Neurophysiology

Vision II

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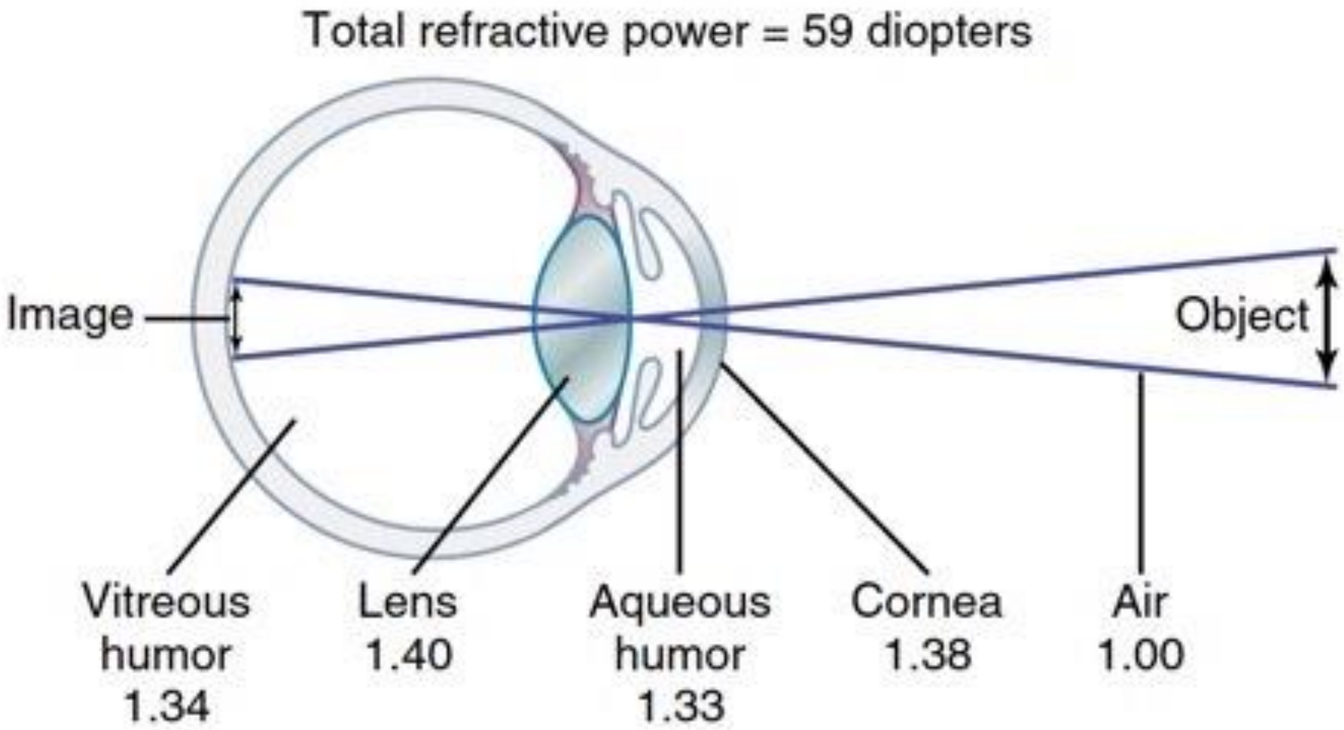
Refraction

- The lens system of the eye is composed of four refractive interfaces:
- (1) the interface between air and the anterior surface of the cornea.
- (2) the interface between the posterior surface of the cornea and the aqueous humor.
- (3) the interface between the aqueous humor and the anterior surface of the lens.
- (4) the interface between the posterior surface of the lens and the vitreous humor.


Total refractive power = 59 diopters
Image
Object
Vitreous humor 1.34
Lens 1.40
Aqueous humor 1.33
Cornea 1.38
Air 1.00

Refraction

- In the reduced eye, a single refractive surface is considered to exist, with a total refractive power of 59 diopters when the lens is accommodated for distant vision.

- About two-thirds of the 59 diopters of refractive power of the eye is provided by the anterior surface of the cornea (not the lens).

- The principal reason for this phenomenon is that the refractive index of the cornea is markedly different from that of air.

Accomodation

- However, the importance of the internal lens is that in response to nervous signals from the brain, its curvature can be increased markedly to provide "accommodation,"

- The ability to adjust the strength of the lens is known as accommodation.

Accomodation

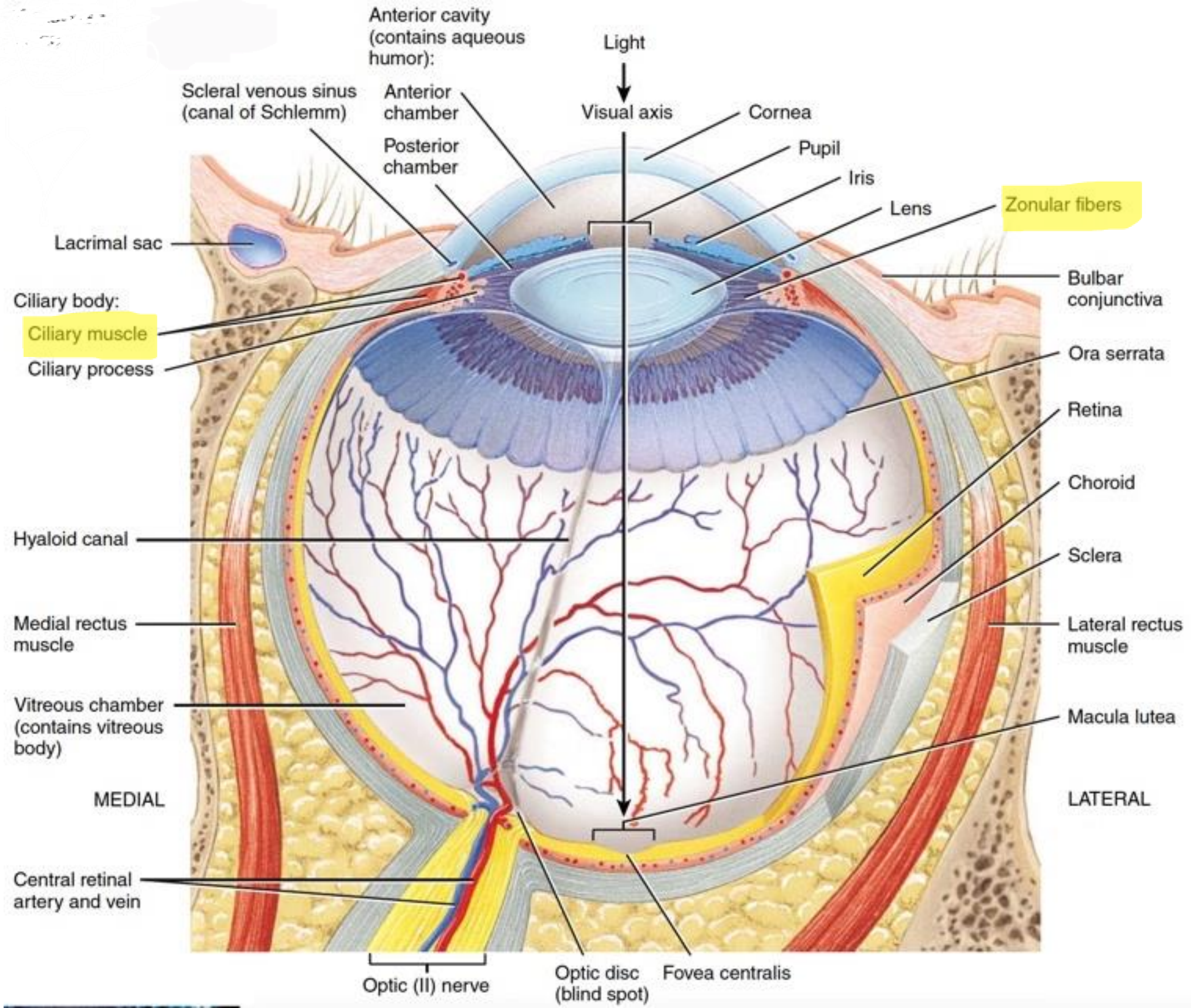
- In a young person, the lens is composed of a strong elastic capsule filled with viscous, proteinaceous, but transparent fluid.

- However, about 70 suspensory ligaments attach radially around the lens, pulling the lens edges toward the outer circle of the eyeball.
- These ligaments are constantly tensed by their attachments at the anterior border of the choroid and retina.
- The tension on the ligaments causes the lens to remain relatively flat under normal eye conditions.

Accomodation

- Also located at the lateral attachments of the lens ligaments to the eyeball is the ciliary muscle, which has two separate sets of smooth muscle fibers—meridional fibers and circular fibers.

- Contraction of either set of smooth muscle fibers in the ciliary muscle relaxes the ligaments to the lens capsule, and the lens assumes a more spherical shape because of the natural elasticity of the lens capsule.



Anterior cavity
(contains aqueous
humor):
Light
Scleral venous sinus
(canal of Schlemm)
Anterior
chamber
Visual axis
Cornea
Posterior
chamber
Pupil
Iris
Lens
Zonular fibers
Lacrimal sac
Bulbar
conjunctiva
Ciliary body:
Ciliary muscle
Ciliary process
Ora serrata
Retina
Choroid
Hyaloid canal
Sclera
Medial rectus
muscle
Lateral rectus
muscle
Vitreous chamber
(contains vitreous
body)
Macula lutea
MEDIAL
LATERAL
Central retinal
artery and vein
Optic (II) nerve
Optic disc
(blind spot)
Fovea centralis

Accomodation

- Ciliary muscle is controlled almost entirely by parasympathetic nerve signals transmitted to the eye through the third cranial nerve from the third nerve nucleus in the brain stem.

- Stimulation of parasympathetic nerves contracts both sets of ciliary muscle fibers, which relaxes the lens ligaments, thus allowing the lens to become thicker and increase its refractive power.

Accomodation

- In children, the refractive power of the lens of the eye can be increased voluntarily from 20 diopters to about 34 diopters, which is an “accommodation” of 14 diopters.

