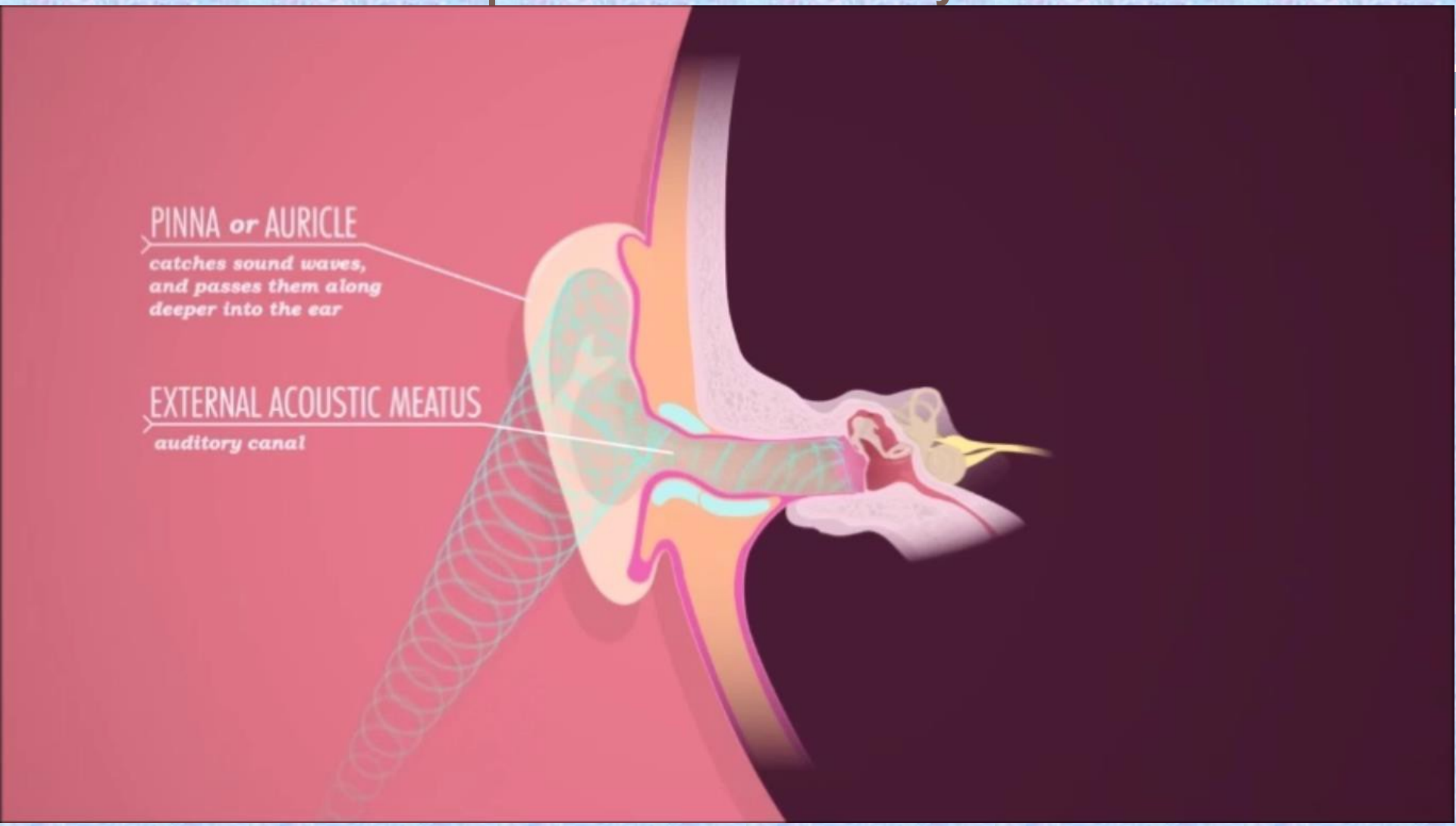
At the **AUDITORY system** is an array of miniature acoustical detectors packed into a space **no larger than a pea.**

These detectors can faithfully transduce vibrations as small as the diameter of an atom, and they can respond a **thousand times faster** than visual photoreceptors

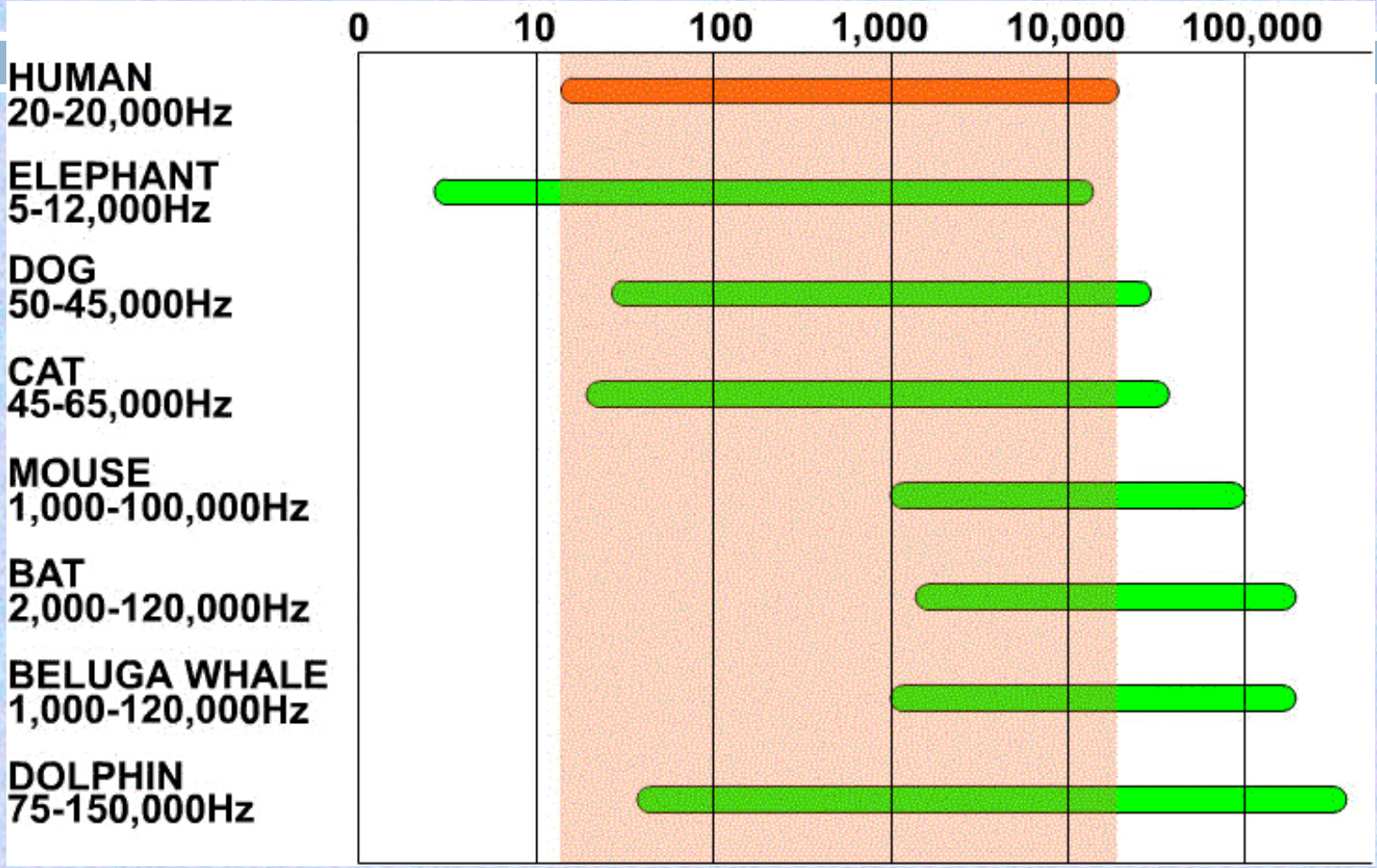
Outer ear / middle ear



Middle ear – transport acustic stimuli by air



The Audible Spectrum



Middle ear: Impedance Matching

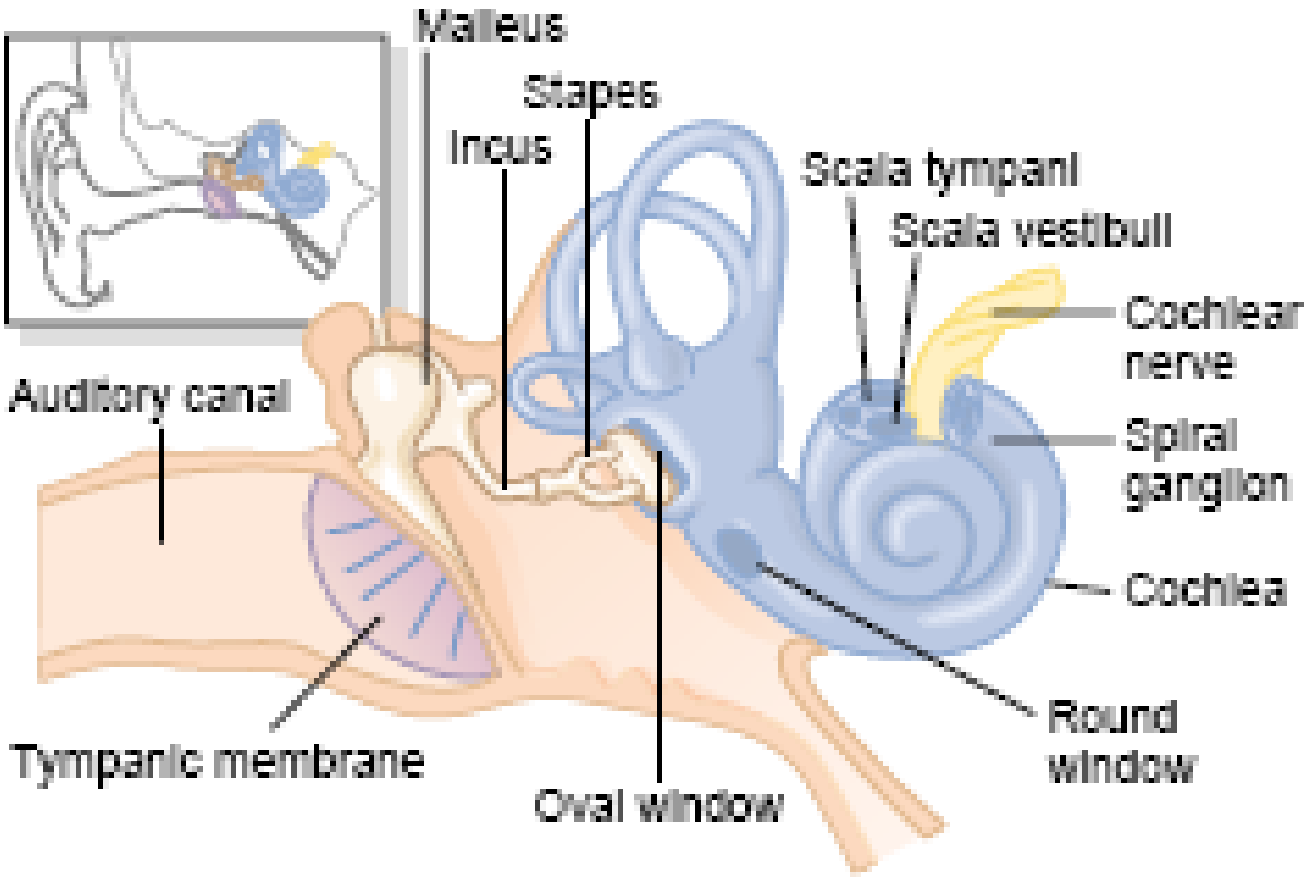


Figure 52–1

Tympanic membrane, ossicular system of the middle ear, and inner ear.

