Физиология зрительного анализатора

The layers of the eyeball provide protection, nourishment, and the "screen" that transduces light images into nerve impulses.

Layers of the eye

Fibrous tunic consists of cornea and sclera.

Vascular tunic ciliary body, lens, and choroid.

Neural tunic consists of the retina.

Cornea admits and bends light.

Light

Visual axis

Anterior cavity contains aqueous humor that maintains shape and supplies oxygen and nutrients to lens and cornea.

Pupil is the opening.

Iris regulates the size of the pupil and the amount of light entering the eye.

Lens bends light.

Ciliary body secretes aqueous humor and alters shape of the lens for near or far vision.

Retina converts light into nerve impulses (output to brain).

Choroid provides blood supply and absorbs scattered light.

Medial rectus muscle moves eye medially.

Sclera provides shape and protects inner parts.

Inside is the **vitreous chamber**, which contains the vitreous body that maintains shape and keeps the retina attached.

MEDIAL

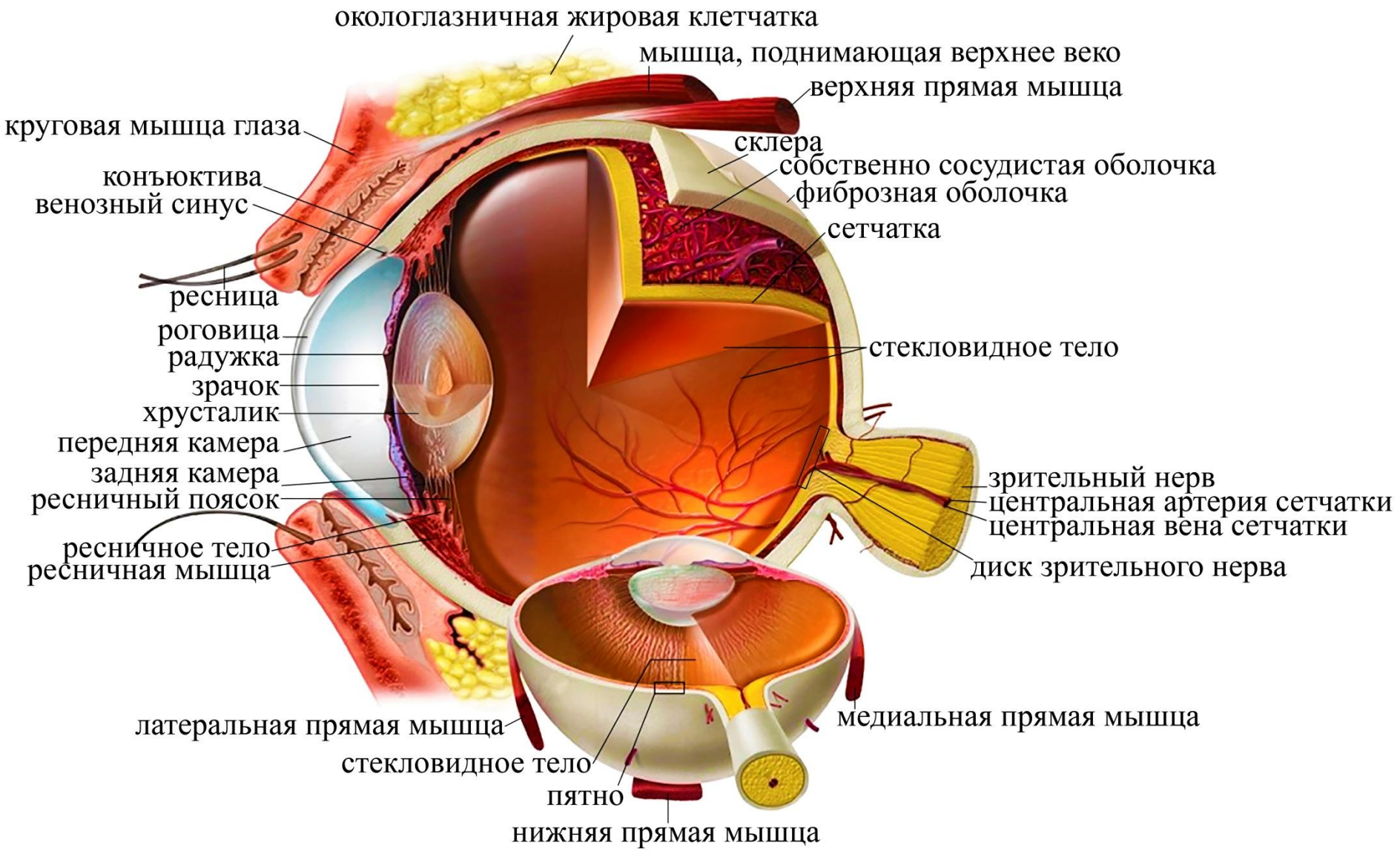
Blood vessels

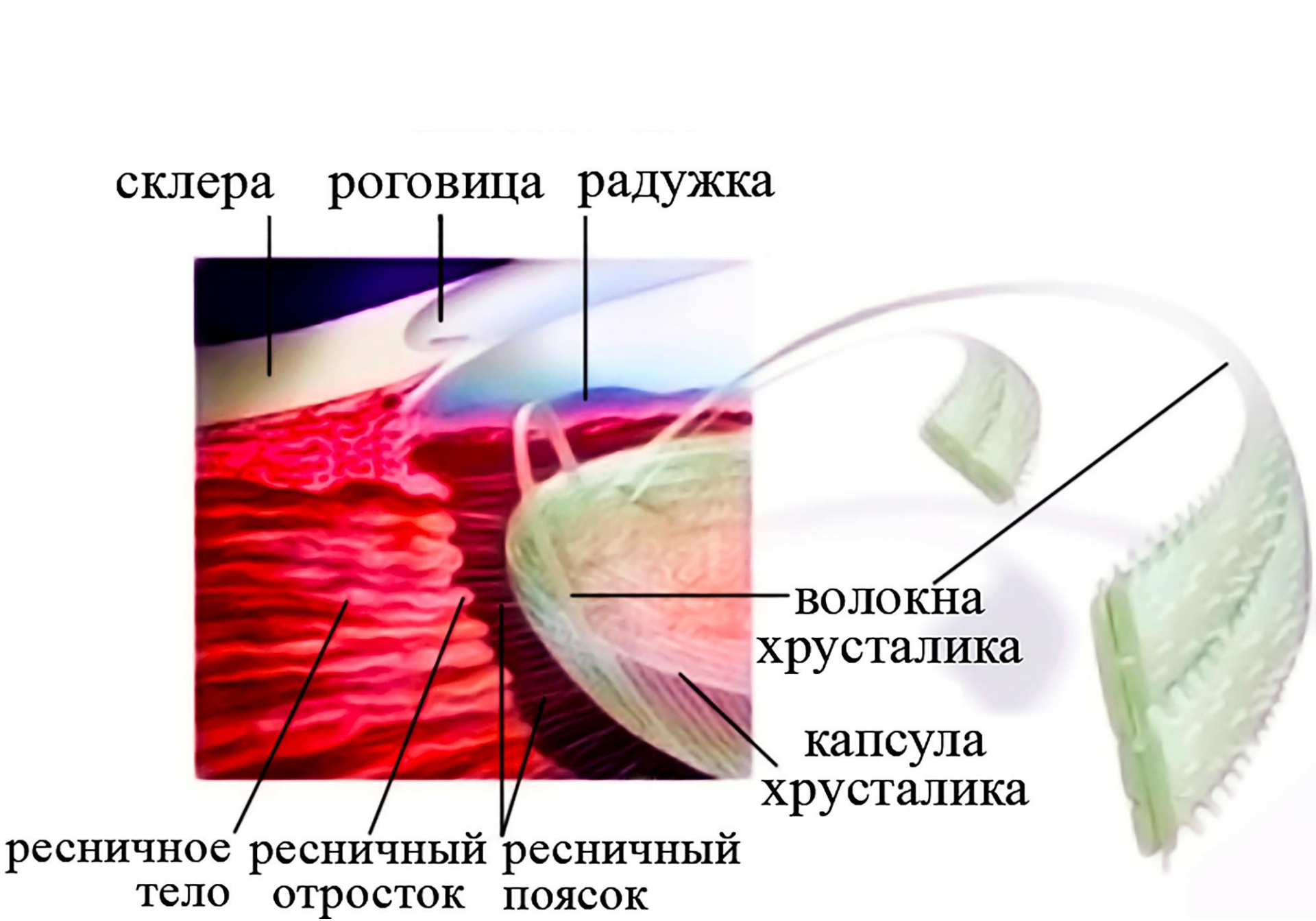
Lateral rectus muscle moves eye laterally.

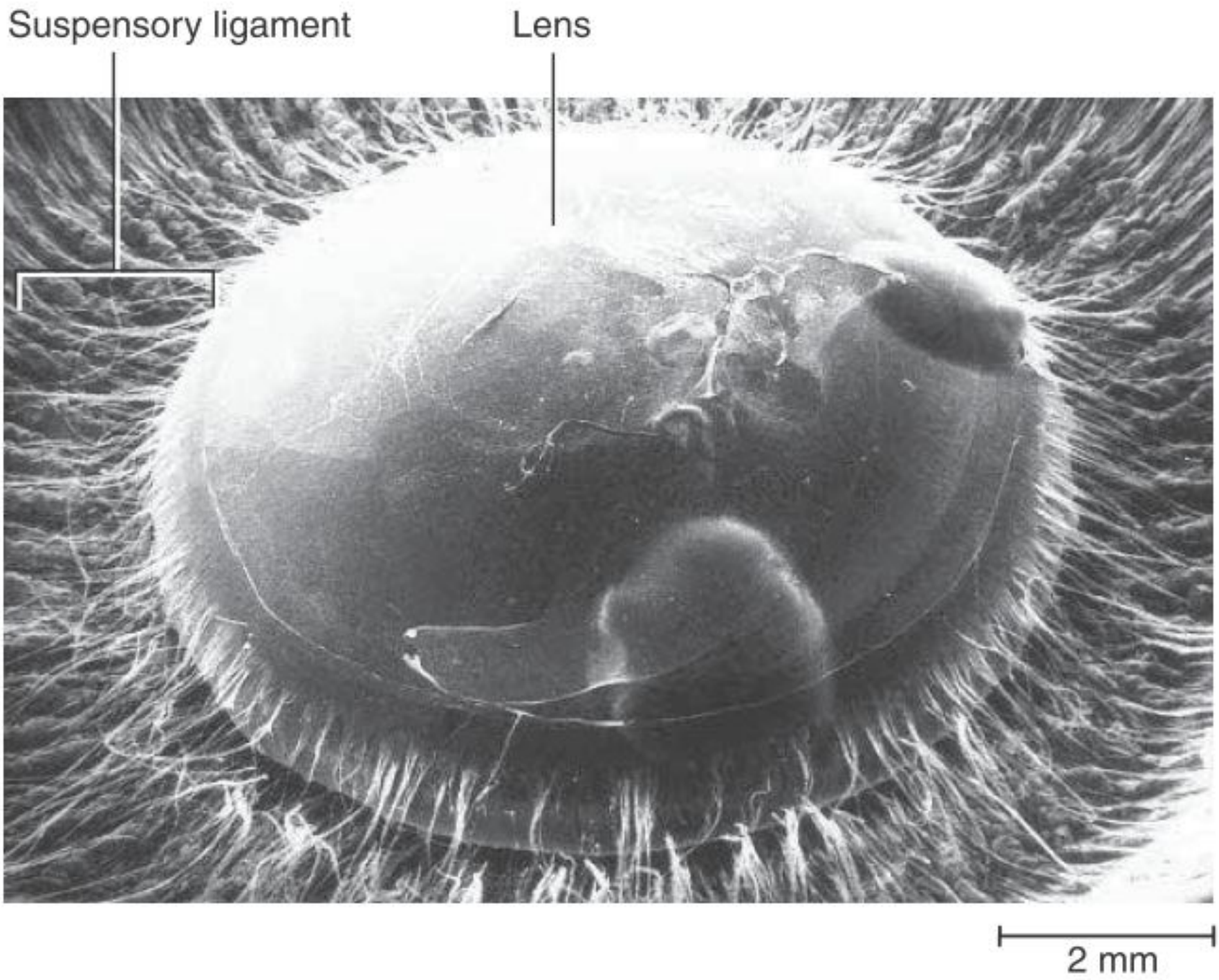
Optic nerve carries axons of ganglion cells to the brain.

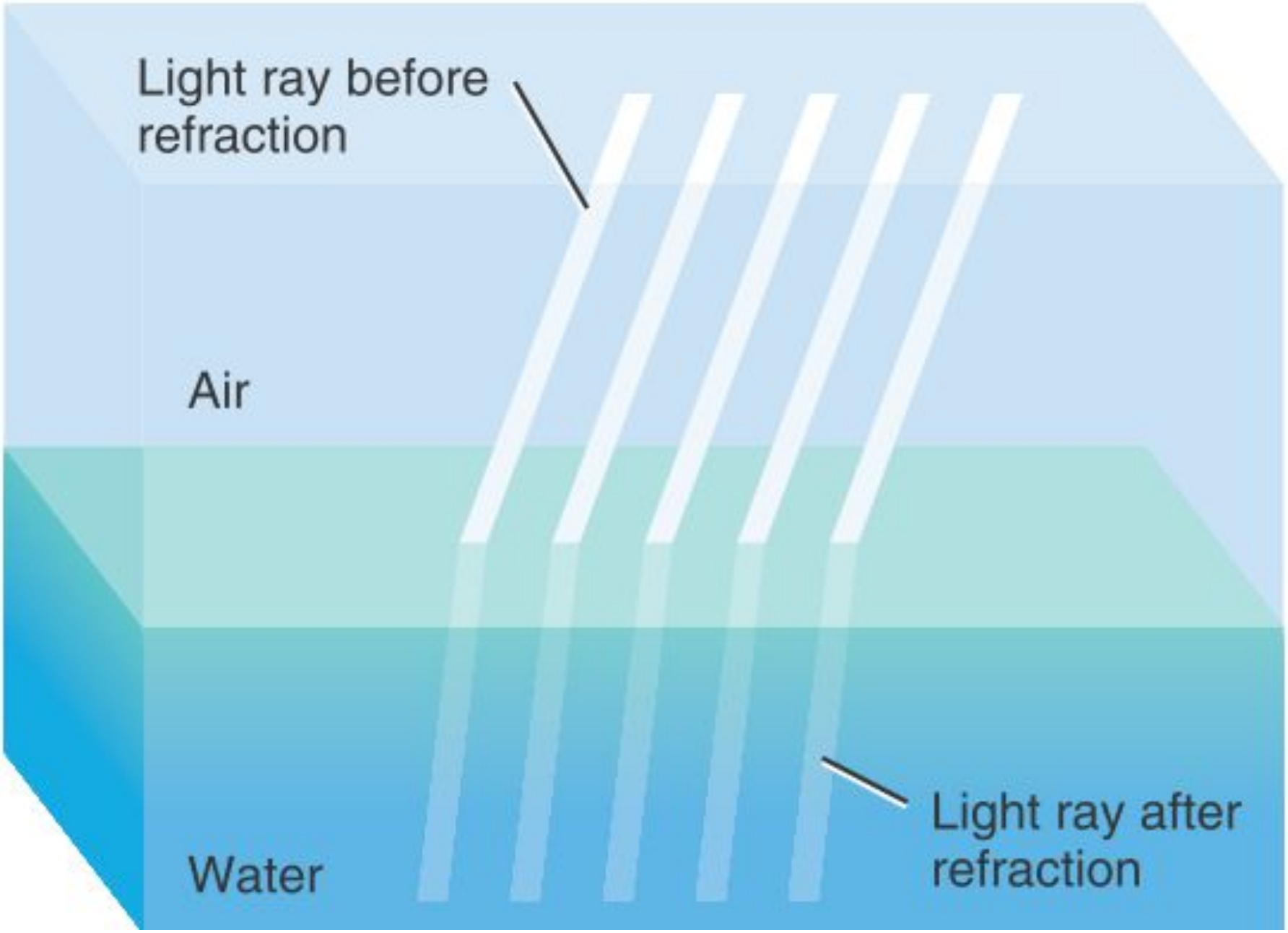
Optic disc is site where axons exit and has no rods or cones (blind spot).

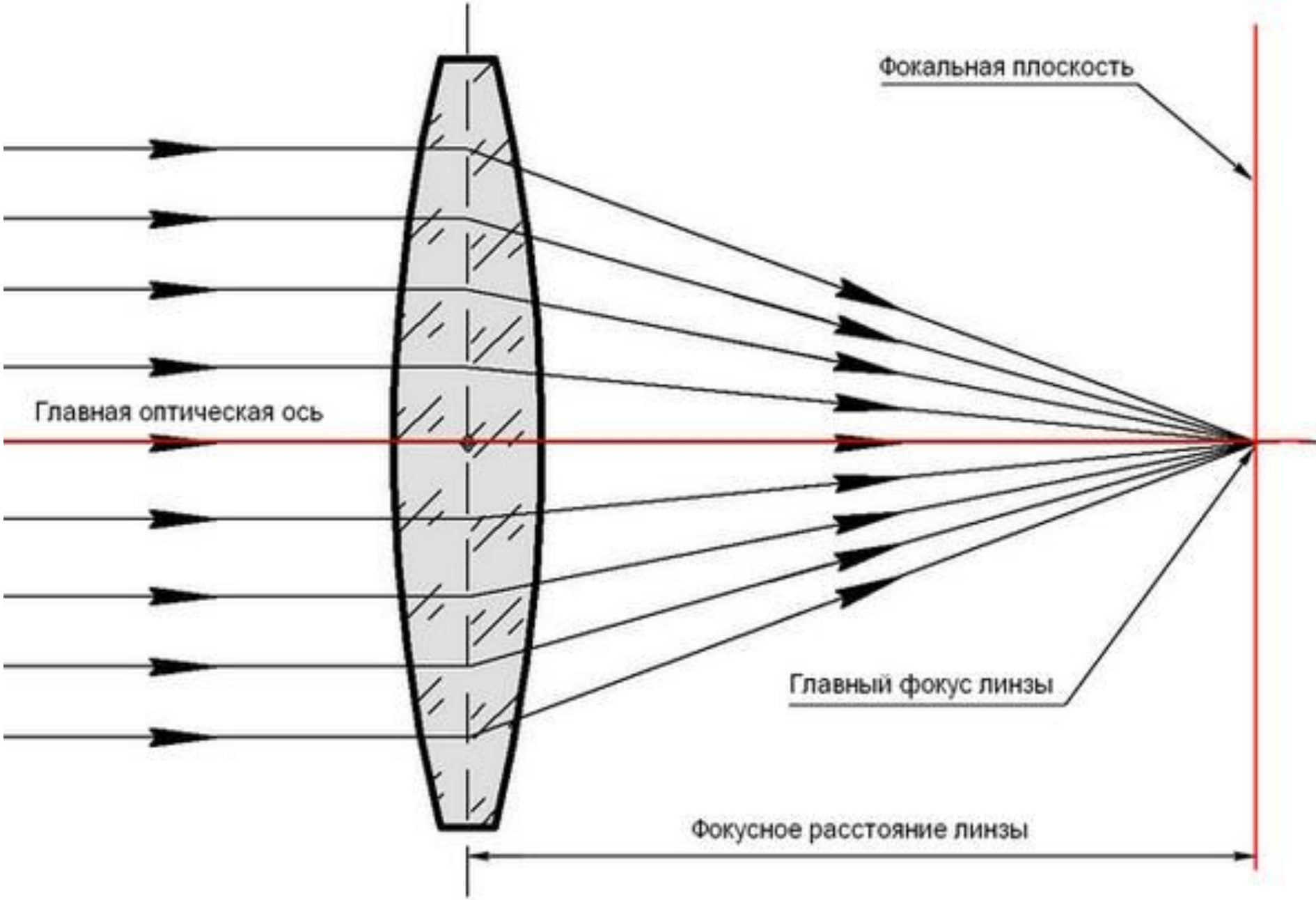
Fovea centralis is the center of the retina and has the highest concentrations of cone cells, which makes it the area of highest visual acuity.

