SENSES

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RECEPTORS

Sensory (afferent) nerve endings - terminate in periphery as bare **unmyelinated endings (**or in the form of specialized **capsulated structures)**

Give response to the stimulus.
When stimulated, receptors produce a series of impulses, which are transmitted through the afferent nerves.

Biological transducers - convert various forms of **energy** (stimuli) in the environment into **action potentials** in nerve fiber.

CLASSIFICATION

A. Exteroceptors - give response to stimuli arising from **outside the body.**

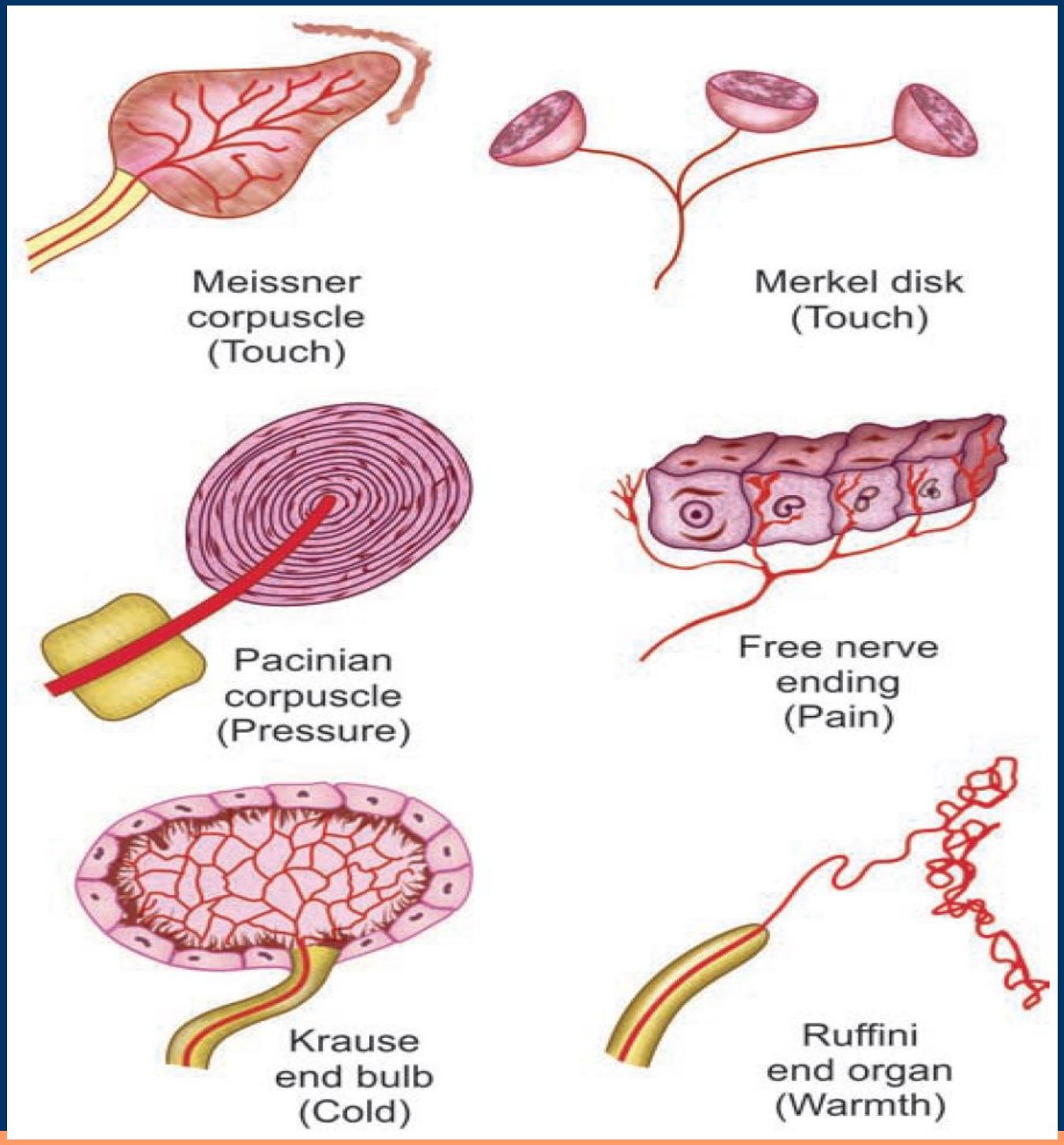
B. Interoceptors - give response to stimuli arising from **within the body.**

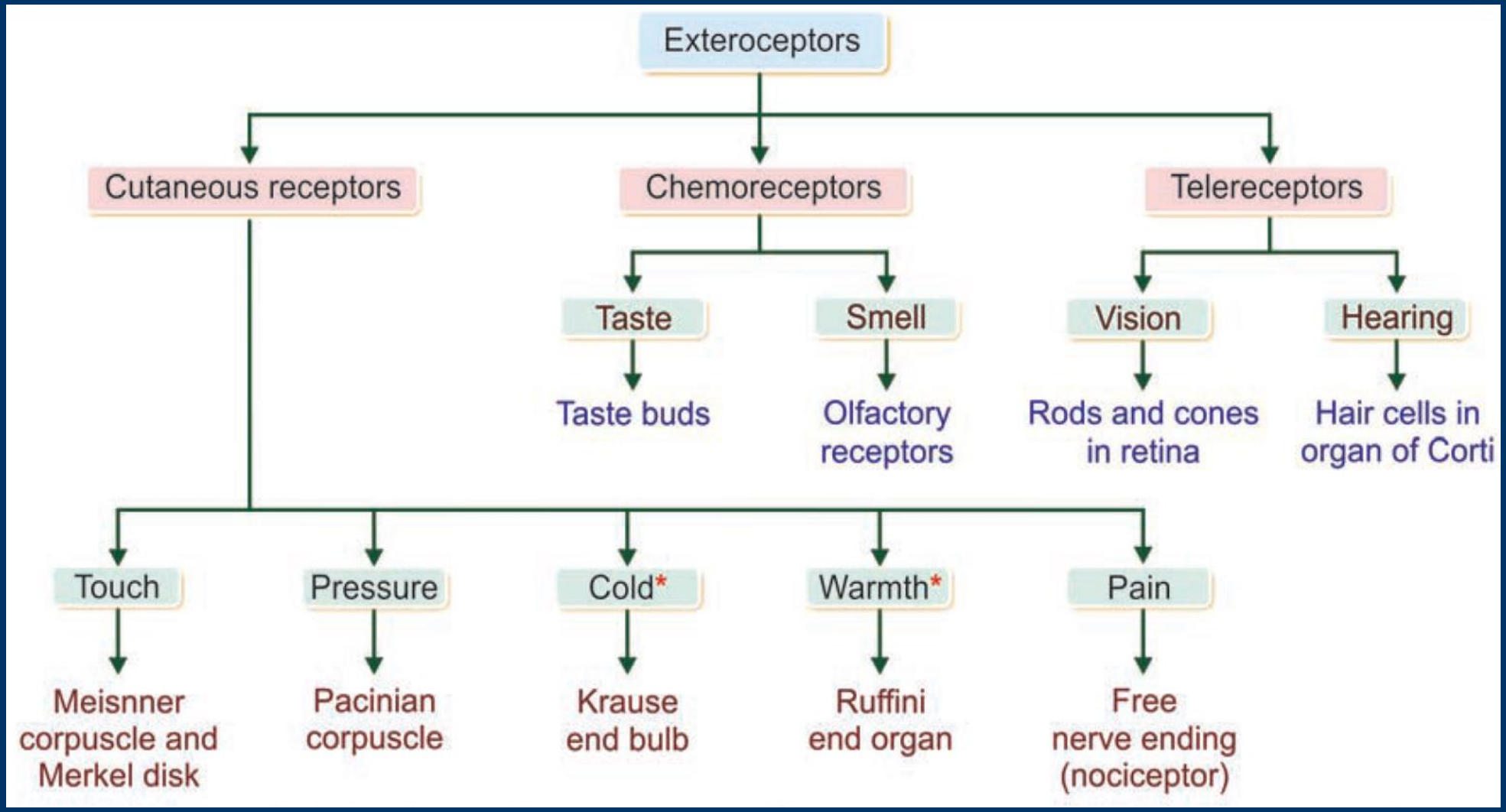
EXTERORECEPTORS

1. *Cutaneous Receptors or Mechanoreceptors*
situated in the skin, are also called mechanoreceptors because of their response to **mechanical stimuli** such as touch, pressure and pain.

2. *Chemoreceptors*
give response to **chemical stimuli.**

3. *Telereceptors*
give response to stimuli arising **away from the body, al**so called the **distance receptors**


Meissner corpuscle (Touch)
Merkel disk (Touch)
Pacinian corpuscle (Pressure)
Free nerve ending (Pain)
Krause end bulb (Cold)
Ruffini end organ (Warmth)


Exteroceptors
Cutaneous receptors
Chemoreceptors
Telereceptors
Taste
Smell
Vision
Hearing
Taste buds
Olfactory receptors
Rods and cones in retina
Hair cells in organ of Corti
Touch
Pressure
Cold*
Warmth*
Pain
Meisnner corpuscle and Merkel disk
Pacinian corpuscle
Krause end bulb
Ruffini end organ
Free nerve ending (nociceptor)

INTEROCEPTORS

1. *Visceroceptors*
situated in the viscera.

2. *Proprioceptors*
response to **change in the position** of different parts of the body.

Interoceptors

Visceroceptors

Receptors	Situation
1. Stretch receptors 2. Baroreceptors 3. Chemoreceptors 4. Osmoreceptors	Heart Blood vessels GI tract Urinary tract Brain

Proprioceptors

Receptors	Situation
1. Muscle spindle 2. Golgi tendon organ 3. Pacinian corpuscle 4. Free nerve ending	Muscle Tendon Ligament Facia Joint
5. Hair cells	Vestibular apparatus

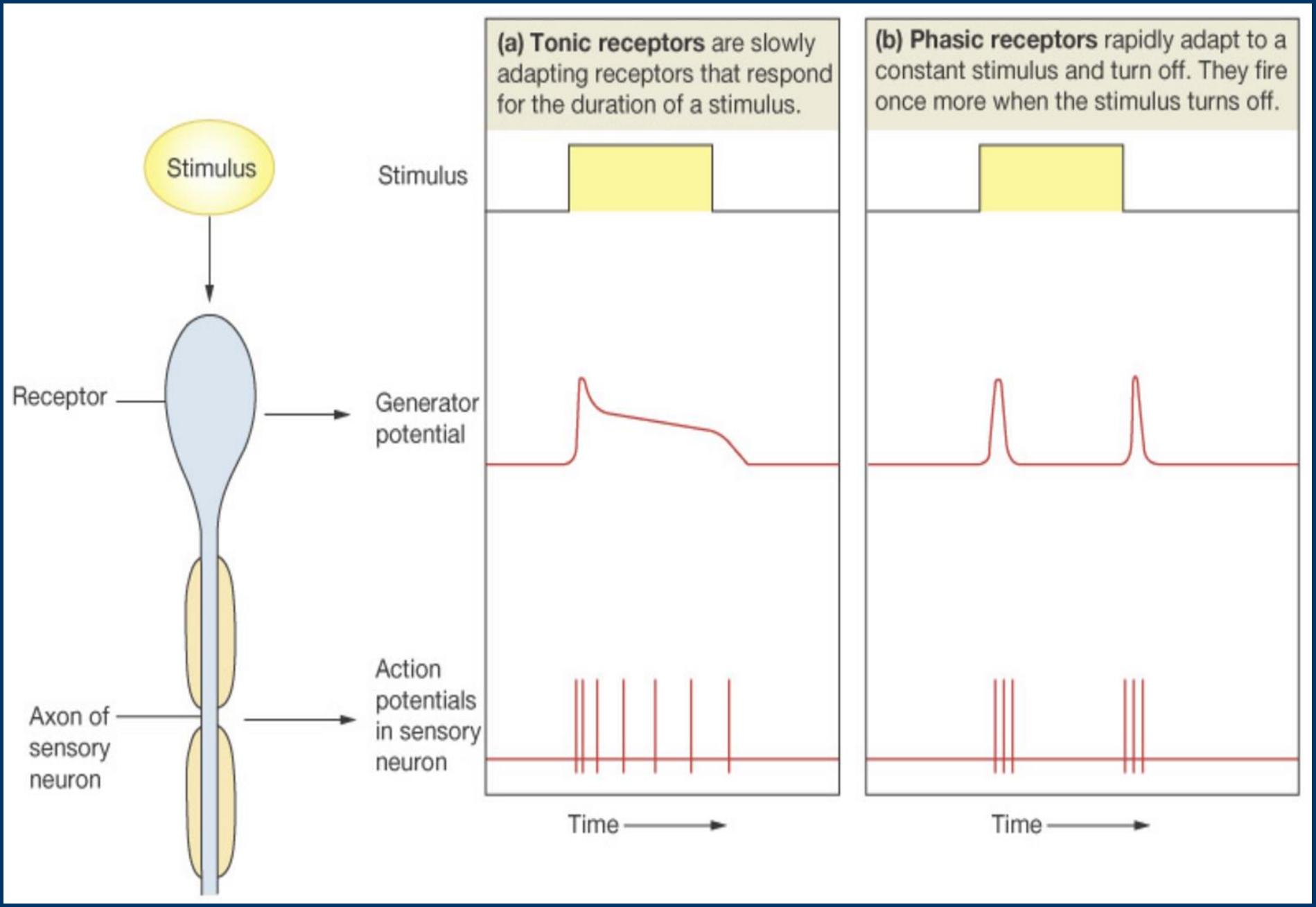
ADAPTATION

Adaptation is the decline in discharge of sensory impulses when a receptor is stimulated continuously with constant strength.
(called sensory adaptation or desensitization)

Depending upon adaptation time, receptors are
divided into two types:

i. **Phasic receptors,** which get adapted rapidly (touch and pressure)

ii. **Tonic receptors,** which adapt slowly. Muscle spindle, pain receptors and cold receptors


Stimulus
Receptor
Axon of sensory neuron
(a) Tonic receptors are slowly adapting receptors that respond for the duration of a stimulus.
(b) Phasic receptors rapidly adapt to a constant stimulus and turn off. They fire once more when the stimulus turns off.
Stimulus
Generator potential
Action potentials in sensory neuron
Time
Time

GENERATOR POTENTIAL

Properties of Receptor Potential

Receptor potential has two important properties:

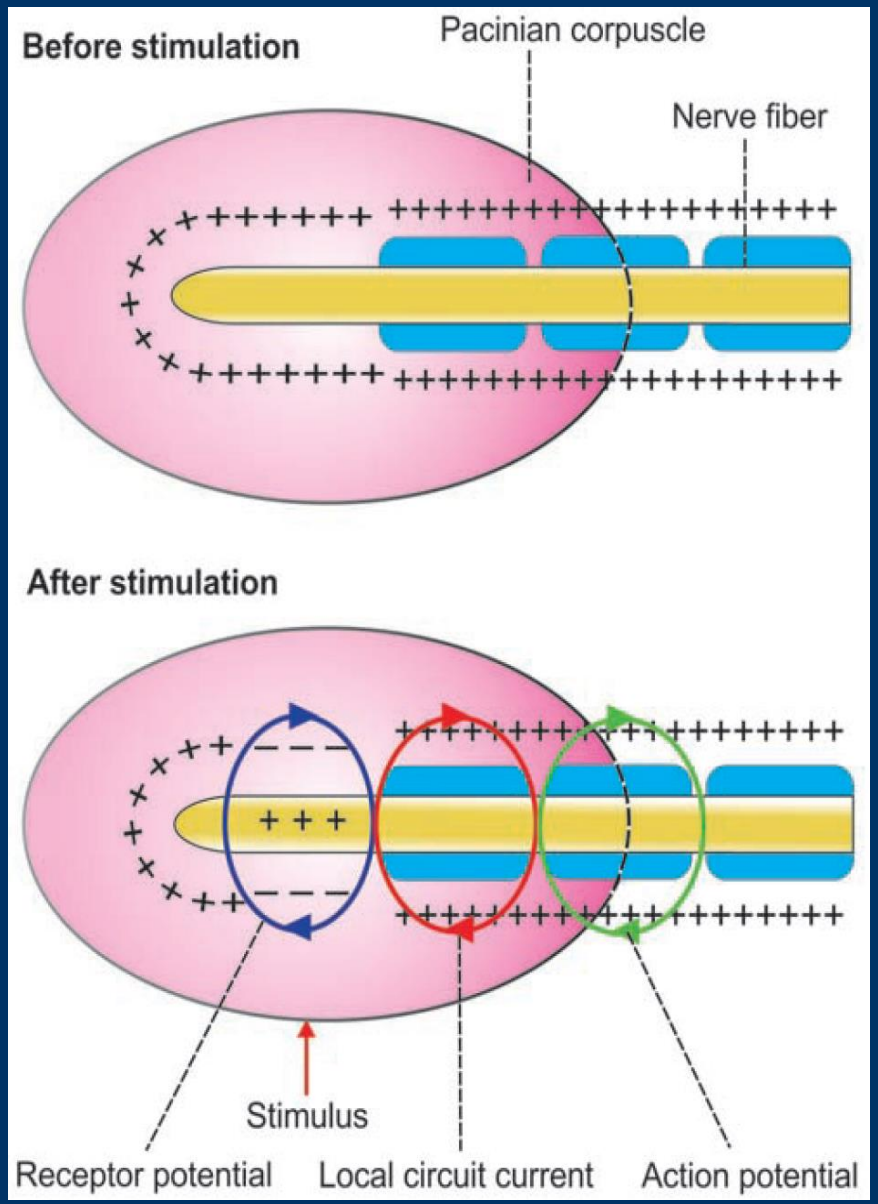
i. Receptor potential is **nonpropagated;** it is confined within the receptor itself ; short lived; is not action potential, is a graded potential.
ii. It does not obey **all-or-none** law.

Significance of Receptor Potential

When receptor potential is sufficiently strong (when the magnitude is about 10 mV), it causes development of action potential in the sensory nerve.

Receptor potential in pacinian corpuscle:

Receptor potential leads to development of local circuit which spreads up to first node within the capsule.
It leads to development of action potential in the first node of nerve fiber



PAIN

defined as an unpleasant and emotional experience associated with or without actual tissue damage.

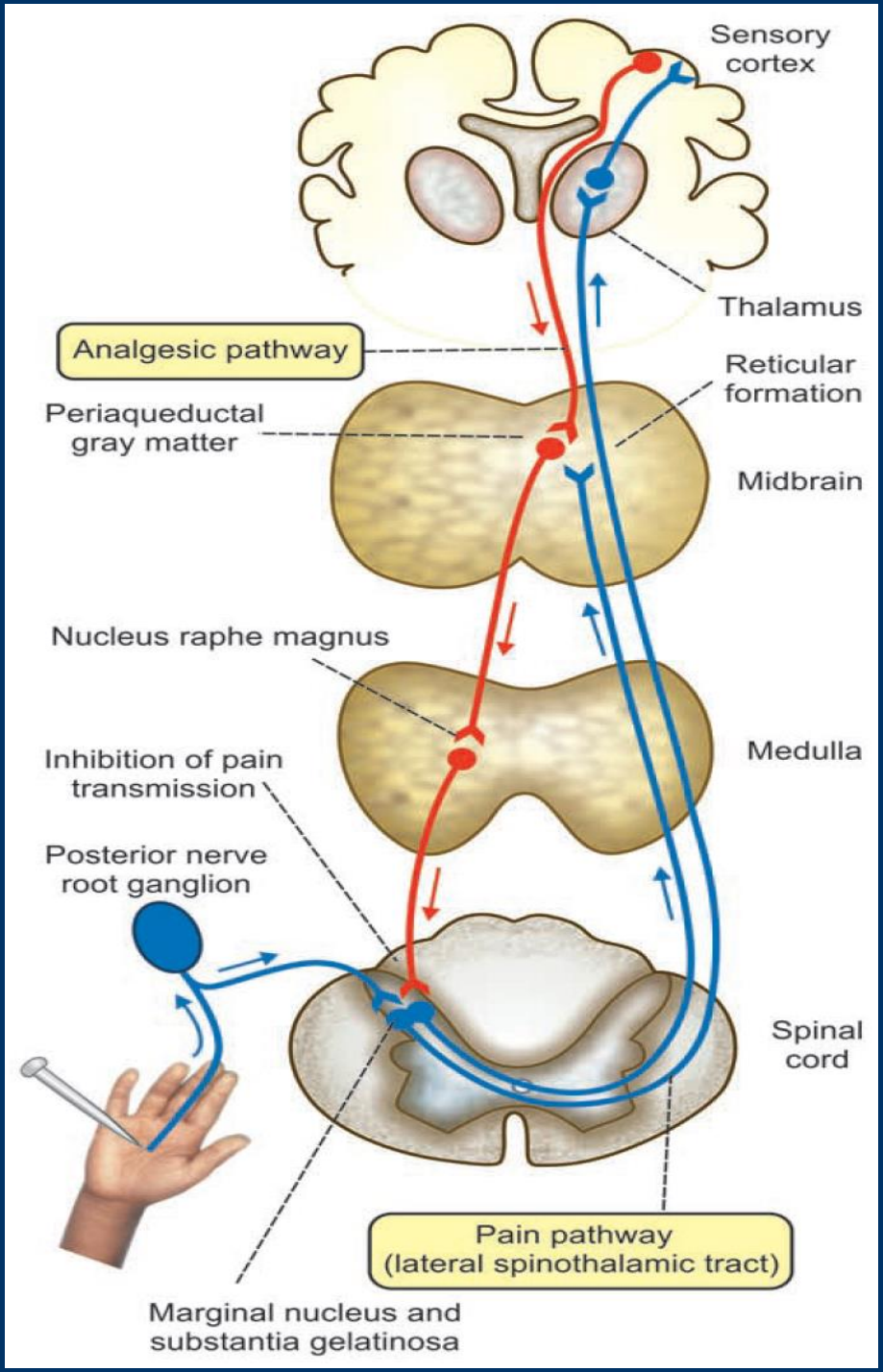
.**Acute pain** is a sharp pain of short duration with easily identified cause. Often it is localized in a small area before spreading to neighboring areas, treated by medications.

.**Chronic pain** is the intermittent or constant pain with different intensities. It lasts for longer periods. It is somewhat difficult to treat chronic pain and it needs professional expert care.

COMPONENTS OF PAIN SENSATION

- Fast pain - is the first sensation whenever a pain stimulus is applied. It is experienced as a bright, sharp and localized pain sensation; is carried by Aδ fibers

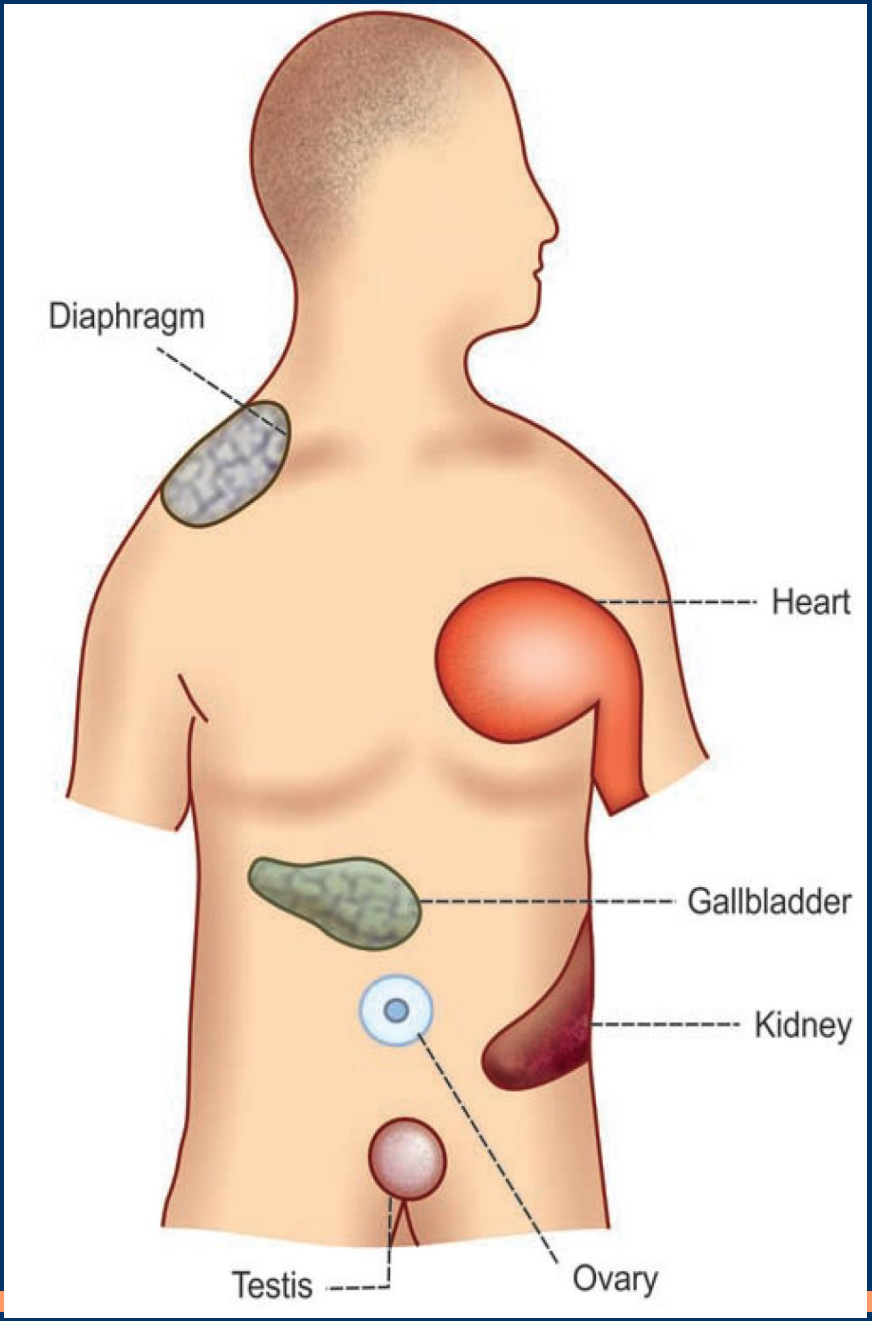
- Slow pain- follows the fast pain, is experienced as a dull, diffused and unpleasant pain; is carried by C type of nerve fibers.


Sensory cortex
Thalamus
Analgesic pathway
Reticular formation
Periaqueductal gray matter
Midbrain
Nucleus raphe magnus
Medulla
Inhibition of pain transmission
Posterior nerve root ganglion
Spinal cord
Pain pathway (lateral spinothalamic tract)
Marginal nucleus and substantia gelatinosa

REFERRED PAIN

is perceived at a site adjacent to or away from the site of origin. Deep pain and some visceral pain are referred to other areas. But, superficial pain is not referred.

1. Cardiac pain is felt at inner part of left arm and left shoulder
2. Pain in ovary is referred to umbilicus
3. Pain from testis is felt in abdomen
4. Pain in diaphragm is referred to shoulder
5. Pain in gallbladder is referred to epigastric region
6. Renal pain is referred to loin.



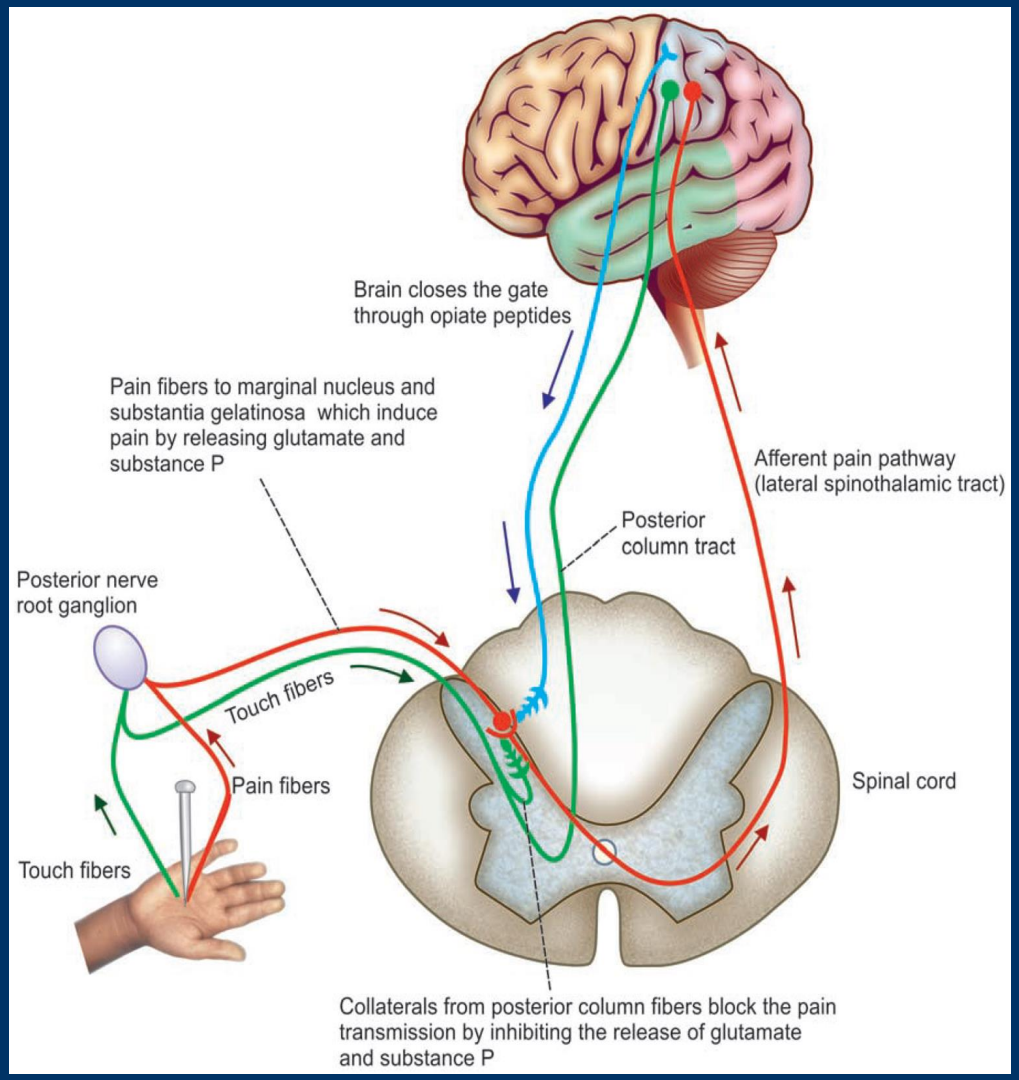
GATE CONTROL THEORY

Psychologist **Ronald Melzack** and the anatomist **Patrick Wall** proposed the gate control theory for pain in 1965 to explain the pain suppression.

- Mechanism of Gate Control at Spinal Level

- Inhibition of the brain

If the gate is opened, pain is felt. If the gate is closed, pain is suppressed.

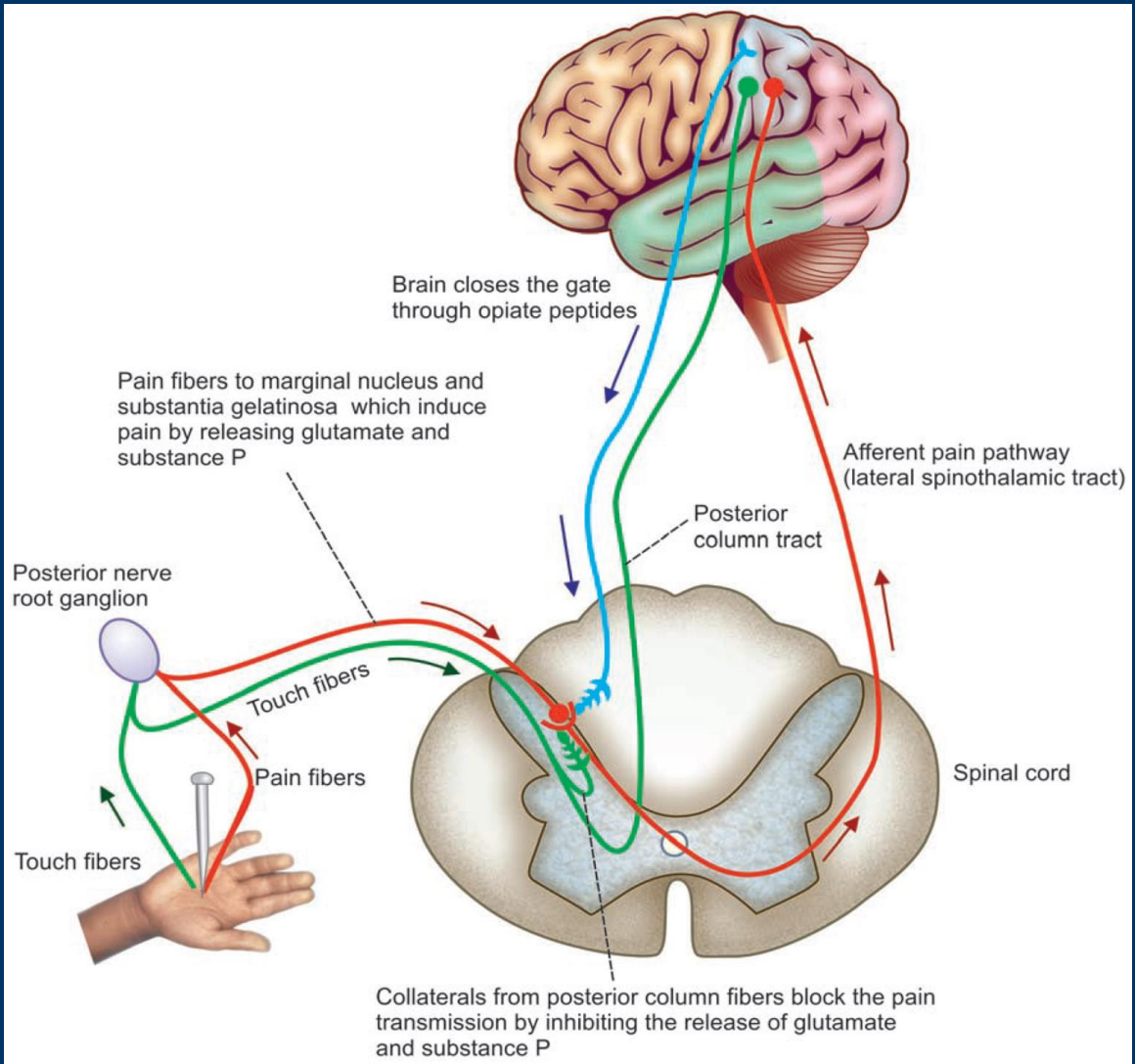


BRAIN

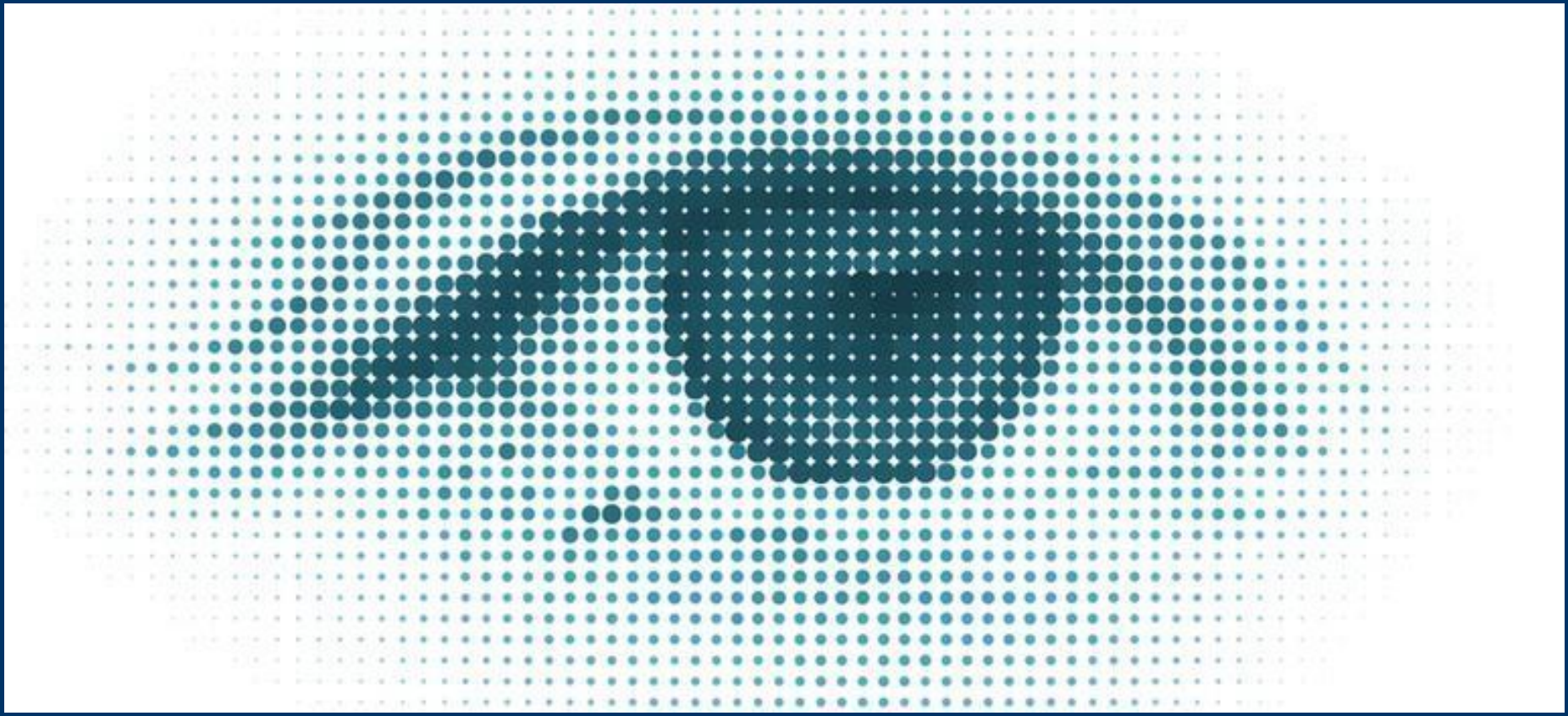
Perception of pain occurs in cortical level in context of the person's emotional status. The brain:

- determines the severity and extent of pain

- sends message back to spinal cord to close the gate by releasing pain relievers such as opiate peptides



Vision



- Complex sense organ
- Gathers information about the environment
- Layer of photoreceptors that respond to light
- Converts energy in the visible spectrum into
- action potentials in the optic nerve
- The wavelength of visible light ranges
- from **400 to 750 nm.**

Anatomy

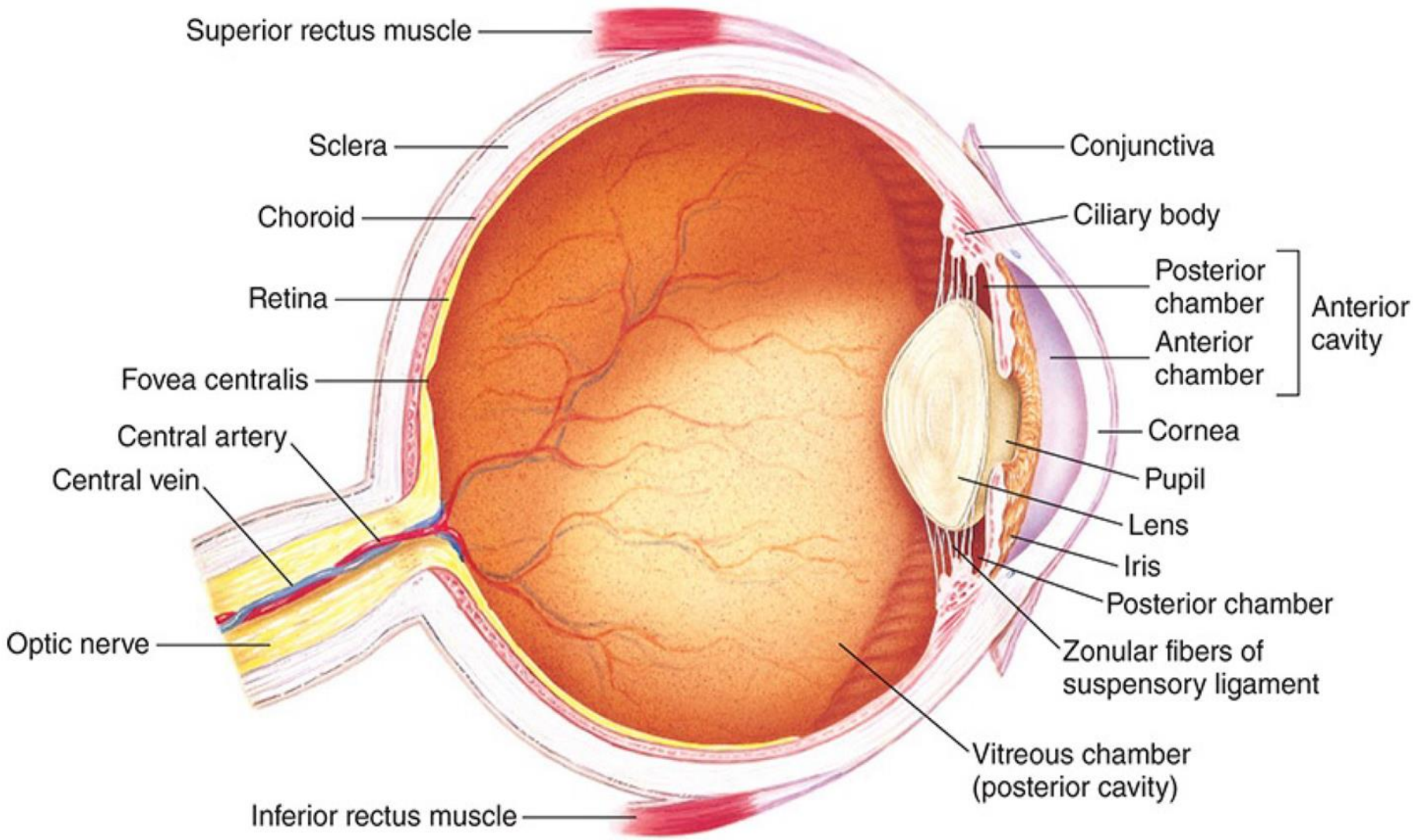
Human eyeball **(bulbus oculi)** is approximately globe shaped, with a diameter of about **24 mm**. It is slightly flattened from above downwards.

