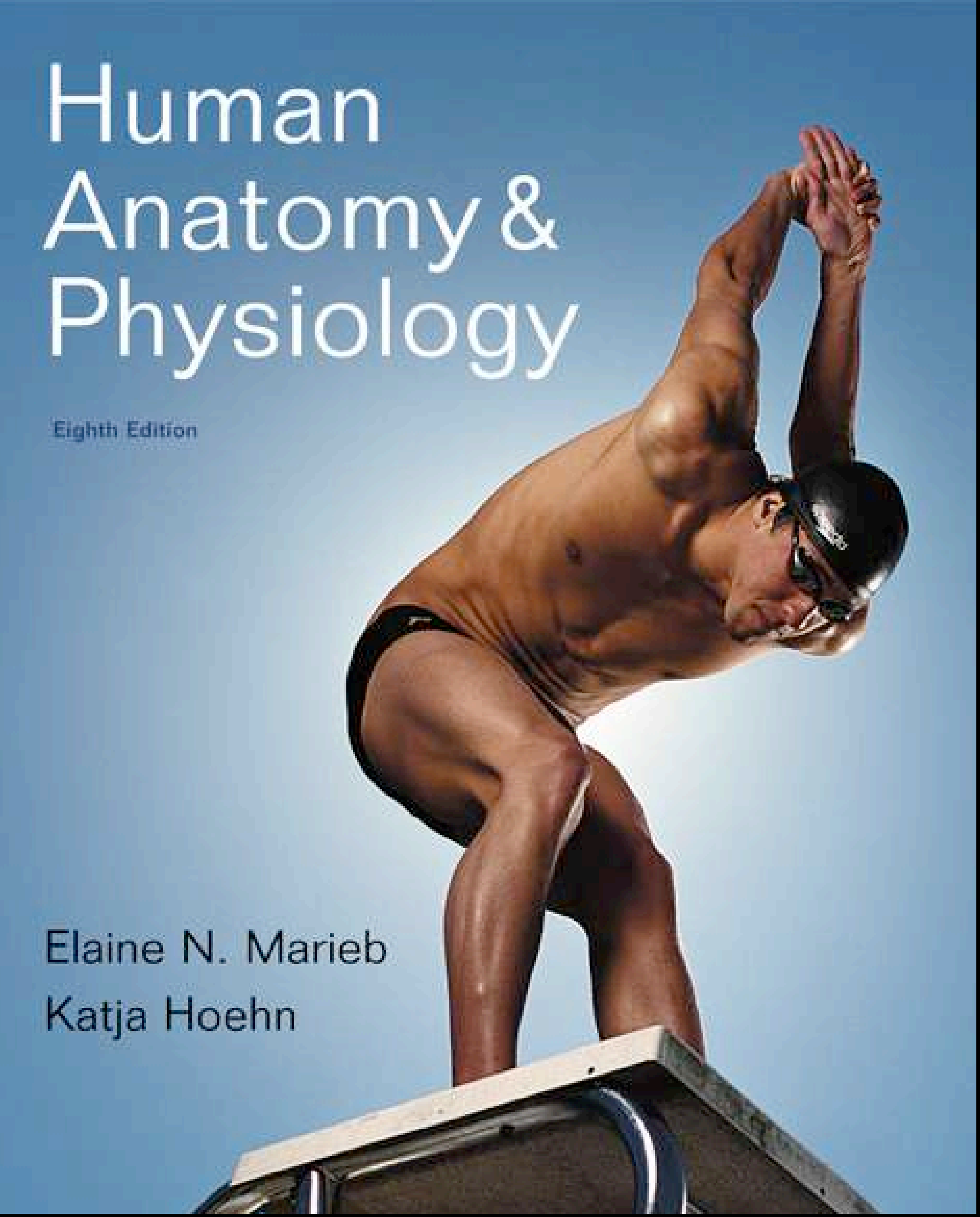


PowerPoint® Lecture Slides

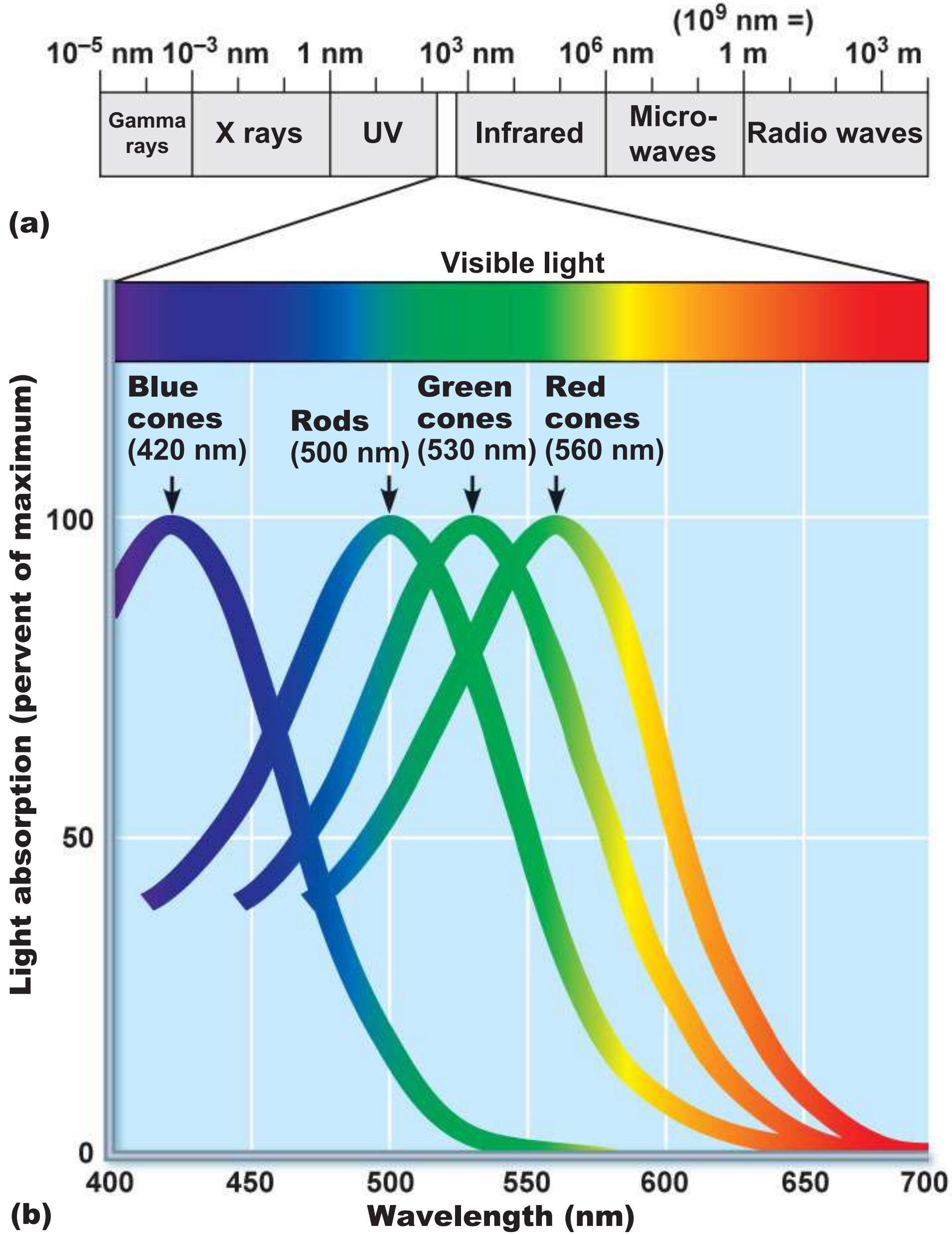
prepared by
Janice Meeking,
Mount Royal College

CHAPTER 15

The Special Senses: Part B

Light

- Our eyes respond to visible light, a small portion of the electromagnetic spectrum
- Light: packets of energy called photons (quanta) that travel in a wavelike fashion
- Rods and cones respond to different wavelengths of the visible spectrum



(10^{9} nm =)
10^{-5} nm 10^{-3} nm 1 nm 10^{3} nm 10^{6} nm 1 m 10^{3} m
Gamma rays
X rays
UV
Infrared
Micro- waves
Radio waves
(a)
Visible light
Blue cones (420 nm)
Rods (500 nm)
Green cones (530 nm)
Red cones (560 nm)
Light absorption (pervent of maximum)
100
50
0
400 450 500 550 600 650 700
Wavelength (nm)
(b)