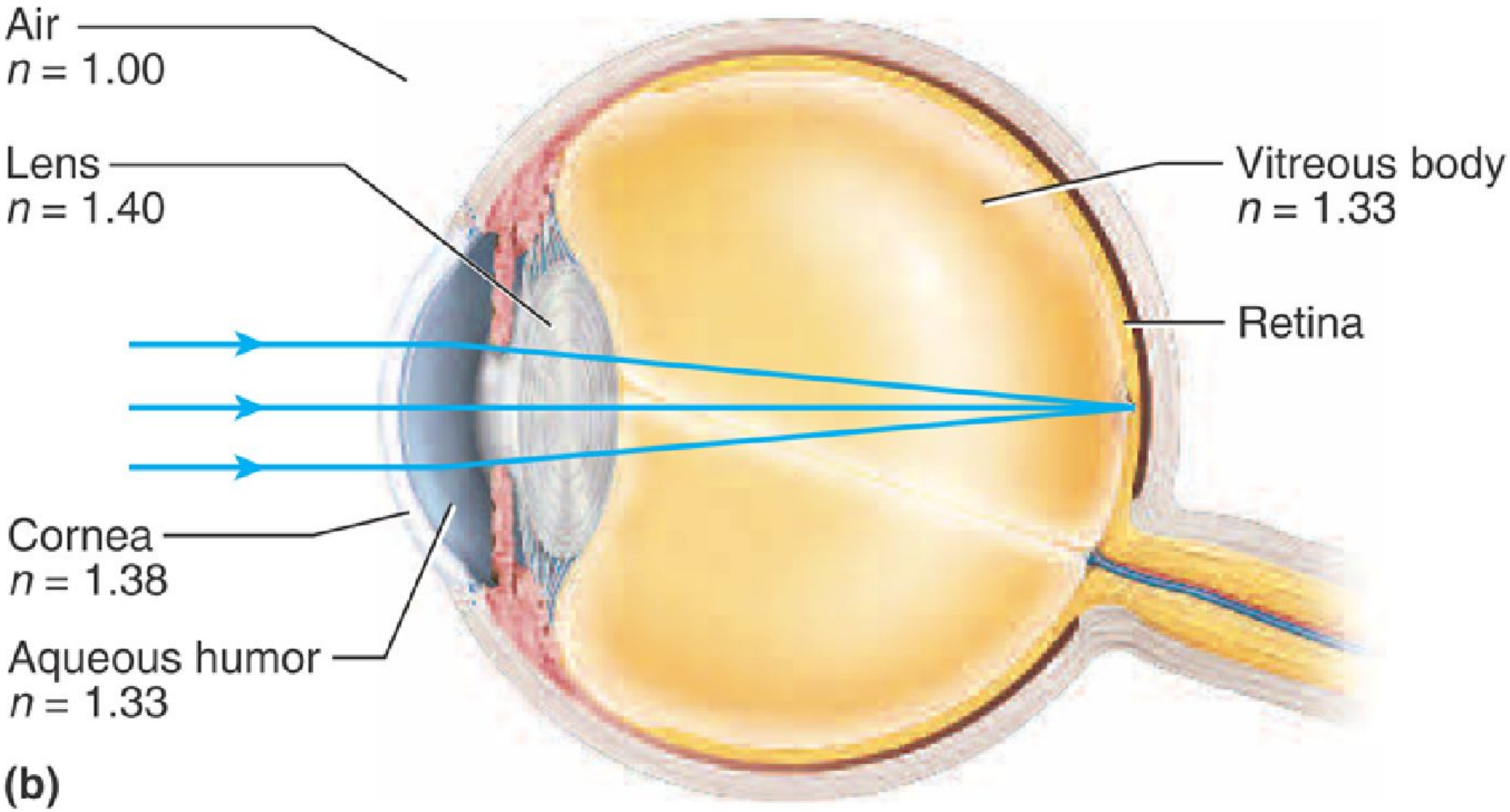

окологлазничная жировая клетчатка
мышца, поднимающая верхнее веко
верхняя прямая мышца
круговая мышца глаза
склера
конъюктива
собственно сосудистая оболочка
венозный синус
фиброзная оболочка
сетчатка
ресница
роговица
стекловидное тело
радужка
зрачок
хрусталик
передняя камера
задняя камера
зрительный нерв
ресничный поясок
центральная артерия сетчатки
центральная вена сетчатки
ресничное тело
ресничная мышца
диск зрительного нерва
латеральная прямая мышца
медиальная прямая мышца
стекловидное тело
пятно
нижняя прямая мышца

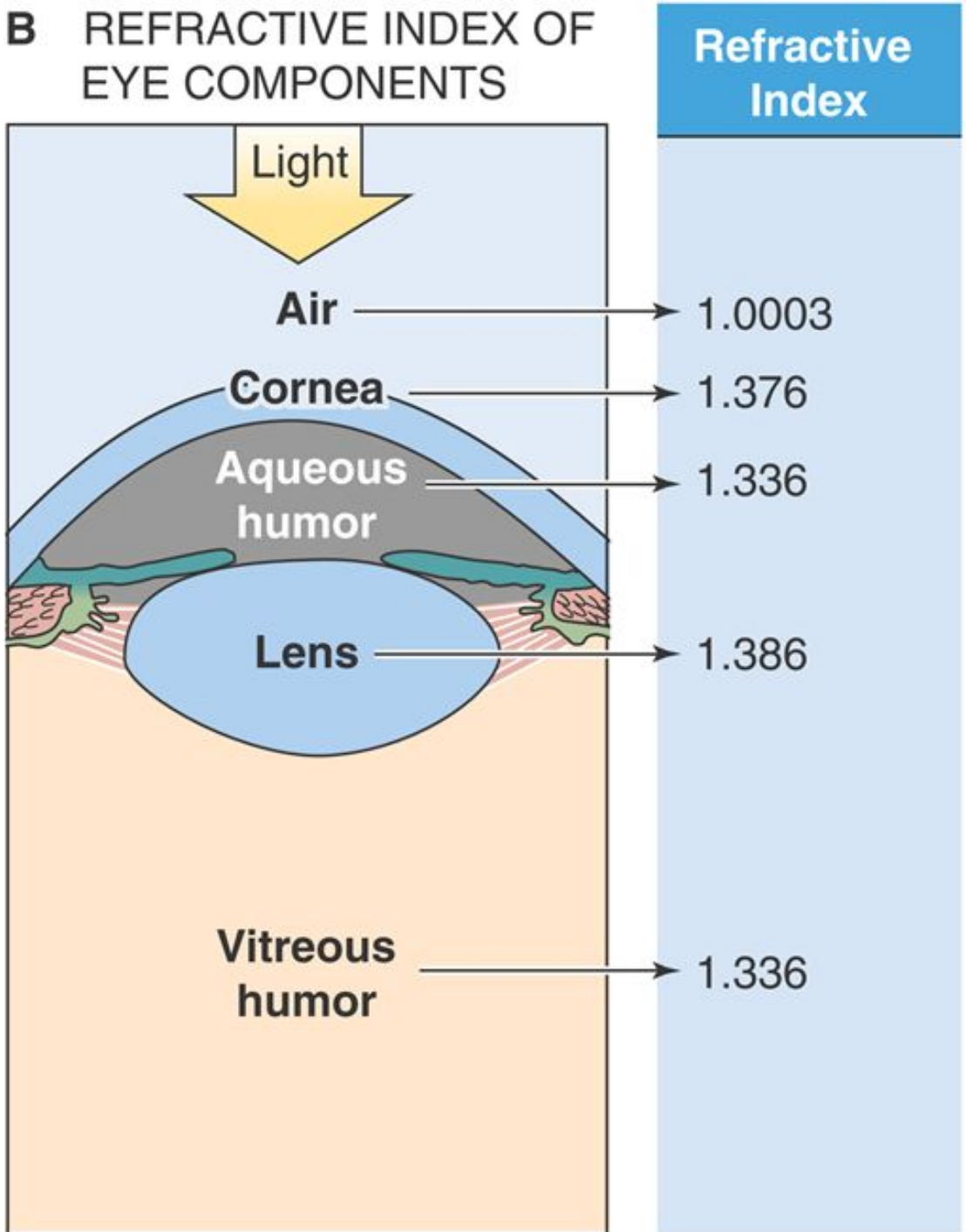

склера
роговица
радужка
волокна
хрусталика
капсула
хрусталика
ресничное
тело
ресничный
отросток
ресничный
поясок

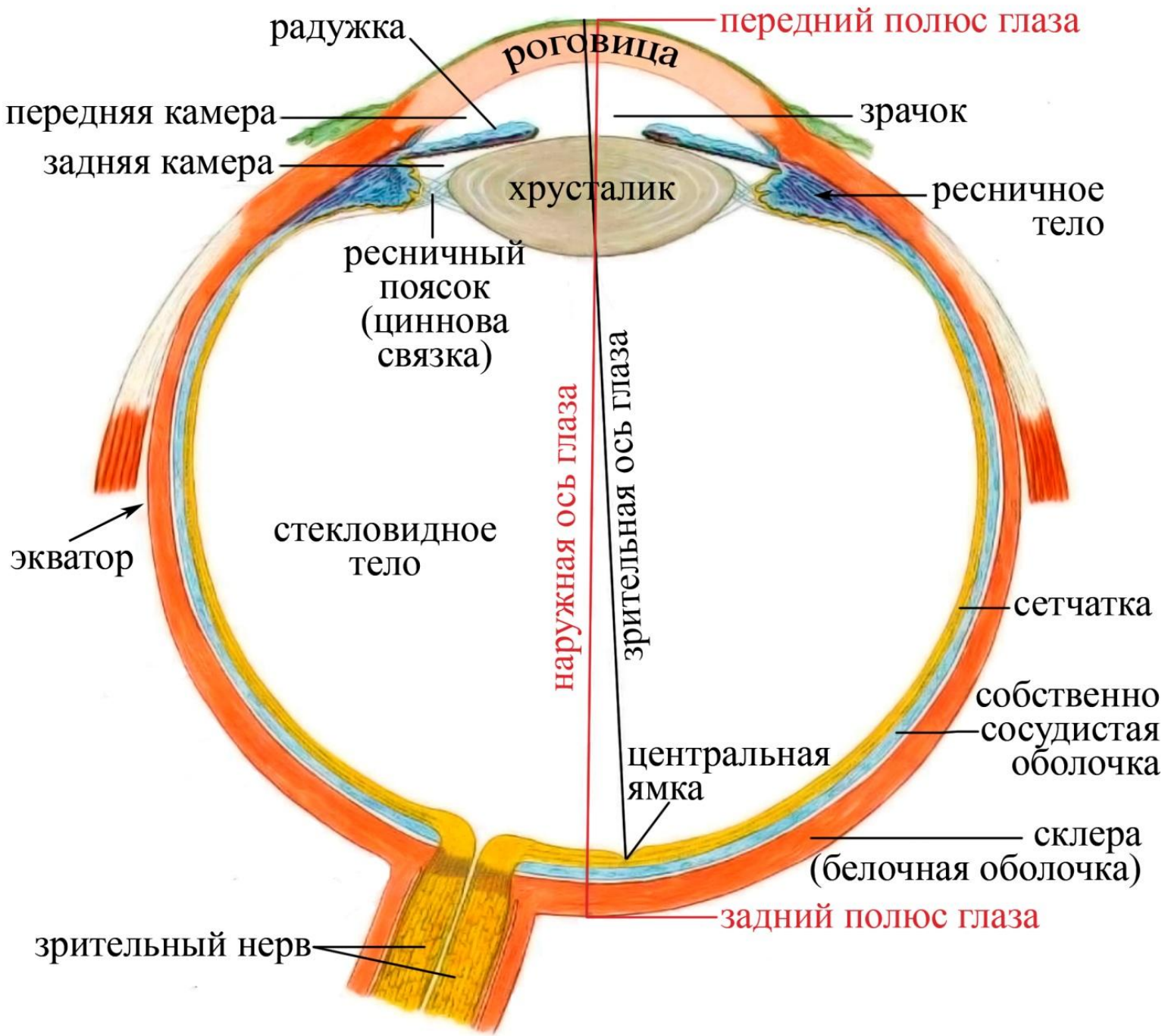

Suspensory ligament
Lens
2 mm


Light ray before refraction
Air
Water
Light ray after refraction

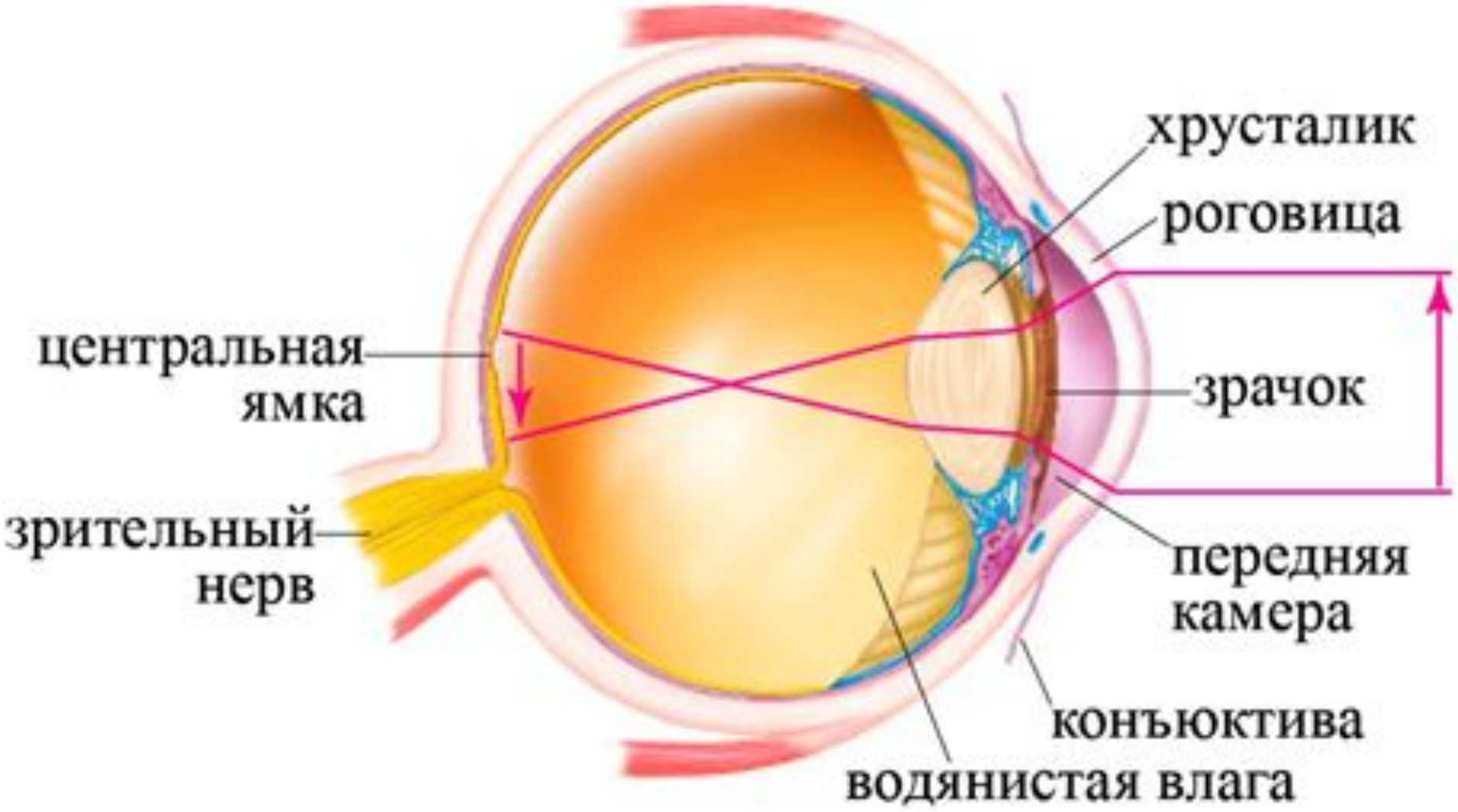

Фокальная плоскость
Главная оптическая ось
Главный фокус линзы
Фокусное расстояние линзы

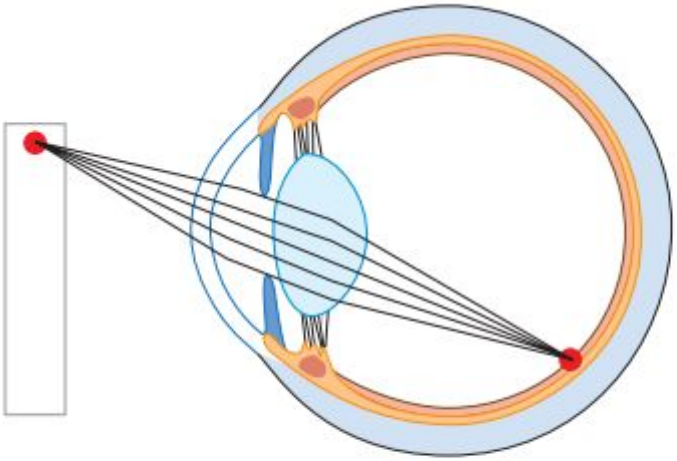

Air
n = 1.00
Lens
n = 1.40
Cornea
n = 1.38
Aqueous humor
n = 1.33
Vitreous body
n = 1.33
Retina
(b)


B REFRACTIVE INDEX OF EYE COMPONENTS
Refractive Index
Light
Air
1.0003
Cornea
1.376
Aqueous humor
1.336
Lens
1.386
Vitreous humor
1.336

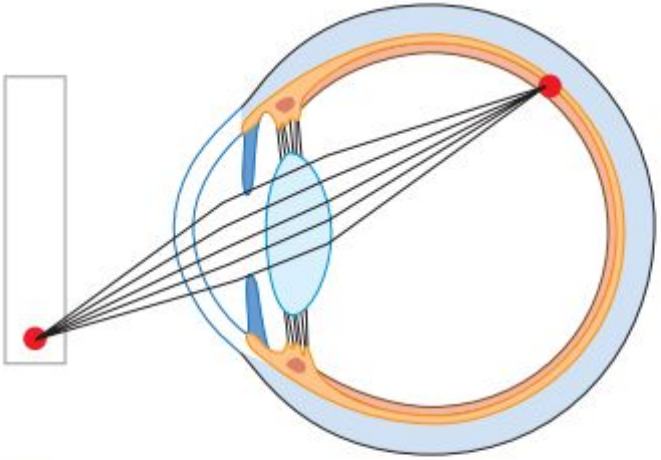

радужка
передний полюс глаза
роговица
передняя камера
зрачок
задняя камера
хрусталик
ресничное тело
ресничный поясок (циннова связка)
наружная ось глаза
зрительная ось глаза
экватор
стекловидное тело
сетчатка
собственно сосудистая оболочка
центральная ямка
склера (белочная оболочка)
задний полюс глаза
зрительный нерв

Светопреломляющий аппарат

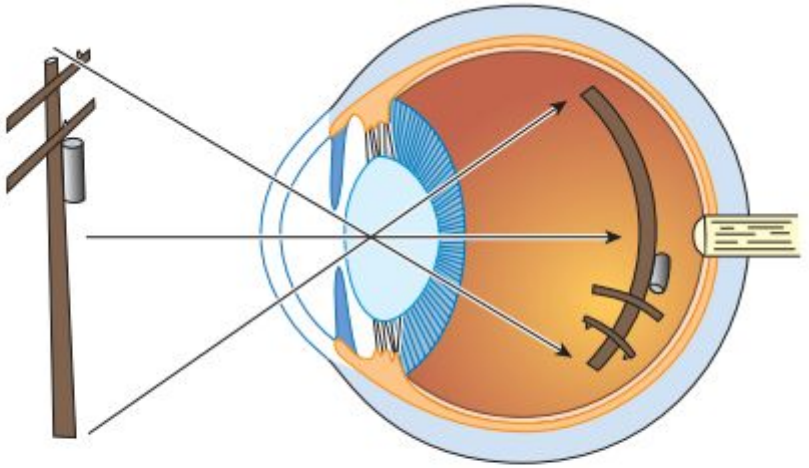




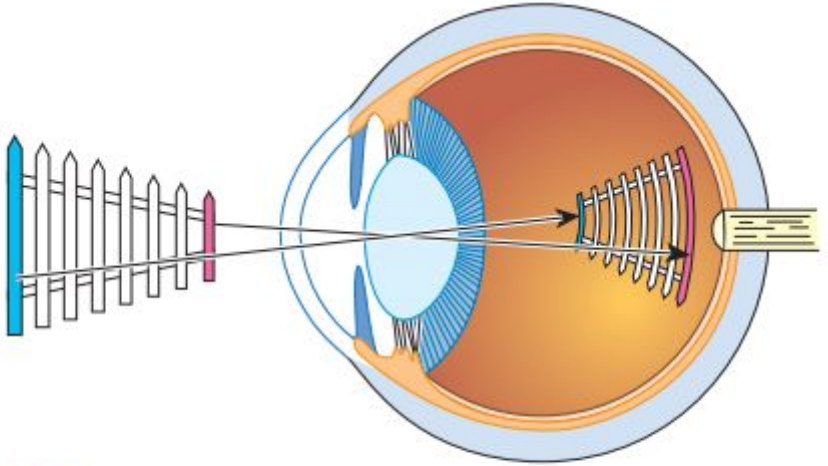
a Light from a point at the top of an object is focused on the lower retinal surface.



