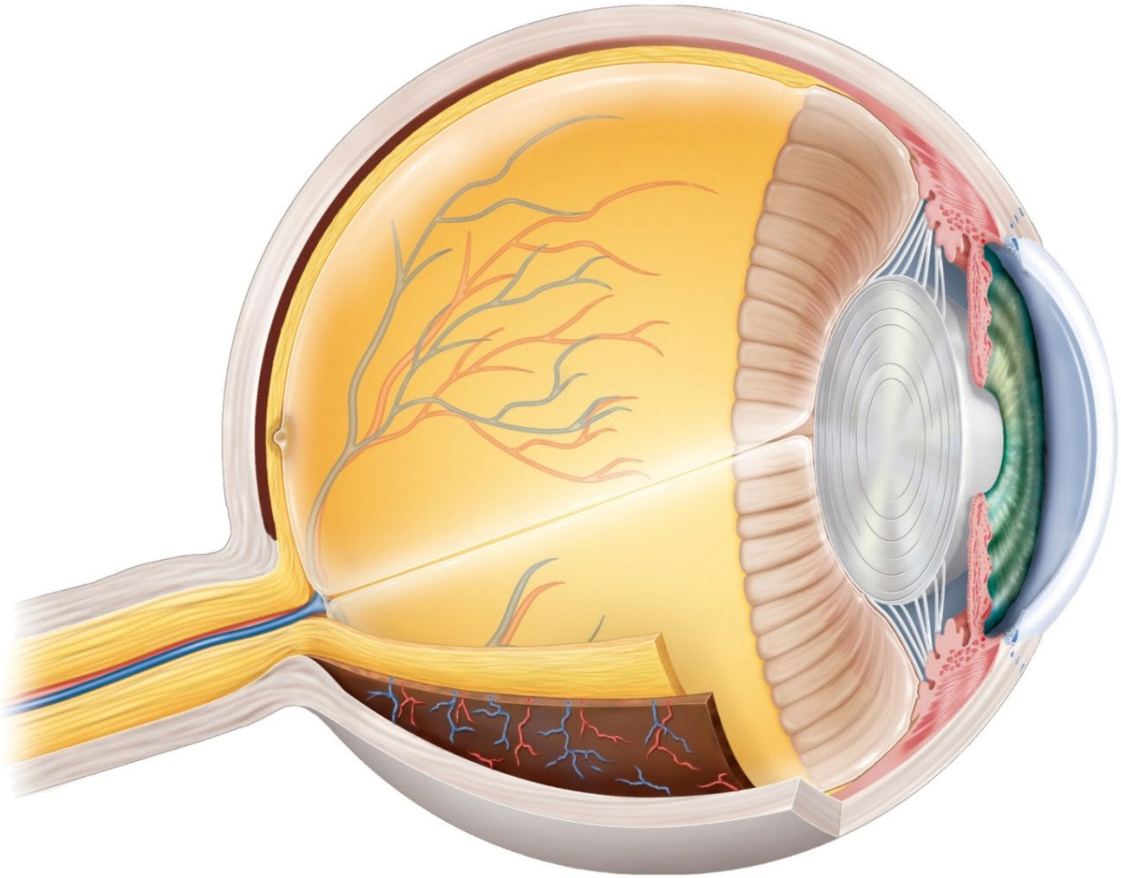
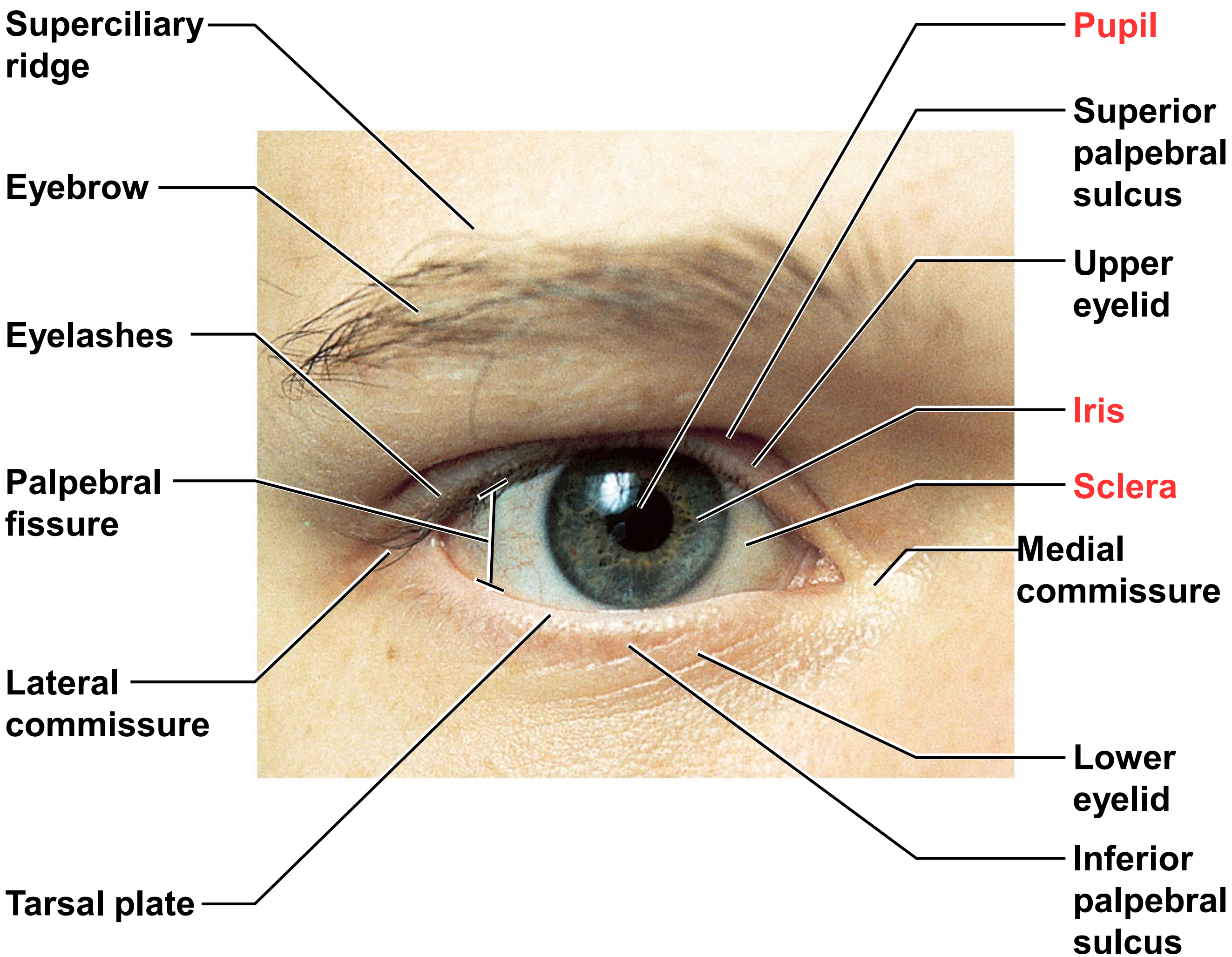
Chapter 16.2

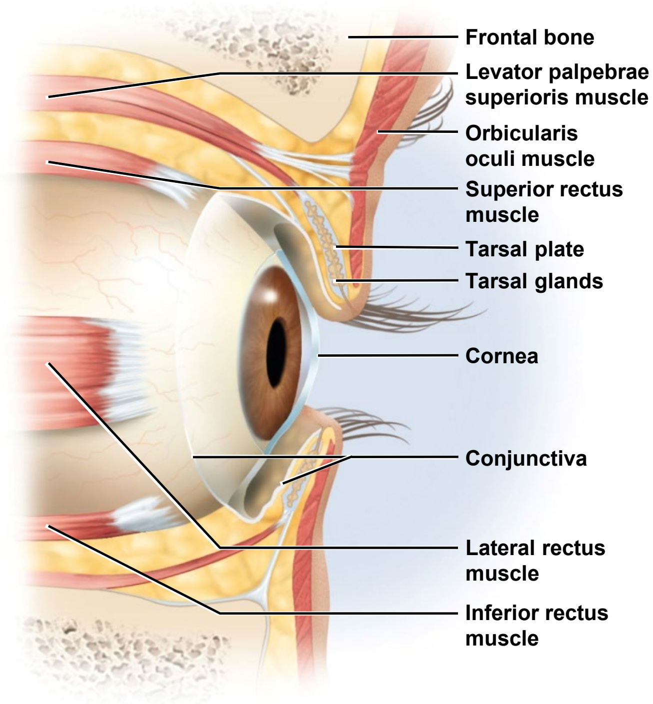
The Structure and Function of Vision



External Anatomy of Eye



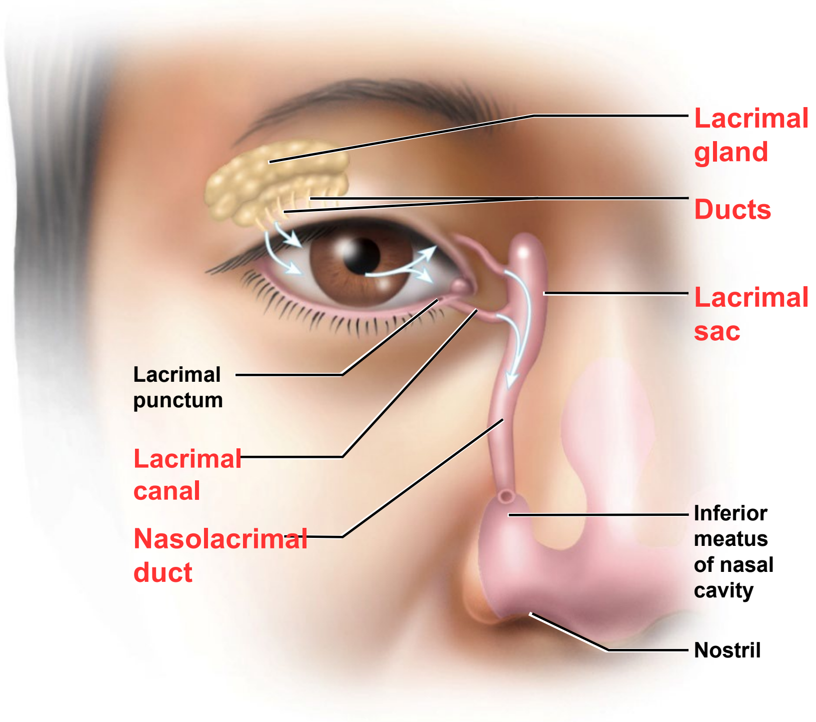
Conjunctiva



- a transparent mucous membrane
- lines inner surface of *eyelids and "rolls onto" eye-ball to cover anterior surface of eyeball*
- does not extend over cornea // stops at edge of cornea (Why?)
- richly innervated and highly vascular (i.e. heals quickly)
- secretes a thin mucous film that prevents the eyeball from drying
- secretions also have antibacterial properties

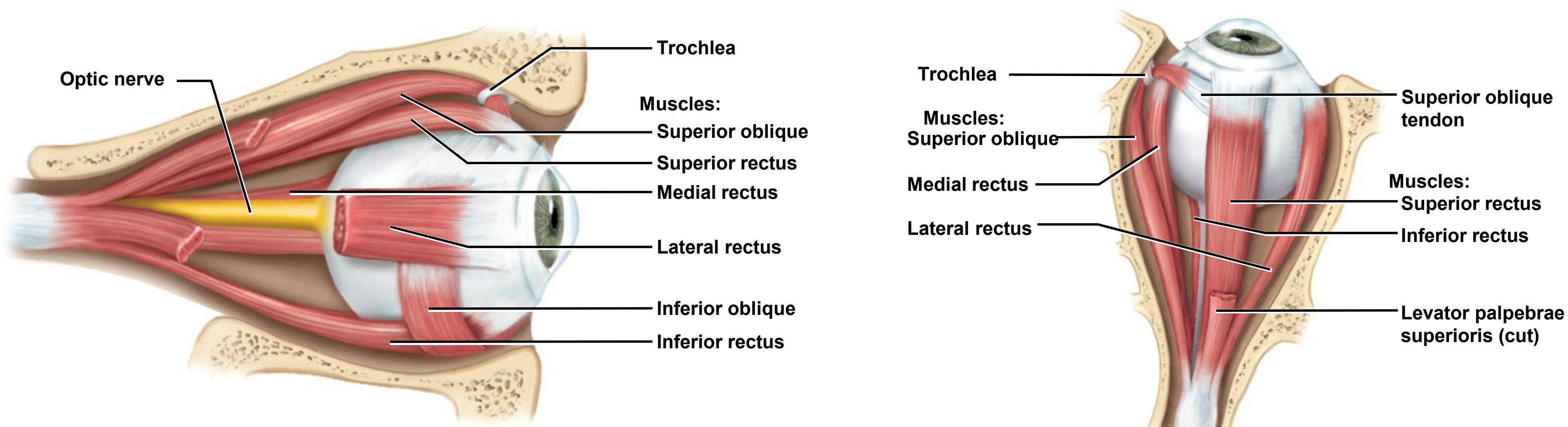
Conjunctivitis – inflammation of the Conjunctiva membrane (pink eye)

Lacrimal Apparatus
(Lab Objectives)



- tears flow across eyeball help to wash away foreign particles, deliver O_2 and nutrients, and prevent infection with a bactericidal lysozyme
- tears flow through lacrimal punctum (opening on edge of each eyelid) to the lacrimal sac, then into the nasolacrimal duct emptying into nasal cavity
- Humans are only animals to produce tears due to emotional stress

Extrinsic Eyes Muscles



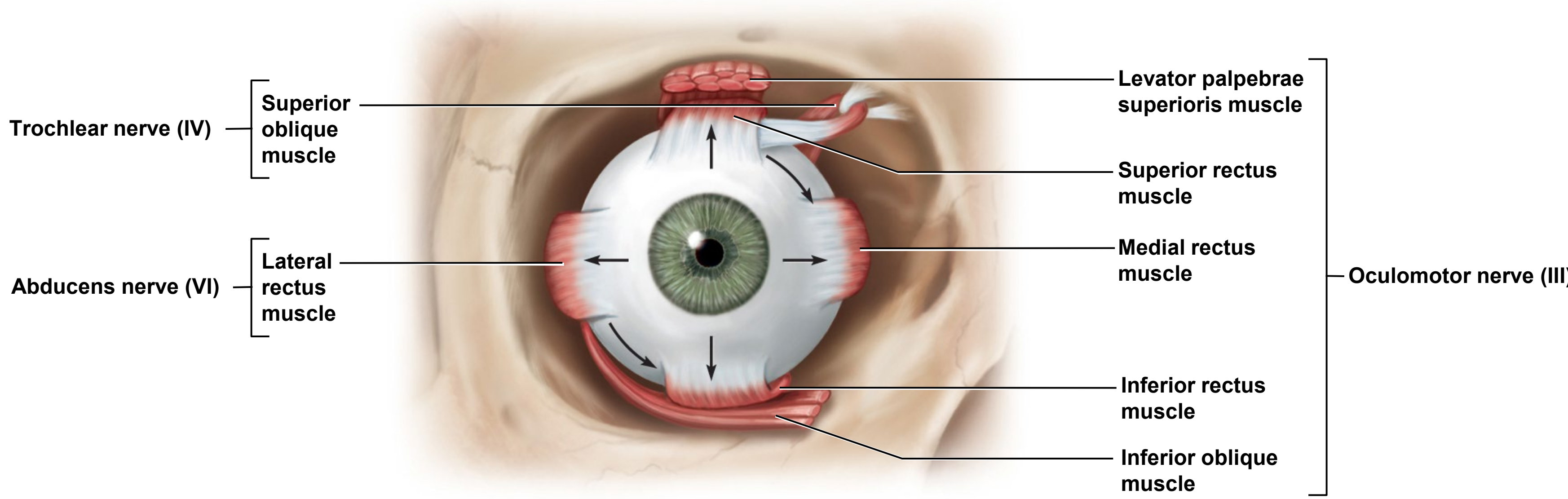
(a) Lateral view

(b) Superior view

- 6 muscles attached to exterior surface of eyeball // superior, inferior, lateral, and medial rectus muscles, superior and inferior oblique muscles

- innervated by cranial nerves oculomotor (III), trochlear (IV) and abducens (VI)

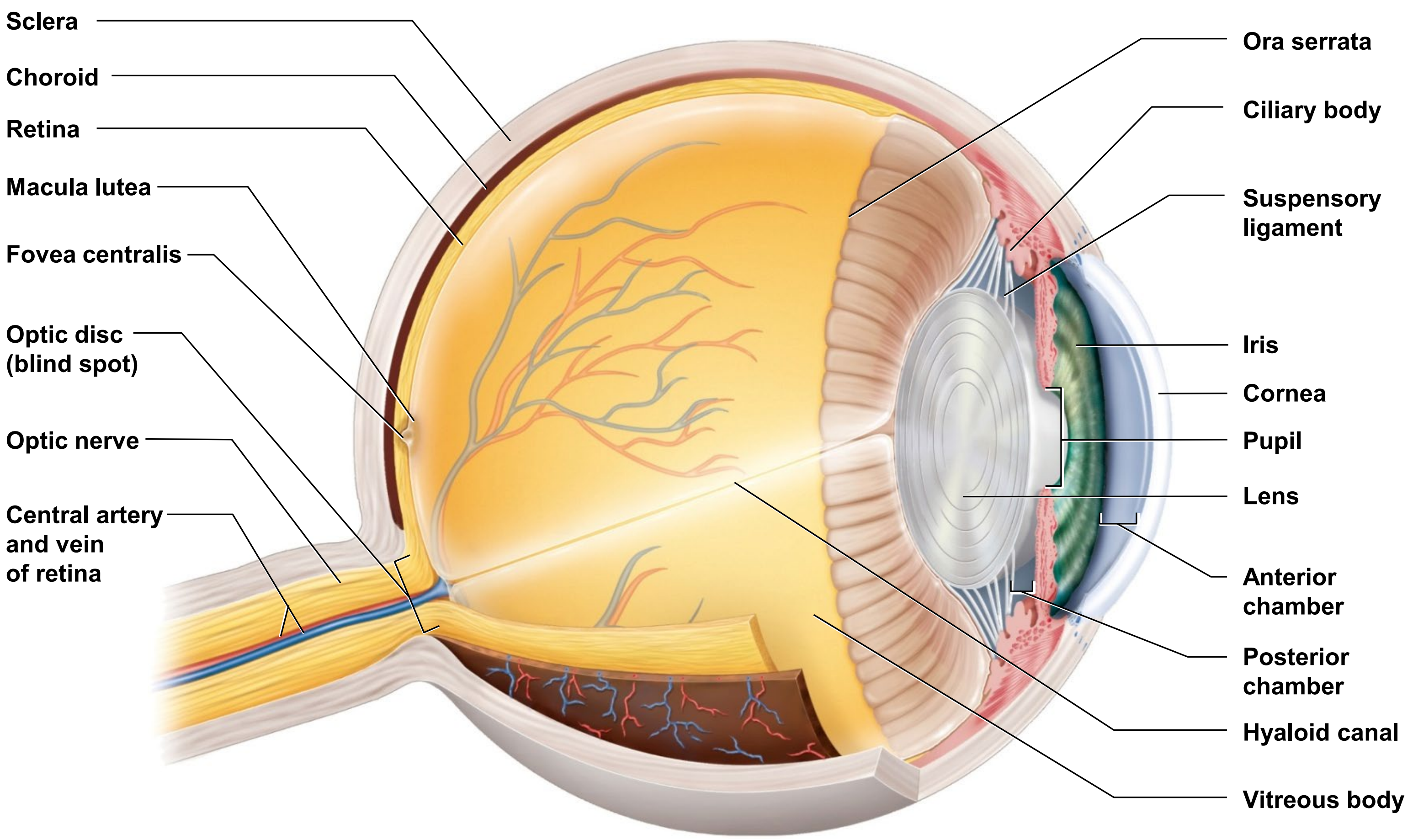
Innervation of Extrinsic Eye Muscles



(c) Frontal view

- superior, inferior, medial and lateral rectus muscles move the eye up, down, medially & laterally
- superior and inferior oblique mm. turn the “twelve o’clock pole” of each eye toward or away from the nose
- orbital fat – surrounds sides and back of eye, cushions eye and allows free movement, protects blood vessels, and nerves

Three Principal Components of the Eyeball (Lab Objectives)



- 1) tunics that form the wall of the eyeball
- 2) optical component that admits and focuses light
- 3) neural component = the retina and optic nerve