Transmission of Sound Waves in the Coc

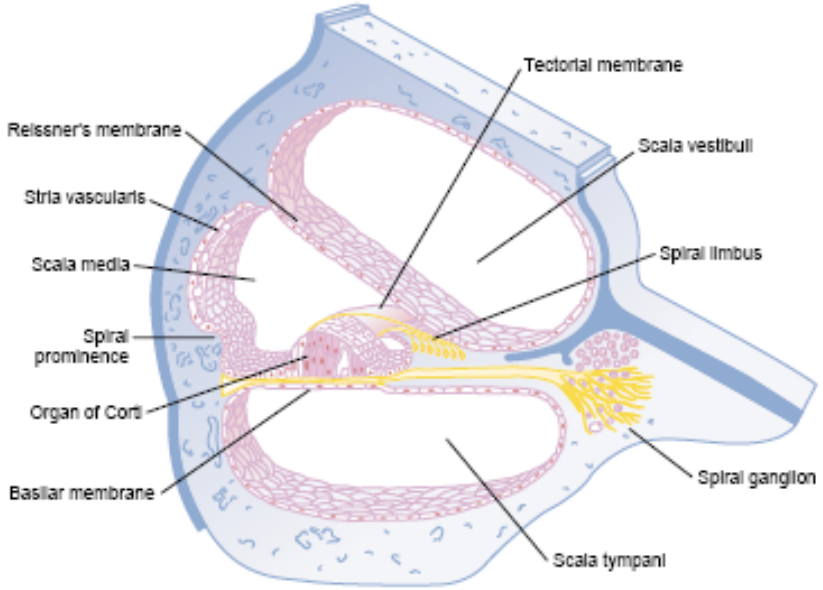


Figure 52–3

Section through one of the turns of the cochlea. (Drawn by Sylvia Colard Keene. From Fawcett DW: Bloom & Fawcett: A Textbook of Histology, 11th ed. Philadelphia: WB Saunders, 1986.)

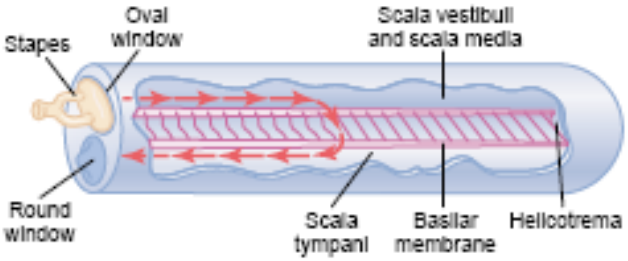


Figure 52–4

Movement of fluid in the cochlea after forward thrust of the stapes.

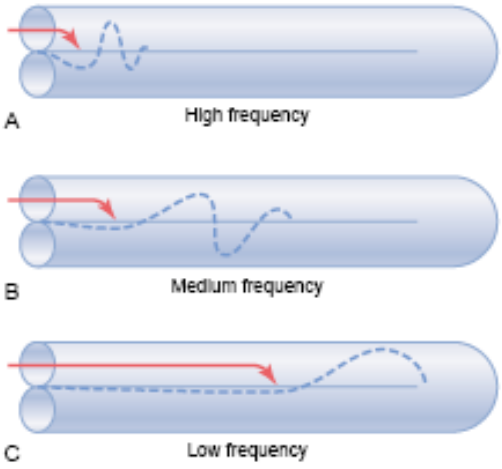
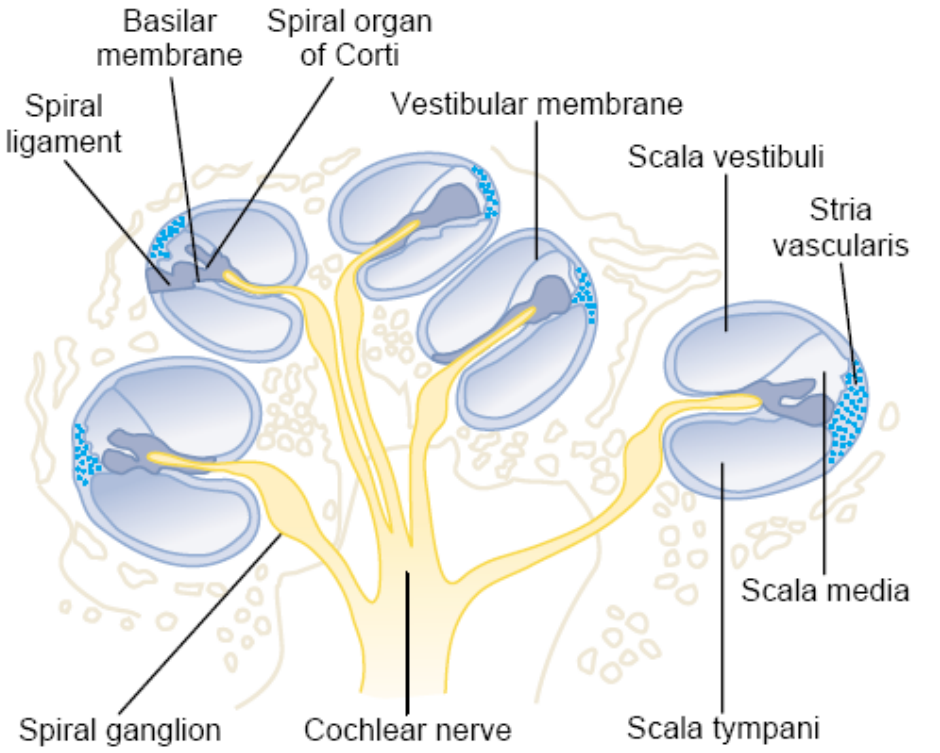


Figure 52–5

"Traveling waves" along the basilar membrane for high-, medium-, and low-frequency sounds.

The Organ of Corti



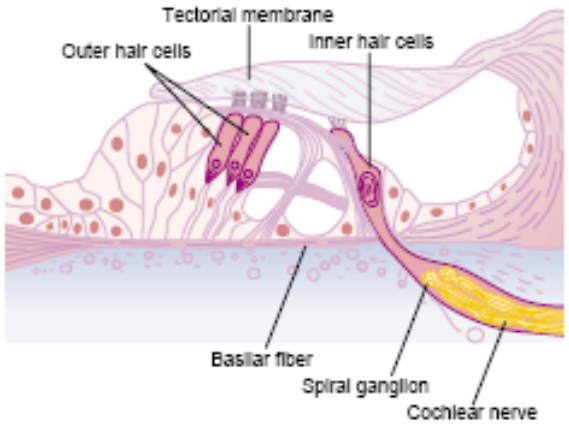


Figure 52–7

Organ of Corti, showing especially the hair cells and the tectorial membrane pressing against the projecting hairs.

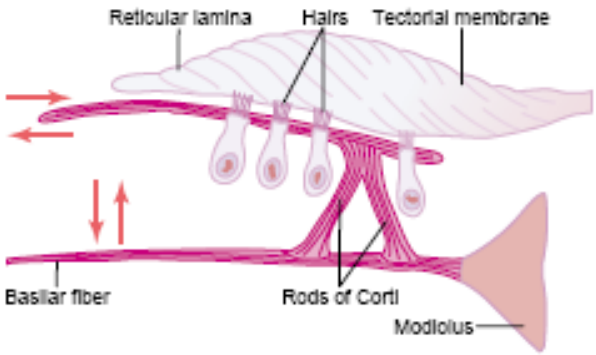
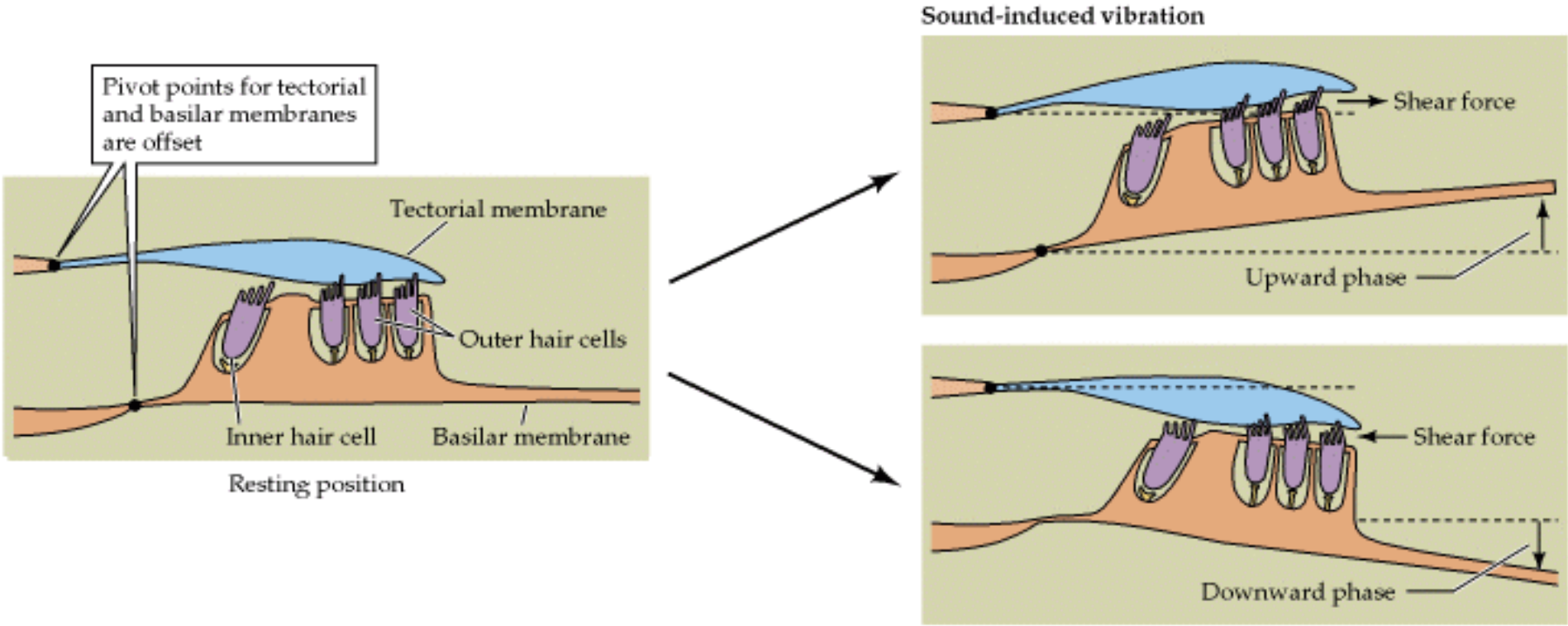