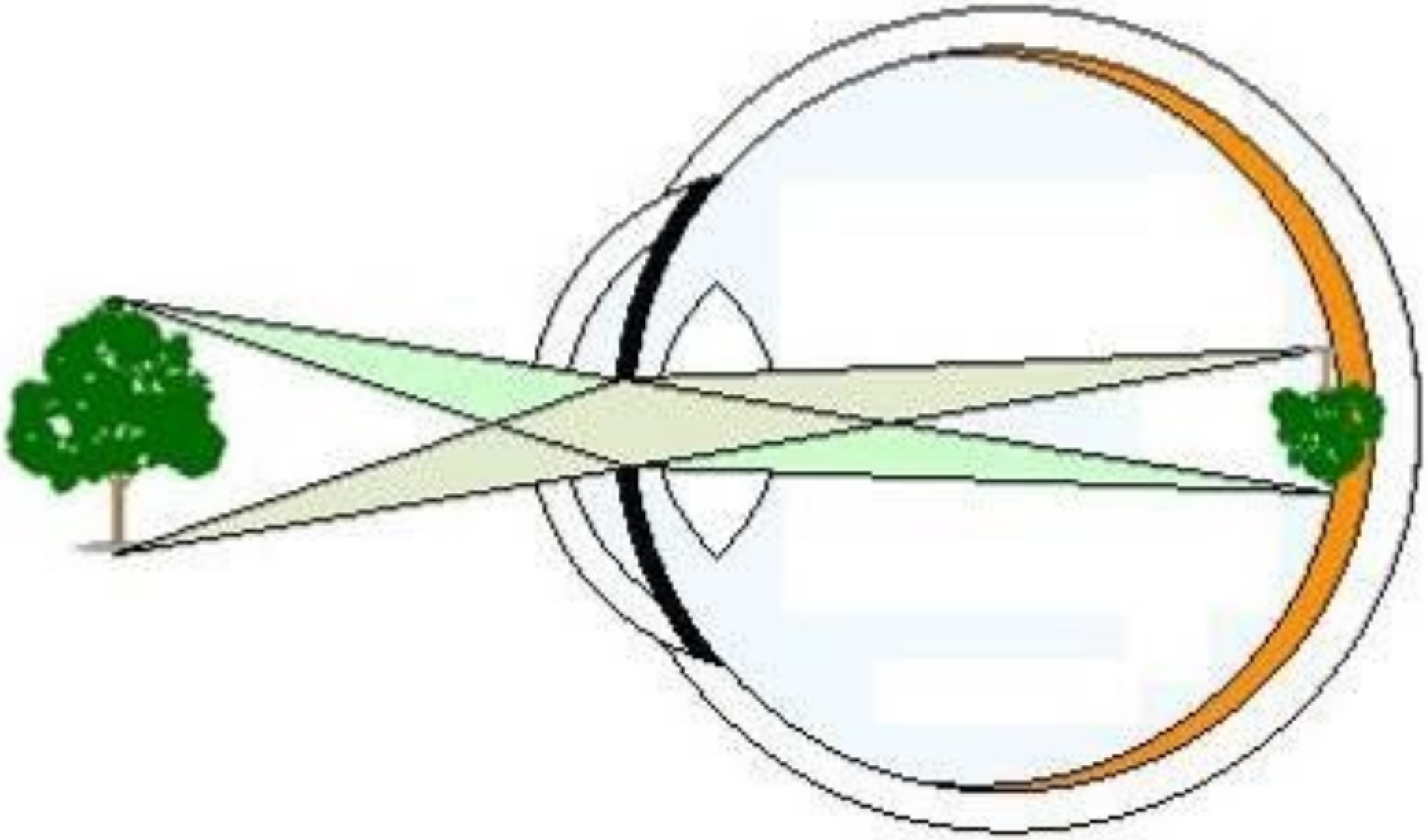
b Light from a point at the bottom of an object is focused on the upper retinal surface.

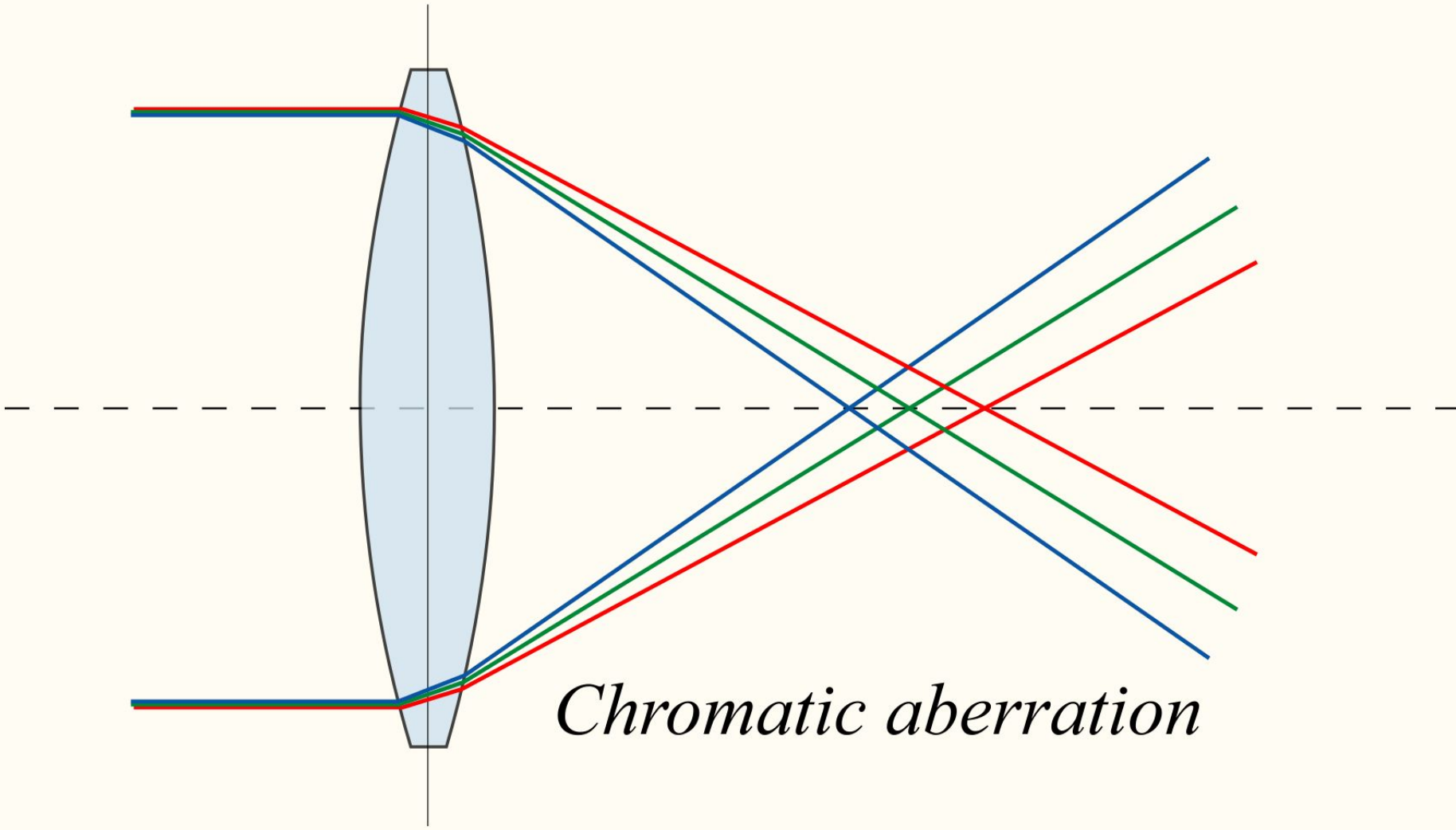


c Light rays projected from a vertical object show why the image arrives upside down. (Note that the image is also reversed.)



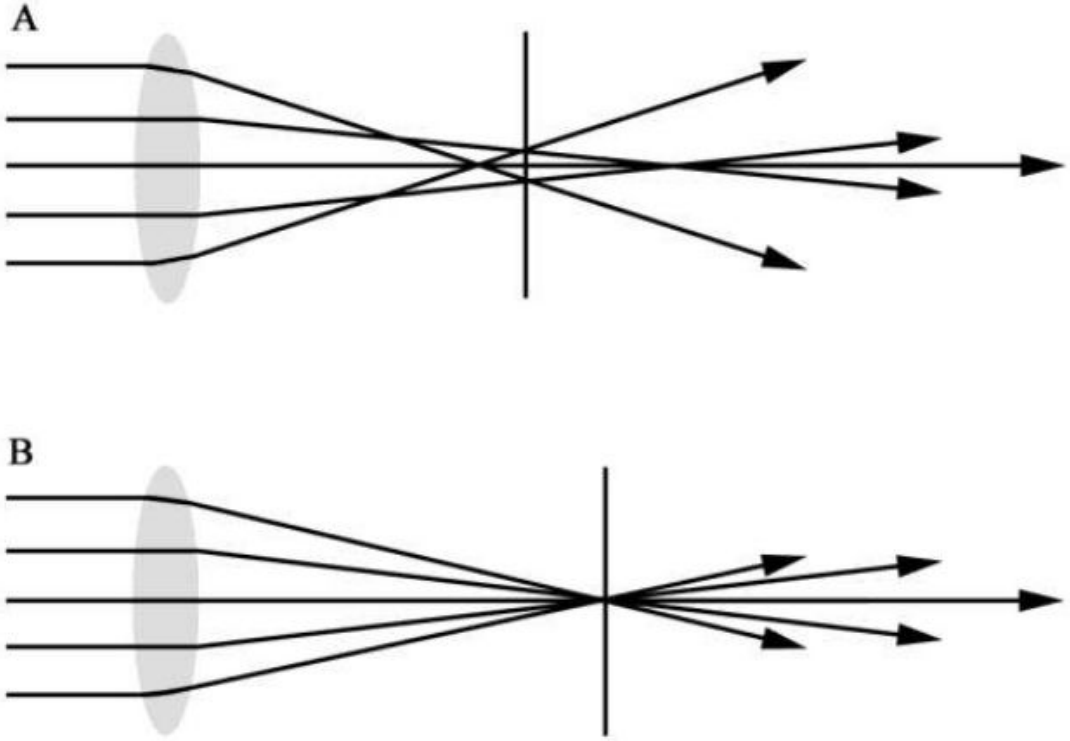
d Light rays projected from a horizontal object show why the image arrives with a left and right reversal. The image also arrives upside down. (As noted in the text, these representations are not drawn to scale.)

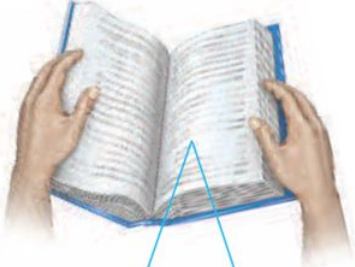



Chromatic aberration

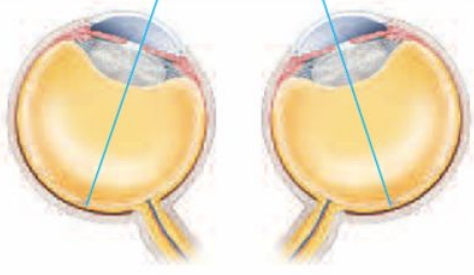
Spherical aberrations

A convex spherical lens refracts peripheral rays more strongly than paraxial rays, so peripheral rays are focused closer.



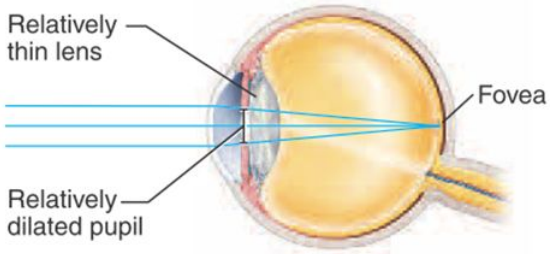


Emmetropia

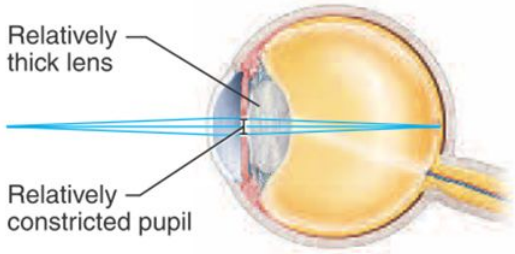


Convergence

(a)

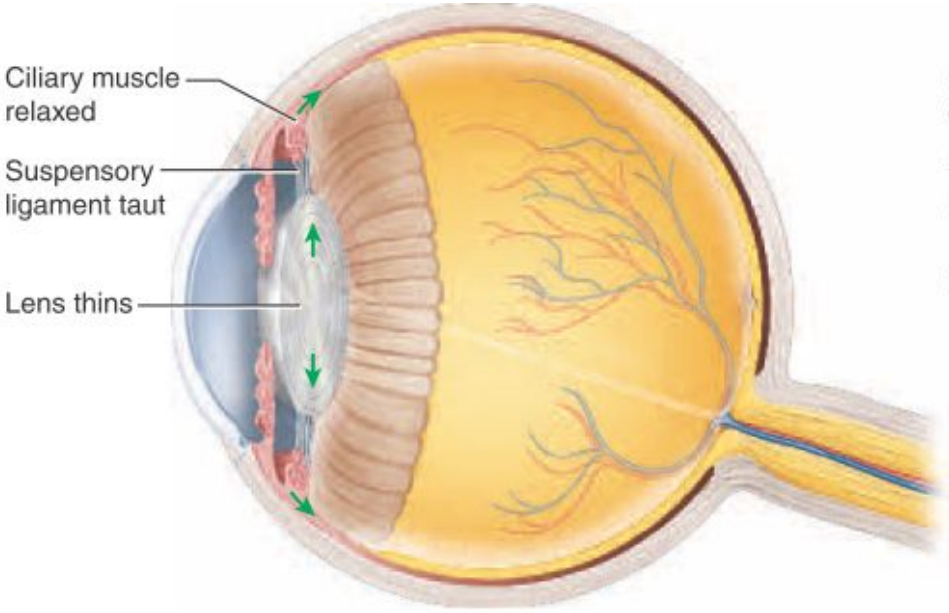


Emmetropia

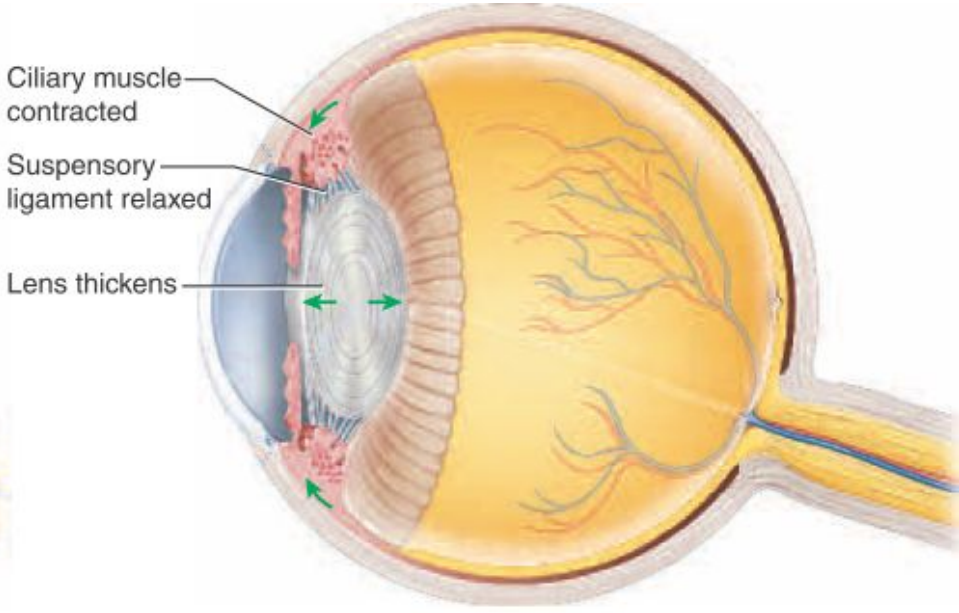


Pupillary miosis and lens accommodation

(b)

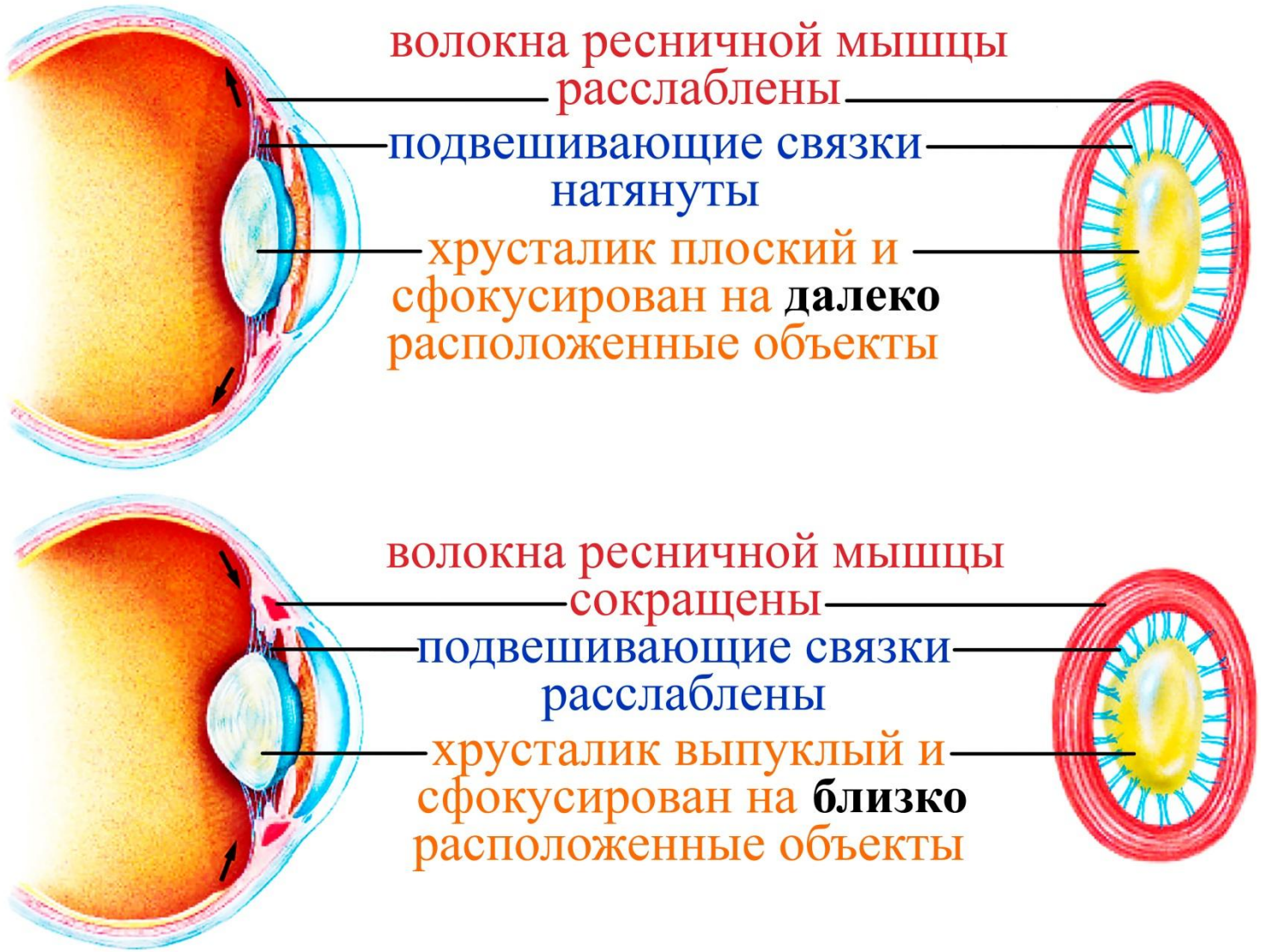


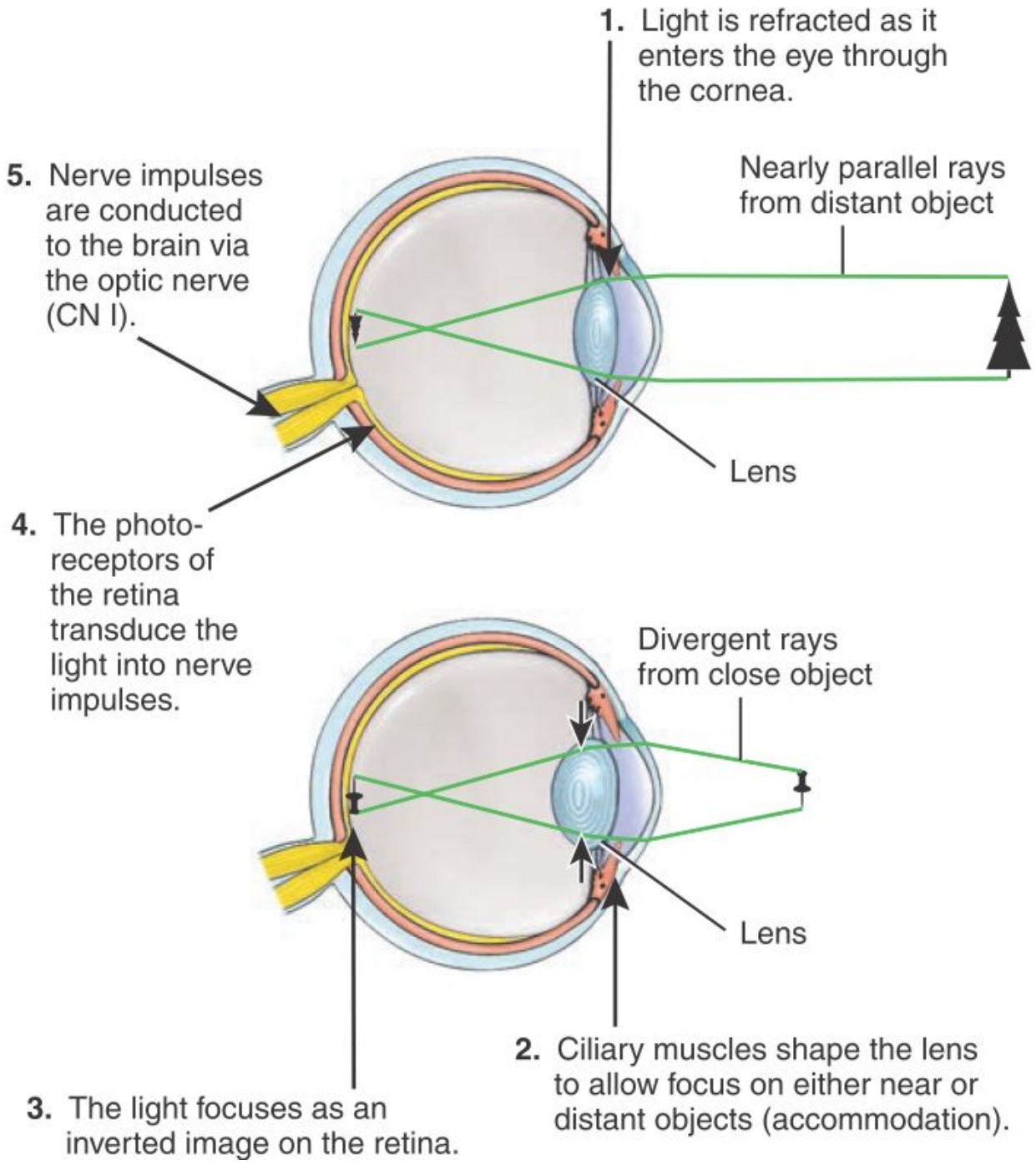
(a) Distant vision (emmetropia)