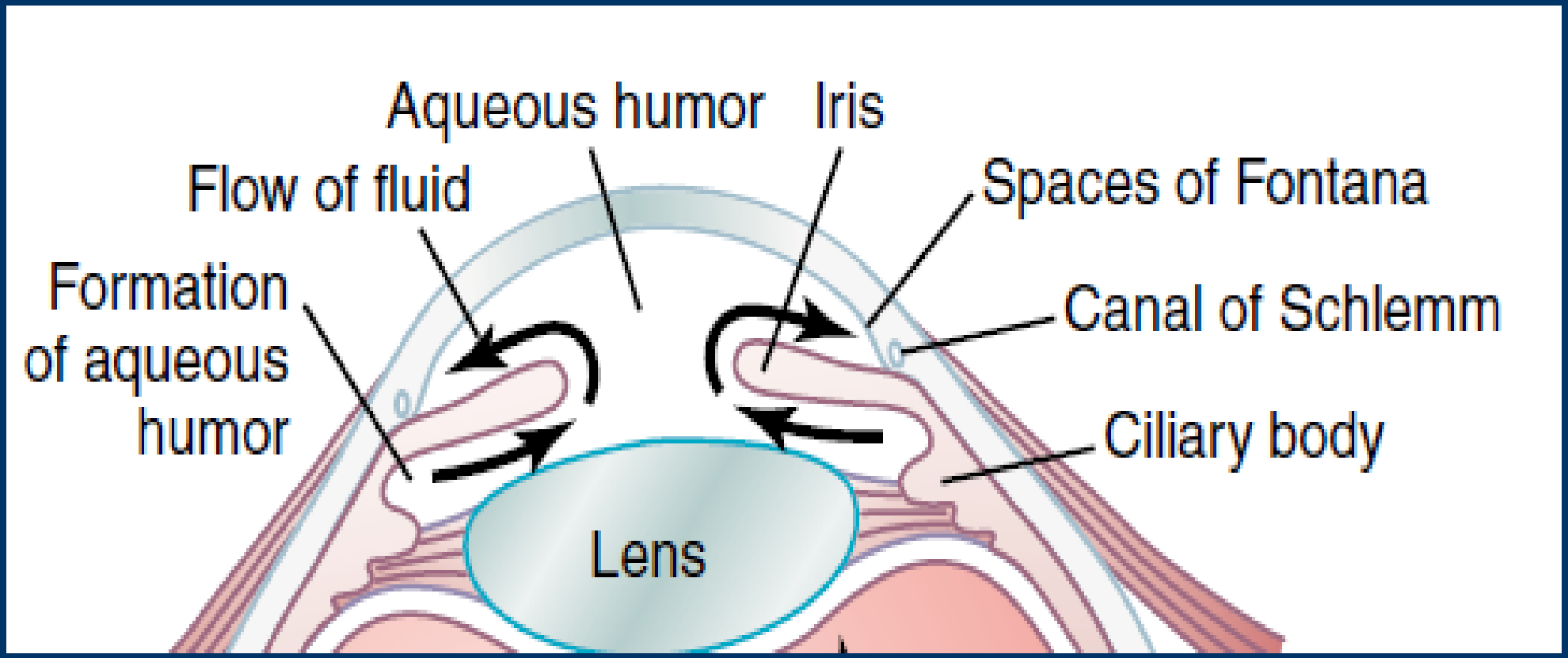
Wall of the eyeball is composed of three layers:

A. **Outer layer**, which includes **sclera** through which no light can pass, is modified anteriorly to form **cornea**, through which light rays enter the eye

B. **Middle layer**, which includes choroid, **ciliary body** and **iris** – a vascular layer that provides oxygen and nutrients structeres in the eye

C. **Inner layer -** the retina


Superior rectus muscle
Sclera
Choroid
Retina
Fovea centralis
Central artery
Central vein
Optic nerve
Inferior rectus muscle
Conjunctiva
Ciliary body
Posterior chamber
Anterior chamber
Anterior cavity
Cornea
Pupil
Lens
Iris
Posterior chamber
Zonular fibers of suspensory ligament
Vitreous chamber (posterior cavity)


Aqueous humor
Iris
Flow of fluid
Spaces of Fontana
Formation of aqueous humor
Canal of Schlemm
Ciliary body
Lens

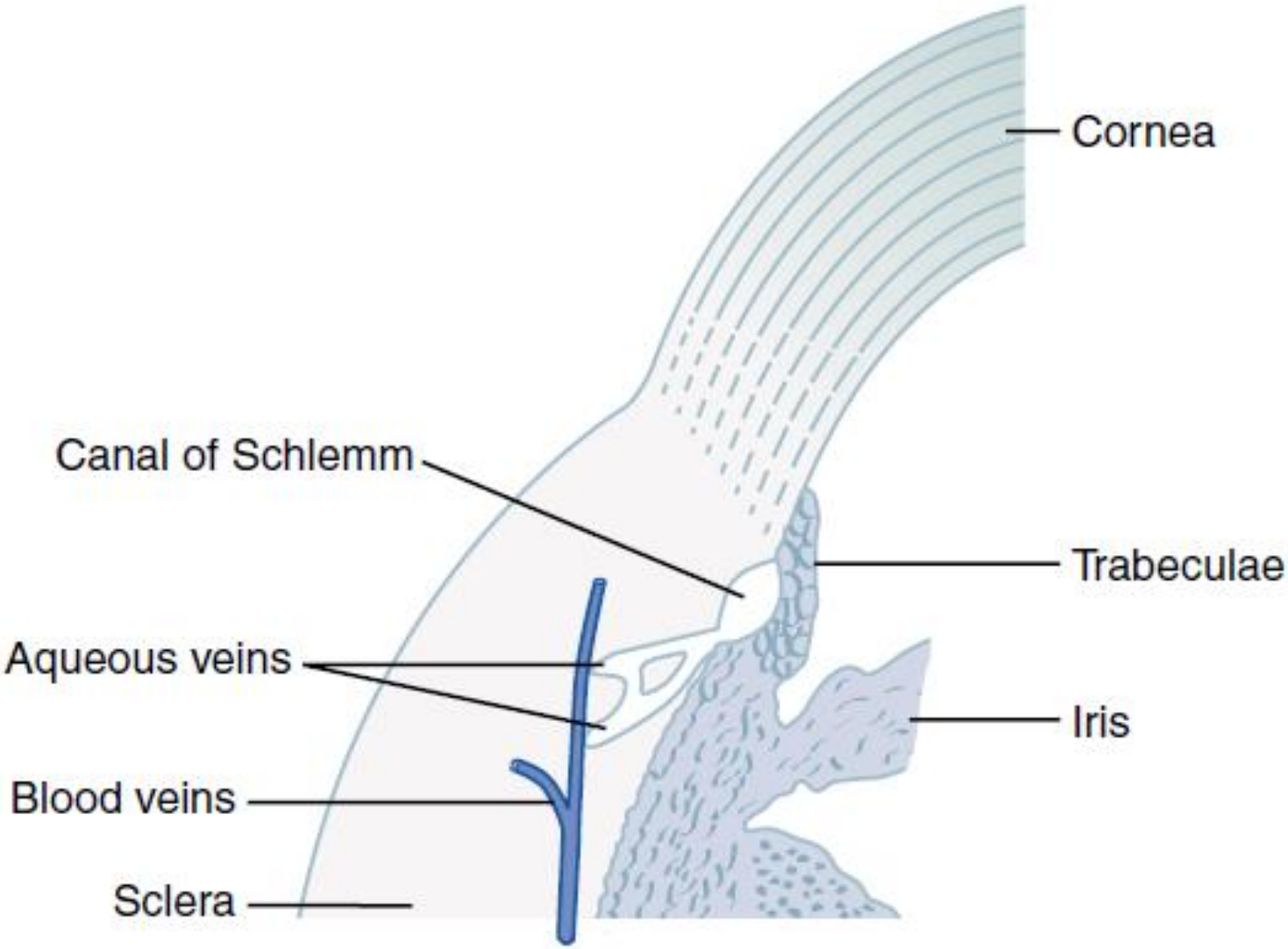


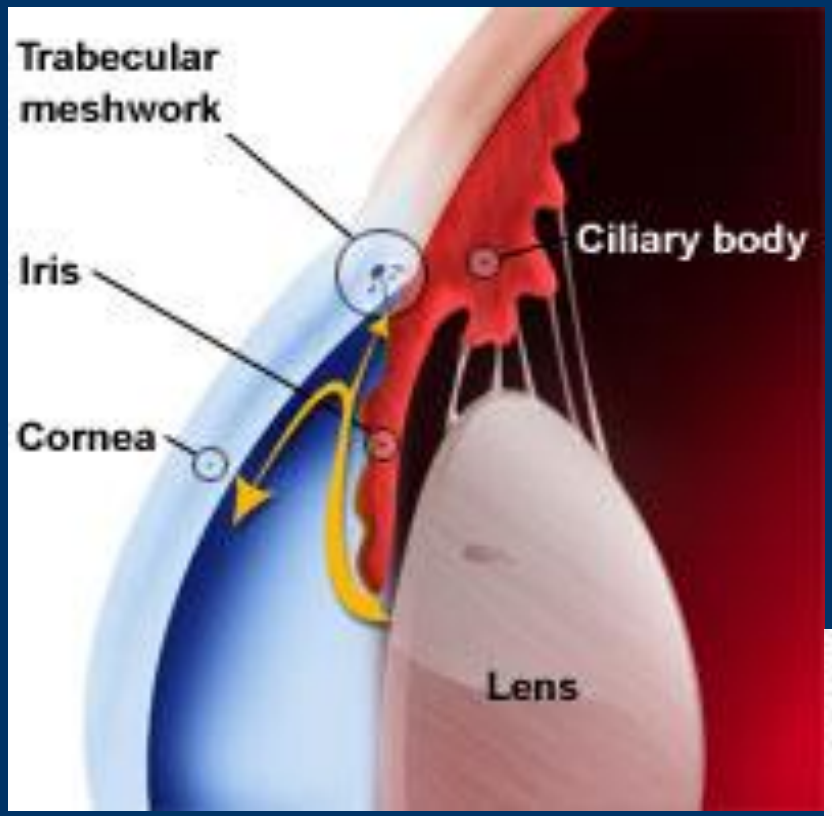
Figure 49-21 Anatomy of the iridocorneal angle, showing the system for outflow of aqueous humor from the eyeball into the conjunctival veins.

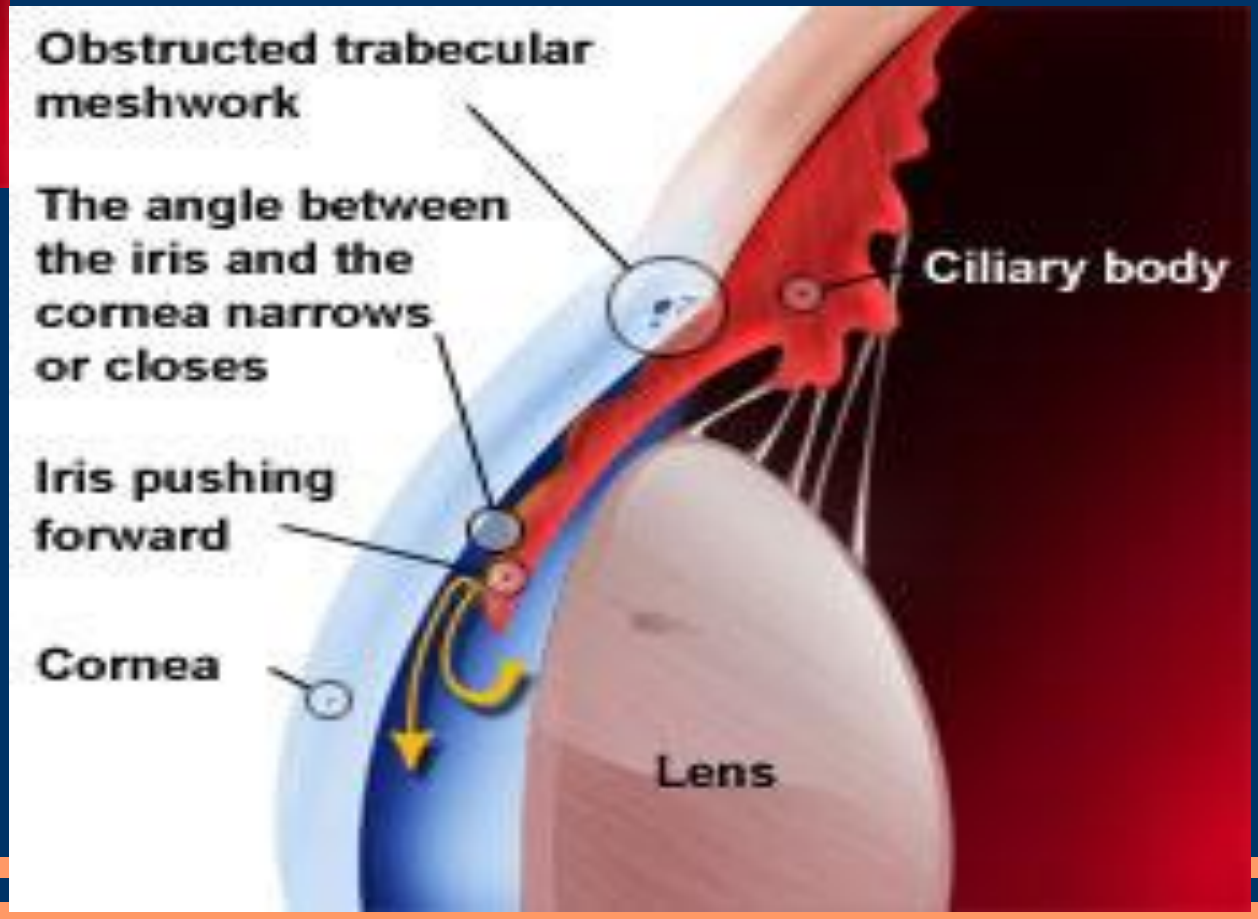
Glaucoma

Glaucoma is a group of diseases characterized by increased intraocular pressure (**normal pressure varies between 12 and 21 mm Hg**), which causes damage of optic nerve, resulting in blindness.Generally is divided into two types:

1) Open-angle glaucoma - a chronic disease, is caused by decreased permeability through the trabeculae into the canal of Schlemm, which leads to an increase in IOP

2) Closed-angle glaucoma results from a forward ballooning of the iris so that it reaches the back of the cornea and obliterates the filtration angle, thus reducing the outflow of aqueous humor.

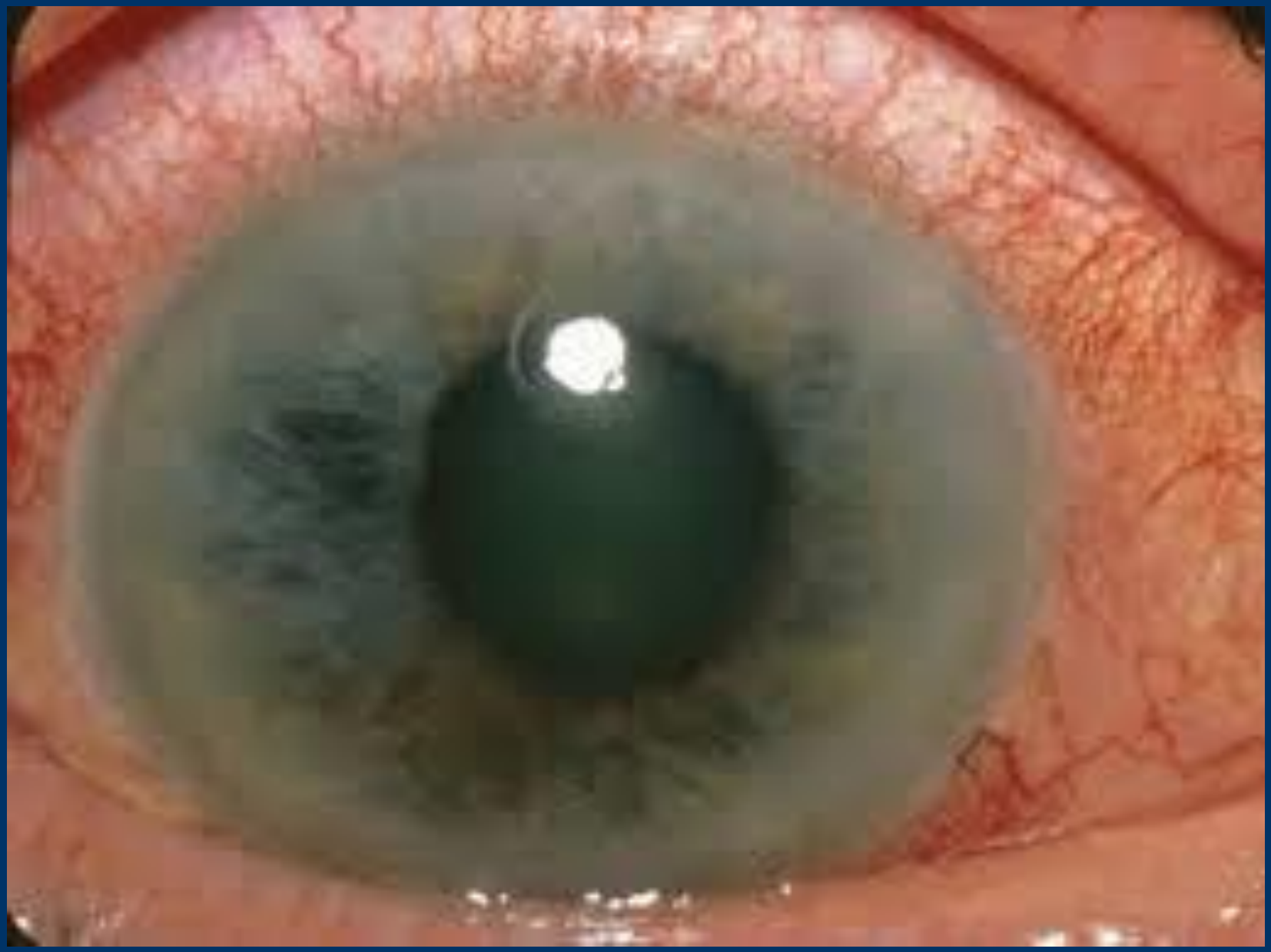

Trabecular meshwork
Iris
Cornea
Ciliary body
Lens


Obstructed trabecular meshwork
The angle between the iris and the cornea narrows or closes
Iris pushing forward
Cornea
Ciliary body
Lens

Symptoms of angle-closure glaucoma

- Severe pain in eye or eyebrow
- Headache
- Nausea
- Blurred vision and rainbow halo (colored rings) around bulb light

Immediate care should be taken if two or more of these symptoms appear together!

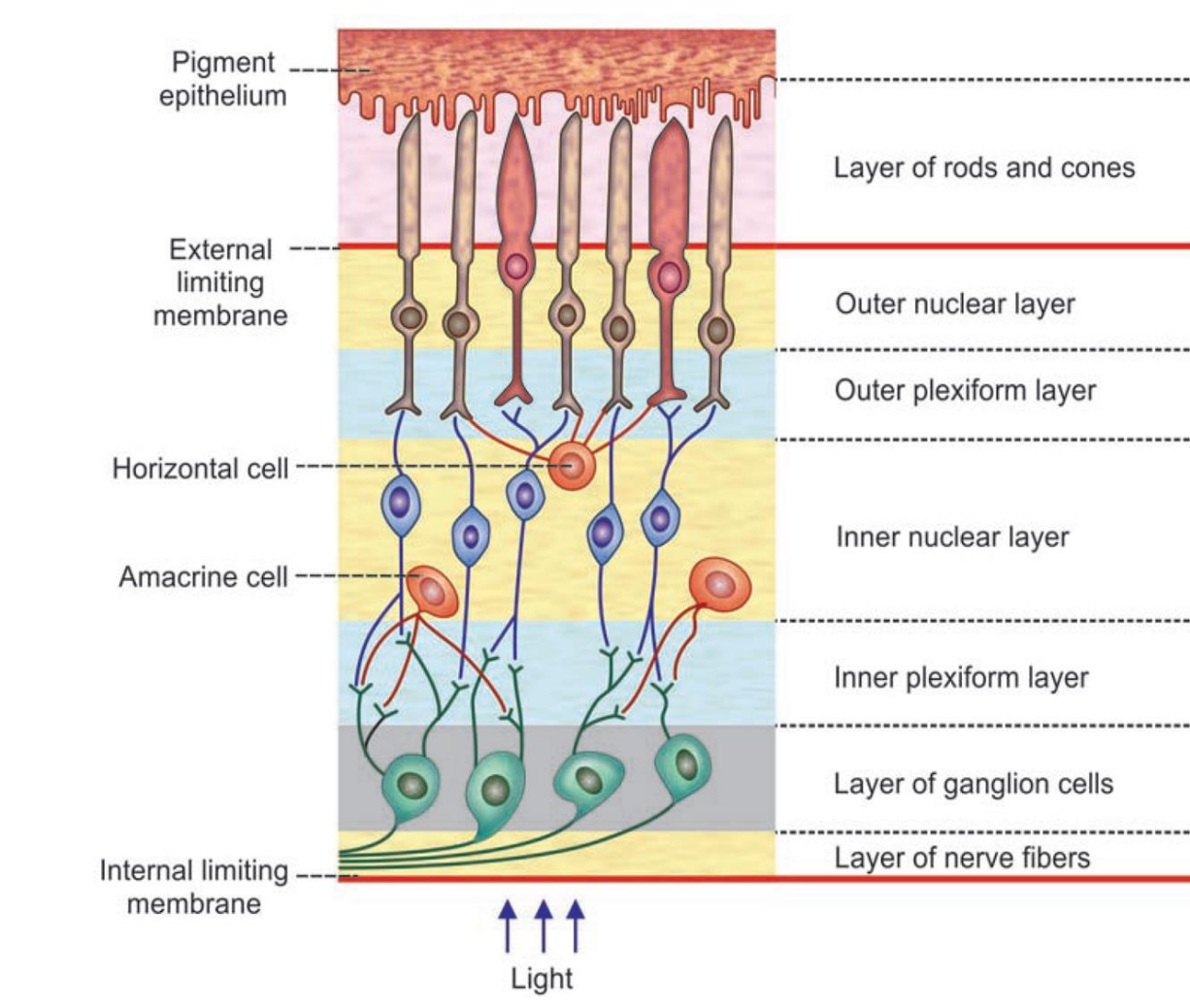


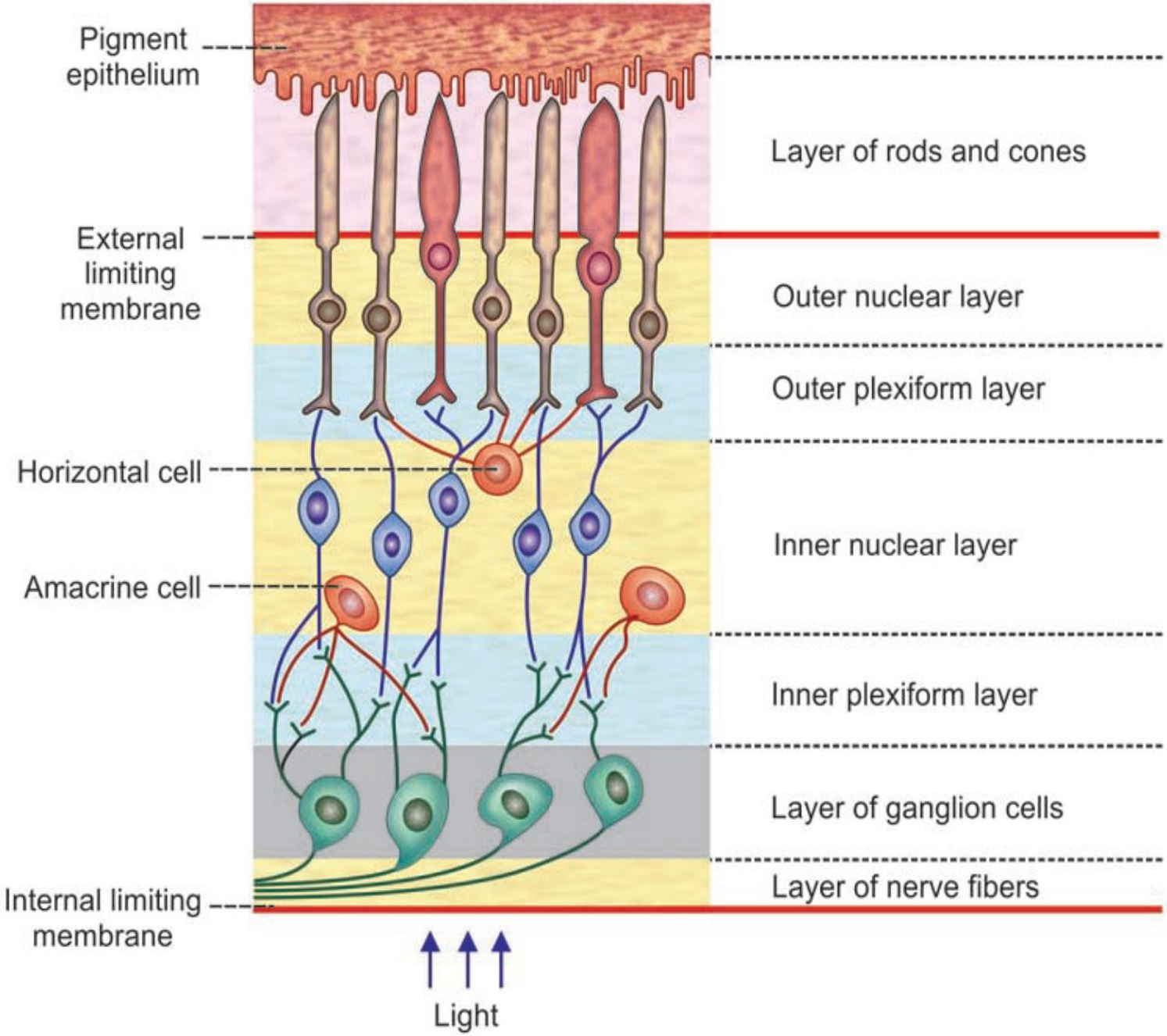
Retina

- Retina is a delicate light-sensitive membrane that forms the innermost layer of eyeball.
- It extends from the margin of optic disk to just behind ciliary body.
- Retina has the receptors of vision: **rods** and **cones**
- Retina is made up of **10 layers**

Layers of retina (from outside)

1. Layer of pigment epithelium
2. Layer of rods and cones
3. External limiting membrane
4. Outer nuclear layer
5. Outer plexiform layer
6. Inner nuclear layer
7. Inner plexiform layer
8. Ganglion cell layer
9. Layer of nerve fibers
10. Internal limiting membrane




Pigment epithelium
Layer of rods and cones
External limiting membrane
Outer nuclear layer
Outer plexiform layer
Horizontal cell
Inner nuclear layer
Amacrine cell
Inner plexiform layer
Layer of ganglion cells
Layer of nerve fibers
Internal limiting membrane
Light

Layer of Pigment Epithelium

- Light rays must pass through the ganglion cell and bipolar cell layers to reach the rods and cones.

- The pigment epithelium absorbs light and prevents reflection of light rays back from retina.

- Epithelial cells store **vitamin A** (retinol) and remove the debris from rod cells and cone cells by phagocytic action.

- The pigment present in this layer is a **melanin** called **fuscin**.

Fundus Oculi

Fundus oculi is the posterior part of interior eyeball. Fundus is examined by ophthalmoscope and has two important structures:

1**. Optic disk -** The optic nerve leaves the eye at a point 3 mm medial to and slightly above the posterior pole of the globe. Since there are no visual receptors over the disk, this area of the retina does not respond to light and is known as the **blind spot**.

2. **Macula lutea with fovea centralis -** Near the posterior pole of the eye, is a yellowish pigmented spot ; the fovea is in the center of the macula; it is a thinned-out, rod-free portion of the retina in which cones are densely packed. . There are no blood vessels; here visual acuity is greatest.

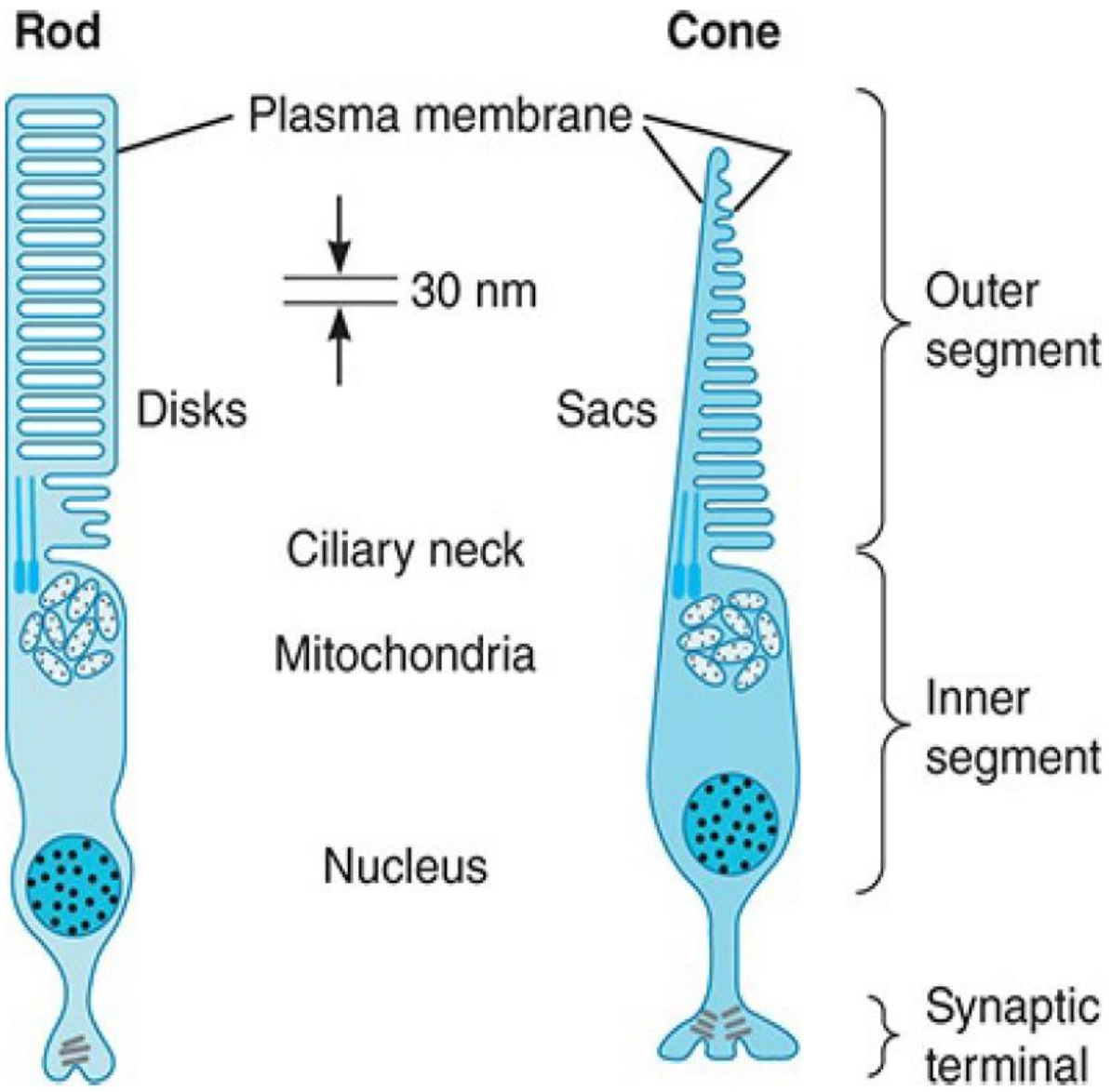
Photoreceptors

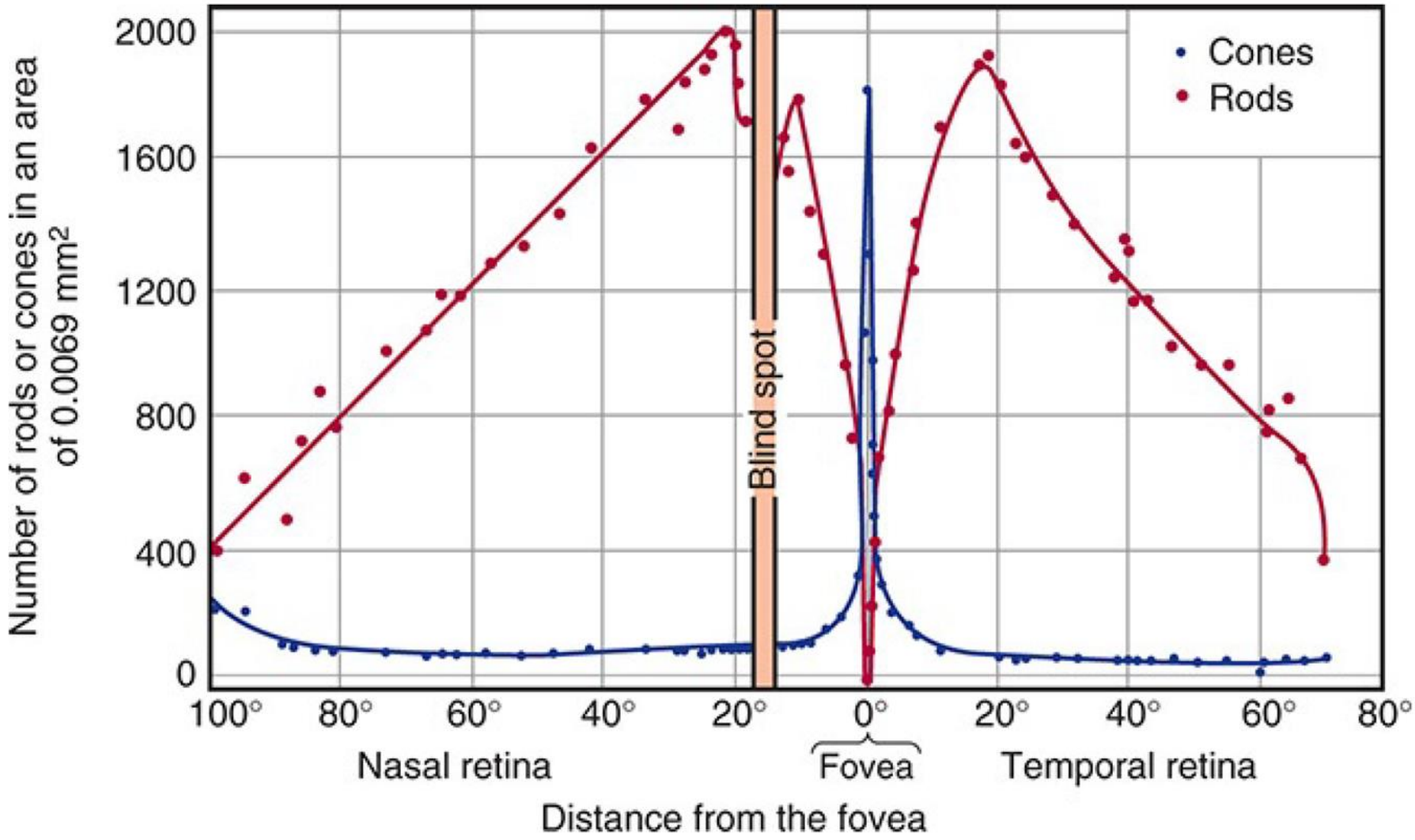
Photoreceptor is divided into :

.**an outer segment** - are modified **cilia** composed of regular stacks of flattened **saccules (cone)** or membranous **disks (rod) ;** contain the photosensitive compounds that react to light

.**an inner segment** that includes a nuclear region, is rich in mitochondria; this is the region that synthesizes the photosensitive compounds

.**a synaptic terminal zone**


Rod
Cone
Plasma membrane
30 nm
Disks
Sacs
Ciliary neck
Mitochondria
Nucleus
Outer segment
Inner segment
Synaptic terminal


Number of rods or cones in an area of 0.0069 mm²
2000
1600
1200
800
400
0
Cones
Rods
Blind spot
100°
80°
60°
40°
20°
0°
20°
40°
60°
80°
Nasal retina
Fovea
Temporal retina
Distance from the fovea

Features	Rods	Cones
Number in each eye	12 million	6 million
Length	40 to 60 μ	35 to 40 μ
Diameter	2 μ	5 μ
Shape	Cylindrical	Flask shaped
Outer segment	Long and slender	Small and conical
Sensitivity to light	More sensitive	Sensitive only to bright light
Threshold	Low	High
Type of vision responsible for	Dim light vision or night vision or scotopic vision	Bright light vision or day light vision or photopic vision
Acuity of vision	Not responsible	Responsible
Color vision	Not responsible	Responsible
Photosensitive pigment	Rhodopsin	Porphyropsin or iodopsin or cyanopsin

The photoreceptor mechanism

When light is absorbed by photosensitive compounds in the rods and cones. their structure changes, and this triggers a sequence of events that initiates neural activity.