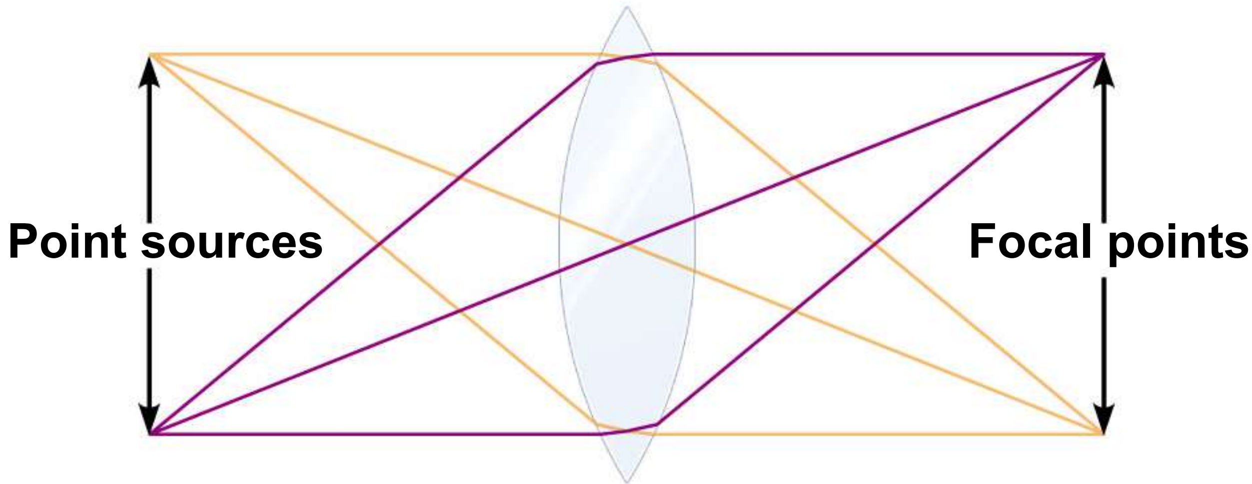
Figure 15.10

Refraction and Lenses

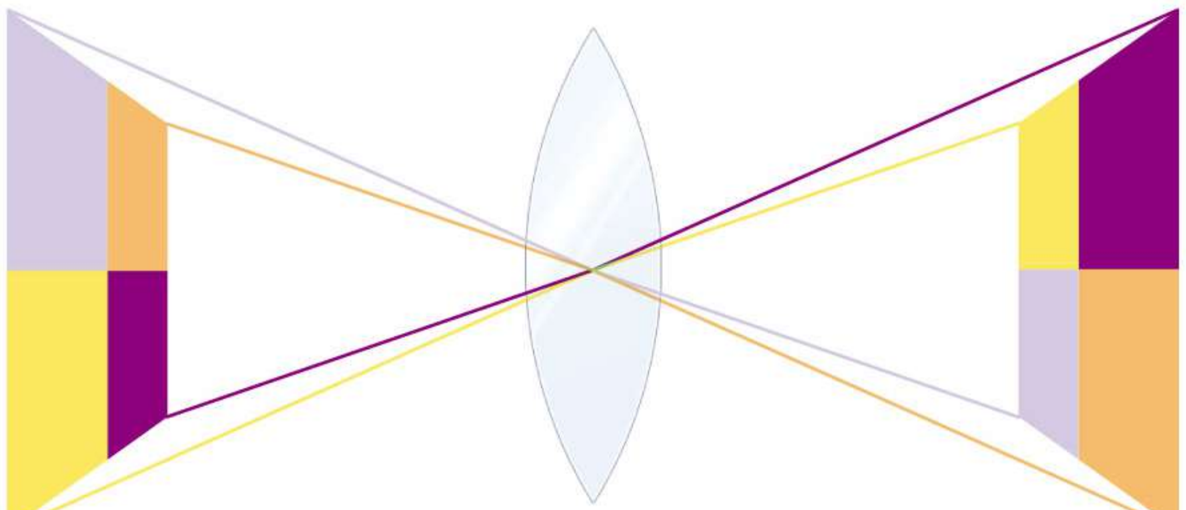
- Refraction
  - Bending of a light ray due to change in speed when light passes from one transparent medium to another
  - Occurs when light meets the surface of a different medium at an oblique angle

Refraction and Lenses

- Light passing through a convex lens (as in the eye) is bent so that the rays converge at a focal point
- The image formed at the focal point is upside-down and reversed right to left



(a) Focusing of two points of light.



(b) The image is inverted—upside down and reversed.

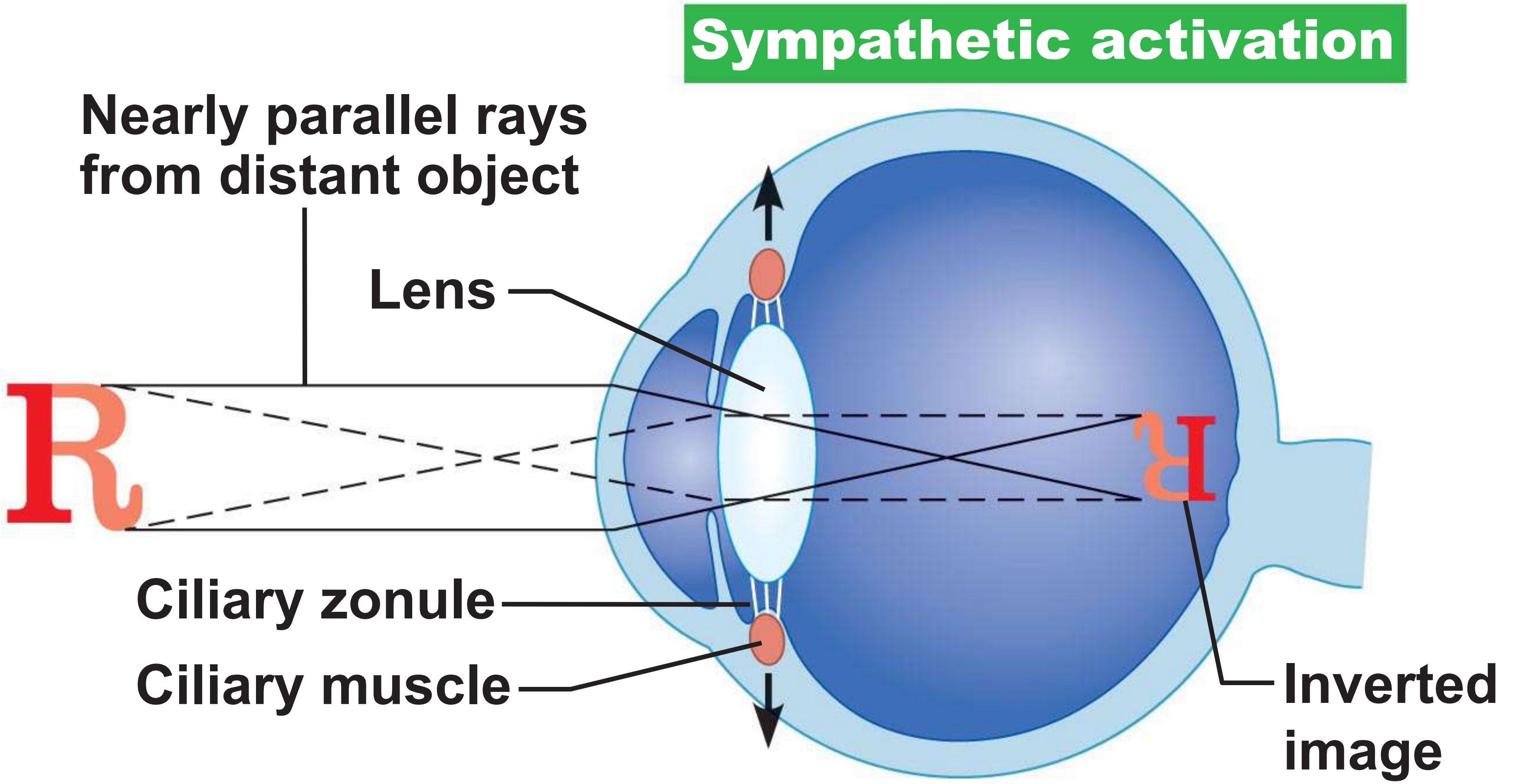
Figure 15.12

Focusing Light on the Retina

- Pathway of light entering the eye: cornea, aqueous humor, lens, vitreous humor, neural layer of retina, photoreceptors
- Light is refracted
  - At the cornea
  - Entering the lens
  - Leaving the lens
- Change in lens curvature allows for fine focusing of an image

Focusing for Distant Vision

- Light rays from distant objects are nearly parallel at the eye and need little refraction beyond what occurs in the at-rest eye
- Far point of vision: the distance beyond which no change in lens shape is needed for focusing; 20 feet for emmetropic (normal) eye
- Ciliary muscles are relaxed
- Lens is stretched flat by tension in the ciliary zonule



(a) Lens is flattened for distant vision. Sympathetic input relaxes the ciliary muscle, tightening the ciliary zonule, and flattening the lens.