Tunics of the Eyeball (Three Layers)

tunica fibrosa – the outer fibrous layer

- –sclera – dense, collagen, white of the eye // as it progresses to anterior surface it transforms into the cornea
- –cornea - transparent area of sclera that admits light into eye

tunica vasculosa (uvea) – middle vascular layer

- –the choroid (see next slide)

tunica interna – inner layer

- –retina = photoreceptors (i.e. part of CNS)
- –origin of optic nerve

Tunics of the Eyeball (Three Layers)

tunica vasculosa (uvea) – middle vascular layer // the choroid

–choroid – highly vascular, deeply pigmented layer behind retina

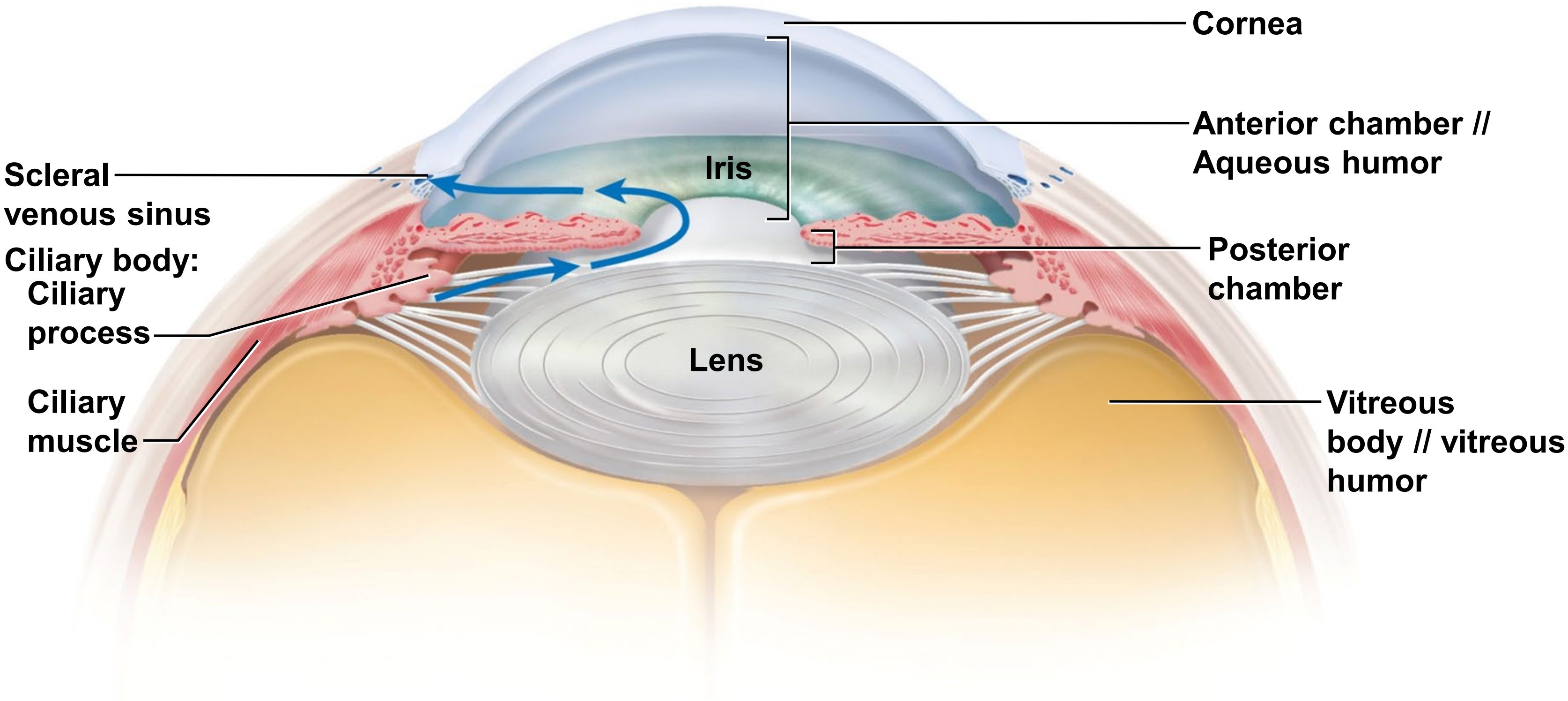
- –ciliary body – extension of choroid at anterior margin of choroid // three structures
    - –extension of choroid makes 3 structures
        - –ciliary muscle /// forms a muscular ring around lens
        - –ciliary process /// secretes aqueous humor
        - –iris

–iris - colored smooth muscles (i.e. radial and sphincter fascicles) = diaphragm that controls size of pupil

•iris center = pupil - is open to allow light to pas through to retina

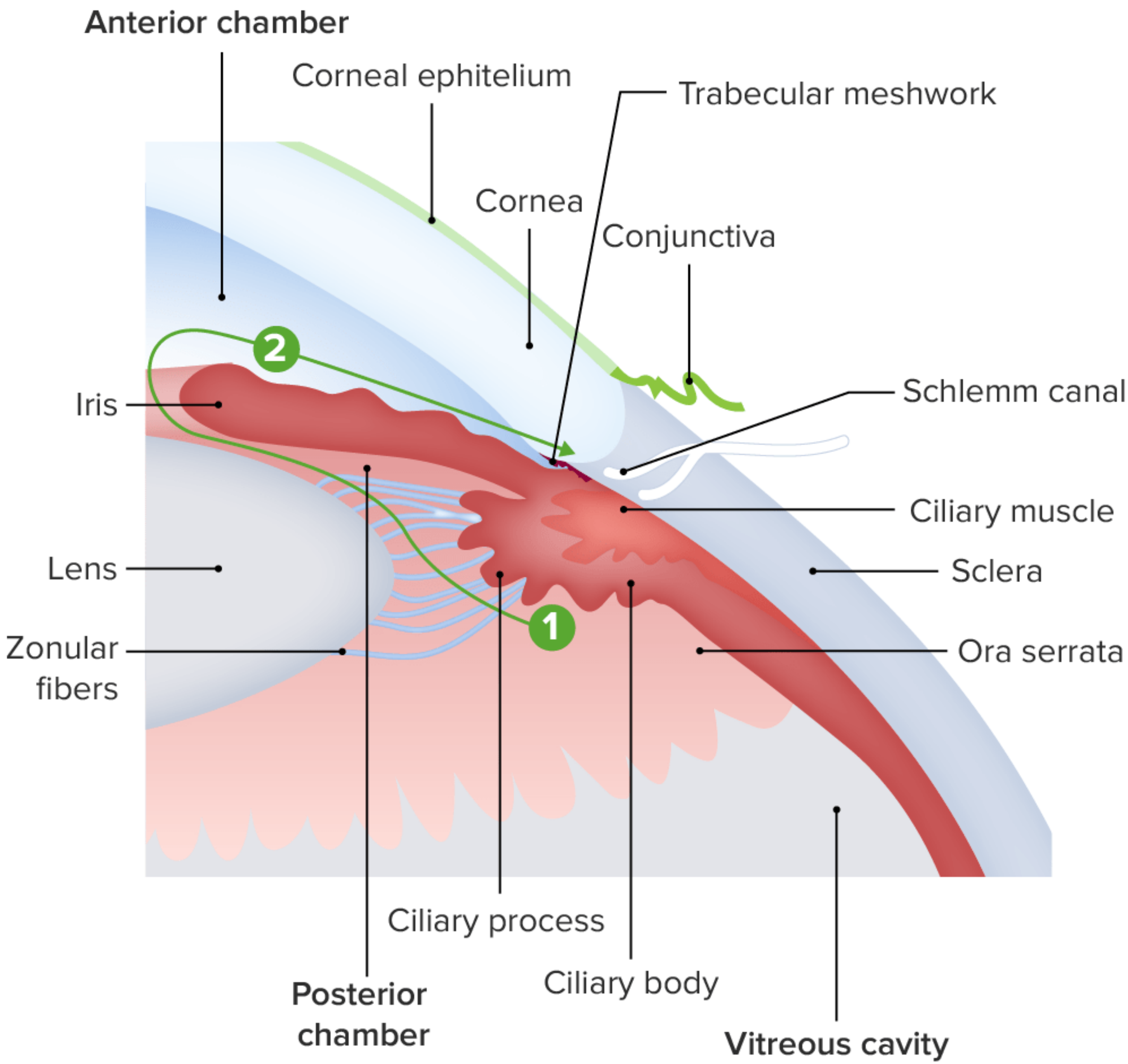
•melanin in chromatophores of iris - brown or black eye color

Optical Components



- fluid (created by filtration) by ciliary body enters posterior chamber, passes through pupil then flows into anterior chamber

- reabsorbed into canal of Schlemm


Anterior chamber
Corneal ephitelium
Trabecular meshwork
Cornea
Conjunctiva
2
Iris
Schlemm canal
Ciliary muscle
Lens
Sclera
1
Zonular fibers
Ora serrata
Ciliary process
Posterior chamber
Ciliary body
Vitreous cavity

Optical Components

•transparent elements that admit light rays, refract (bend) them, and focus images on the retina

•**cornea /// ** transparent cover on anterior surface of eyeball

•**aqueous humor**

–fills anterior chamber

–serous fluid posterior to cornea

–anterior to lens

–reabsorbed by scleral venous sinus (canal of Schlemm)

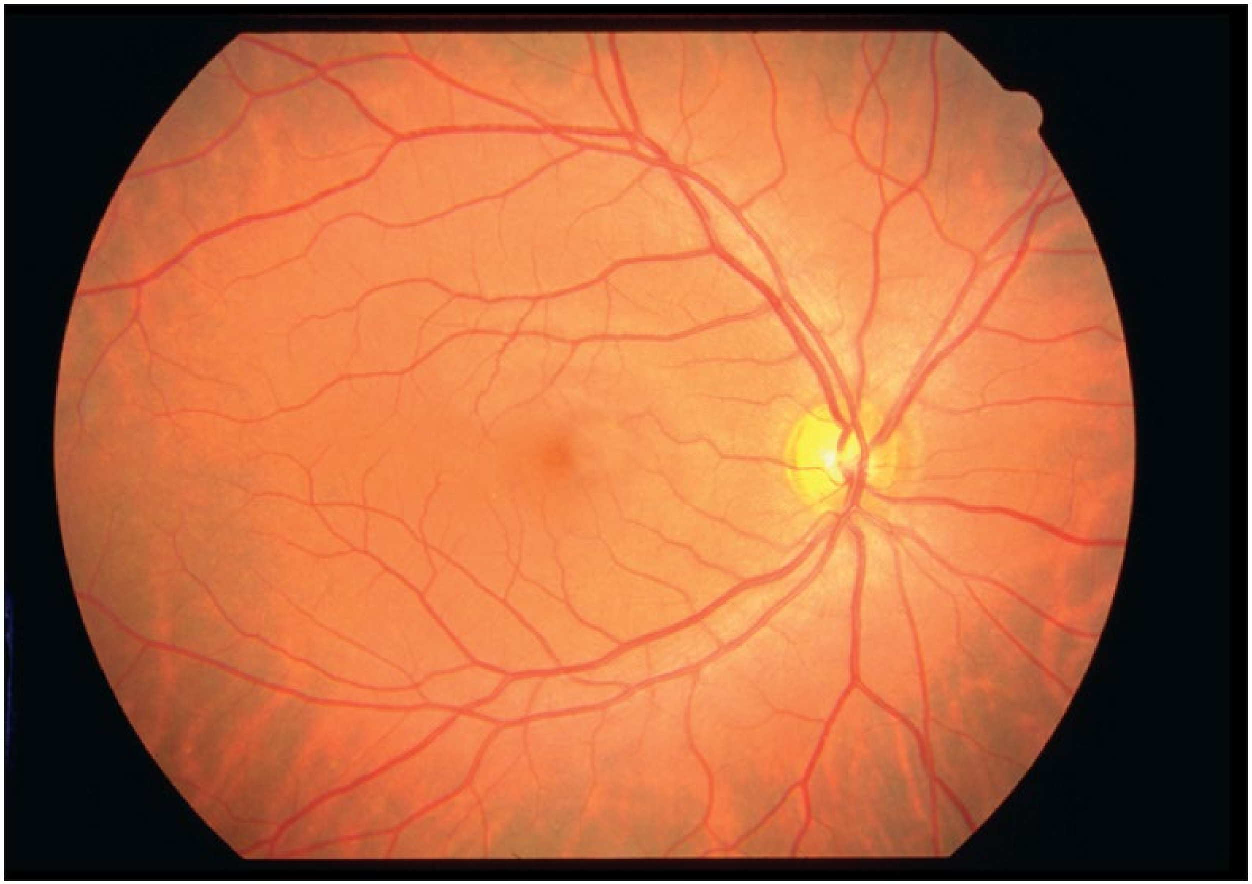
–continuously produced and reabsorbed at same rate

Optical Components

- lens
  - –lens fibers – flattened, tightly compressed, transparent cells that form lens
  - –suspended by suspensory ligaments from ciliary body
  - –changes shape to help focus light
    - •more rounded with no tension on lens (bends light rays more)
    - •lens becomes more flattened with pull of suspensory ligaments (bends light rays less)

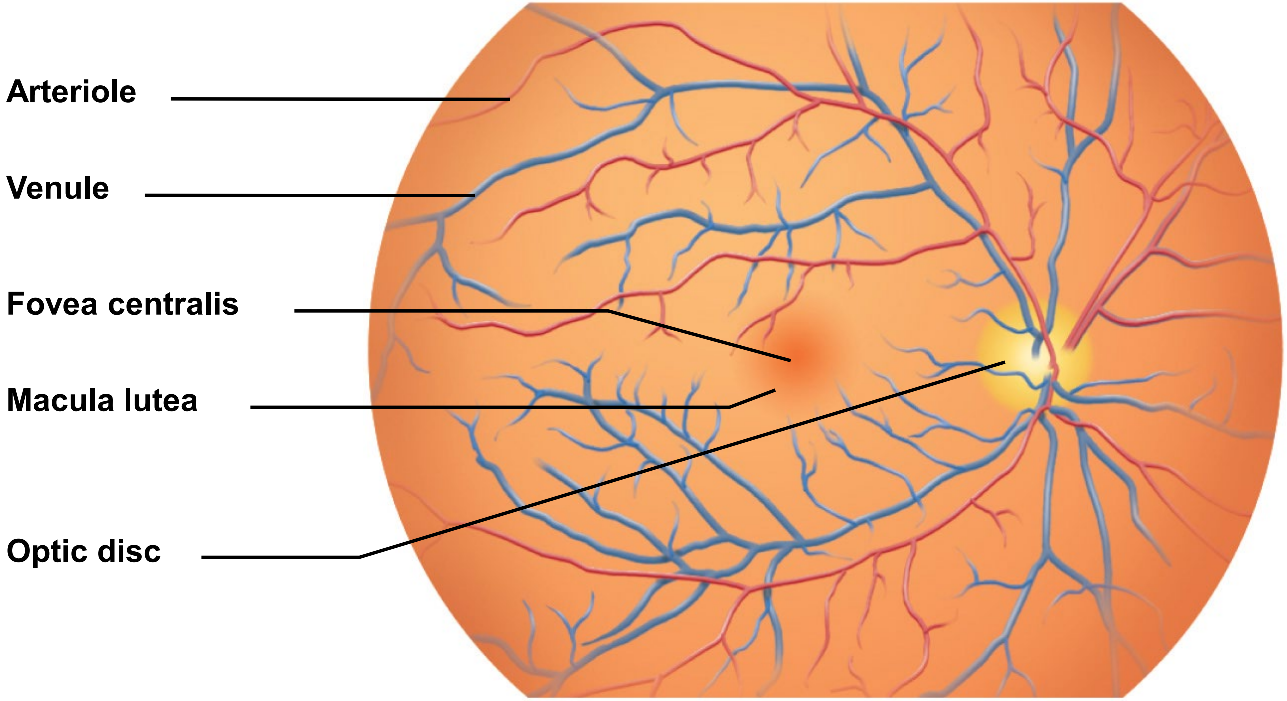
- vitreous body (humor)
  - – fills vitreous chamber
  - –hydrated protein (hyaluronic acid) fills space between lens and retina

Neural Components



Surface of retina

Ophthalmoscopic Exam of Eye



•macula lutea - cells on the visual axis of eye (3 mm)

–*fovea centralis* - center of macula; finely detailed images due to packed receptor cells

–Only area in body where you have direct vision of blood vessels

Neural Components

•includes retina and optic nerve

•**retina**

–forms as an outgrowth of the diencephalon

–attached to the rest of the eye only at optic disc and at ora serrata

–pressed against rear of eyeball by vitreous humor

–detached retina causes blurry areas in field of vision and leads to blindness

Neural Components

•If you examine retina with opthalmoscope then here is what you will see:

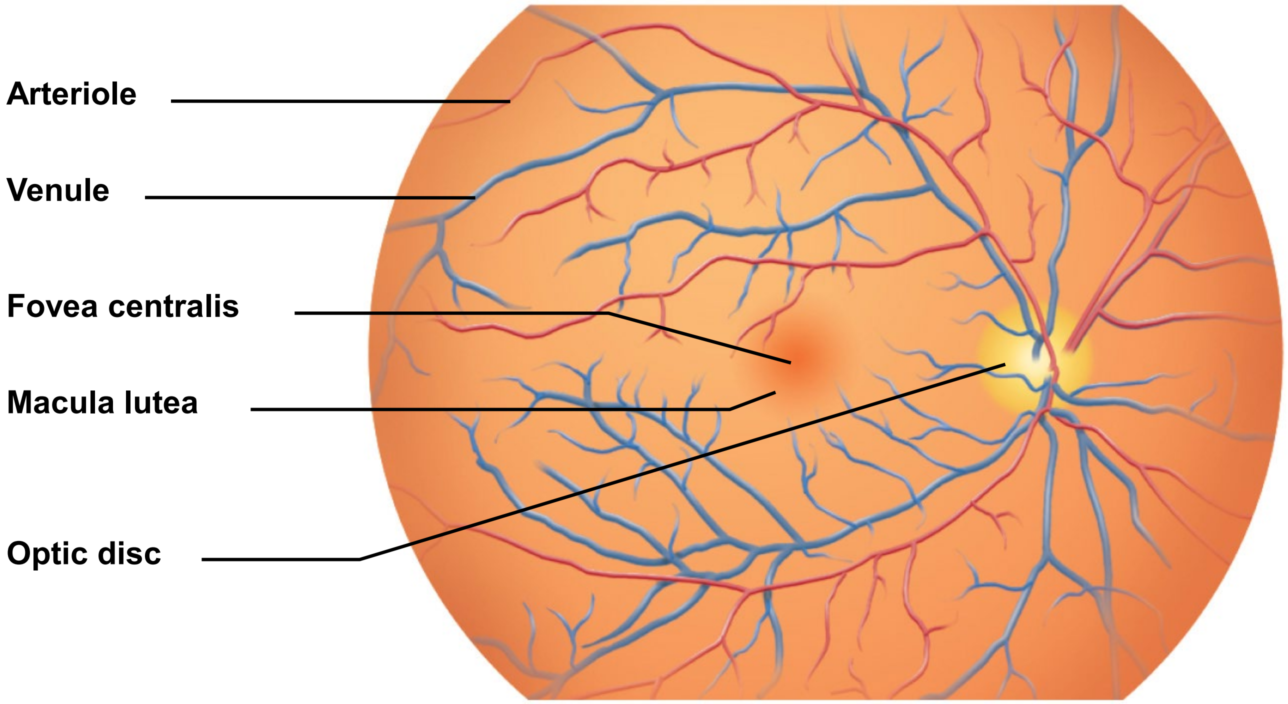
–macula lutea – a patch of cells on visual axis of eye

–fovea centralis – a pit in center of macula lutea

–the blood vessels of the retina

–optic disc

Ophthalmoscopic Exam of Eye



- macula lutea - cells on the visual axis of eye (3 mm)

–*fovea centralis* - center of macula; finely detailed images due to packed receptor cells

–Retina is the only area in body where you have direct visual access to see blood vessels