Most of the other neural elements in the retina are local, graded potentials, and it is only in the ganglion cells that all-or-none action potentials are generated.

The responses of the rods, cones, and horizontal cells are **hyperpolarizing** !!!
(Responses of the bipolar cells are either hyperpolarizing or depolarizing)

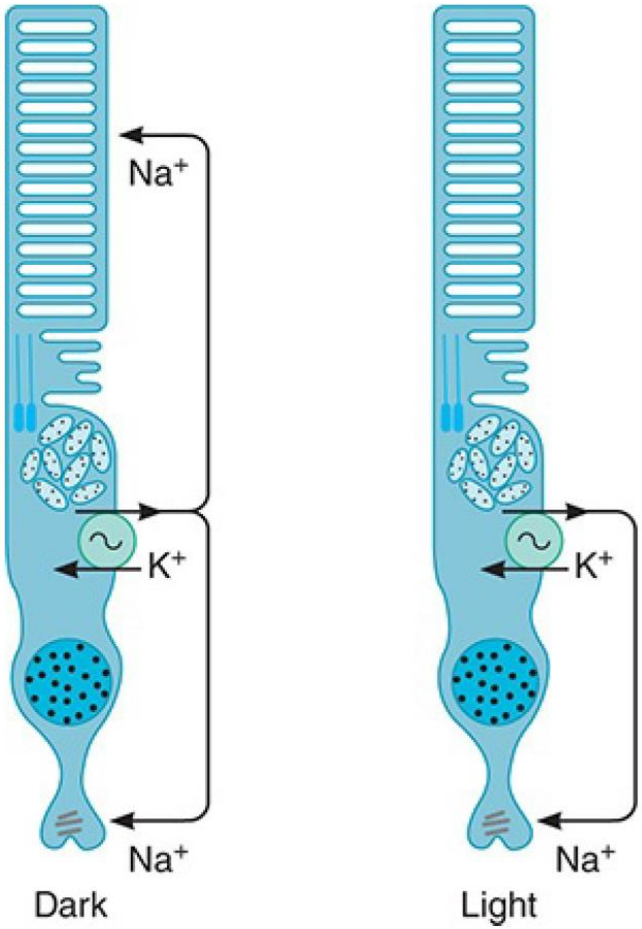
DARK

During darkness resting membrane potential is about **–40 mV**. Sodium ions are pumped out of inner segments of rod cell. These sodium ions leak back into the rod cells through membrane of outer segment. Influx of sodium ions into outer segment of rod cell occurs mainly because of cyclic guanosine monophosphate (cGMP). The cGMP always keeps the sodium channels opened. Concentration of sodium ions inside the rod cell is regulated by sodium potassium pump.

LIGHT

Light leads to increased conversion of cGMP to 5′-GMP, and some of the channels close. This produces **hyperpolarization -70mV** of the synaptic terminal of the photoreceptor.

(Resting membrane potential in other sensory receptor cells is usually between –70 and –90 mV).

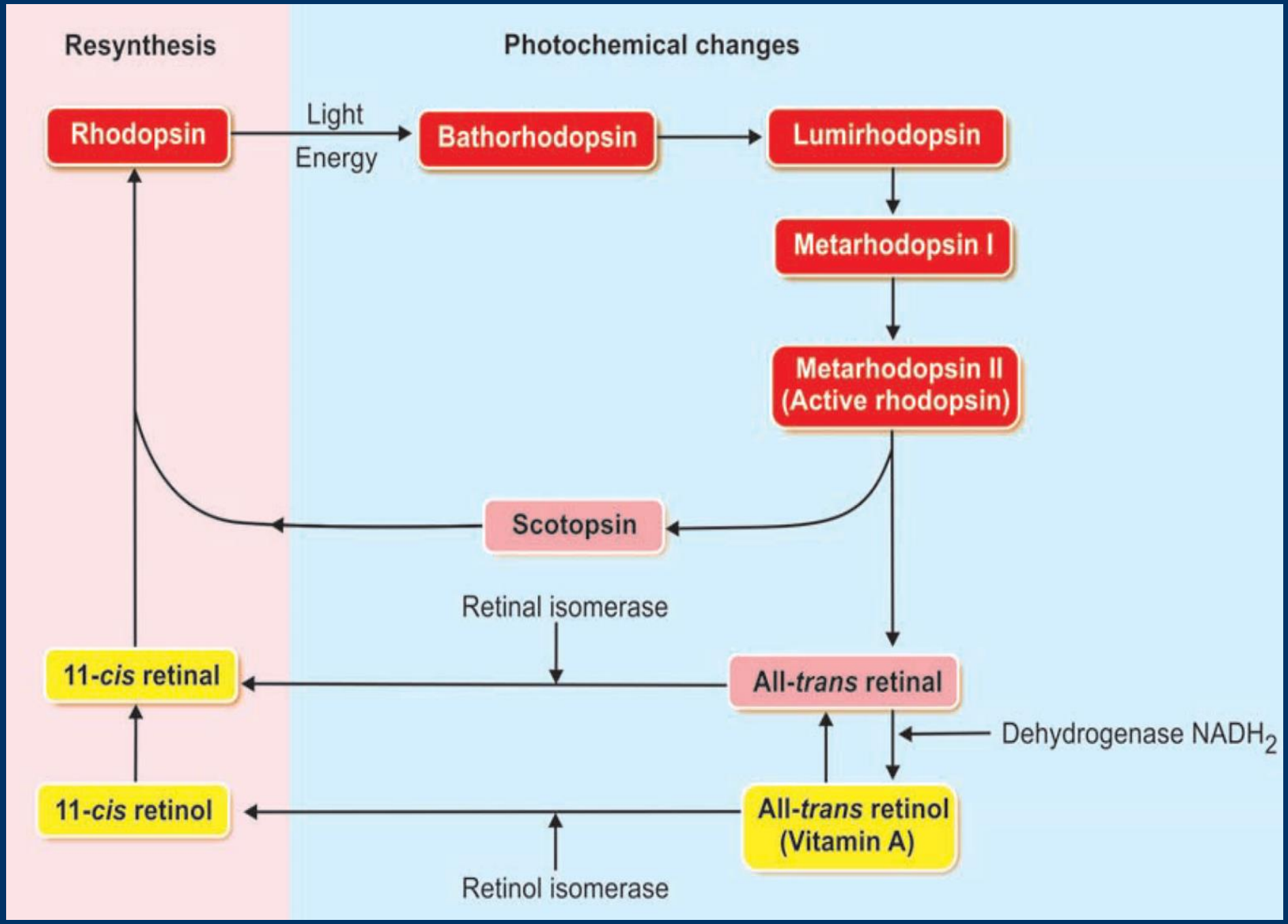

Na+
K+
Na+
Dark
K+
Na+
Light

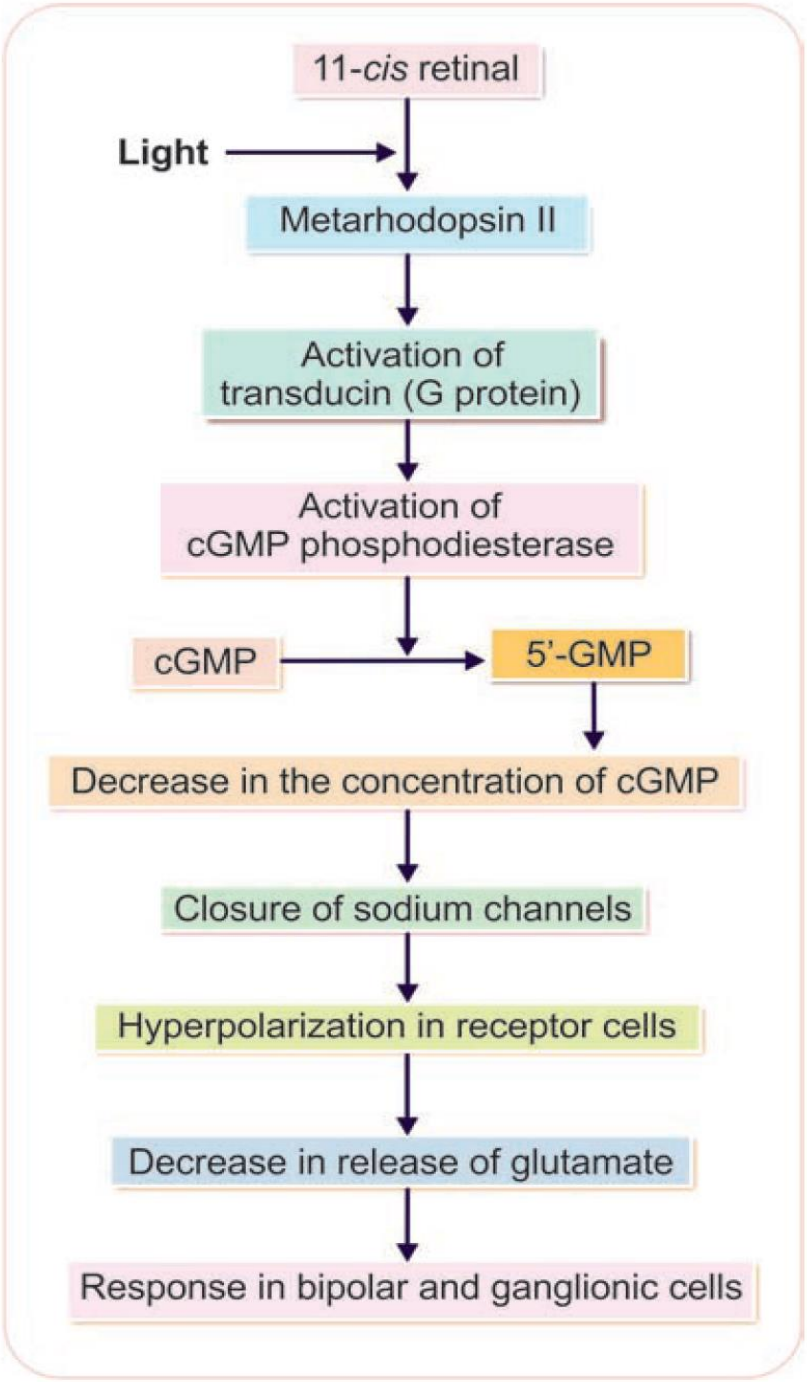
Rhodopsin

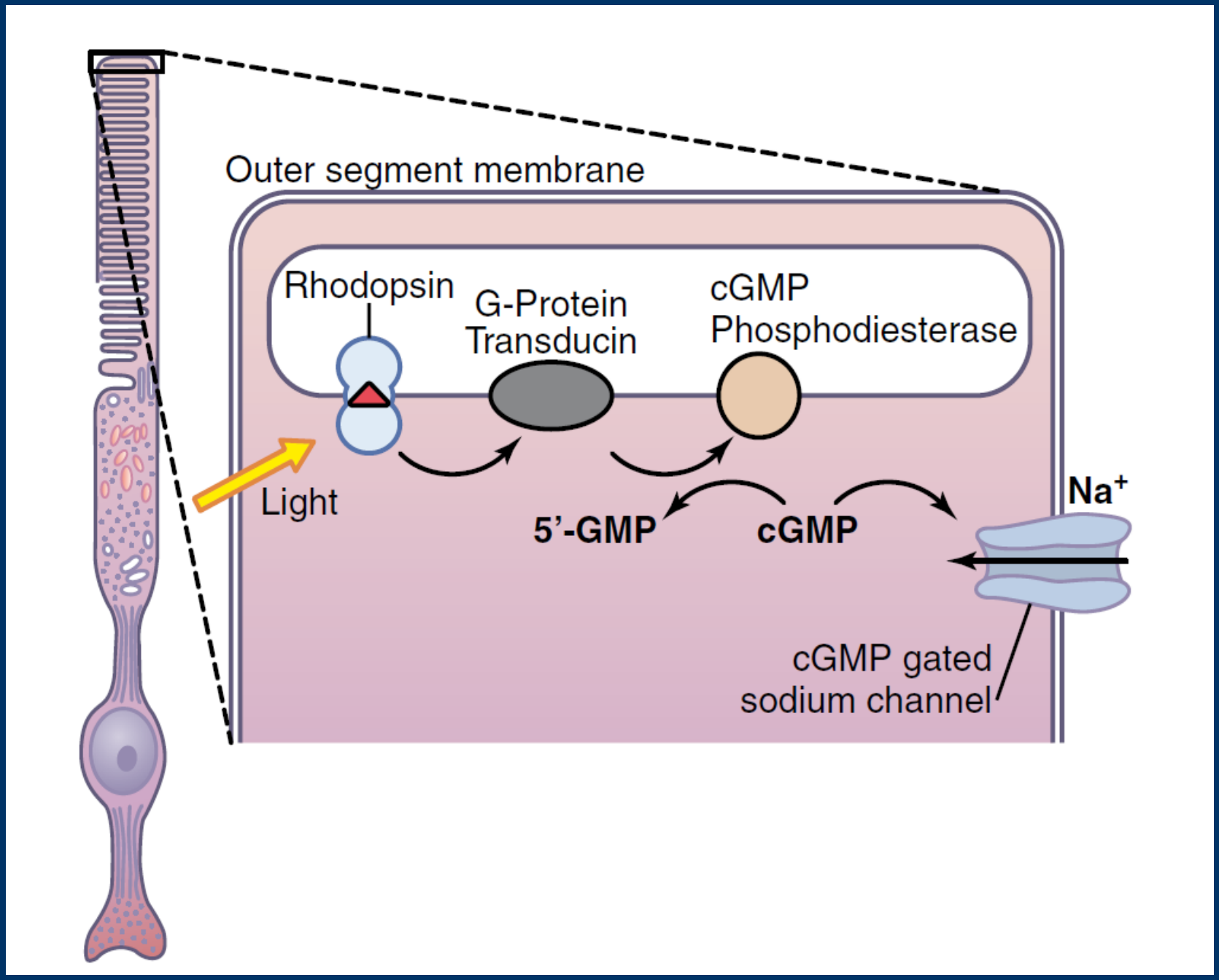
Rhodopsin (visual purple) is the photosensitive pigment in the rods and is composed of **retinal**, an aldehyde of vitamin A, and the protein **opsin**. Vitamin A is needed for the synthesis of retinal, so a deficiency in this vitamin produces visual abnormalities. Opsin present in rhodopsin is known as **scotopsin**.

Photosensitive pigment in cone cells is of three types, namely **porphyropsin, iodopsin** and **cyanopsin.** Protein in cone pigment is called **photopsin.**

Pigment	Sensitive to	Wavelength of maximum response
Porphyropsin	Red	665 nm
Iodopsin	Green	535 nm
Cyanopsin	Blue	445 nm


Resynthesis
Photochemical changes
Rhodopsin
Light
Energy
Bathorhodopsin
Lumirhodopsin
Metarhodopsin I
Metarhodopsin II
(Active rhodopsin)
Scotopsin
Retinal isomerase
11-cis retinal
All-trans retinal
Dehydrogenase NADH2
11-cis retinol
All-trans retinol
(Vitamin A)
Retinol isomerase


11-*cis* retinal
Light
Metarhodopsin II
Activation of transducin (G protein)
Activation of cGMP phosphodiesterase
cGMP
5'-GMP
Decrease in the concentration of cGMP
Closure of sodium channels
Hyperpolarization in receptor cells
Decrease in release of glutamate
Response in bipolar and ganglionic cells


Outer segment membrane
Rhodopsin
G-Protein
Transducin
cGMP
Phosphodiesterase
Light
5'-GMP
cGMP
Na+
cGMP gated
sodium channel

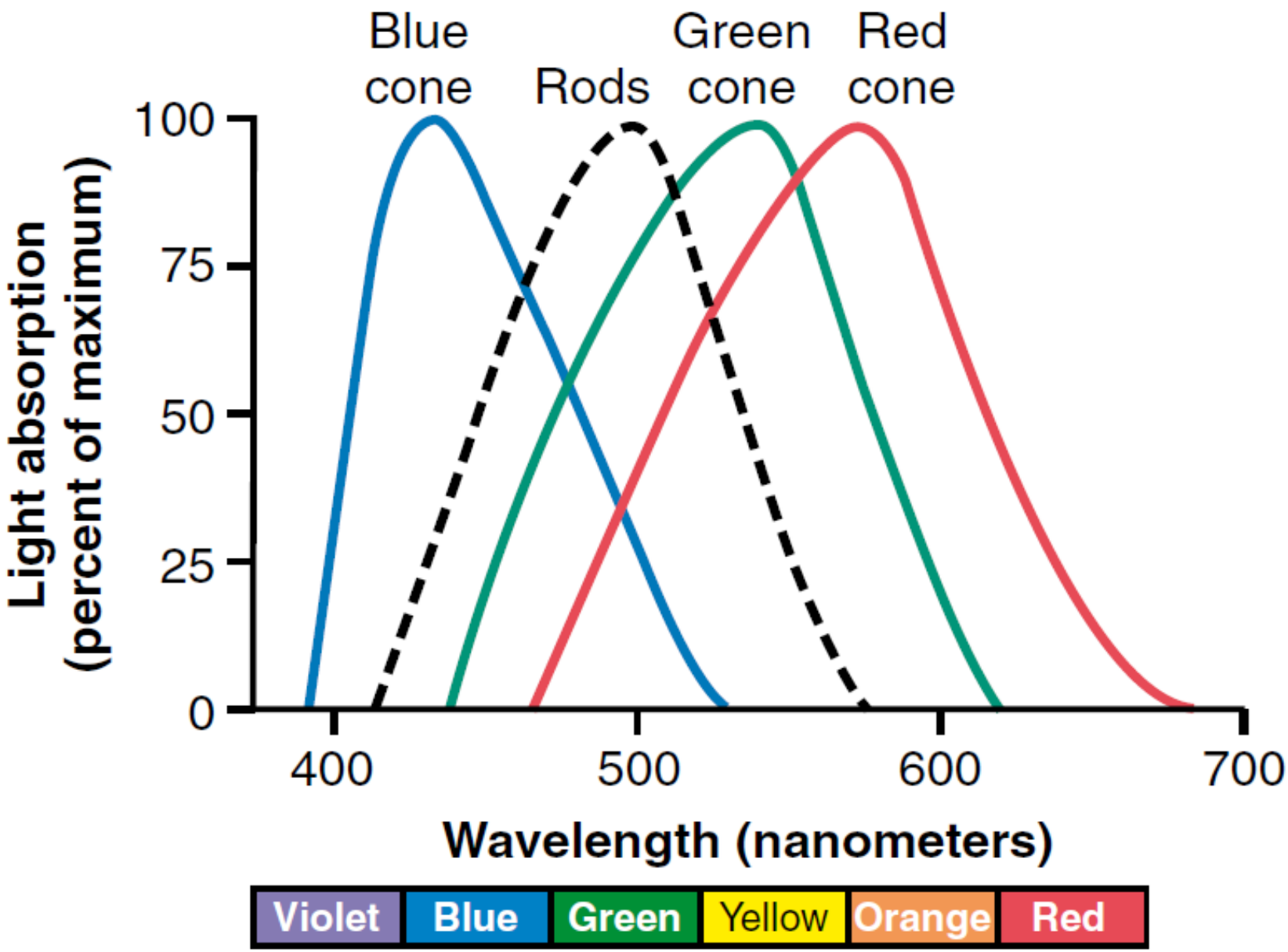
The Young–Helmholtz theory

Theory of color vision is based on the existence of three kinds of cones, each containing a different photopigment that is maximally sensitive to one of the three primary colors.

.**The blue-sensitive**, or short-wave, pigment absorbs light maximally in the blue-violet portion of the spectrum.

.**The green-sensitive**, or middle-wave, pigment absorbs maximally in the green portion.

.**The red-sensitive**, or long-wave, pigment absorbs maximally in the red portion.


Blue cone
Rods
Green cone
Red cone
Light absorption (percent of maximum)
100
75
50
25
0
400
500
600
700
Wavelength (nanometers)
Violet
Blue
Green
Yellow
Orange
Red

CLASSIFICATION OF COLOR BLINDNESS

Based on Young-Helmholtz trichromatic theory, color blindness is classified into three types:

1. **Monochromatism (achromatopsia)** is characterized by total inability to perceive color- color blindness They see the whole spectrum
in only black, white and different shades of grey

.***Rod monochromatism***- cones functionless and the vision depends purely on rods, visual acuity is lowered and foveal vision is absent - central scotoma (blind spot)

.***Cone monochromatism*** - vision depends upon one single type of cone. Central scotoma does not occur.

2. *Dichromatism*

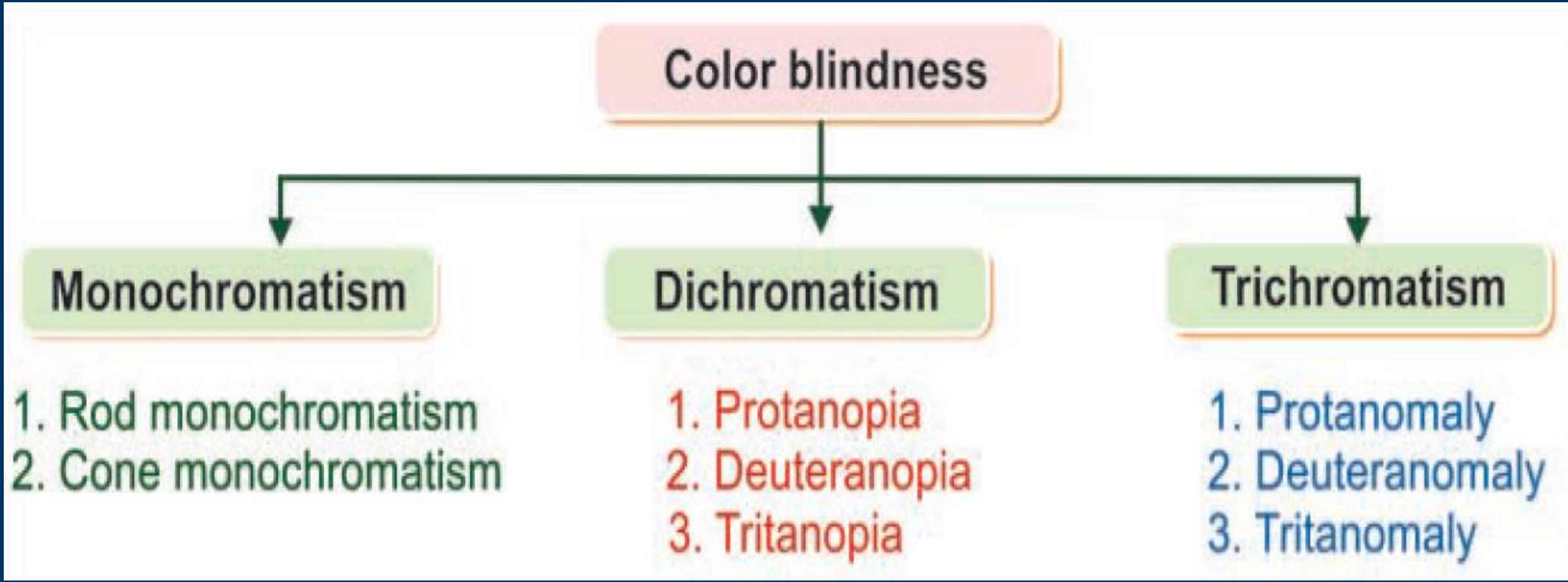
The subject can appreciate only two colors (dichromats).

.***Protanopia*** - defect in red receptors
.***Deuteranopia*** – *green receptors*
.***Tritanopia*** – *blue receptors*

3. *Trichromatism*

Intensity of one of the primary colors cannot be appreciated correctly

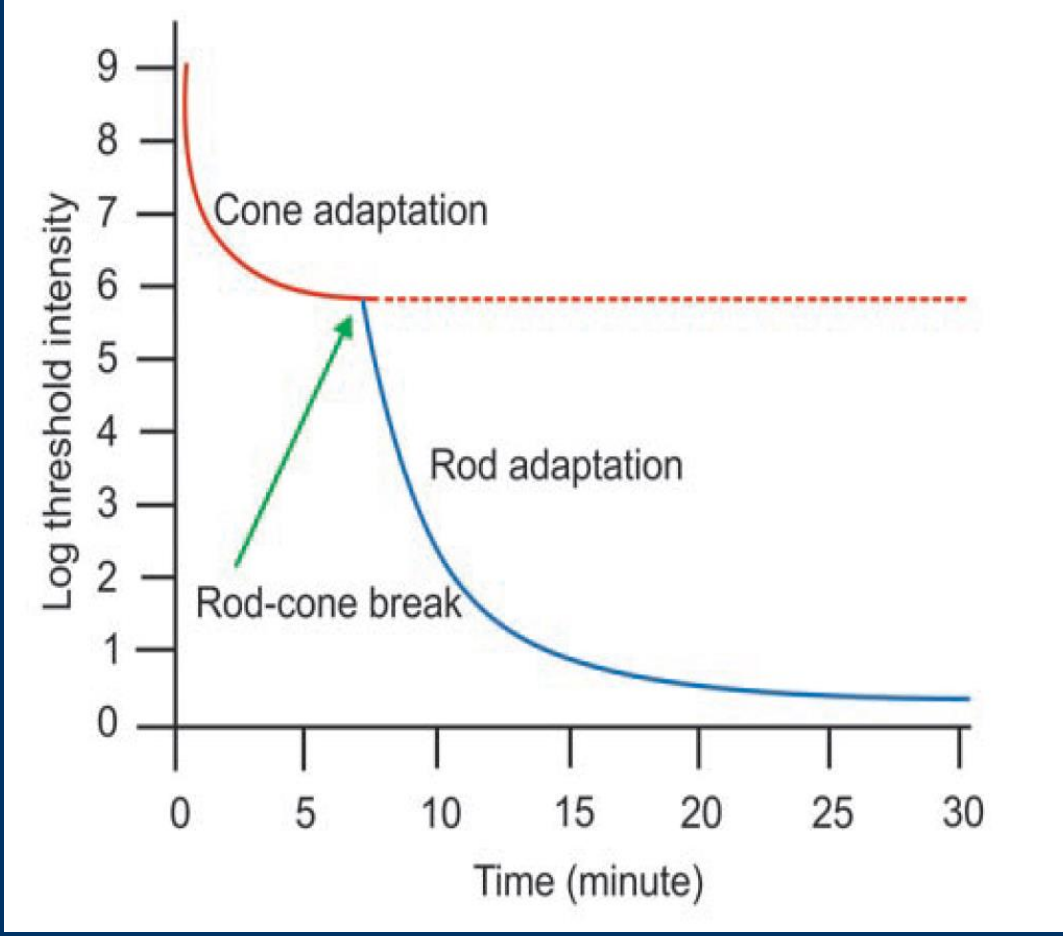
.***Protanomaly*** *i*n which the perception for red is weak.
.***Deuteranomaly*** – perception for green is weak
.***Tritanomaly***- weak perception for blue.


Color blindness
Monochromatism
Dichromatism
Trichromatism
1. Rod monochromatism
2. Cone monochromatism
1. Protanopia
2. Deuteranopia
3. Tritanopia
1. Protanomaly
2. Deuteranomaly
3. Tritanomaly

Dark adaptation

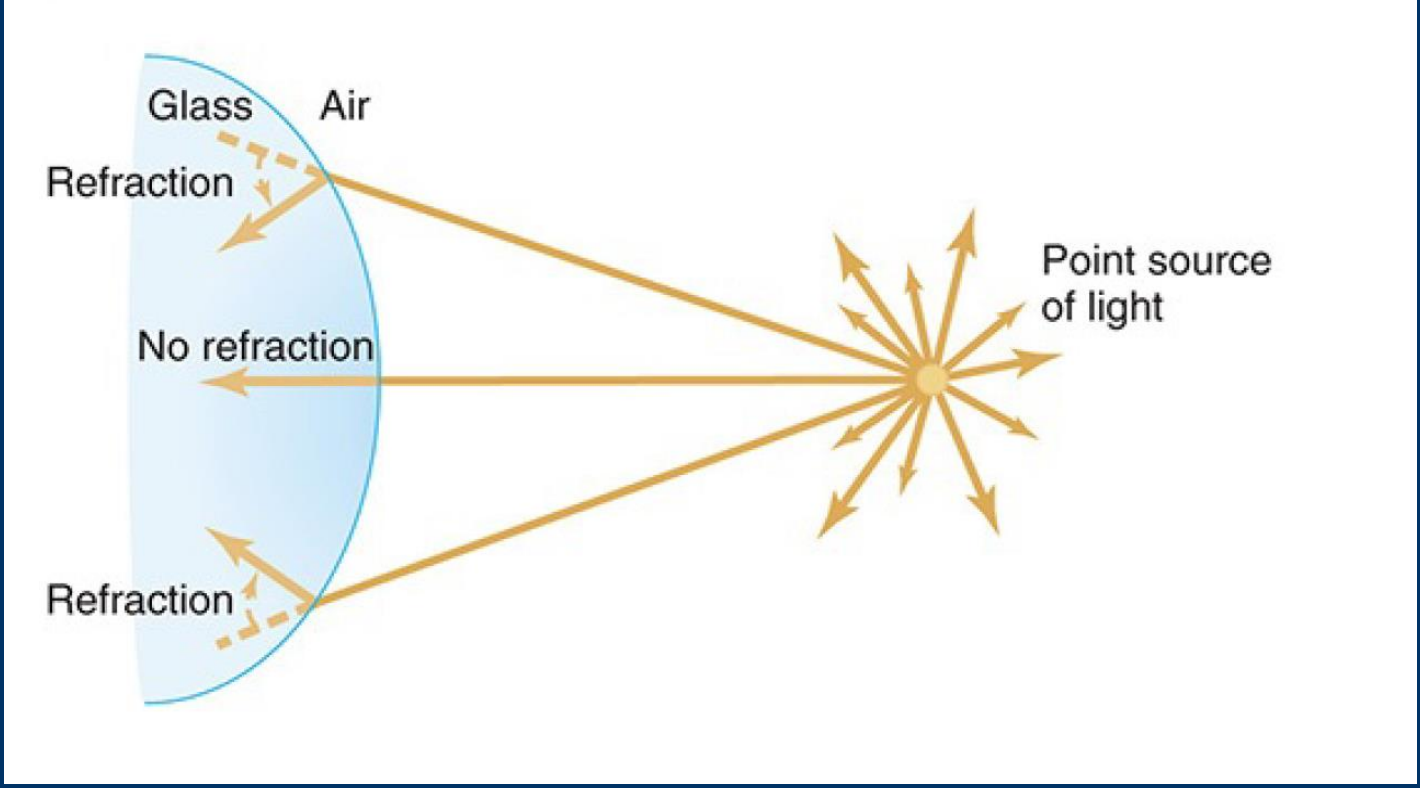
Dark adaption is the process by which the person is able to see the objects in dim light. The curve is biphasic:

- The first curve represents threshold of photopic vision, which indicates the cone adaptation, is rapid and it is completed in 8 to 10 minutes.
- The second curve represents threshold of scotopic vision, which indicates the rod adaptation; is slow, there is a gradual decrease in the threshold and it is completed in 20 to 30 minutes.



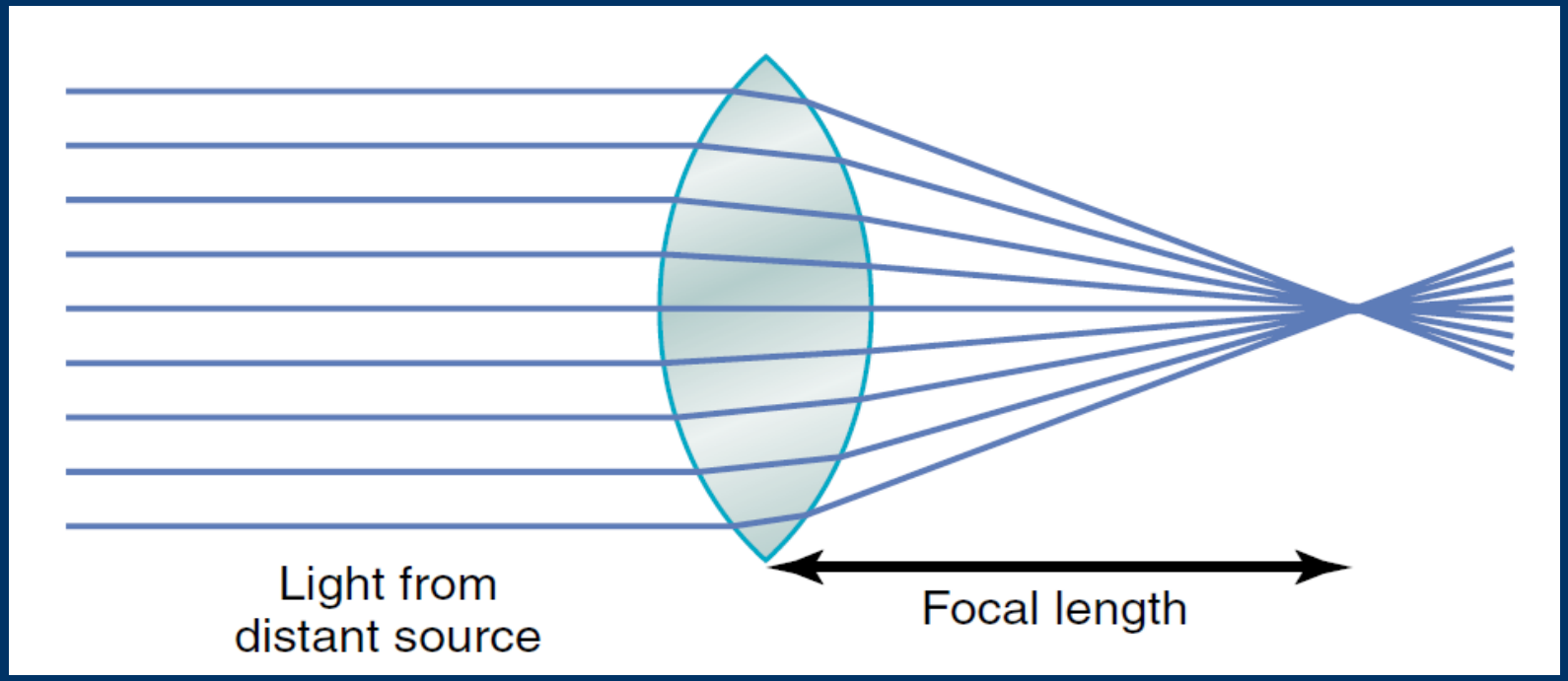
PRINCIPLES OF OPTICS

Light rays are bent when they pass from a medium of one density into a medium of a different density, except when they strike perpendicular to the interface.

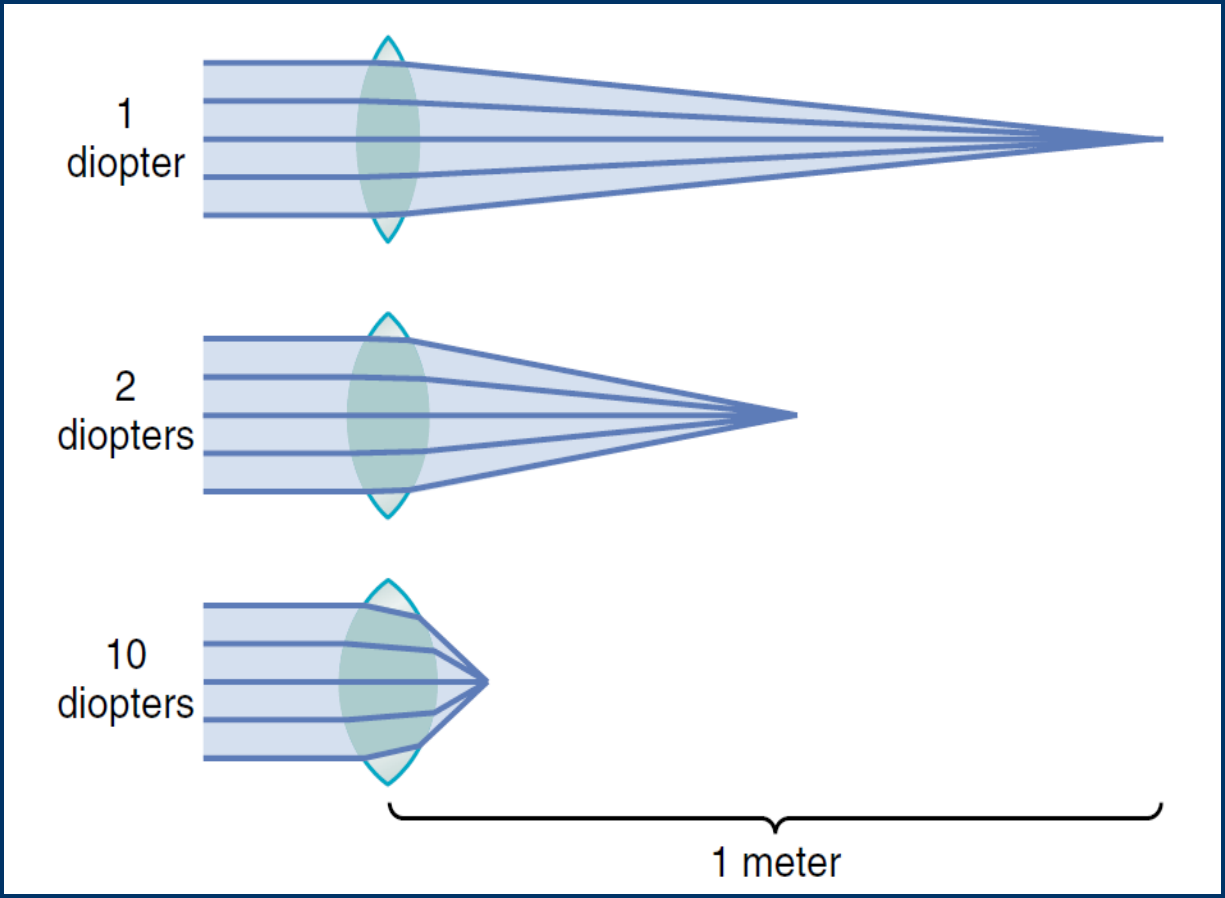


REFRACTION

Mechanism that allows one to focus an accurate image onto the retina. Parallel light rays striking a **biconvex lens** are refracted to a point behind the lens - **focal point or principal focus -** is on a line passing through the centers of curvature of the lens - **the principal axis**. The distance between the lens and the principal focus is **the focal length**.