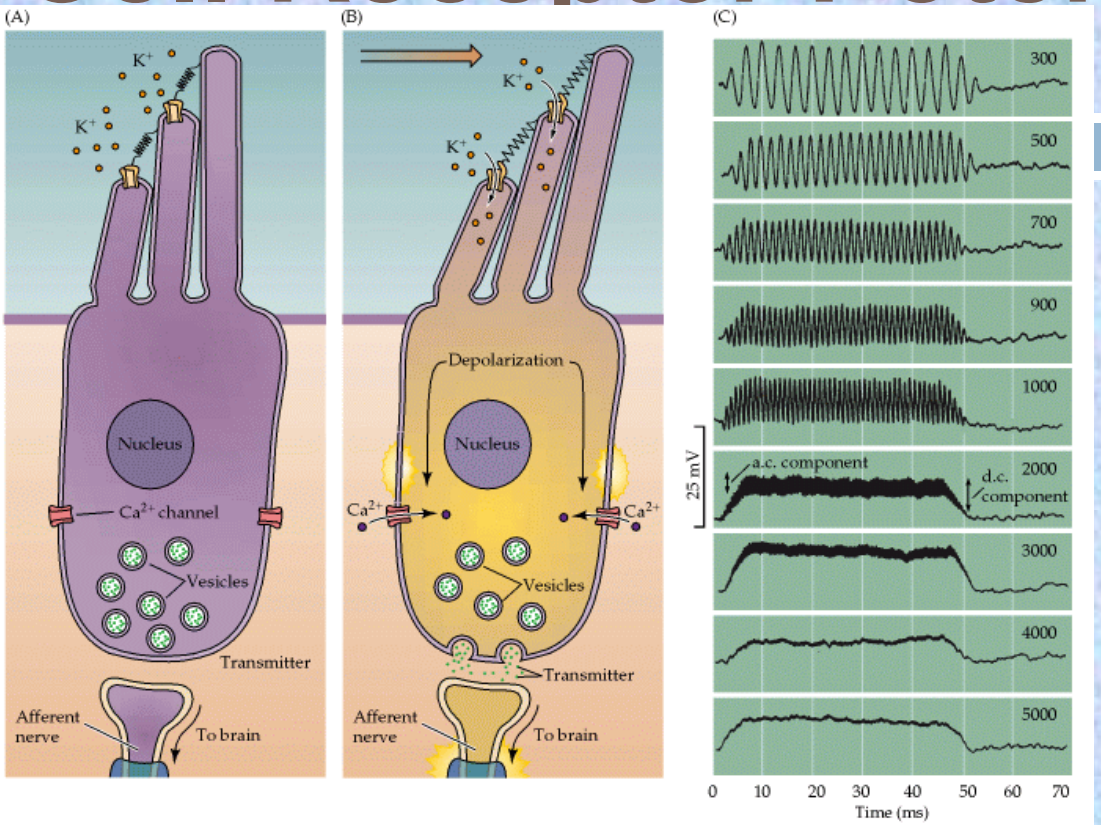
Figure 52–8

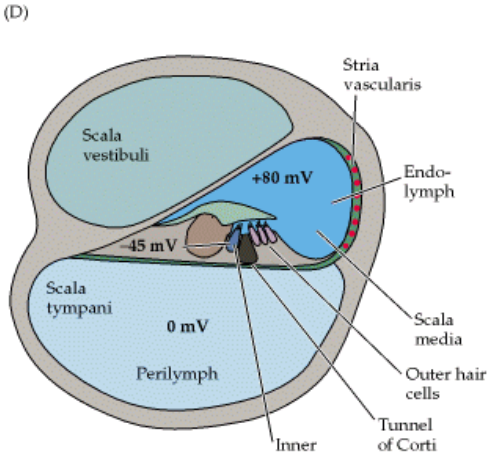
Stimulation of the hair cells by to-and-fro movement of the hairs projecting into the gel coating of the tectorial membrane.