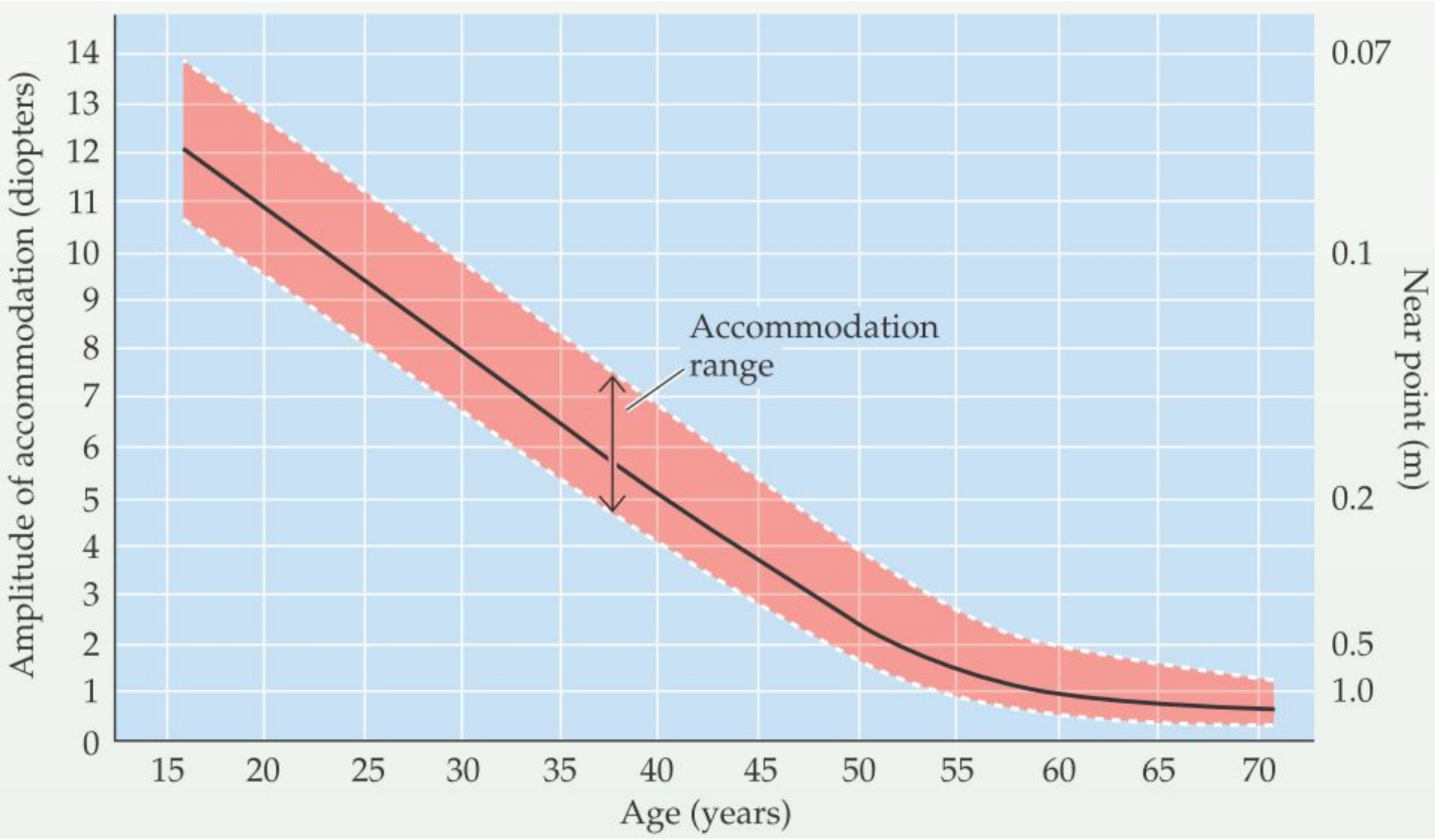


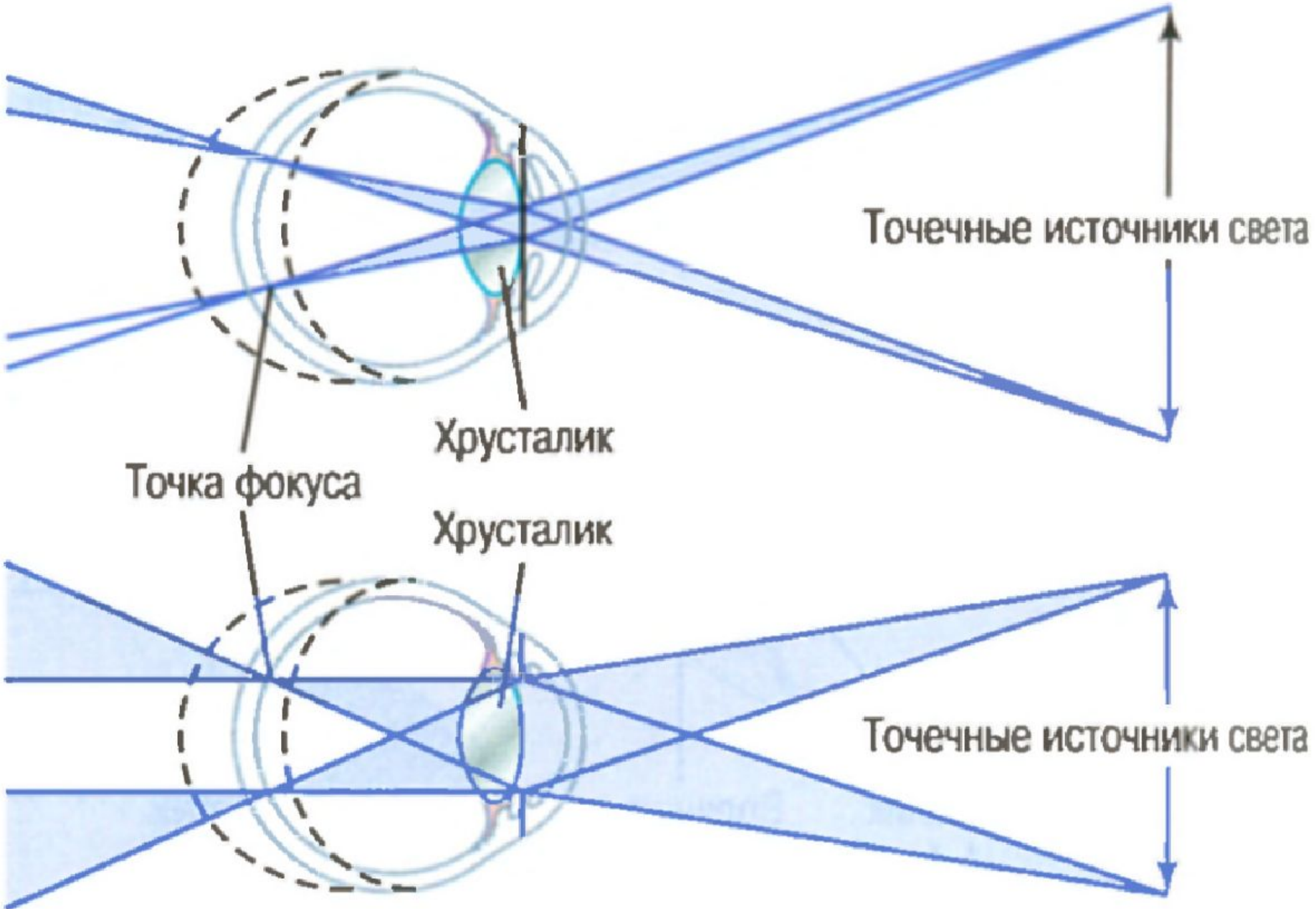
(b) Near vision (accommodation)

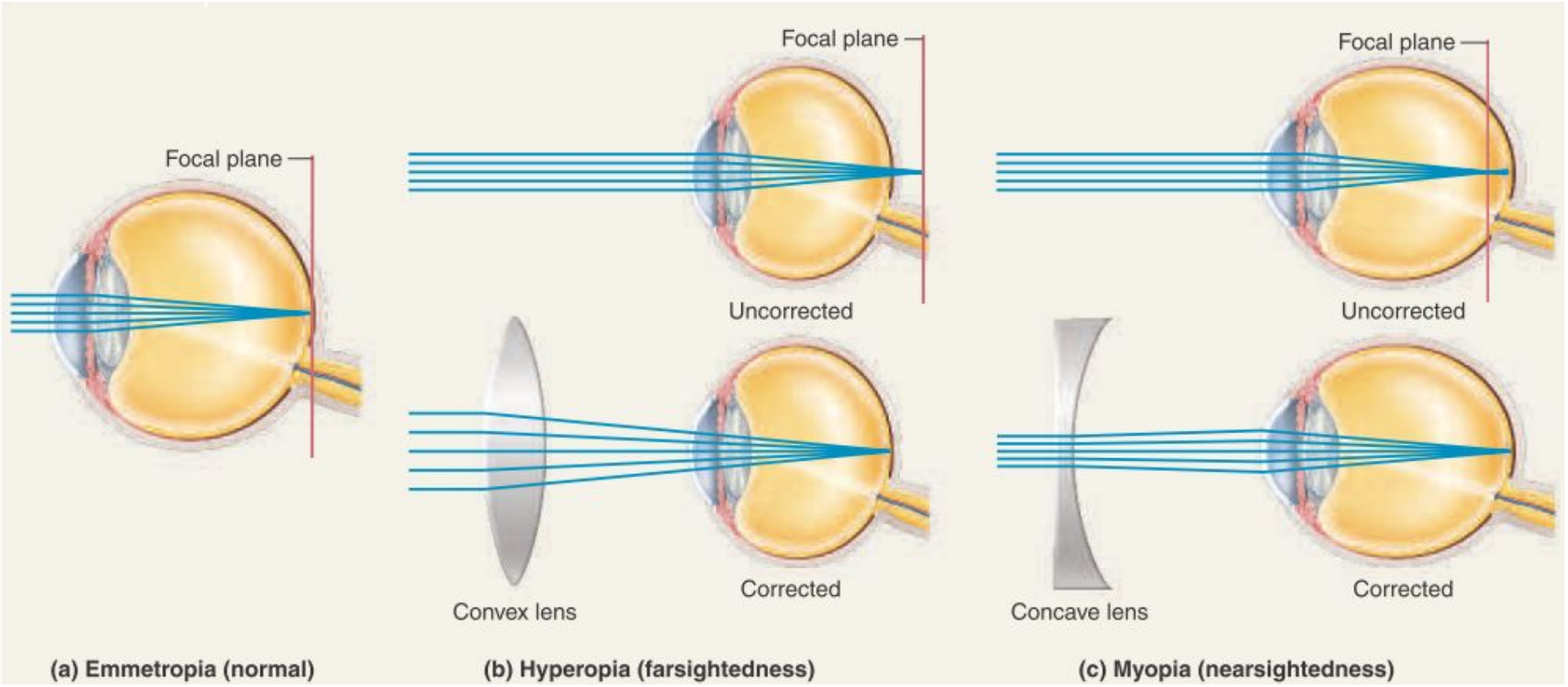
Аккомодационный аппарат, хрусталик

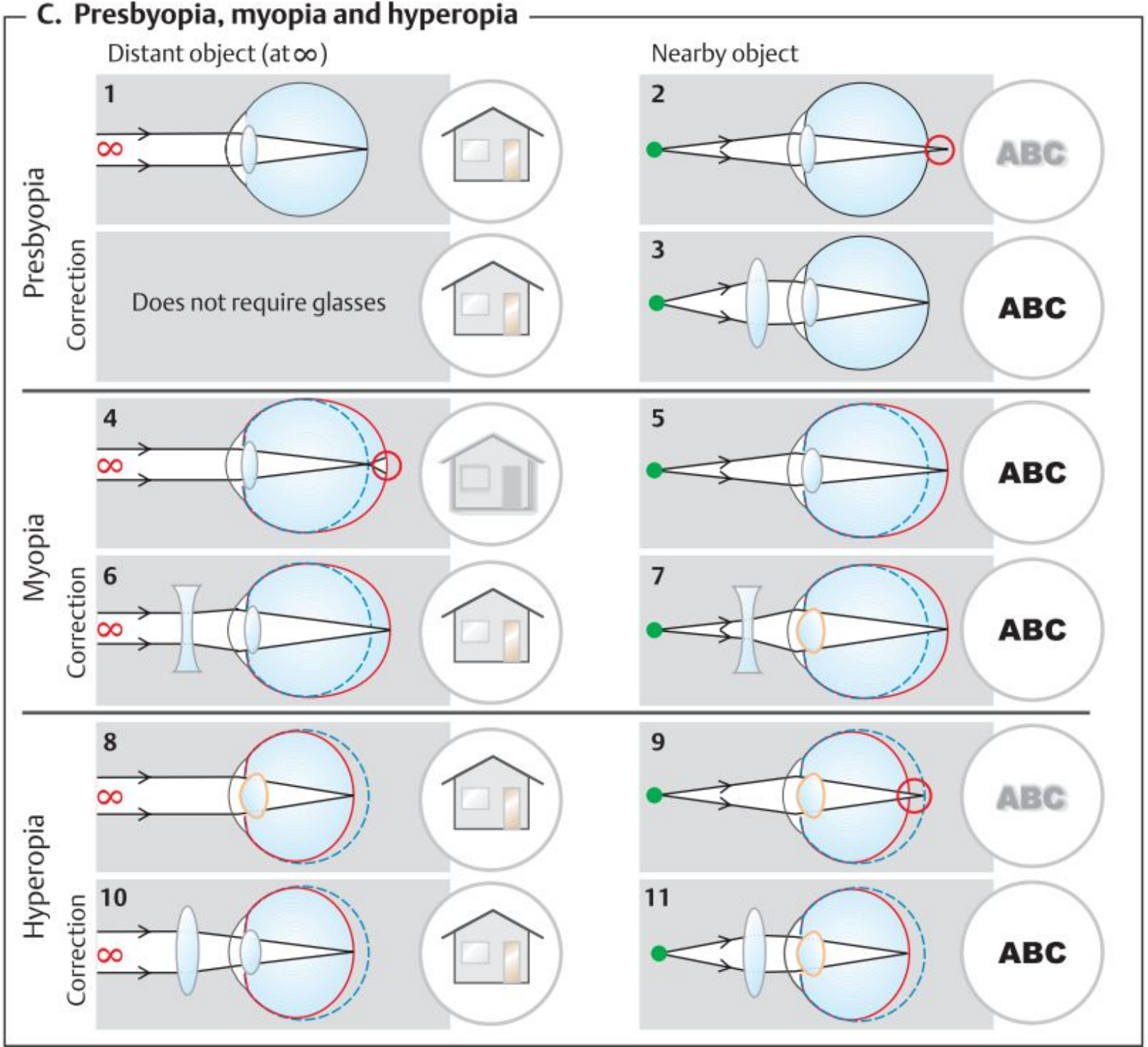


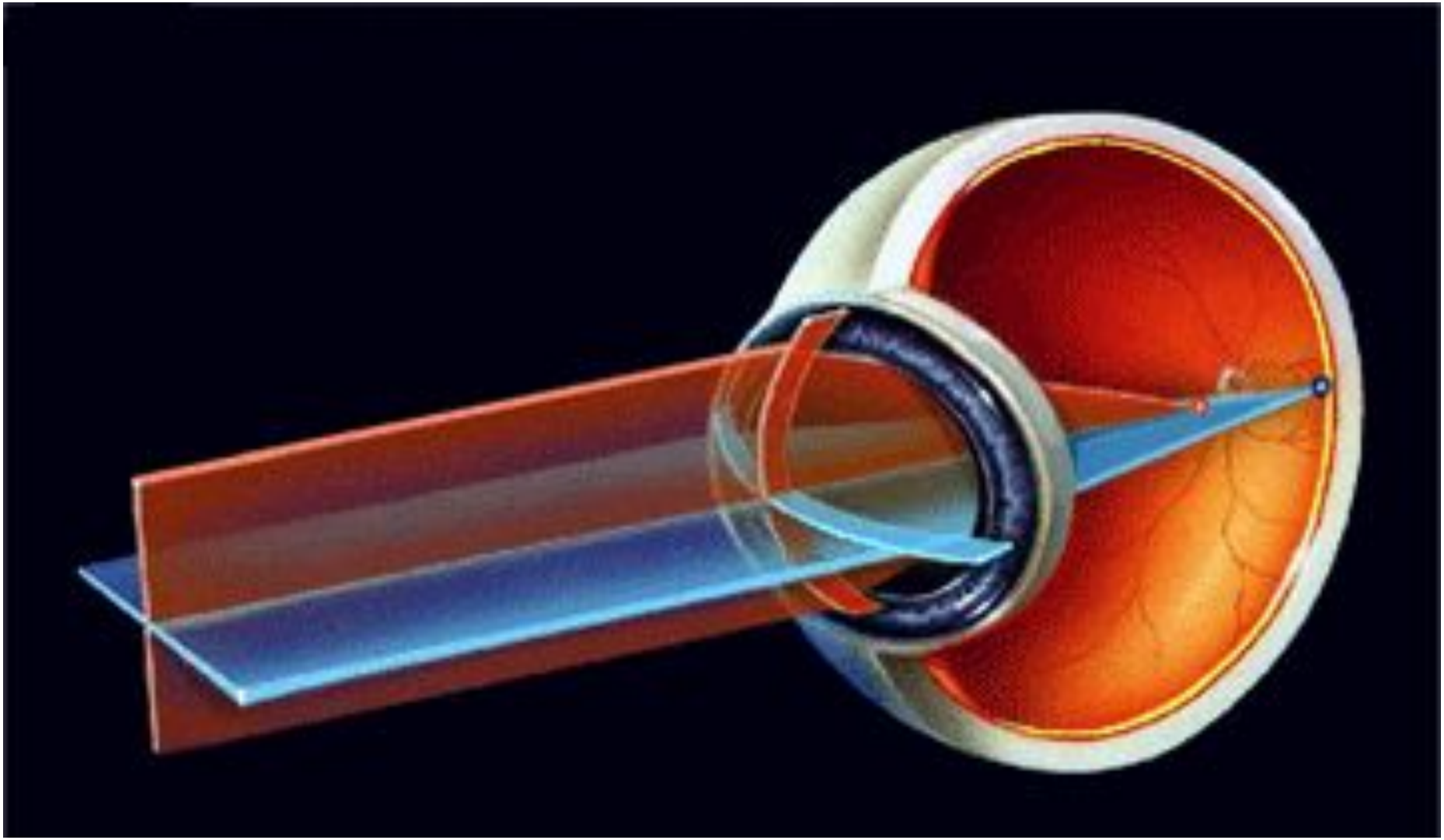

1. Light is refracted as it enters the eye through the cornea.
Nearly parallel rays from distant object
5. Nerve impulses are conducted to the brain via the optic nerve (CN I).
Lens
4. The photo-receptors of the retina transduce the light into nerve impulses.
Divergent rays from close object
Lens
2. Ciliary muscles shape the lens to allow focus on either near or distant objects (accommodation).
3. The light focuses as an inverted image on the retina.