Refractive power is greatest when the curvature of a lens is greatest

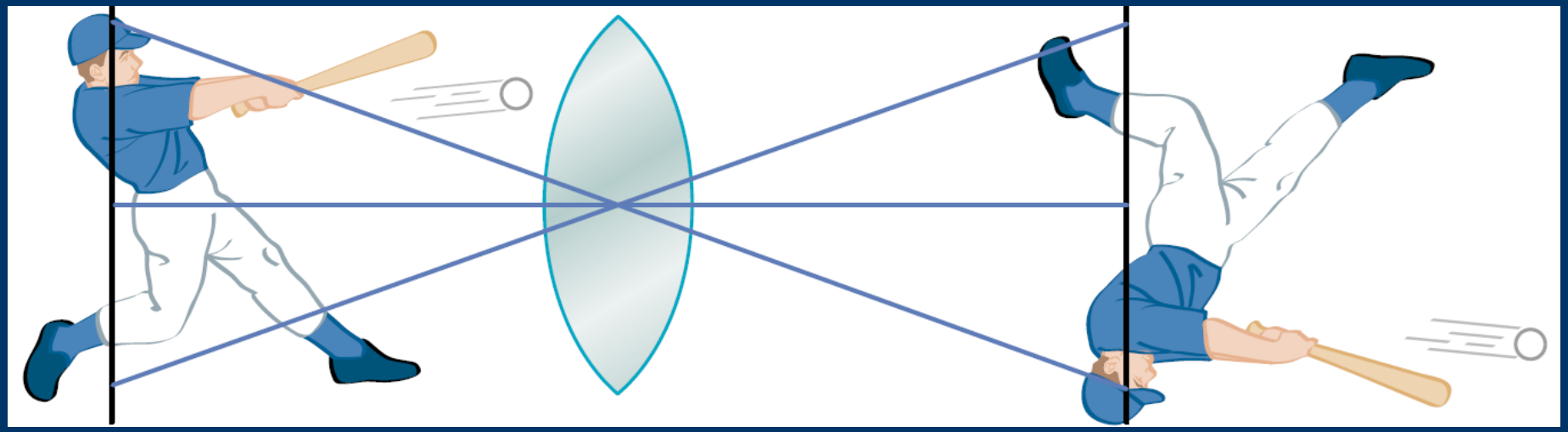


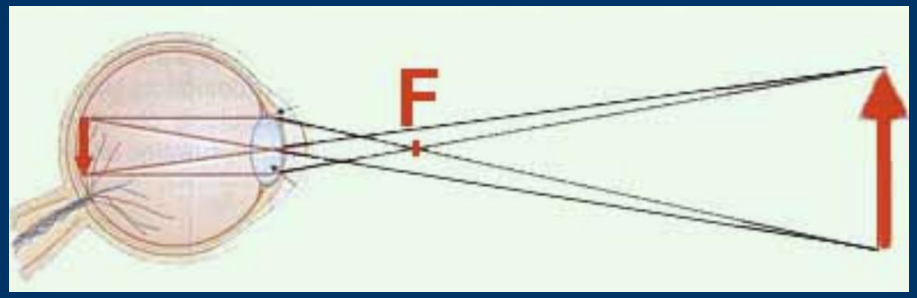
The refractive power of a lens is measured in diopters, the number of diopters being the reciprocal of the principal focal distance in meters.

$$P=1/f$$

P refractive power [D]
f focal length of the lens for parallel rays [m]

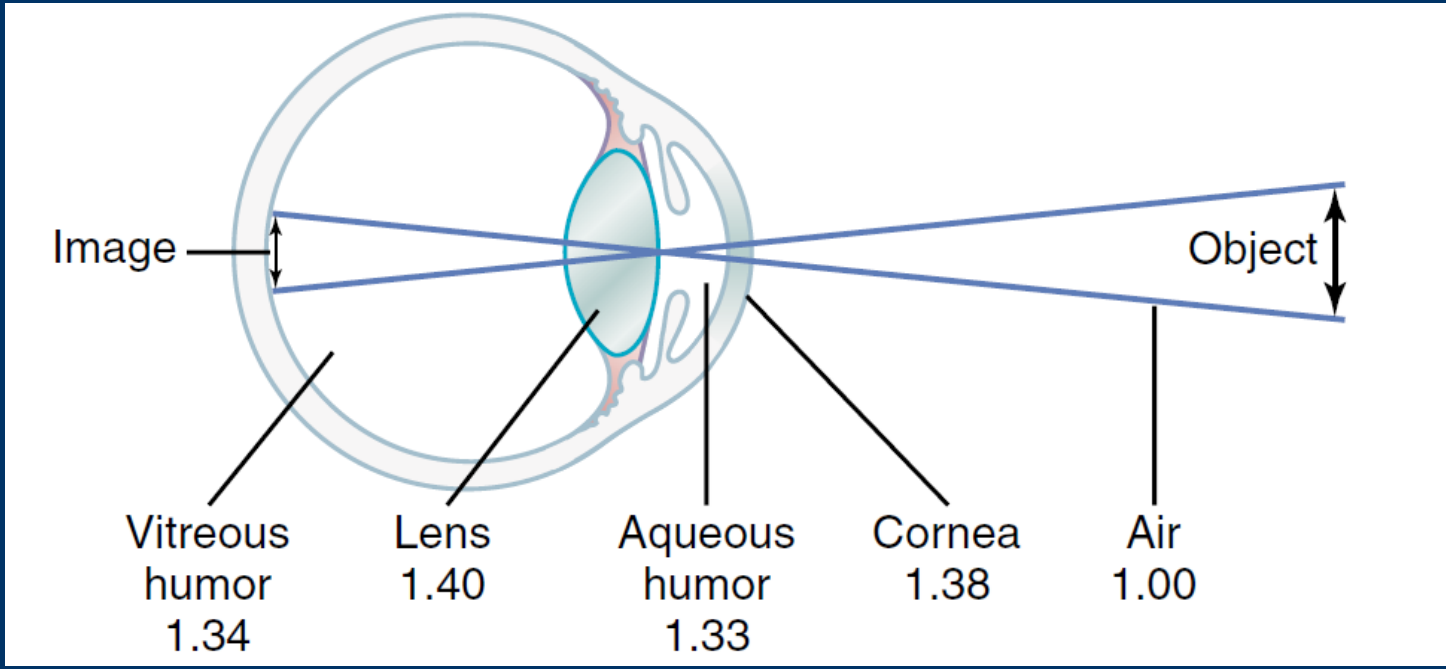
Image of the object falls on the retina in an inverted position and reversed side to side. Inspite of this, the object is seen in an upright position. It is because of the role played by cerebral cortex.





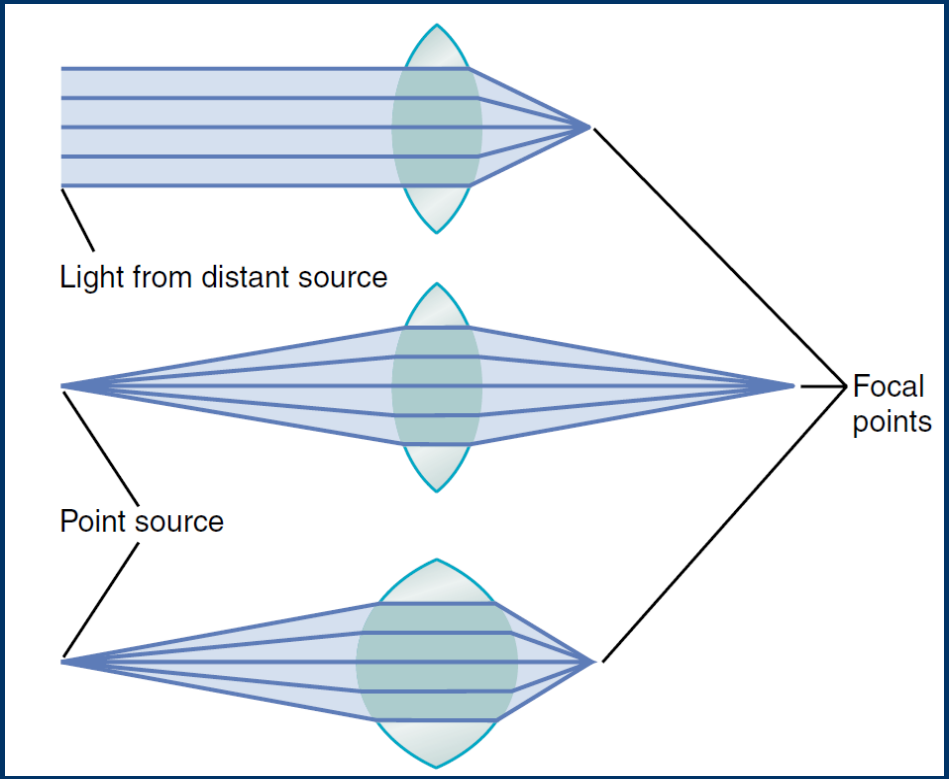
The human eye has a refractive power of **60 diopters** at rest.

- two thirds **(40D)** is provided by the anterior surface of the cornea (refractive index of the cornea is markedly different from that of air).
-
- One-third **(20 D)** is provide by the lens (is not greatly different from the indices of the aqueous humor and vitreous humor)



ACCOMMODATION

Accommodation is the adjustment of eye to see either near or distant objects clearly. It is the process by which light rays from near objects or distant objects are brought to a focus on sensitive part of retina.

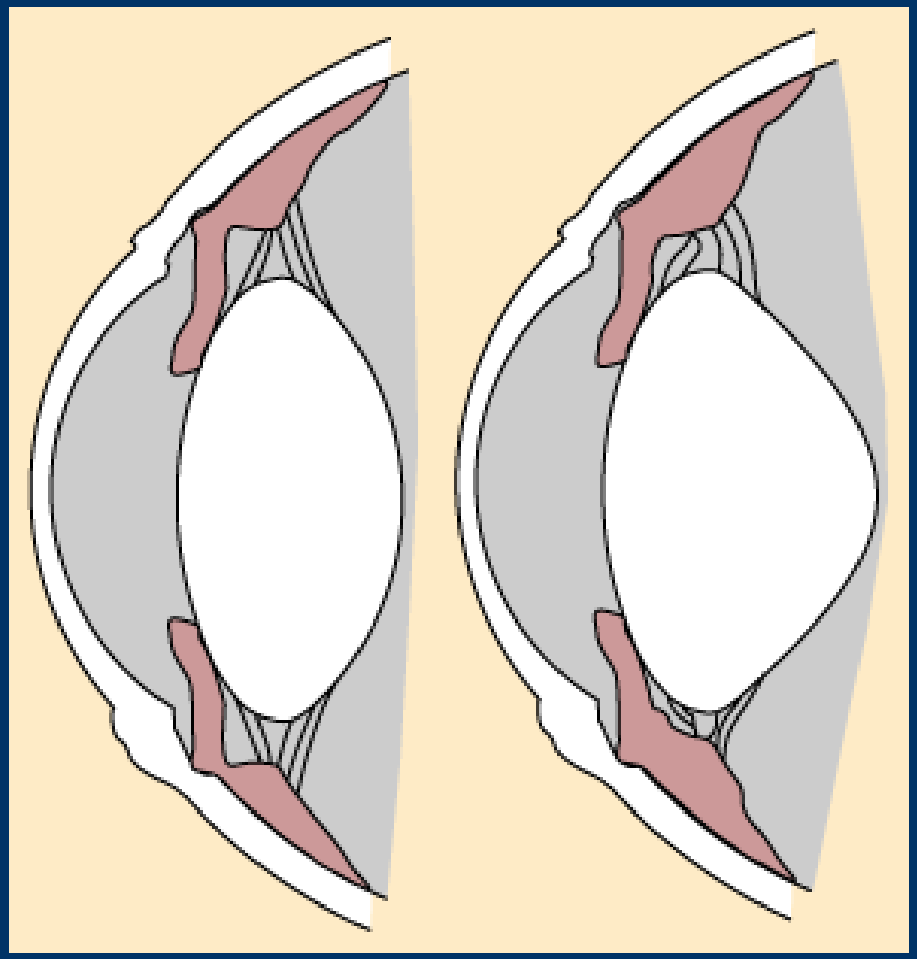


- rays from objects <u>further than 6 m</u> from the observer the ciliary muscle is relaxed
- – **no accommodation**

- rays from objects <u>closer than 6 m</u> from the observer - **accommodation**

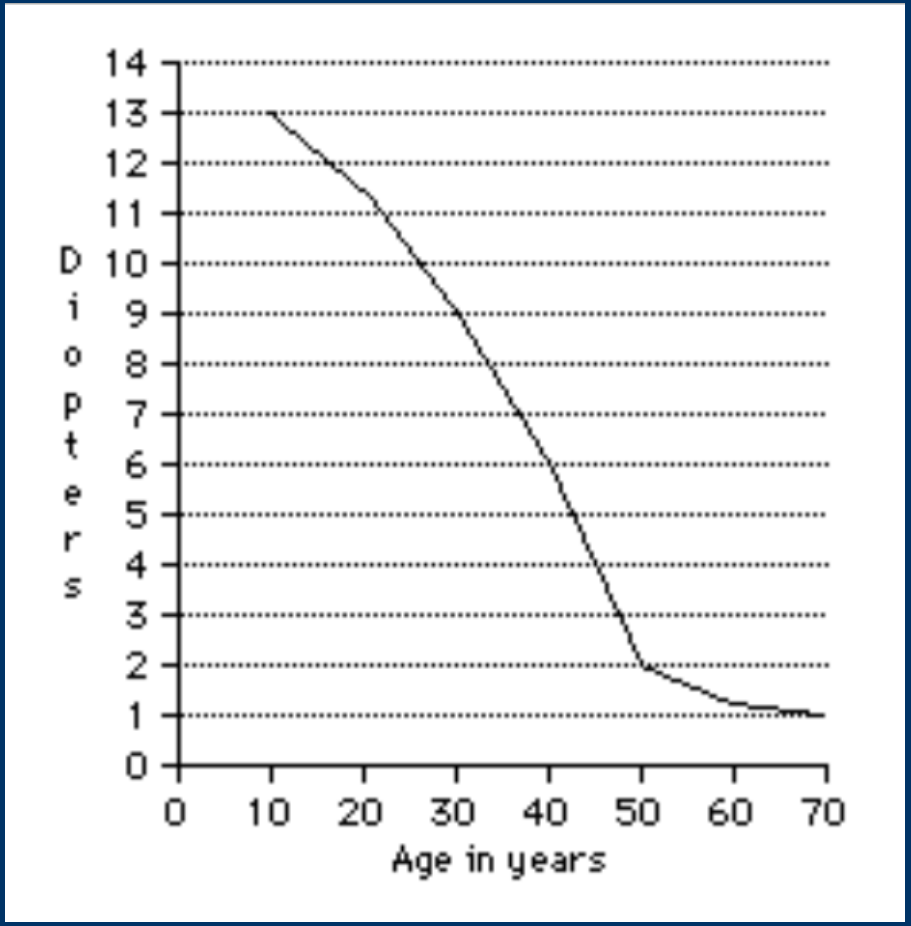
At rest, the lens is held under tension by the lens ligaments. Because the lens substance is malleable and the lens capsule has considerable elasticity, the lens is pulled into a flattened shape.

If the gaze is directed at a near object, the ciliary muscle contracts. This decreases the distance between the edges of the ciliary body and relaxes the lens ligaments, so that the lens springs into a more convex shape



The nearest point to the eye at which an object can be brought into clear focus by accommodation is called the **near point of vision**. The near point recedes throughout life.

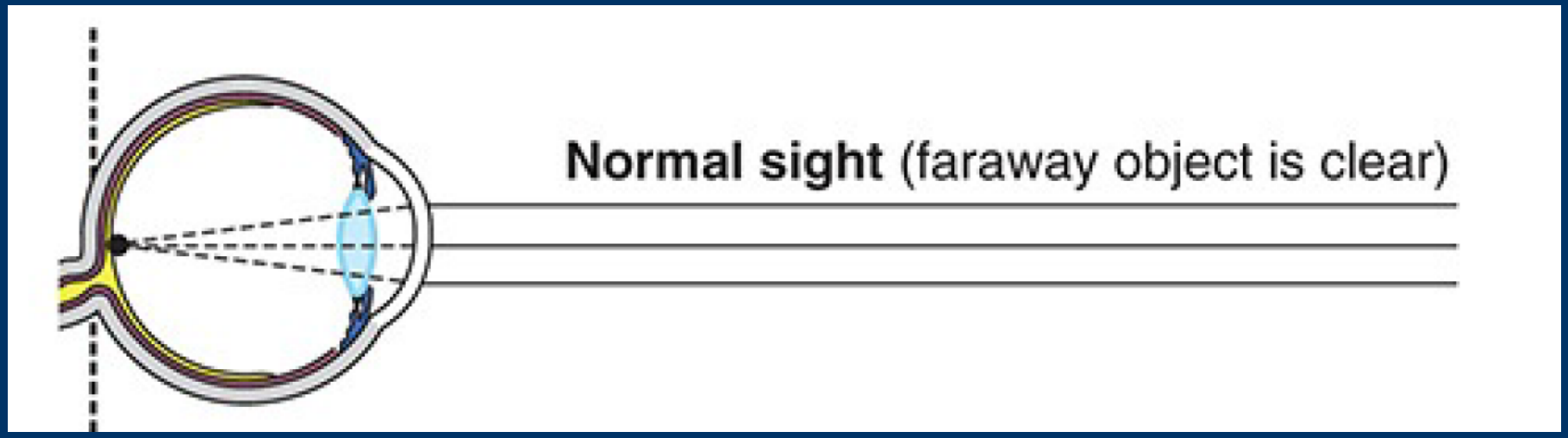
Recession is due to increasing hardness of the lens, (known as **presbyopia -** can be corrected by wearing glasses with convex lenses)



AMETROPIA

The eye with normal refractive power is called **emmetropic eye.** Any deviation in the refractive power from normal condition, resulting in inadequate focusing on retina is called **ametropia.**

1. Myopia
2. Hypermetropia
3. Astigmatism



MYOPIA OR SHORT SIGHTEDNESS

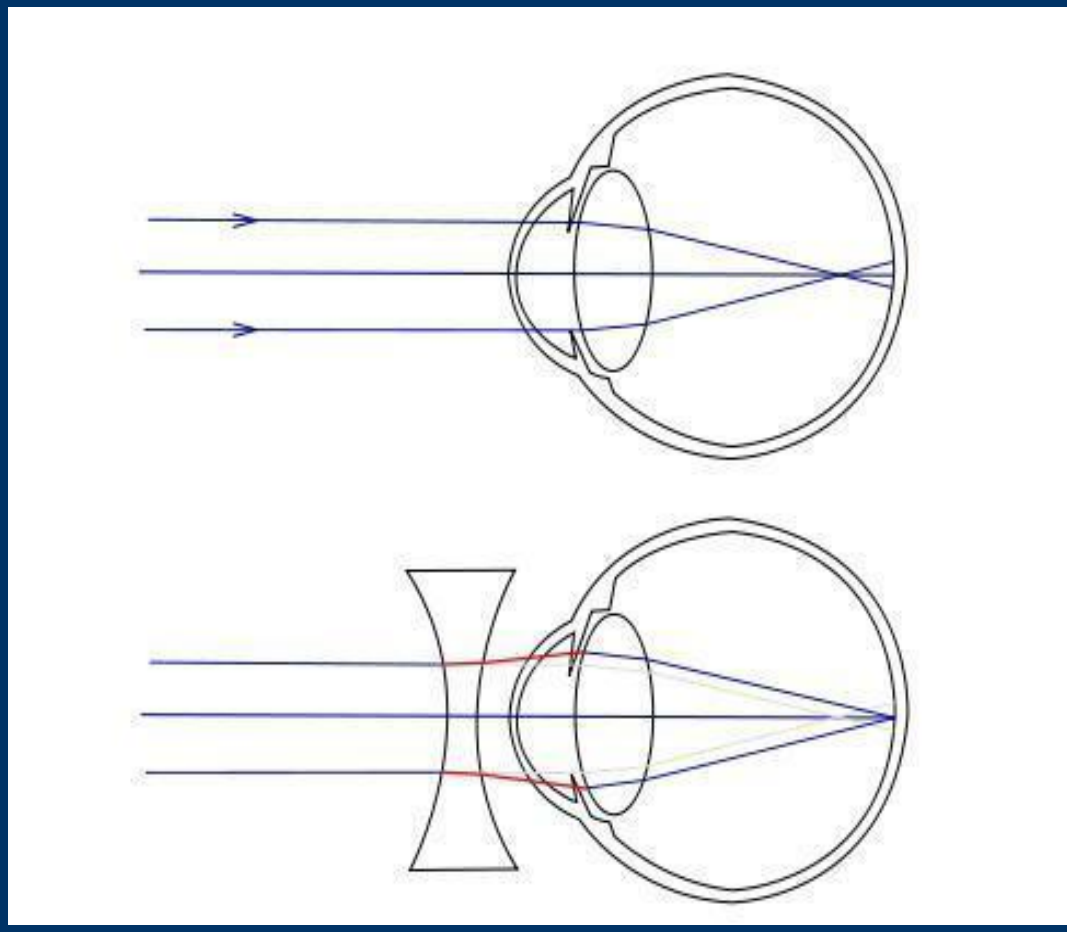
The inability to see the distant object. The person can see near objects clearly but not the distant objects. The near vision is normal but the far point is not infinite, it is at a definite distance

Cause

The refractive power of lens is usually normal. But, the **anteroposterior diameter** of the eyeball is abnormally long – the image is brought to focus a little in front of retina.

Correction

-biconcave lens. Light rays are diverged by the concave lens before entering the eye



HYPERMETROPIA OR LONG SIGHTEDNESS

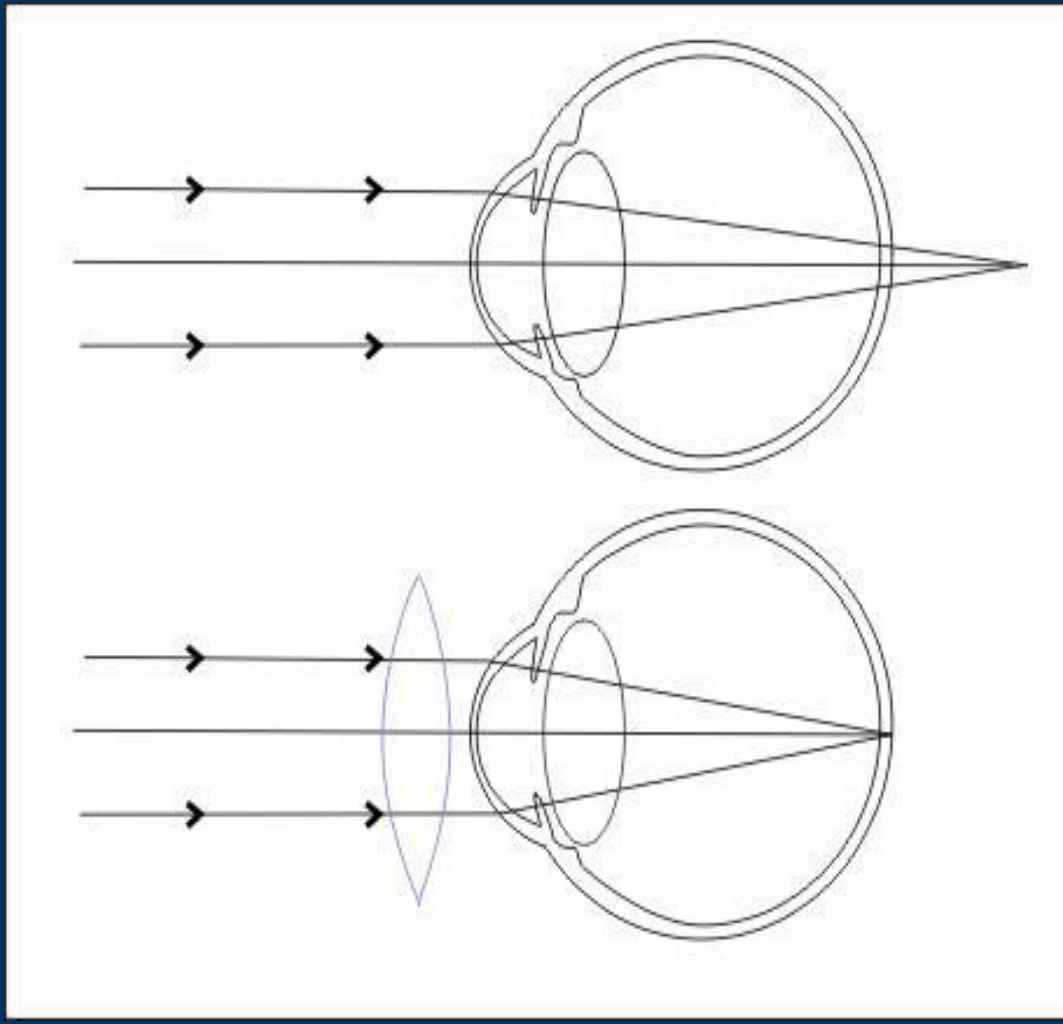
The inability to see near object. The person can see the distant objects clearly but not the near objects.

Cause

It is due to **decreased anteroposterior diameter** of the eyeball. The light rays are brought to a focus behind retina. It causes a blurred image of near objects.

Correction

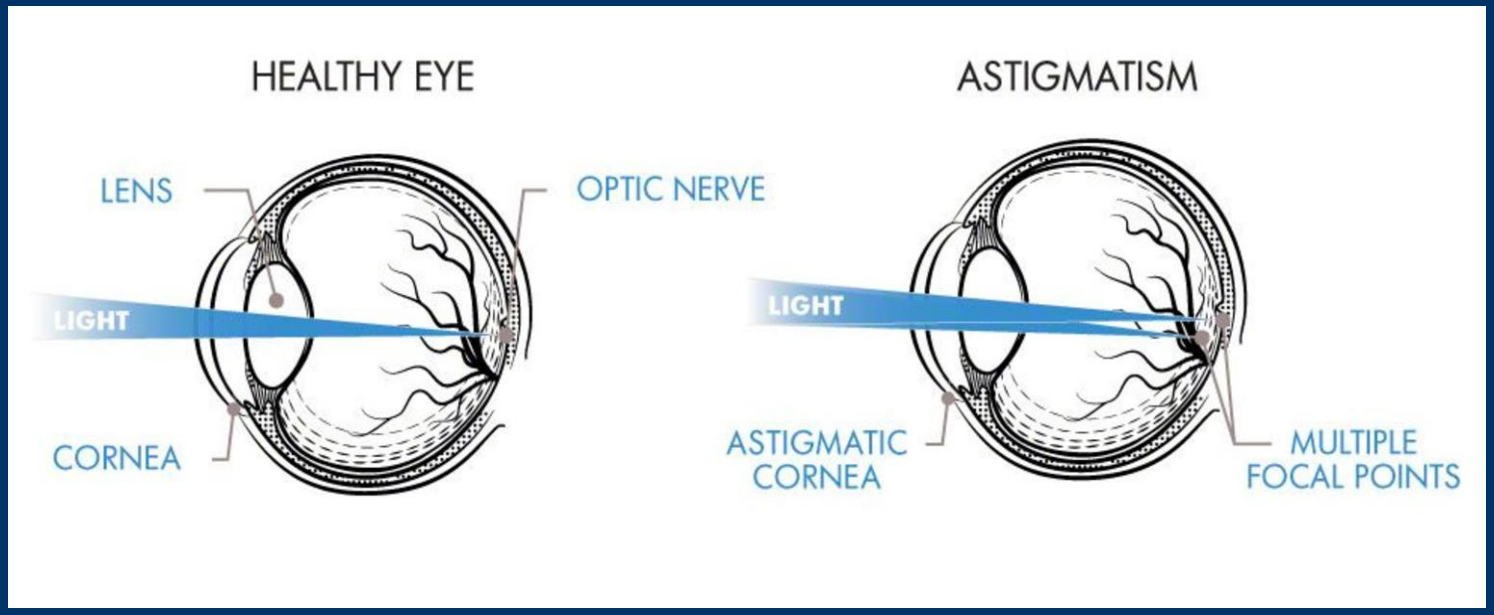
Hypermetropia is corrected by using **biconvex lens.** Light rays are converged by convex lens before entering the eye



ASTIGMATISM

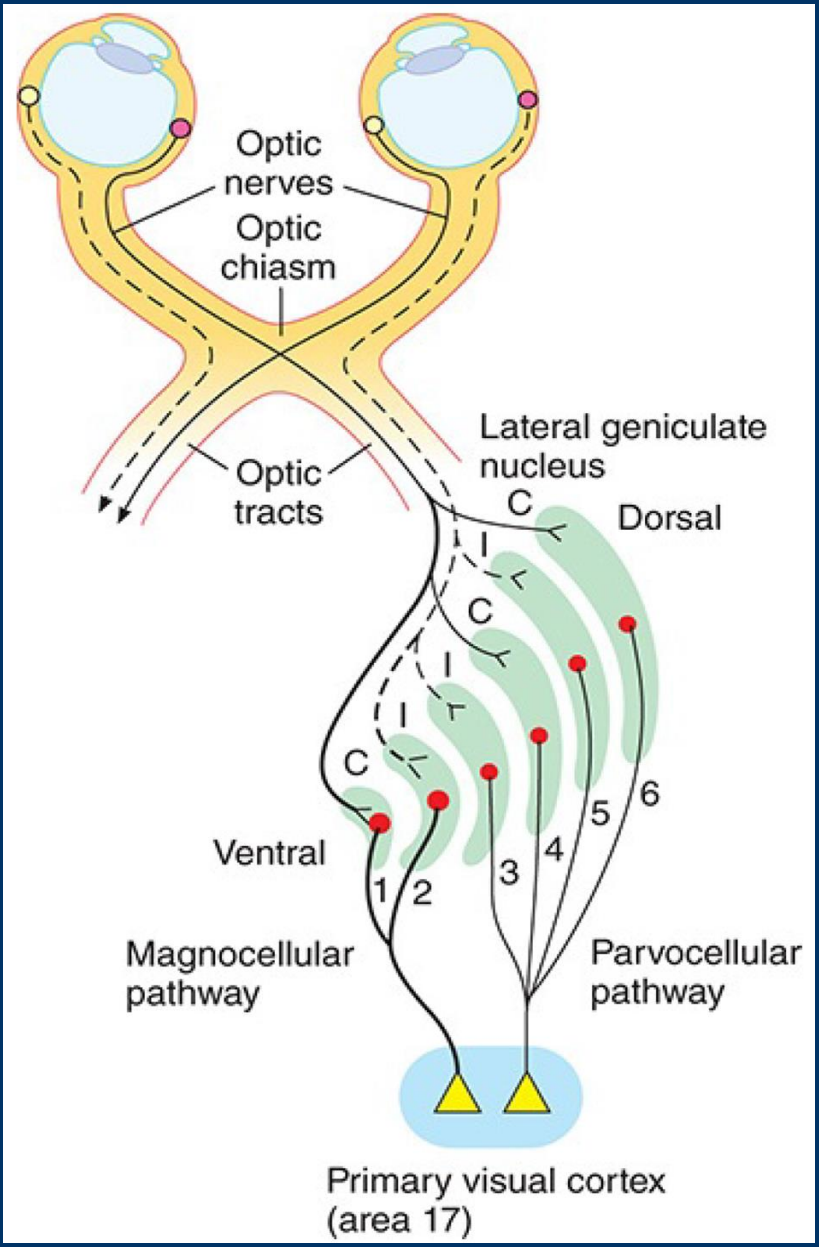
The curvature of the cornea is not uniform. When the curvature in one meridian is different from that in others, light rays in that meridian are refracted to a different focus.

- can usually be corrected with cylindric lenses placed in such a way that they equalize the refraction in all meridians.



VISUAL PATHWAYS

The axons of the ganglion cells pass caudally in the optic nerve and **optic tract** to end in the **lateral geniculate body** in the thalamus.
The fibers from each nasal hemiretina decussate in the **optic chiasm.** In the geniculate body, the fibers from the nasal half of one retina and the temporal half of the other synapse on the cells whose axons form the **geniculocalcarine tract.** This tract passes to the occipital lobe of the cerebral cortex.



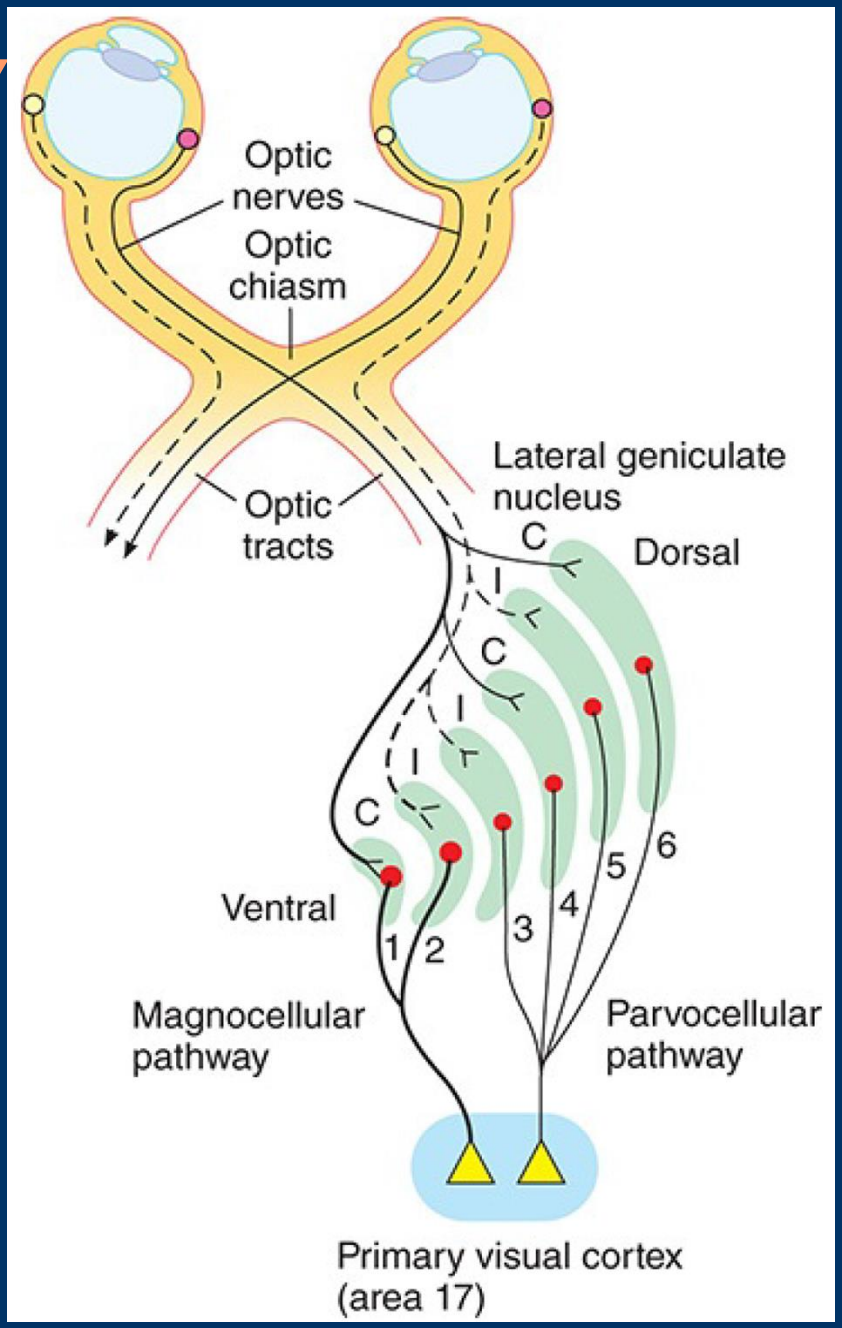
Lateral Geniculate Body

The geniculate body contains six layers:

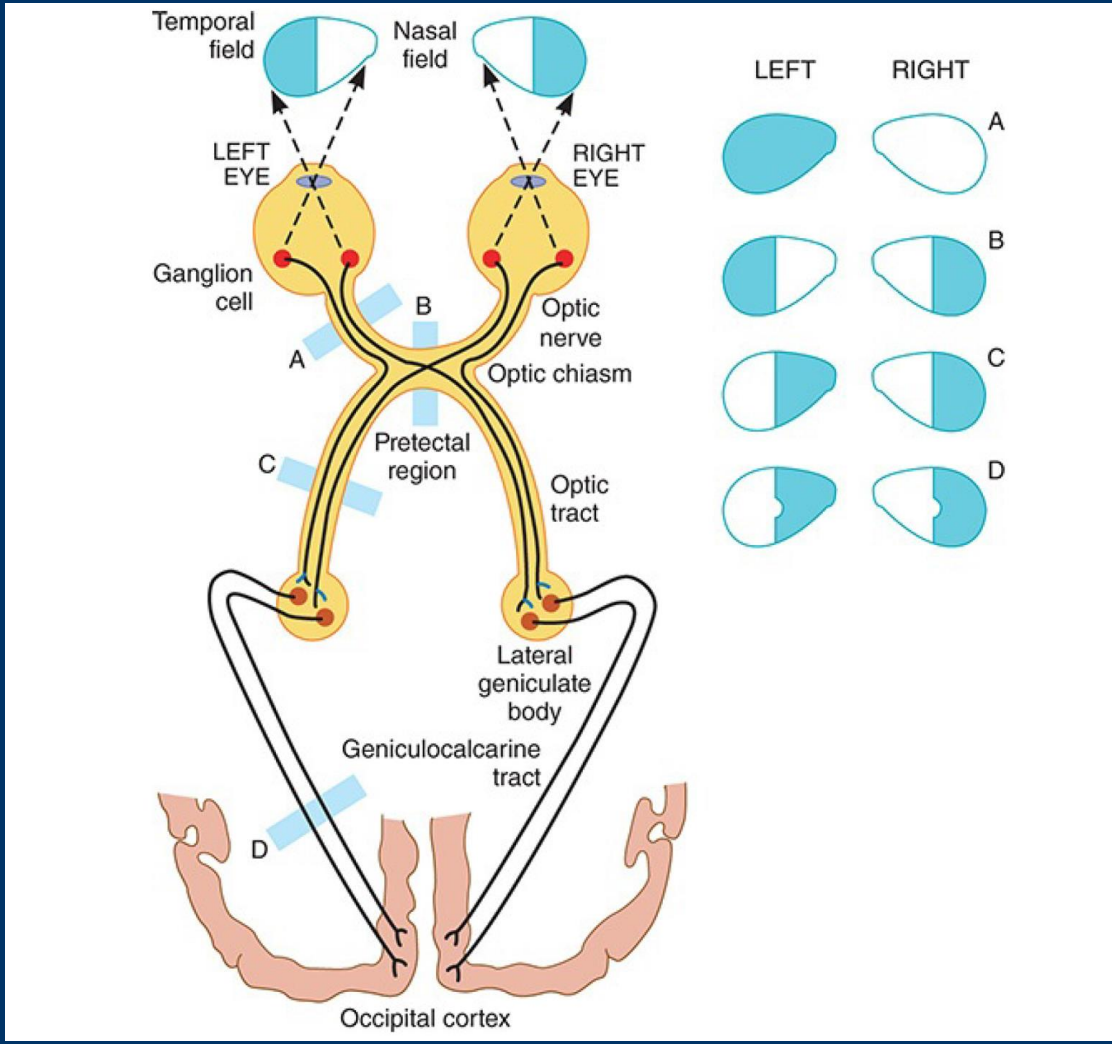
- layers 1 and 2 have large cells and are called magnocellular.

- layers 3–6 have small cells and are called parvocellular.

- Layers 1, 4, and 6 receive input from the contralateral eye, whereas layers 2, 3, and 5 receive input from the ipsilateral eye.



VISUAL PATHWAYS

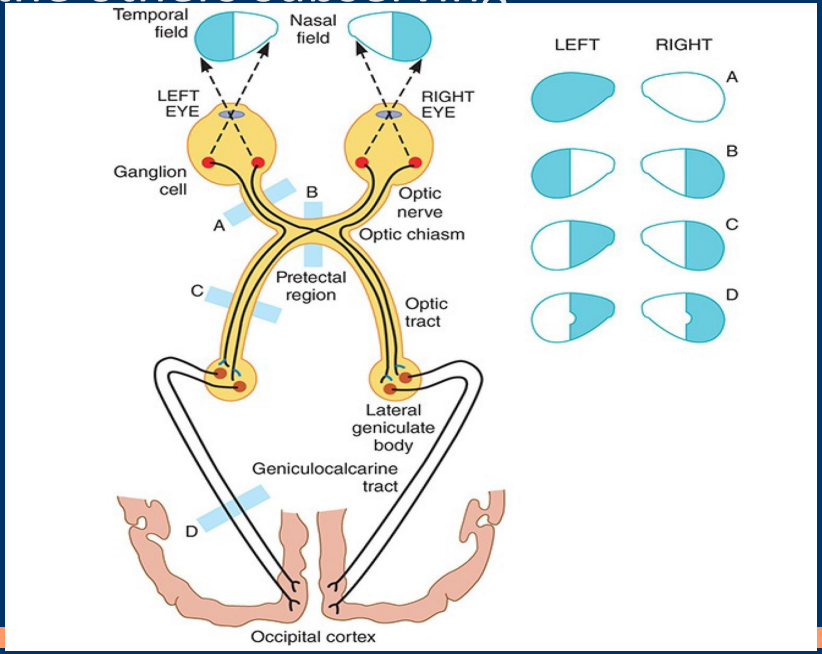


A - A lesion that interrupts one optic nerve causes blindness in that eye

B - Lesions affecting the optic chiasm destroy fibers from both nasal hemiretinas and produce a heteronymous (opposite sides of the visual fields) hemianopia

C - A lesion in one optic tract causes blindness in half of the visual field and is called homonymous (same side of both visual fields) hemianopia (half-blindness).