Test for Blind Spot

Optic Disk = the blind spot

– optic nerve exits posterior surface of eyeball

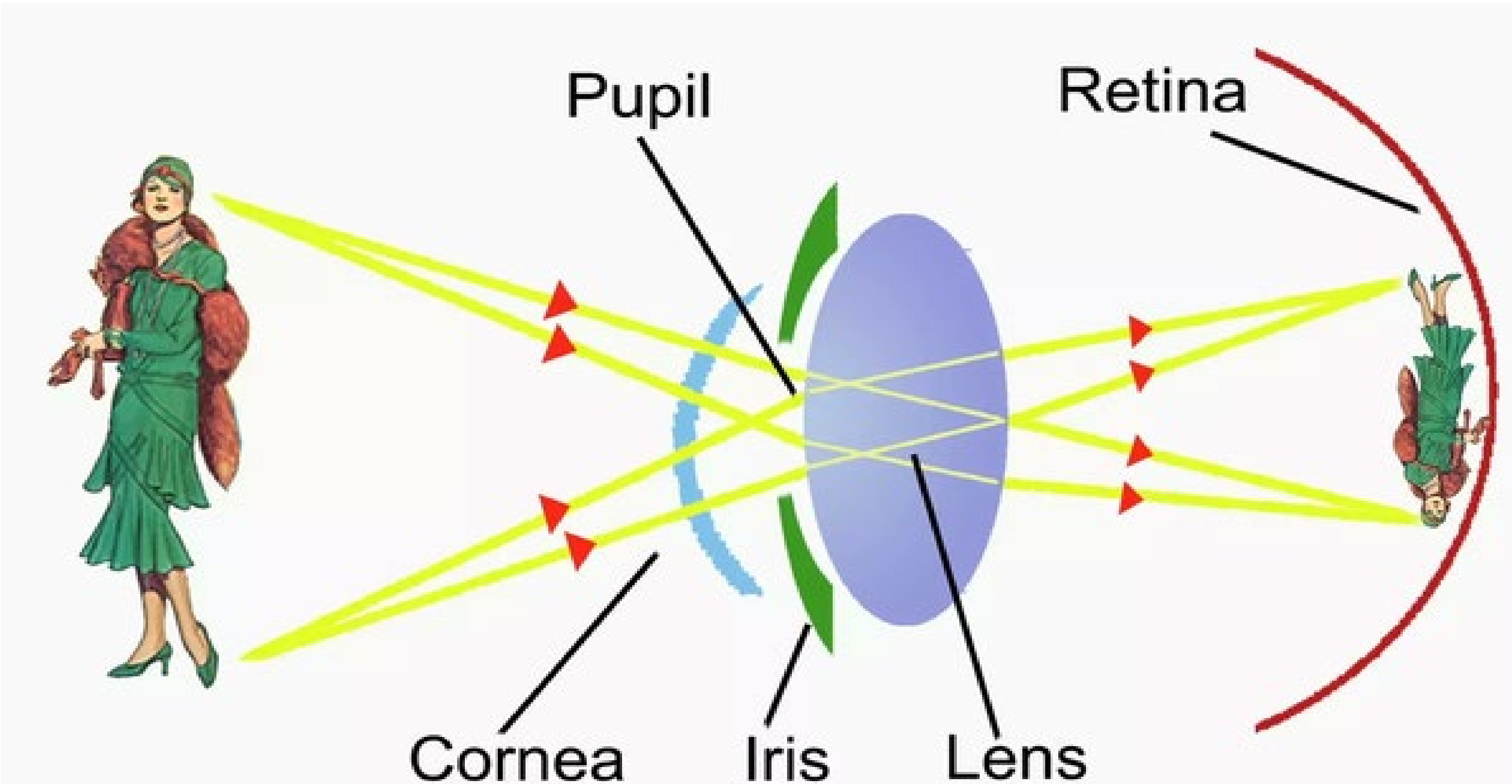
– no receptor cells at that location

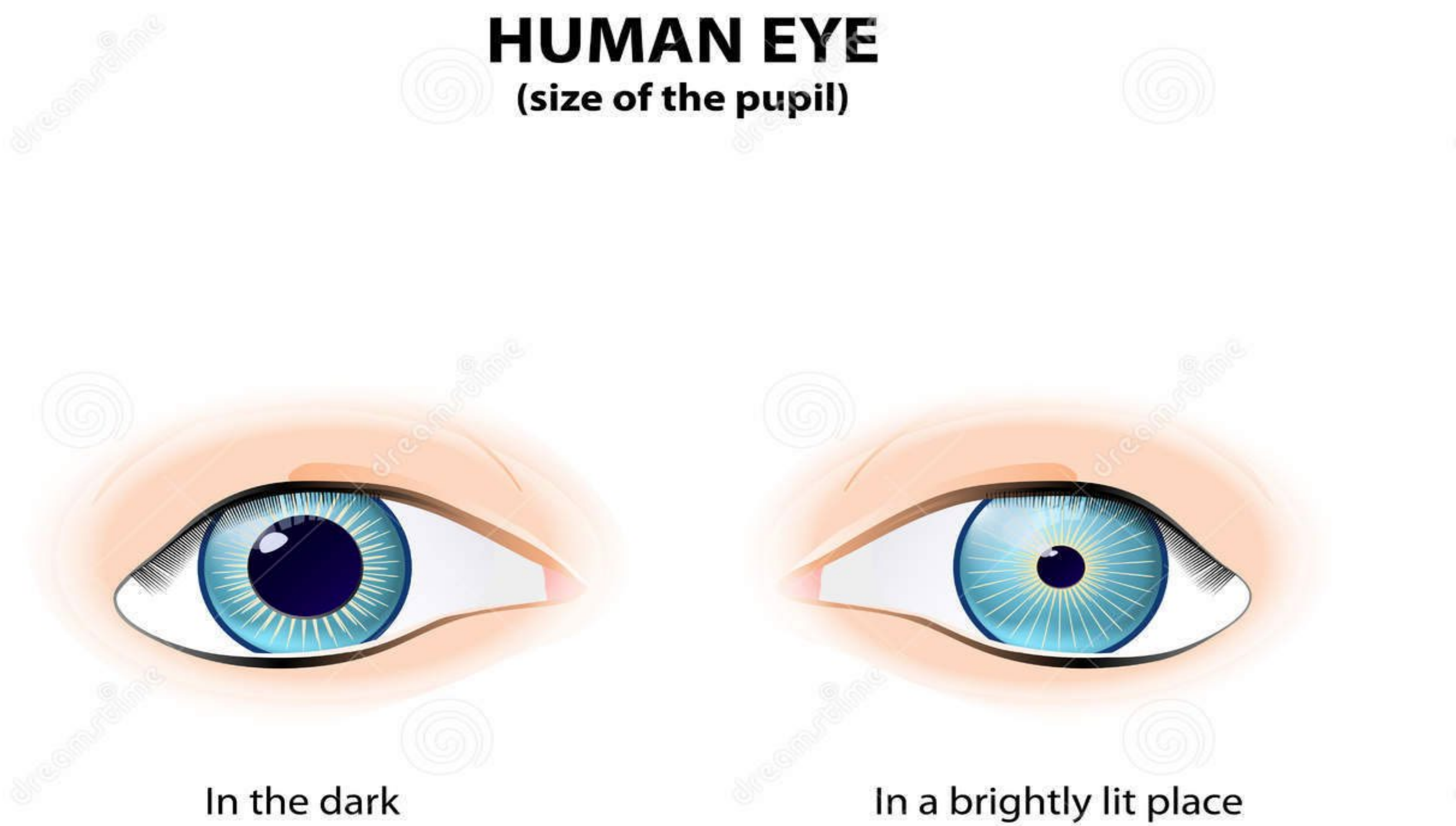
– use this test to illustrate the blind spot
  - – stare at X and close right eye, the red dot disappears
  - – stare at red dot and close left eye, the x disappears

visual filling - brain fills in green bar across blind spot area

How is an image formed on the retina?

- light passes through lens to form tiny inverted image on retina




HUMAN EYE
(size of the pupil)
In the dark
In a brightly lit place

How is the size of the pupil changed? Why?

iris // pupil diameter controlled by two sets of contractile elements

pupillary constrictor - smooth muscle encircling the pupil

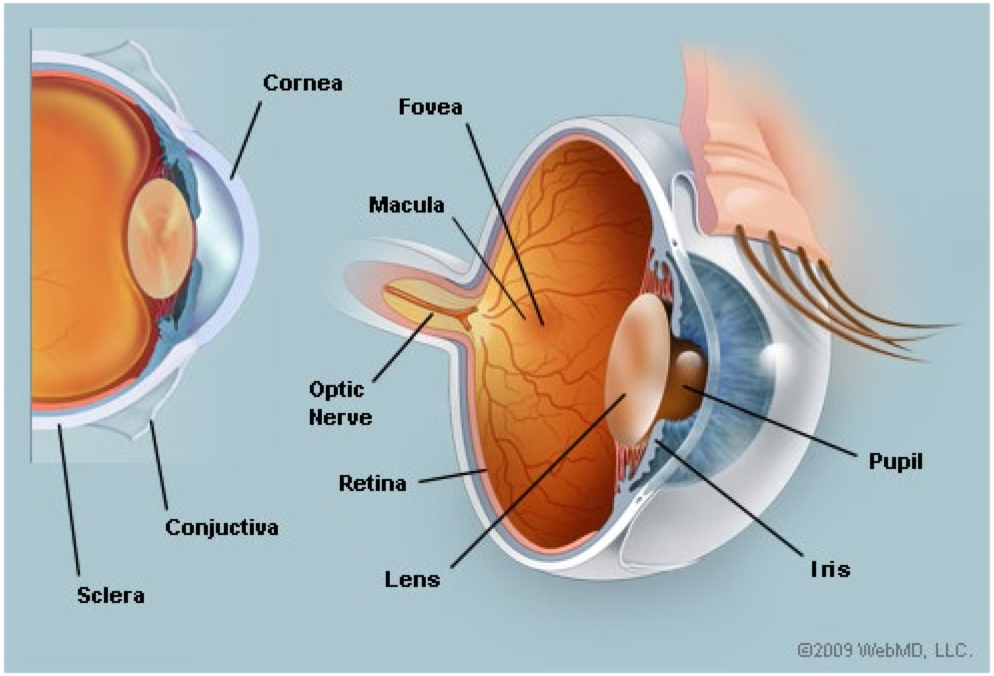
•sphincter fascicles

•parasympathetic stimulation narrows pupil (pupil smaller)

pupillary dilator – spoke like myoepithelial cells

•radial fascicles

•sympathetic stimulation widens pupil (pupil larger)



What happens when bright light shined into eye?

•pupillary constriction or dilation

–occurs in two situations

•when light intensity changes

•when our gaze shifts between distant and nearby objects

•photo-pupillary reflex

–pupillary constriction in response to light

–consensual light reflex = both pupils constrict even if only one eye is illuminated

Emmetropia vs Near Response

- **Emmetropia** = state in which the eye is relaxed and focused on an object more than 6 m (20 ft) away

–light rays coming from distant objects are essentially parallel

–distant rays focused onto retina without any required adjustment to lens // the eye evolved to focus on distant objects / not near objects!

–light rays coming from a closer object are too divergent to be focused without effort // requires a near response to see object

Three Conditions Change During the Near Response

- Adjustments to close range vision requires three processes

–**convergence of eyes** **//** eyes orient their visual axis towards object

–**constriction of pupil** **//** blocks peripheral light rays and reduces spherical aberration (blurry edges)

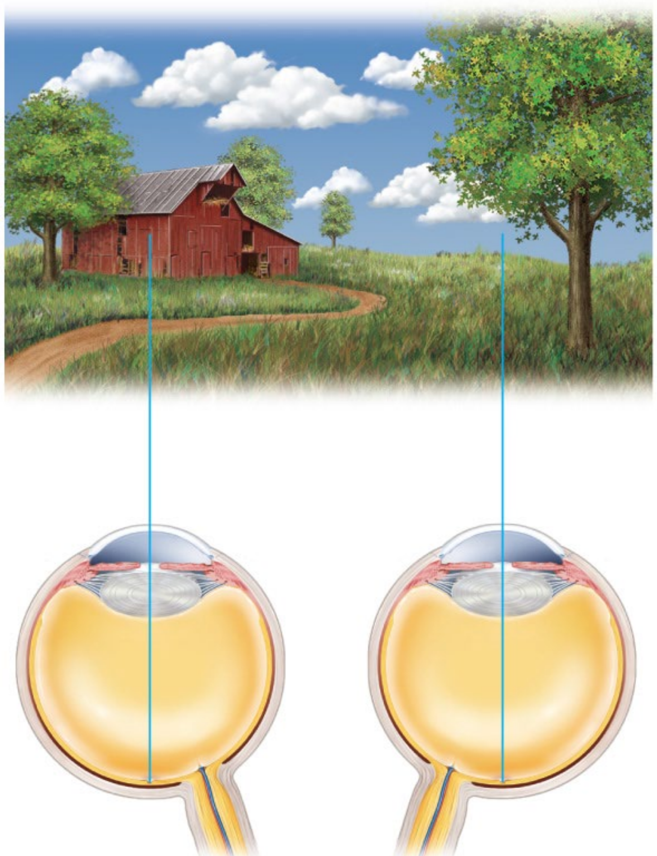
–**accommodation of lens** // change in the curvature of the lens that enables you to focus on nearby objects

- ciliary muscle contracts, lens takes convex shape

- light refracted more strongly and focused onto retina

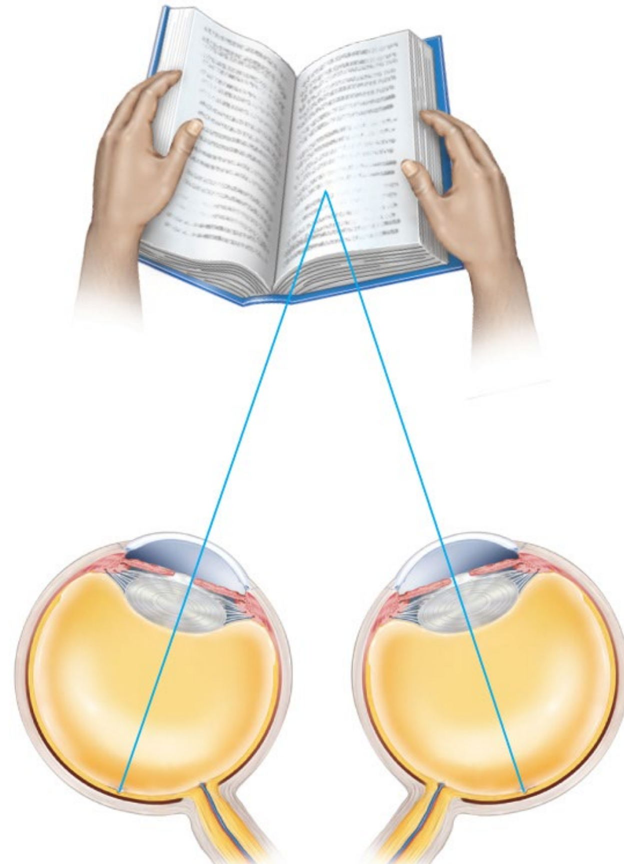
- **near point of vision** – closest an object can be and still come into focus

Emmetropia VS Near Response Convergence



Emmetropia

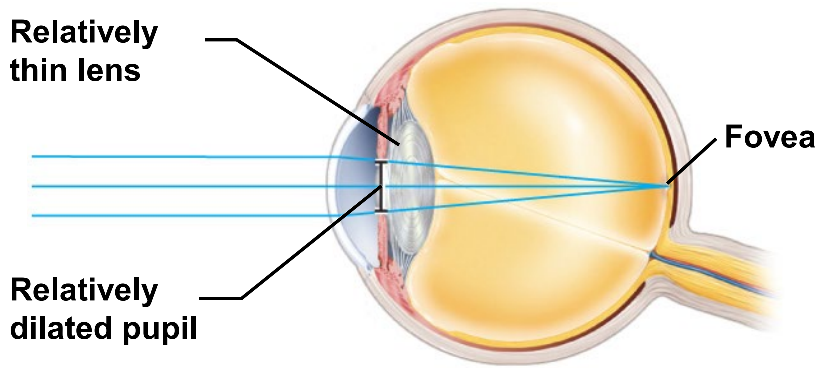
distant object



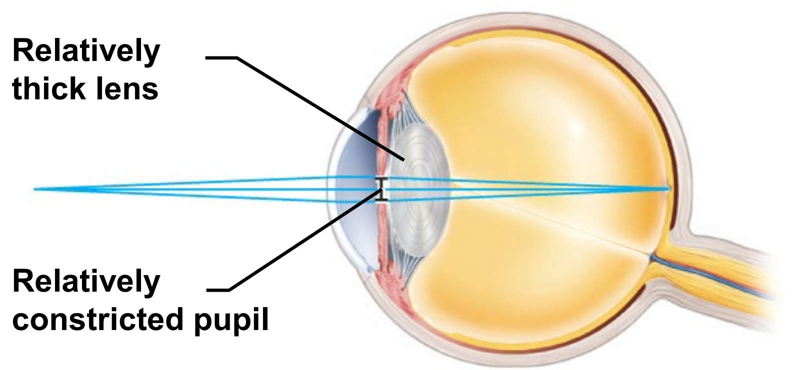
Convergence

close object

Emmetropia VS Near Response Pupil Constriction

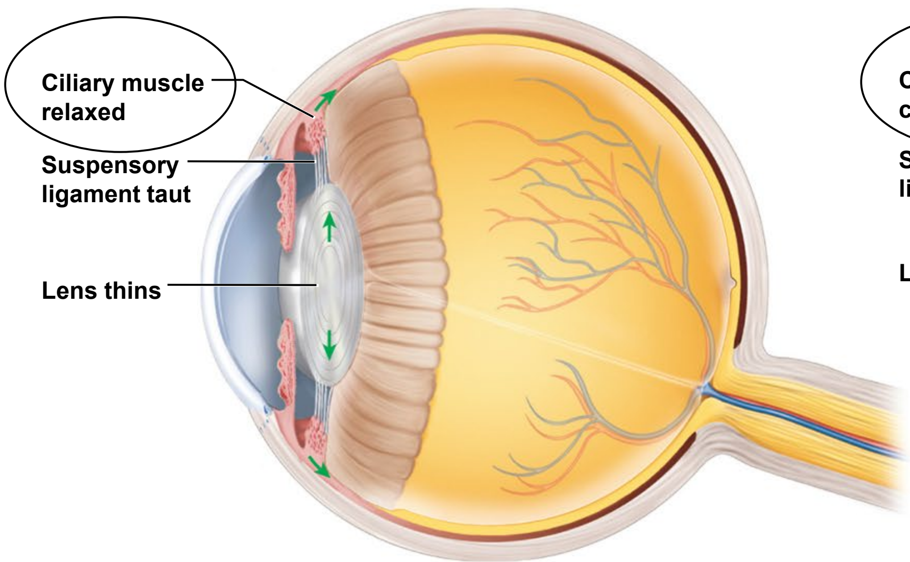


Emmetropia

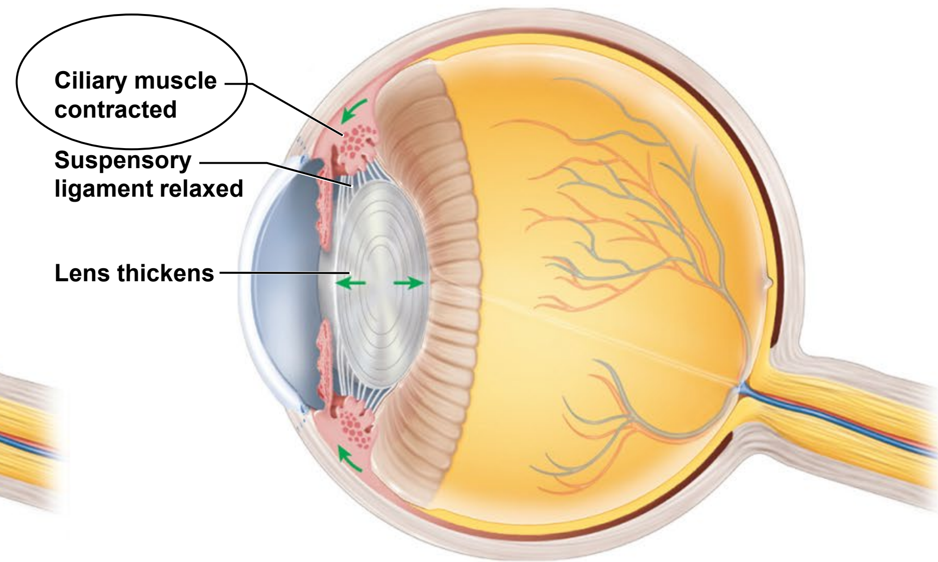


Near Vision

Emmetropia VS Near Response Accommodation of Lens



(a) Distant vision (emmetropia)