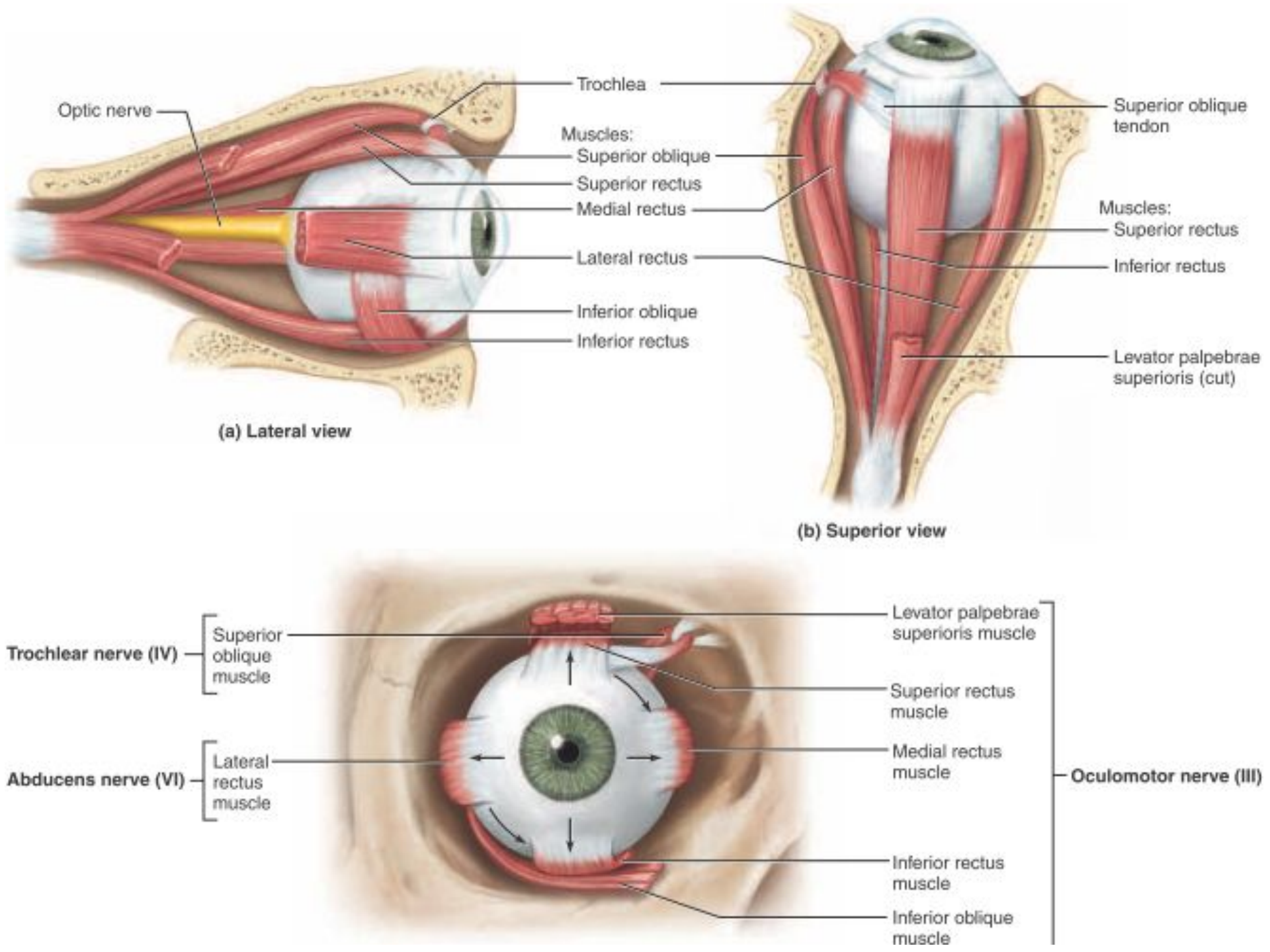

Amplitude of accommodation (diopters)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Accommodation range
15
20
25
30
35
40
45
50
55
60
65
70
Age (years)
0.07
0.1
0.2
0.5
1.0
Near point (m)

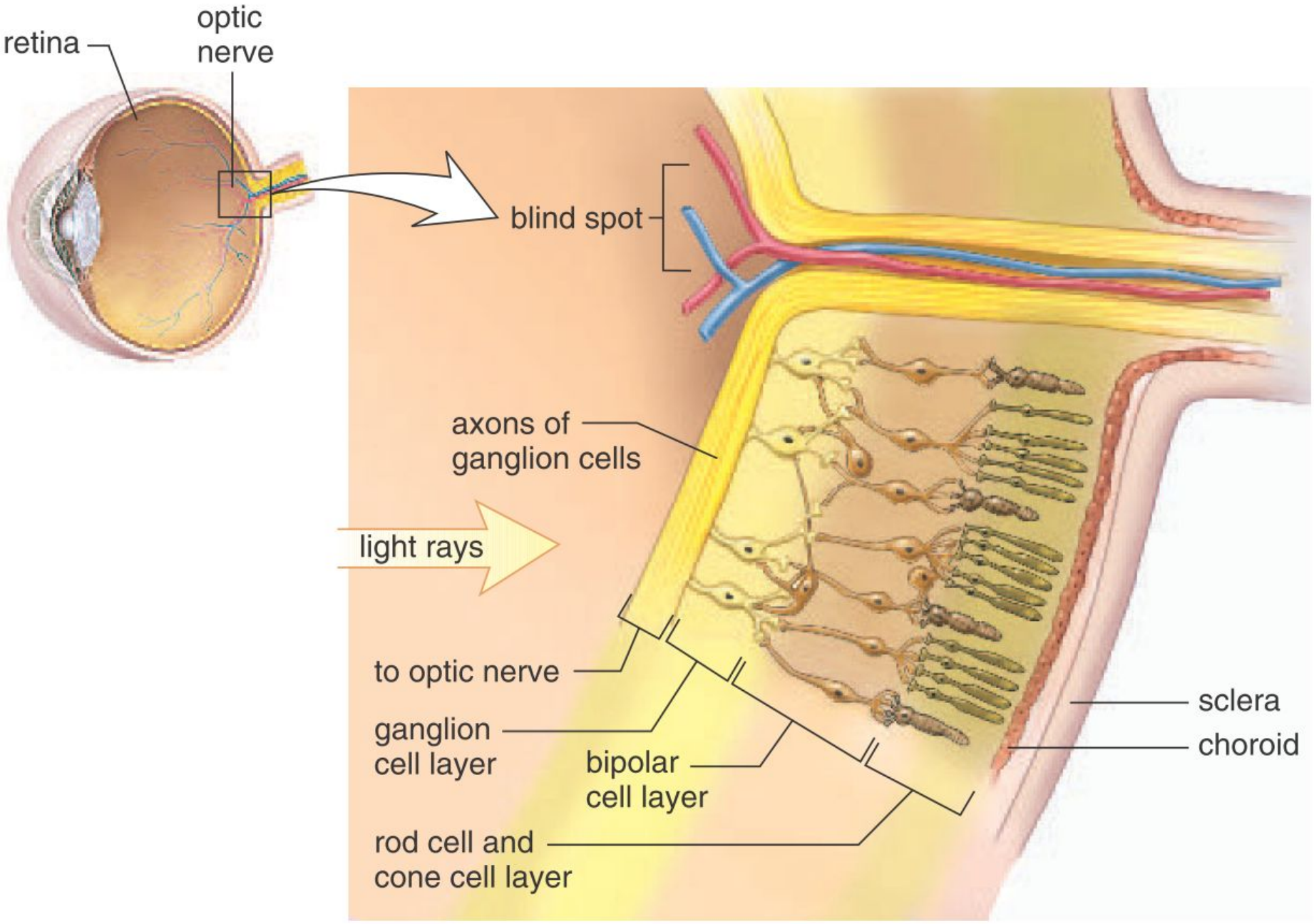

Точечные источники света
Хрусталик
Точка фокуса
Хрусталик
Точечные источники света


Focal plane
Focal plane
Uncorrected
Convex lens
Corrected
Focal plane
Uncorrected
Concave lens
Corrected
(a) Emmetropia (normal)
(b) Hyperopia (farsightedness)
(c) Myopia (nearsightedness)

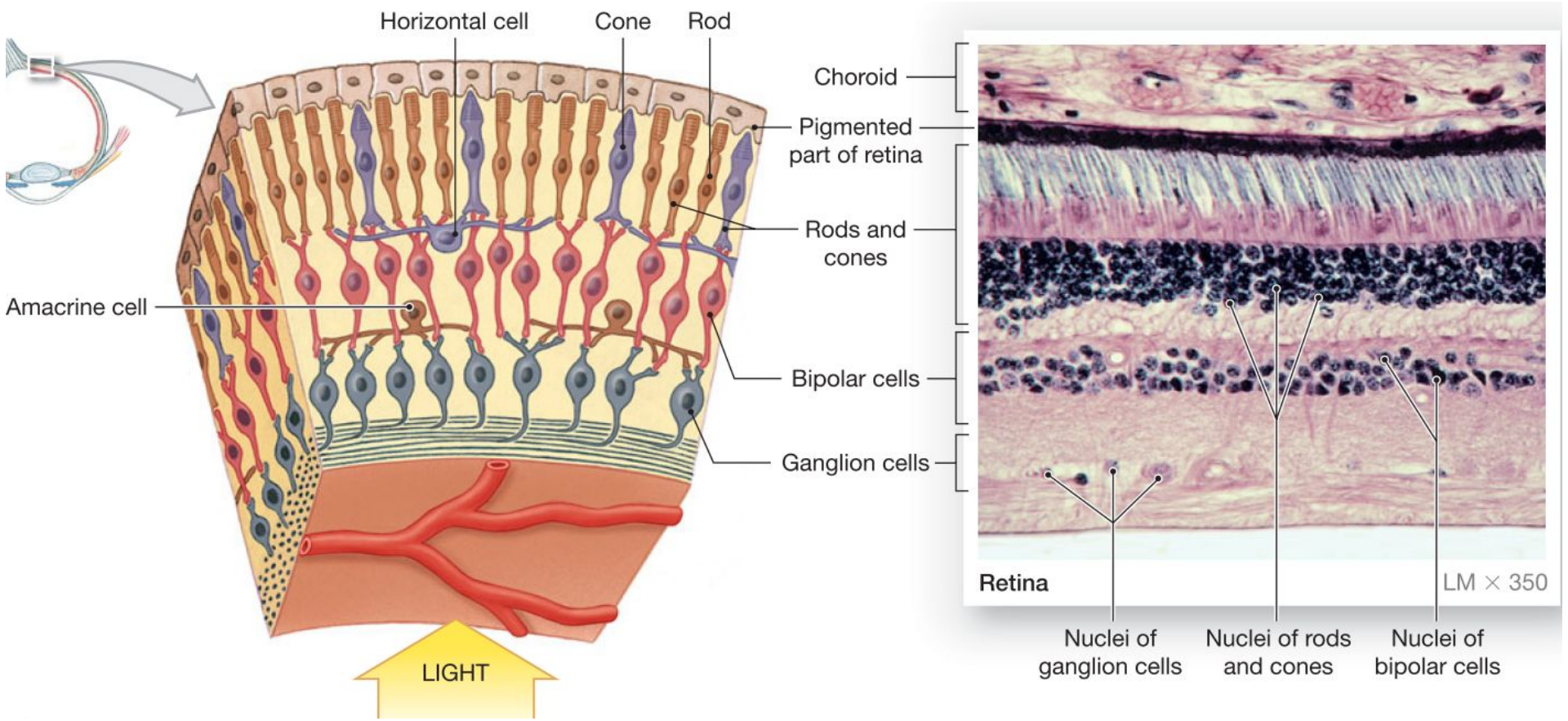

C. Presbyopia, myopia and hyperopia
Distant object (at ∞)
Nearby object
Presbyopia
Correction
Does not require glasses
Myopia
Hyperopia
1
2
3
4
5
6
7
8
9
10
11
ABC



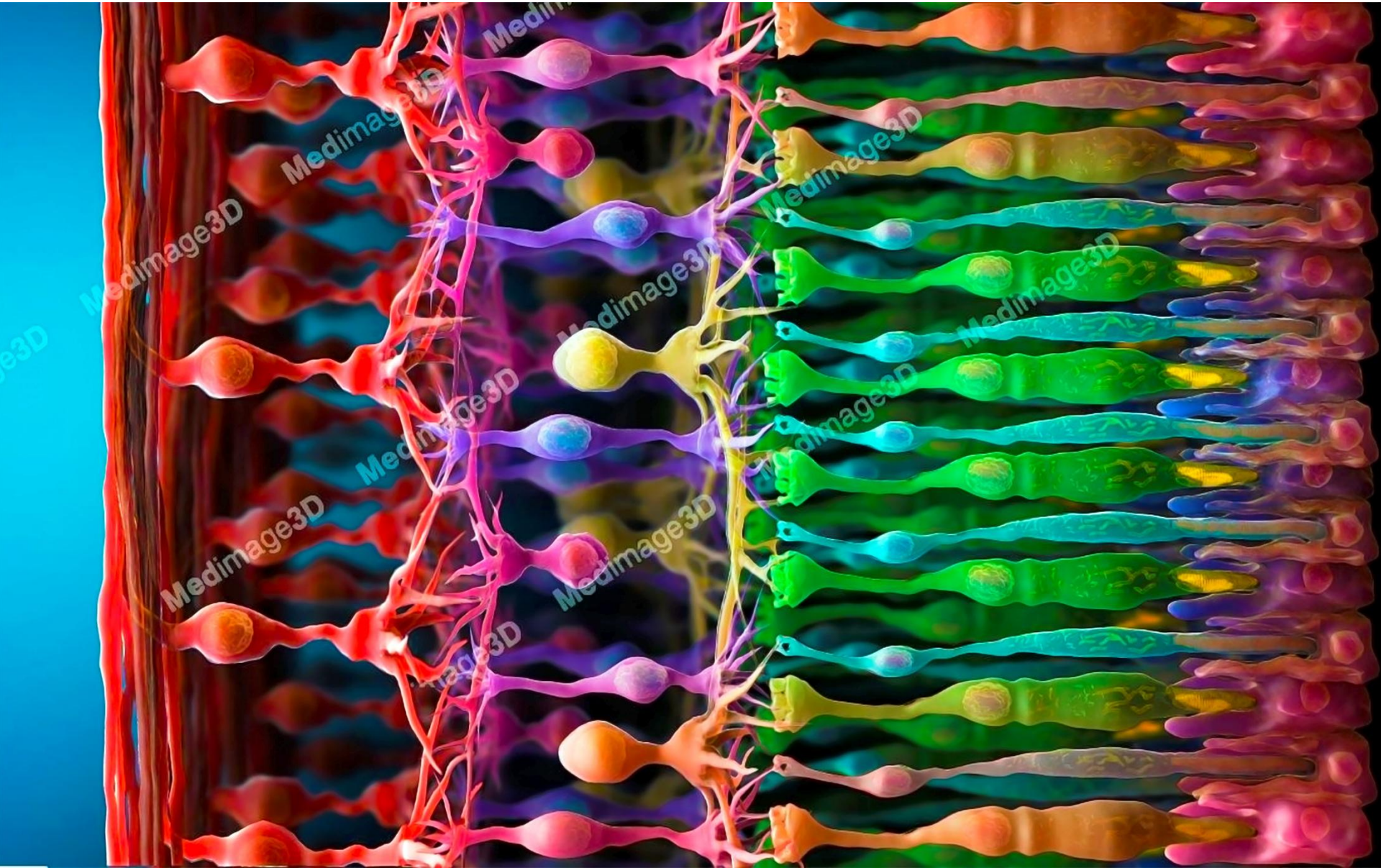

Optic nerve
Trochlea
Muscles:
Superior oblique
Superior rectus
Medial rectus
Lateral rectus
Inferior oblique
Inferior rectus
(a) Lateral view
Superior oblique tendon
Muscles:
Superior rectus
Inferior rectus
Levator palpebrae superioris (cut)
(b) Superior view
Trochlear nerve (IV)
Superior oblique muscle
Abducens nerve (VI)
Lateral rectus muscle
Levator palpebrae superioris muscle
Superior rectus muscle
Medial rectus muscle
Inferior rectus muscle
Inferior oblique muscle
Oculomotor nerve (III)