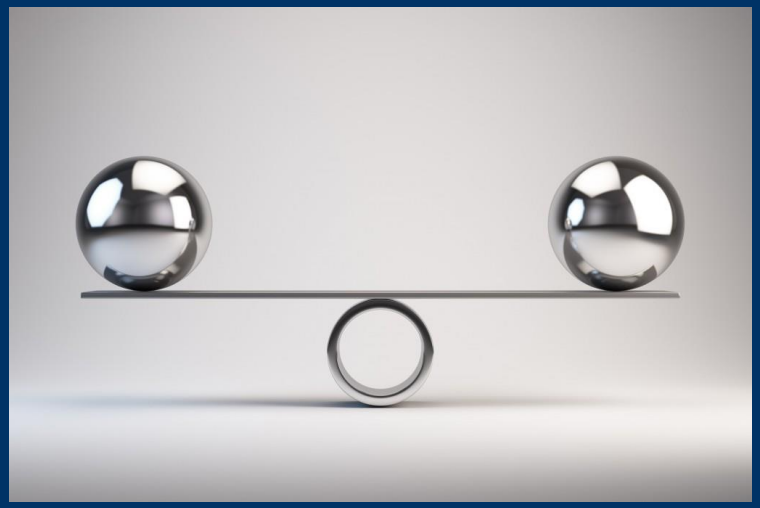
D - Occipital lesions may spare the fibers from the macula (as in D) because of the separation in the brain of these fibers from the others subserving vision.



Hearing & Equilibrium

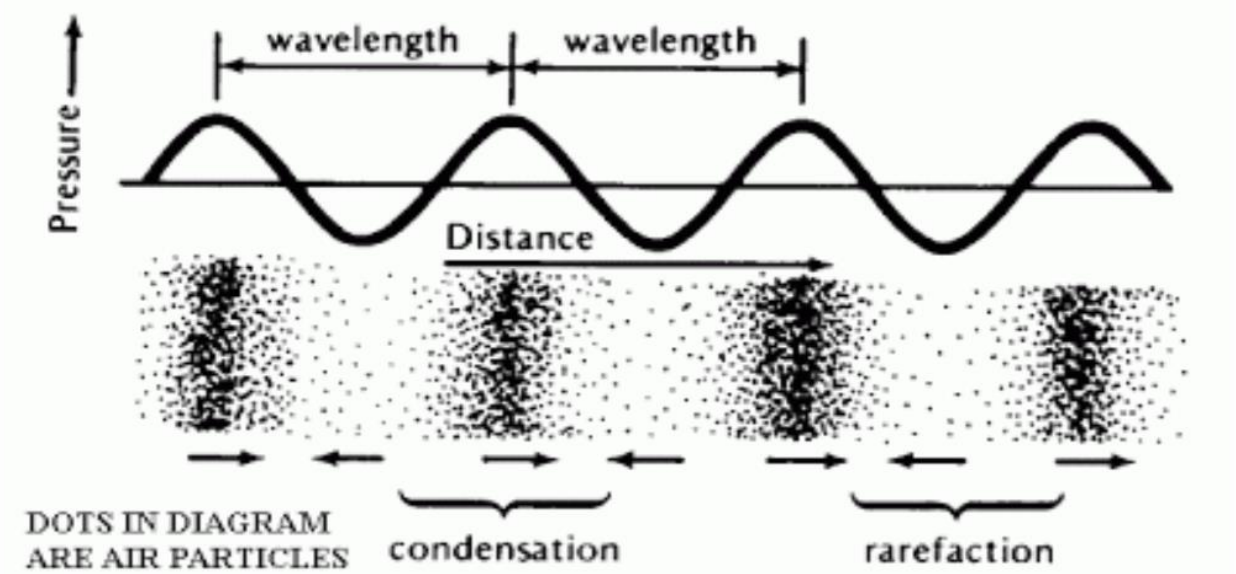
Receptors for two sensory: hearing and equilibrium are housed in the ear.

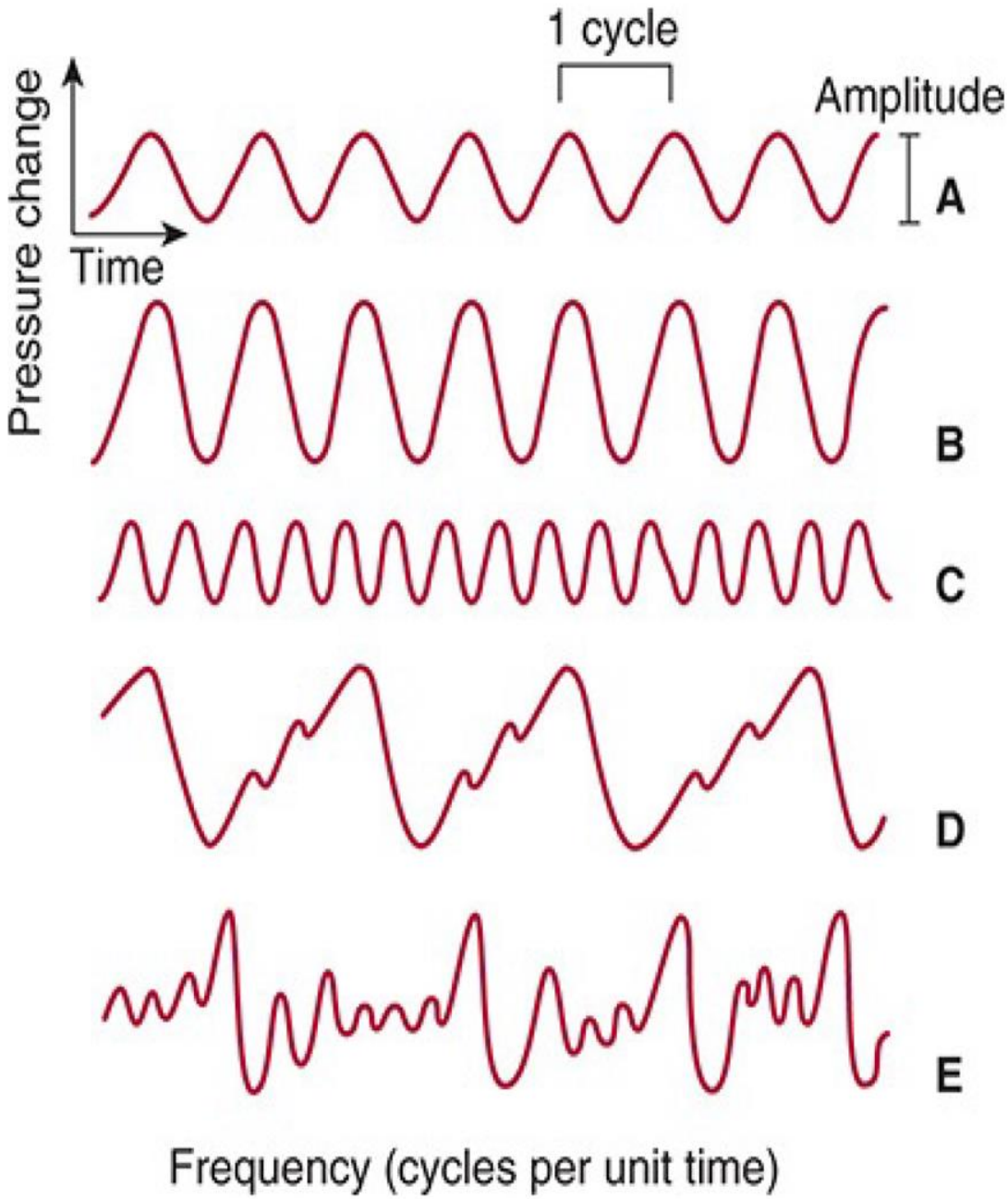
- The external ear, the middle ear, and the cochlea of the inner ear are involved with **hearing**.
-
- The semicircular canals, the utricle, and the saccule of the inner ear are involved with **equilibrium**.



Sound waves

Sound waves - changes in pressure in the environment per unit of time.
The **loudness** of a sound is directly correlated with the **amplitude** of a sound wave. The **pitch** of a sound is directly correlated with the **frequency** (number of waves per unit of time) of the sound wave.




1 cycle
Amplitude
Pressure change
Time
A
B
C
D
E
Frequency (cycles per unit time)

SPEED OF SOUND

The waves travel through air at a speed of 344 m/s (770 mph) at 20°C at sea level.
The speed increases with temperature or altitude.

Medium	Speed (m s^{-1})
Gases	
Air (0 °C)	331
Air (20 °C)	343
Helium	965
Hydrogen	1284
Liquids	
Water (0 °C)	1402
Water (20 °C)	1482
Seawater	1522
Solids	
Aluminium	6420
Copper	3560
Steel	5941
Granite	6000
Vulcanised Rubber	54

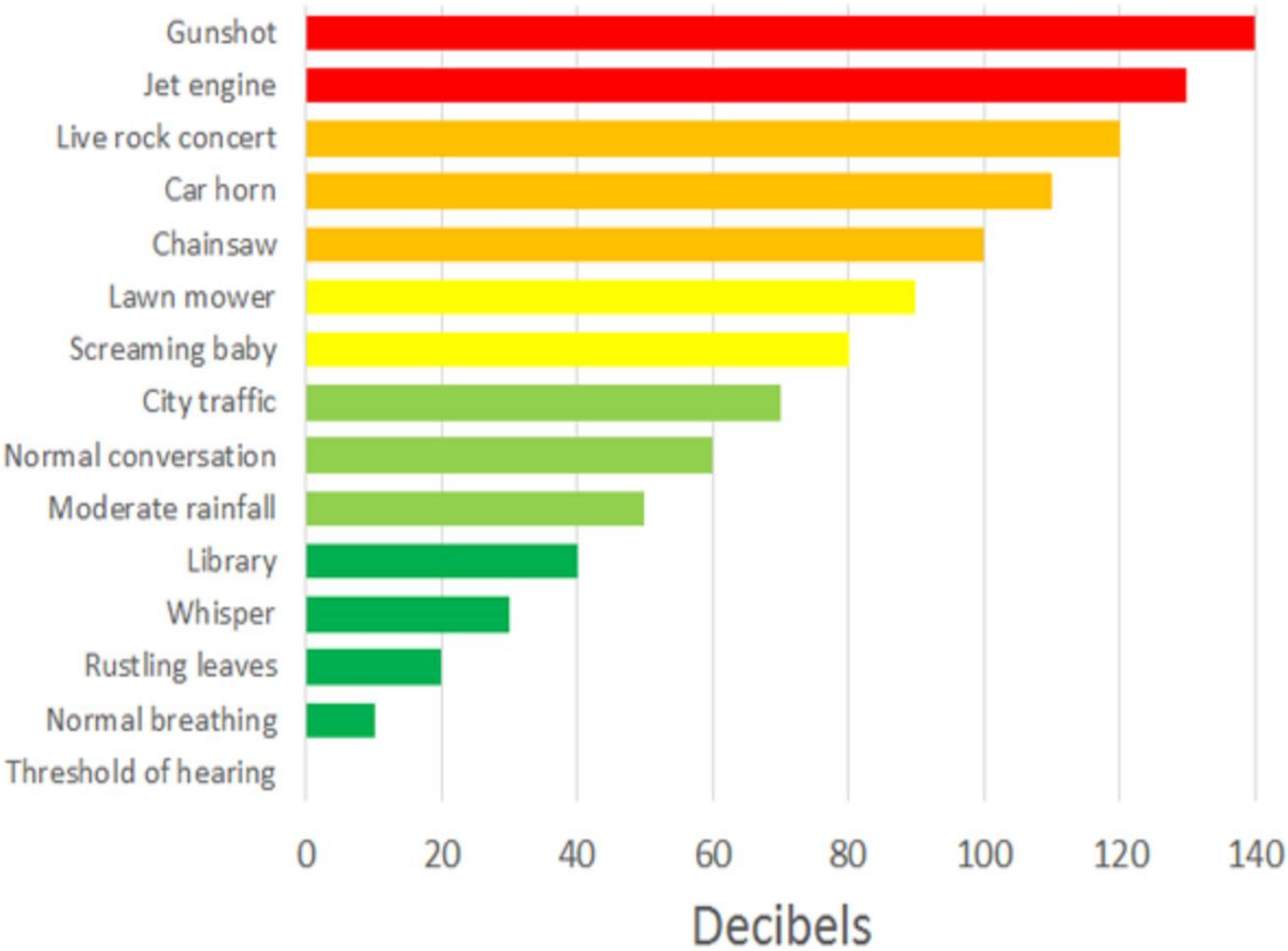
Amplitude

The amplitude of a sound wave is expressed on a **decibel scale**.
A decibel (dB) is 0.1 bel
The intensity of a sound in **bels** is the logarithm of the ratio of the intensity of that sound (P) and a standard sound (PS)

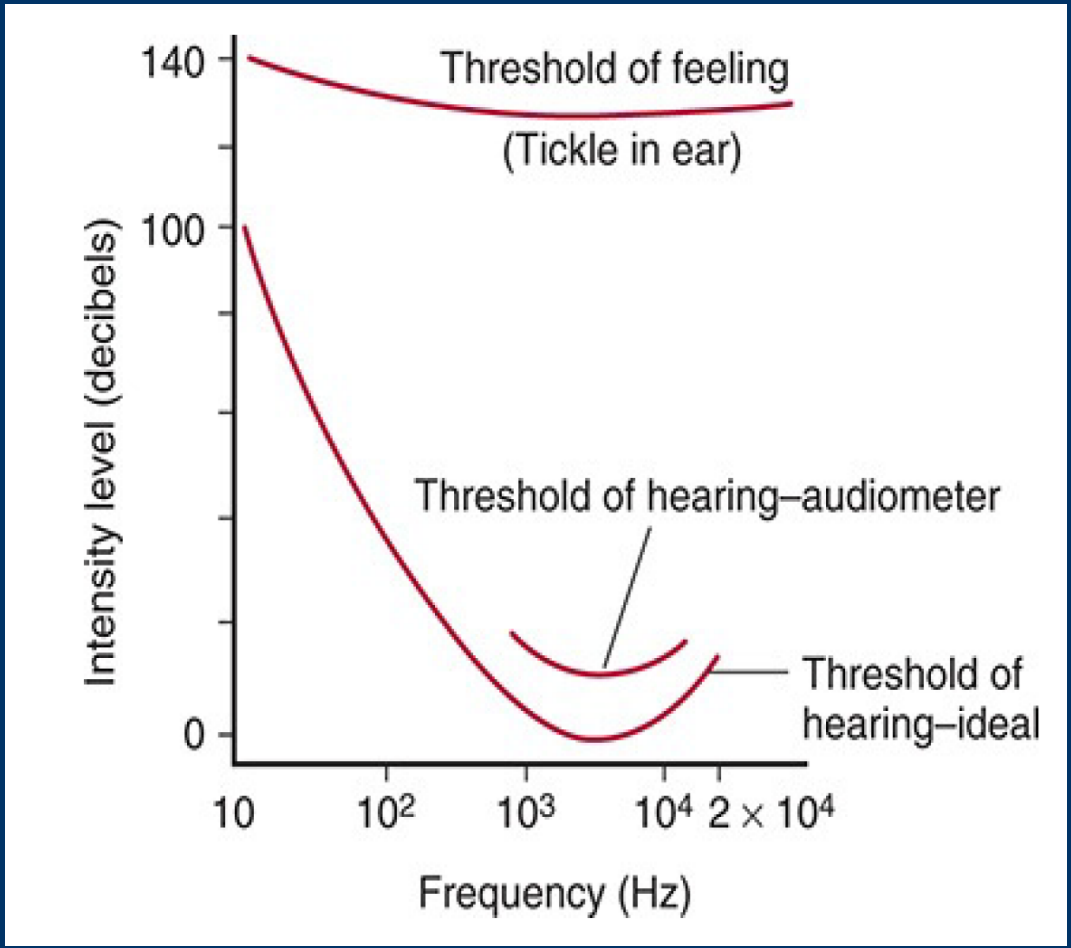
dB=20 x log P / PS

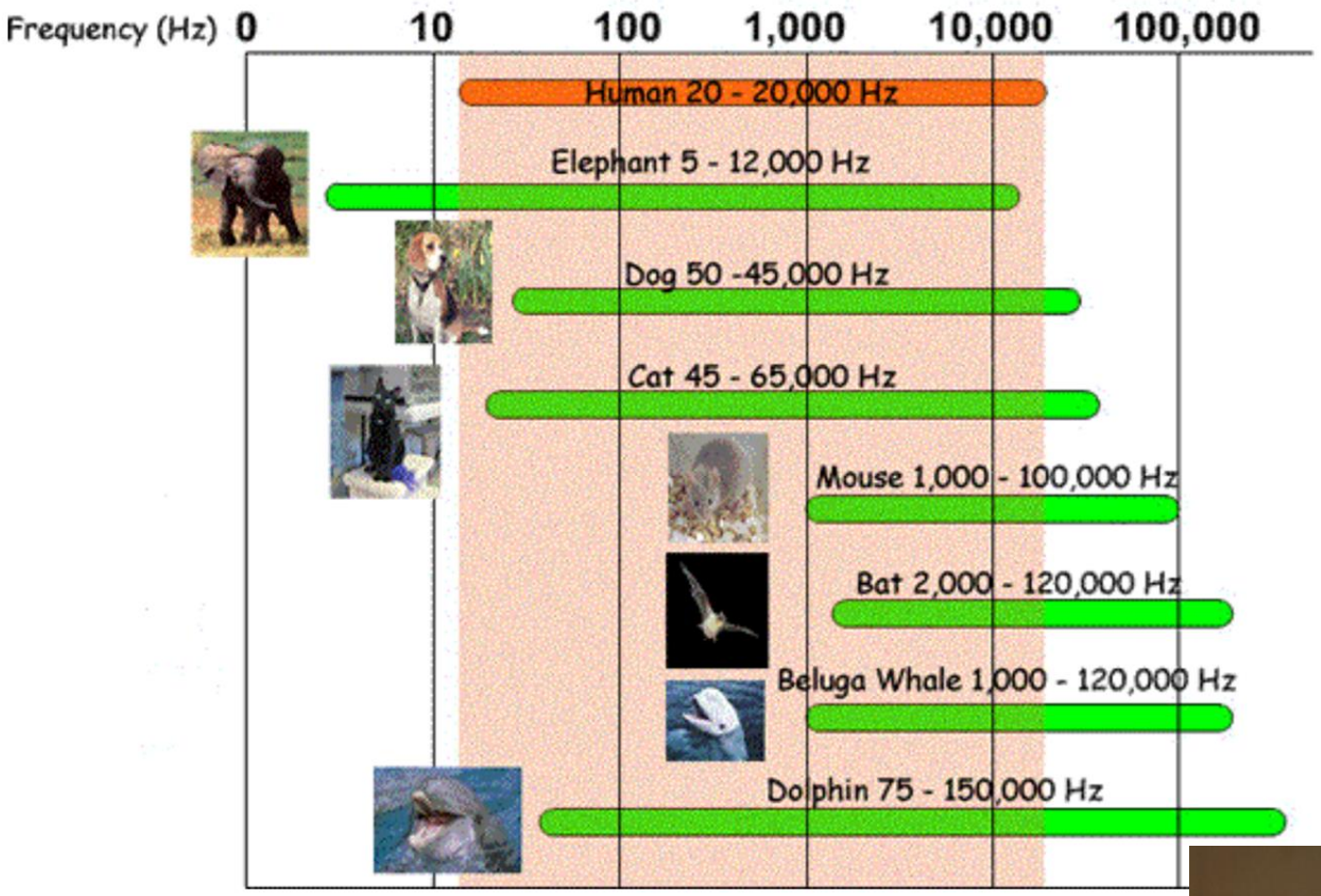
.
The standard sound reference level corresponds to 0 dB, the auditory threshold for the average human.

A value of 0 dB does not mean the absence of sound!


Gunshot
Jet engine
Live rock concert
Car horn
Chainsaw
Lawn mower
Screaming baby
City traffic
Normal conversation
Moderate rainfall
Library
Whisper
Rustling leaves
Normal breathing
Threshold of hearing
0
20
40
60
80
100
120
140
Decibels

The sound frequencies audible to humans range from about 20 to a maximum of 20,000 cycles per second (Hz). Greatest sensitivity being in the 1000- to 4000-Hz range.



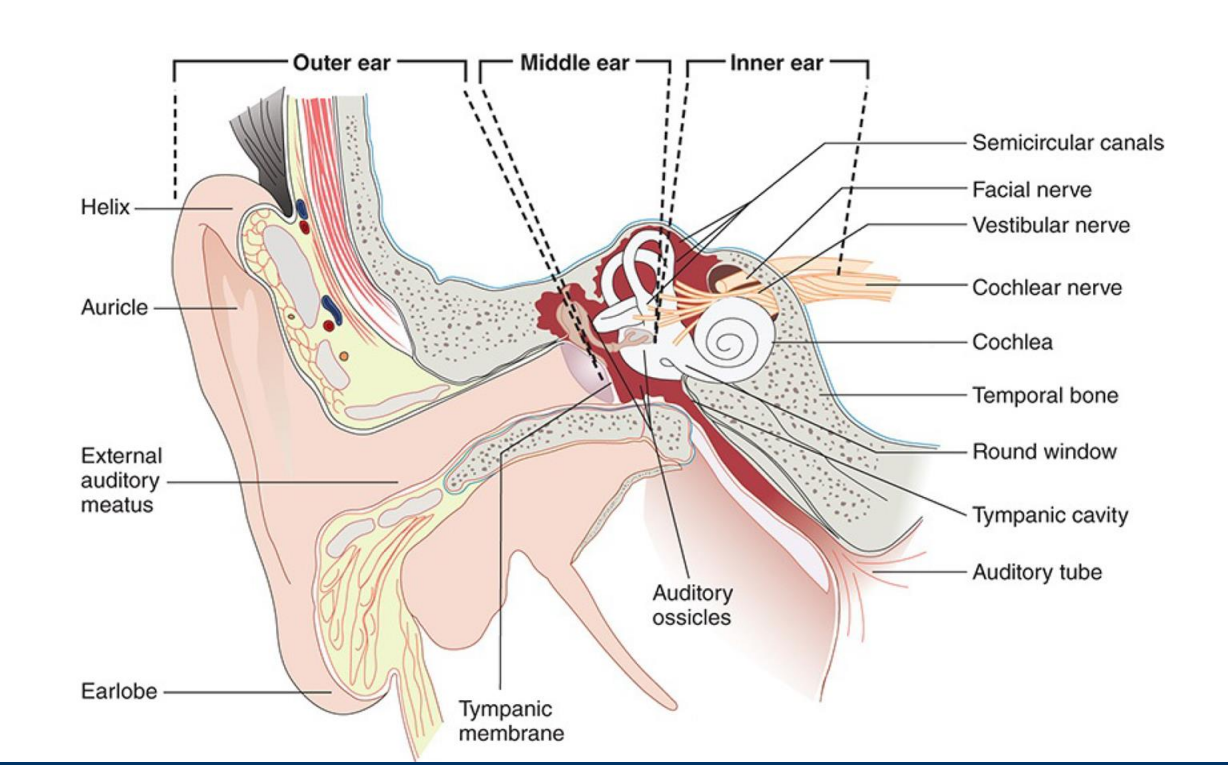


„The best of" is Galleria mellonella hears frequency
300 000Hz!

STRUCTURE OF THE EAR

Ear consists of three parts:

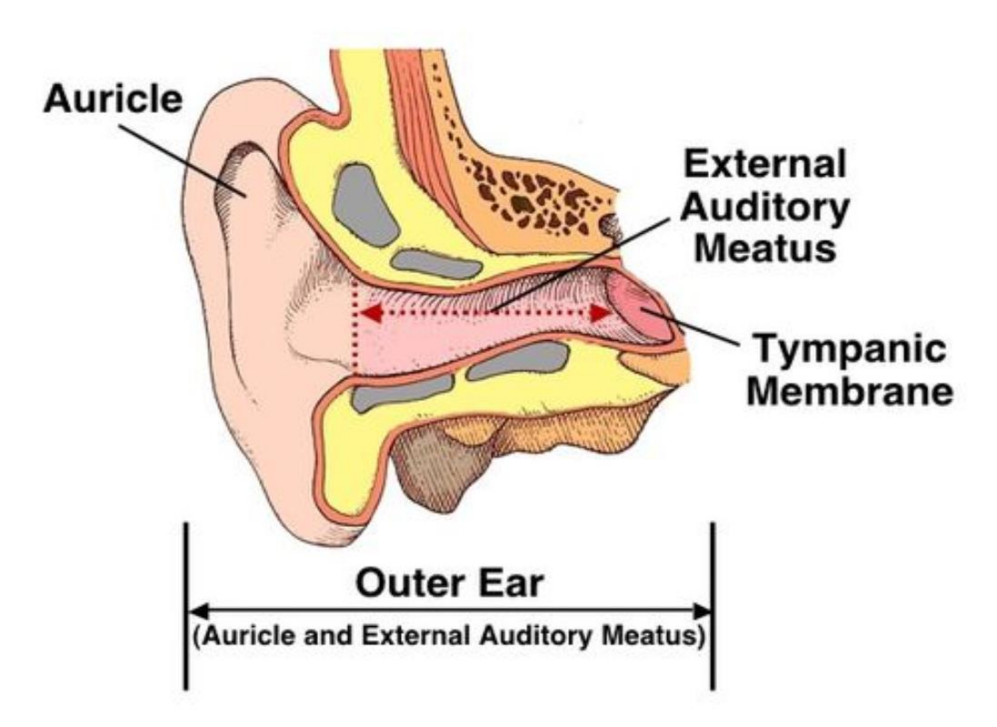
- external ear
- middle ear
- internal ear



EXTERNAL EAR

The external ear is composed of :

- the **auricle** (pinna) that captures sound waves,
- the **external auditory meatus** (ear canal) through which sound waves travel,
- the **tympanic membrane** (eardrum) that moves in and out in response to sound



MIDDLE EAR

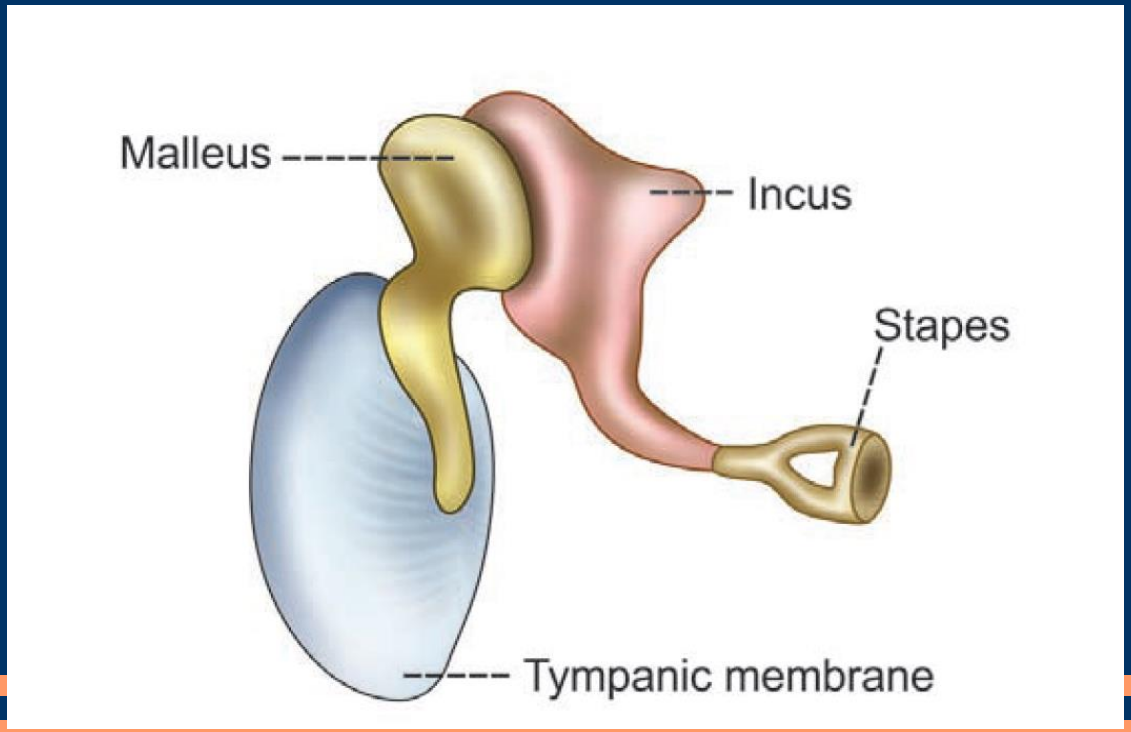
The middle ear is an air-filled cavity in the temporal bone that consists of:

- **the eustachian (auditory) tube** - connects middle ear with the nasopharynx . The tube is usually closed, but during swallowing, chewing, and yawning it opens, keeping the air pressure on the two sides of the eardrum equalized
- the three tiny auditory ossicles : **malleus (hammer)**, **incus (anvil)**, and **stapes (stirrup)**

- Two small skeletal muscles **(tensor tympani** and **stapedius)**.

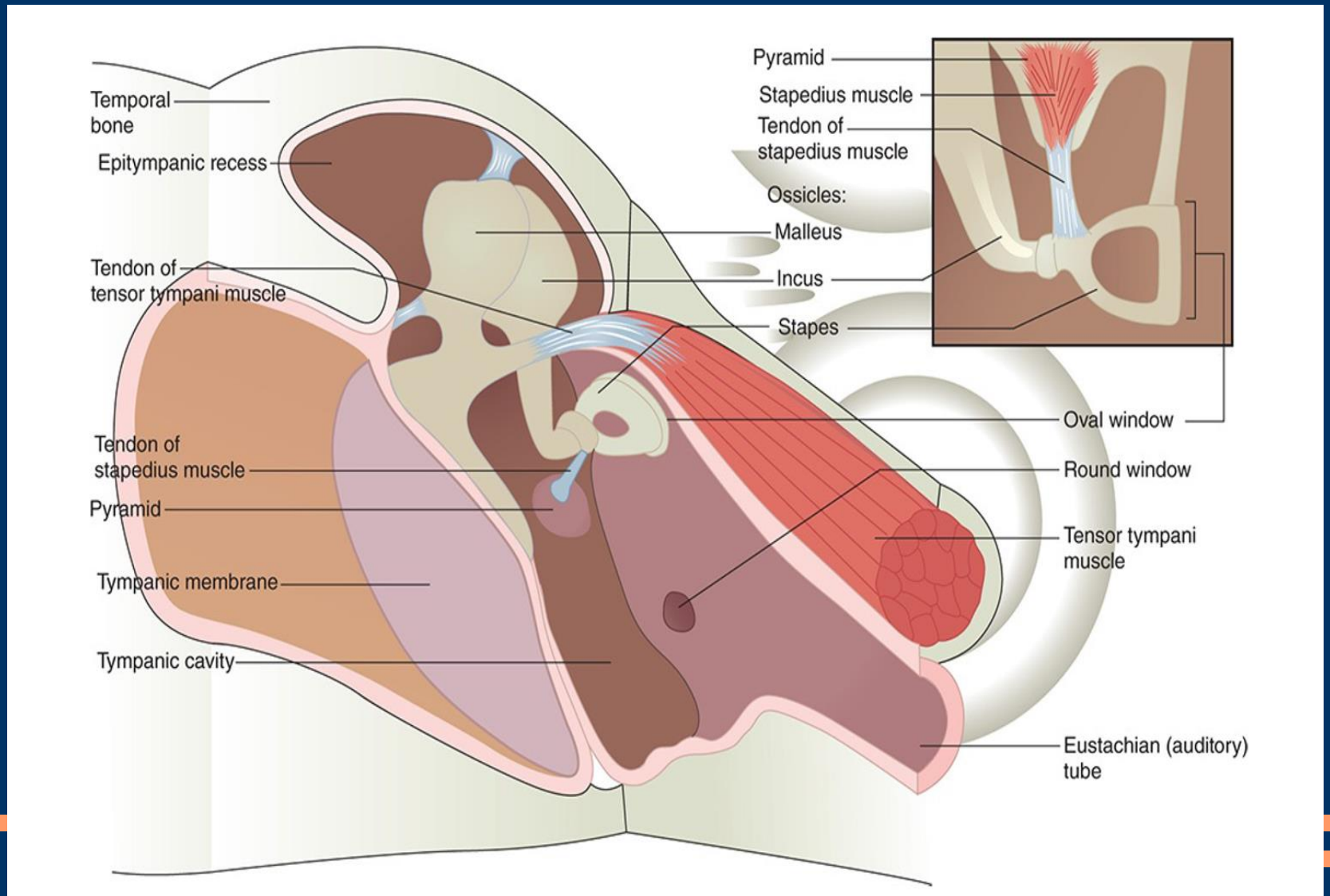
AUDITORY OSSICLES

- The **manubrium** (handle of the malleus) is attached to the back of the tympanic membrane. Its head is attached to the wall of the middle ear, and its short process is attached to the incus
- Incus articulates with the head of the stapes (stirrup).
- Stapes with Its **footplate** is attached by an annular ligament to the walls of the **oval window .**



.Tensor tympani - pulls the manubrium of the malleus medially and decreases the vibrations of the tympanic membrane

.Stapedius - pulls the footplate of the stapes out of the oval window

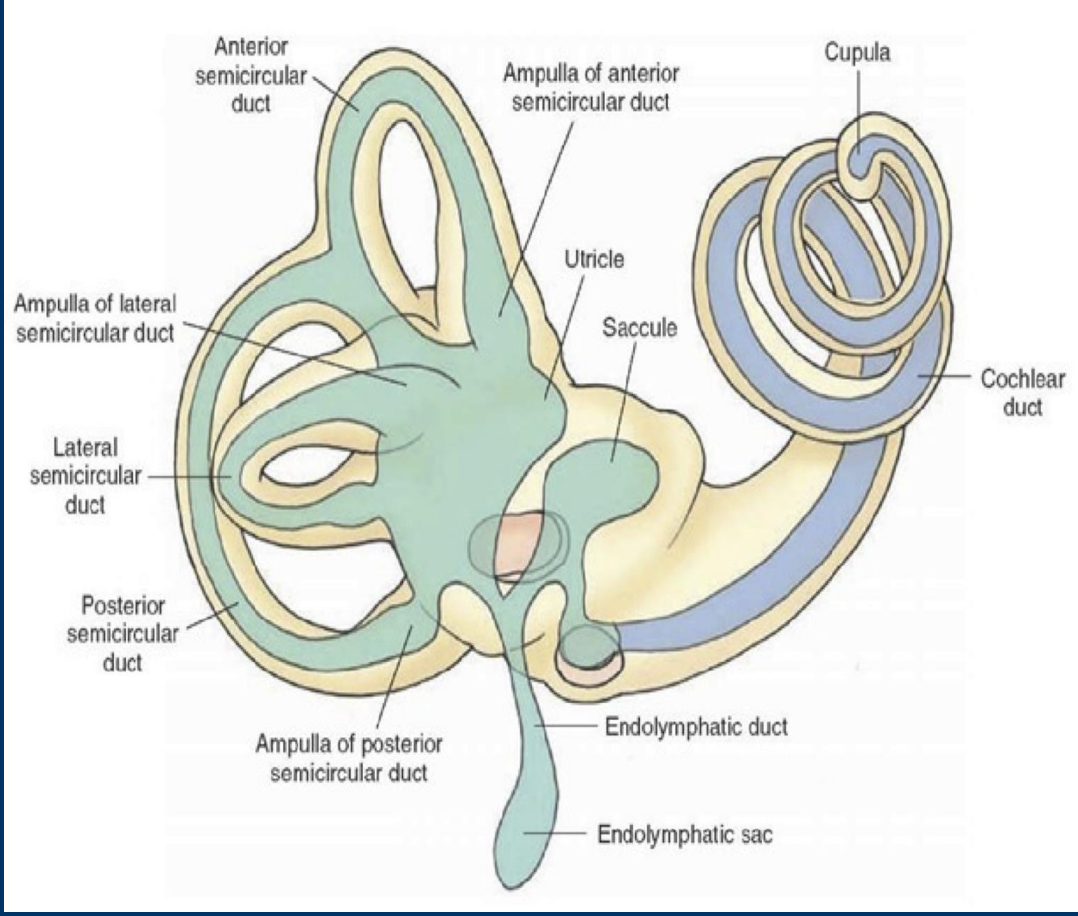


INNER EAR

The **inner ear (labyrinth)** is made up of two parts, one within the other:

- The bony labyrinth is a series of channels in the petrous portion of the temporal bone and is filled with a fluid called **perilymph** (low concentration of K+, similar to that of plasma or the cerebrospinal fluid)

- The membranous labyrinth is inside of these bony channels, surrounded by the perilymph; is filled **endolymph** (a K+-rich fluid).