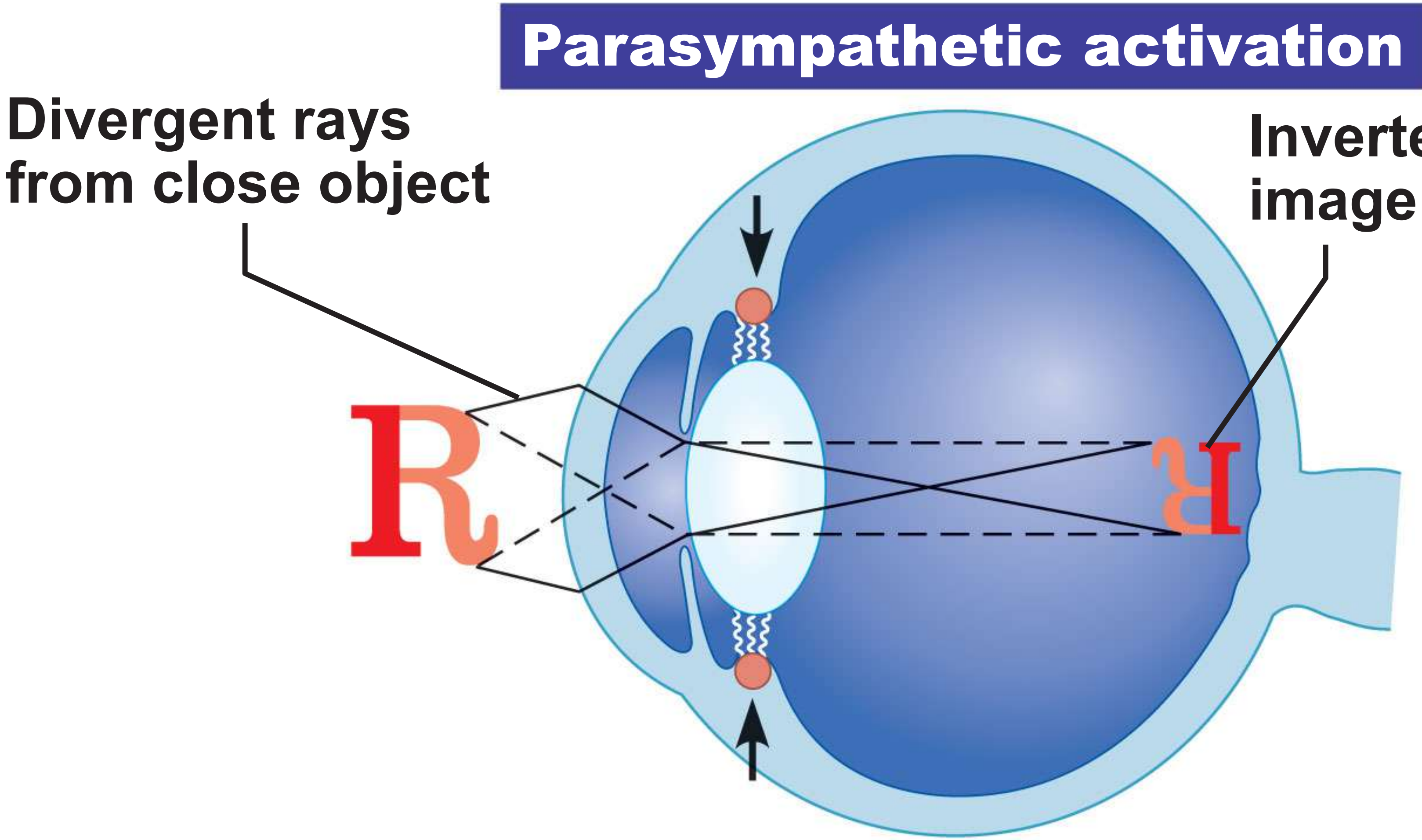
Figure 15.13a

Focusing for Close Vision

- Light from a close object diverges as it approaches the eye; requires that the eye make active adjustments

Focusing for Close Vision

- Close vision requires
  - Accommodation—changing the lens shape by ciliary muscles to increase refractory power
    - Near point of vision is determined by the maximum bulge the lens can achieve
    - Presbyopia—loss of accommodation over age 50
  - Constriction—the accommodation pupillary reflex constricts the pupils to prevent the most divergent light rays from entering the eye
  - Convergence—medial rotation of the eyeballs toward the object being viewed



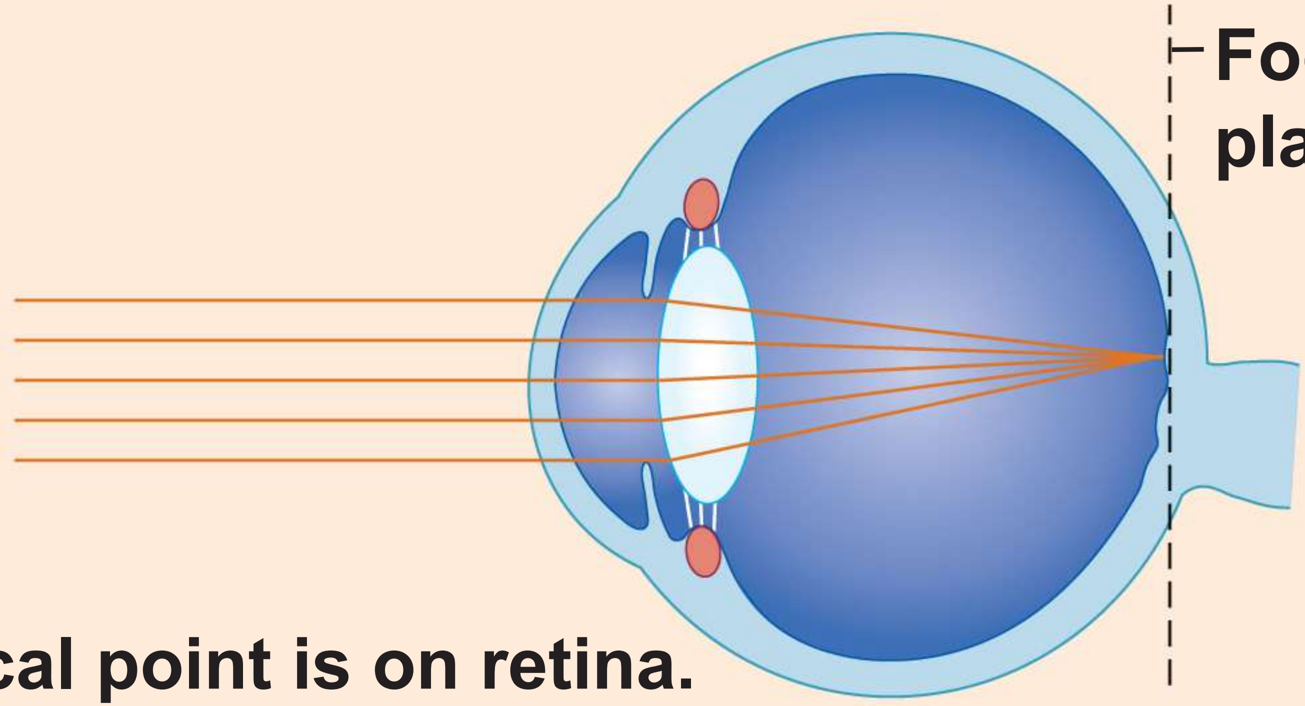
(b) Lens bulges for close vision. Parasympathetic input contracts the ciliary muscle, loosening the ciliary zonule, allowing the lens to bulge.

Figure 15.13b

Problems of Refraction

- Myopia (nearsightedness)—focal point is in front of the retina, e.g. in a longer than normal eyeball
  - Corrected with a concave lens
- Hyperopia (farsightedness)—focal point is behind the retina, e.g. in a shorter than normal eyeball
  - Corrected with a convex lens
- Astigmatism—caused by unequal curvatures in different parts of the cornea or lens
  - Corrected with cylindrically ground lenses, corneal implants, or laser procedures

Emmetropic eye (normal)



Focal point is on retina.