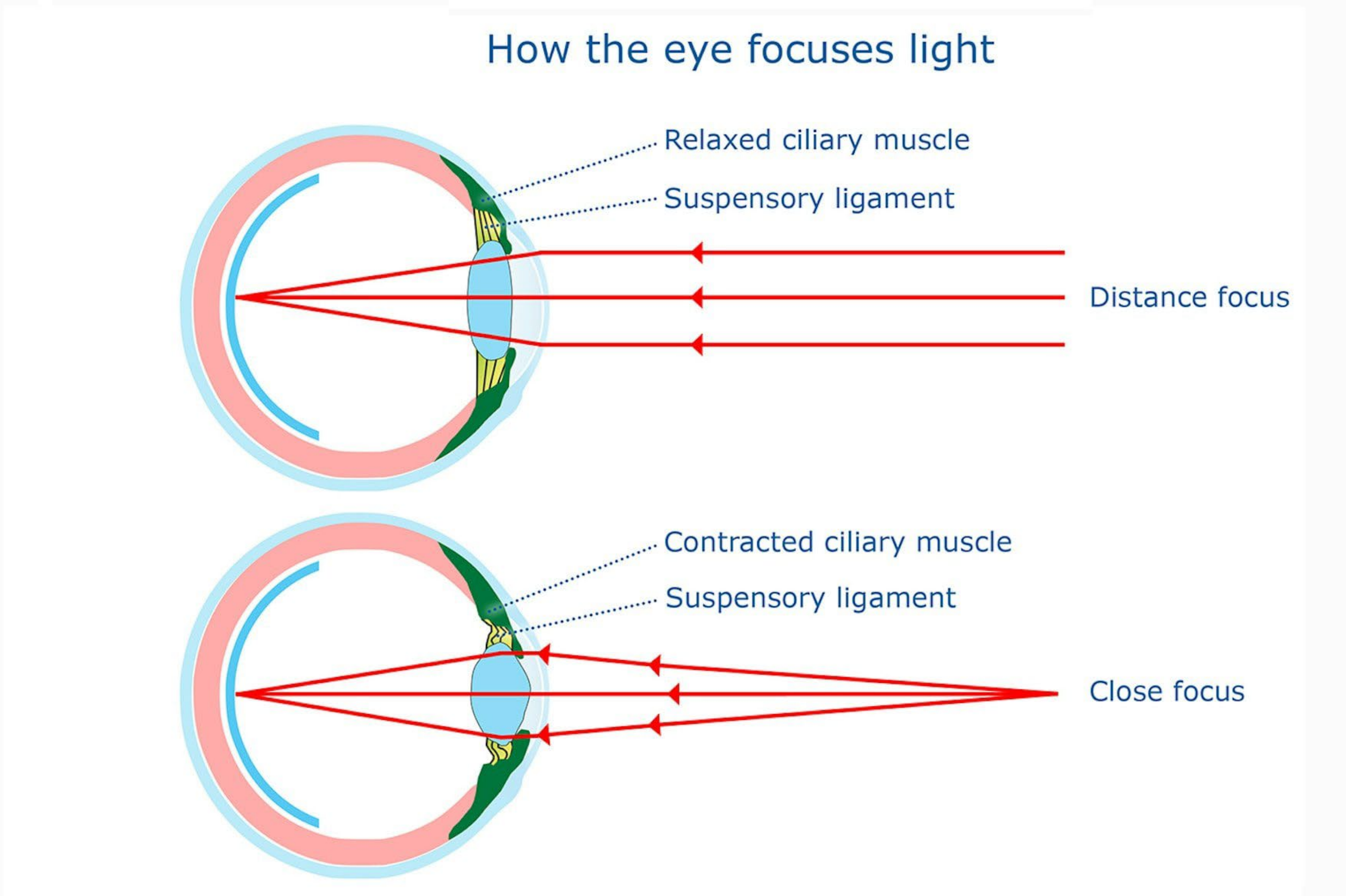


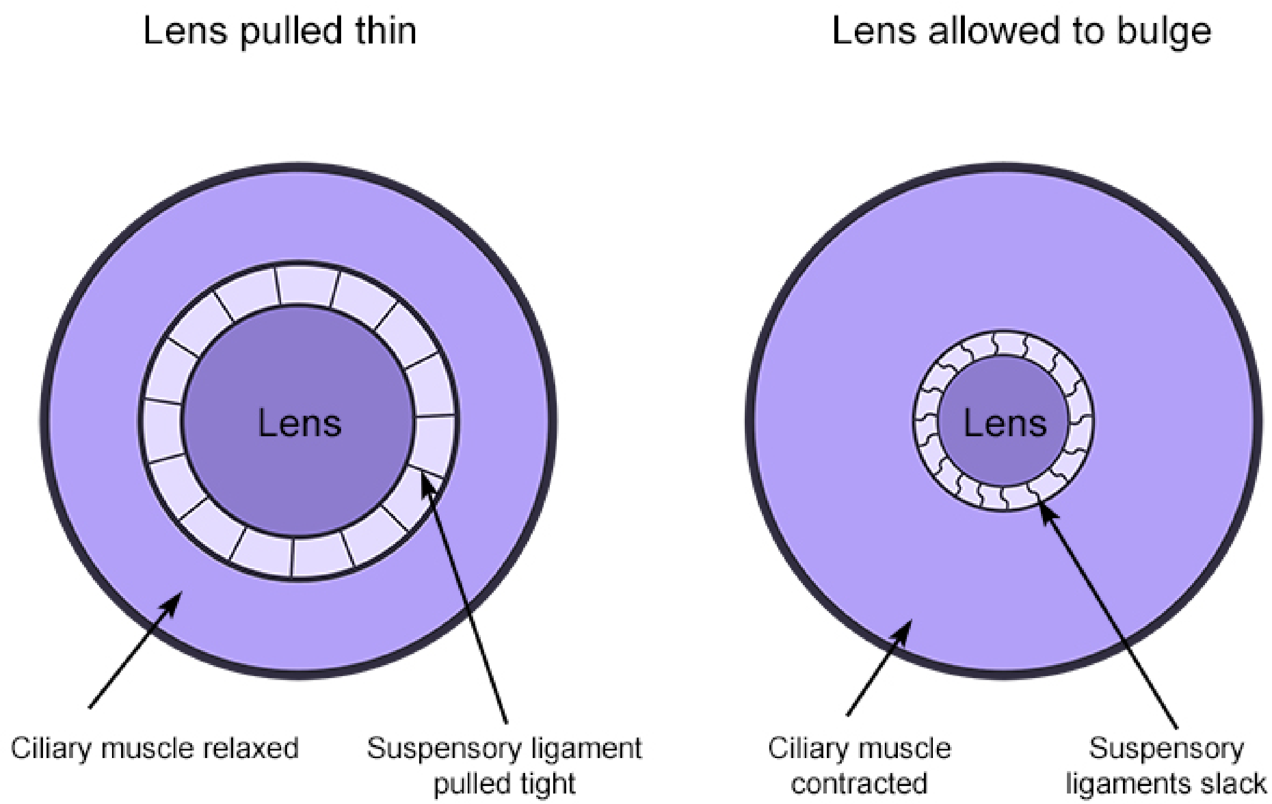
(b) Near vision (accommodation)

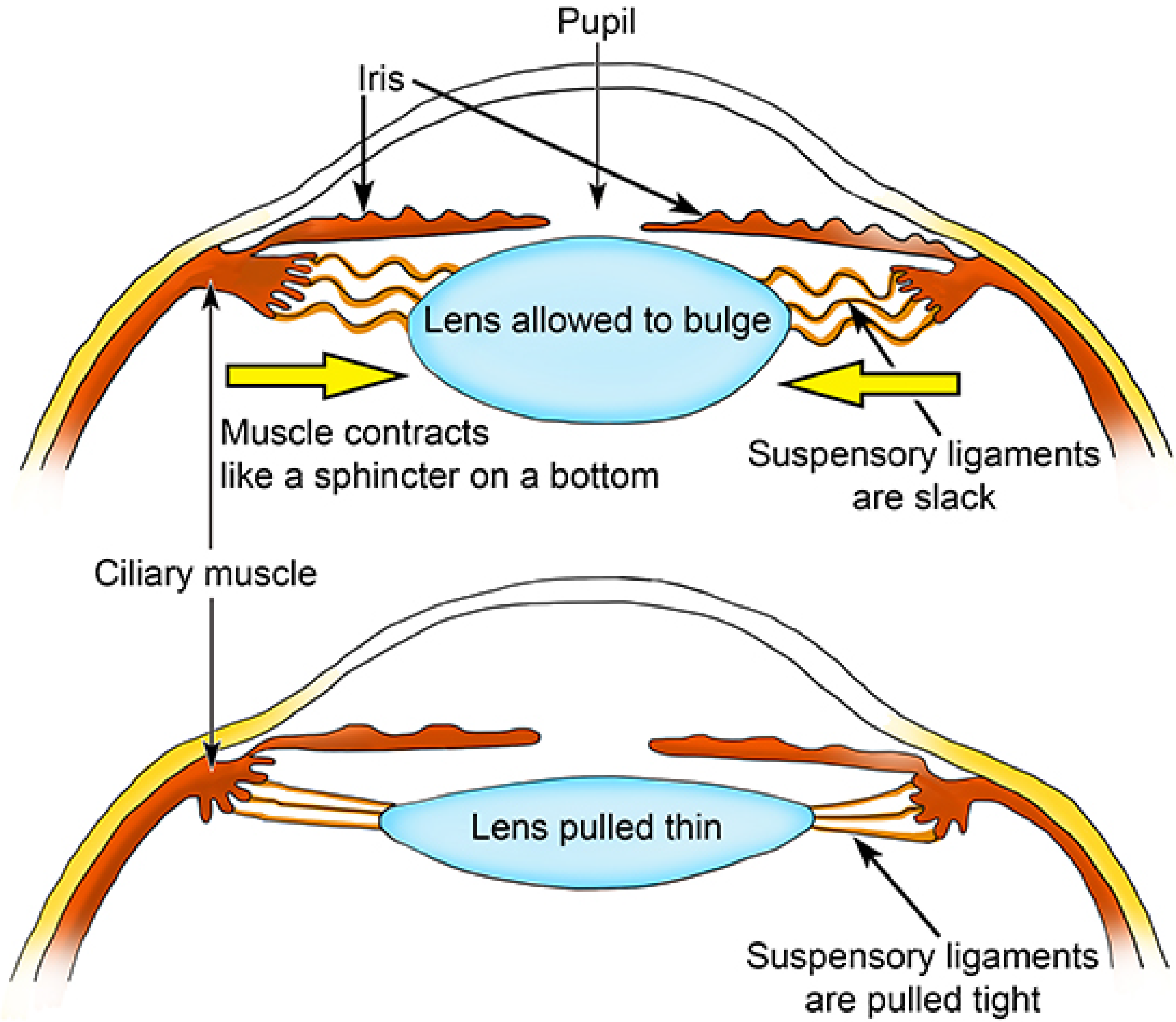
lens flatter

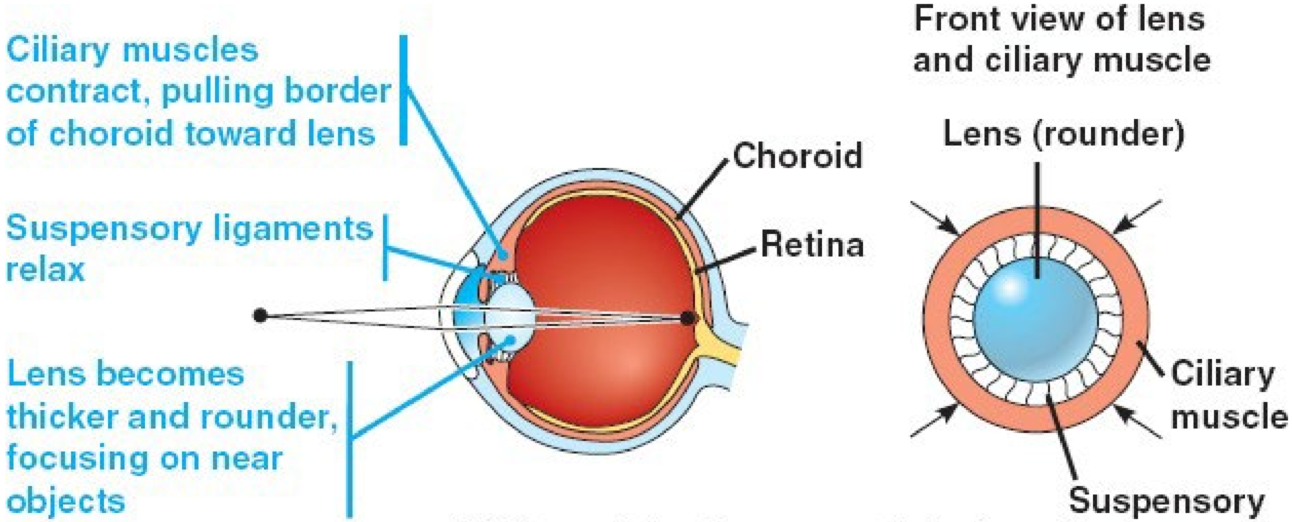
lens thicker

Note: The ciliary muscle functions like a sphincter muscle. When CM is relaxed there is tension on lens, and this makes the lens flatten and light passes straight through the lens. When the CM contracts, it brings the tissue surrounding the lens closer together and this reduces the size of the diameter of the pupil. This also reduces the tension on the suspensory ligament that holds the lens. Now the lens becomes thicker and bends the light rays more.

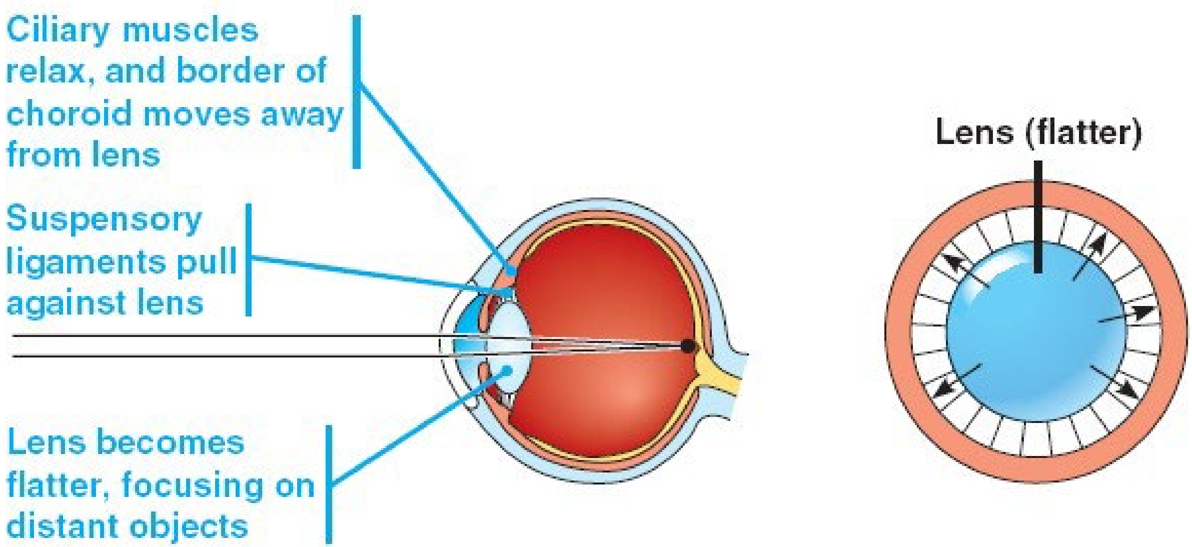

How the eye focuses light
Relaxed ciliary muscle
Suspensory ligament
Distance focus
Contracted ciliary muscle
Suspensory ligament
Close focus


Lens pulled thin
Lens allowed to bulge
Lens
Lens
Ciliary muscle relaxed
Suspensory ligament pulled tight
Ciliary muscle contracted
Suspensory ligaments slack


Pupil
Iris
Lens allowed to bulge
Muscle contracts
like a sphincter on a bottom
Suspensory ligaments
are slack
Ciliary muscle
Lens pulled thin
Suspensory ligaments
are pulled tight



(a) Near vision (accommodation)

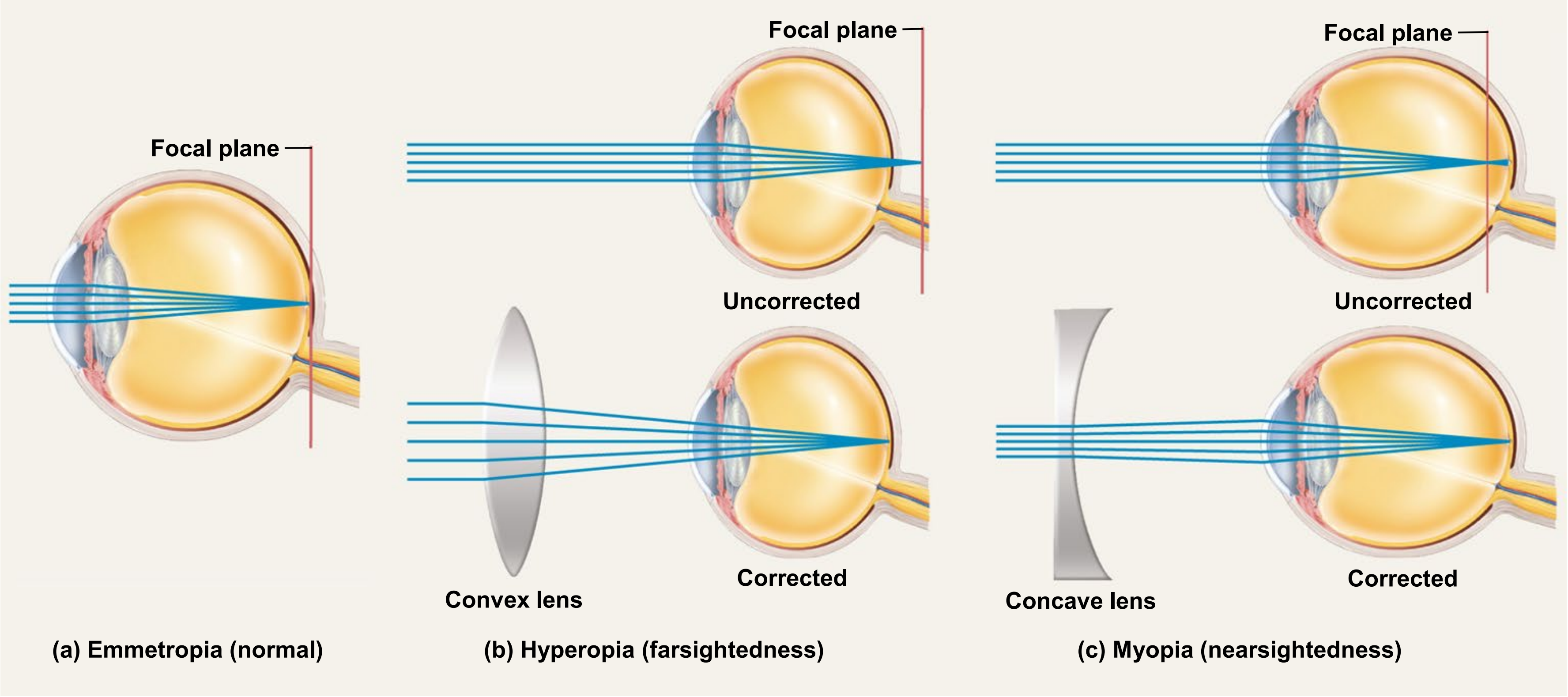


(b) Distance vision

When a Distorted Shape of the Eyeball Prevents the Lens to Focus Image on Retina

How is the shape (depth) of the eyeball changed between emmetroia, hyperopia, and myopia?

Note: here the lens is OK! The problem is the shape of the eyeball.



Cataracts

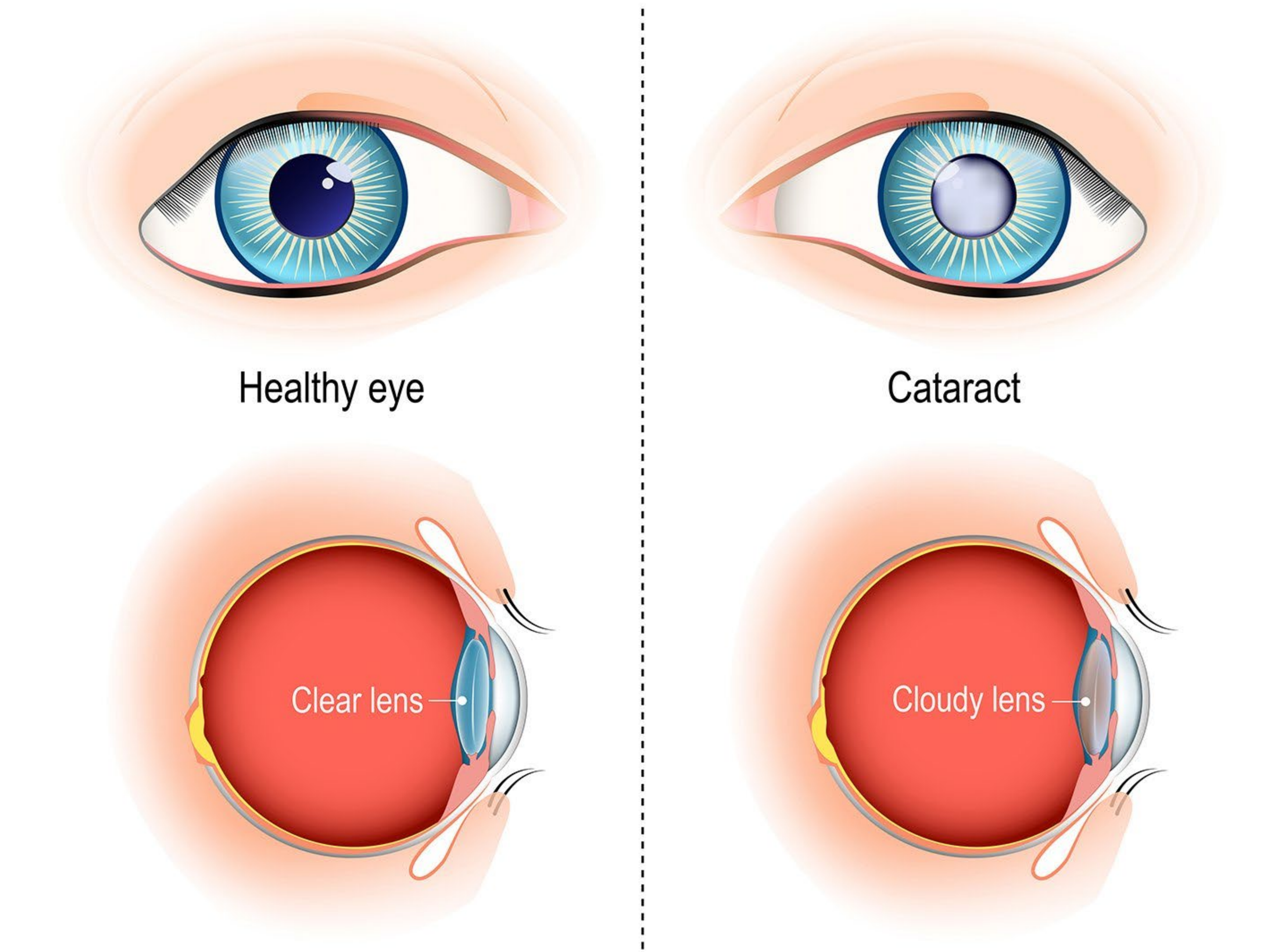
Clouding of lens

–lens fibers darken with age

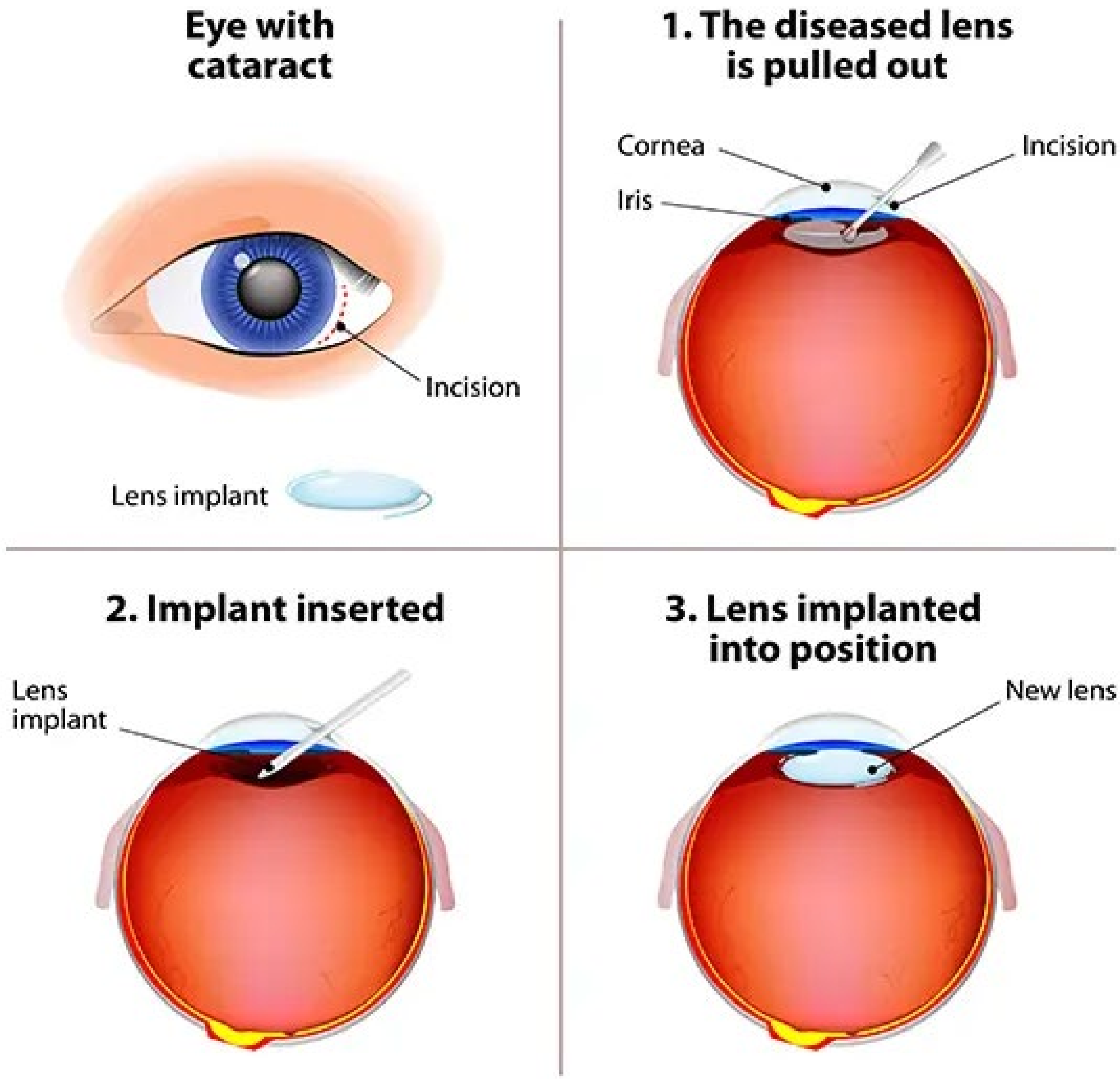
– fluid-filled bubbles and clefts filled with debris appear between the fibers