- To make this accommodation, the shape of the lens is changed from that of a moderately convex lens to that of a very convex lens.

Accomodation

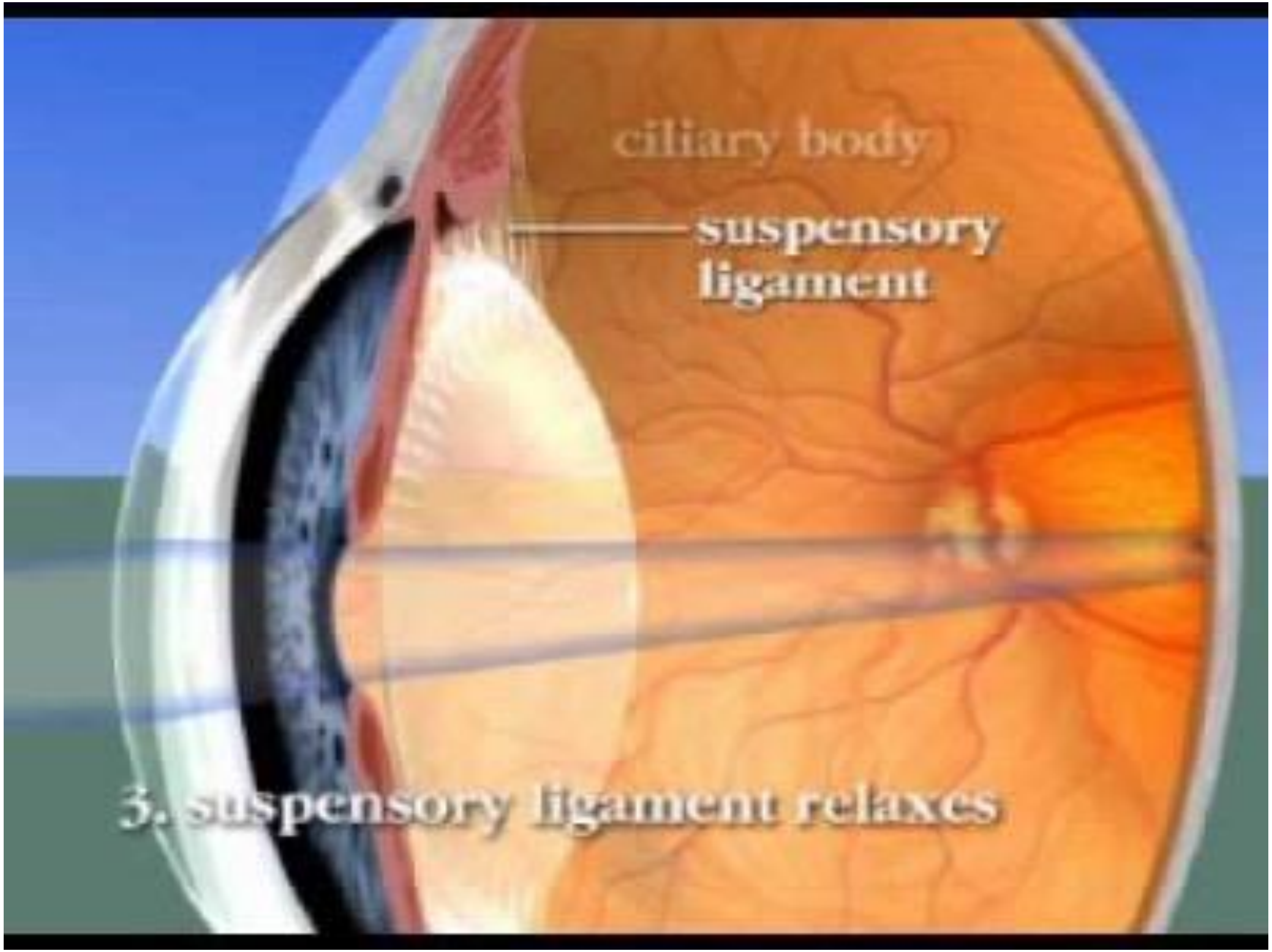
- As a person grows older, the lens grows larger and thicker and becomes far less elastic, partly because of progressive denaturation of the lens proteins. The ability of the lens to change shape decreases with age.
- The power of accommodation decreases from about 14 diopters in a child to less than 2 diopters by the time a person reaches 45 to 50 years and to essentially 0 diopters at age 70 years.
- Thereafter, the lens remains almost totally nonaccommodating, a condition known as **presbyopia**.

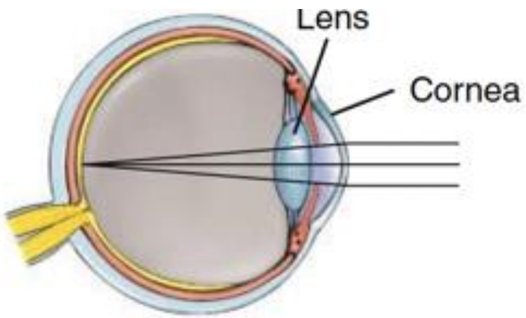
- Once a person has reached the state of presbyopia, each eye remains focused permanently at an almost constant distance; this distance depends on the physical characteristics of each person’s eyes.

- The eyes can no longer accommodate for both near and far vision. To see clearly both in the distance and nearby, an older person must wear bifocal glasses, with the upper segment focused for far-seeing and the lower segment focused for near-seeing (e.g., for reading).

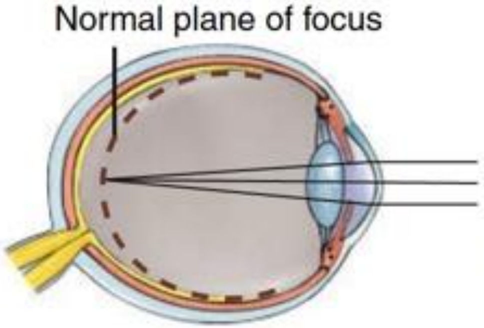
Near vision

- Accomodation
- Pupillary constriction
- Convergence

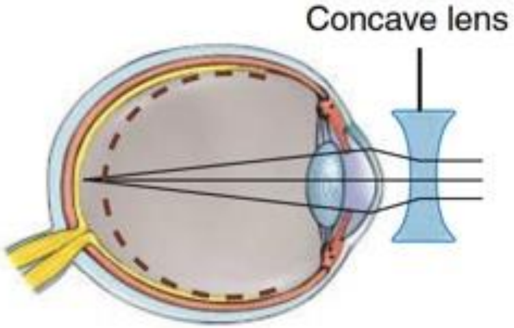

ciliary body
suspensory
ligament
3. suspensory ligament relaxes



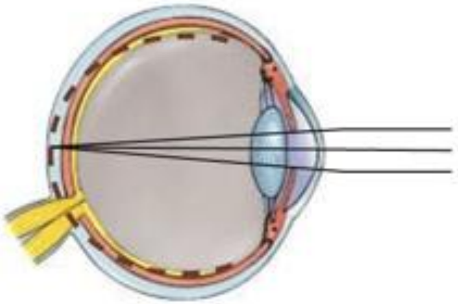
(a) Normal (emmetropic) eye



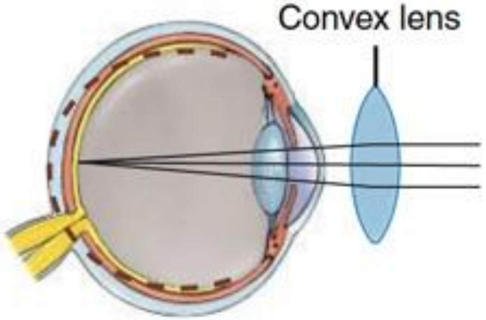
(b) Nearsighted (myopic) eye, uncorrected