Figure 15.14 (1 of 3)

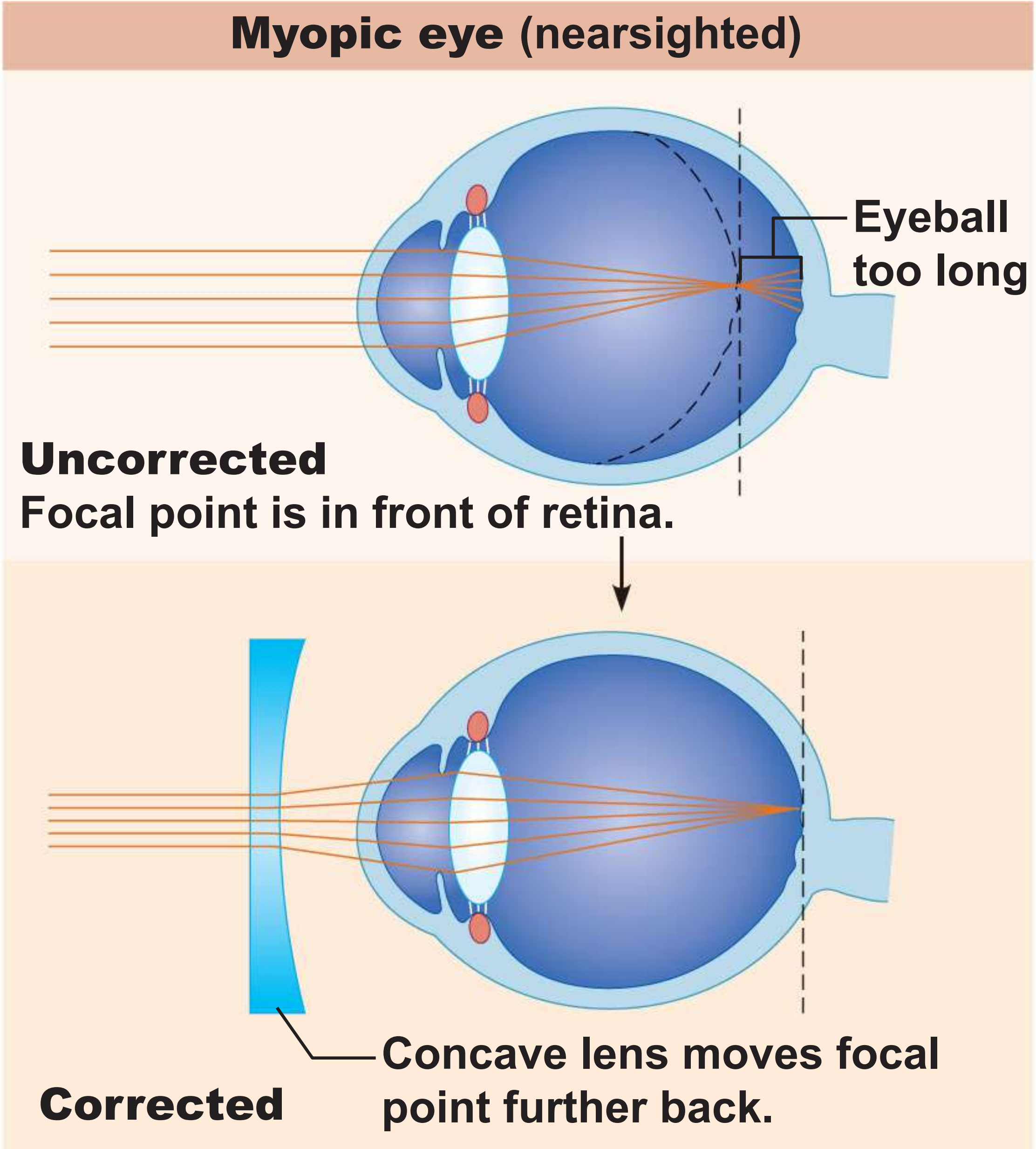


Figure 15.14 (2 of 3)

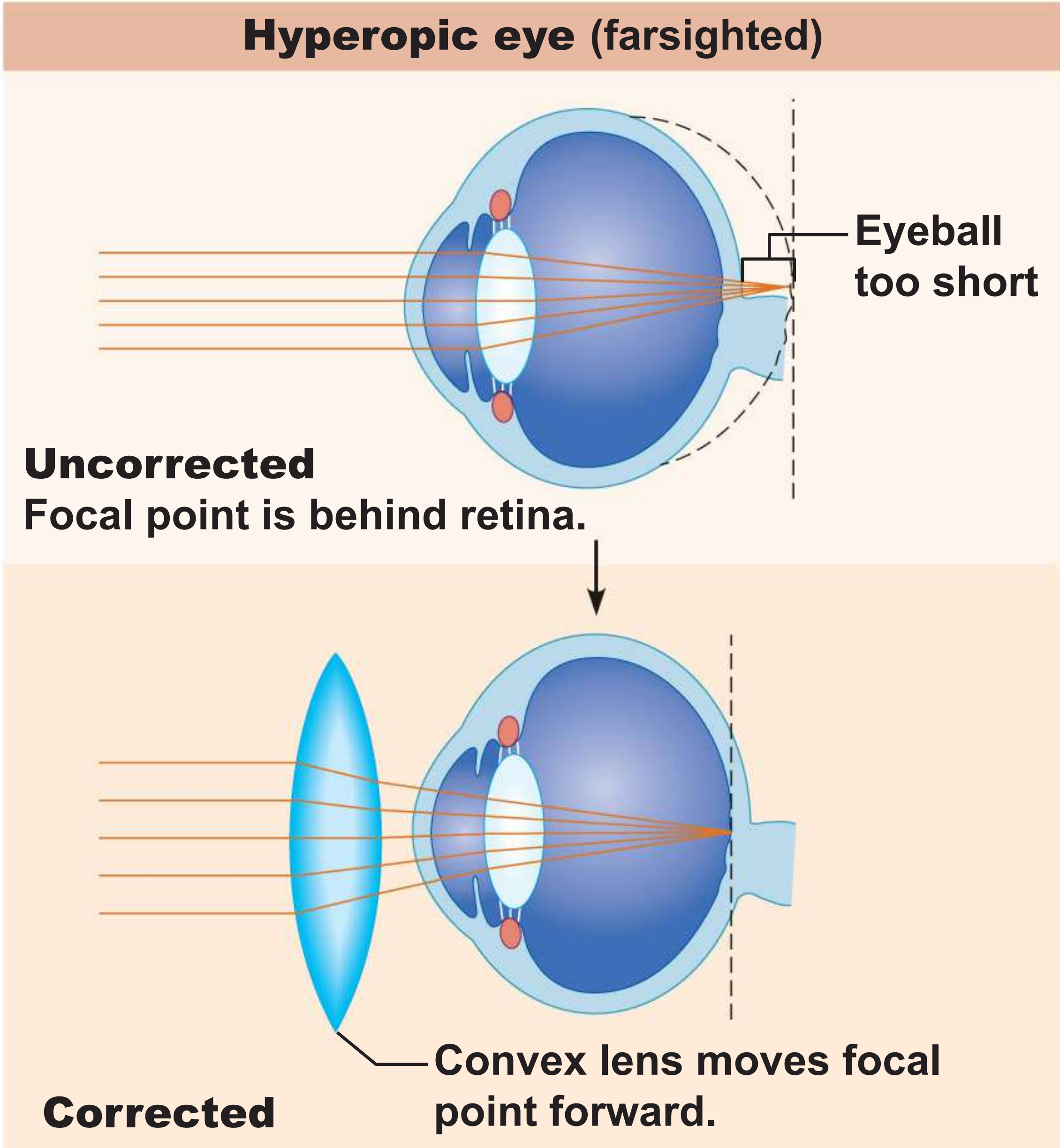
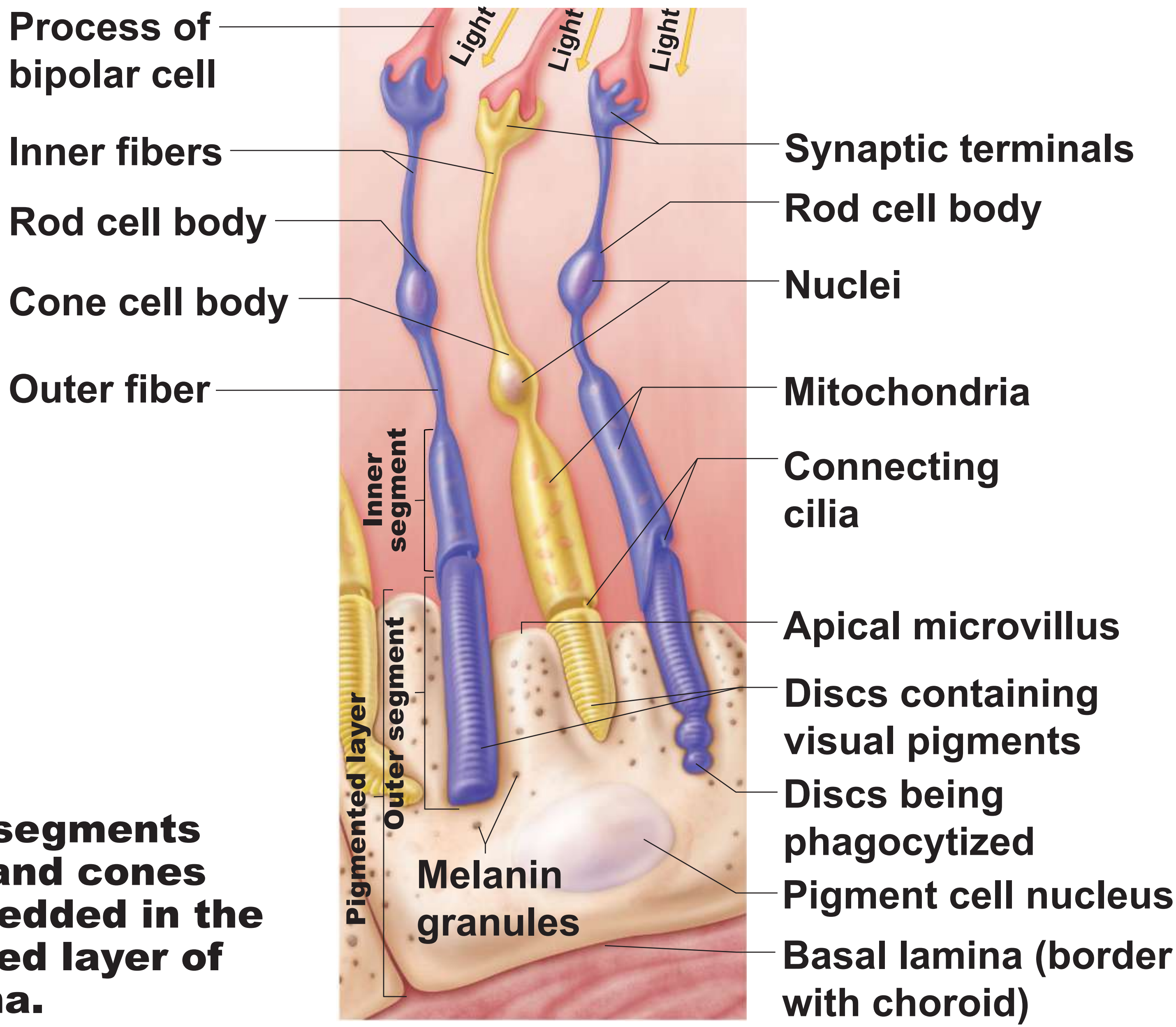