Excitation of the Hair Cells

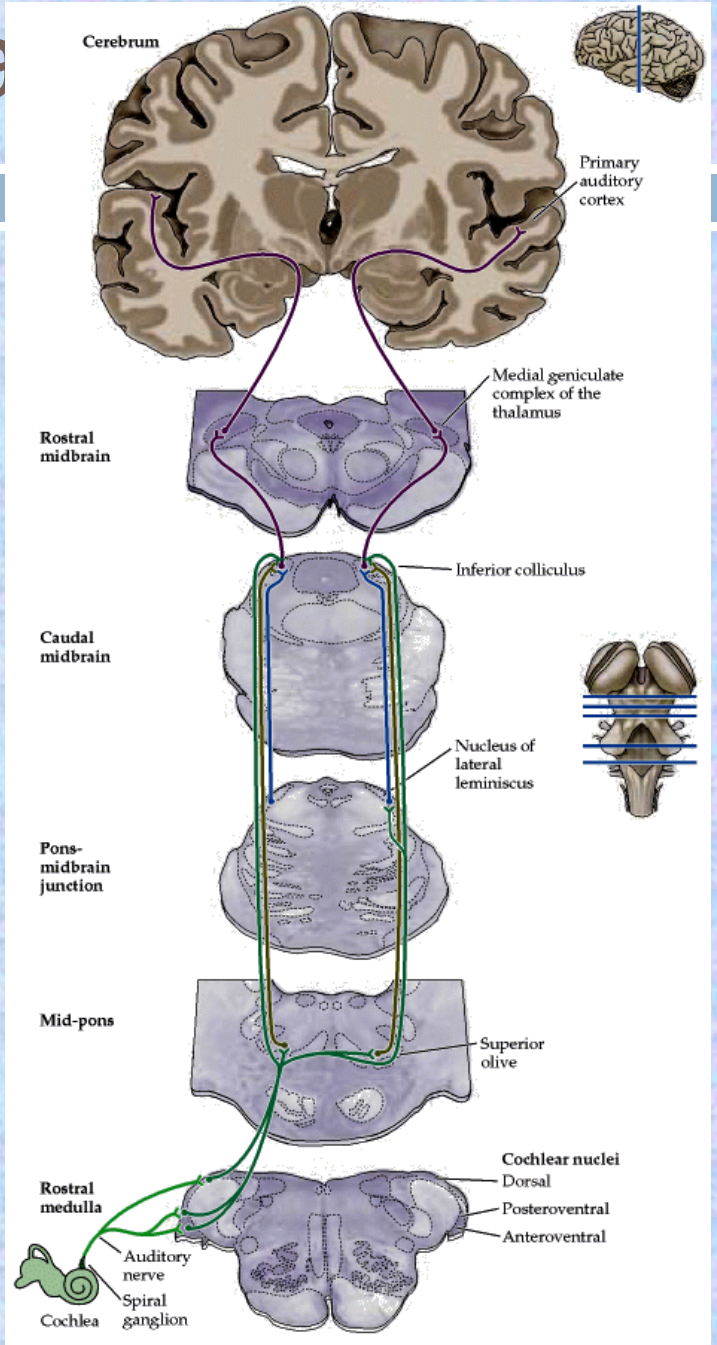


Hair Cell Receptor Potentials

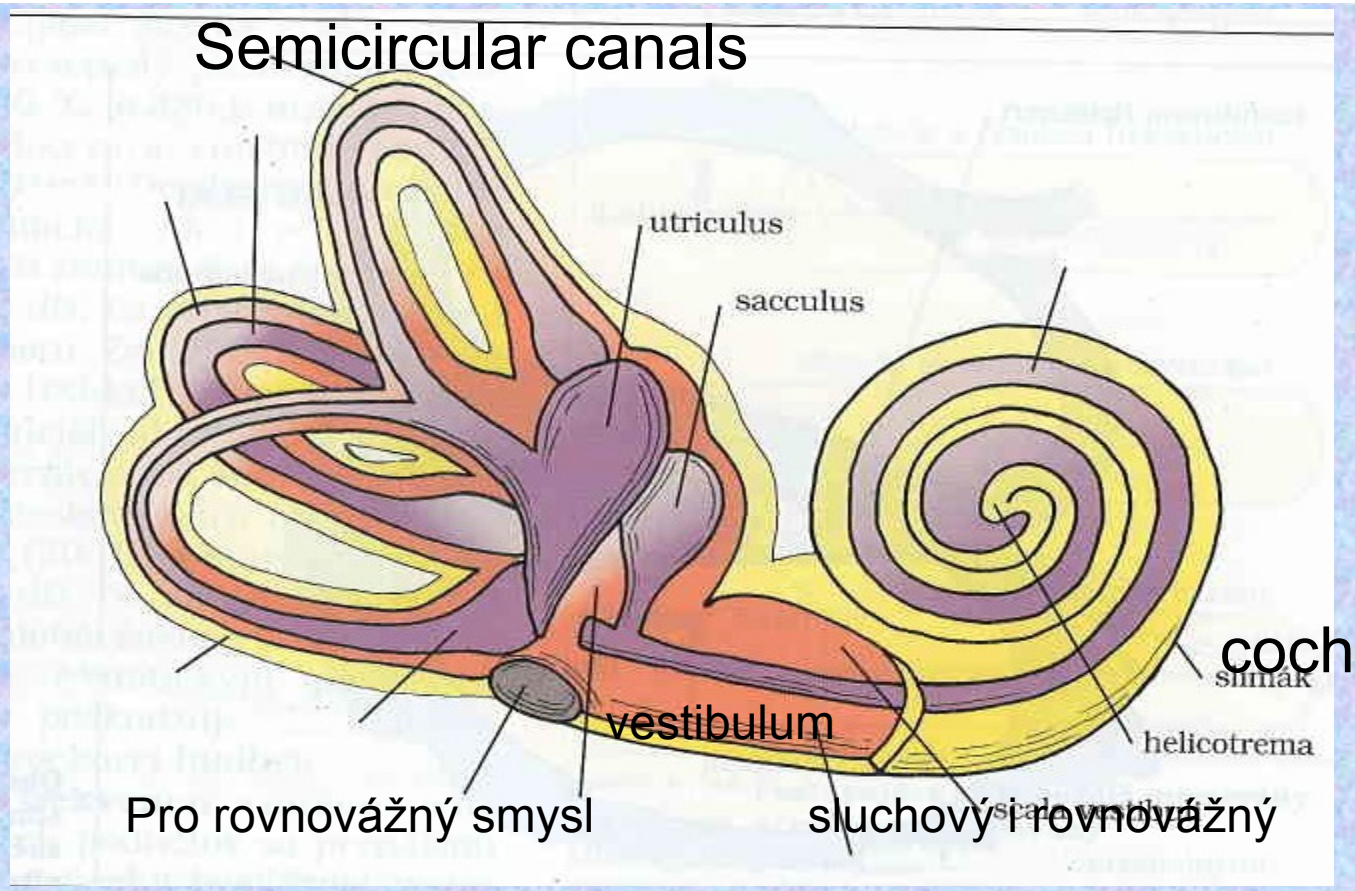


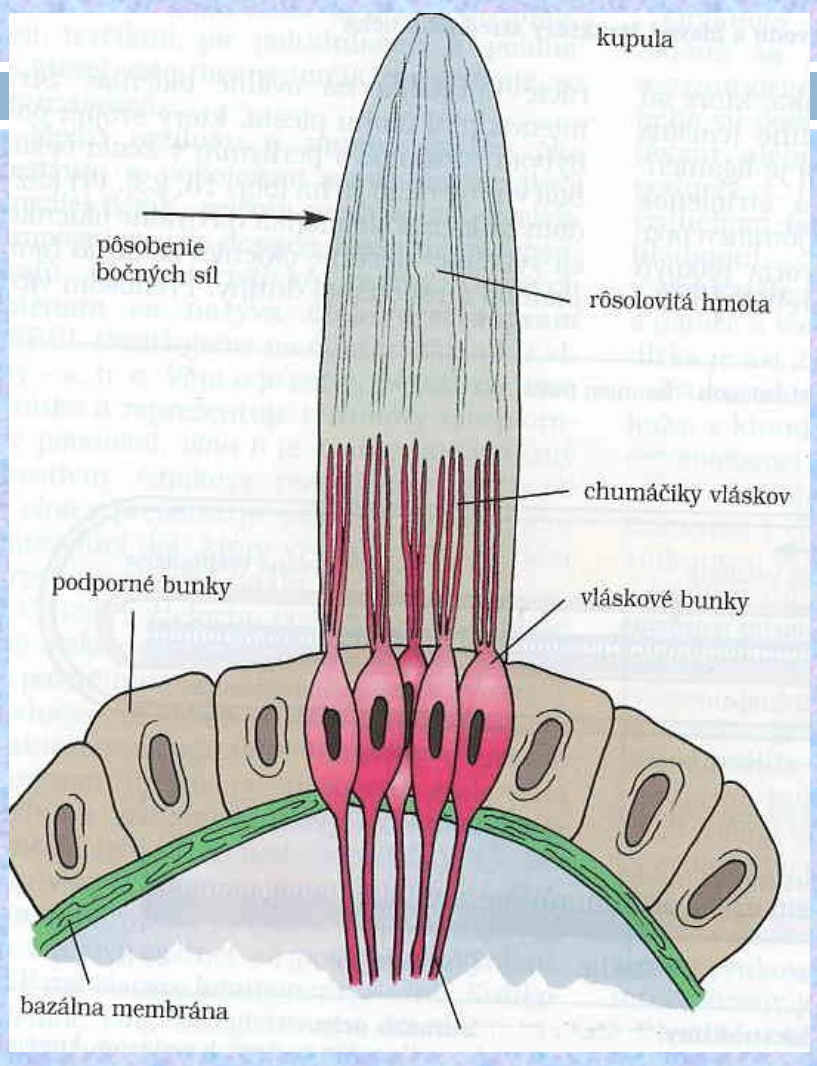


Auditory Pathwa

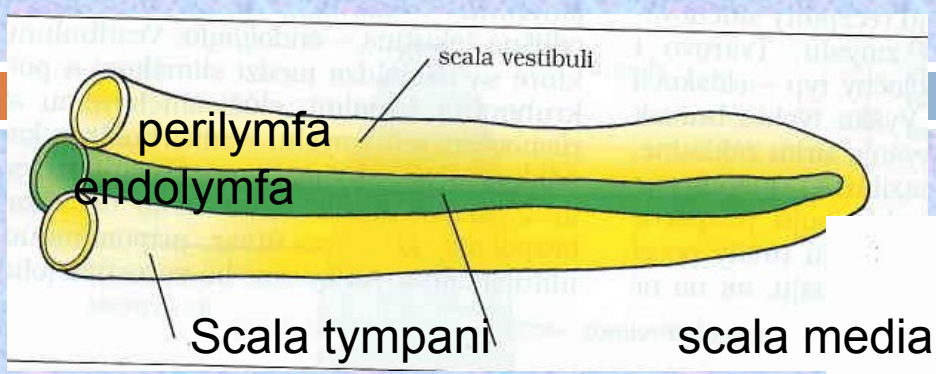


Inner ear

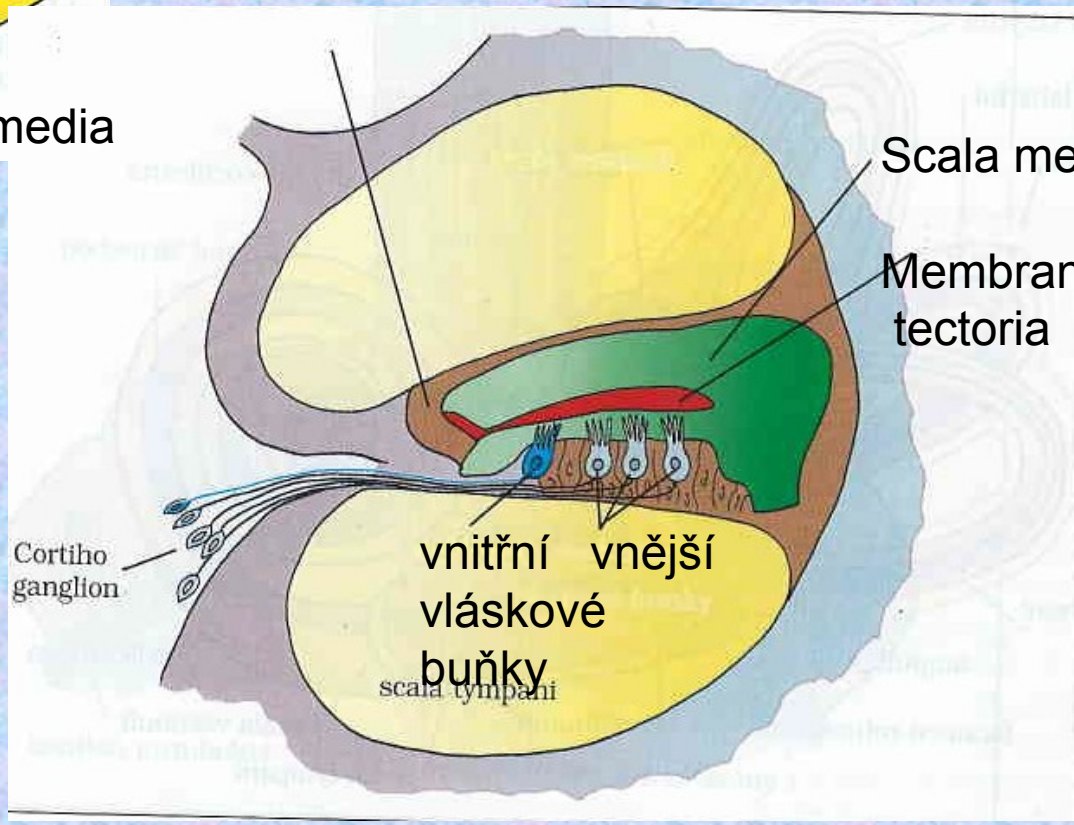

Semicircular canals
utriculus
sacculus
cochlea
helicotrema
vestibulum
Pro rovnovážný smysl
sluchový i rovnovážný



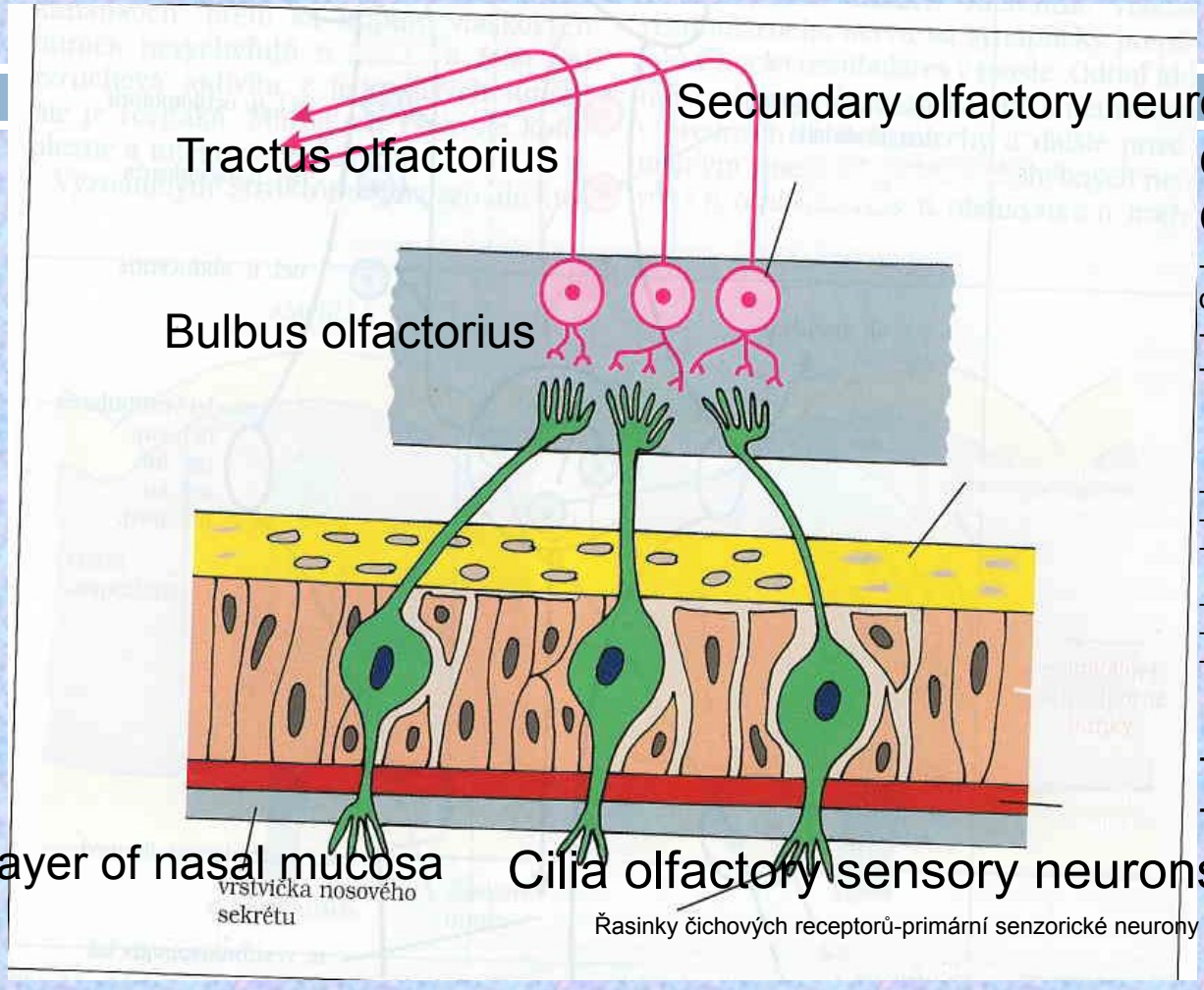
Structure of hair cell
Lateral movement stimulate receptor – receptor potencial



The intensity of the sound is encoded as an amplitude receptor potential, in centripetal fibres
As the frequency of AP; expression in decibels
Pitch with frequency (number of waves/time)