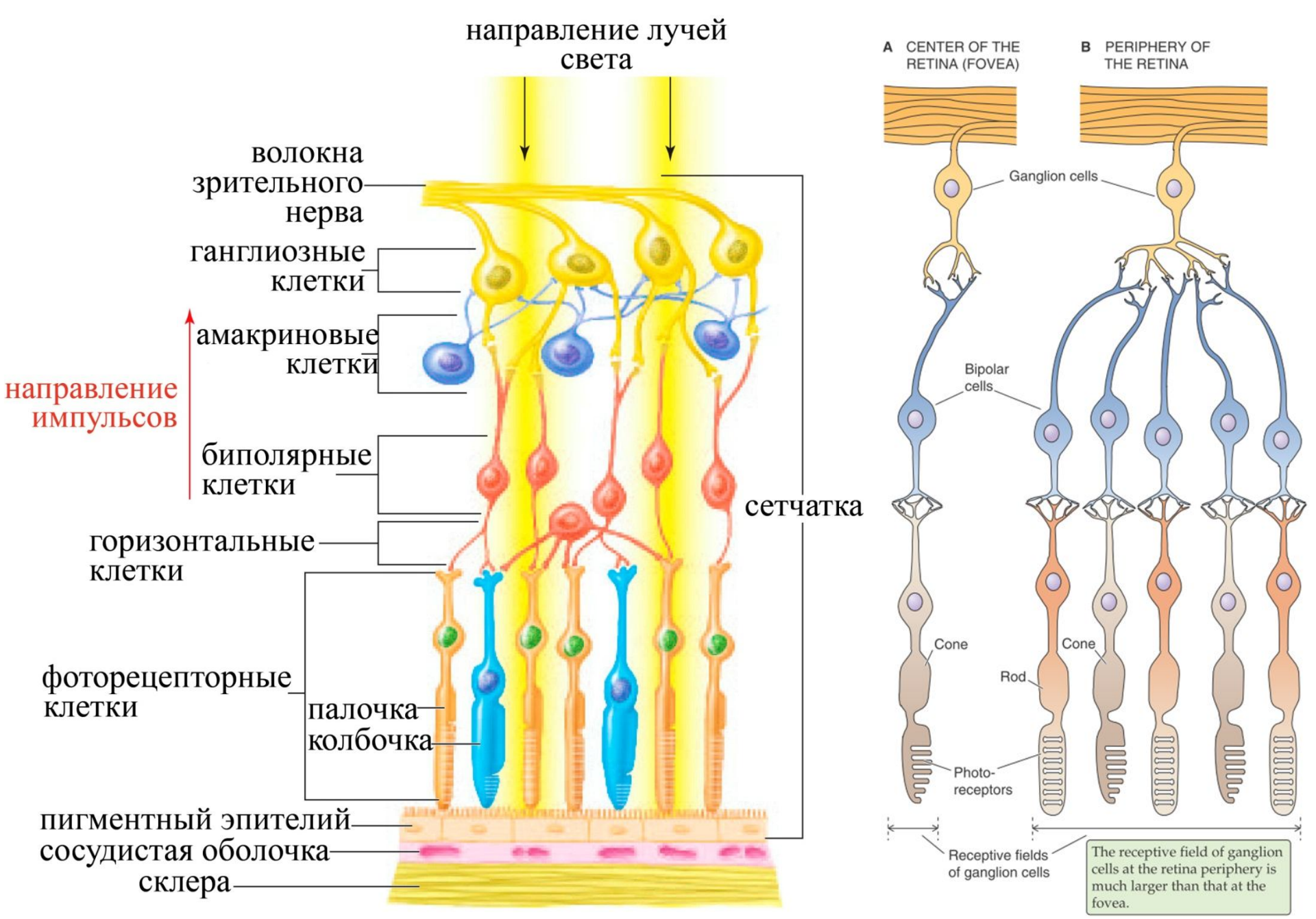


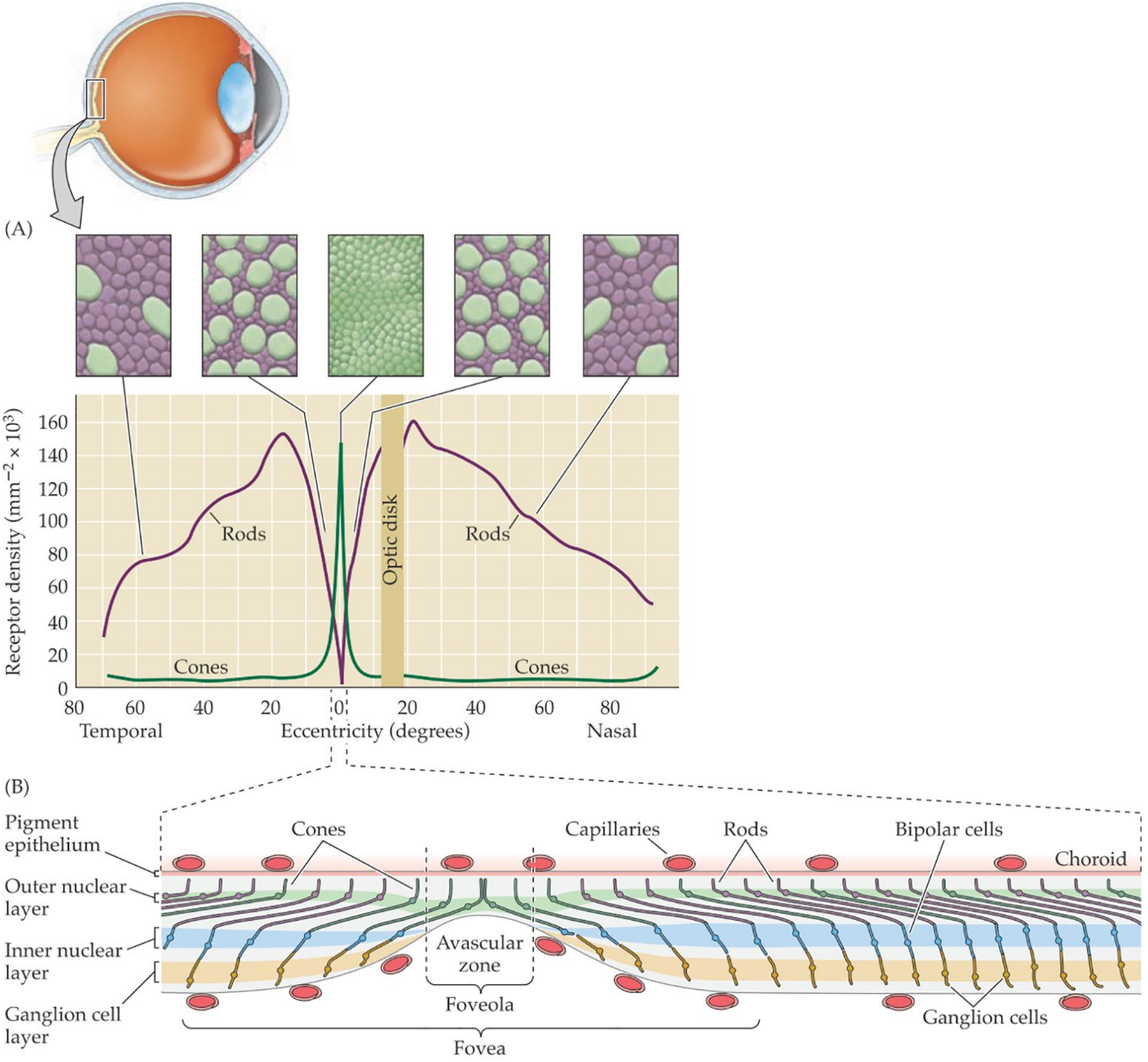
a. Drawing of retina

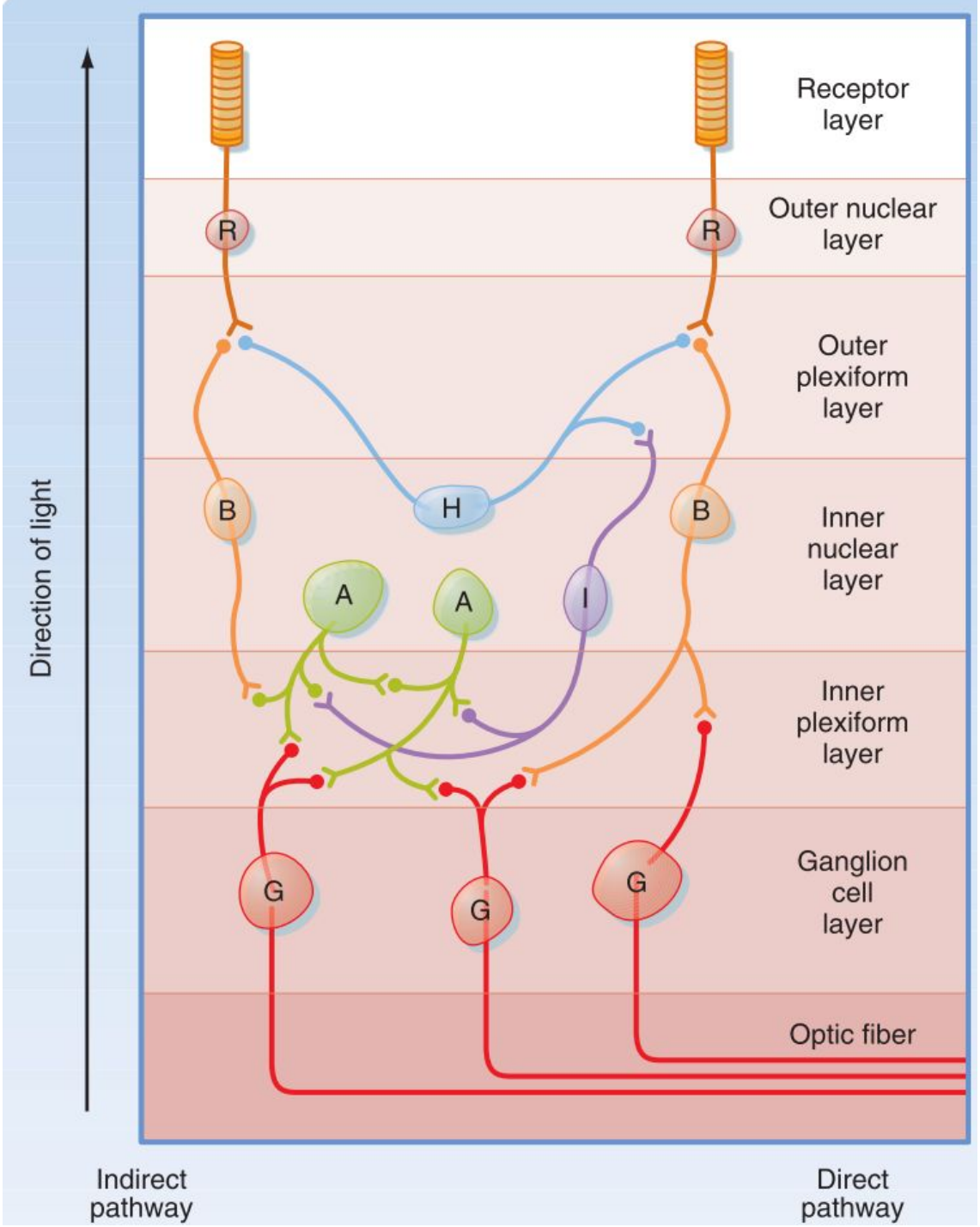

Horizontal cell
Cone
Rod
Choroid
Pigmented part of retina
Rods and cones
Amacrine cell
Bipolar cells
Ganglion cells
LIGHT
Retina
LM × 350
Nuclei of ganglion cells
Nuclei of rods and cones
Nuclei of bipolar cells

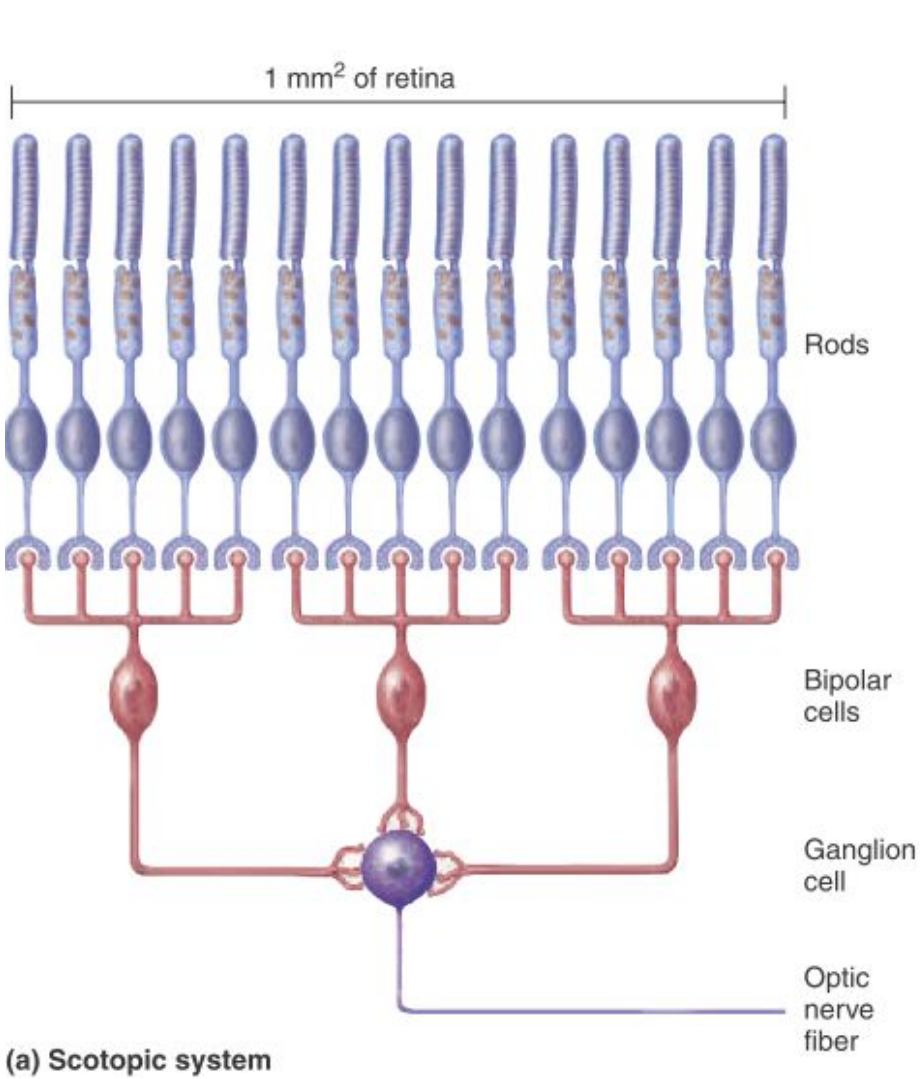
Сетчатка



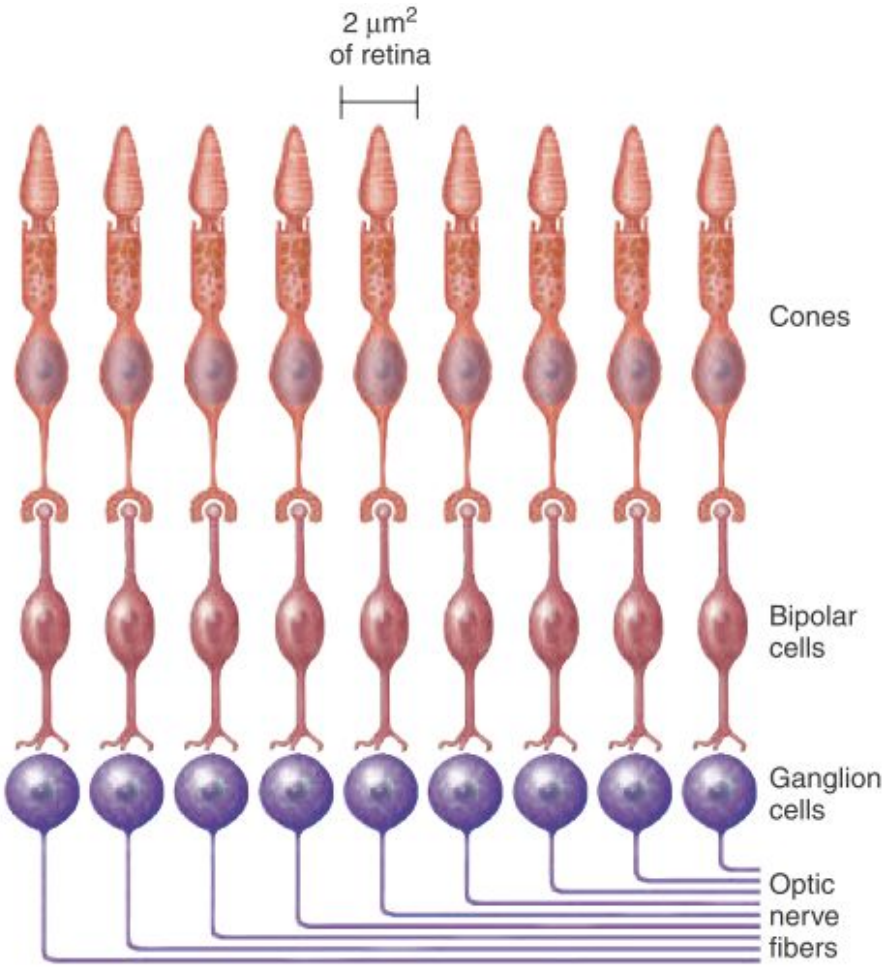

направление лучей света
волокна зрительного нерва
ганглиозные клетки
амакриновые клетки
направление импульсов
биполярные клетки
горизонтальные клетки
фоторецепторные клетки
палочка
колбочка
пигментный эпителий
сосудистая оболочка
склера
сетчатка
A CENTER OF THE RETINA (FOVEA)
B PERIPHERY OF THE RETINA
Ganglion cells
Bipolar cells
Cone
Rod
Cone
Photo-receptors
Receptive fields of ganglion cells
The receptive field of ganglion cells at the retina periphery is much larger than that at the fovea.


(A)
Receptor density (mm^{-2} × 10^3)
160
140
120
100
80
60
40
20
0
Rods
Cones
Optic disk
Rods
Cones
80
60
40
20
0
20
40
60
80
Temporal
Eccentricity (degrees)
Nasal
(B)
Pigment epithelium
Outer nuclear layer
Inner nuclear layer
Ganglion cell layer
Cones
Capillaries
Rods
Bipolar cells
Choroid
Avascular zone
Foveola
Fovea
Ganglion cells

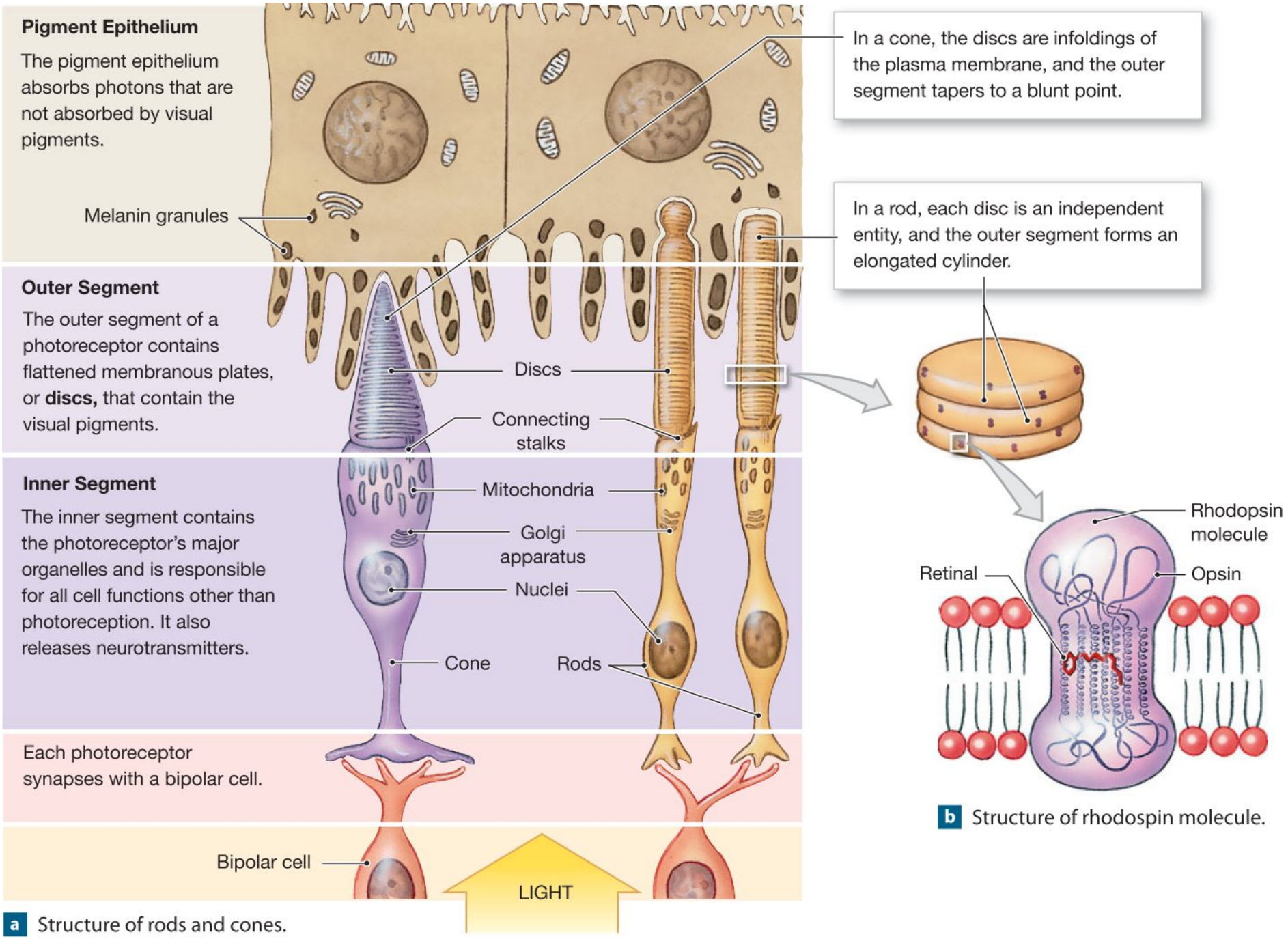

Receptor layer
Outer nuclear layer
Outer plexiform layer
Inner nuclear layer
Inner plexiform layer
Ganglion cell layer
Optic fiber
Direction of light
R
R
B
H
B
A
A
I
G
G
G
Indirect pathway
Direct pathway