Figure 15.14 (3 of 3)

Functional Anatomy of Photoreceptors

- Rods and cones
  - Outer segment of each contains visual pigments (photopigments)—molecules that change shape as they absorb light
  - Inner segment of each joins the cell body



The outer segments of rods and cones are embedded in the pigmented layer of the retina.

Figure 15.15a

Rods

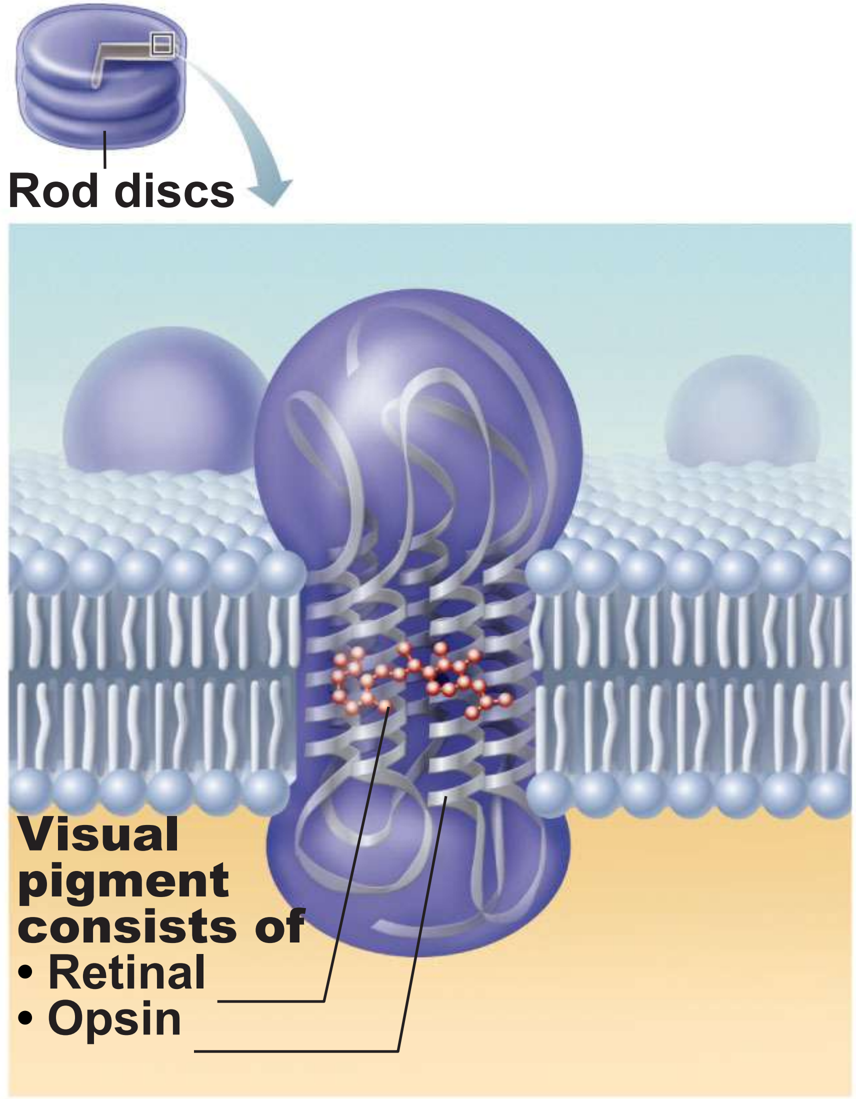
- Functional characteristics
  - Very sensitive to dim light
  - Best suited for night vision and peripheral vision
  - Perceived input is in gray tones only
  - Pathways converge, resulting in fuzzy and indistinct images

Cones

- Functional characteristics
  - Need bright light for activation (have low sensitivity)
  - Have one of three pigments that furnish a vividly colored view
  - Nonconverging pathways result in detailed, high-resolution vision

Chemistry of Visual Pigments

- Retinal
  - Light-absorbing molecule that combines with one of four proteins (opsin) to form visual pigments
  - Synthesized from vitamin A
  - Two isomers: 11-*cis*-retinal (bent form) and all-*trans*-retinal (straight form)
- Conversion of 11-*cis*-retinal to all-*trans*-retinal initiates a chain of reactions leading to transmission of electrical impulses in the optic nerve