Smell



Odorant chemoreceptors

Olfactory epithelium

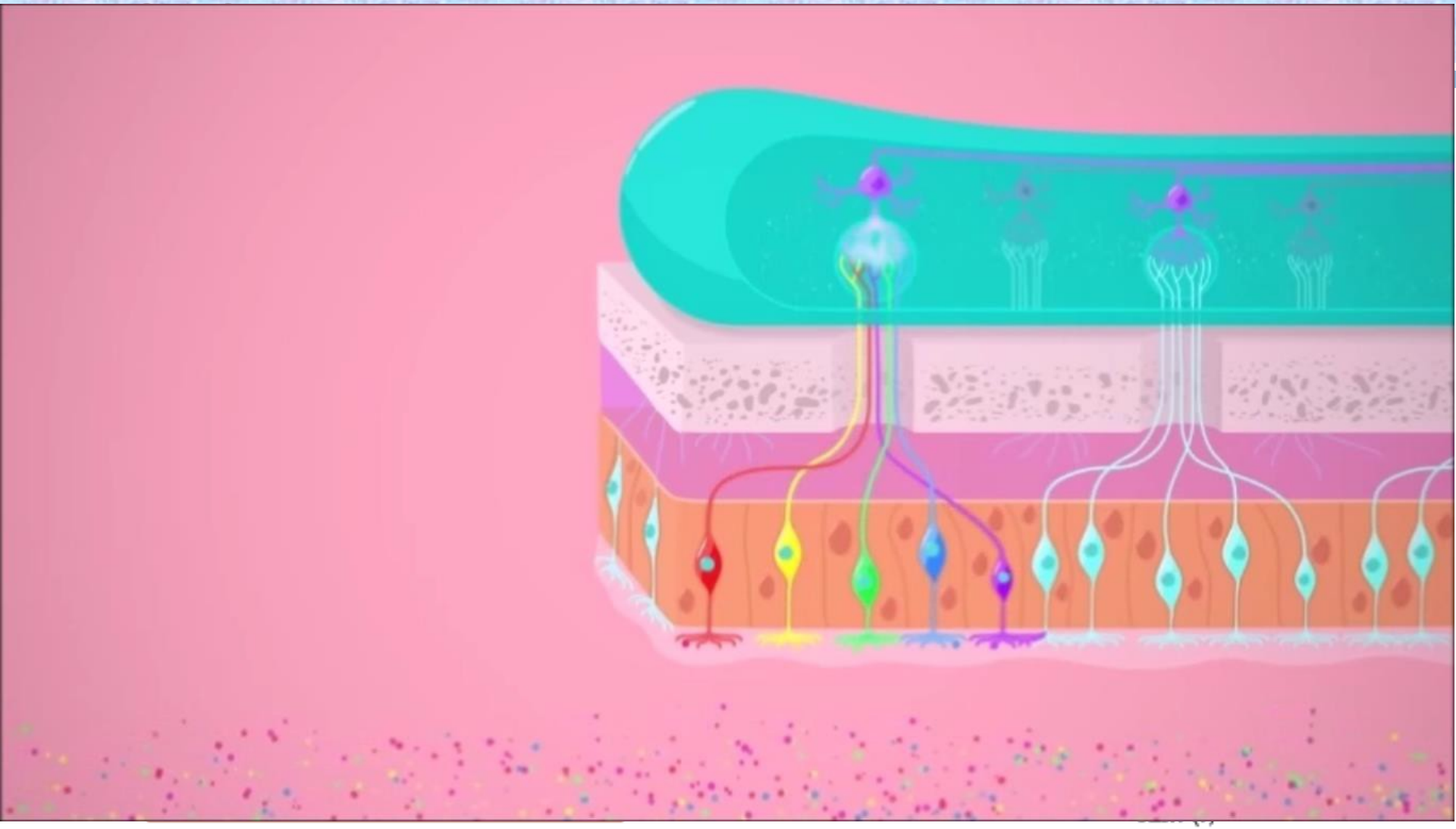
- Irritated by substances which: dissolves in nasal mucus,
- area 5 cm2
- Phylogenetically the oldest sense

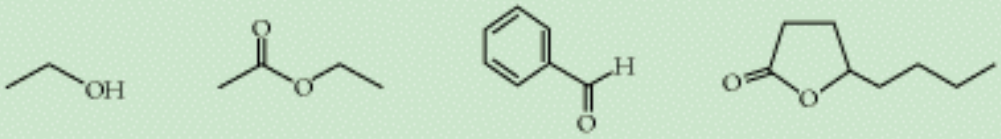
- Henning's classification of odors:
- Floral, fruity, bitumen,
- Spicy, putrefactive, burnt

- Sensitive sense
- (methyl mercaptan=garlic-400pg/1 l air)
- receptors adapt quickly