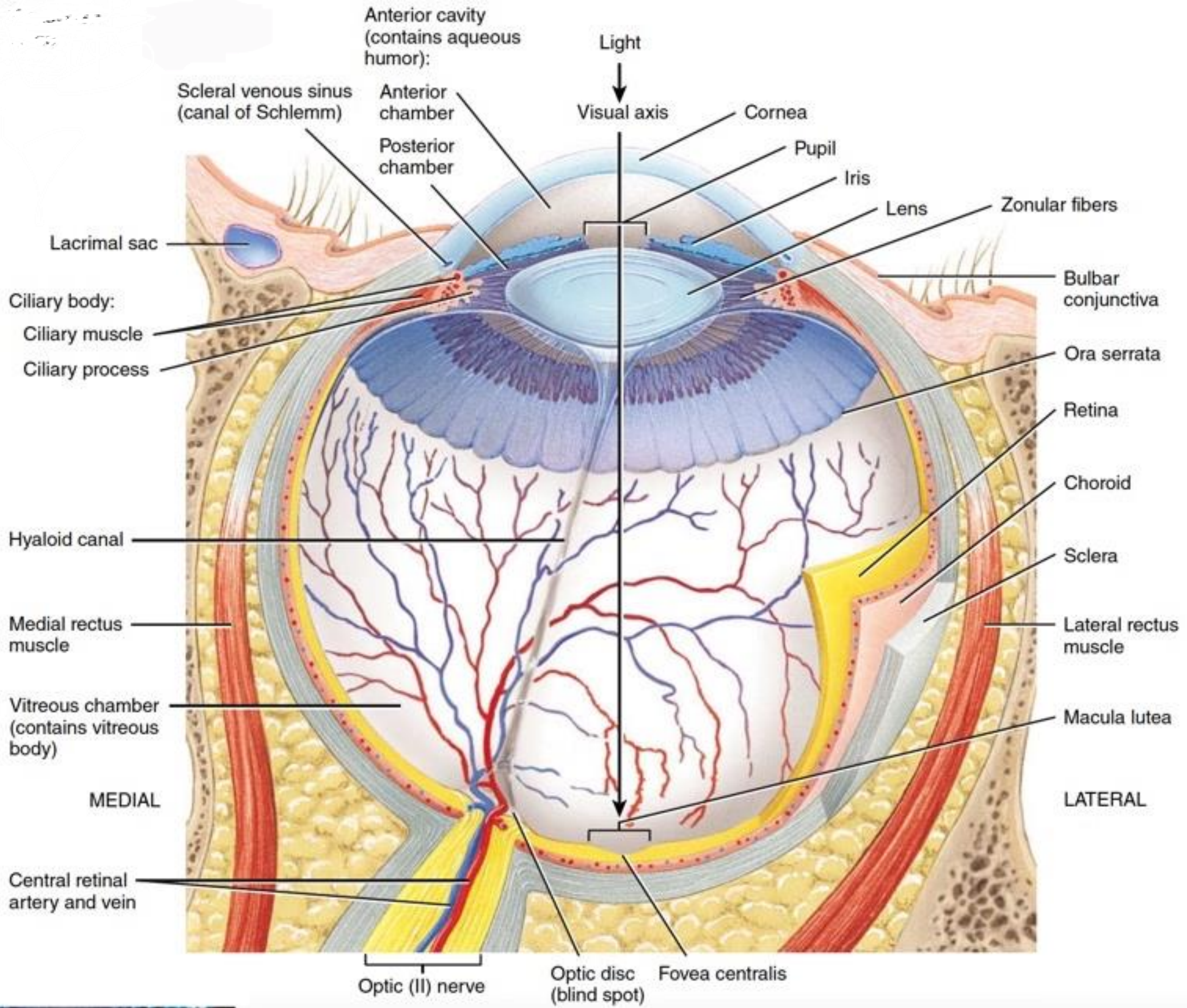
(c) Nearsighted (myopic) eye, corrected



(d) Farsighted (hyperopic) eye, uncorrected



(e) Farsighted (hyperopic) eye, corrected



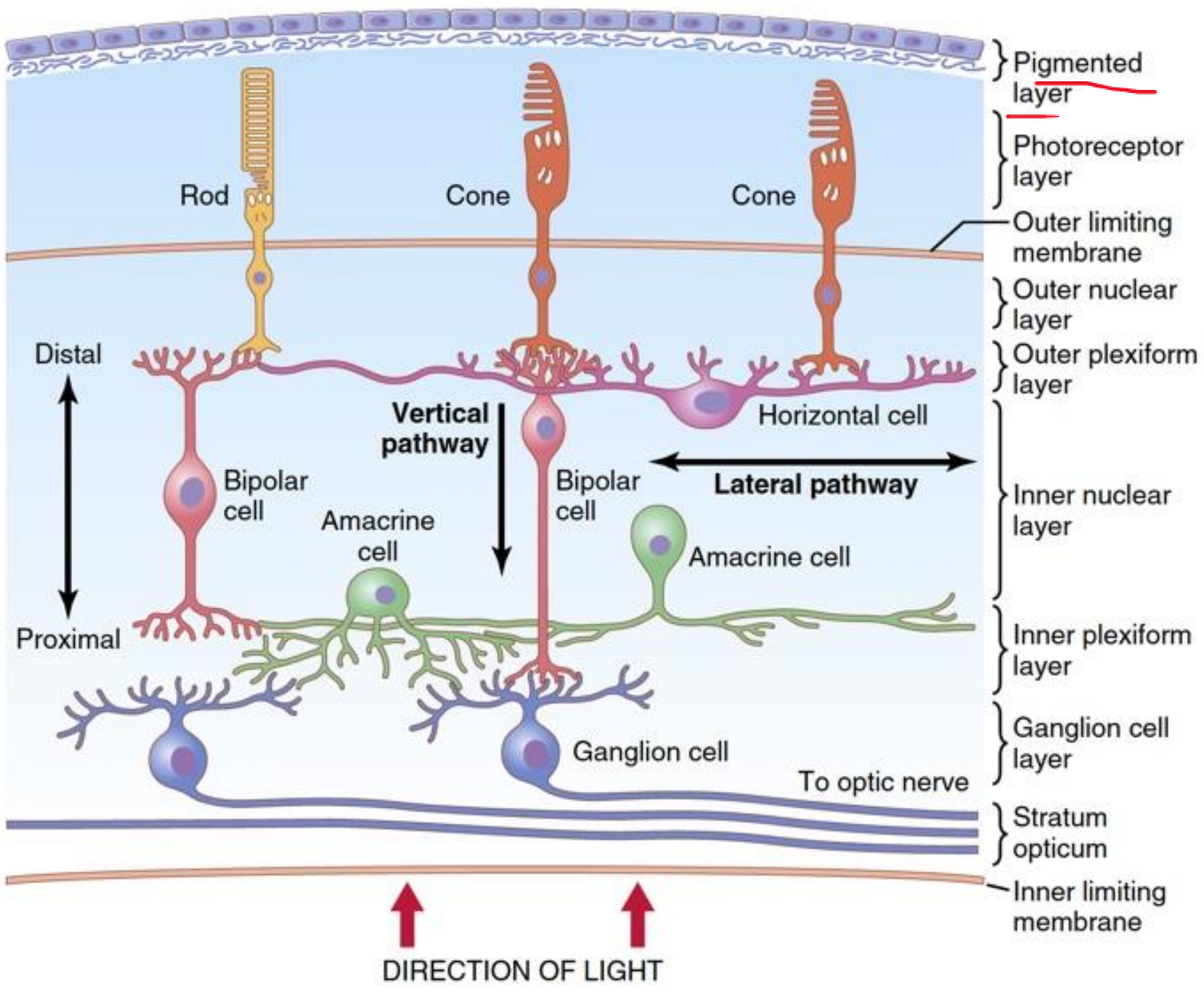
Anterior cavity (contains aqueous humor):
Light
Scleral venous sinus (canal of Schlemm)
Anterior chamber
Visual axis
Cornea
Posterior chamber
Pupil
Iris
Lens
Zonular fibers
Lacrimal sac
Bulbar conjunctiva
Ciliary body:
Ciliary muscle
Ciliary process
Ora serrata
Retina
Choroid
Hyaloid canal
Sclera
Medial rectus muscle
Lateral rectus muscle
Vitreous chamber (contains vitreous body)
Macula lutea
MEDIAL
LATERAL
Central retinal artery and vein
Optic (II) nerve
Optic disc (blind spot)
Fovea centralis

Optic disc

- The point on the retina at which the optic nerve leaves and through which blood vessels pass is the optic disc.

- This region is often called the blind spot; no image can be detected in this area because it has no rods and cones.

- We are normally not aware of the blind spot because central processing somehow “fills in” the missing spot.


Pigmented layer
Photoreceptor layer
Outer limiting membrane
Outer nuclear layer
Outer plexiform layer
Inner nuclear layer
Inner plexiform layer
Ganglion cell layer
Stratum opticum
Inner limiting membrane
Rod
Cone
Cone
Distal
Proximal
Vertical pathway
Horizontal cell
Lateral pathway
Bipolar cell
Bipolar cell
Amacrine cell
Amacrine cell
Ganglion cell
To optic nerve
DIRECTION OF LIGHT

Fovea

- Light must pass through the ganglion and bipolar layers before reaching the photoreceptors in all areas of the retina except the fovea, located in the center of the retina.

- Because of this feature, and because only cones (which have greater acuity or discriminative ability than the rods) are found here, the fovea is the point of most distinct vision.

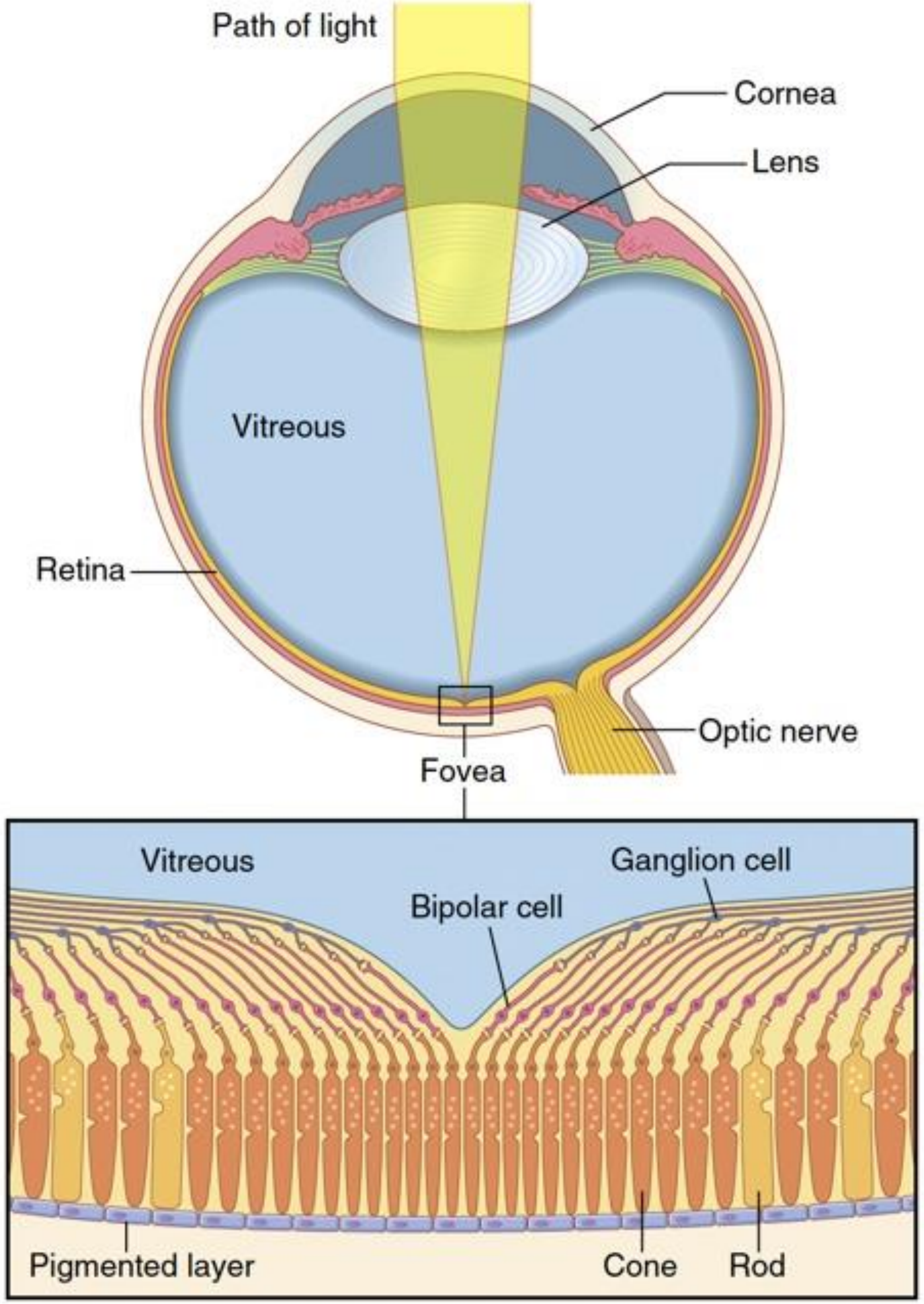
Fovea

- The fovea is a minute area in the center of the retina, especially capable of acute and detailed vision.