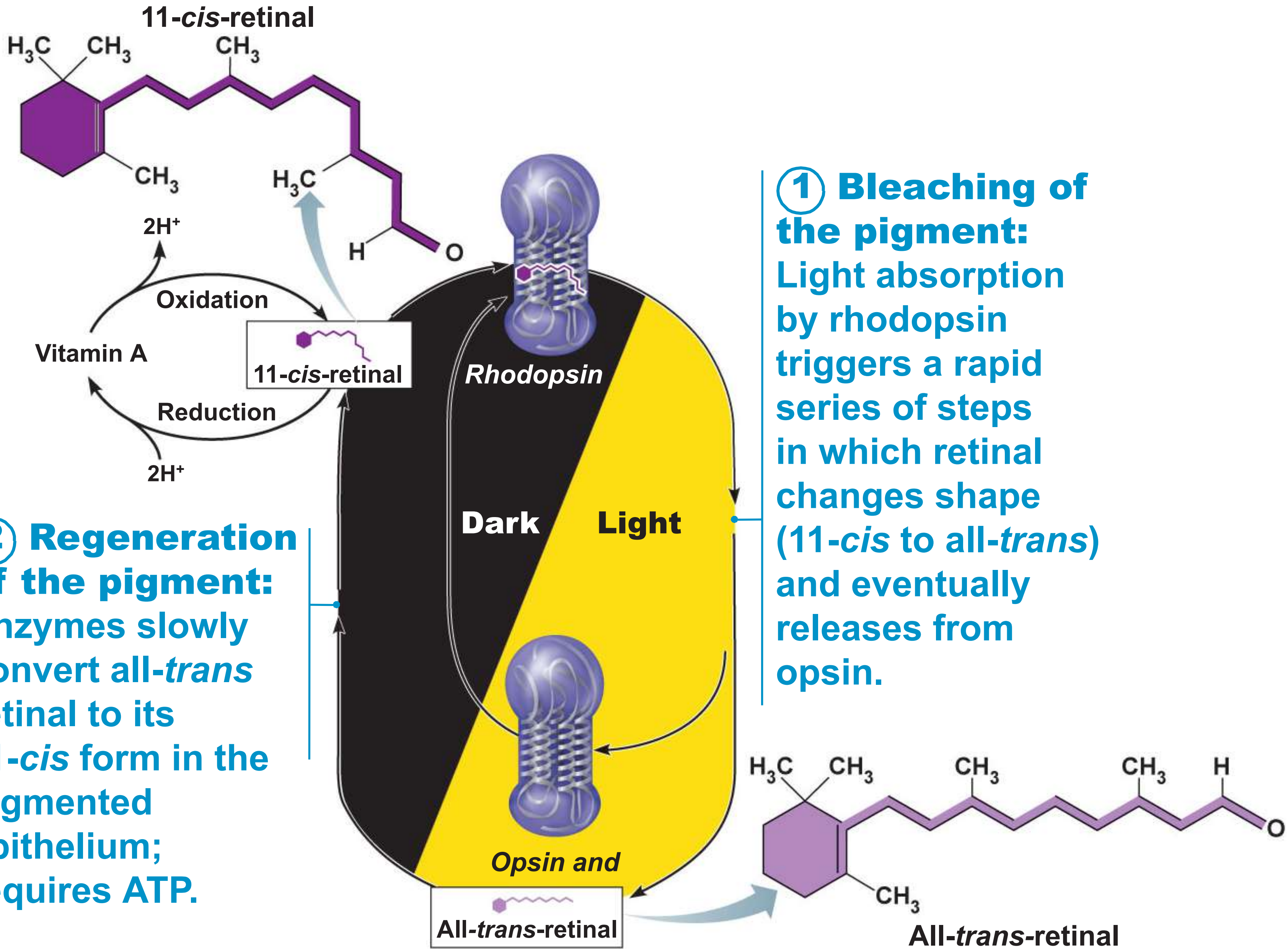


(b) Rhodopsin, the visual pigment in rods, is embedded in the membrane that forms discs in the outer segment.

Figure 15.15b

Excitation of Rods

- The visual pigment of rods is rhodopsin (opsin + 11-*cis*-retinal)
- In the dark, rhodopsin forms and accumulates
  - Regenerated from all-*trans*-retinal
  - Formed from vitamin A
- When light is absorbed, rhodopsin breaks down
- 11-*cis* isomer is converted into the all-*trans* isomer
- Retinal and opsin separate (bleaching of the pigment)



① Bleaching of the pigment: Light absorption by rhodopsin triggers a rapid series of steps in which retinal changes shape (11-*cis* to all-*trans*) and eventually releases from opsin.

② Regeneration of the pigment: Enzymes slowly convert all-*trans* retinal to its 11-*cis* form in the pigmented epithelium; requires ATP.

Figure 15.16

Excitation of Cones

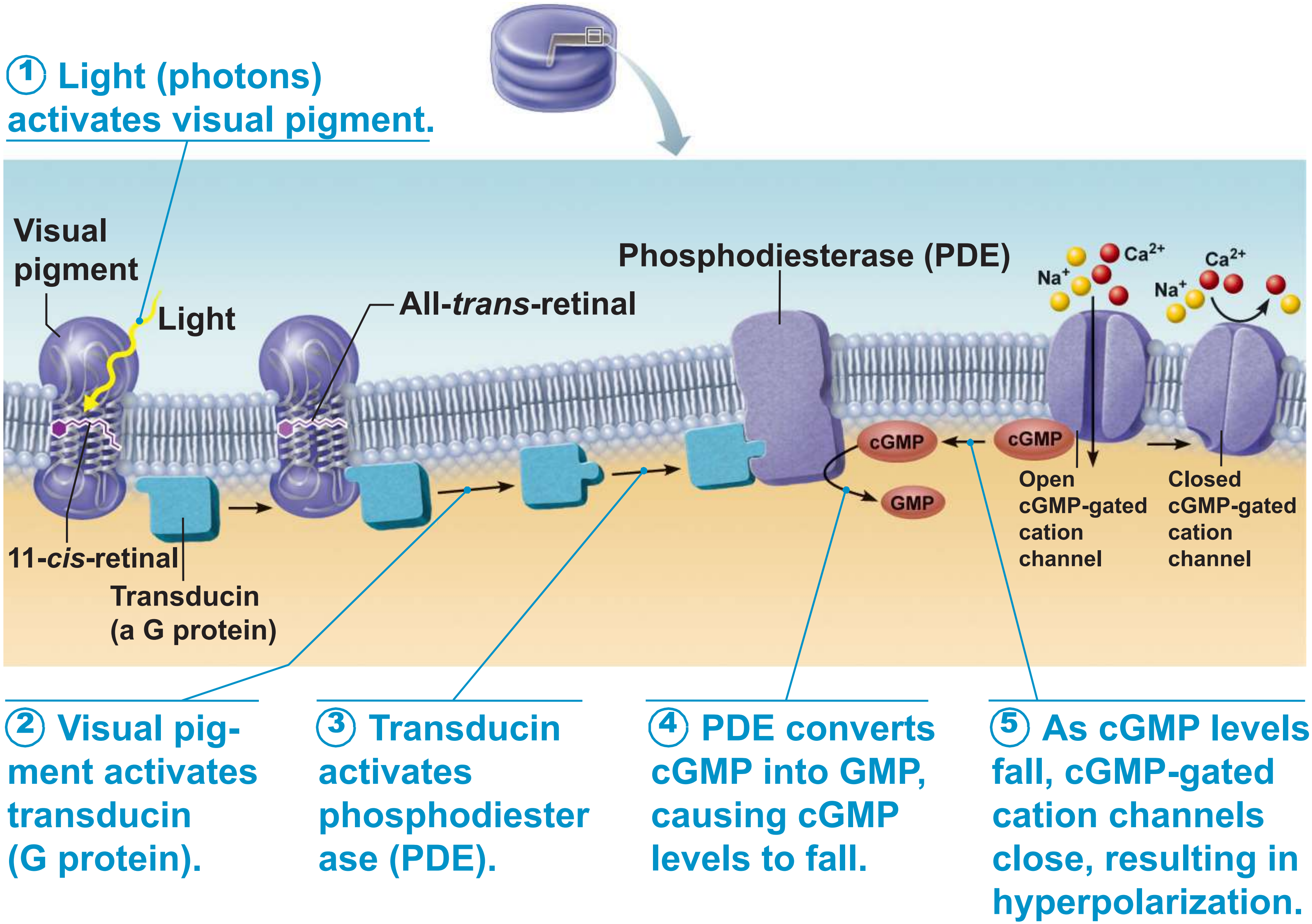
- Method of excitation is similar to that of rods
- There are three types of cones, named for the colors of light absorbed: blue, green, and red
- Intermediate hues are perceived by activation of more than one type of cone at the same time
- Color blindness is due to a congenital lack of one or more of the cone types

Phototransduction

- In the dark, cGMP binds to and opens cation channels in the outer segments of photoreceptor cells
  - Na^{+} and Ca^{2+} influx creates a depolarizing dark potential of about –40 mV

Phototransduction

- In the light, light-activated rhodopsin activates a G protein, transducin
  - Transducin activates phosphodiesterase (PDE)
  - PDE hydrolyzes cGMP to GMP and releases it from sodium channels
  - Without bound cGMP, sodium channels close; the membrane hyperpolarizes to about –70 mV



1 Light (photons) activates visual pigment.
Visual pigment
Light
11-cis-retinal
Transducin (a G protein)
All-trans-retinal
Phosphodiesterase (PDE)
Na+
Ca2+
cGMP
GMP
Open cGMP-gated cation channel
Closed cGMP-gated cation channel
2 Visual pigment activates transducin (G protein).
3 Transducin activates phosphodiesterase (PDE).
4 PDE converts cGMP into GMP, causing cGMP levels to fall.
5 As cGMP levels fall, cGMP-gated cation channels close, resulting in hyperpolarization.