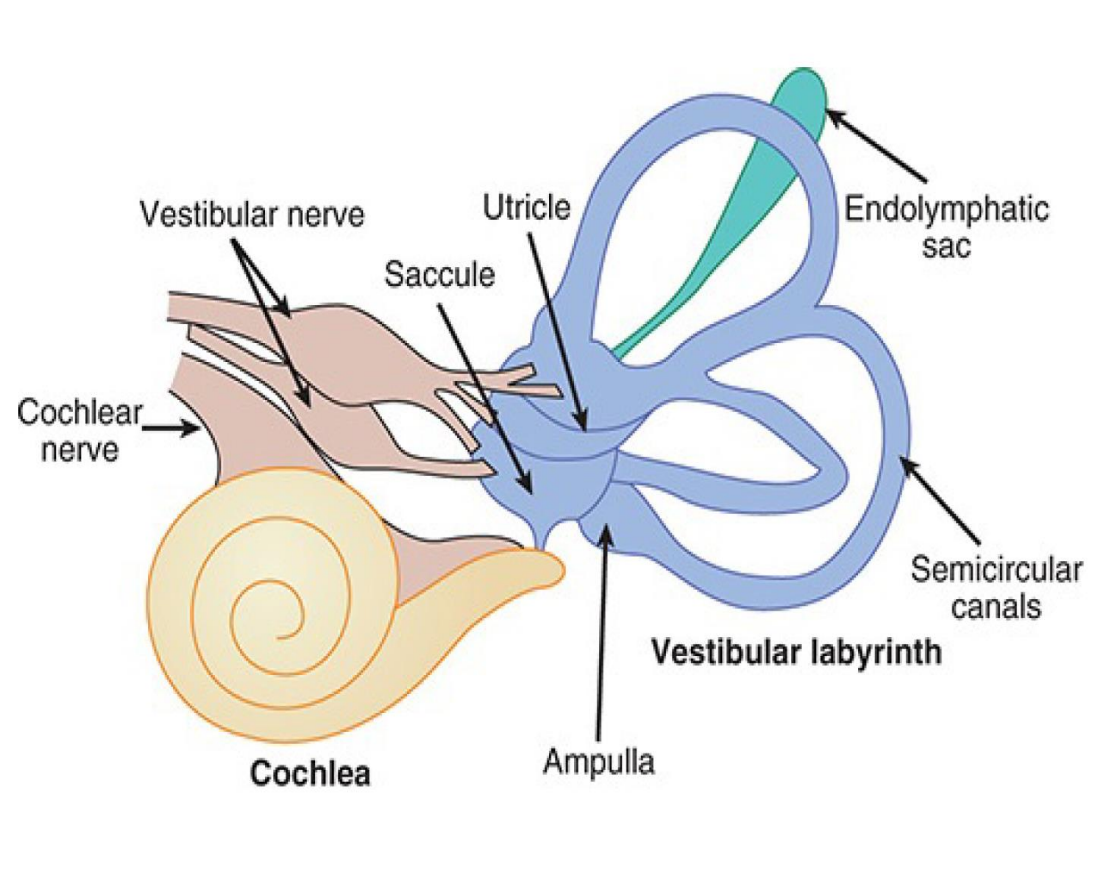
INNER EAR

The labyrinth has three components:

.**the cochlea** that contains hair cells (receptors) for hearing,

.**semicircular canals** respond to head rotation

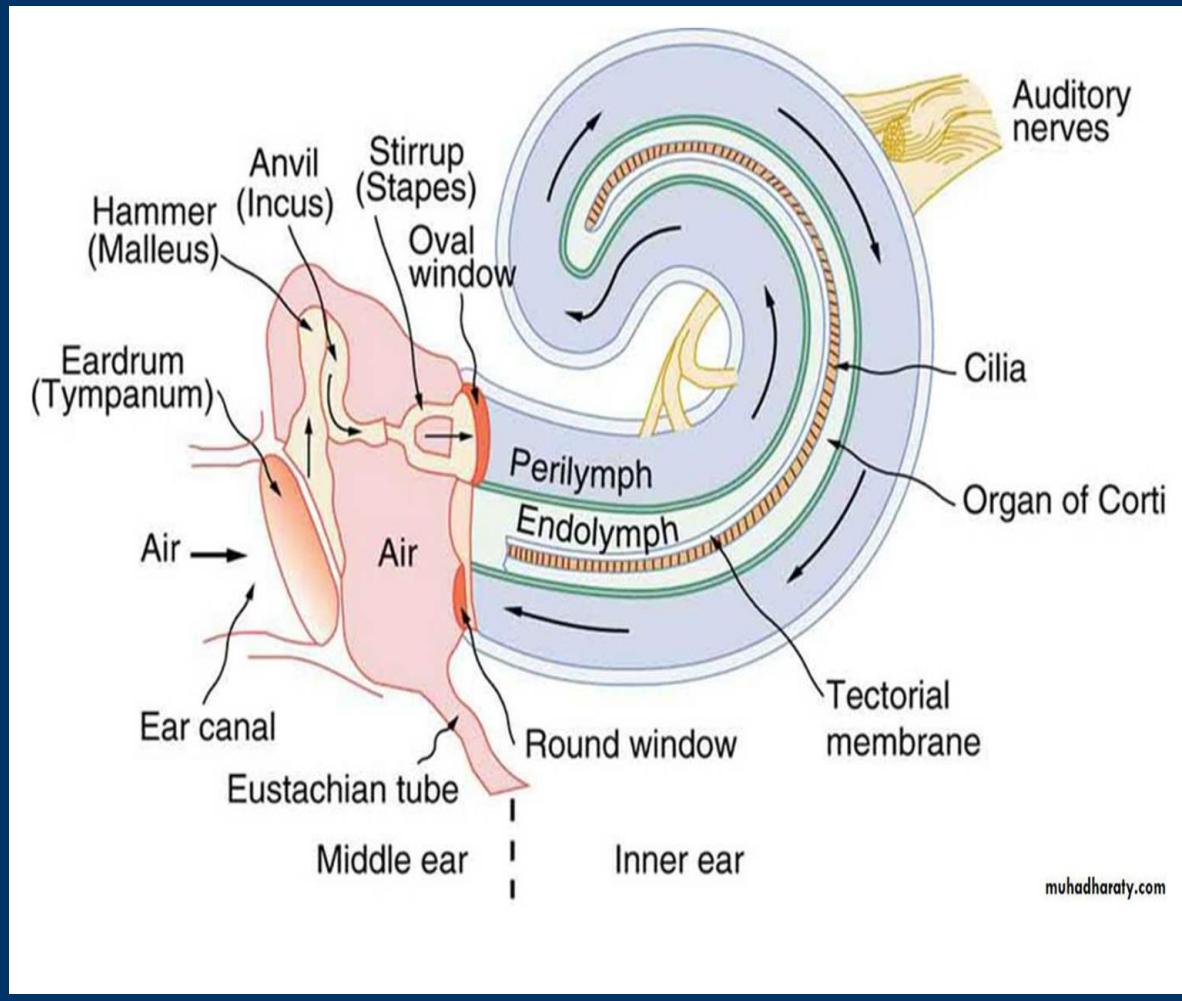
.**otolith organs** (saccule and utricle) respond to changes in gravity and head tilt

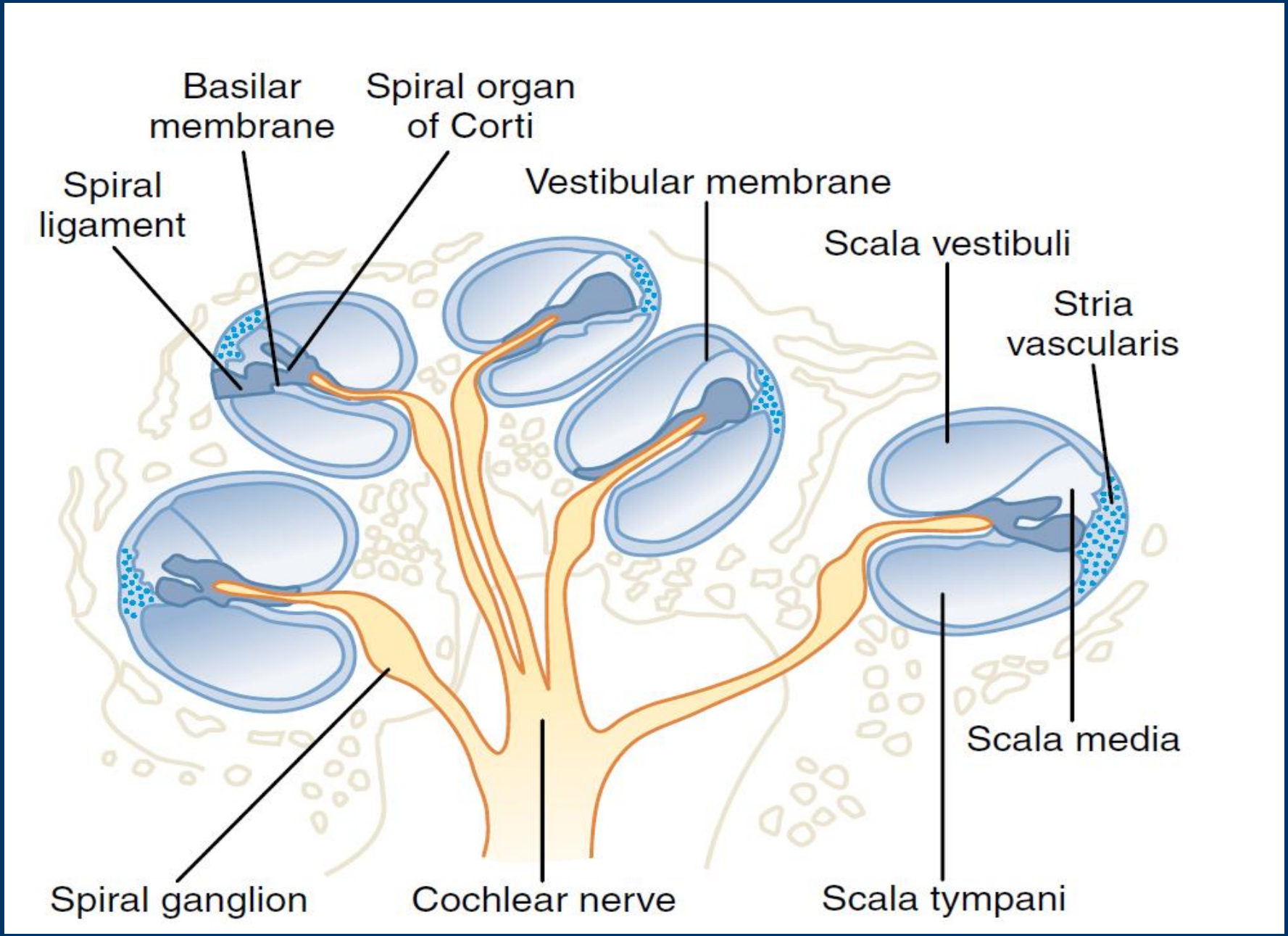


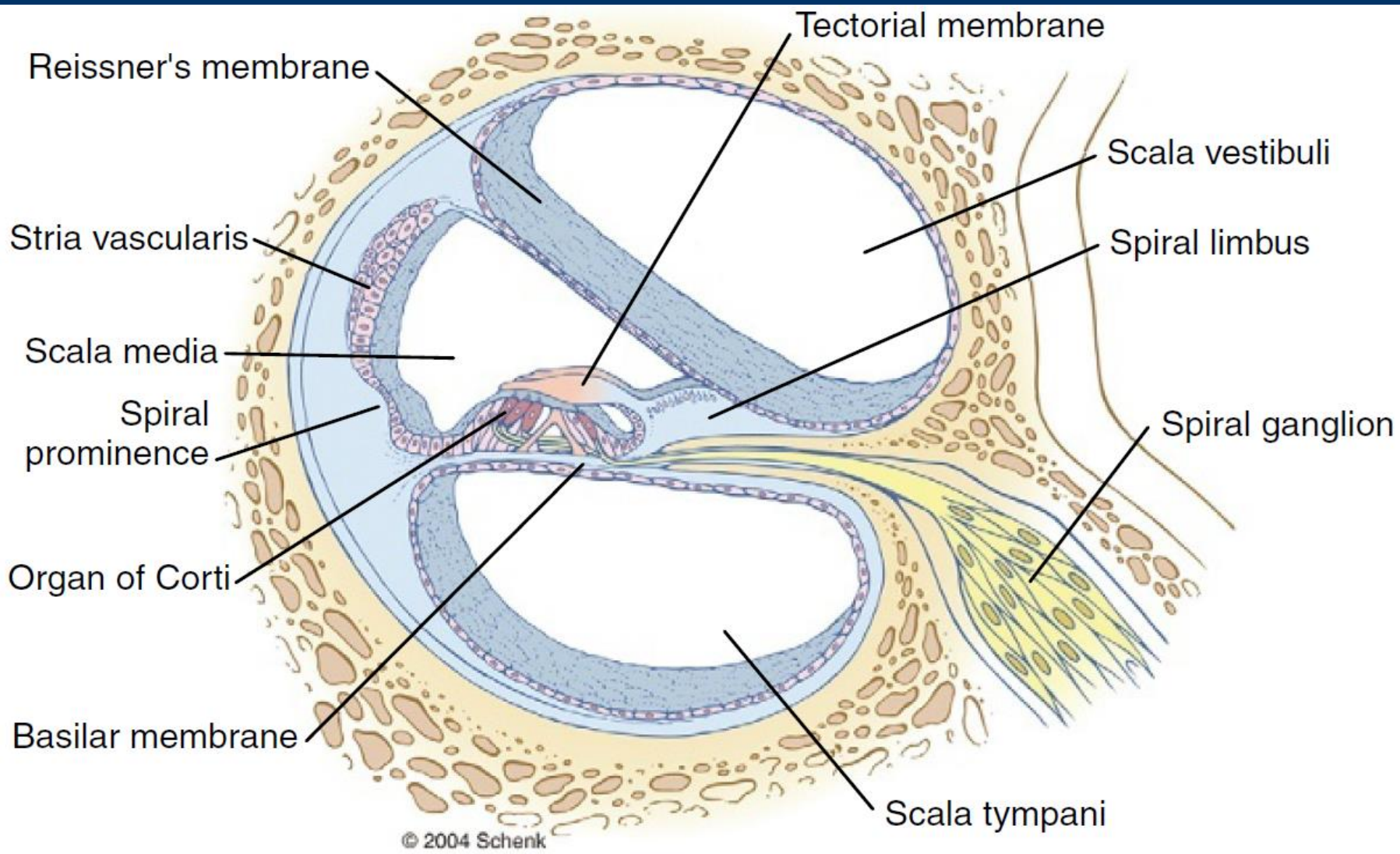
COCHLEA

The cochlea is a 35-mm-long coiled tube that makes two and three quarter turns. **The basilar membrane** and **Reissner membrane** divide it into three chambers or **scalae :**

- The upper **scala vestibuli**
- The **scala media** is continuous does not communicate with the other two scalae.
- lower **scala tympani**




Basilar membrane
Spiral organ of Corti
Spiral ligament
Vestibular membrane
Scala vestibuli
Stria vascularis
Scala media
Spiral ganglion
Cochlear nerve
Scala tympani


Tectorial membrane
Reissner's membrane
Scala vestibuli
Stria vascularis
Spiral limbus
Scala media
Spiral
prominence
Spiral ganglion
Organ of Corti
Basilar membrane
Scala tympani
© 2004 Schenk

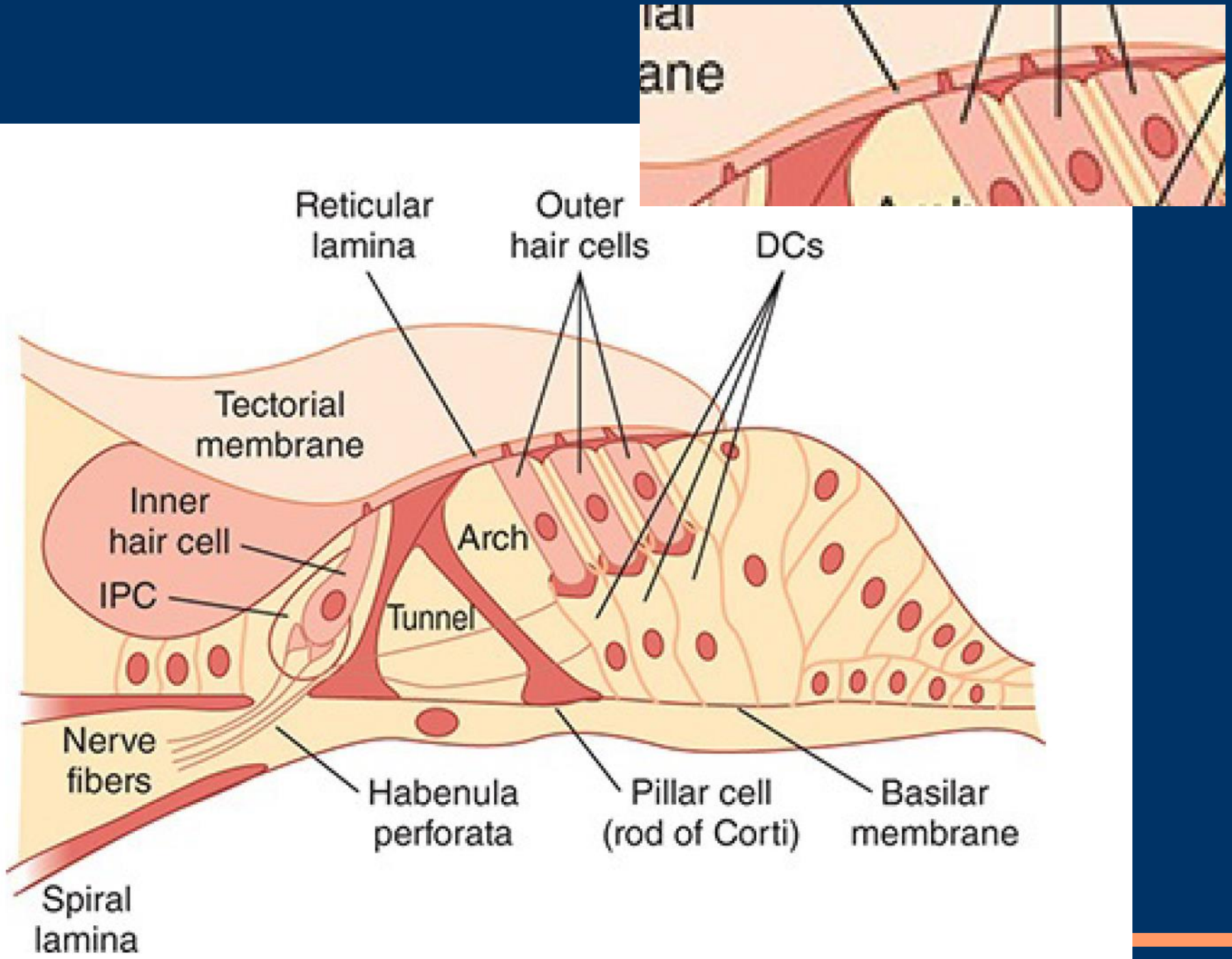
ORGAN OF CORTI

Organ of Corti is on the basilar membrane, contains auditory receptors (hair cells) whose processes pierce the tough, membrane-like **reticular lamina** that is supported by the **pillar cells** or **rods of Corti.**

The hair cells are arranged in four rows:

- three rows of **outer hair cells (20000)**lateral to the tunnel formed by the rods of Corti
- one row of **inner hair cells (3500)** medial to the tunnel.

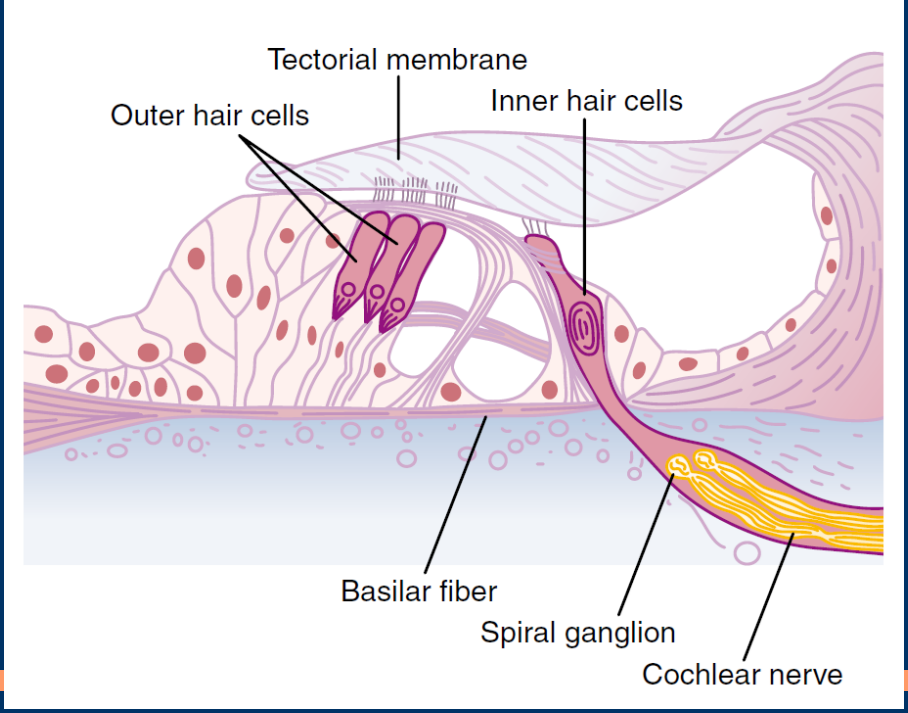
T**ectorial membrane covers the rows of hair cells,** in which the tips of the hairs of the outer but not the inner hair cells are embedded.


Reticular lamina
Outer hair cells
DCs
Tectorial membrane
Inner hair cell
IPC
Arch
Tunnel
Nerve fibers
Habenula perforata
Pillar cell (rod of Corti)
Basilar membrane
Spiral lamina

- Most (90–95%) of these sensory neurons innervate the inner hair cells;
-
- only 5–10% innervate the more numerous outer hair cells.

Most of the efferent fibers in the auditory nerve terminate on the outer rather than inner hair cells.

The axons of the afferen neurons that innervate the hair cells form the **auditory (cochlear) division** of the eighth cranial nerve.

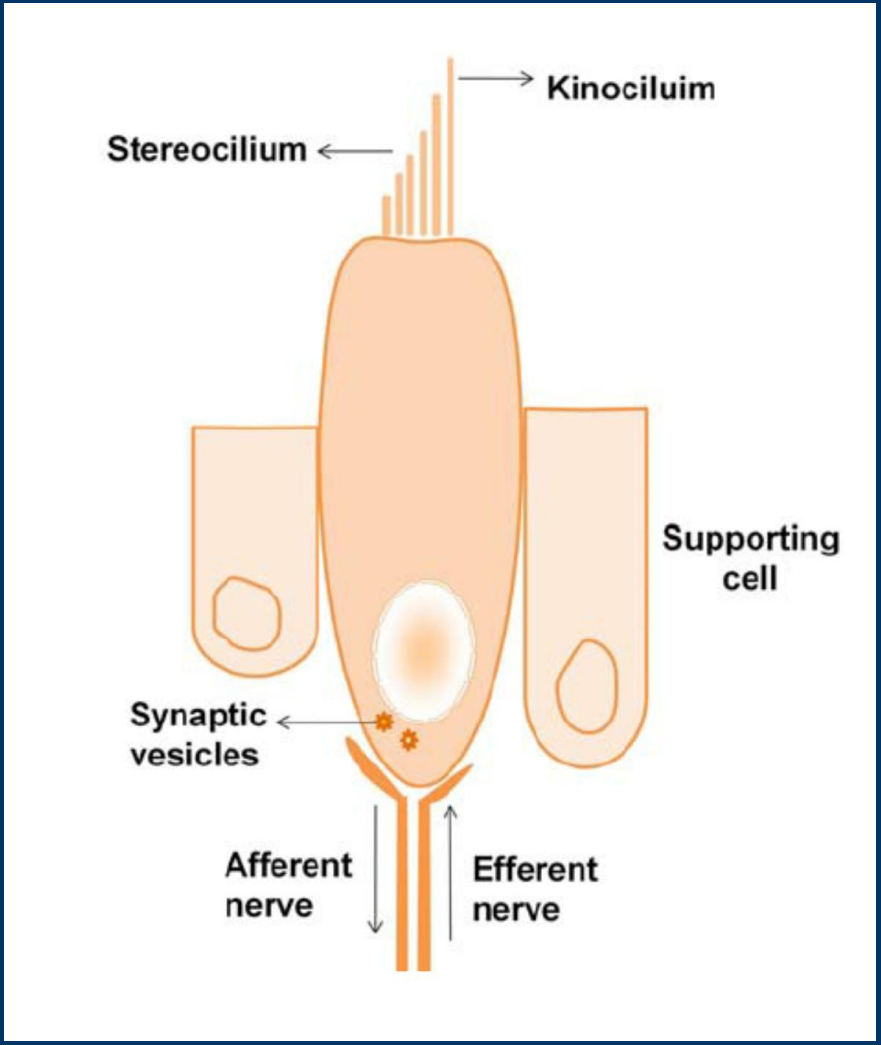


Hair cell

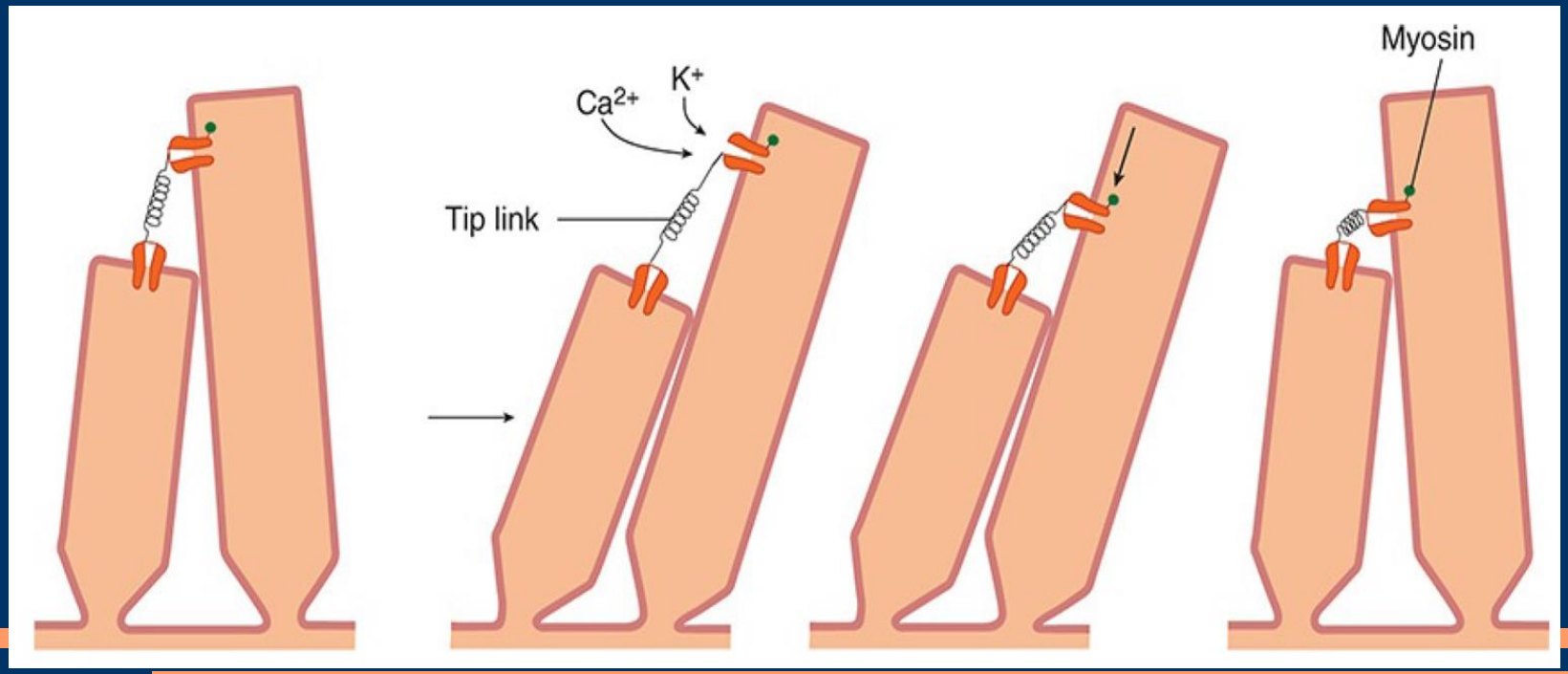
Hair cell has :

- one large **kinocilium,** a true but nonmotile cilium,
- the other 30–150 processes **(stereocilia)**

Along an axis toward the kinocilium, the stereocilia increase progressively in height; along the perpendicular axis, all the stereocilia are of the same height.

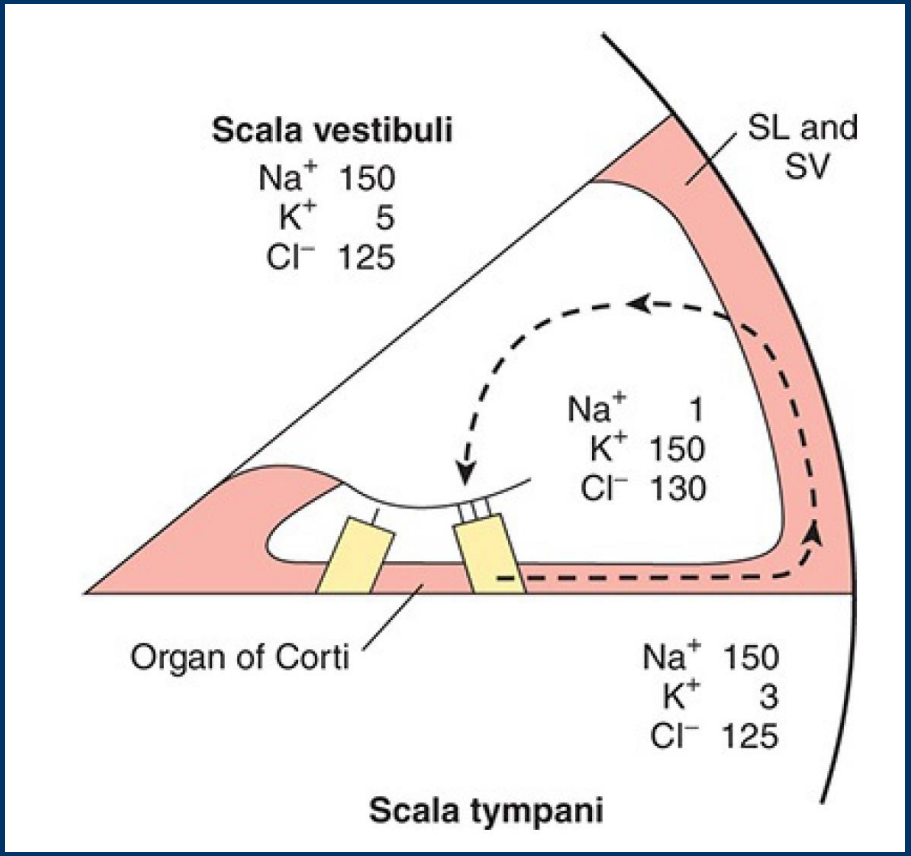


- Very fine processes called **tip links** tie the tip of each stereocilium
- Mechanically sensitive cation channels are at the junction in the taller process.
- When the shorter stereocilia are pushed toward the taller ones, the channel open time is increased. K+ and Ca2+ enter via the channel and induce depolarization.
- A myosin-based molecular motor in the taller neighbor then moves the channel toward the base, releasing tension in the tip link.
- Channel is close and restores the resting state.



Cycle of K+

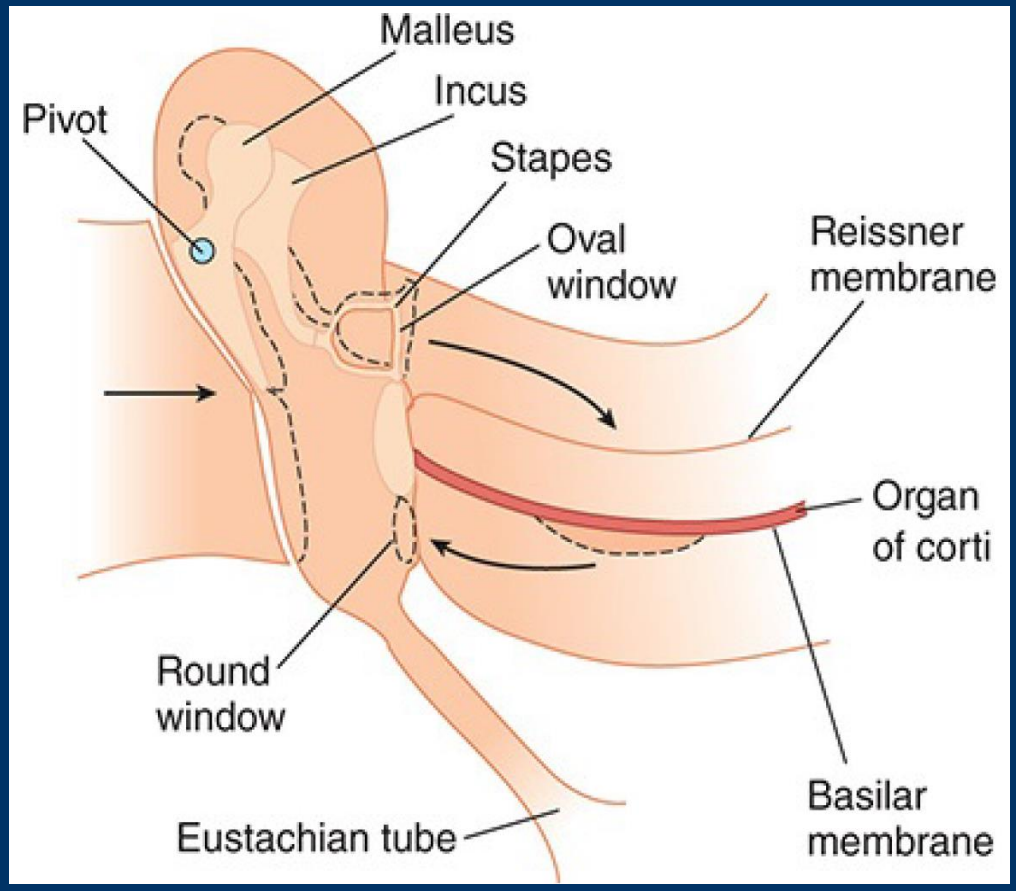
- The K+ that enters hair cells is recycled.
-
- It enters supporting cells and reaches the **stria vascularis**
-
- It is secreted back into the endolymph



SOUND TRANSMISSION

- The waves are transformed by the eardrum and auditory ossicles into movements of the footplate of the stapes.

- These movements set up waves in the fluid of the inner ear
- The action of the waves on the organ of Corti generates action potentials in the nerve fibers.

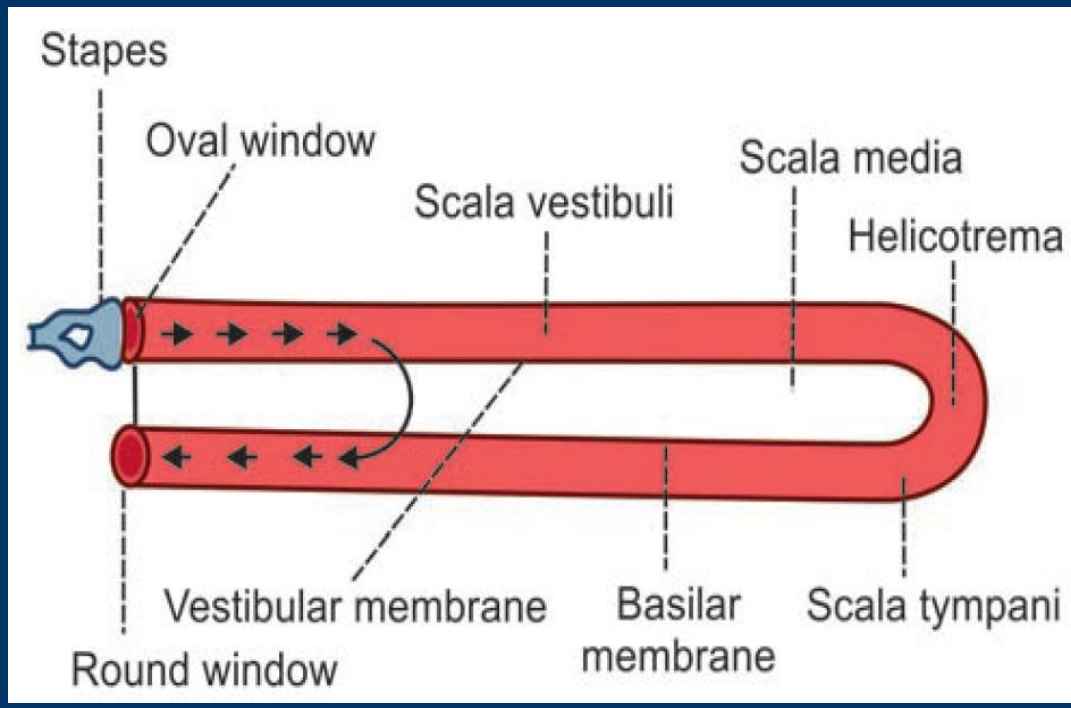


TRAVELING WAVES

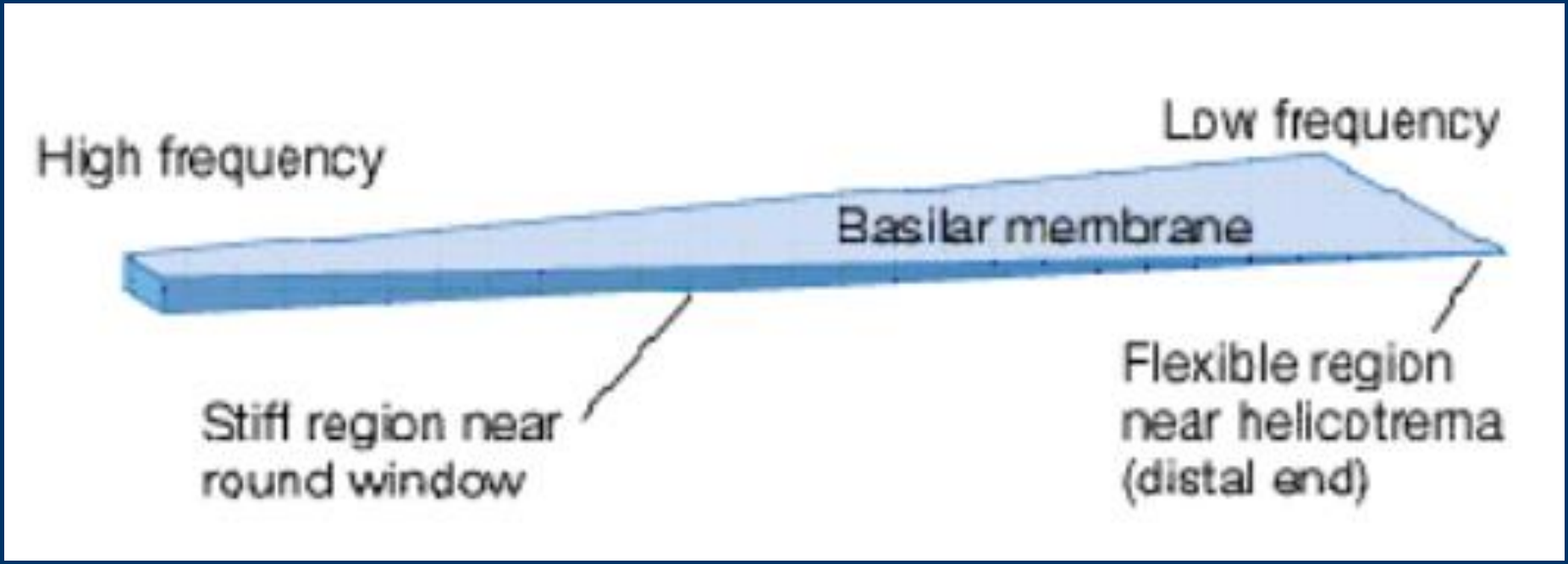
- Movement of footplate of stapes against oval window causes movement of perilymph in scala vestibuli.
-
- This causes movement of fluid in scala media.