- The central fovea is composed almost entirely of cones. These cones have a special structure that aids their detection of detail in the visual image—that is, the foveal cones have especially long and slender bodies, in contradistinction to the much fatter cones located more peripherally in the retina.

Fovea

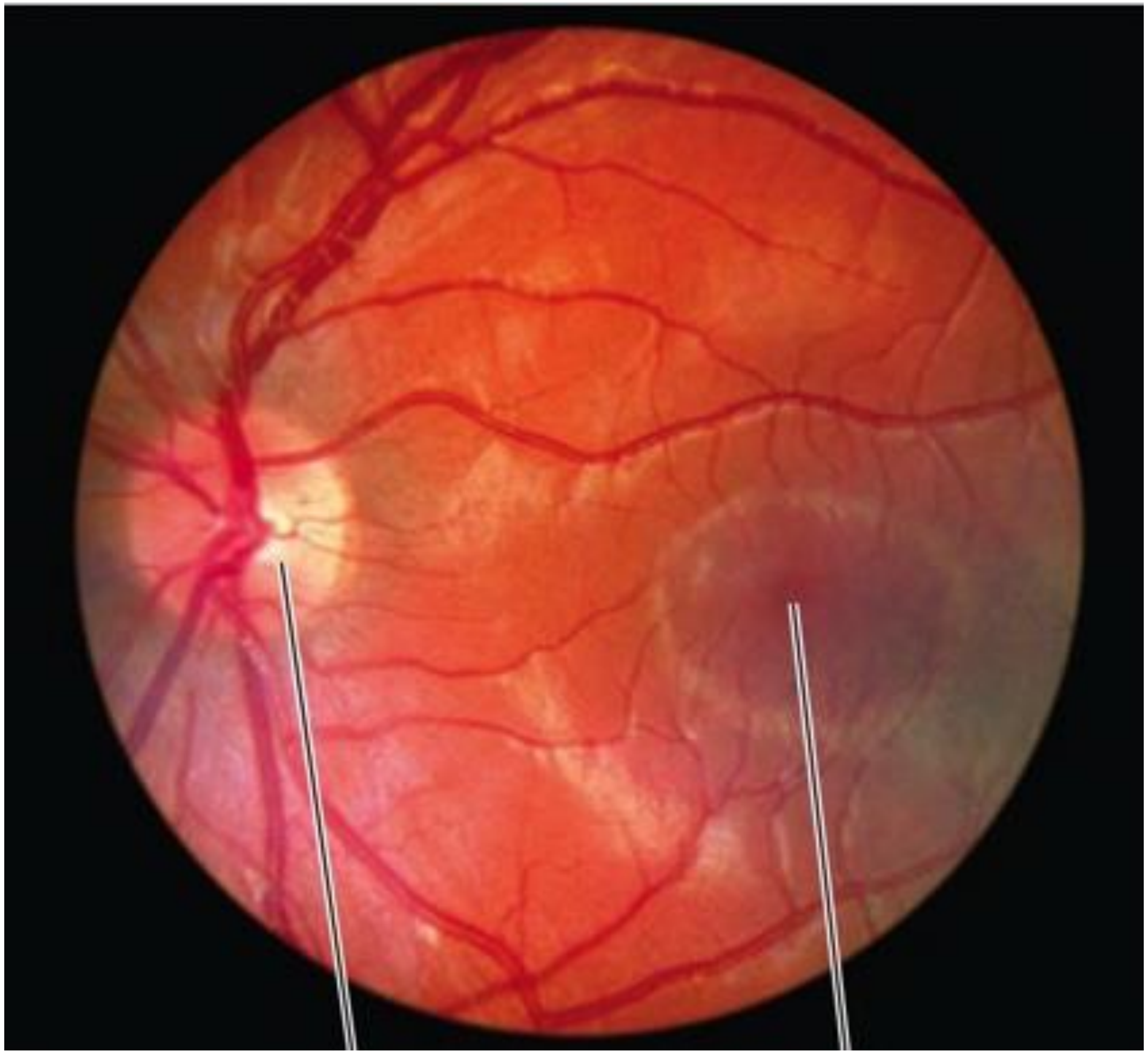
- Also, in the foveal region, the blood vessels, ganglion cells, inner nuclear layer of cells, and plexiform layers are all displaced to one side rather than resting directly on top of the cones, which allows light to pass unimpeded to the cones.

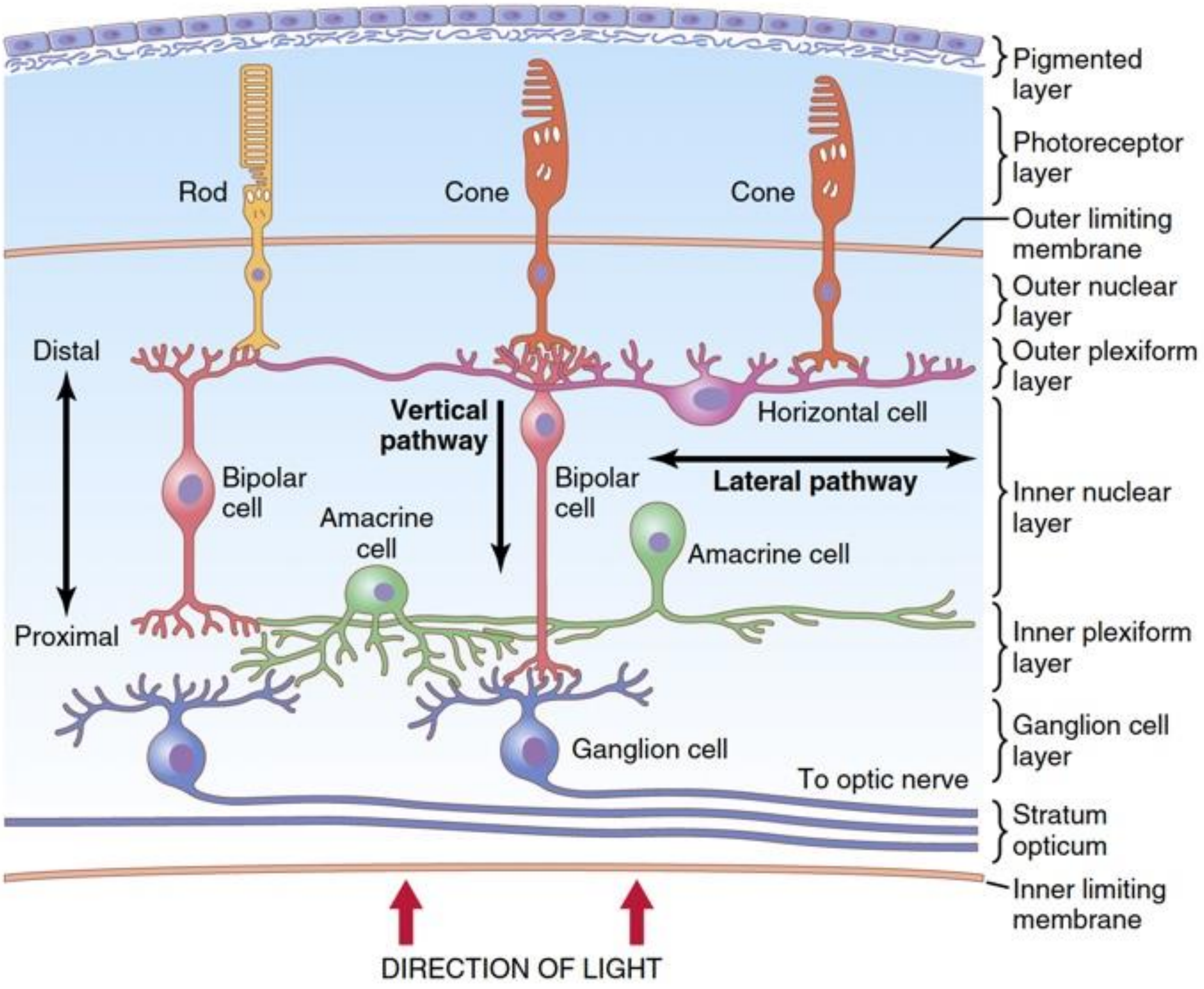


Path of light
Cornea
Lens
Vitreous
Retina
Optic nerve
Fovea
Vitreous
Ganglion cell
Bipolar cell
Pigmented layer
Cone
Rod

Macula

- The area immediately surrounding the fovea is called the macula lutea, has a high concentration of cones and fairly high acuity.
- Macular acuity is less than that of the fovea because of the overlying ganglion and bipolar cells in the macula.
- Macular degeneration.

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Inner limiting membrane
Rod
Cone
Cone
Distal
Proximal
Horizontal cell
Vertical pathway
Bipolar cell
Bipolar cell
Lateral pathway
Amacrine cell
Amacrine cell
Ganglion cell
To optic nerve
DIRECTION OF LIGHT

Pigment

- The black pigment melanin in the pigment layer prevents light reflection throughout the eye ball, which is extremely important for clear vision.