- Hypoosmia –anosmia
- -hyperosmia

The Olfactory Epithelium and



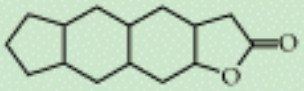


Ethanol
alcoholic
2 m*M*

Ethyl acetate
ethereal
0.06 m*M*

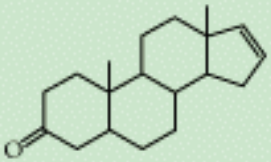
Benzaldehyde
bitter almond
0.3 m*M*

4-Hydroxyoctanoic acid lactone
coconut
0.05 m*M*

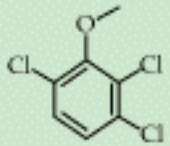


Pentadecalactone
musky
7 n*M*

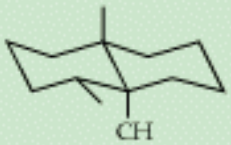
Dimethylsulfide
putrid
5 n*M*



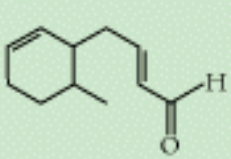
5a-Androst-16-en-3-one
urinous
0.6 n*M*



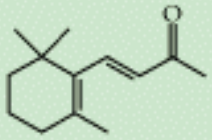
2,3,6-Trichloroanisole
moldy
0.1 n*M*



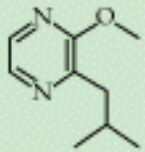
Geosmin
earthy
0.1 n*M*



2-*trans*-6-*cis*-Nonadienal
cucumber
0.07 n*M*

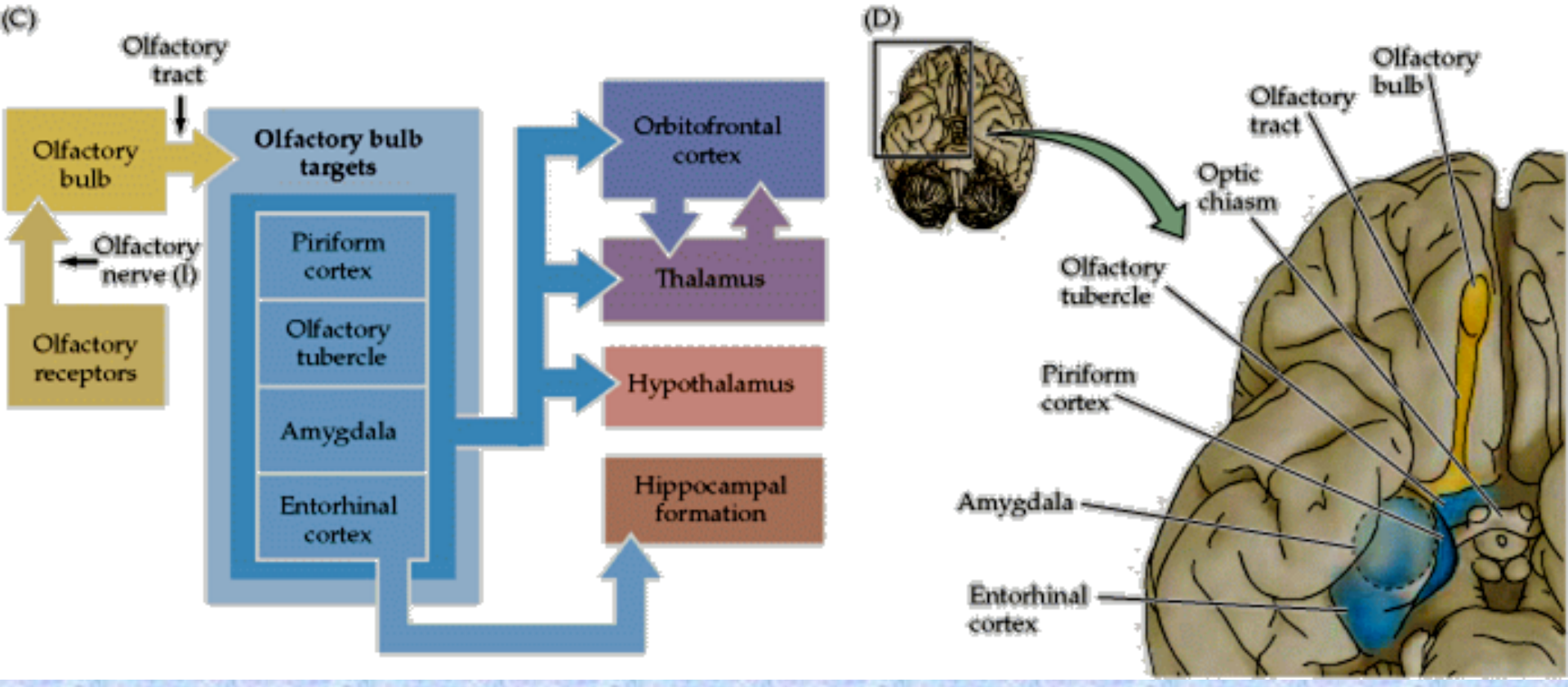


b-Ionone
violet
0.03 n*M*



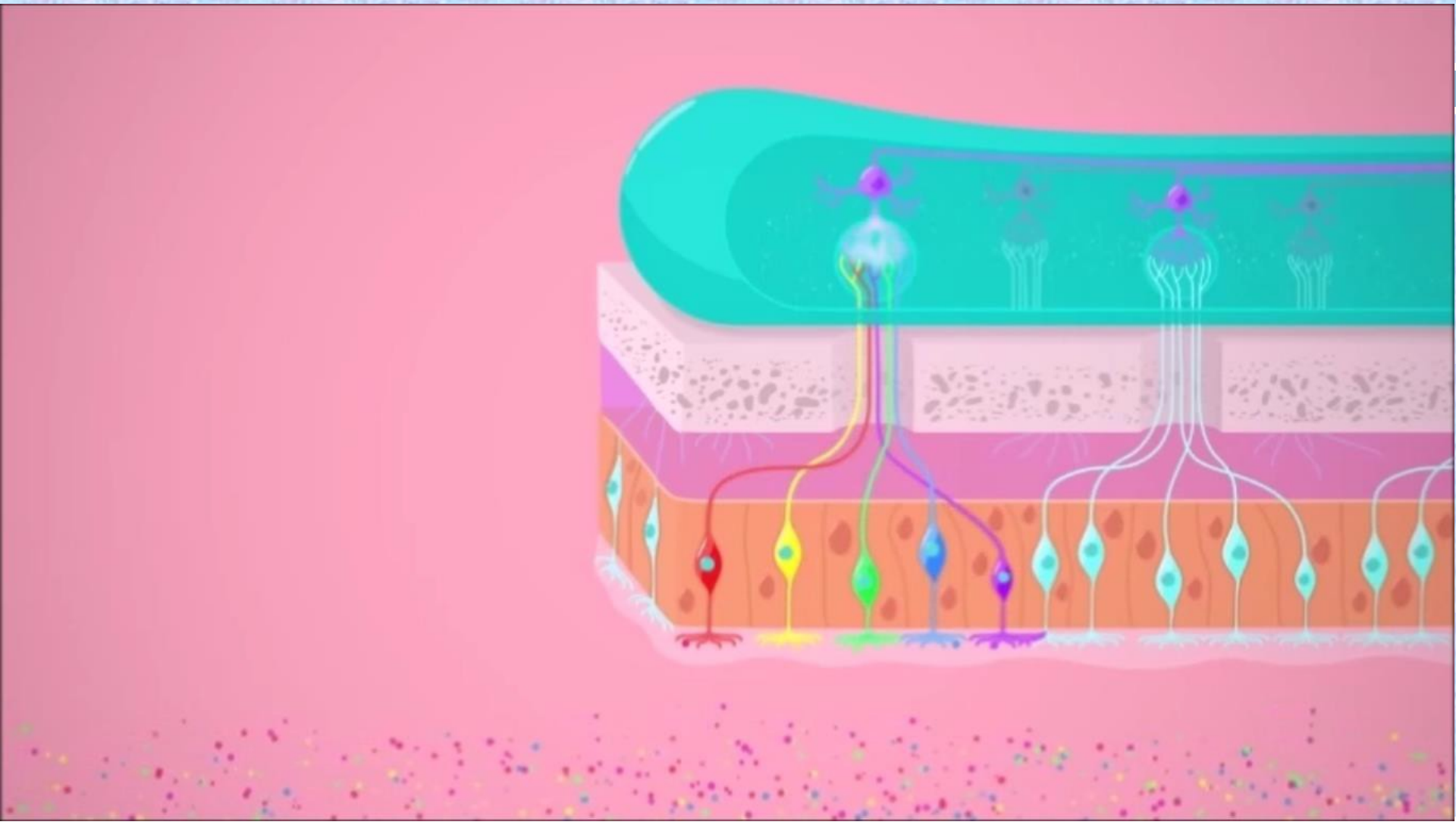
2-Isobutyl-3-methoxypyrazine
bell pepper
0.01 n*M*

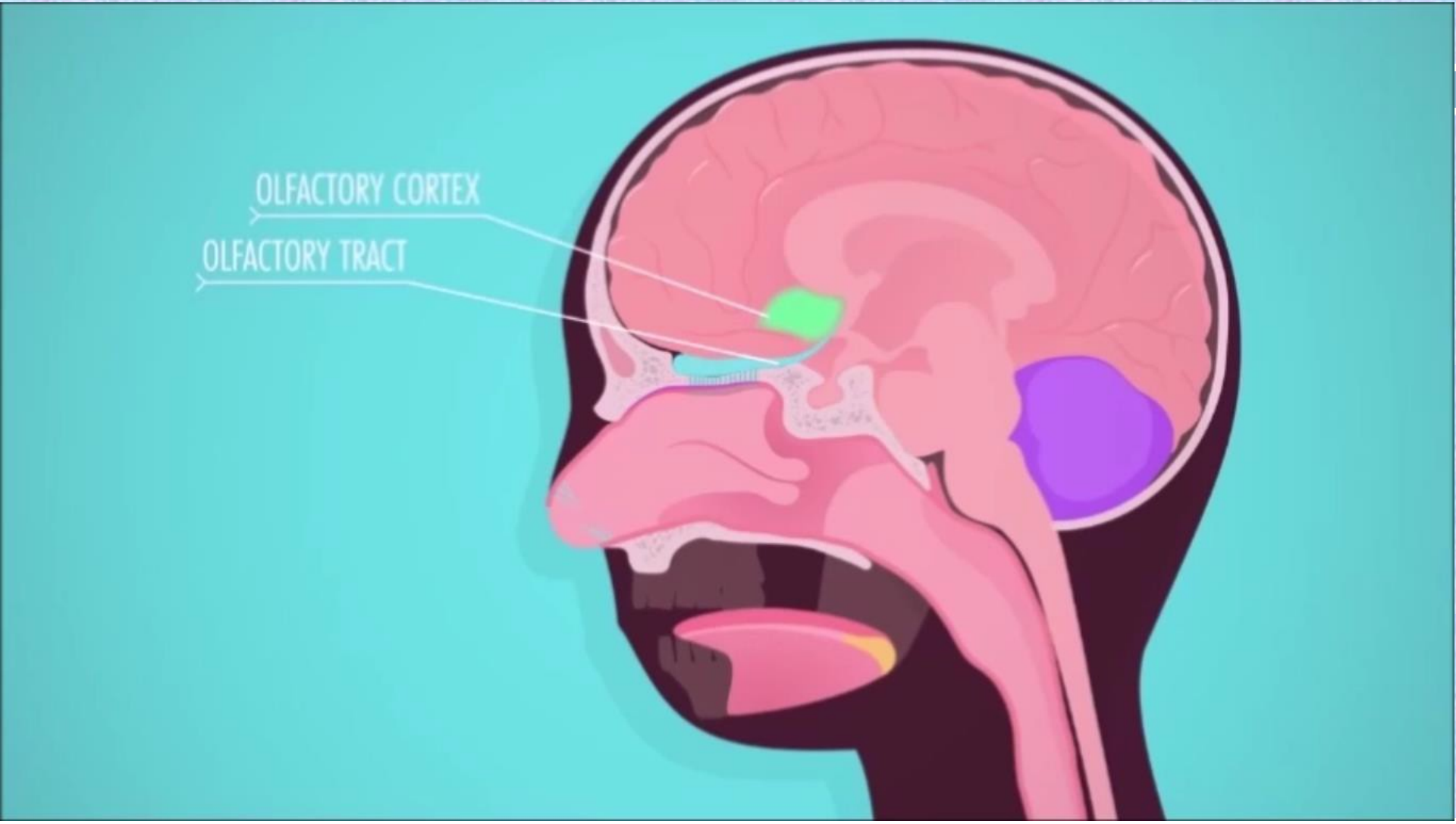
Olfactory System



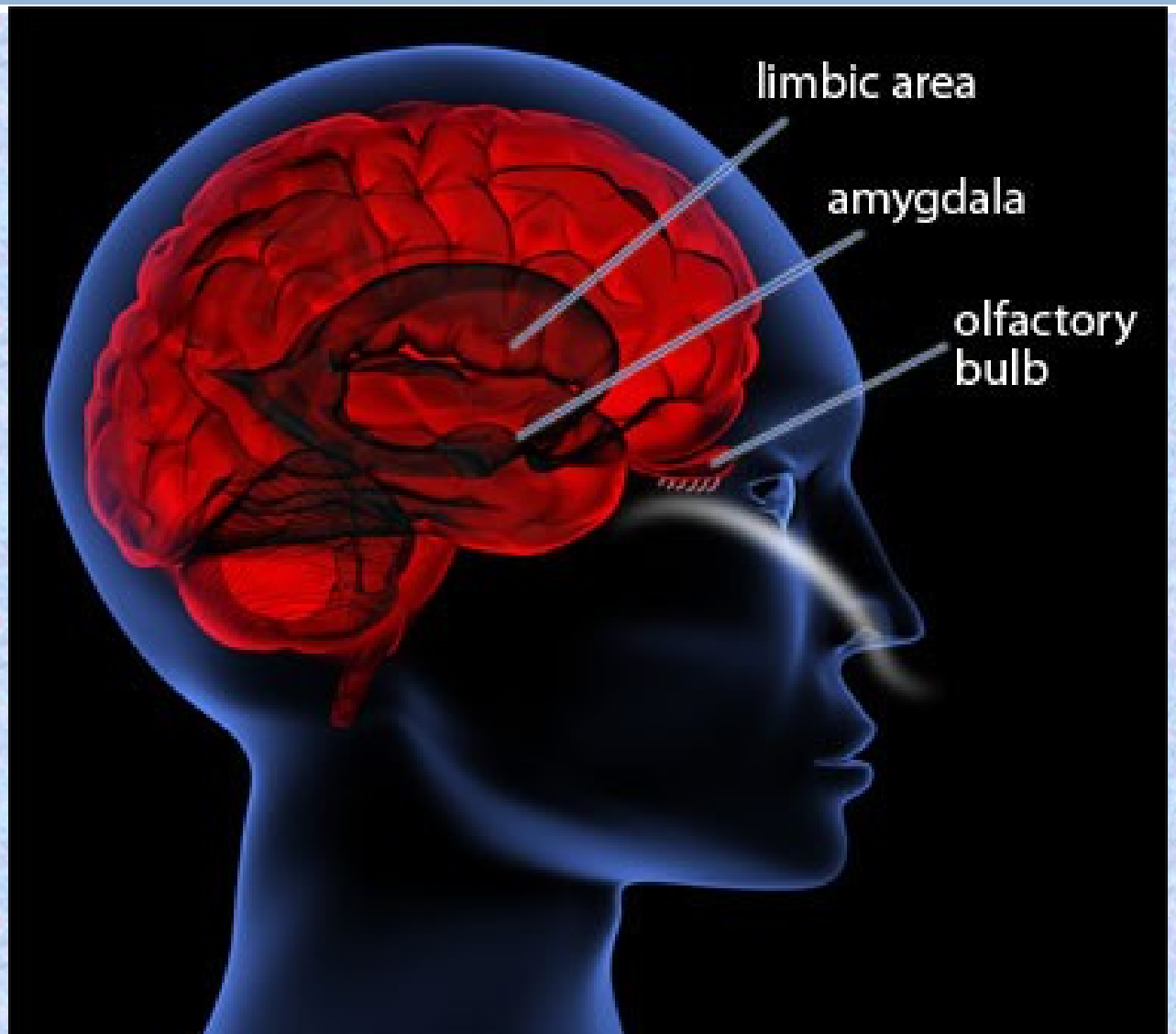
(C) Diagram of the basic pathways for processing olfactory information.

(D) Central components of the olfactory system.