Figure 15.17

Signal Transmission in the Retina

- Photoreceptors and bipolar cells only generate graded potentials (EPSPs and IPSPs)
- Light hyperpolarizes photoreceptor cells, causing them to stop releasing the inhibitory neurotransmitter glutamate
- Bipolar cells (no longer inhibited) are then allowed to depolarize and release neurotransmitter onto ganglion cells
- Ganglion cells generate APs that are transmitted in the optic nerve

In the dark

1. cGMP-gated channels open, allowing cation influx; the photoreceptor depolarizes.
2. Voltage-gated Ca^{2+} channels open in synaptic terminals.
3. Neurotransmitter is released continuously.
4. Neurotransmitter causes IPSPs in bipolar cell; hyperpolarization results.
5. Hyperpolarization closes voltage-gated Ca^{2+} channels, inhibiting neurotransmitter release.
6. No EPSPs occur in ganglion cell.
7. No action potentials occur along the optic nerve.

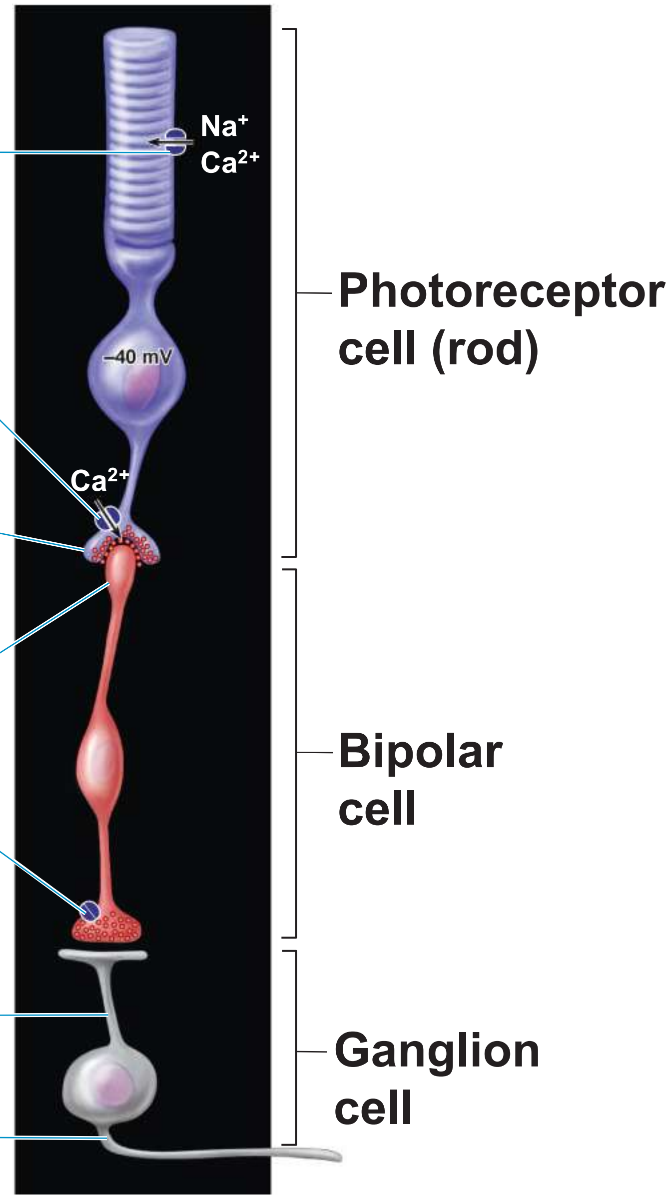
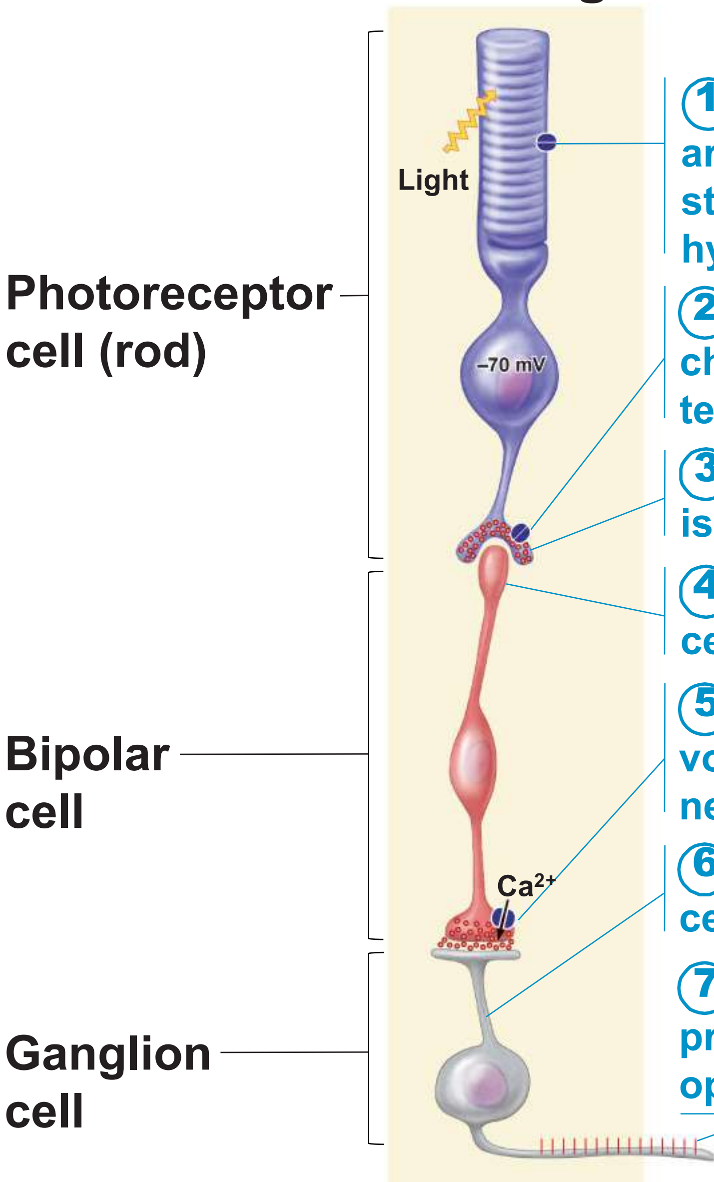


Figure 15.18 (1 of 2)

In the light



1. cGMP-gated channels are closed, so cation influx stops; the photoreceptor hyperpolarizes.
2. Voltage-gated Ca^{2+} channels close in synaptic terminals.
3. No neurotransmitter is released.
4. Lack of IPSPs in bipolar cell results in depolarization.
5. Depolarization opens voltage-gated Ca^{2+} channels; neurotransmitter is released.
6. EPSPs occur in ganglion cell.
7. Action potentials propagate along the optic nerve.

Light Adaptation

- Occurs when moving from darkness into bright light
  - Large amounts of pigments are broken down instantaneously, producing glare
  - Pupils constrict
  - Dramatic changes in retinal sensitivity: rod function ceases
  - Cones and neurons rapidly adapt
  - Visual acuity improves over 5–10 minutes

Dark Adaptation

- Occurs when moving from bright light into darkness
  - The reverse of light adaptation
  - Cones stop functioning in low-intensity light
  - Pupils dilate
  - Rhodopsin accumulates in the dark and retinal sensitivity increases within 20–30 minutes