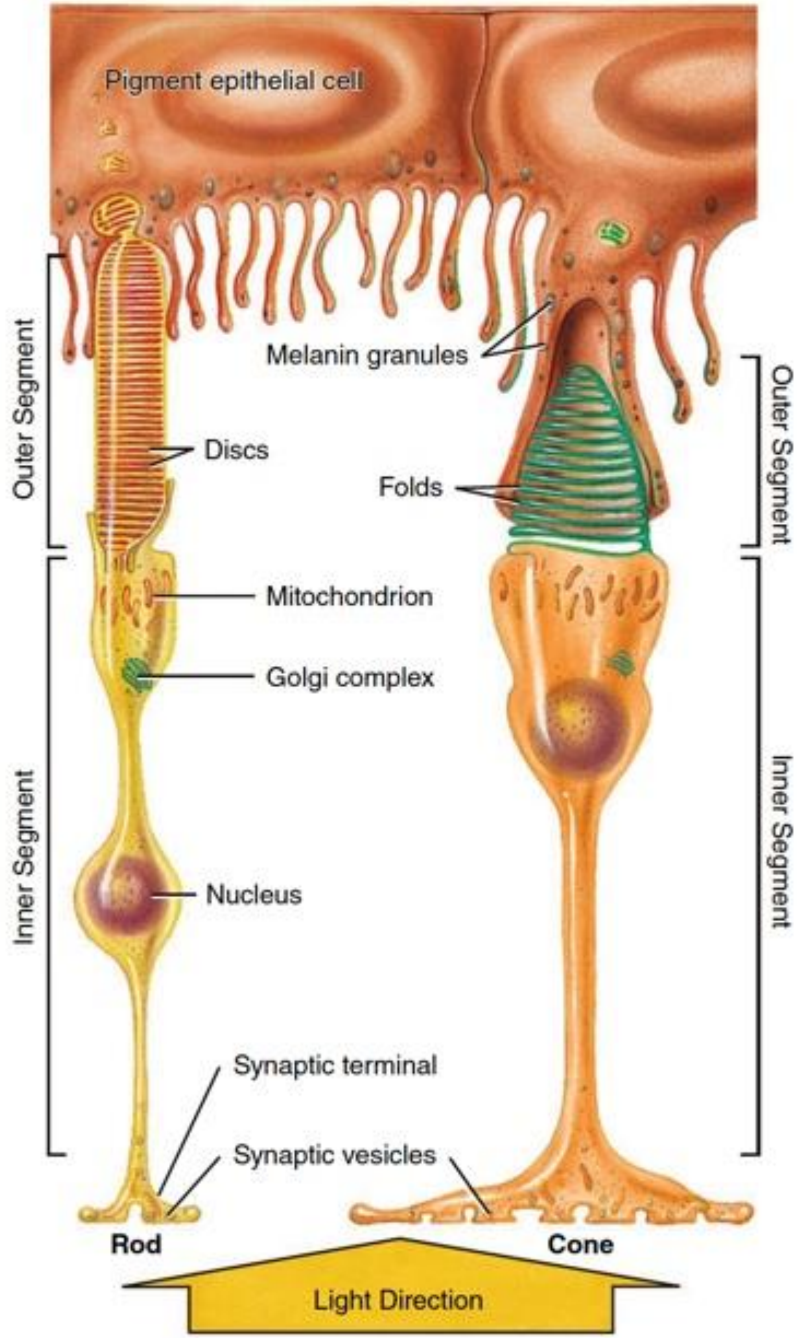
- Albinism

Vitamin A

- The pigment layer also stores large quantities of vitamin A. That is exchanged back and forth through the cell membranes of the outer segments of the rods and cones, which are embedded in the pigment.

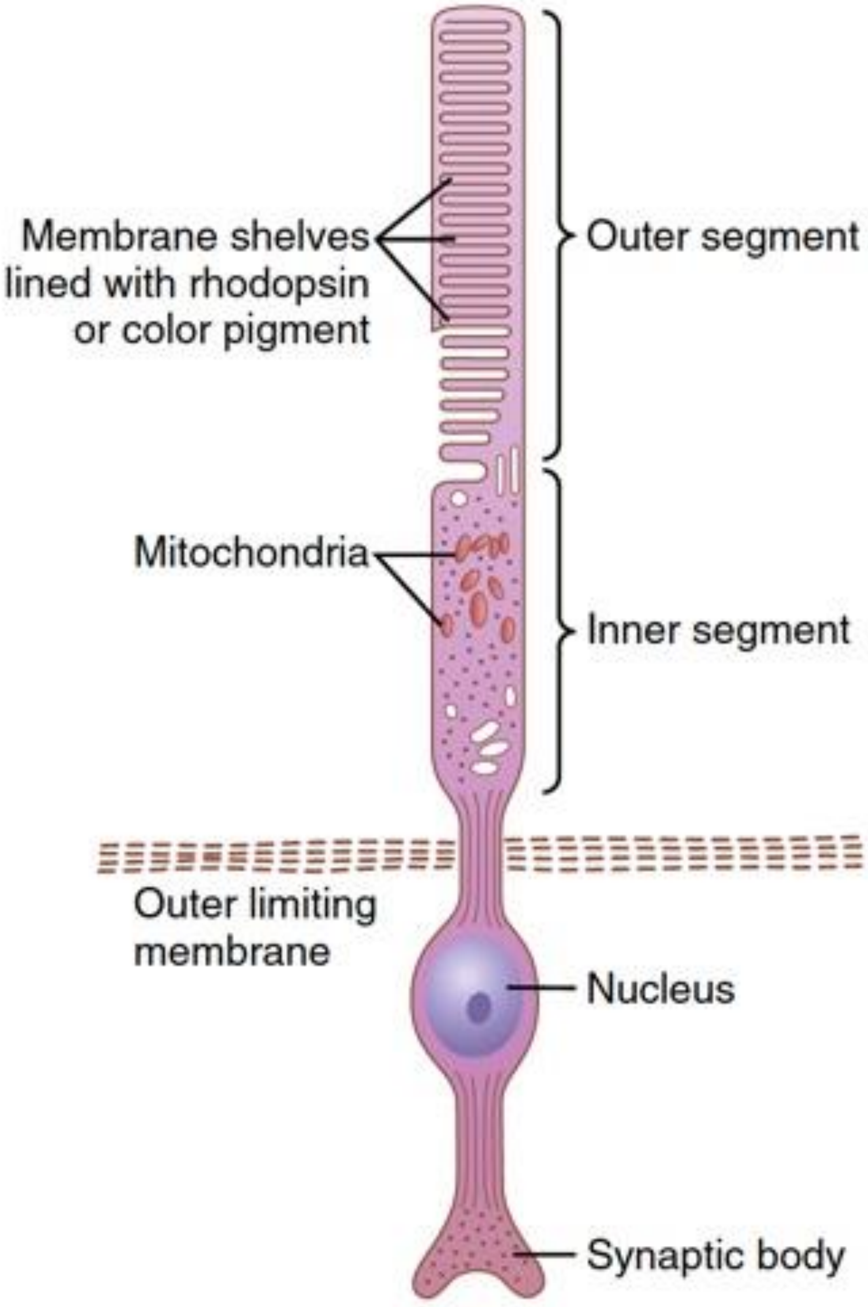
- vitamin A is an important precursor of the photosensitive chemicals of the rods and cones.

- Night blindness



Rods vs cones:

shape
location
number
sensitivity to light
visual acuity
color vision



Membrane shelves
lined with rhodopsin
or color pigment
Outer segment
Mitochondria
Inner segment
Outer limiting
membrane
Nucleus
Synaptic body

Photoreceptors

- The light-sensitive photochemical is found in the outer segment. In the case of the rods, this photochemical is rhodopsin; in the cones, it is one of three color pigments, that function almost exactly the same as rhodopsin except for differences in spectral sensitivity.
- In the outer segments of the rods and cones, note the large numbers of discs. Each disc is actually an infolded shelf of cell membrane. There are as many as 1000 discs in each rod or cone.

Photoreceptors

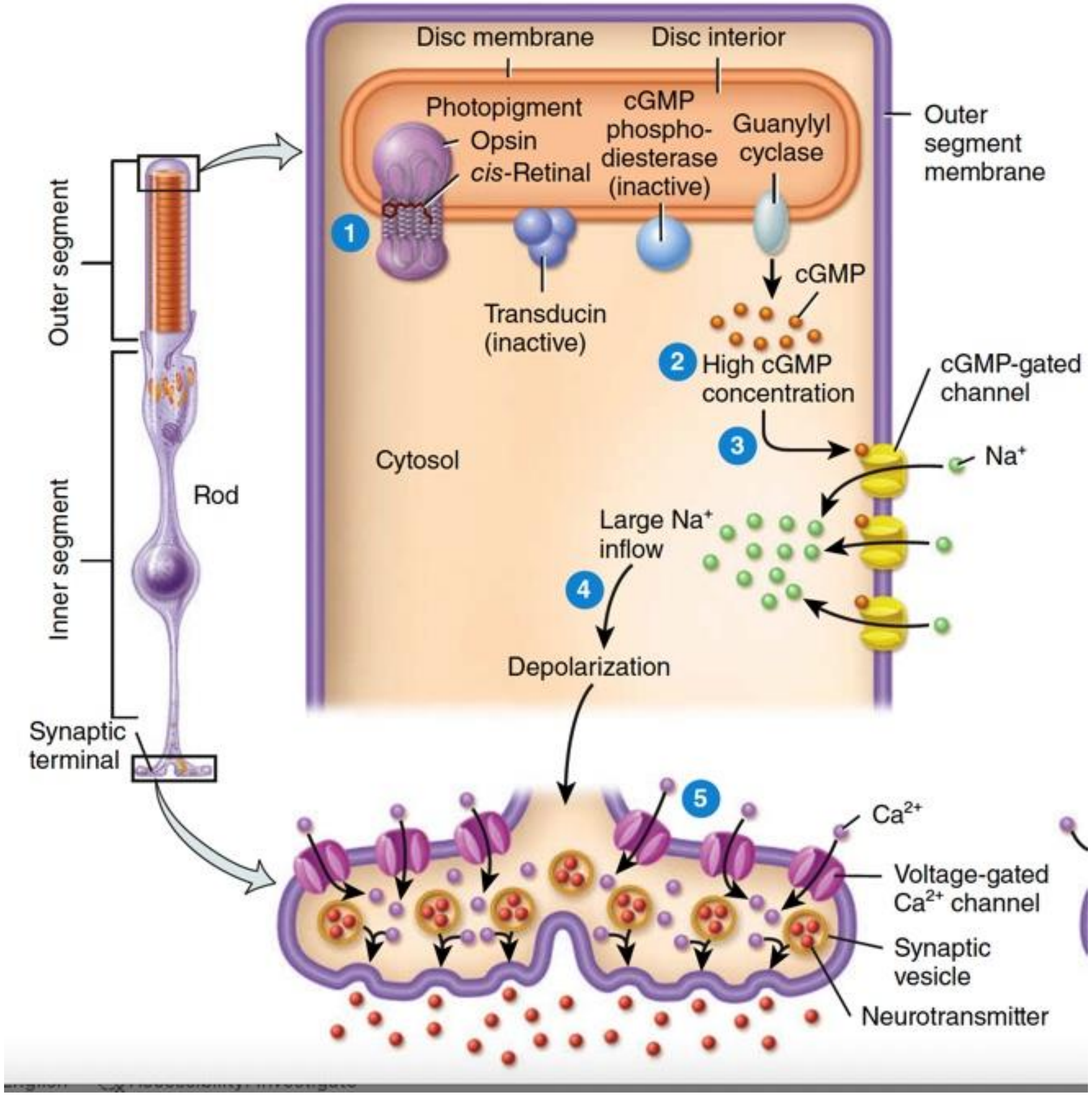
- The inner segment of the rod or cone contains the usual cytoplasm, with cytoplasmic organelles. Especially important are the mitochondria, which play the important role of providing energy for function of the photoreceptors.