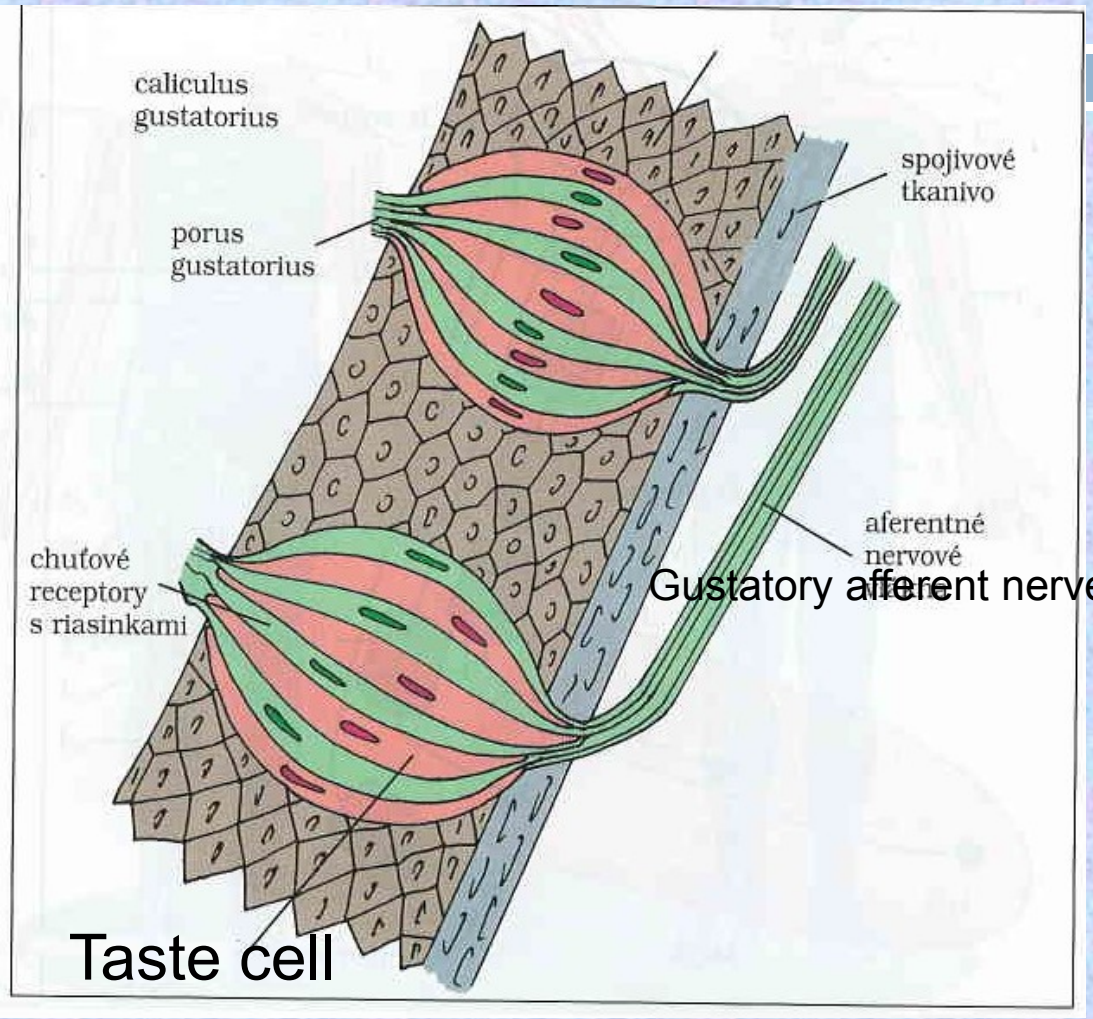



OLFACTORY CORTEX
OLFACTORY TRACT

Physiological and Behavioral Responses to Odorants



Taste



Gustatory afferent nerve

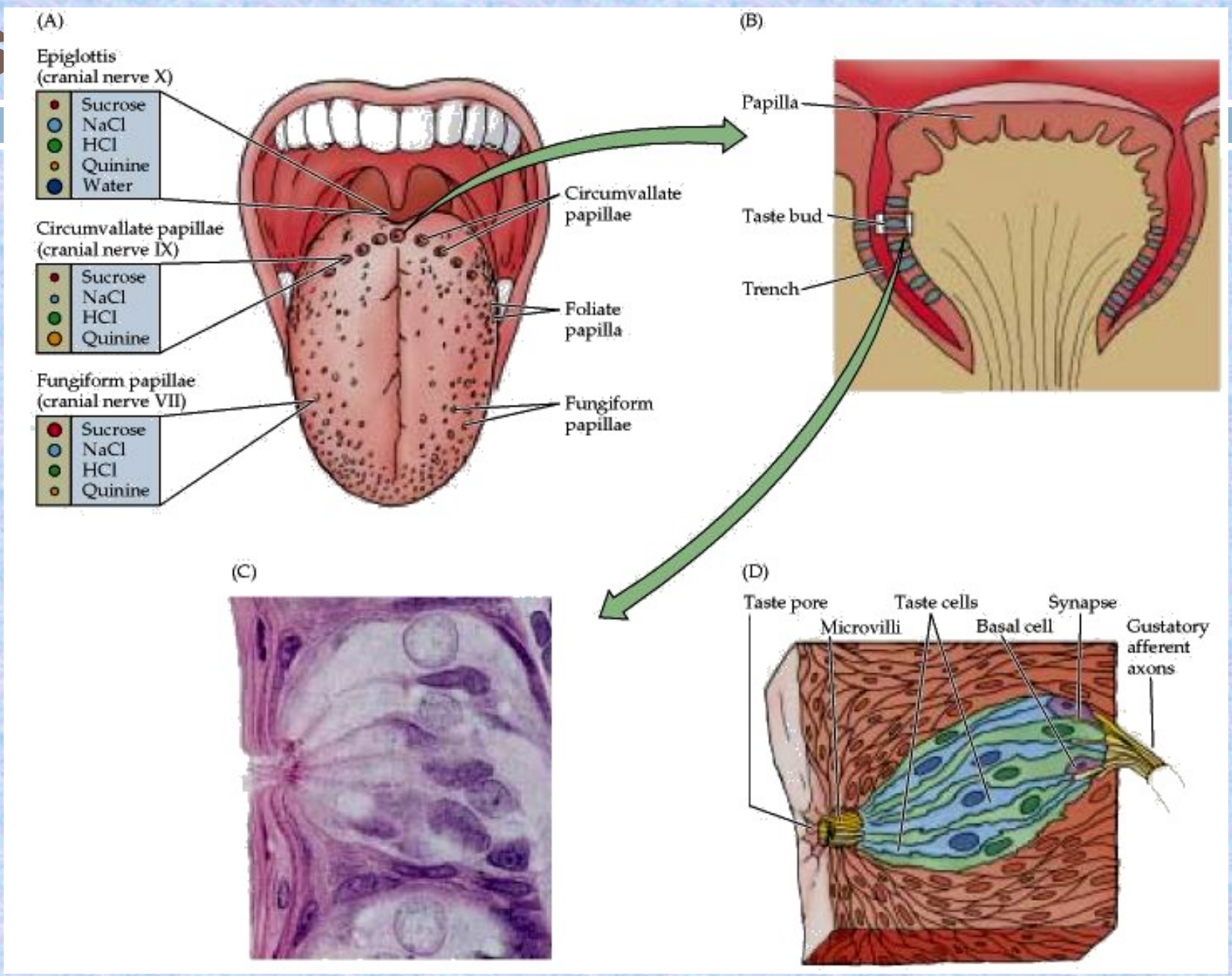
Taste buds – taste chemoreceptors

irritated by flavor substances dissolved in saliva

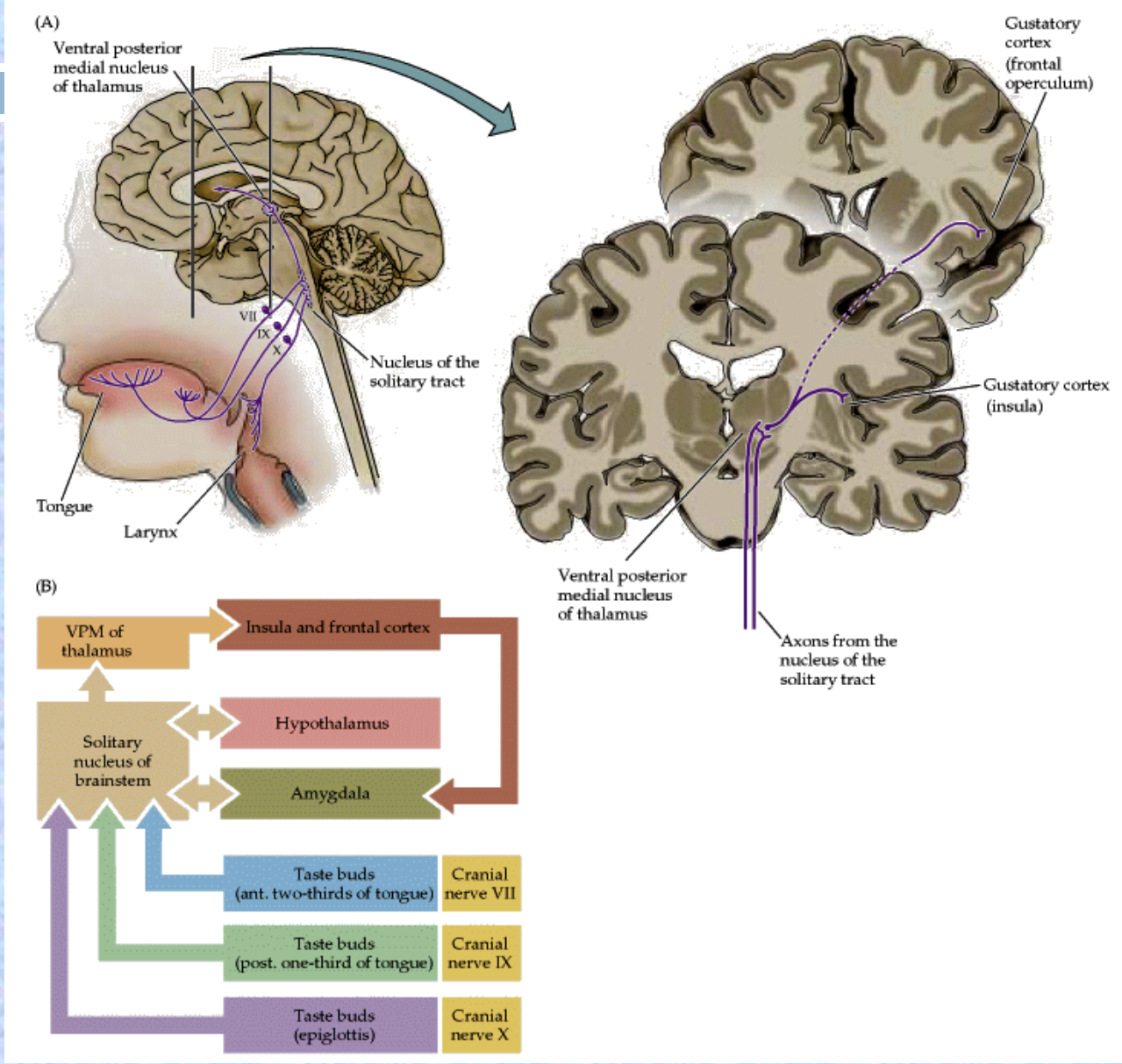
Taste receptors in the cups on the mucous membrane of the tongue, epiglottis, palate and pharynx
Ovoid shape, 50-60sterri, 40 own flavors
Receptors=hair cells protruding into the oral cavity
Afferent fibers adhere to the base of the taste bud
(50 threads per 1 cup)