Visual Pathway

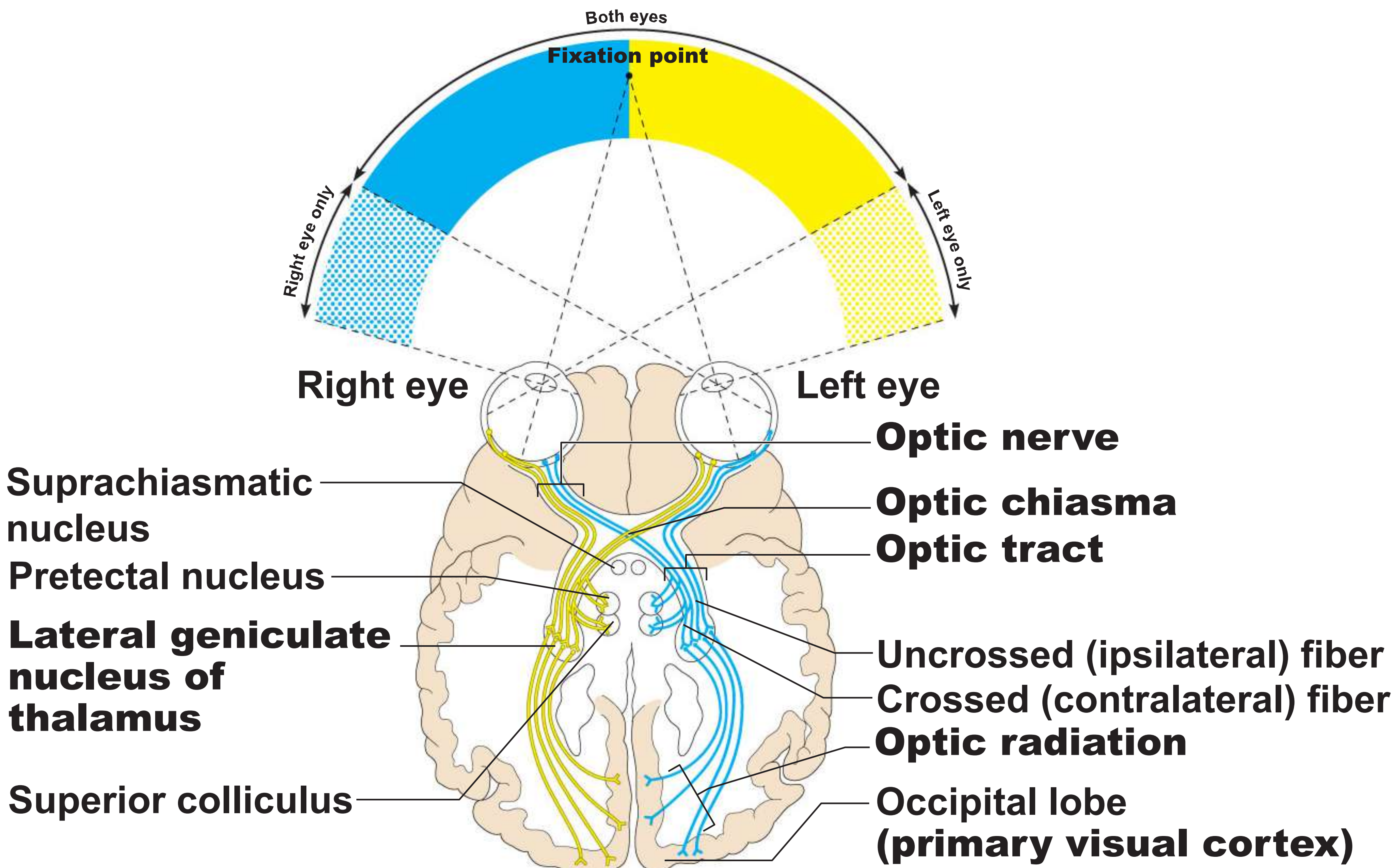
- Axons of retinal ganglion cells form the optic nerve
- Medial fibers of the optic nerve decussate at the optic chiasma
- Most fibers of the optic tracts continue to the lateral geniculate body of the thalamus

Visual Pathway

- The optic radiation fibers connect to the primary visual cortex in the occipital lobes
- Other optic tract fibers send branches to the midbrain, ending in superior colliculi (initiating visual reflexes)

Visual Pathway

- A small subset of ganglion cells in the retina contain melanopsin (circadian pigment), which projects to:
  - Pretectal nuclei (involved with pupillary reflexes)
  - Suprachiasmatic nucleus of the hypothalamus, the timer for daily biorhythms



The visual fields of the two eyes overlap considerably.

Note that fibers from the lateral portion of each retinal field do not cross at the optic chiasma.

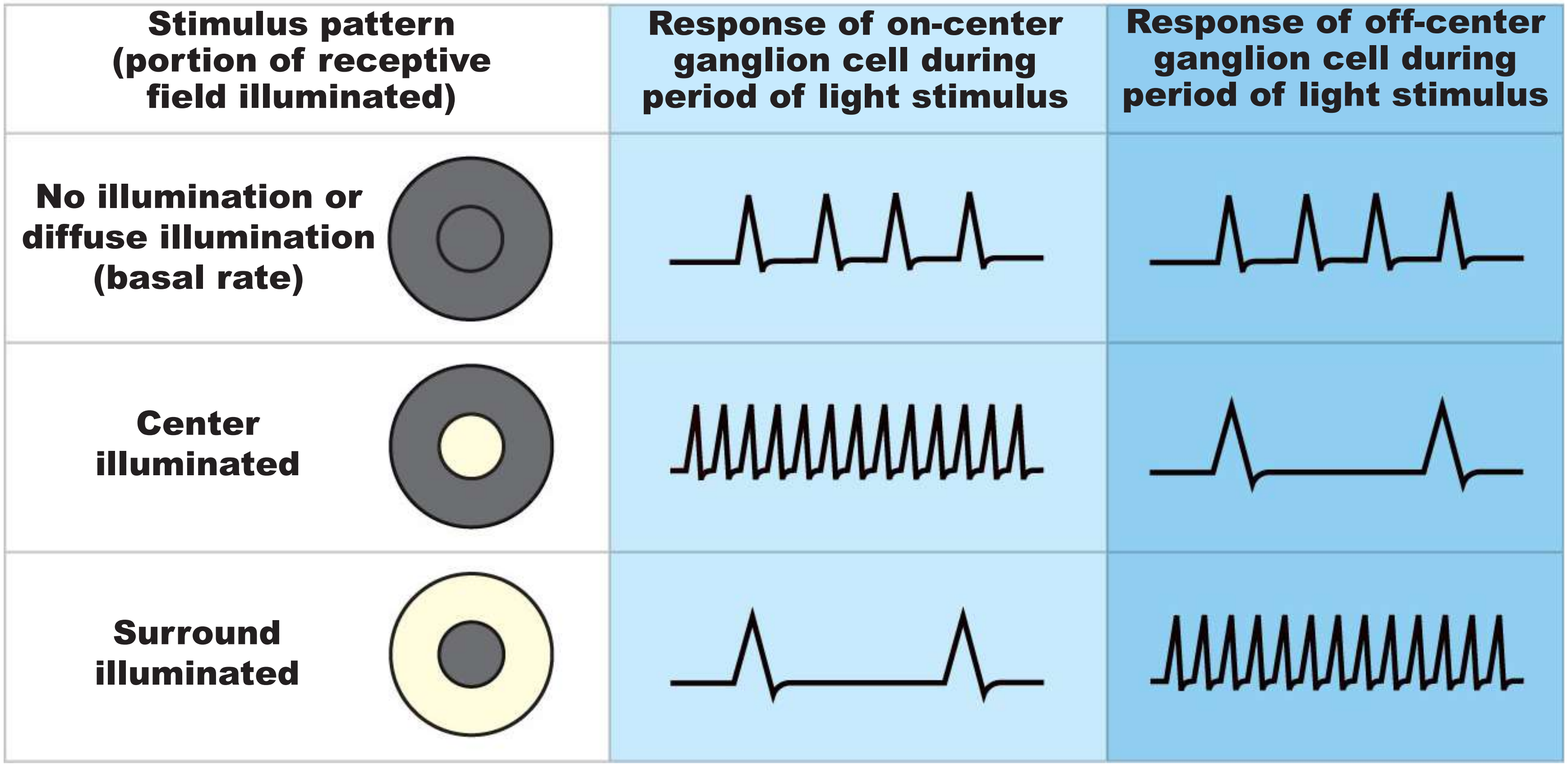
Figure 15.19a

Depth Perception

- Both eyes view the same image from slightly different angles
- Depth perception (three-dimensional vision) results from cortical fusion of the slightly different images

Retinal Processing

- Several different types of ganglion cells are arranged in doughnut-shaped receptive fields
  - On-center fields
    - Stimulated by light hitting the center of the field
    - Inhibited by light hitting the periphery of the field
  - Off-center fields have the opposite effects
- These responses are due to different receptor types for glutamate in the “on” and “off” fields



Stimulus pattern (portion of receptive field illuminated)
Response of on-center ganglion cell during period of light stimulus
Response of off-center ganglion cell during period of light stimulus
No illumination or diffuse illumination (basal rate)
Center illuminated
Surround illuminated

Figure 15.20

Thalamic Processing

- Lateral geniculate nuclei of the thalamus
  - Relay information on movement
  - Segregate the retinal axons in preparation for depth perception
  - Emphasize visual inputs from regions of high cone density
  - Sharpen contrast information

Cortical Processing

- Two areas in the visual cortex

1. Striate cortex (primary visual cortex)
   - Processes contrast information and object orientation
2. Prestriate cortices (visual association areas)
   - Processes form, color, and motion input from striate cortex

- Complex visual processing extends into other regions
  - Temporal lobe—processes identification of objects
  - Parietal cortex and postcentral gyrus—process spatial location