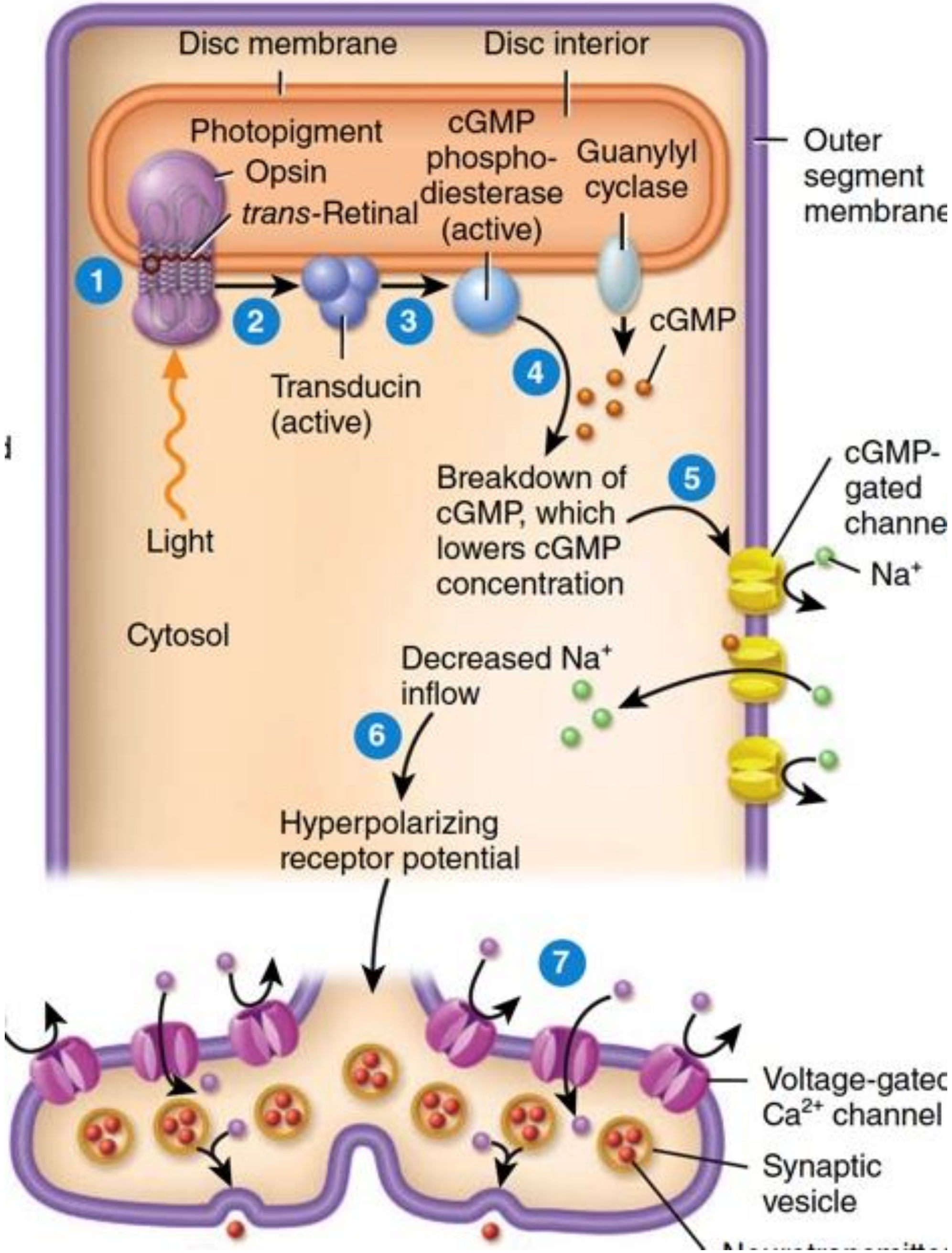
- The synaptic body is the portion of the rod or cone that connects with subsequent neuronal cells, the horizontal and bipolar cells, which represent the next stages in the vision chain.

Photoreceptors

- Both rhodopsin and the color pigments are conjugated proteins. They are incorporated into the membranes of the discs in the form of transmembrane proteins.

- The concentrations of these photosensitive pigments in the discs are so great that the pigments themselves constitute about 40% of the entire mass of the outer segment.


Disc membrane
Disc interior
Photopigment
Opsin
cis-Retinal
cGMP phospho-diesterase (inactive)
Guanylyl cyclase
Outer segment membrane
1
Transducin (inactive)
cGMP
2 High cGMP concentration
cGMP-gated channel
3
Na+
Cytosol
Large Na+ inflow
4
Depolarization
Outer segment
Inner segment
Rod
Synaptic terminal
5
Ca2+
Voltage-gated Ca2+ channel
Synaptic vesicle
Neurotransmitter



Disc membrane
Disc interior
Photopigment
Opsin
trans-Retinal
cGMP phosphodiesterase (active)
Guanylyl cyclase
Outer segment membrane
1
2
3
Transducin (active)
cGMP
4
Breakdown of cGMP, which lowers cGMP concentration
5
cGMP-gated channe
Na+
Light
Cytosol
Decreased Na+ inflow
6
Hyperpolarizing receptor potential
7
Voltage-gatec Ca2+ channel
Synaptic vesicle

Photo-transduction

- The outer segment of the rod that projects into the pigment layer of the retina has light-sensitive pigment called rhodopsin.

- This substance is a combination of the protein scotopsin and the carotenoid pigment retinal.

- Furthermore, the retinal is a particular type called 11-cis retinal. This cis form of retinal is important because only this form can bind with scotopsin to synthesize rhodopsin.

Re-formation

- The first stage in re-formation of rhodopsin is to reconvert the all-trans retinal into 11-cis retinal.

- This process requires metabolic energy and is catalyzed by the enzyme retinal isomerase.

- Once the 11-cis retinal is formed, it automatically recombines with the scotopsin to re-form rhodopsin, which then remains stable until its decomposition is again triggered by absorption of light energy.

Cones

- photochemicals in the cones have almost exactly the same chemical composition as that of rhodopsin in the rods.
- The only difference is that the protein portions, or the opsins—called photopsins in the cones—are slightly different from the scotopsin of the rods.
- The retinal portion of all the visual pigments is exactly the same in the cones and rods.