–induced by diabetes, smoking, drugs, ultraviolet radiation, and certain viruses

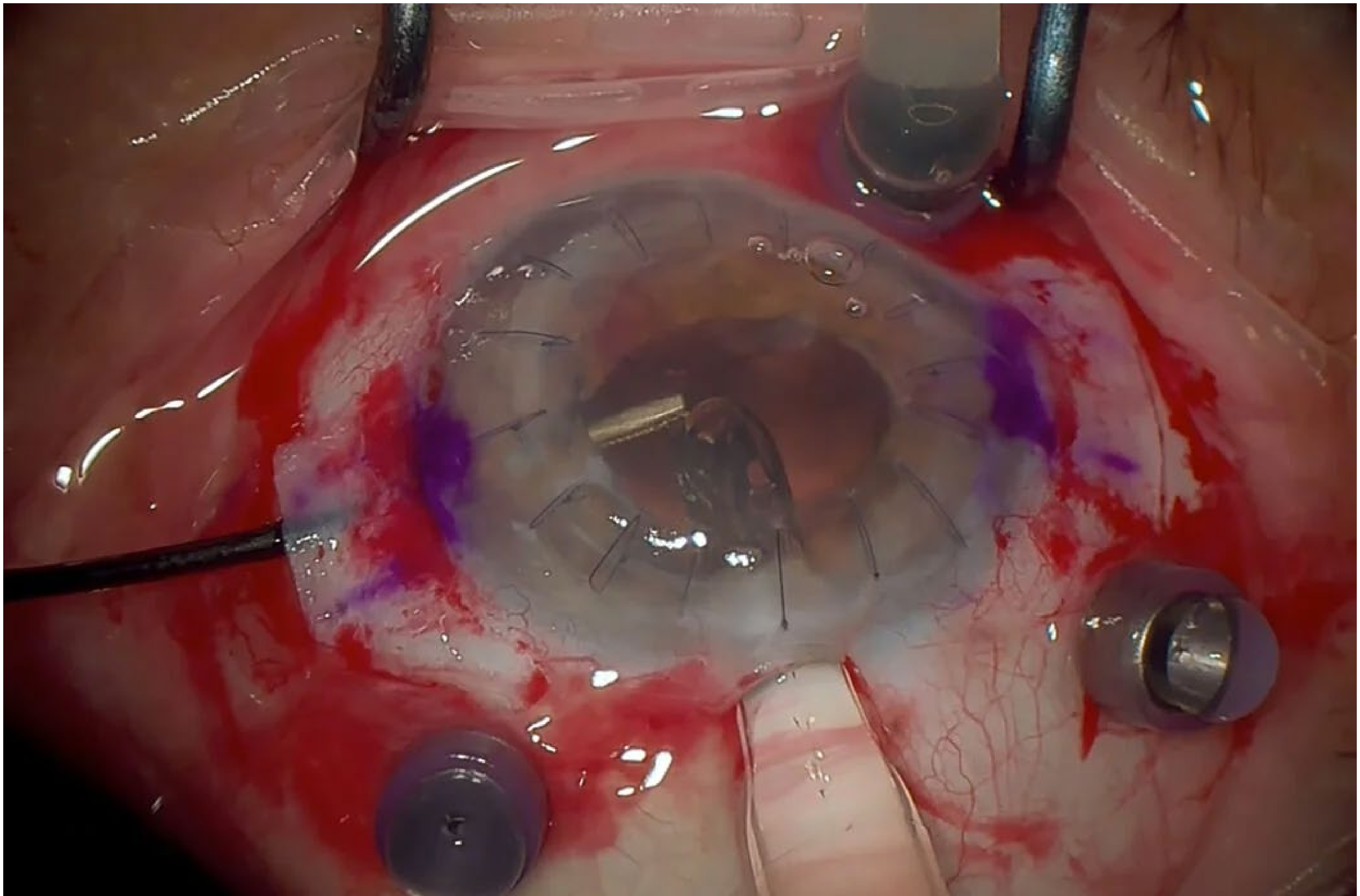
–able to replace natural lens with plastic one

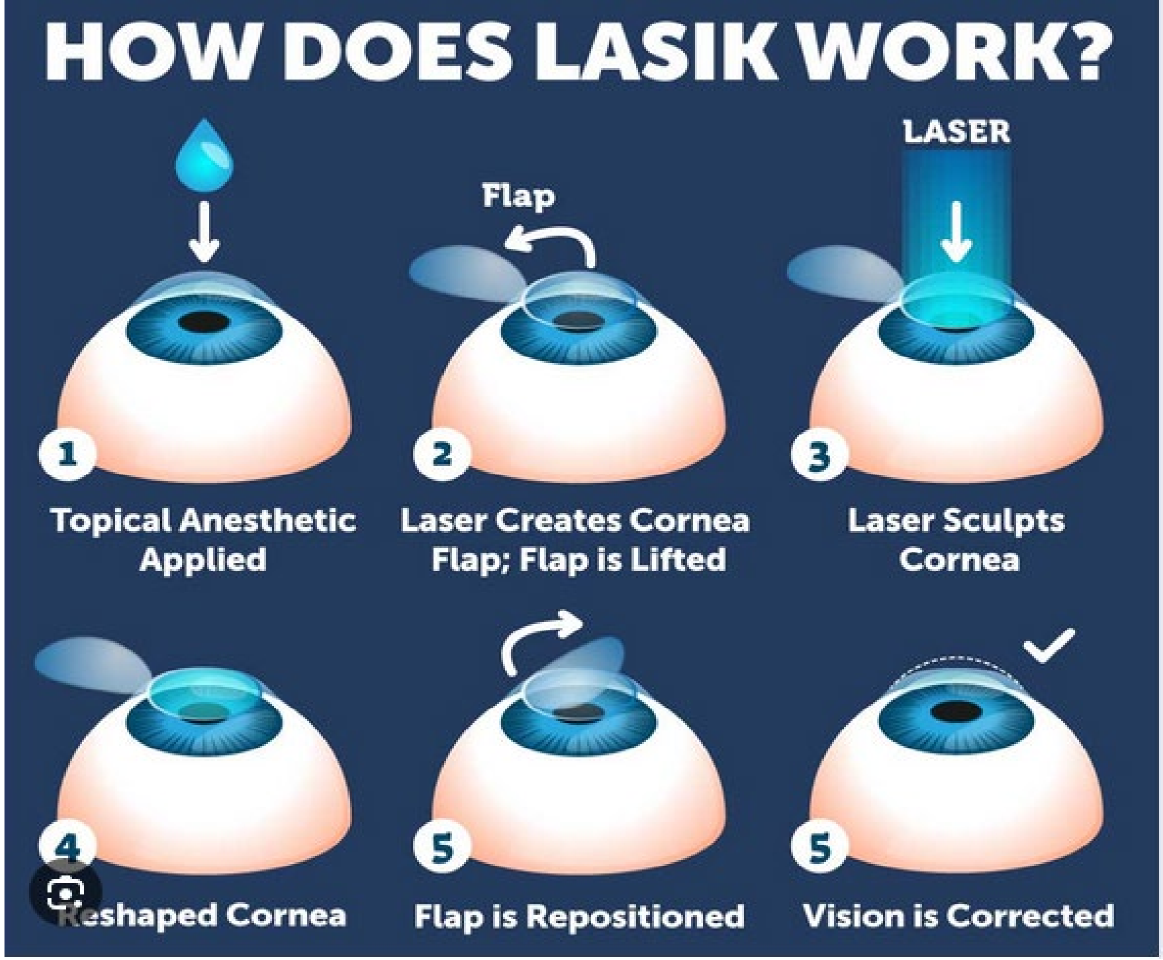

Healthy eye
Cataract
Clear lens
Cloudy lens

CATARACT SURGERY



Cataracts Surgery





LASIK eye surgery corrects vision by using a laser to permanently reshape the cornea, the clear front part of the eye, to treat near-sightedness, farsightedness, and astigmatism. A thin, protective flap is created on the cornea, a laser reshapes the underlying tissue, and the flap is then repositioned to allow for healing and vision correction. This procedure can reduce or eliminate the need for glasses or contact lenses.

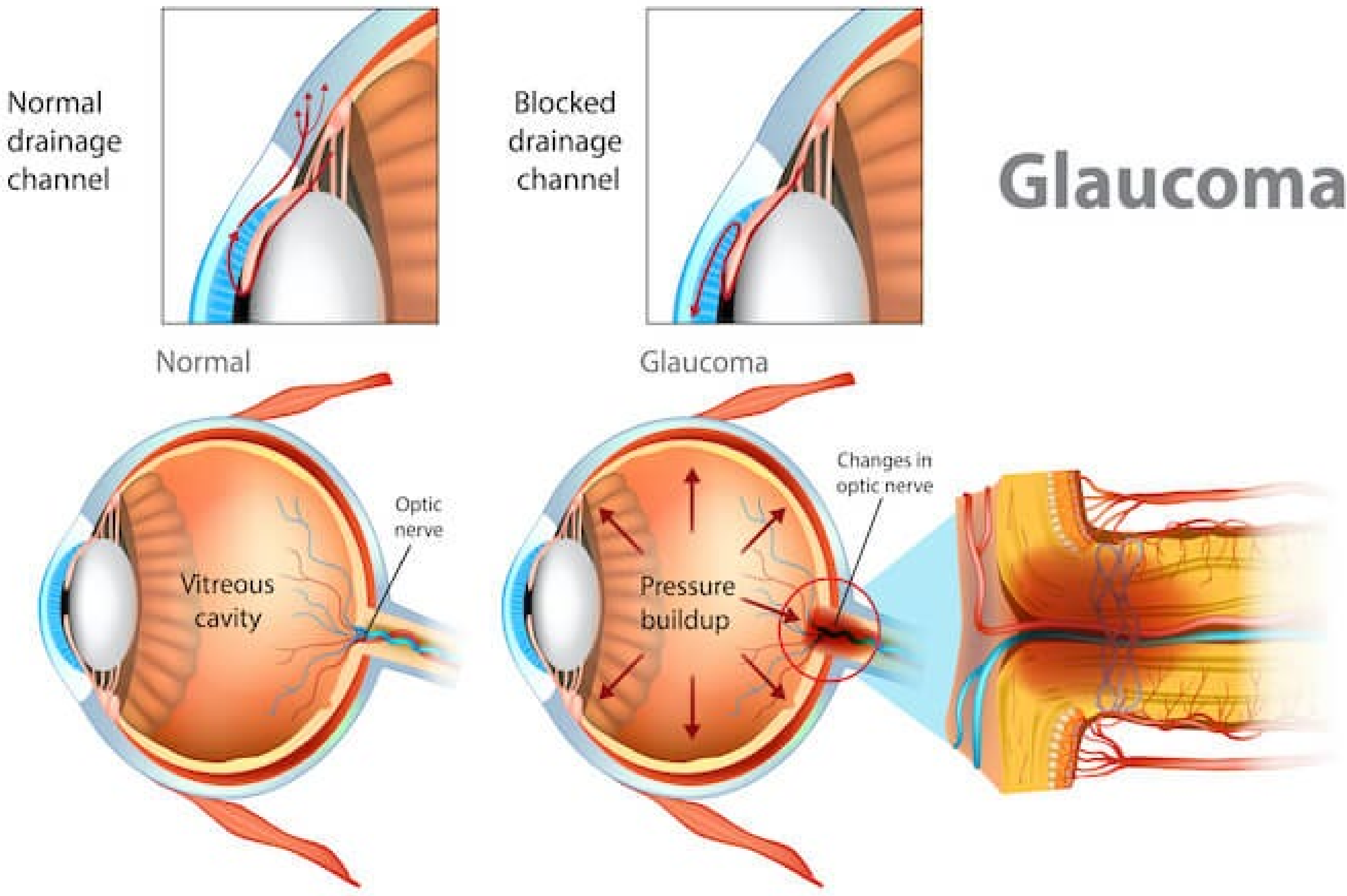
Glaucoma

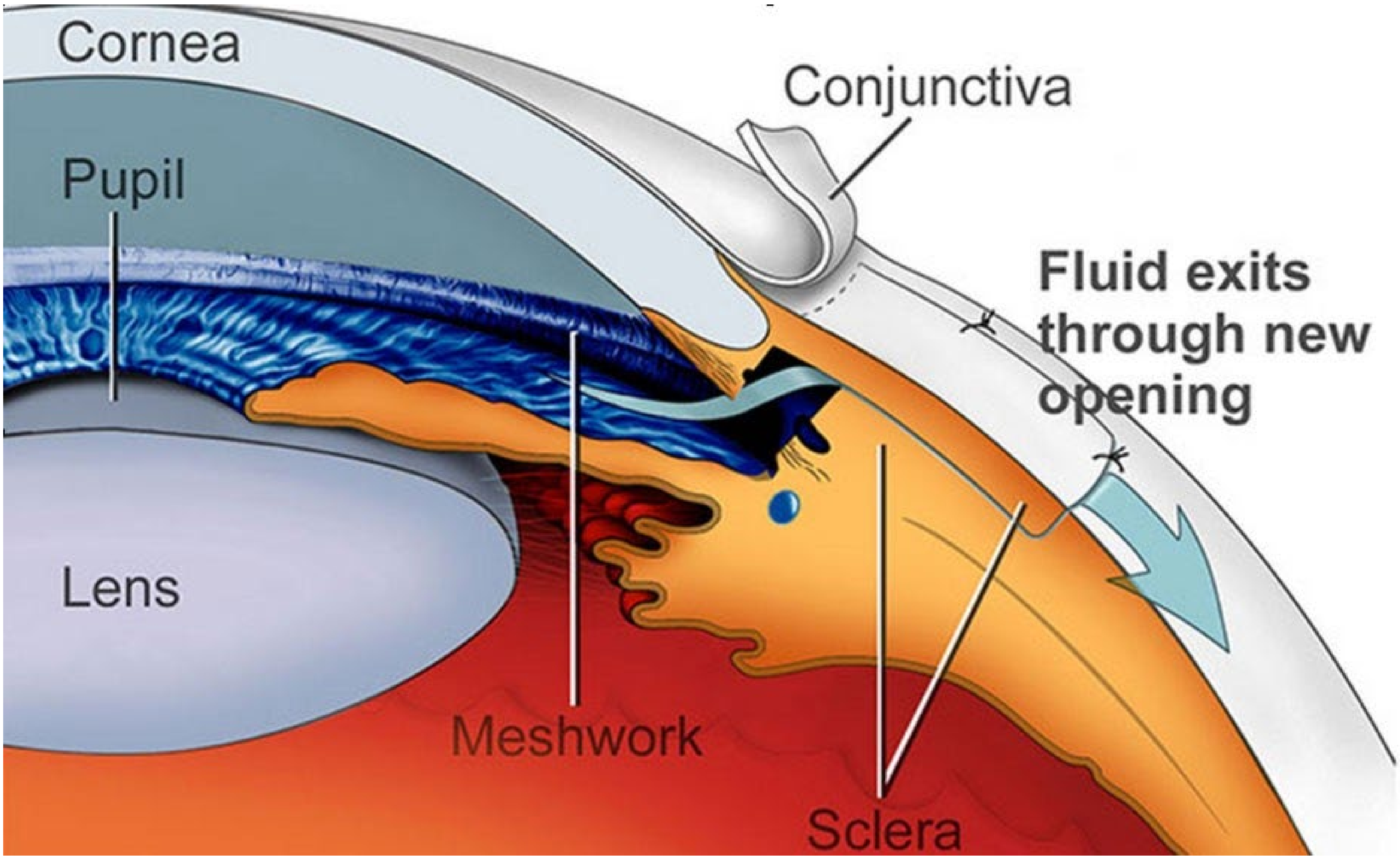
- elevated pressure within the eye due to obstruction of scleral venous sinus and improper drainage of aqueous humor

- death of retinal cells due to compression of blood vessels and lack of oxygen

  – illusory flashes of light are an early symptom
  – colored halos around lights are late symptom
  – lost vision can not be restored

- intra-ocular pressure measured with tonometer


Normal drainage channel
Blocked drainage channel
Glaucoma
Normal
Glaucoma
Changes in optic nerve
Optic nerve
Vitreous cavity
Pressure buildup


Cornea
Conjunctiva
Pupil
Fluid exits
through new
opening
Lens
Meshwork
Sclera

Photoreceptor Cells of the Retina

Light absorbing cells // derived from same stem cells as ependymal cells of the brain

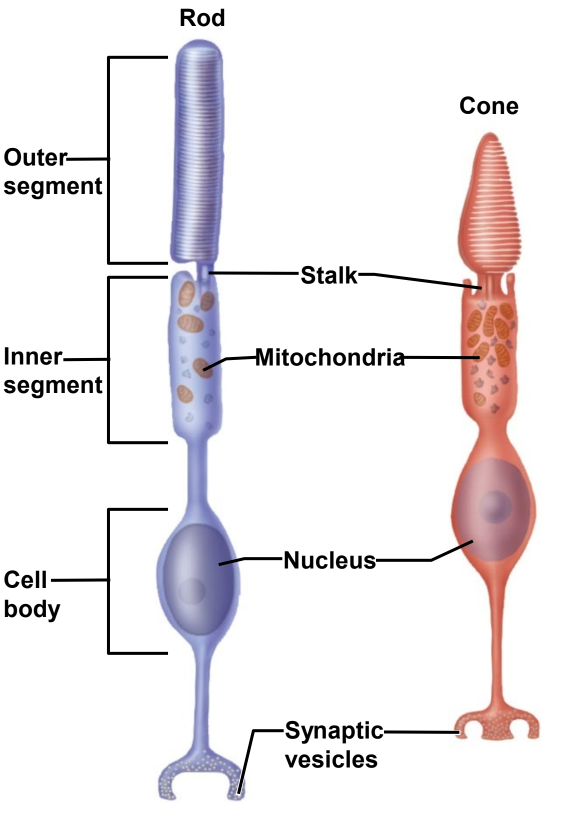
Rod cells = responsible for night vission (also called scotopic vision or monochromatic vision)

outer segment – modified cilium specialized to absorb light

stack of 1,000 membranous discs studded with globular proteins, the visual pigment, rhodopsin

inner segment – contains organelles

sitting atop cell body with nucleus



Photoreceptor Cells of the Retina

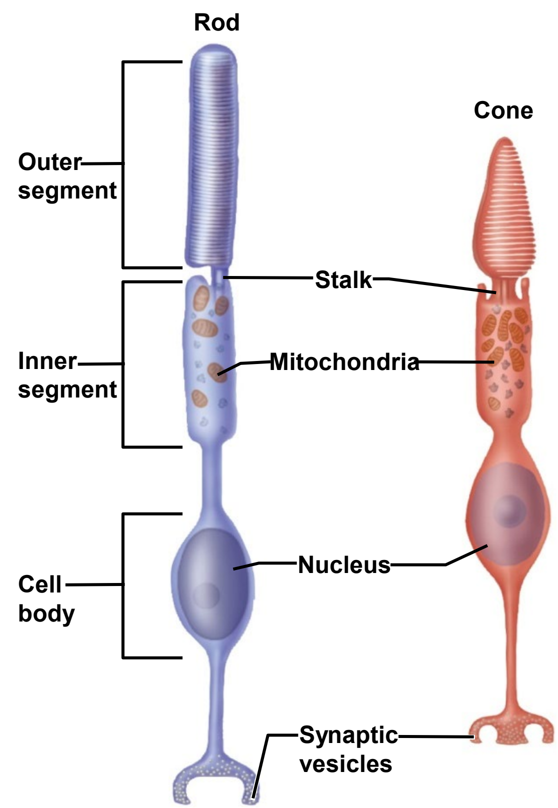
Light absorbing cells

Cone cells = color vision (also called , photopic or day vision)