(a) Scotopic system

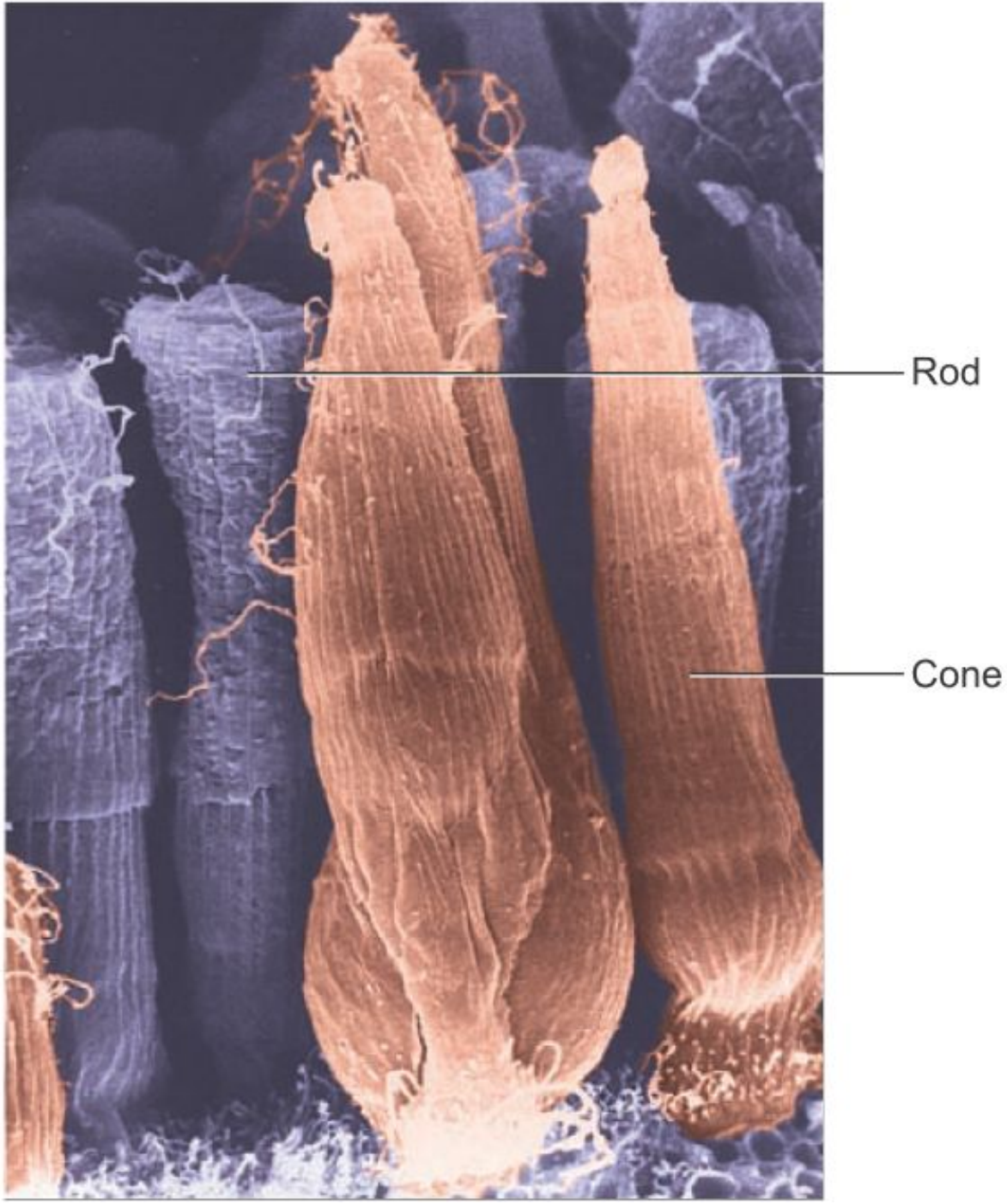


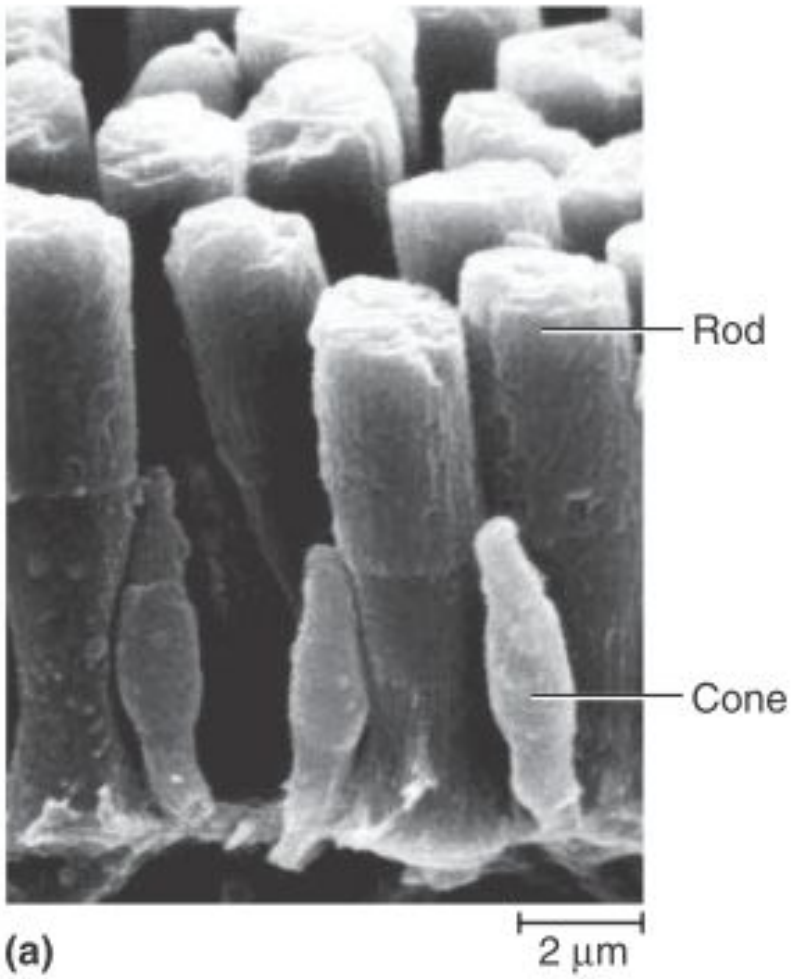
(b) Photopic system



a Structure of rods and cones.

b Structure of rhodospin molecule.


Rod
Cone



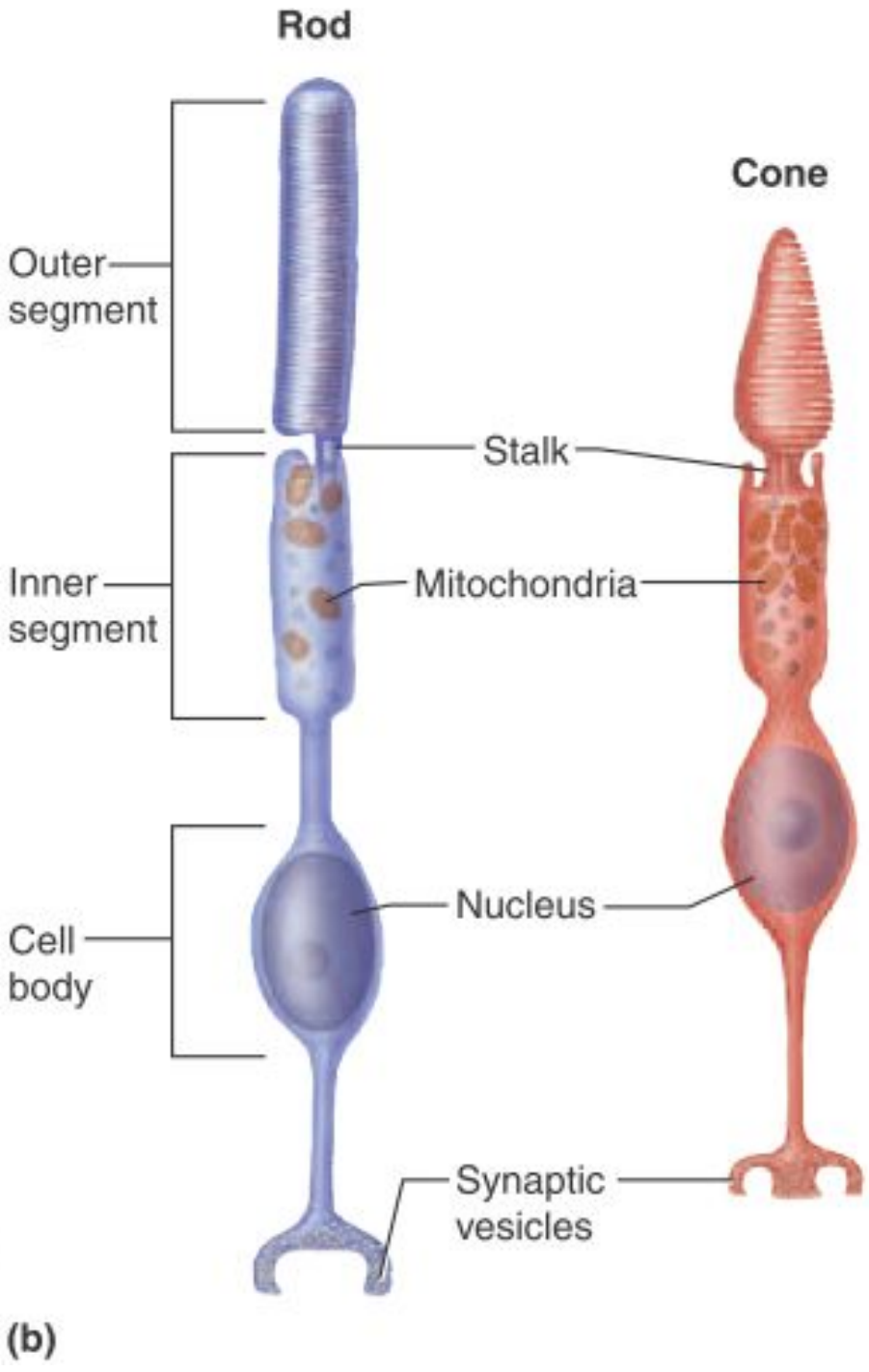
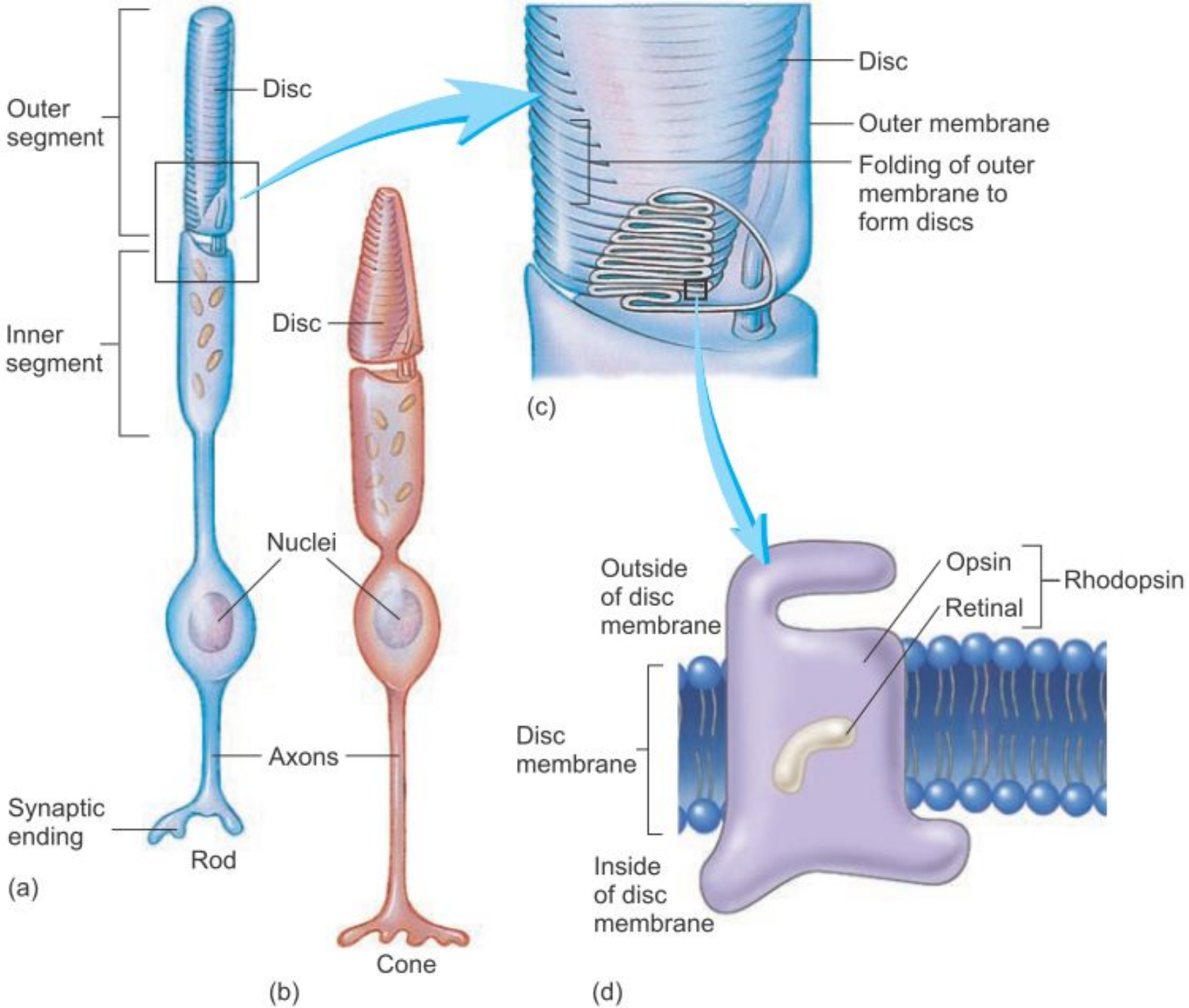


FIGURE 16.35 Rod and Cone Cells. (a) Rods and cones of a salamander retina (SEM). (b) Structure of human rods and cones.


Outer segment
Disc
Inner segment
Synaptic ending
Rod
(a)
Disc
Nuclei
Axons
Cone
(b)
Disc
Outer membrane
Folding of outer membrane to form discs
(c)
Outside of disc membrane
Opsin
Retinal
Rhodopsin
Disc membrane
Inside of disc membrane
(d)

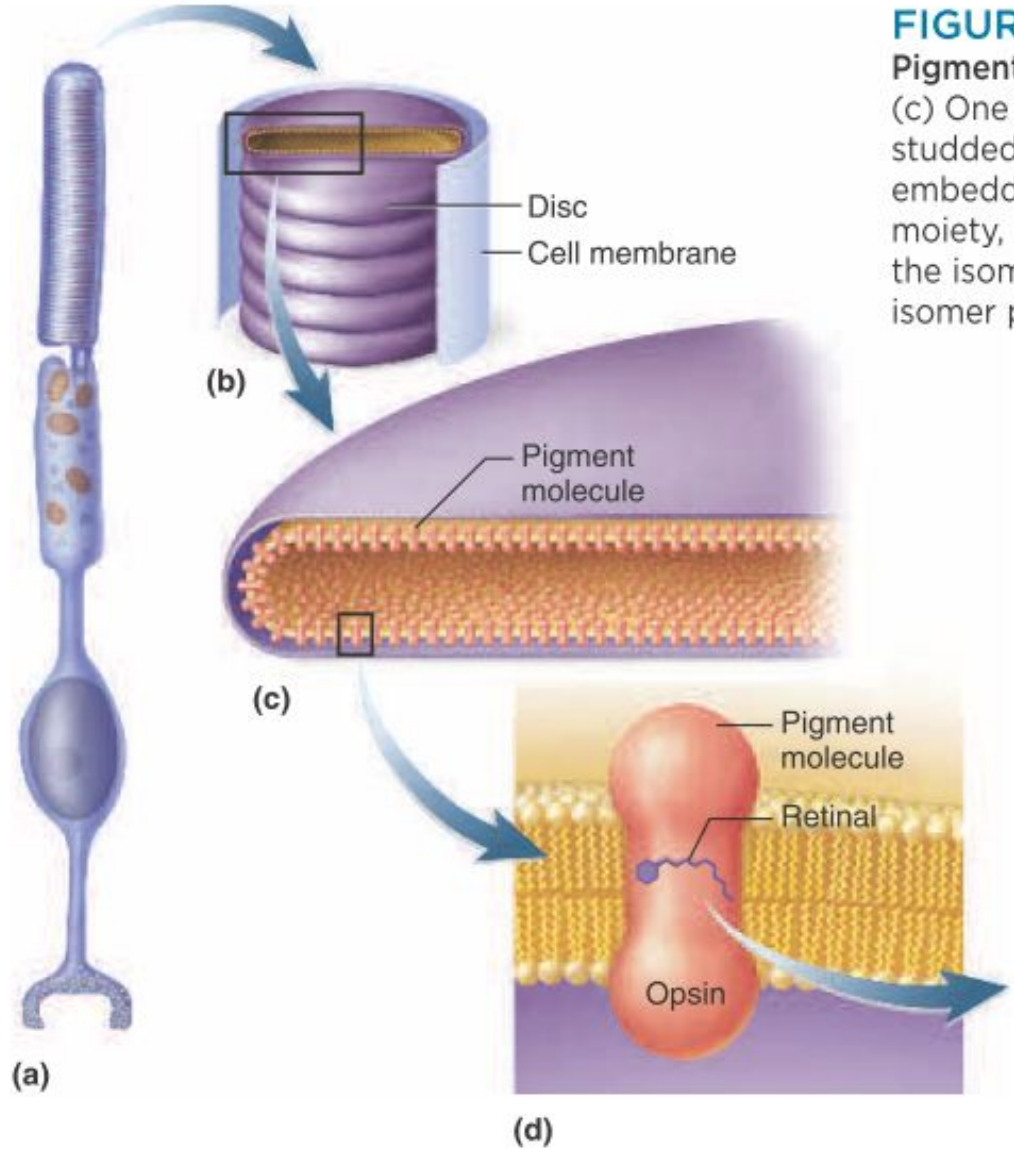
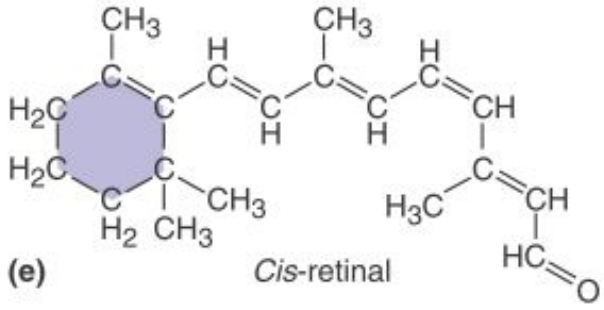
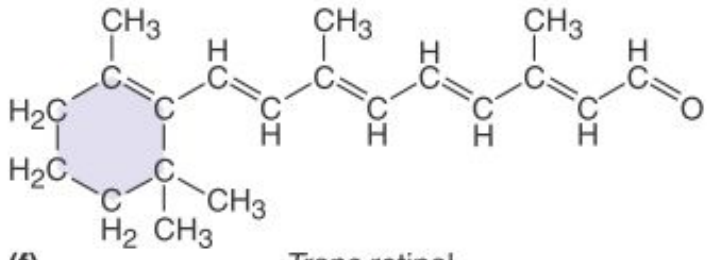
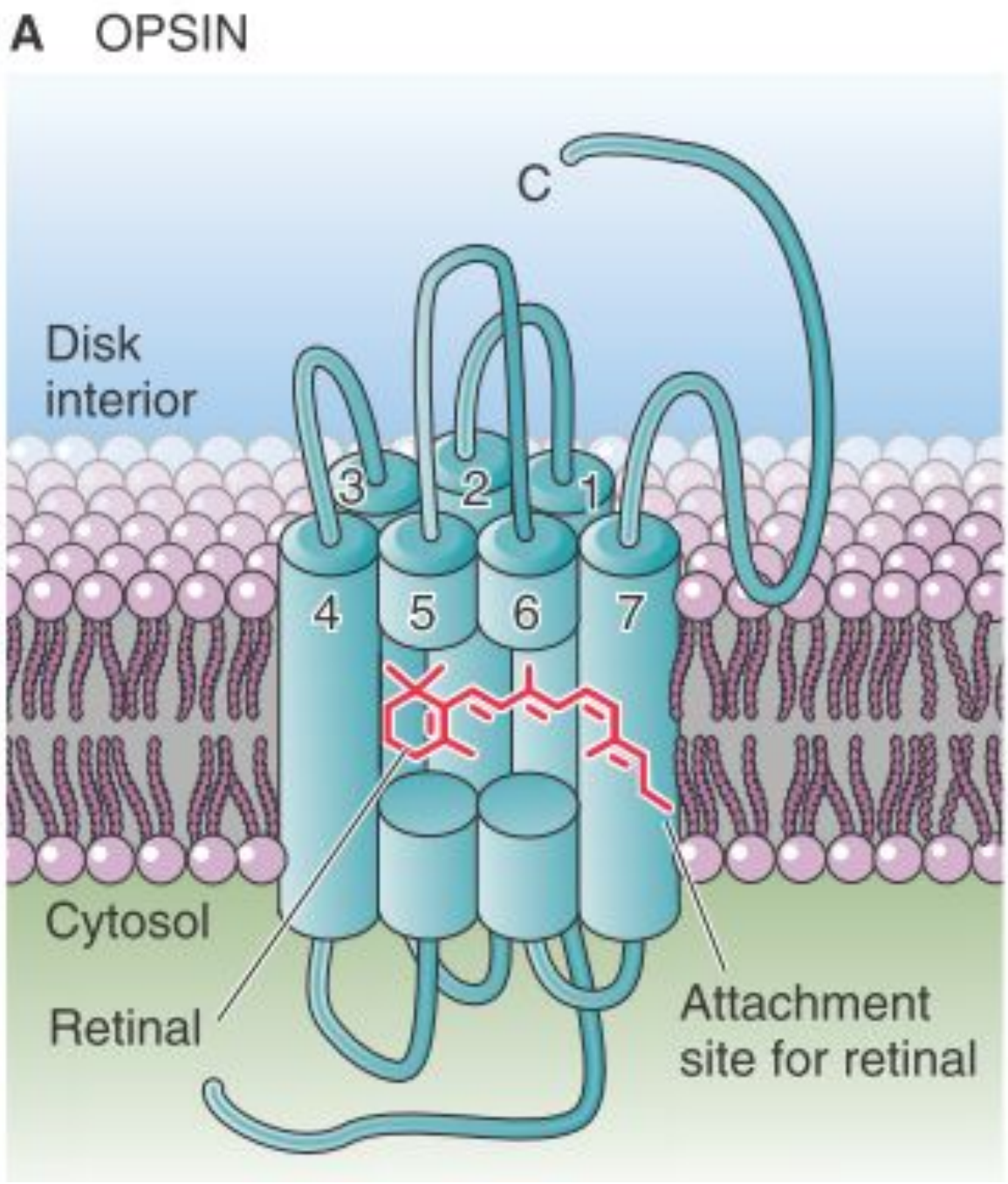
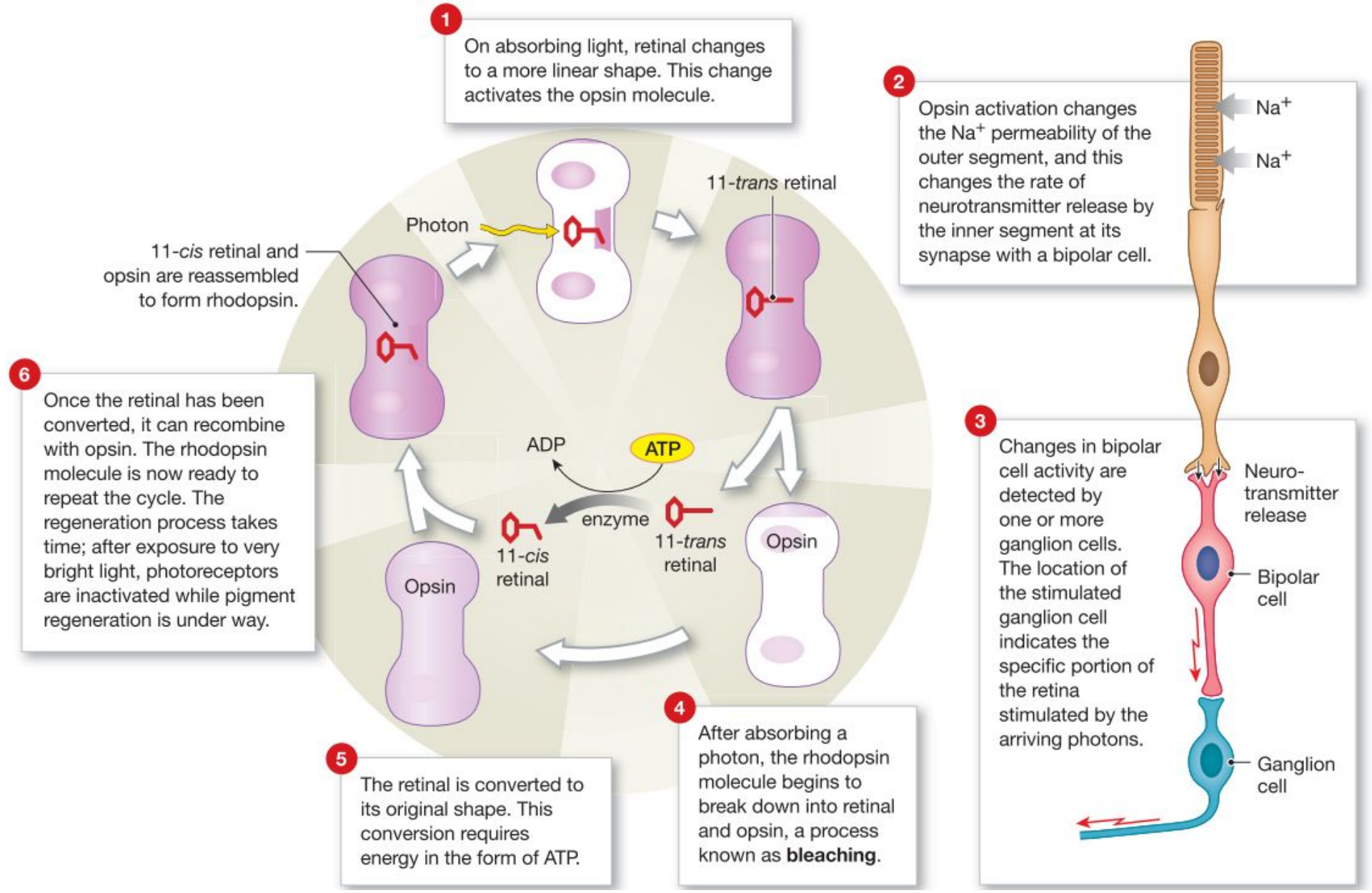