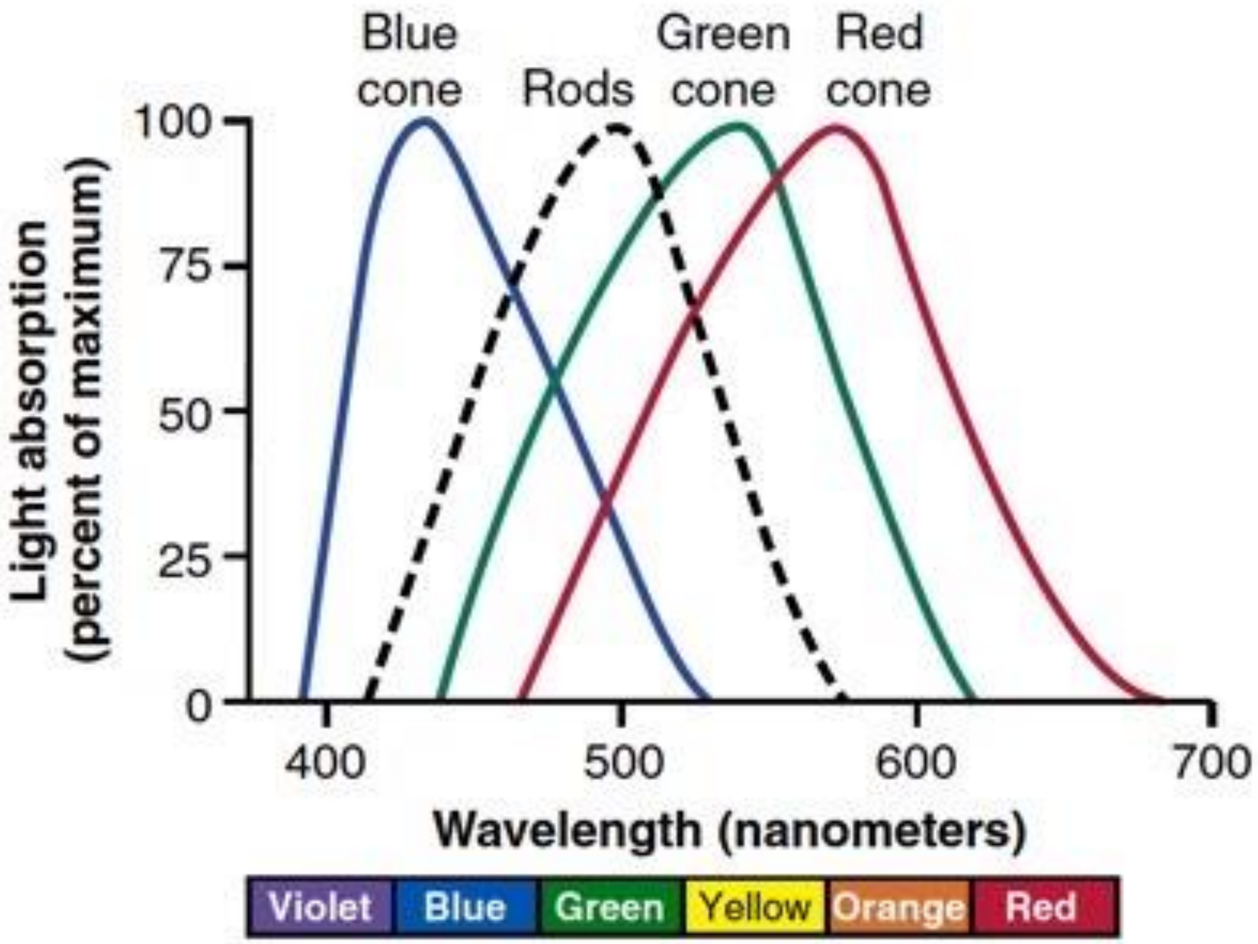
Color vision

- Each photopigment maximally absorbs a particular wavelength but also absorbs a range of wavelengths shorter and longer than this peak absorption.

- The farther a wavelength is from the peak wavelength absorbed, the less strongly the photopigment responds.

- The absorption curves for the three cone types overlap so that two or three cones may respond to a given wavelength but to a different extent.

Color vision

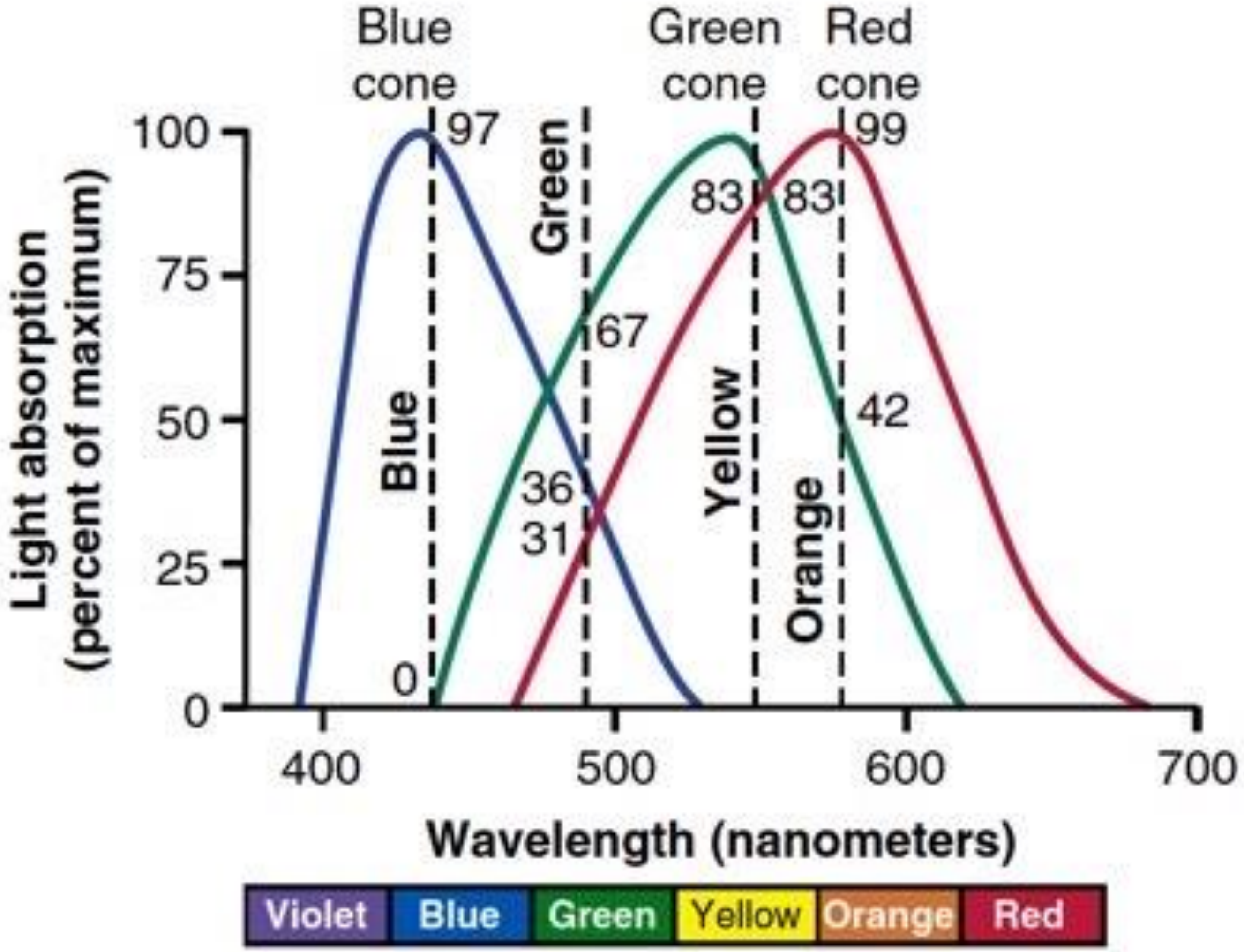


Color vision

- Each cone type is most effectively activated by a particular wavelength of light in the range of color indicated by its name.

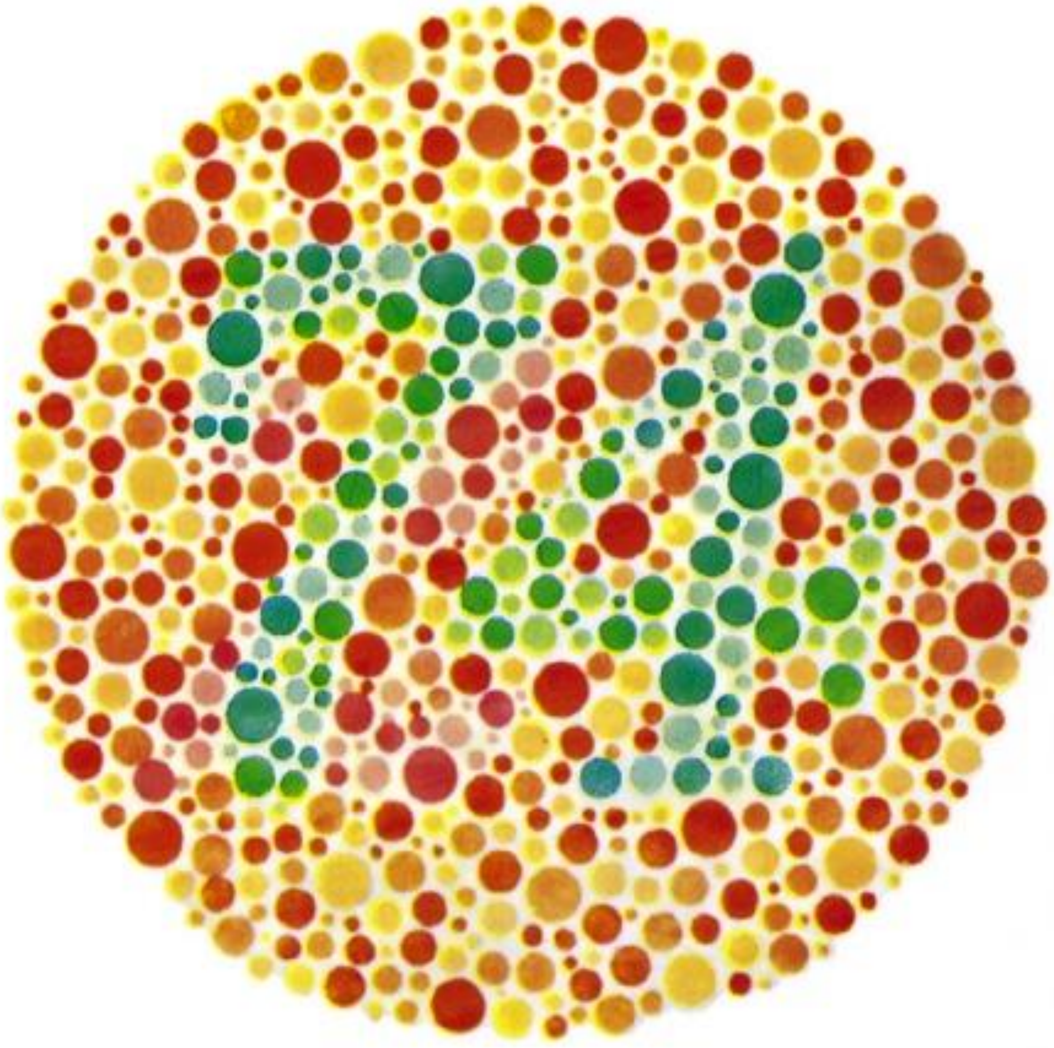
- cones also respond in varying degrees to other wavelengths.