- Movement of fluid in scala media causes bulging of basal portion of basilar membrane towards scala tympani

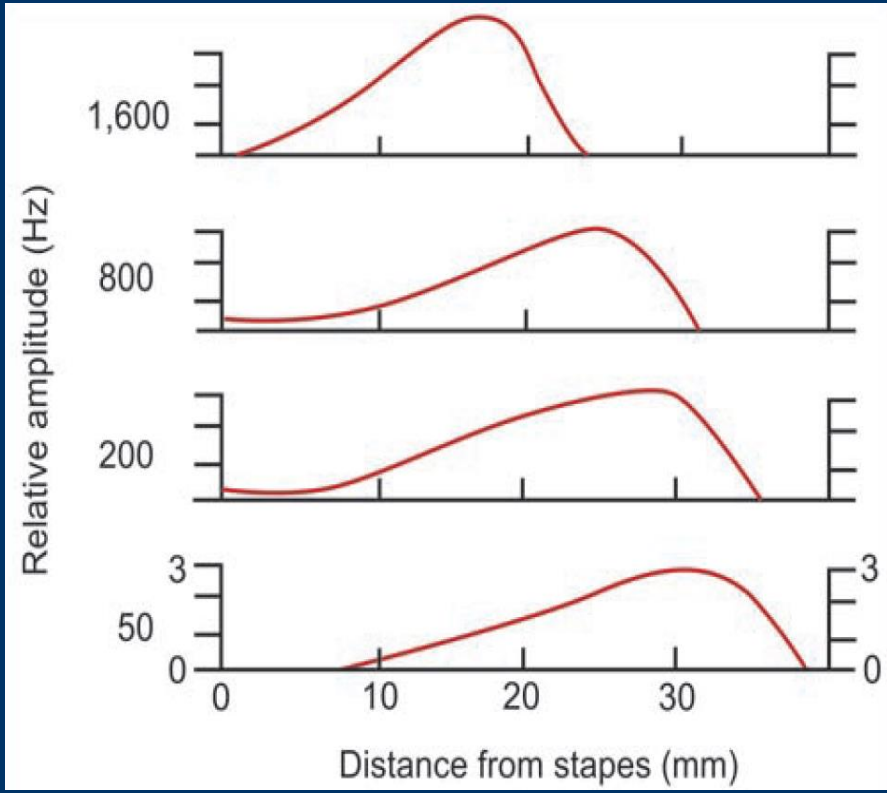
- Elastic tension in basilar fibers initiates a wave, which travels along basilar membrane towards the **helicotrema**

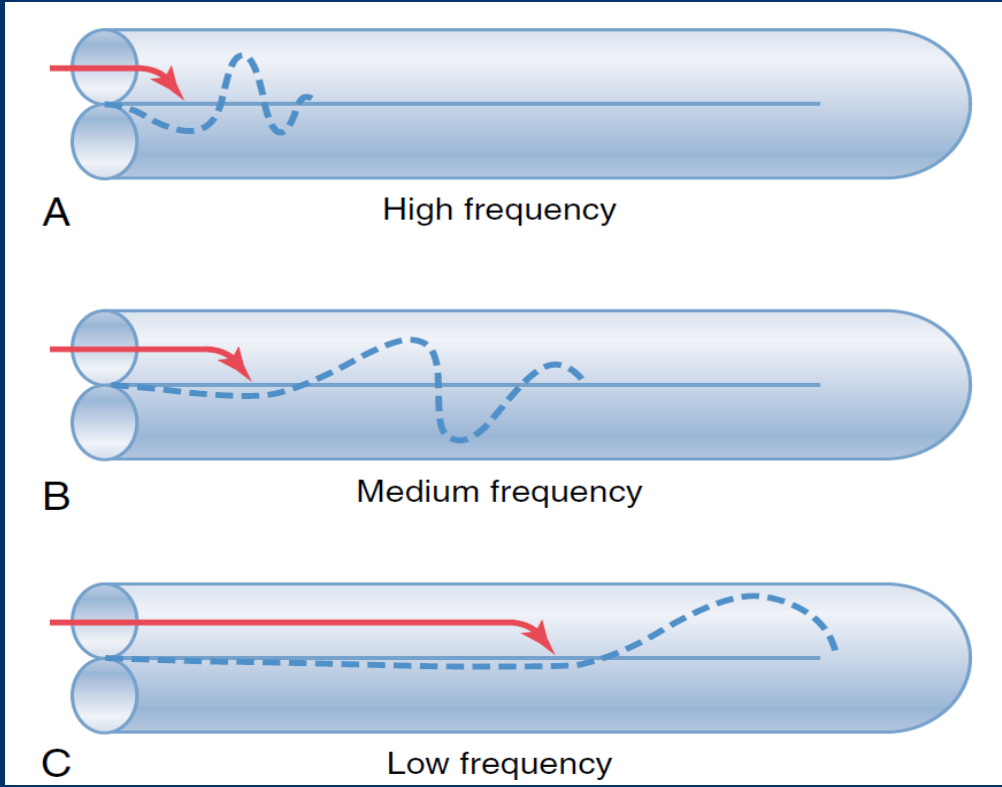


BASILAR MEMBRANE



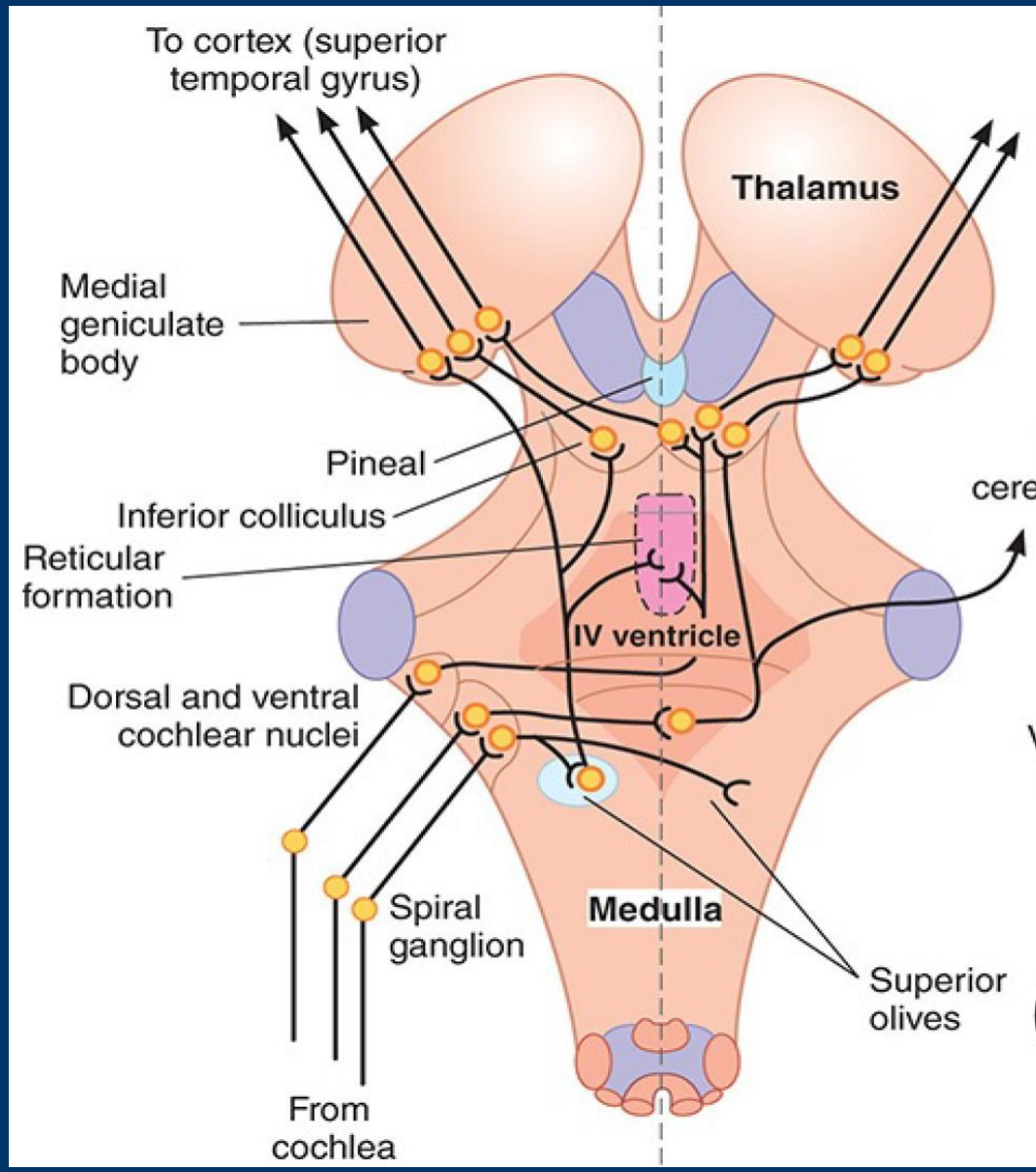
- High-pitched sounds generate waves that reach maximum height near the base of the cochlea;
- low-pitched sounds generate waves that peak near the apex.





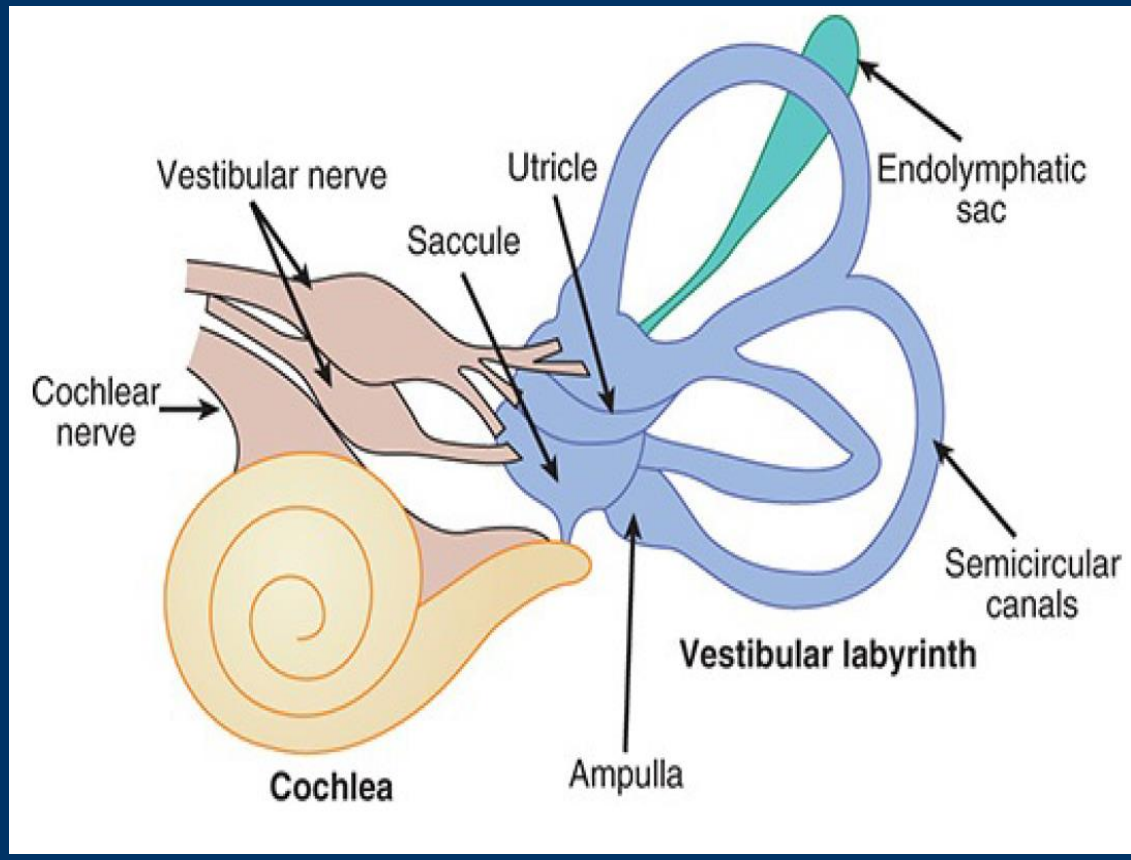
CENTRAL AUDITORY PATHWAY

- The afferent fibers in the auditory division of the eighth cranial nerve end in **dorsal** and **ventral cochlear nuclei**
- From there, auditory impulses pass by various routes to the **inferior colliculi,** the centers for auditory reflexes,
- and via the **medial geniculate body** in the thalamus
- to the **auditory cortex** located on the superior temporal gyrus of the temporal lobe.



VESTIBULAR SYSTEM

It plays an important role in maintaining posture and equilibrium through **statokinetic reflexes.**



Vestibular apparatus is formed by:

- three semicircular canals
- otolith organ (vestibule).

SEMICIRCULAR CANALS

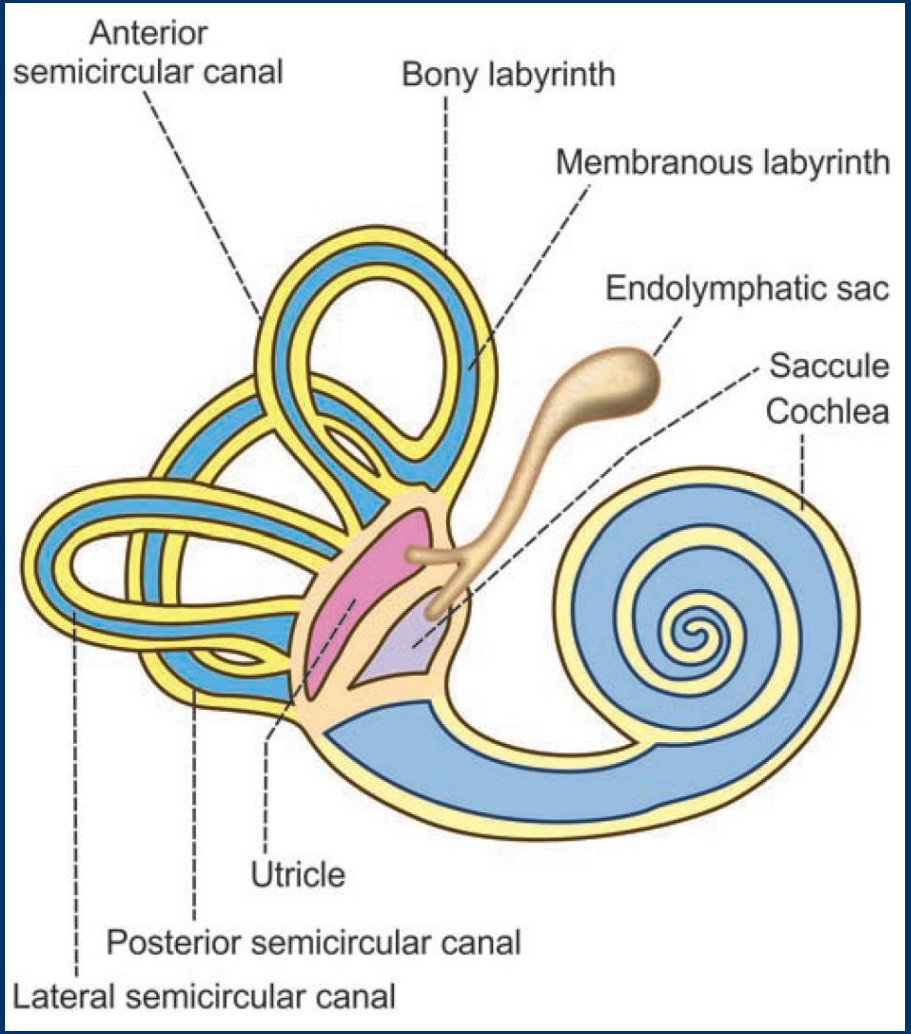
- the tubular structures placed

- at right angles to each other represent the three axes of rotation: Vertical, anteroposterior and transverse axes.

1. Anterior canal (vertically)

2. Posterior canal (vertically)

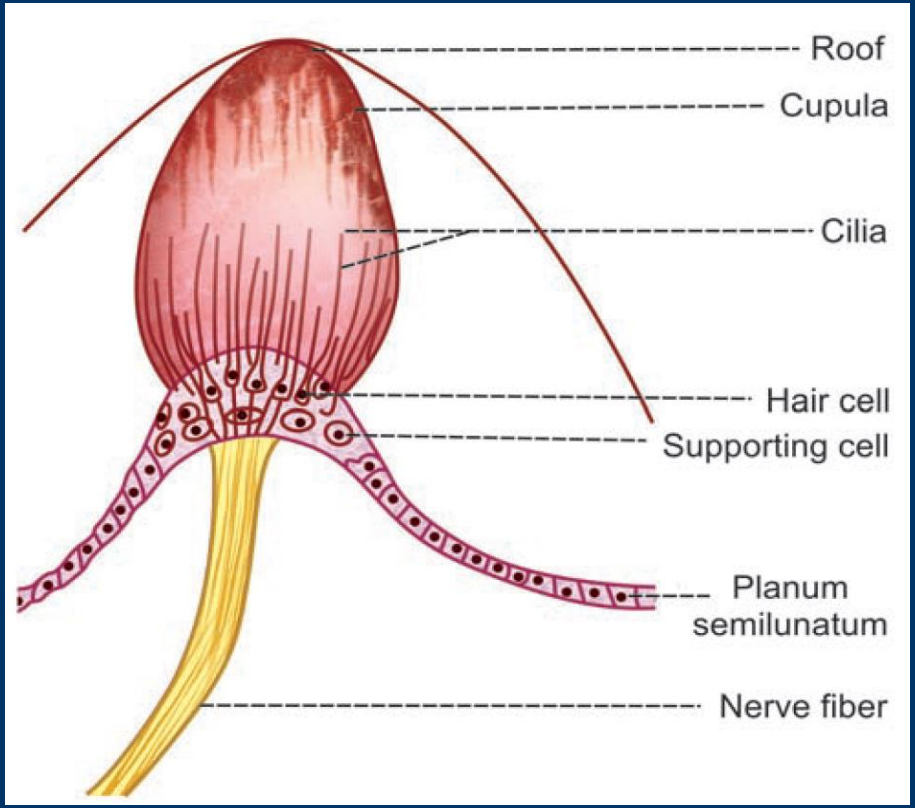
3. Lateral canal (horizontally)



AMPULLA

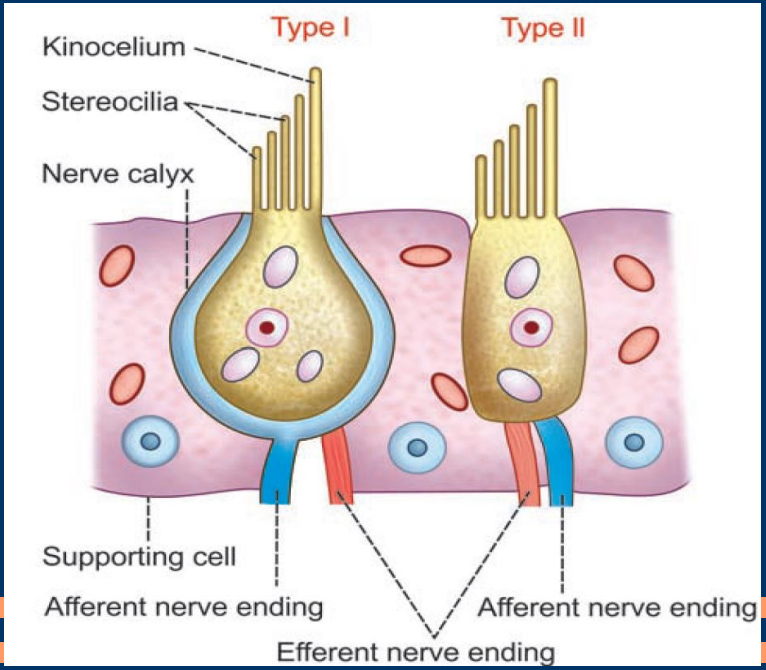
Ampulla – one enlarged end of semicircular canal

.contains the receptor organ cris**ta ampullaris -** formed by a receptor epithelium which consists of hair cells, supporting cells and secreting epithelial cells



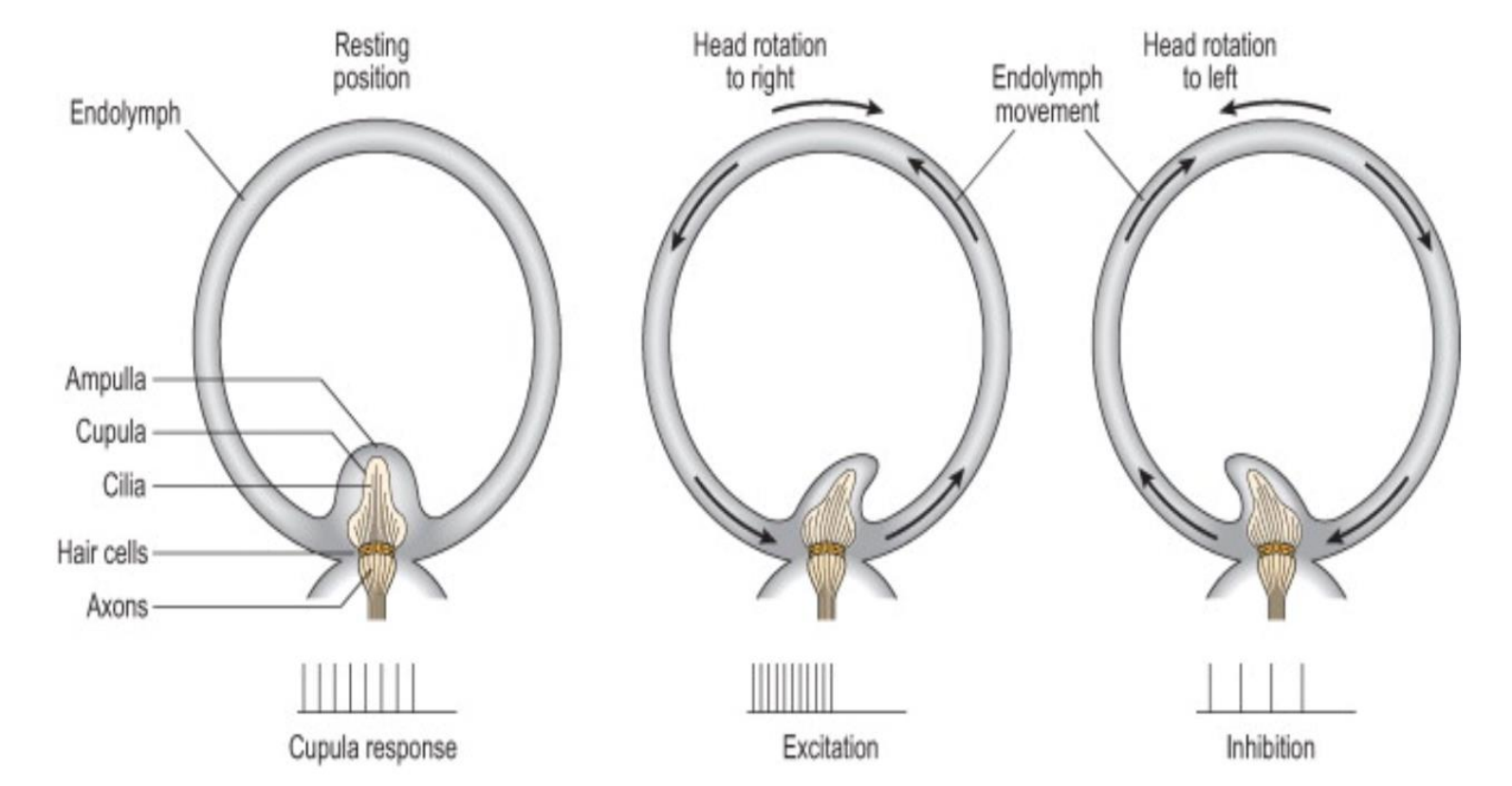
Cupula

From crista ampullaris, a dome-shaped gelatinous structure extends up to the roof of the ampulla. Cilia of hair cells are projected into cupula.



Receptors of semicircular canals give response to **rotatory movements** or **angular acceleration** of the head.

At the beginning of rotation, receptor cells are stimulated by movement of endolymph inside the semicircular canals, the fluid pushes on the cupula, deforming it.-it bends the processes of the hair cells(only at the beginning and at the stoppage of rotatory movements, during rotation at a constant speed - not stimulated).

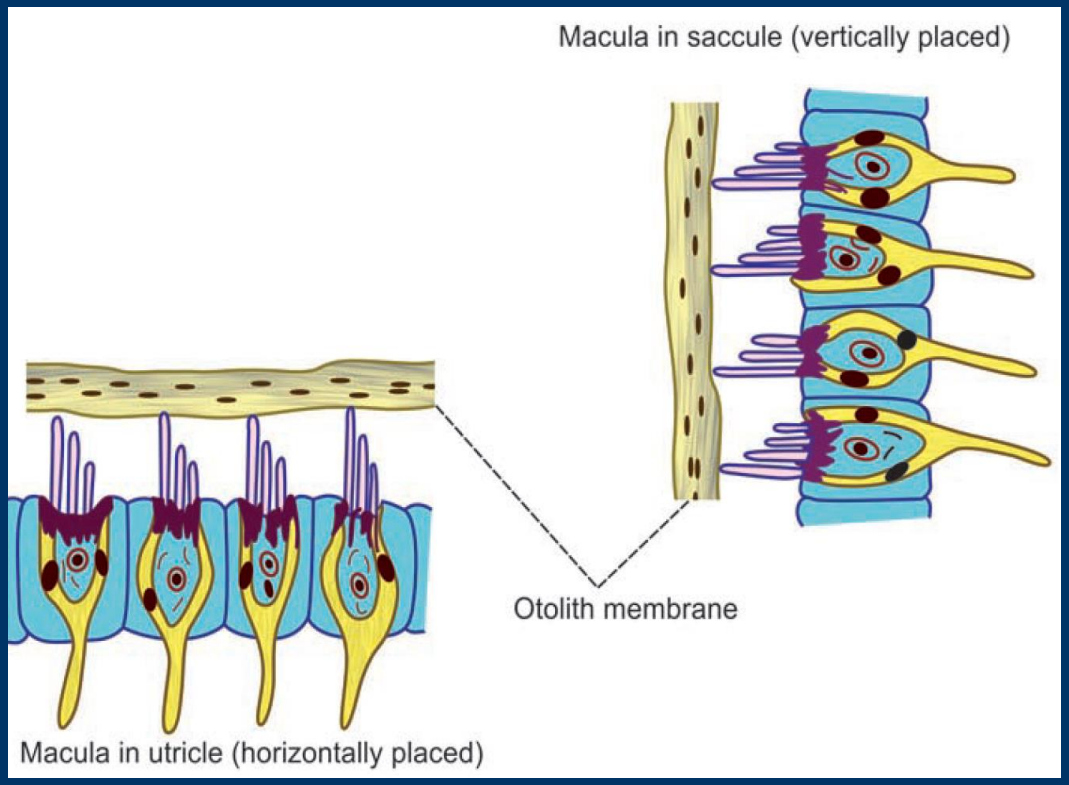


OTOLITH ORGAN

is formed by
.utricle
.saccule

Receptor organ is called **macula** (in semicircular canal - **crista ampullaris) -** formed by two types of hair cells

macula is covered by a gela tinous membrane - **otolith membrane**-contains some crystals, called **ear dust, otoconia** or **statoconia (**calcium carbonate)
The **stereocilia** are embedded in otolith membrane.

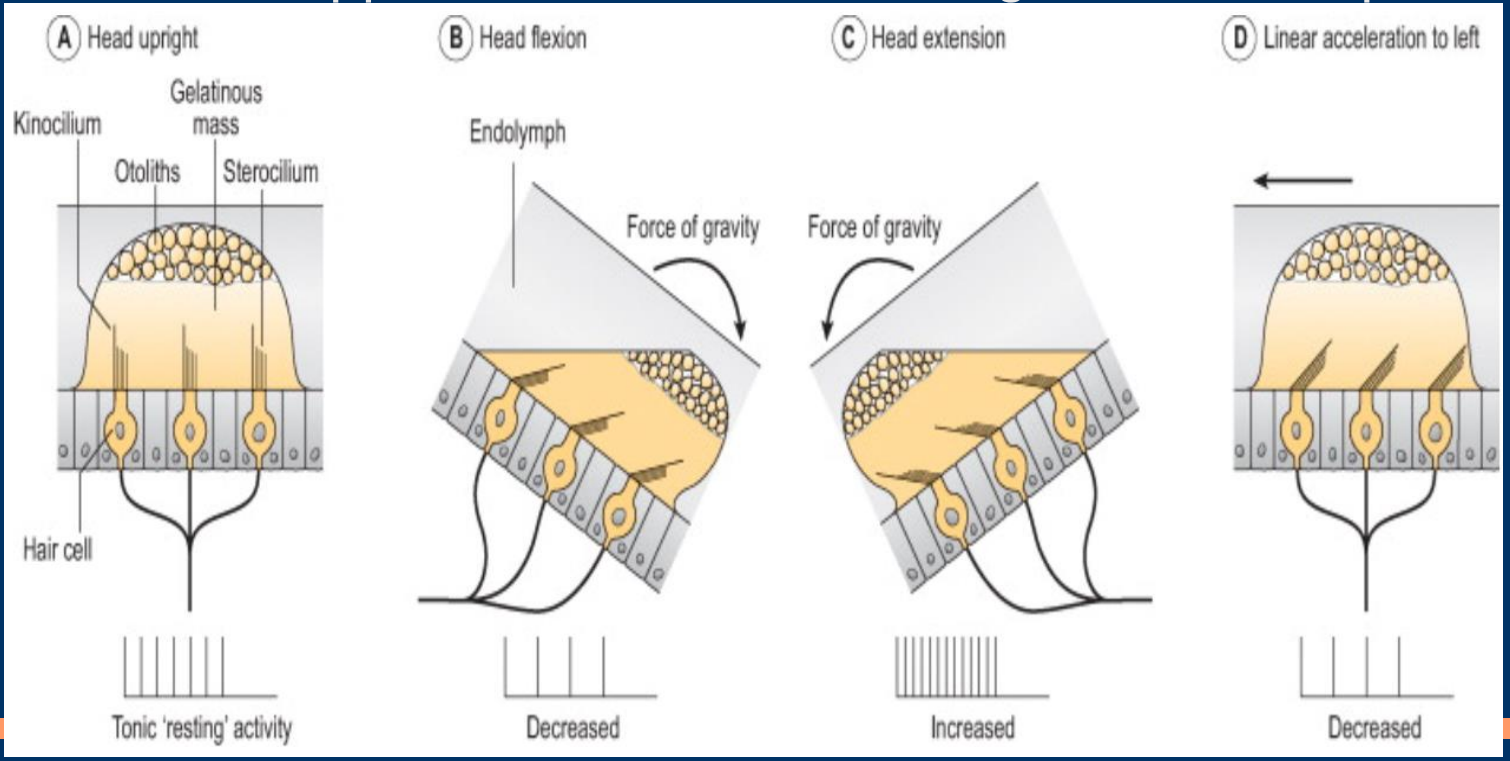


Macula in utricle
.situated in **horizontal plane,** the cilia from hair cells are in **vertical direction.**
Macula in saccule
.in **vertical plane** and the cilia are in **horizontal direction.**

Receptors of utricle and saccule give response to linear acceleration of head.

- utricle- horizontal respond
- saccule – vertical respond

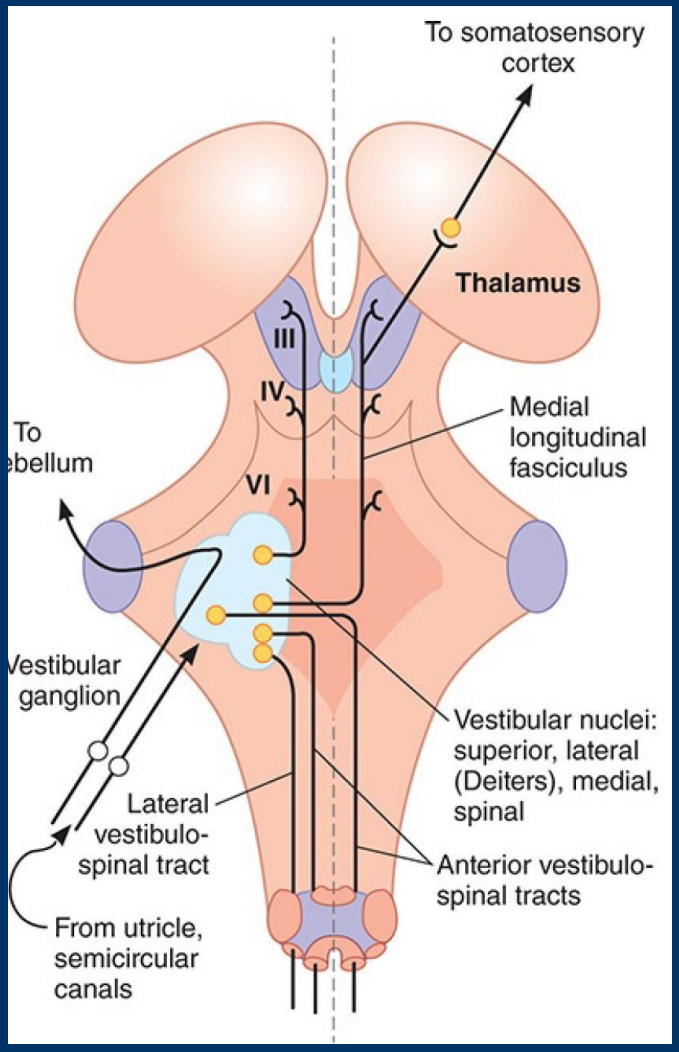
The otoliths in the surrounding membrane are denser than the endolymph, and acceleration in any direction causes them to be displaced in the opposite direction, distorting the hair cell processes



VESTIBULAR PATHWAY

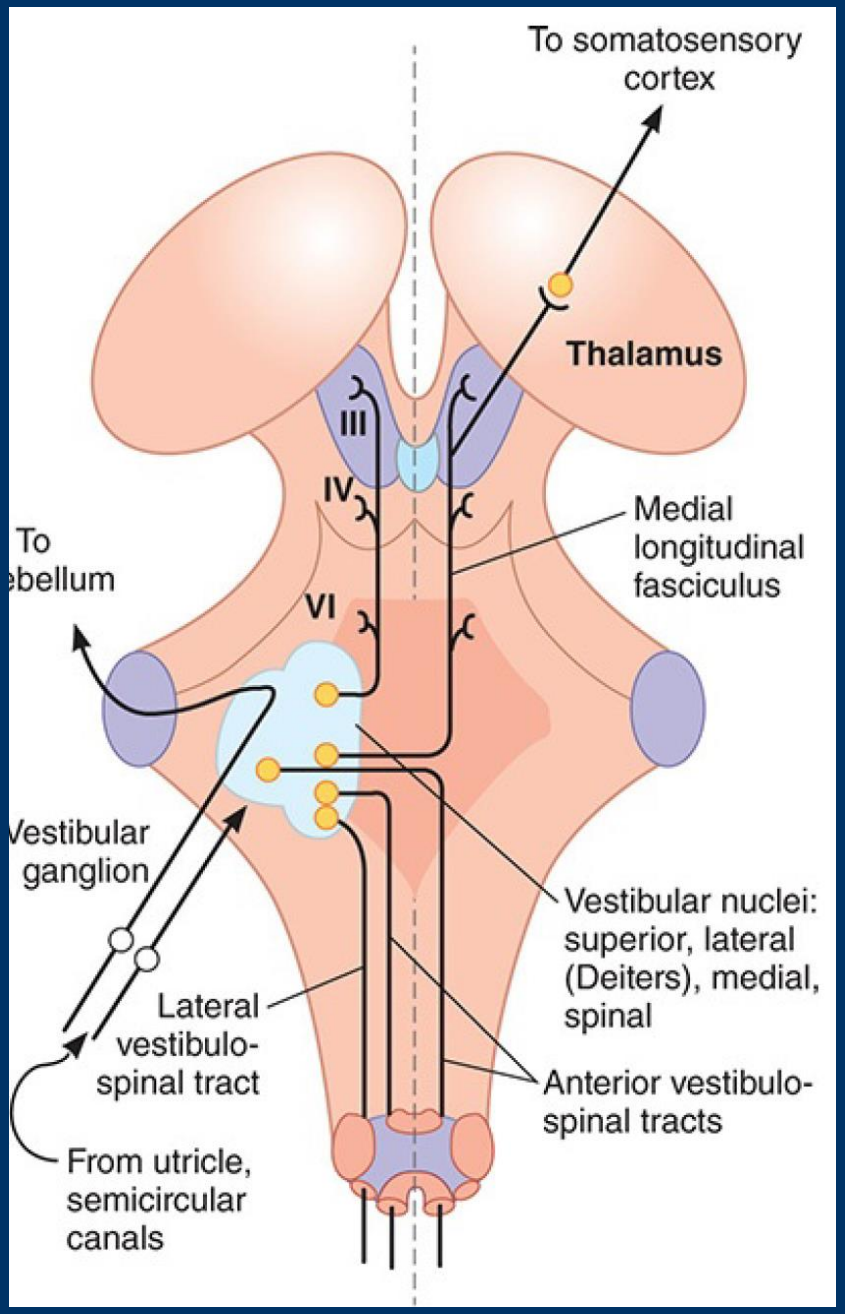
Impulses from the hair cells of crista ampullaris and maculae are transmitted to medulla oblongata and terminate in vestibular nuclei through the fibers of vestibular division of vestibulocochlear (VIII cranial) nerve.

- Some fibers reach cerebellum directly



Axons from vestibular nuclei form four tracts:

1. Vestibulo-ocular tract (with vestibulospinal tract, the medial longitudinal fasciculus terminate in the nuclei of III, IV and VI cranial nerves-concerned with **movements of eyeballs**
2. Vestibulospinal tract (with the vestibulospinal tract and medial longitudinal fasciculus)- reflex **movements of head and body**
3. Vestibuloreticular tract with reticulospinal tract-concerned with the **facilitation of** muscle tone.
4. Vestibulocerebellar tract - form vestibulocerebellar tract and terminate in flocculonodular lobe and fastigial nuclei of cerebellum-**coordination of movements** according to body position.



SMELL/TASTE

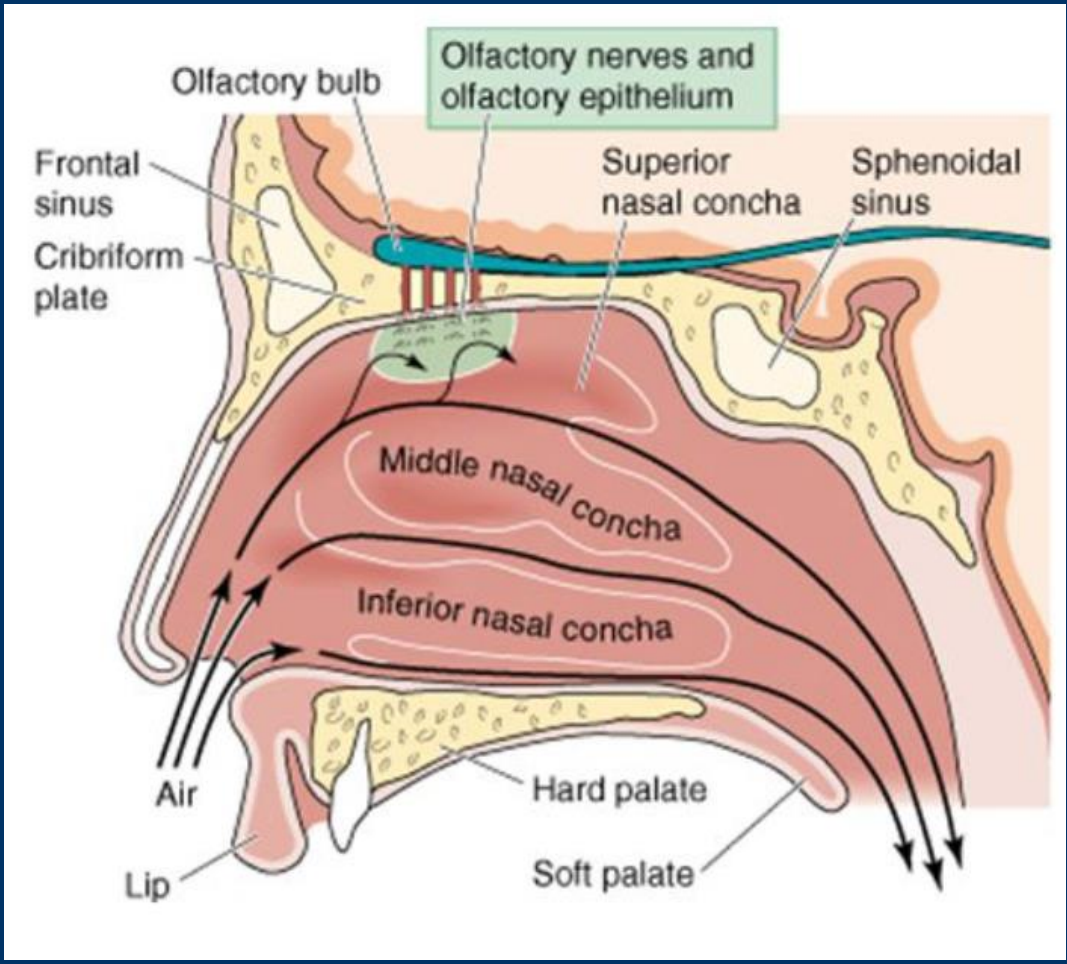
- are examples of visceral senses because of their close association with gastrointestinal function
- they are related to each other as the flavor of food is a combination of its taste and smell.
- Smell and taste receptors are chemoreceptors that are stimulated by chemical molecules in solution in mucus in the nose (odorants) and saliva in the mouth (tastants).
- The sensations of smell and taste likely evolved as protective mechanisms to avoid the intake of potentially harmful substances.