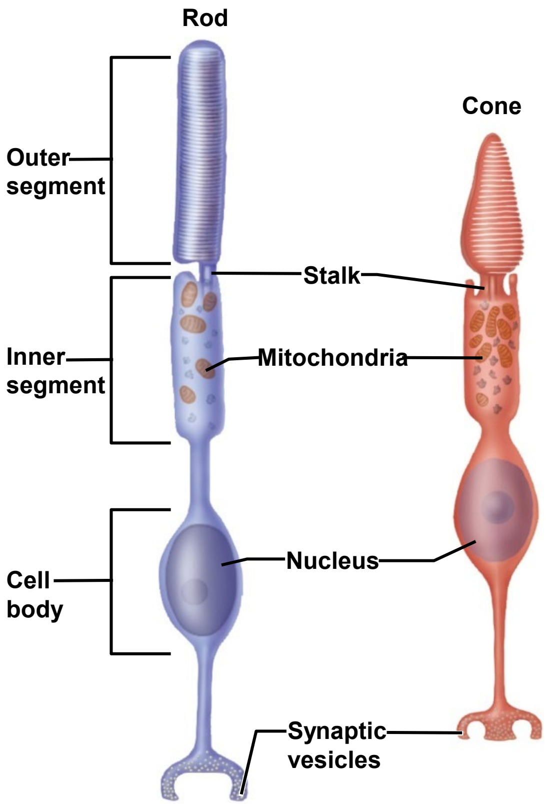
similar except outer segment tapers

outer segment tapers to a point

plasma membrane in-foldings form discs



Visual Pigment in Cones



Cones contain photopsin (iodopsin)

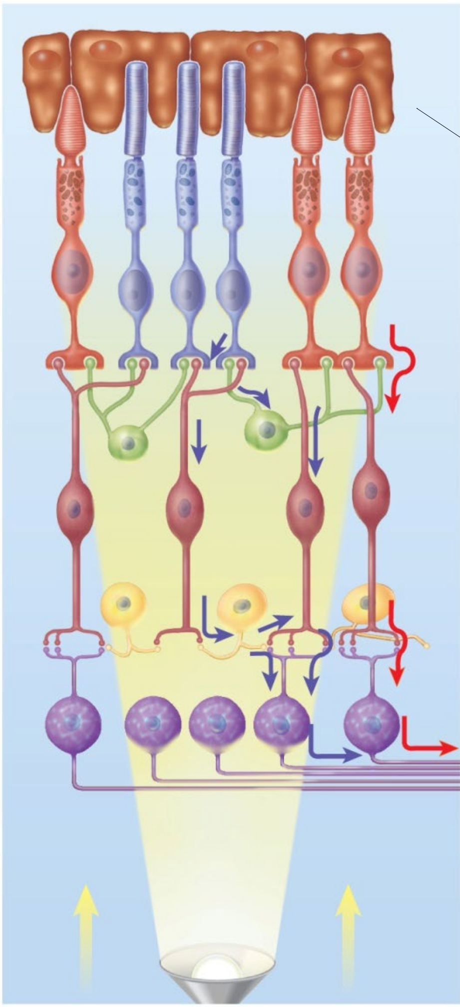
retinal moiety same as in rods

opsin moiety contain different amino acid sequences that determine wavelengths of light absorbed

three different kinds of cones

- identical in appearance
- each absorb different
- wavelengths of light
- produce color vision

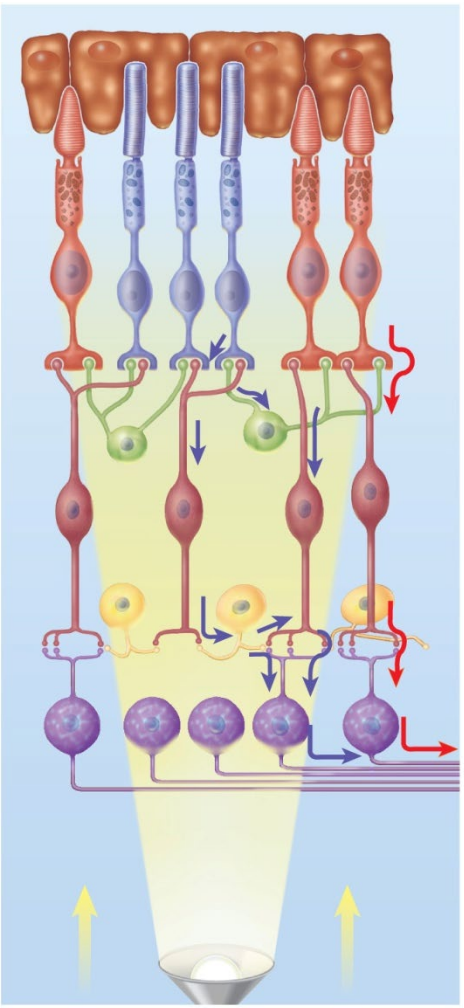
Sensory Transduction in the Retina



“transduction” of light energy into action potentials occurs in the retina

pigment epithelium /// most posterior part of retina // absorbs stray light so visual image is not degraded

Sensory Transduction in the Retina



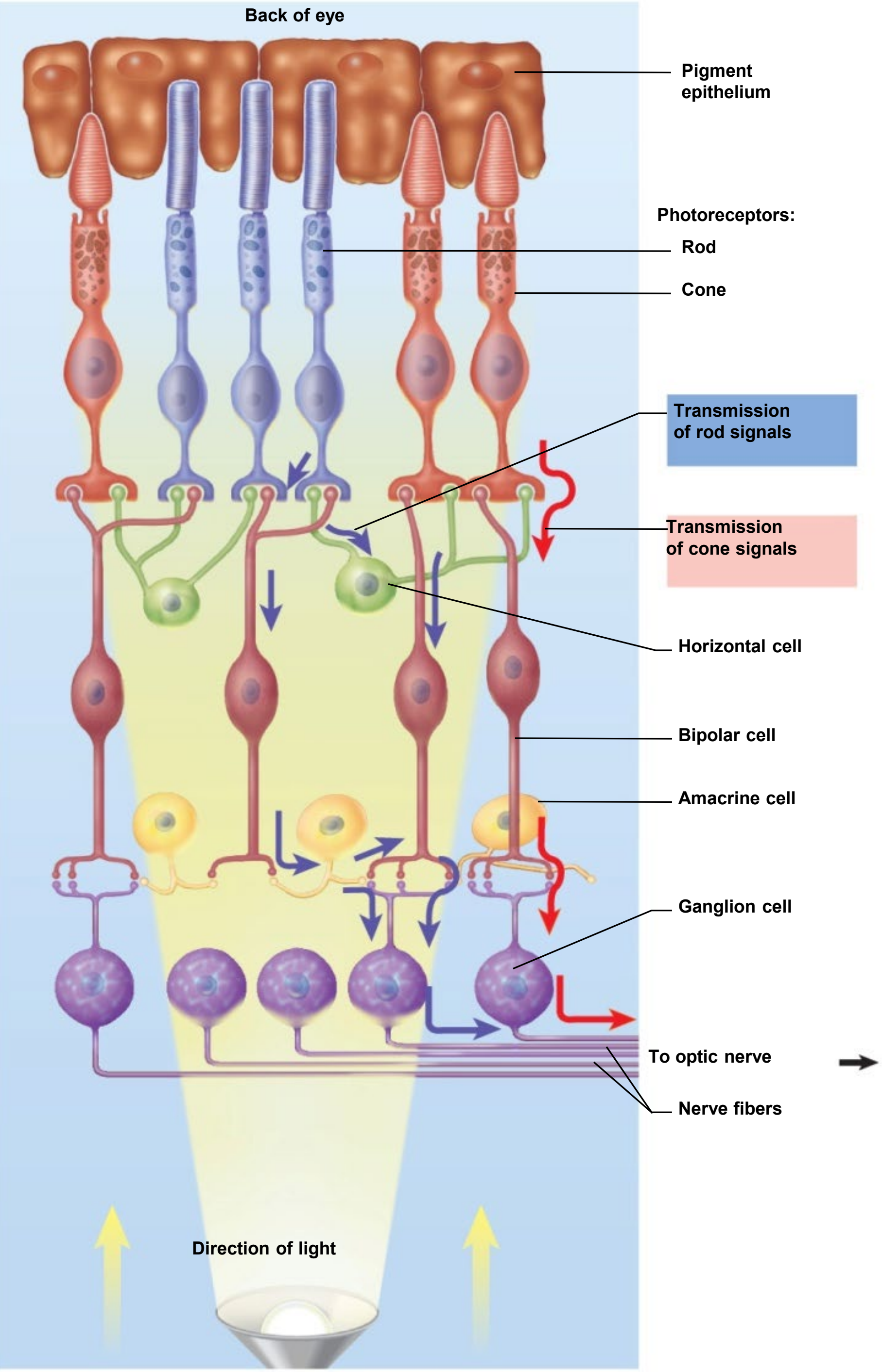
Structure of retina // neural components

Back portion of the eye forward // photoreceptor cells – absorb light and generate a chemical or electrical signal

Rods and cones // only rods and cones produce visual images

Bipolar cells – synapse with rods and cones and are first-order neurons of the visual pathway

Ganglion cells – largest neurons in the retina and are the second-order neurons of the visual pathway



Schematic Layers of the Retina

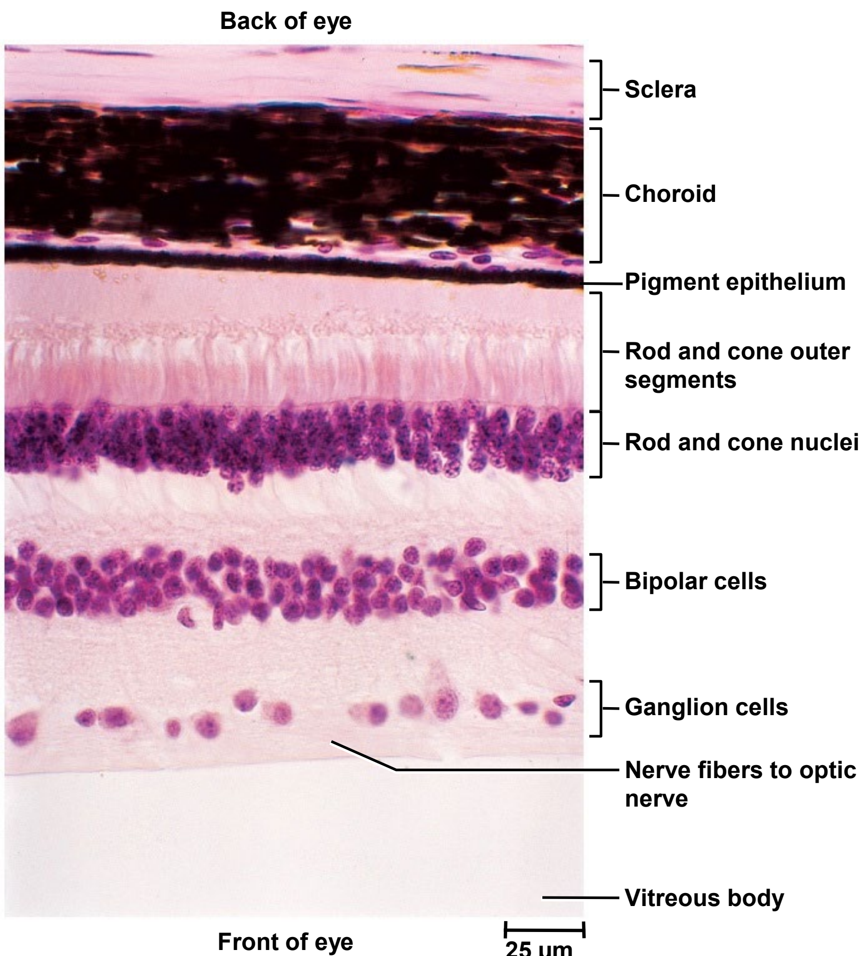
130 million rods and 6.5 million cones in retina

only 1.2 million nerve fibers in optic nerve // must have **neuronal convergence** = information processing in retina before signals reach brain

multiple rod or cone cells synapse on one bipolar cell

multiple bipolar cells synapse on one ganglion cell

Histology - Layers of Retina



(a)

Pigment epithelium

Rod and cone cells

Bipolar cells // rods & cones synapse on bipolar cells

Bipolar cells synapse on ganglion cells

Ganglion cells (neuron) contain sensory pigment – melanopsin // single layer of large neurons near vitreous

–Ganglion cell's axons form optic nerve // absorb light and transmit signals to brainstem // detect light intensity only

Visual Pigments

Rods contain visual pigment molecule = rhodopsin (nickname = visual purple)

Two major parts of molecule

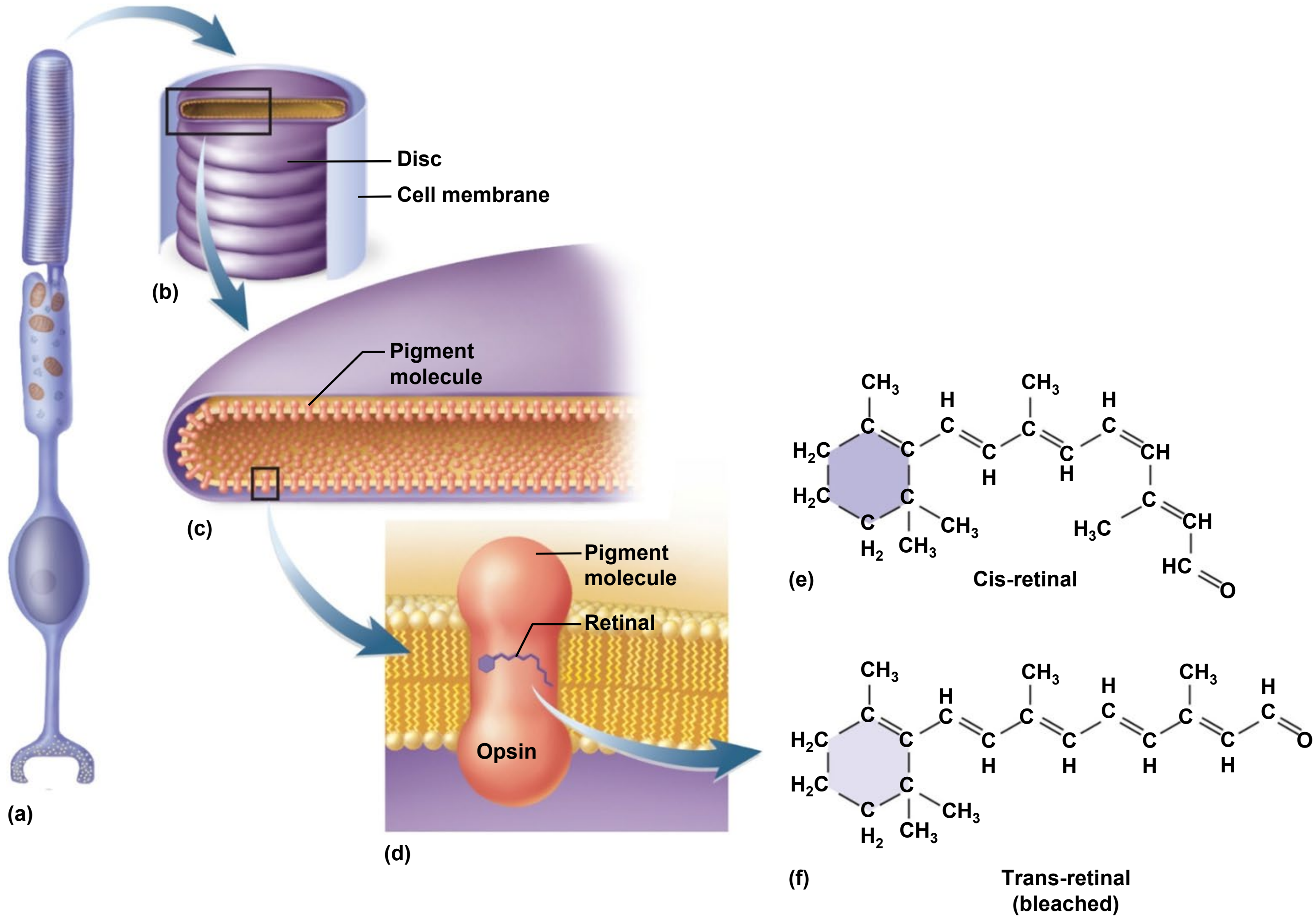
- opsin - protein portion embedded in disc membrane of rod's outer segment

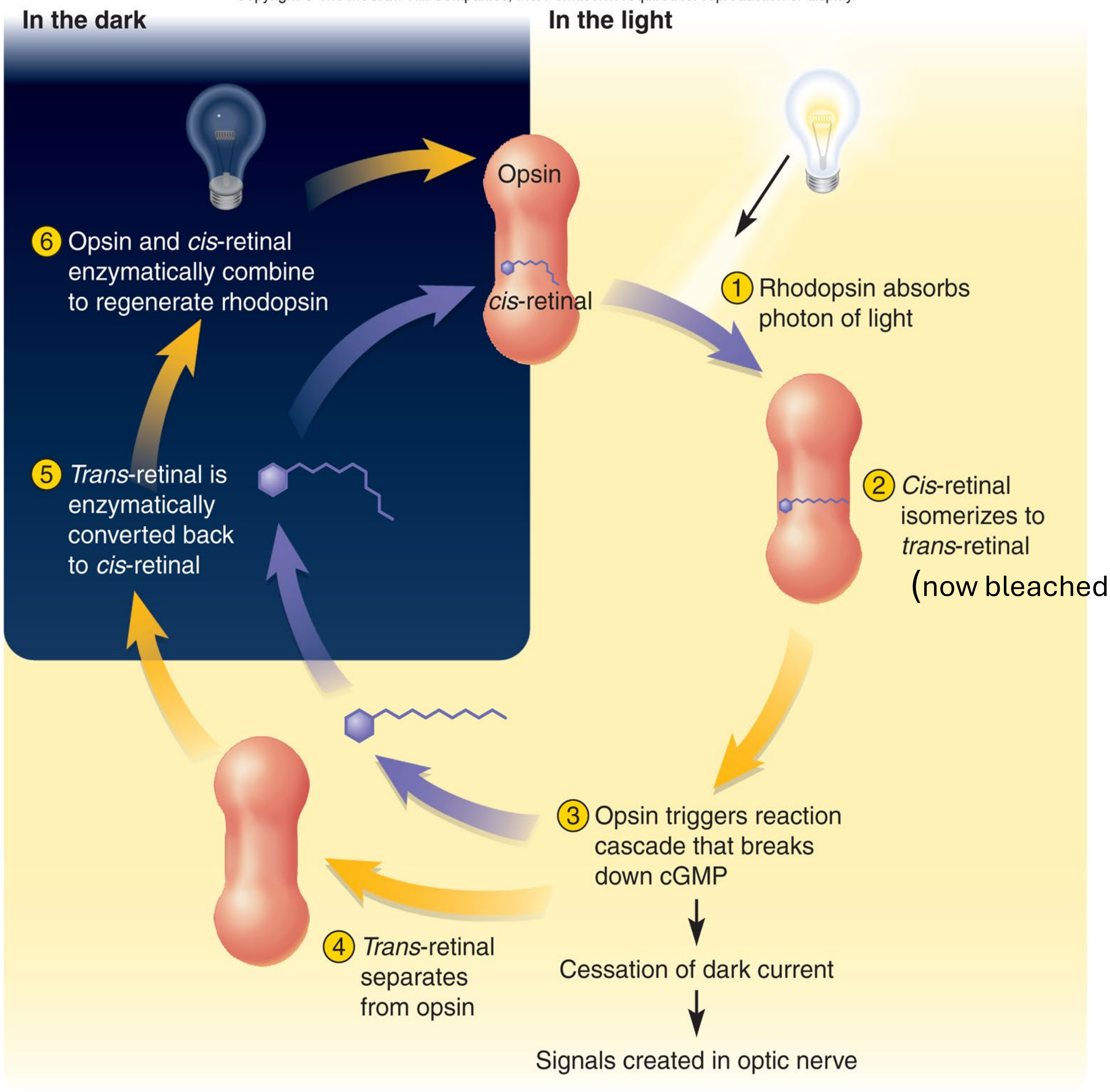
- retinal (retinene) - a vitamin A derivative

absorption peak at wavelength of 500 nm // can not distinguish one color from another

We have a better understanding of visual processing in rods than we have in cones. Cones pigment molecule called iodopsin (retinal + photopsin)

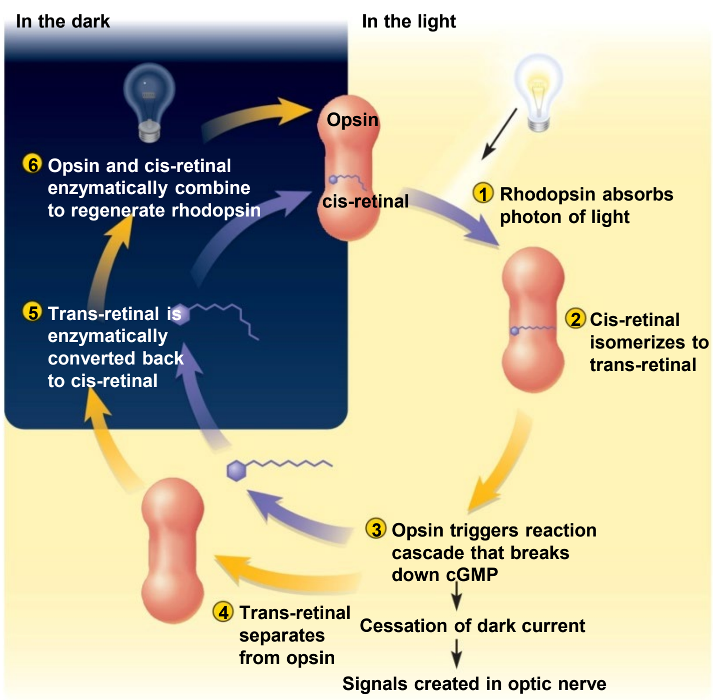
Location of Visual Pigments




In the dark
In the light
Opsin
cis-retinal
6 Opsin and cis-retinal enzymatically combine to regenerate rhodopsin
1 Rhodopsin absorbs photon of light
2 Cis-retinal isomerizes to trans-retinal
(now bleached)
5 Trans-retinal is enzymatically converted back to cis-retinal
3 Opsin triggers reaction cascade that breaks down cGMP
Cessation of dark current
Signals created in optic nerve
4 Trans-retinal separates from opsin

Generating the Optic Nerve Signal

Rhodopsin Bleaching and Regeneration



In the dark, trans-retinal is converted to cis-retinal and cis-retinal combines with opsin to reform rhodopsin. This is the dark reaction.