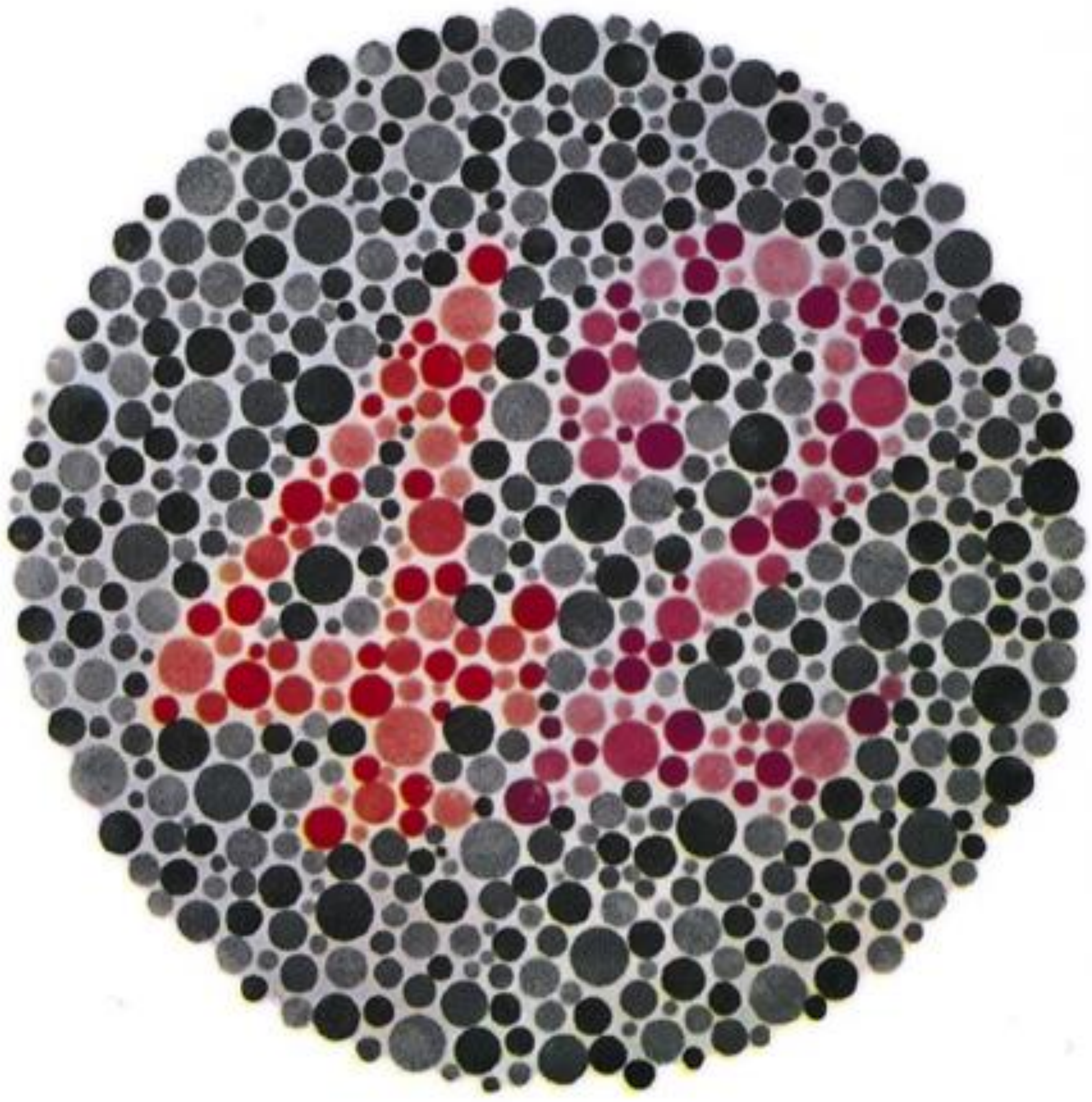
- According to the trichromatic theory of color vision, the perception of the many colors of the world depends on the three cone types' various ratios of stimulation in response to different wavelengths.



the ratios of stimulation of the three types of cones.

About equal stimulation of all the red, green, and blue cones gives one the sensation of seeing white.





Photoreceptor	Sensitivity to Light	Acuity	Dark Adaptation	Color Vision
Rods	Low threshold Sensitive to low-intensity light Night vision	Low acuity Not present on fovea	Adapt late	No
Cones	High threshold Sensitive to high-intensity light Day vision	High acuity Present on fovea	Adapt early	Yes

Dark and light adaptation

- In the dark, the photopigments broken down during light exposure are gradually regenerated.

- As a result, the sensitivity of your eyes gradually increases so that you begin to see in the darkened surroundings.

Dark and light adaptation

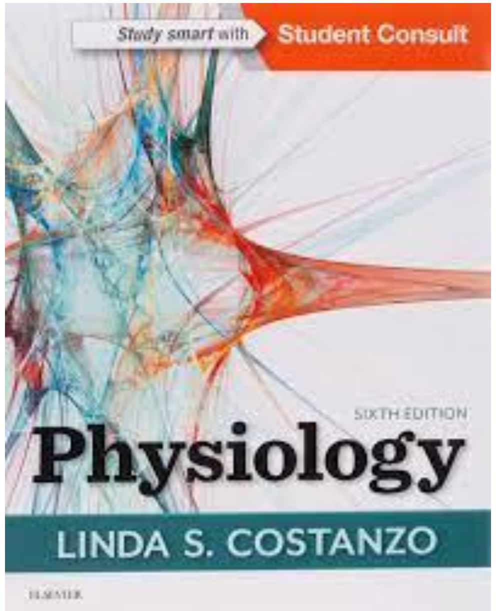
- Conversely, when you move from the dark to the light, at first your eyes are very sensitive to the dazzling light.
- As some of the photopigments are rapidly broken down by the intense light, the sensitivity of the eyes decreases and normal contrasts can again be detected, a process known as light adaptation.

Adaptation

- These adaptive measures are also enhanced by **pupillary reflexes** that adjust the amount of available light permitted to enter the eye.

- The other mechanism is **neural adaptation**, involving the neurons in the successive stages of the visual chain in the retina and in the brain.

References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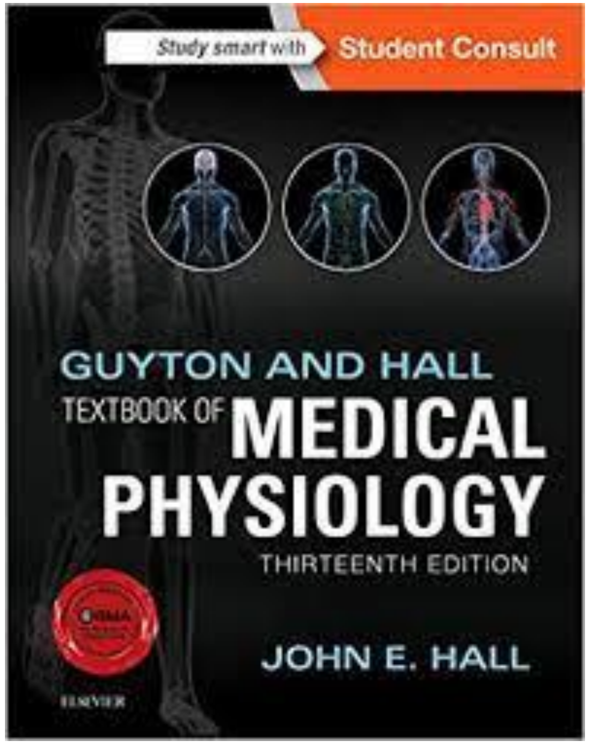
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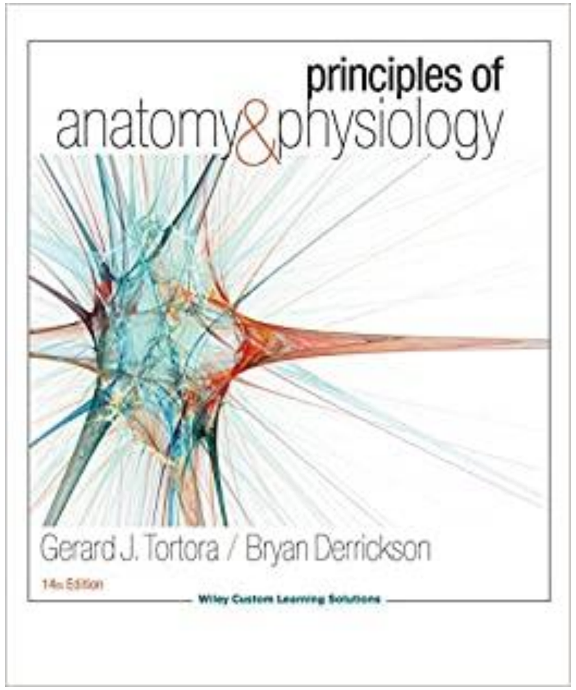
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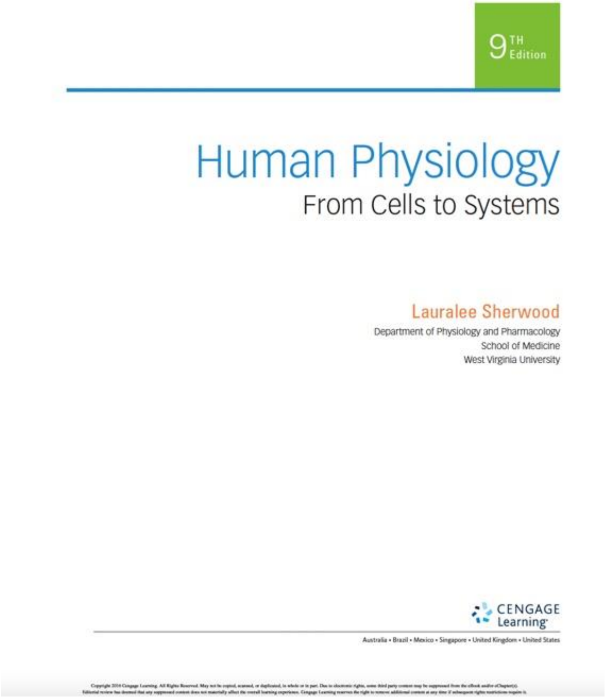
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