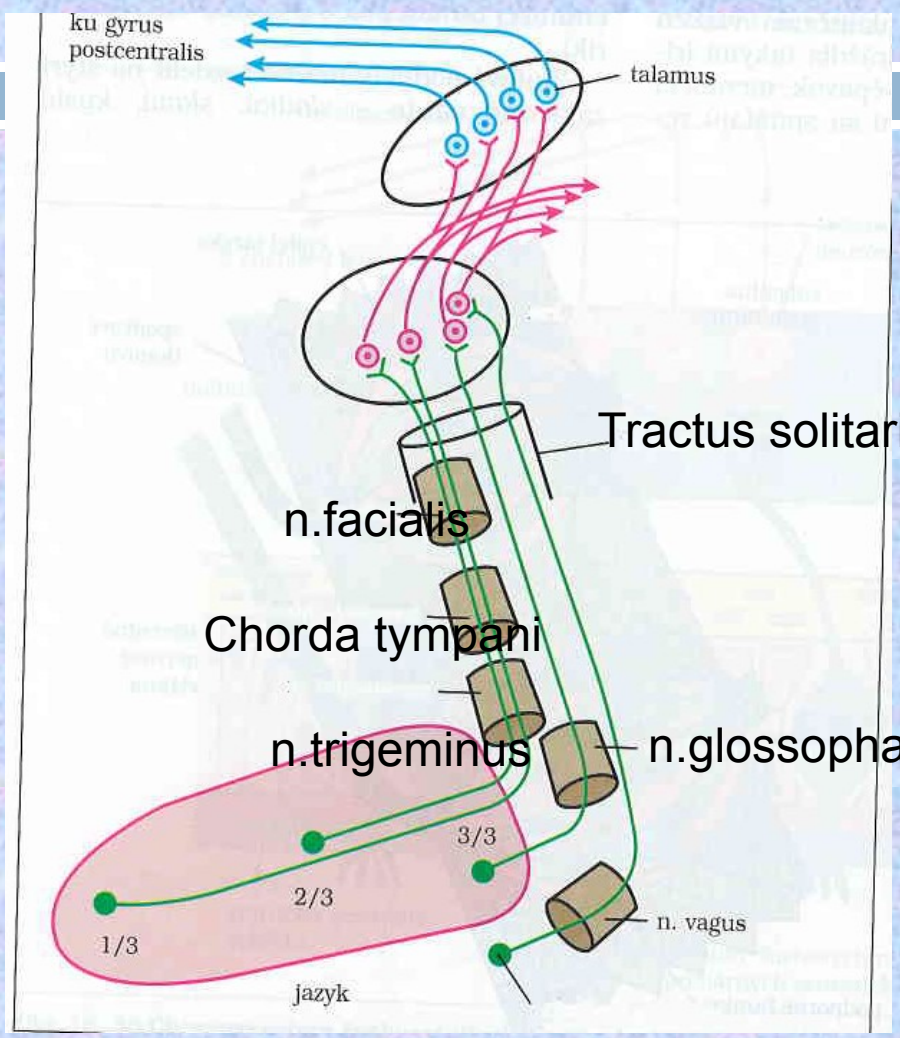
Basic modalities: sweet – salt
sour – bitter
- umami (triggered by glutamate)

The Organization of the Taste Sys



Central Processing of Taste Signals





Taste pathways

From the front 2/3 of the tongue

–chorda tympani – nervus trigeminal

From the back – glossopharyngeus nerve

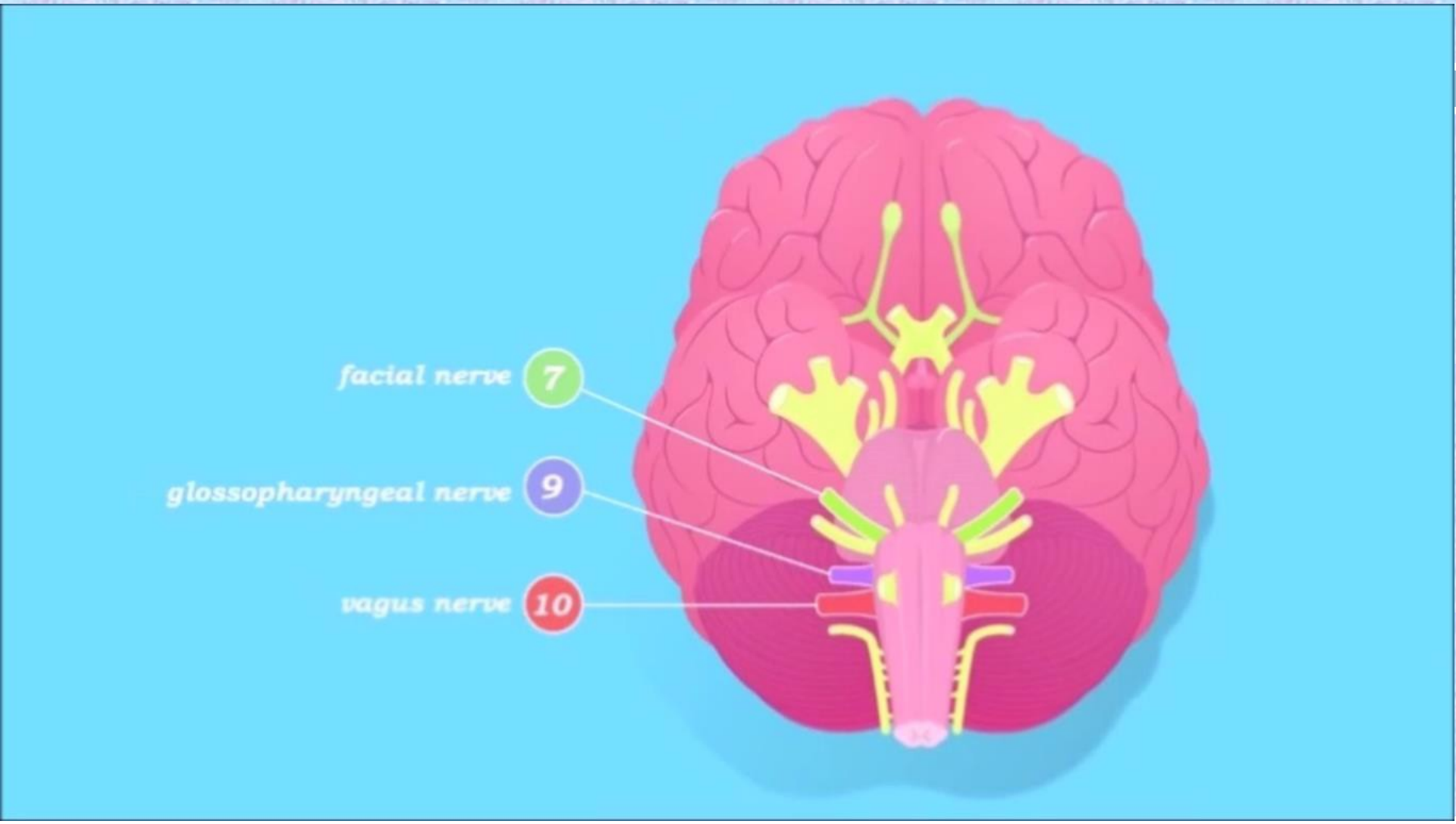
Receptors are also adaptable,

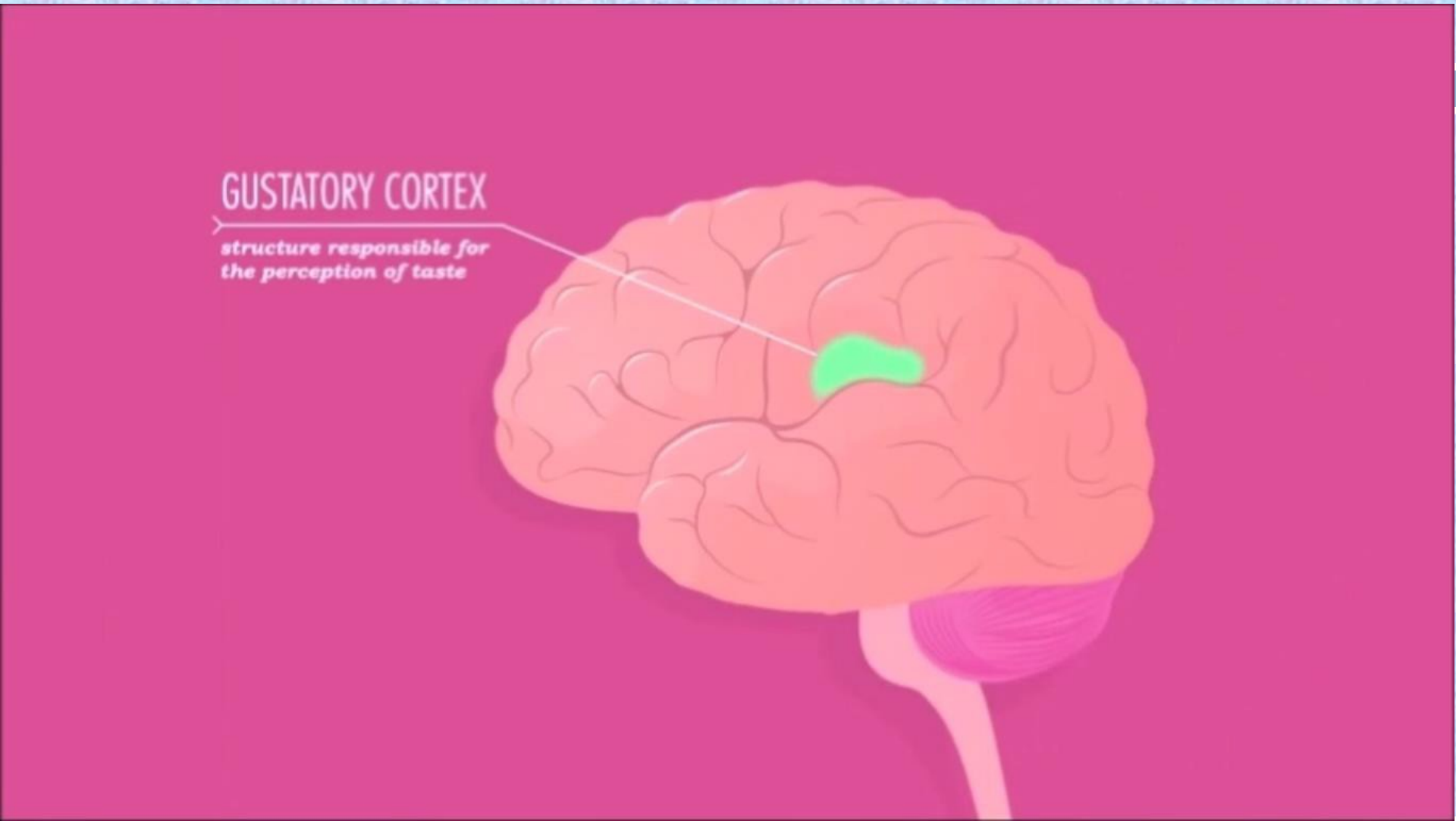
Low resolution between two substances

Constantly renewed

Hypogeuzia (decrease in taste activity)

ageuzia - hypergeuzia


facial nerve
7
glossopharyngeal nerve
9
vagus nerve
10


GUSTATORY CORTEX
structure responsible for
the perception of taste