In the dark, action potentials to optic nerve are blocked.

In the light, rhodopsin absorbs light that converts cis-retinal to trans-retinal and trans-retinal sparatess from opsin

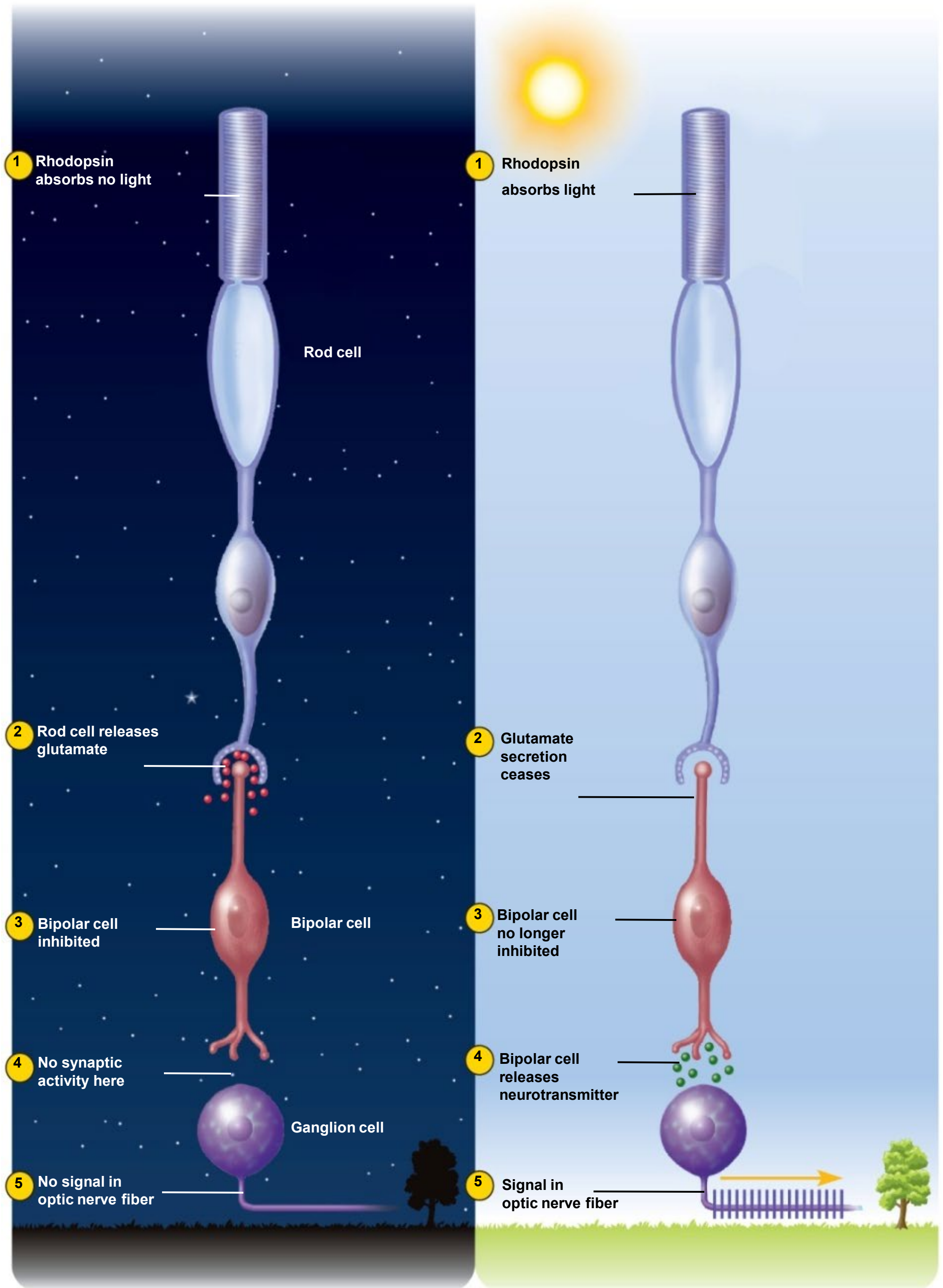
The free opsin now starts cascade of events which result in action potential in optic nerve

Rhodopsin has a purple color = visual purple // when retinal dissociates from opsin /// loss of color is called bleaching

Takes 5 minutes to regenerate 50% of bleached rhodopsin

Cones are faster to regenerate their photopsin – 90 seconds for 50%

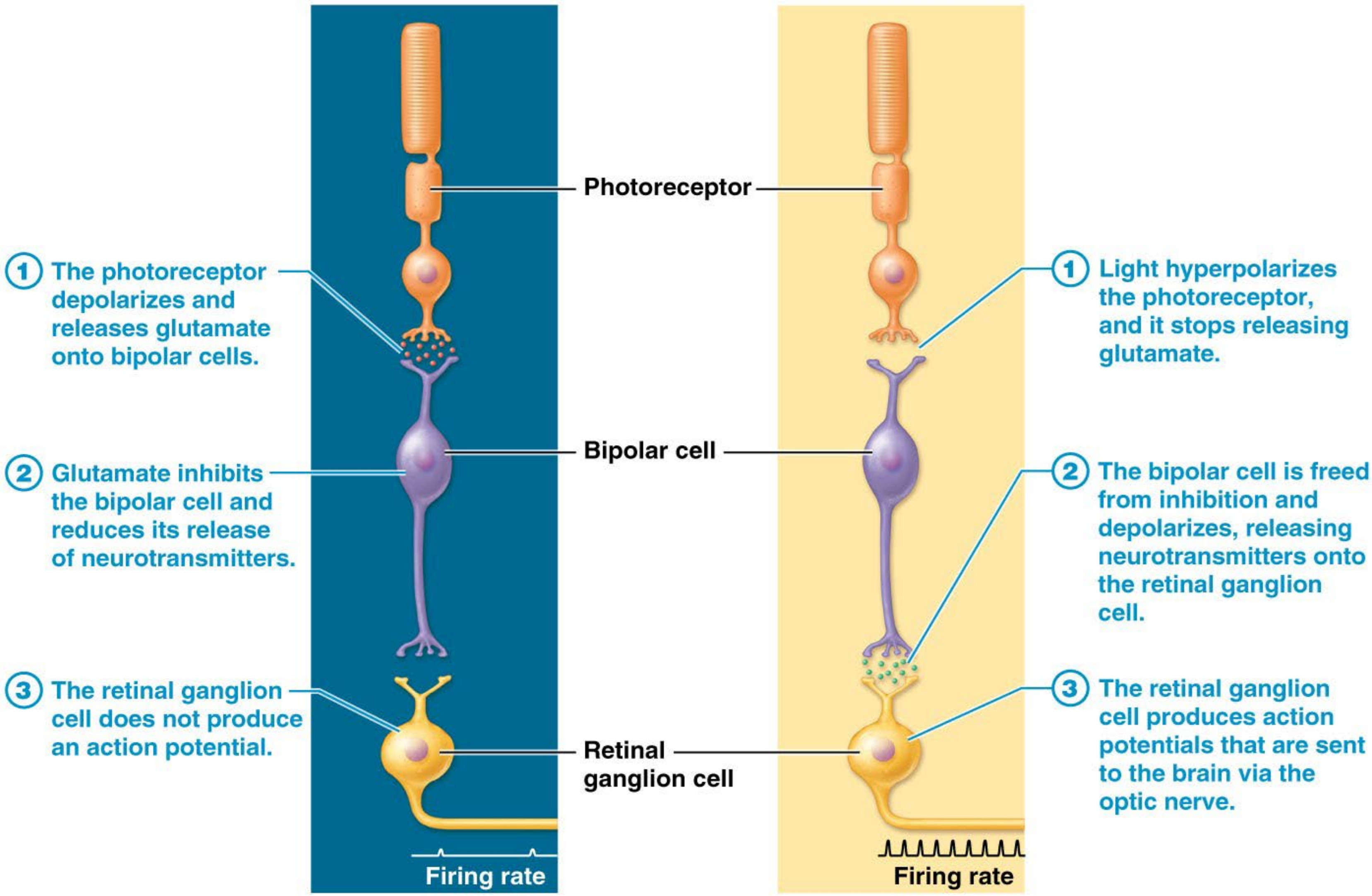
Generating Visual Signals



(a) In the dark

(b) In the light

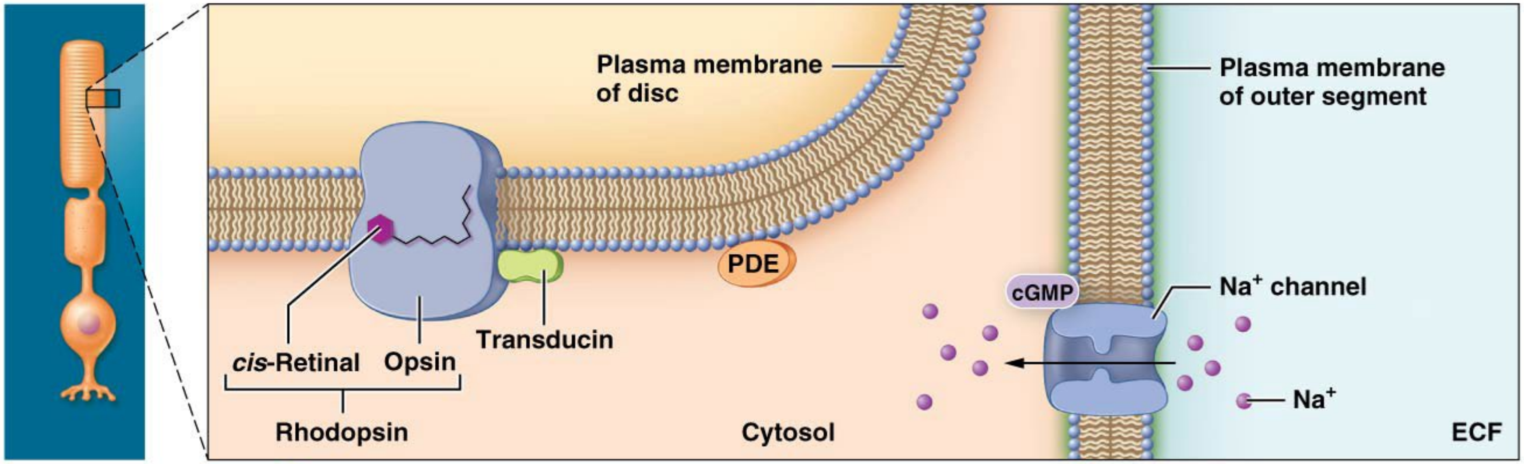
How are action potentials created in the retinal ganglion cells?



(a) In the dark, retinal ganglion cells are not stimulated.

(b) In the light, retinal ganglion cells are stimulated.

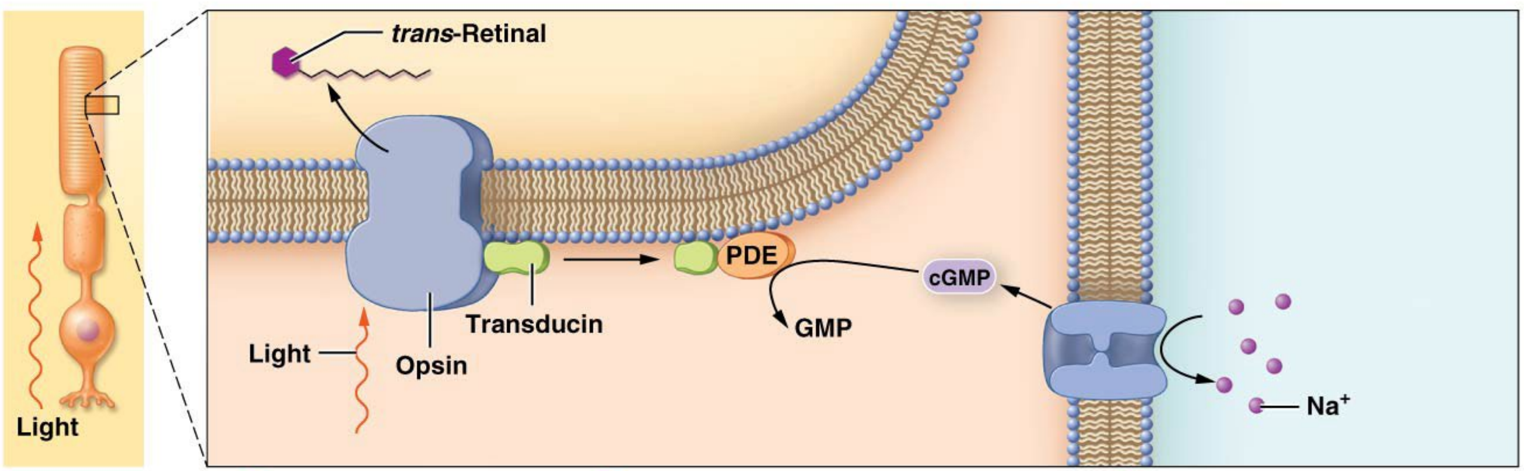
Transduction of light in a photoreceptor cell.



(1) Opsin and *cis*–retinal combine to form rhodopsin in the disc membrane.

(2) Na^+ enter the outer segment of the photoreceptor and depolarize it.

(a) In the dark, photoreceptor cells depolarize.



(1) Light causes retinal to separate from opsin.

(2) Transducin and phosphodiesterase (PDE) are activated.

(3) Na^+ channels close, and the photoreceptor hyperpolarizes.

(b) In the light, photoreceptor cells hyperpolarize.

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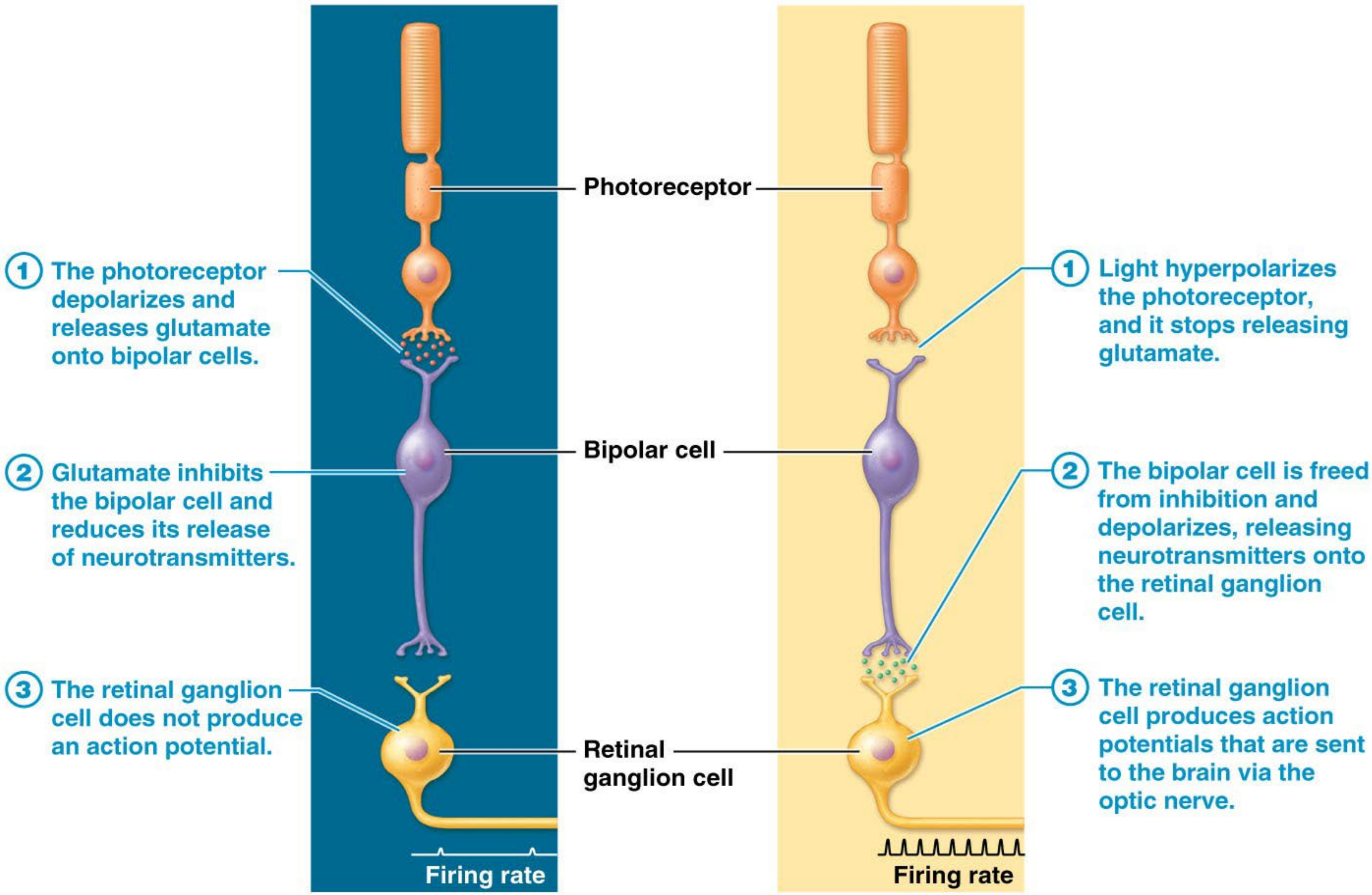


(a) In the dark, retinal ganglion cells are not stimulated.

(b) In the light, retinal ganglion cells are stimulated.