SMELL

The olfactory epithelium is a specialized portion of the nasal mucosa that covers an area of 10 cm2 in the roof of the nasal cavity Nervous system is here closest to the external world.

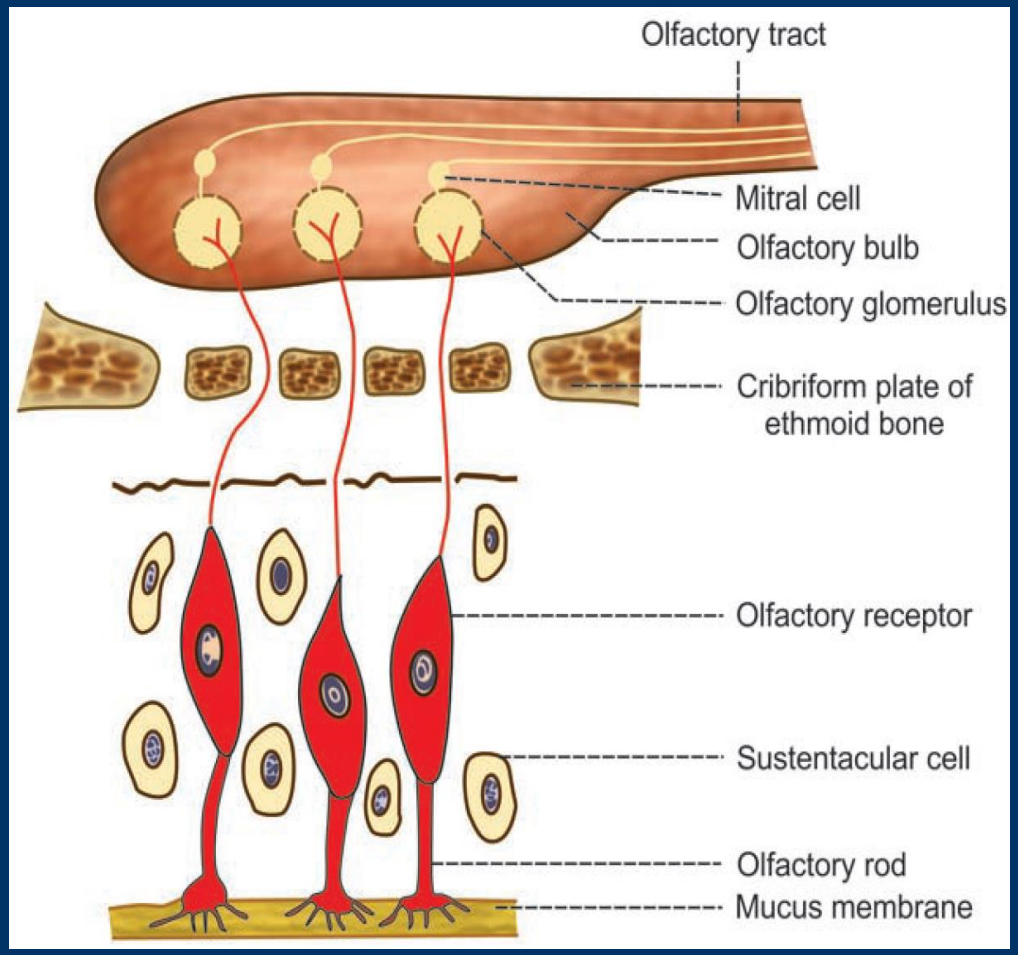
It contains three types of neurons :

- olfactory sensory neurons
- supporting cells
- basal stem cells



Olfactory receptor cells are responsible for olfactory transduction.

- have a short dendrite with 6–12 **cilia**
- The axons (as **olfactory nerve**) pass through the **cribriform plate** of the ethmoid bone to enter the **olfactory bulbs.**

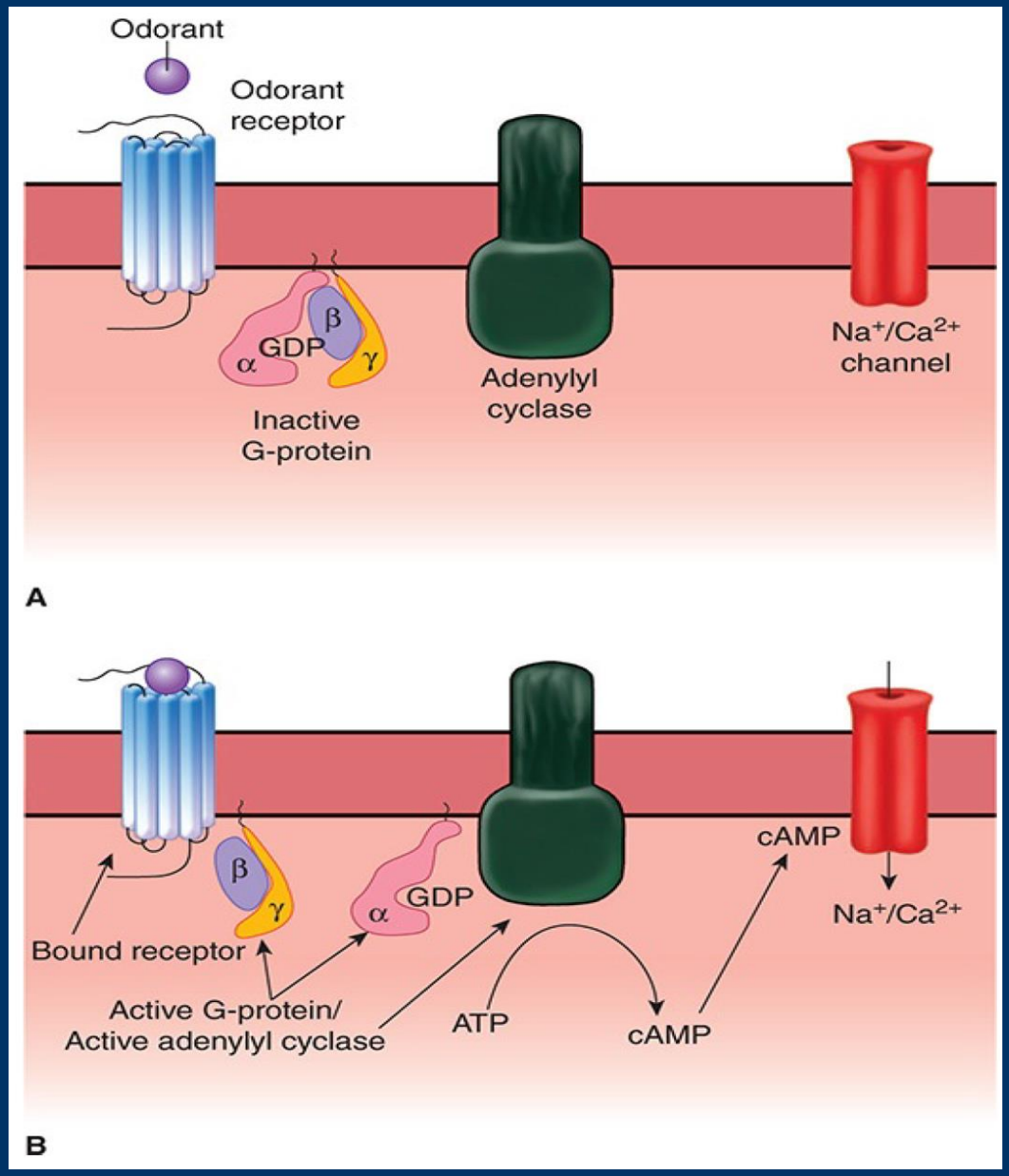


The supporting cells secrete the mucus.

Basal stem cells undergo mitosis to generate new olfactory sensory neurons as needed to replace those damaged by exposure to the environment; olfactory sensory neurons generally survive for only 1–2 months.

ODORANT RECEPTORS

- Olfactory receptors are examples of G-protein-coupled receptors
- They are associated with three G-protein subunits (α, β, γ)
- When an odorant binds to the receptors, the subunits dissociate. The α-subunit of G-proteins activates adenylyl cyclase to catalyze production of cAMP.
- cAMP acts as a second messenger to open cation channels. Inward diffusion of Na+ and Ca2+ produces depolarization.

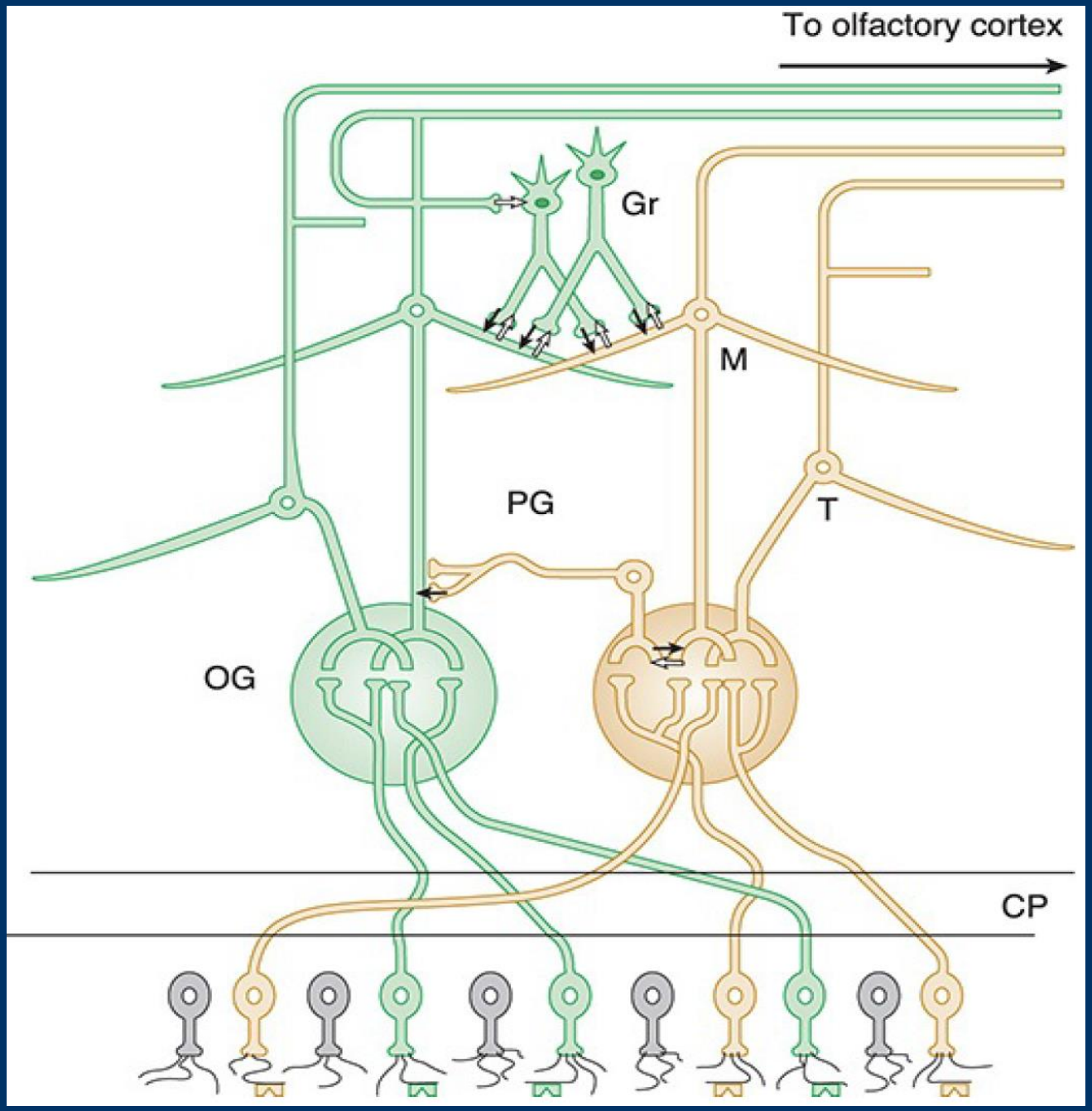


OLFACTORY BULB

Olfactory bulb contains:

. **olfactory glomeruli -** the axons of the olfactory sensory neurons synapse on the primary dendrites of the **mitral cells** and **tufted cells**
.**periglomerular cells**, which are inhibitory neurons connecting one glomerulus to another
.**granule cells**, which have no axons and make reciprocal synapses with the lateral dendrites of the mitral and tufted cells.

The mitral cells with their glomeruli project to different parts of the olfactory cortex.


To olfactory cortex
Gr
M
PG
T
OG
CP

OLFACTORY PATHWAY

The axons of the mitral and tufted cells pass posteriorly through the **lateral olfactory stria** to terminate on apical dendrites of pyramidal cells in five regions of the **olfactory cortex:**

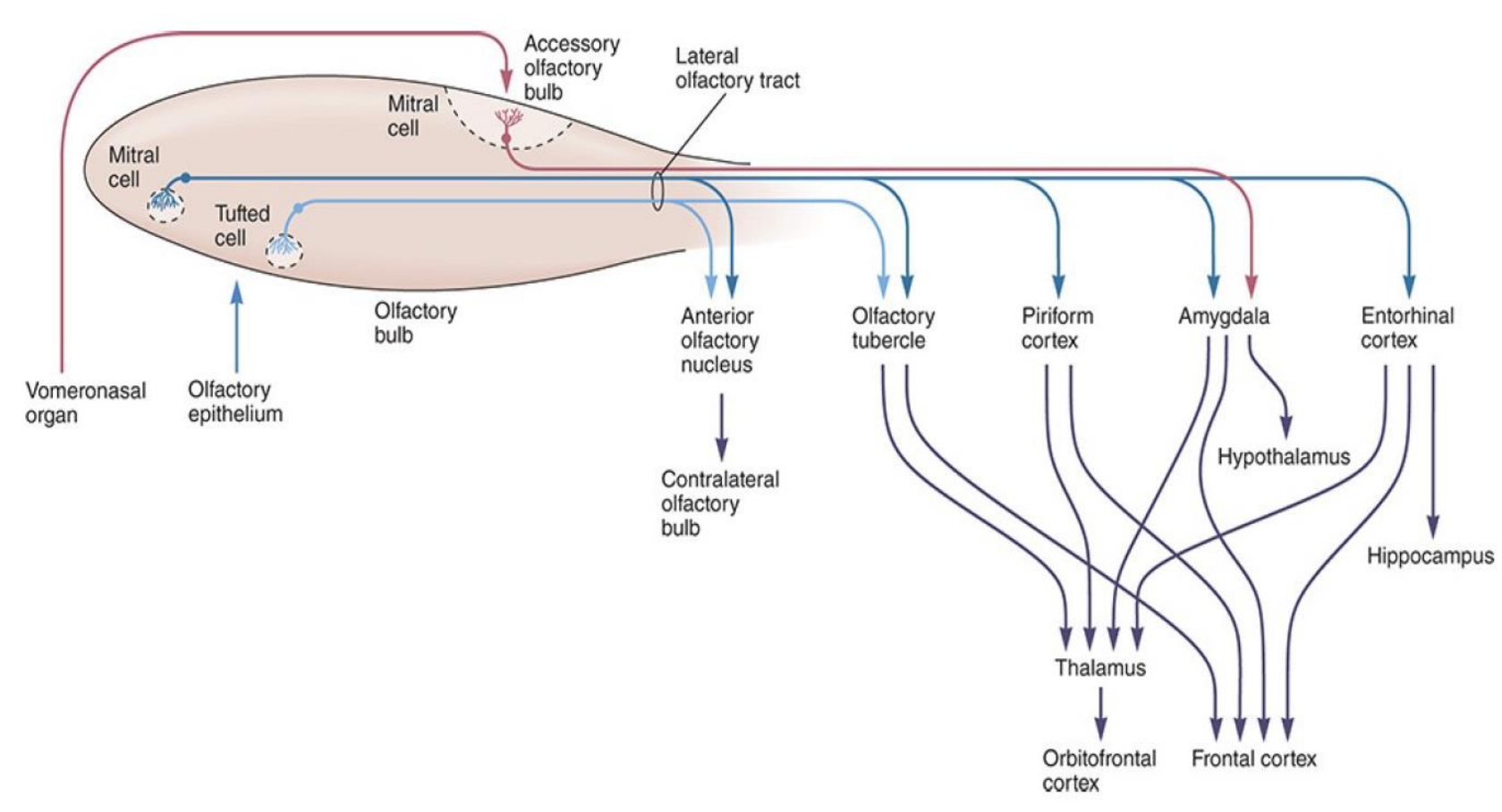
.**anterior olfactory nucleus,**

.**olfactory tubercle,**

.**piriform cortex,**

.**Amygdala-** emotional responses

.**entorhinal cortex -** olfactory memories



From these 5 regions, information travels directly to :

.the frontal cortex

.the orbitofrontal cortex (via thalamus) -conscious discrimination of odors

The vomeronasal organ

- In some mammals
- the nasal cavity contains another patch of olfactory epithelium located along the nasal septum
- concerned with the perception of **pheromones.**
- sensory neurons project to the **accessory olfactory bulb** and from there to regions of the amygdala and hypothalamus
- concerned with reproduction and ingestive behavior
- In human beings was considered as non-functional. Recently, it is found that:
- --this organ is present in the form of vomeronasal pits on the anterior part of nasal septum.
- --receptors detect odorless human pheromones or vomeropherins, at a very low concentration in air. The subconscious detection of odorless chemical messengers in air is considered as *the sixth sense in human beings.*

ODOR DETECTION THRESHOLD

- is the lowest concentration of a chemical that can be detected.

Compound	Odor Threshold in Air (parts per billion)
Methanol	141,000
Acetone	15,000
Formaldehyde	870
Menthol	40
T-butyl mercaptan	0.3

ABNORMALITIES

Hyperosmia - enhanced olfactory sensitivity) - pregnant women
Dysosmia - distorted sense of smell
Anosmia - inability to smell
Hyposmia – diminished olfactory sensitivity

Causes:

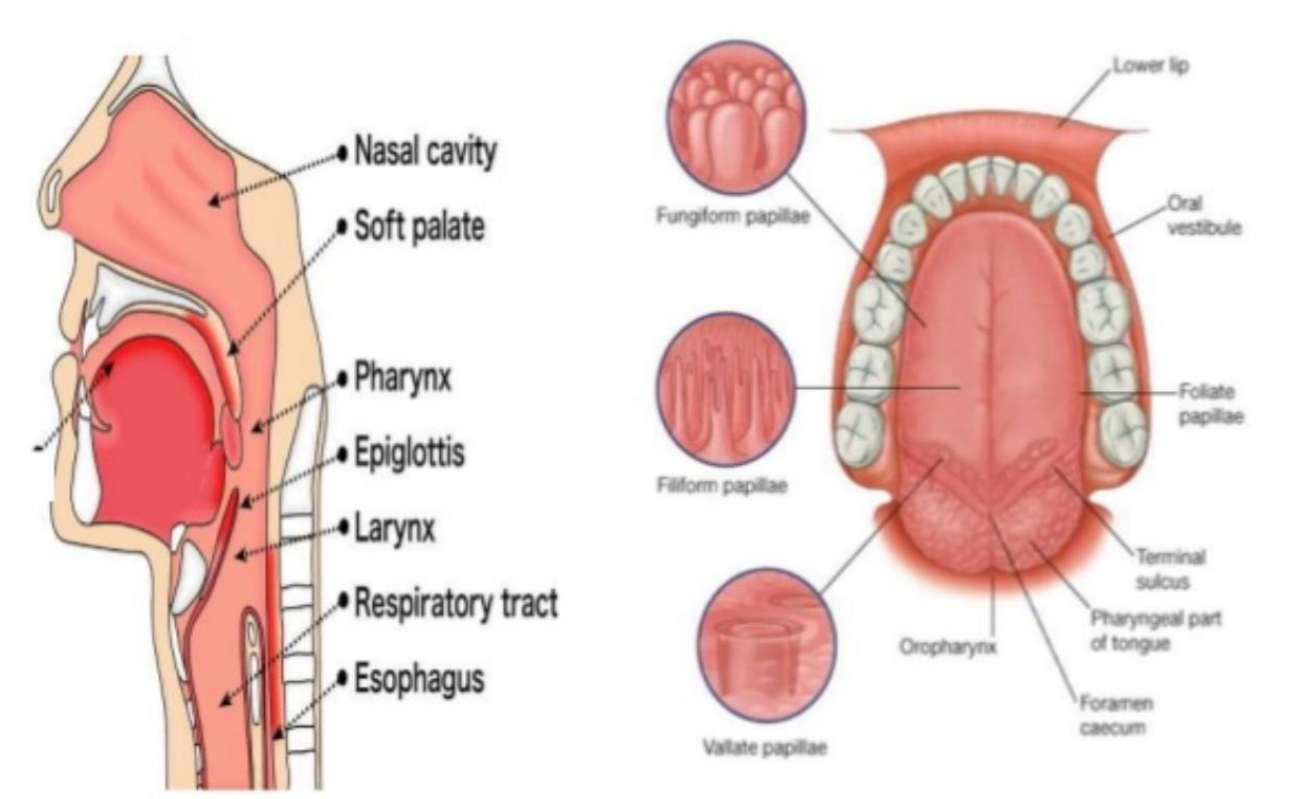
- simple nasal congestion
- nasal polyps
- prolonged use of nasal decongestants
- damage to the olfactory nerves due to fractures of the cribriform plate or head trauma, tumors (eg, neuroblastomas or meningiomas)

- *earliest clinical symptoms of Alzheimer disease*

TASTE

The specialized sense organ for taste (gustation) consists of about 5000 **taste buds** located :

- primarily on the **papillae** of the dorsal surface of the tongue
- the soft palate,
- epiglottis
- pharynx.

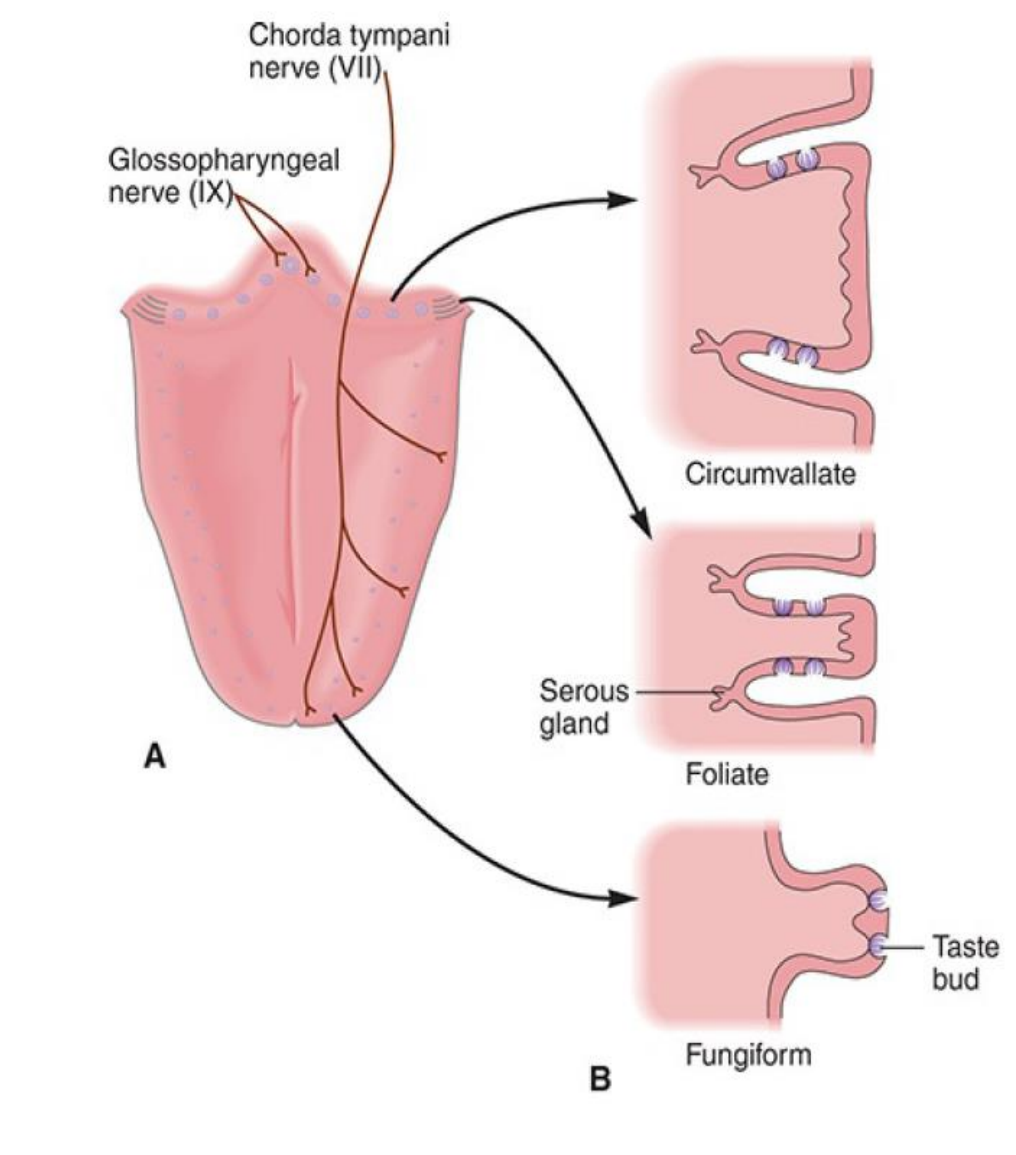


Most of the taste buds are present on the papillae of tongue.Types of papillae located on tongue:

.**Fungiform papillae** are rounded structures most numerous near the tip of the tongue – up to five taste buds, mostly located at the top

.**Foliate papillae** are on the posterior edge of the tongue - up to 100 taste buds, mostly located along the sides of the papillae.

.**Circumvallate papillaeare** prominent structures arranged in a V on the back of the tongue - up to 100 taste buds, along the sides of the papillae.



TASTE BUD

Taste bud is a bundle of taste receptor cells, with supporting cells, each taste bud contains about 40 cells (modified epithelial cells)

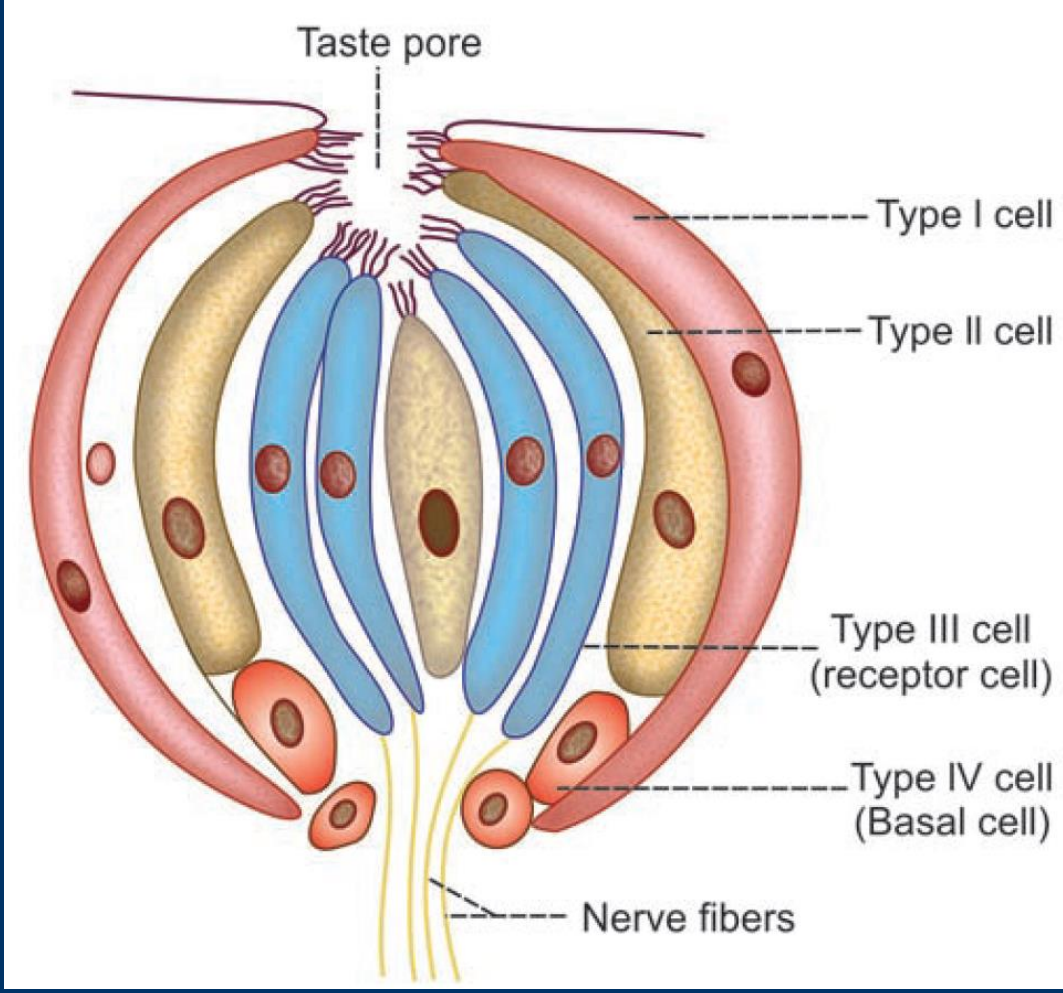
Type of Cells in Taste Bud

1. Type I cells – supporting cells
2. Type II cells – functin unknown
3. Type III cells – taste receptor cells
4. Type IV cells or basal cells – supporting cells

Type I, II and III cells have microvilli.

Cells undergo constant cycle of growth, apoptosis and regeneration!

Taste cells survive for only about 10 days.



TASTE PATHWAYS

RECEPTORS

Receptors are the type III cells of taste buds. Each taste bud is innervated by about 50 sensory nerve fibers

FIRST ORDER NEURON

First order neurons of taste pathway are in the nuclei of three different cranial nerves, situated in medulla oblongata. The fibers reach the cranial nerve nuclei by running along the nerves

1. **Chorda tympani fibers** of facial nerve, which run from anterior two third of tongue

2. **Glossopharyngeal nerve fibers,** which run from posterior one third of the tongue

3. **Vagal fibers,** which run from taste buds in other regions.

Axons terminate in the nucleus of **tractus solitarius.**

SECOND ORDER NEURON

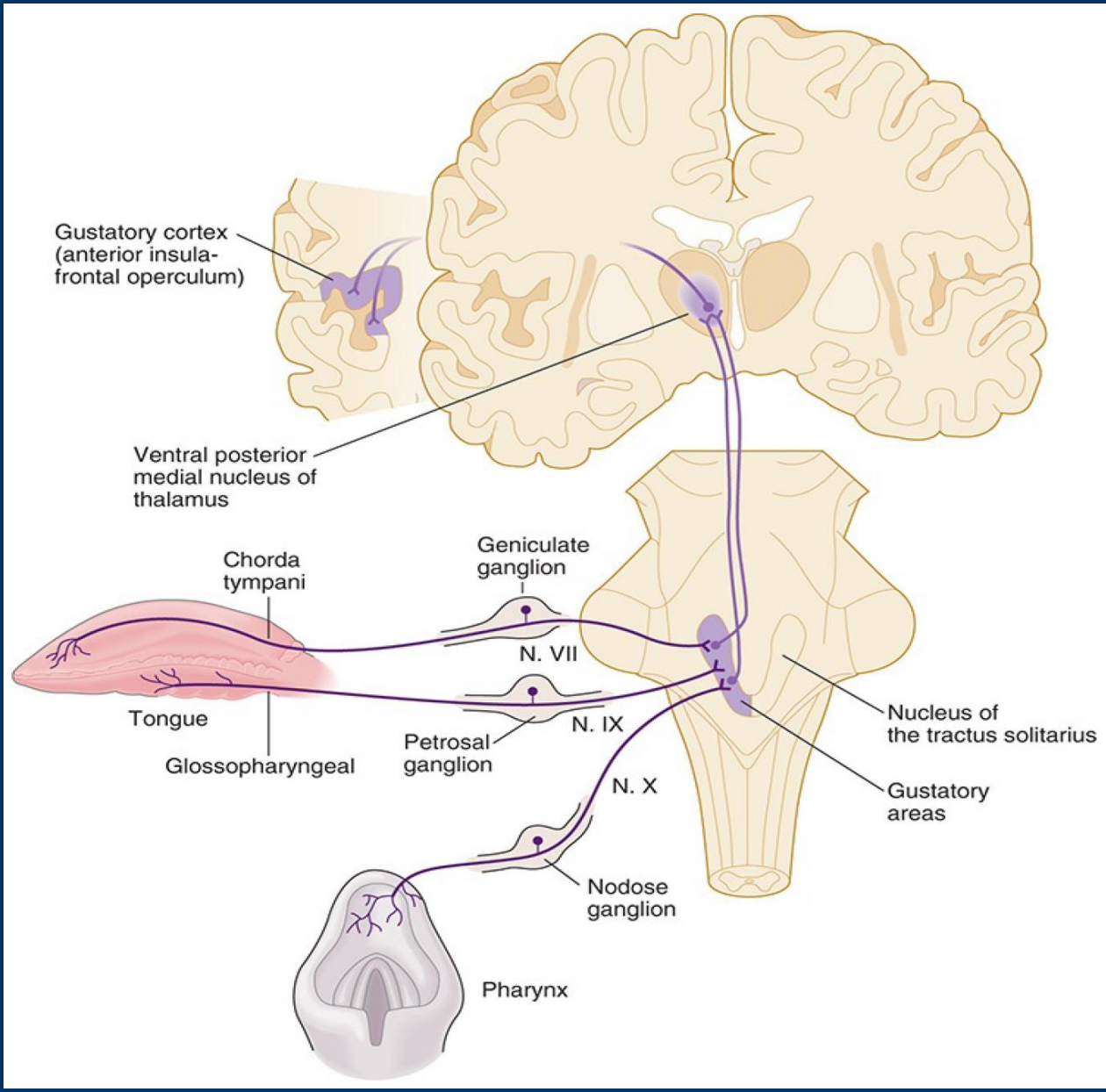
- Nucleus of tractus solitarius

THIRD ORDER NEURON

- Posteroventral nucleus of thalamus.

TASTE CENTER

- Opercular insular cortex



TASTE RECEPTORS

Humans have five basic taste modalities:

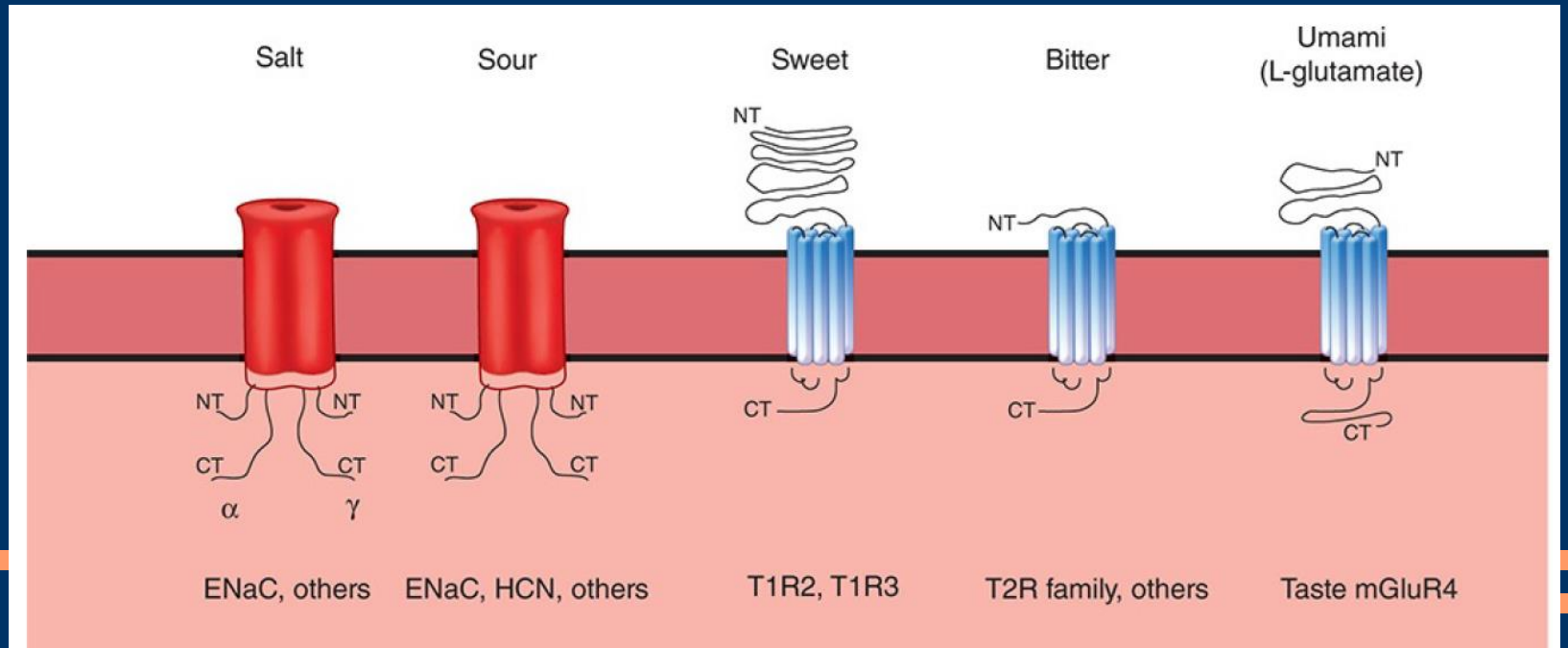
- Salt
- Sweet
- Sour
- Bitter
- Umami

- **All areas of tongue give response to all types of taste sensations!**

The types of receptors

ligand-gated channels (ionotropic receptors)
- Salt - sensed following Na+ movement
- Sour - by movement of H+.

GPCRs (metabotropic receptors)
- Sweet - detected by the T1R2 and T1R3 families
- Bitter - the T2R family
- Umami - mGluR4



TASTE THRESHOLDS

Taste threshold refers to the minimum concentration at which a substance can be perceived.
Bitter substances tend to have the lowest threshold, preventing accidental ingestion of toxic substances.

Substance	Taste	Threshold Concentration (μmol/L)
Hydrochloric acid	Sour	100
Sodium chloride	Salt	2000
Strychnine hydrochloride	Bitter	1.6
Glucose	Sweet	80,000
Sucrose	Sweet	10,000
Saccharin	Sweet	23

ABNORMALITIES

Ageusia - absence of the sense of taste

H**ypogeusia -** diminished taste sensitivity

Dysgeusia or **parageusia -** unpleasant perception of taste

*About 25% of the population has a heightened sensitivity to taste, in particular to bitterness - called **supertasters;** due to the presence of an increased number of fungiform papillae on their tongue*