Generating Optic Nerve Signals

In dark, rods steadily release the neurotransmitter, glutamate from basal end of cell

When rods absorb light, glutamate secretion ceases

Bipolar cells are sensitive to these on and off pulses of glutamate secretion // some bipolar cells inhibited by glutamate and excited when secretion stops // these cells excited by rising light intensities // other bipolar cells are excited by glutamate and respond when light intensity drops

When bipolar cells detect fluctuations in light intensity, they stimulate ganglion cells directly or indirectly

Ganglion cells are the only retinal cells that produce action potentials

Ganglion cells respond to the bipolar cells with rising and falling firing frequencies

By way of the optic nerve, these changes provide visual signals to the brain

Light and Dark Adaptation

Light adaptation (walk out into sunlight)

pupil constriction // pain occurs from over stimulated retina

pupils constrict to reduce pain & intensity

color vision and visual acuity below normal for 5 to 10 minutes

This is the time needed for pigment bleaching to adjust retinal sensitivity to high light intensity

Rod vision is nonfunctional in normal or bright light

Light and Dark Adaptation

Dark adaptation (turn lights off)

dilation of pupils occurs

rod pigment completely bleached while exposed to light

in dark, rhodopsin is regenerated faster than it bleaches

in a minute or two at night (scotopic) vision begins to function

after 20 to 30 minutes the amount of regenerated rhodopsin is sufficient for your eyes to reach maximum sensitivity

Scotopic System (Night Vision)

Rods sensitive – react even in dim light

- –extensive neuronal convergence // increased sensitivity
- –600 rods converge on 1 bipolar cell
- –many bipolar converge on single ganglion cell
- –results in high degree of spatial summation
- –but low resolution system
- –cannot resolve finely detailed images

One ganglion cells receives information from 1 mm^2 of retina producing only a coarse image

Outer margin of retina have widely-spaced rod cells /// these rods act as motion detectors

Color Vision
Photopic System (Day Vision)

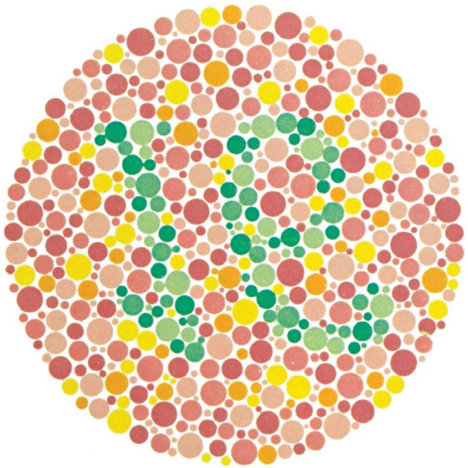
Fovea contains 4000 tiny cone cells (no rods)

No neuronal convergence

Each foveal cone cell single contact with ganglion cell
= one axon = “private line to brain”

High-resolution color vision // little spatial summation
so less sensitivity to dim light

Color Blindness



Color blindness – is a hereditary alteration or lack of one of the photopsin molecules

note: color vision has three variations of photopsin – the color vision pigment

most common is red-green color blindness

results from lack of either L or M type cones

causes difficulty distinguishing these related shades from each other

occurs in 8% of males, and 0.5% in females (sex-linkage)

Stereoscopic Vision (Stereopsis)

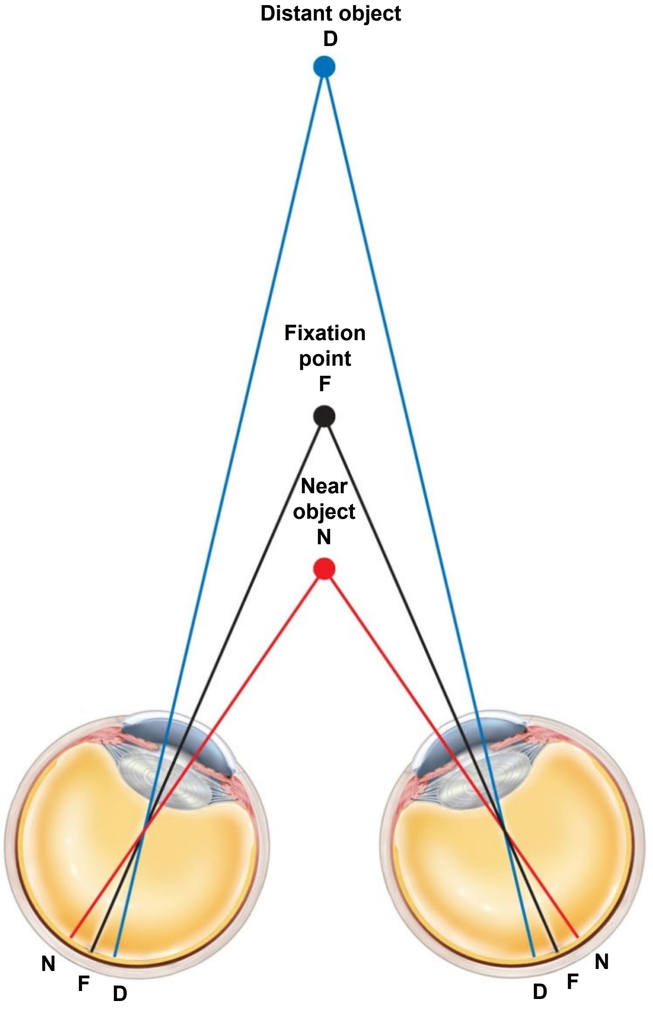
Panoramic vision has eyes on sides of head (horse or rodents – alert to predators but no depth perception)

Stereoscopic vision is depth perception - ability to judge distance to objects

requires two eyes with overlapping visual fields which allows each eye to look at the same object from different angles

fixation point // point in space in which the eyes are focused // looking at object within 100 feet, each eye views from slightly different angle // provides brain with information used to judge position of objects relative to fixation point

Retinal Basis of Stereoscopic Vision



Visual Projection Pathway

Bipolar cells of retina are **first-order neurons**

Retinal ganglion cells are **second-order neurons** whose axons form optic nerve

Two optic nerves combine to form **optic chiasm**

Half the fibers cross over to the opposite side of the brain (**hemidecussation**) and chiasm splits to form **optic tracts**

Right cerebral hemisphere sees objects in the left visual field because their images fall on the right half of each retina

Each side of brain sees what is on side where it has motor control over limbs

Visual Projection Pathway

- optic tracts pass laterally around the hypothalamus with most of their axons ending in the lateral geniculate nucleus of the thalamus

- third-order neurons arise here and form the optic radiation of fibers in the white matter of the cerebrum

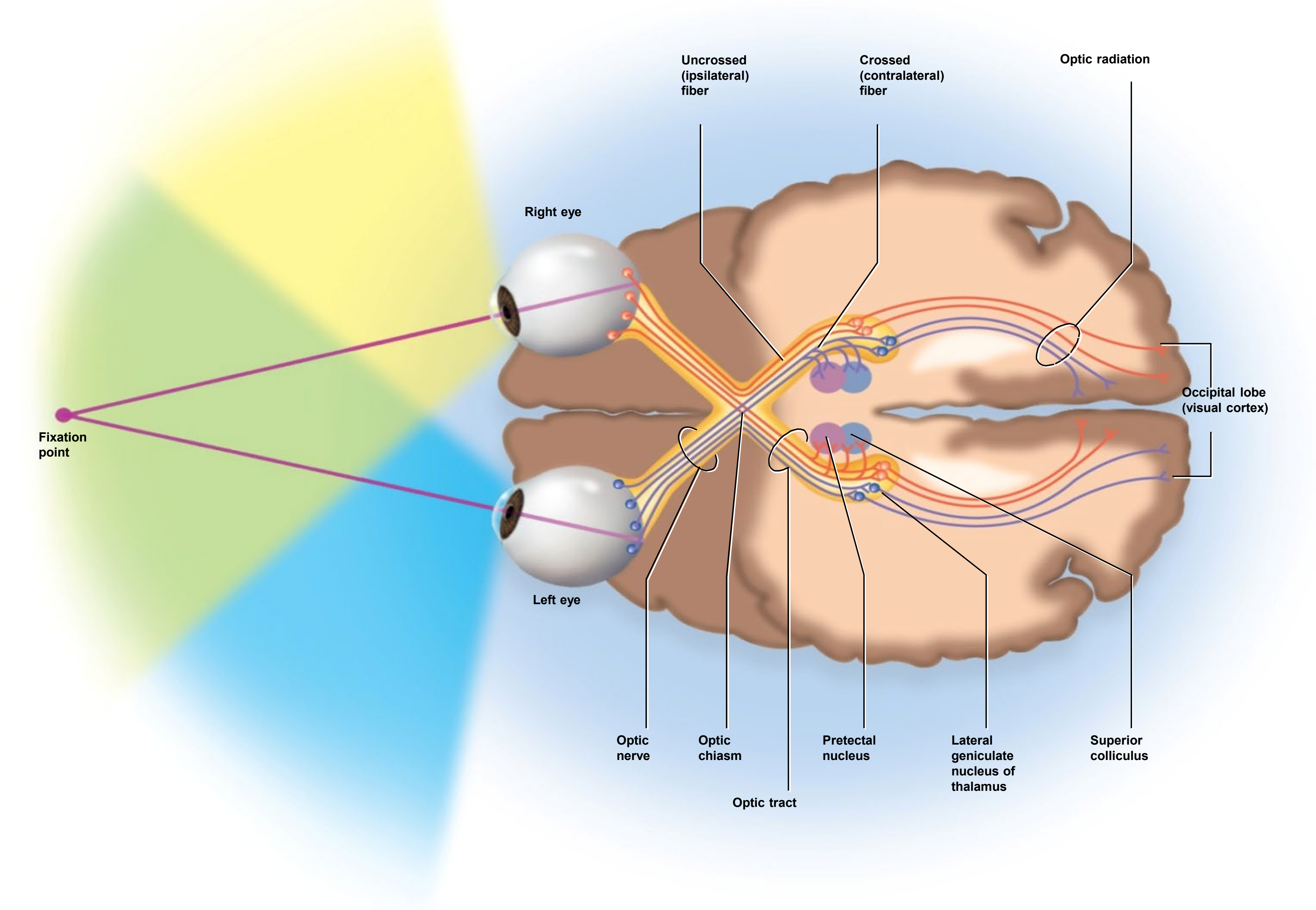
– project to primary visual cortex of occipital lobe where conscious visual sensation occurs

– a few optic nerve fibers project to midbrain and terminate in the superior colliculi and pretectal nuclei

- superior colliculi controls visual reflexes of extrinsic eye muscles

- pretectal nuclei are involved in photopupillary and accommodation reflexes

Visual Projection Pathway



Visual Information Processing

Some processing begins in retina

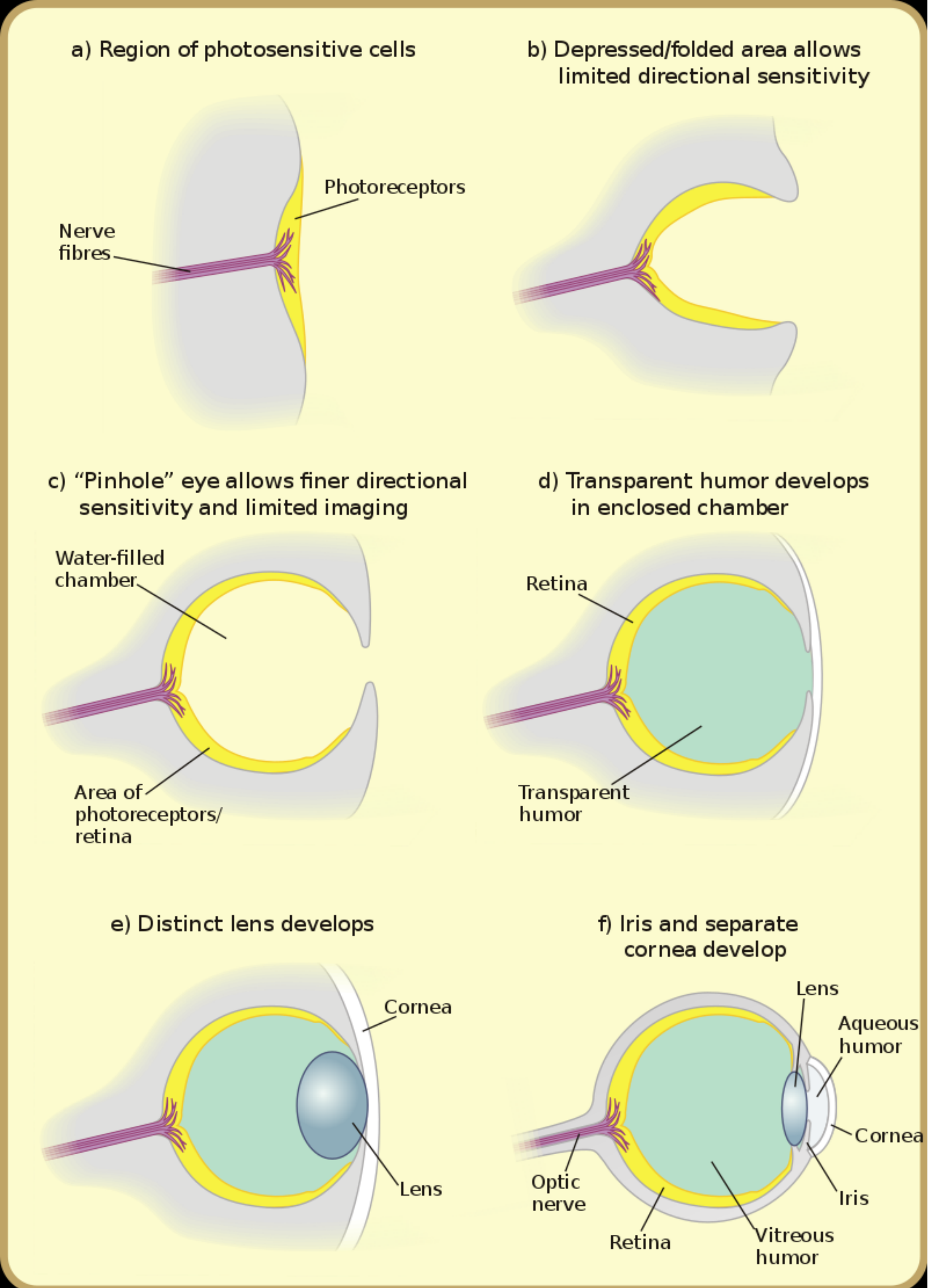
Adjustments for contrast, brightness, motion and stereopsis

Primary visual cortex is connected by association tracts to **visual association areas** in parietal and temporal lobes which process retinal data from occipital lobes

–object location, motion, color, shape, boundaries

–store visual memories

–recognize printed words // language



Evolution of the Modern Eye

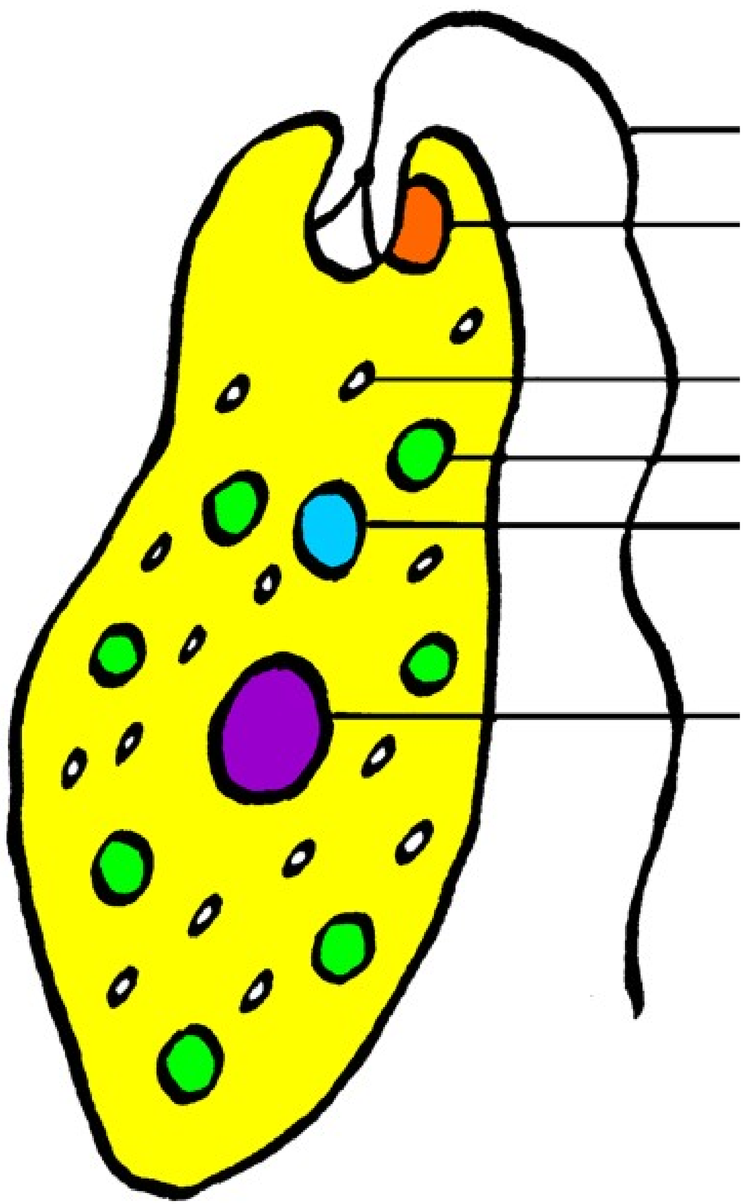
The first animal photosensitive cells evolved 541 million years ago. (Fish first evolved around 500 million years ago.) These steps trace the evolution from a simple photoreceptor to the modern eye.

At one point, a distant "relative" of ours had a third eye called the parietal eye, with an iris and other features resembling the modern eye. Over time, natural selection changed this tissue into what is now the brain's pineal gland and habenula.

Along the way, images where only in gray tone but some animals evolved eyes able to "see color images". Occurred in common ancestor of apes and Old World moneys about 30 million years ago.

What is the advantage of being able to see in color?

Inside the euglena hides a light-sensitive spot.



In the green one-celled organism Euglena, the eyespot is located in the gullet, at the base of the flagellum (a whiplike locomotion structure).
A cup-shaped mass of pigment rods shields a sensitive area of the flagellar base from light coming from the direction of the opposite end of the organism.

Because the Euglena can undergo photosynthesis, they detect light via eyespot and move toward it; a process known as phototaxis.
When an organism responds to light, a stimulus (plural, stimuli), they move either toward or away from light.

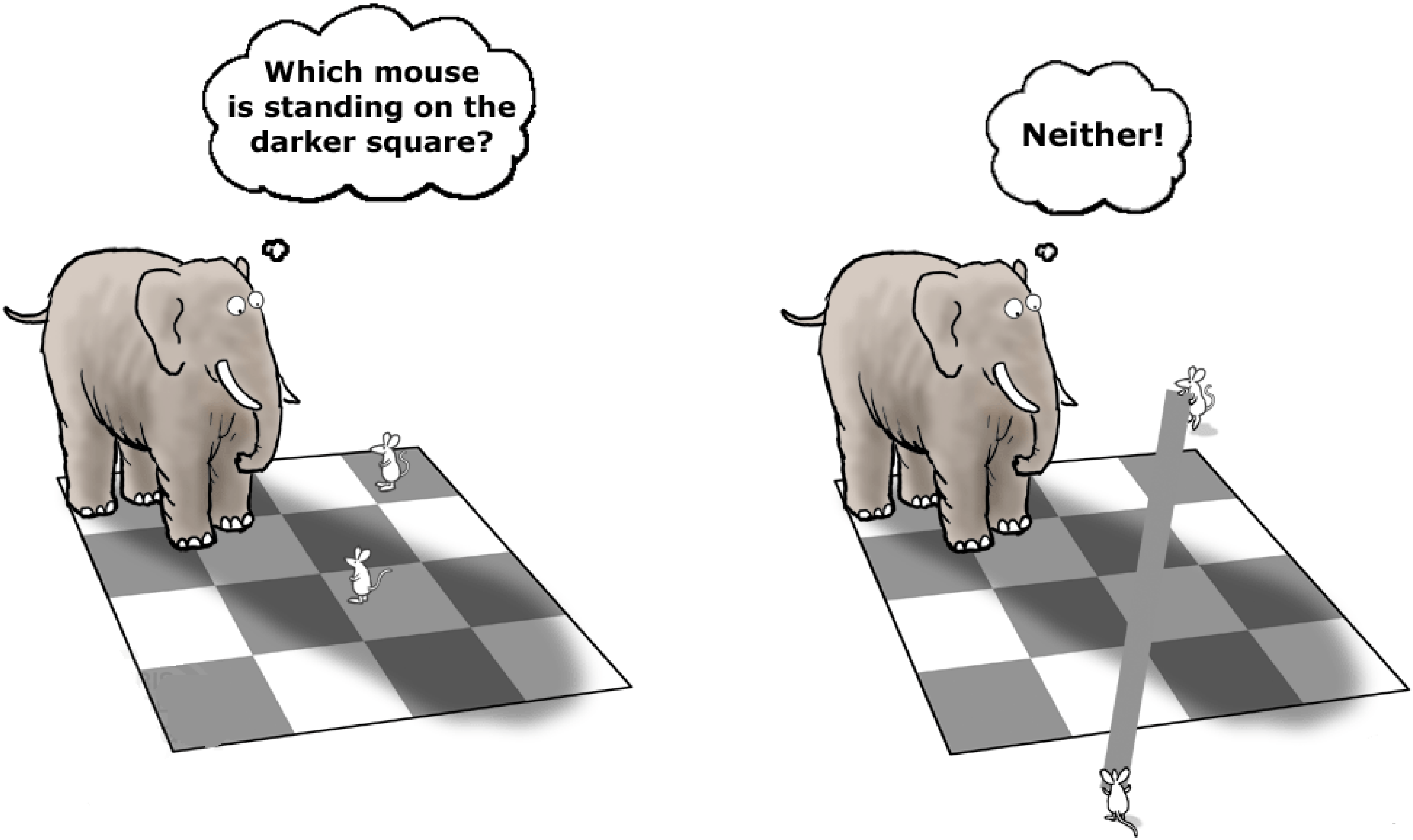
The planarian have "cup" eye-spots that can slightly distinguish light direction.

Although the planarian eye is far simpler than a human eye, there are significant similarities. The planarian eye is composed of a pigmented cell cup and photoreceptor cells, which extend rhabdomeres into the eye cup. These photoreceptors have axons that project directly to the visual center of the planarian brain.

Some time around 600 million years ago, these multicellular animal had three cell layers and bilateral symmetry. In other words, they had a right and left side and a head and tail end.

These “bilateral animals” coexisted in a world of complex single cells – competing with them, and eating them just as their descendants do today.

Third eye called the parietal eye.


Which mouse is standing on the darker square?
Neither!