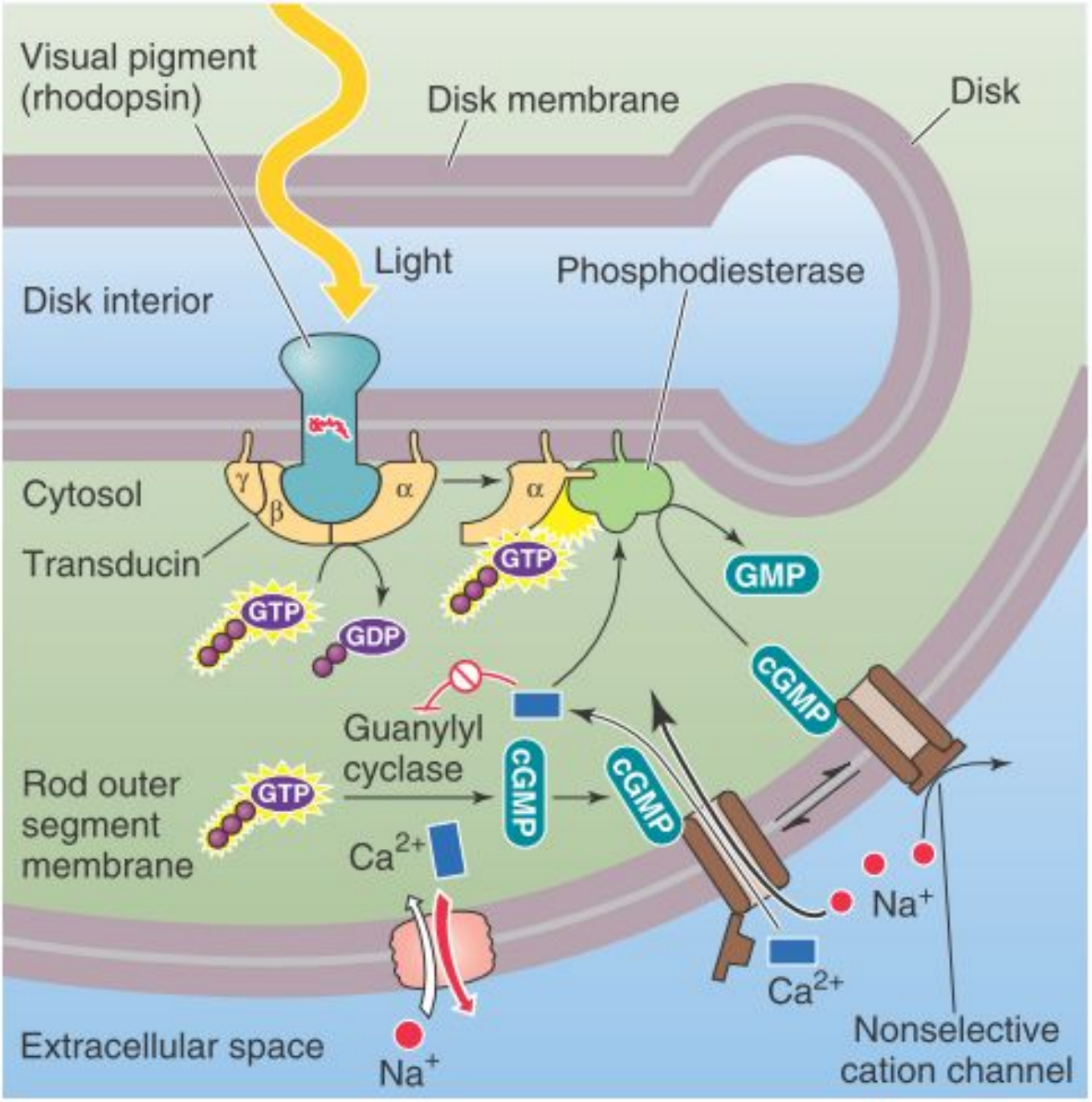
FIGURE 16.36 Structure and Location of the Visual Pigments. (a) A rod cell. (b) Detail of the rod outer segment. (c) One disc of the outer segment showing the membrane studded with pigment molecules. (d) A pigment molecule, embedded in the unit membrane of the disc, showing the protein moiety, opsin, and the vitamin A derivative, retinal. (e) *Cis*-retinal, the isomer present in the absence of light. (f) *Trans*-retinal, the isomer produced when the pigment absorbs a photon of light.

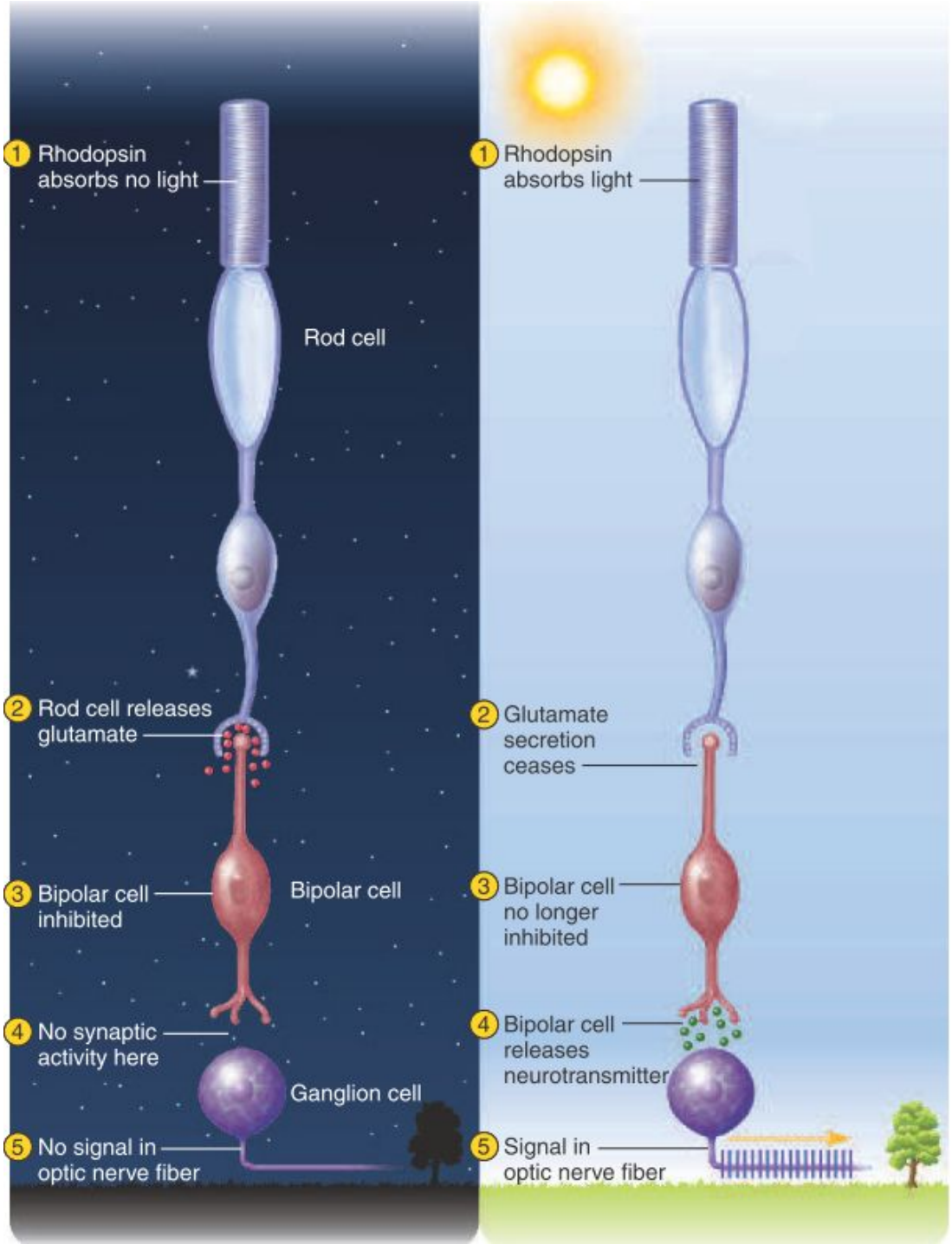


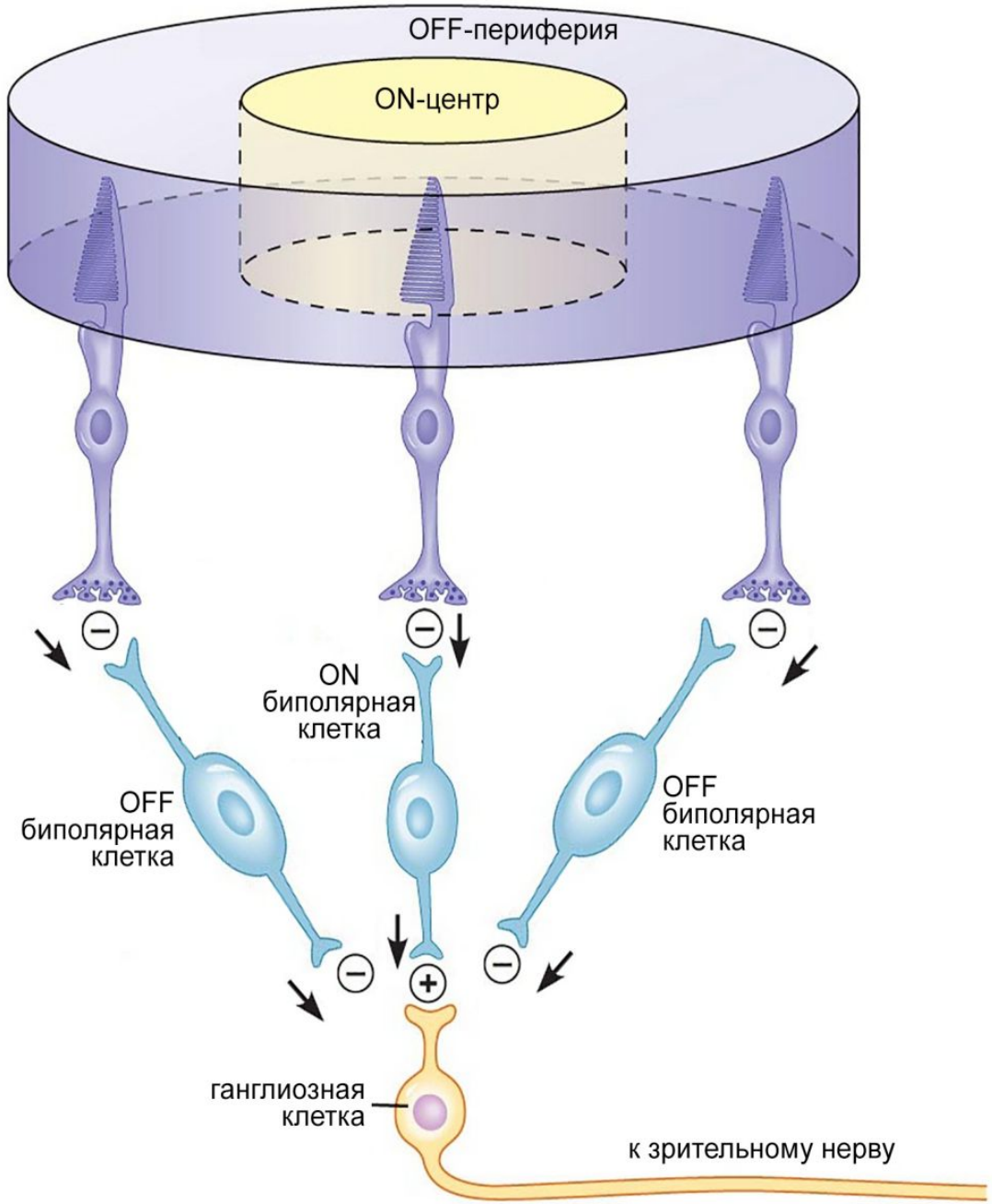


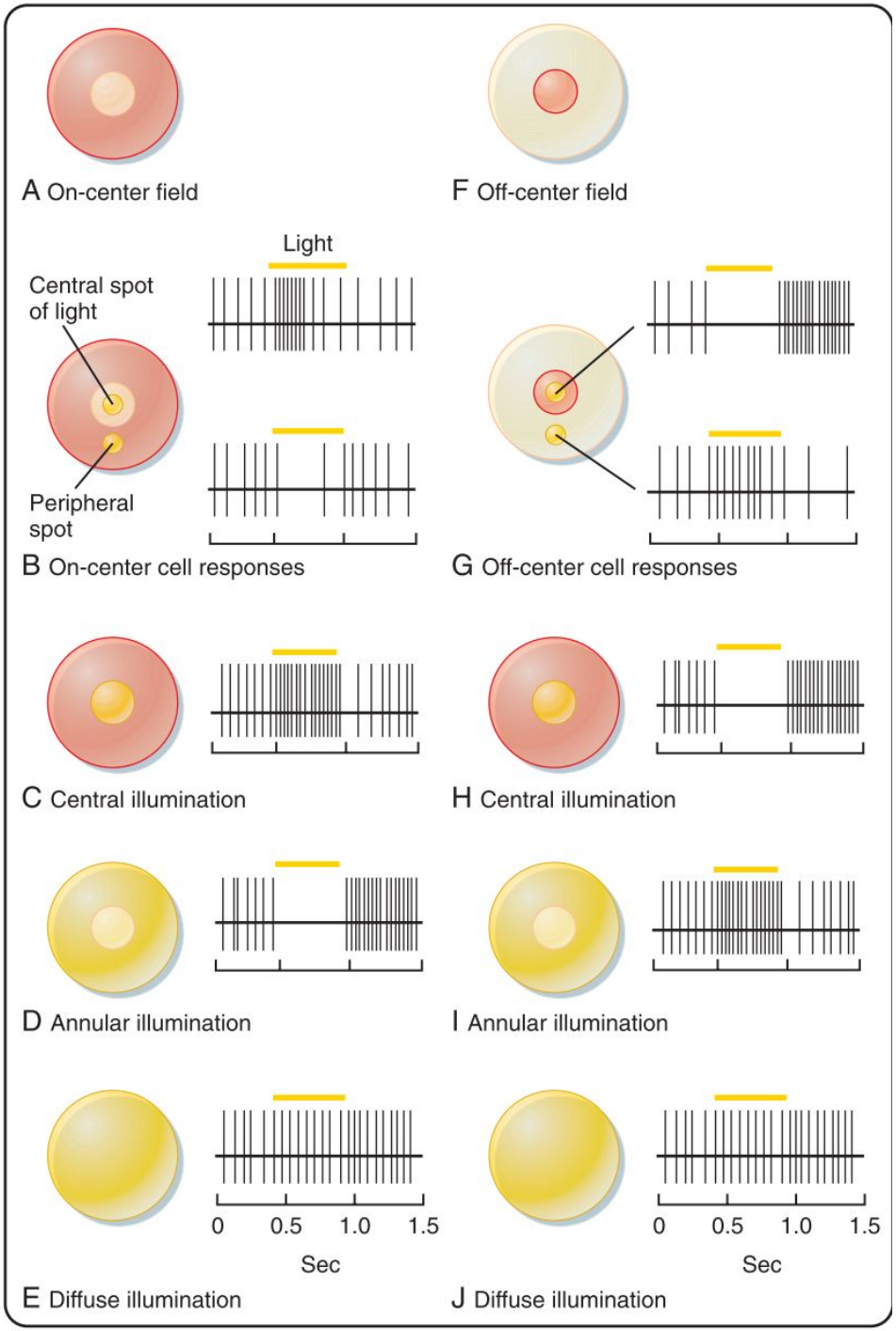

A OPSIN
C
Disk
interior
3
2
1
4
5
6
7
Cytosol
Retinal
Attachment
site for retinal

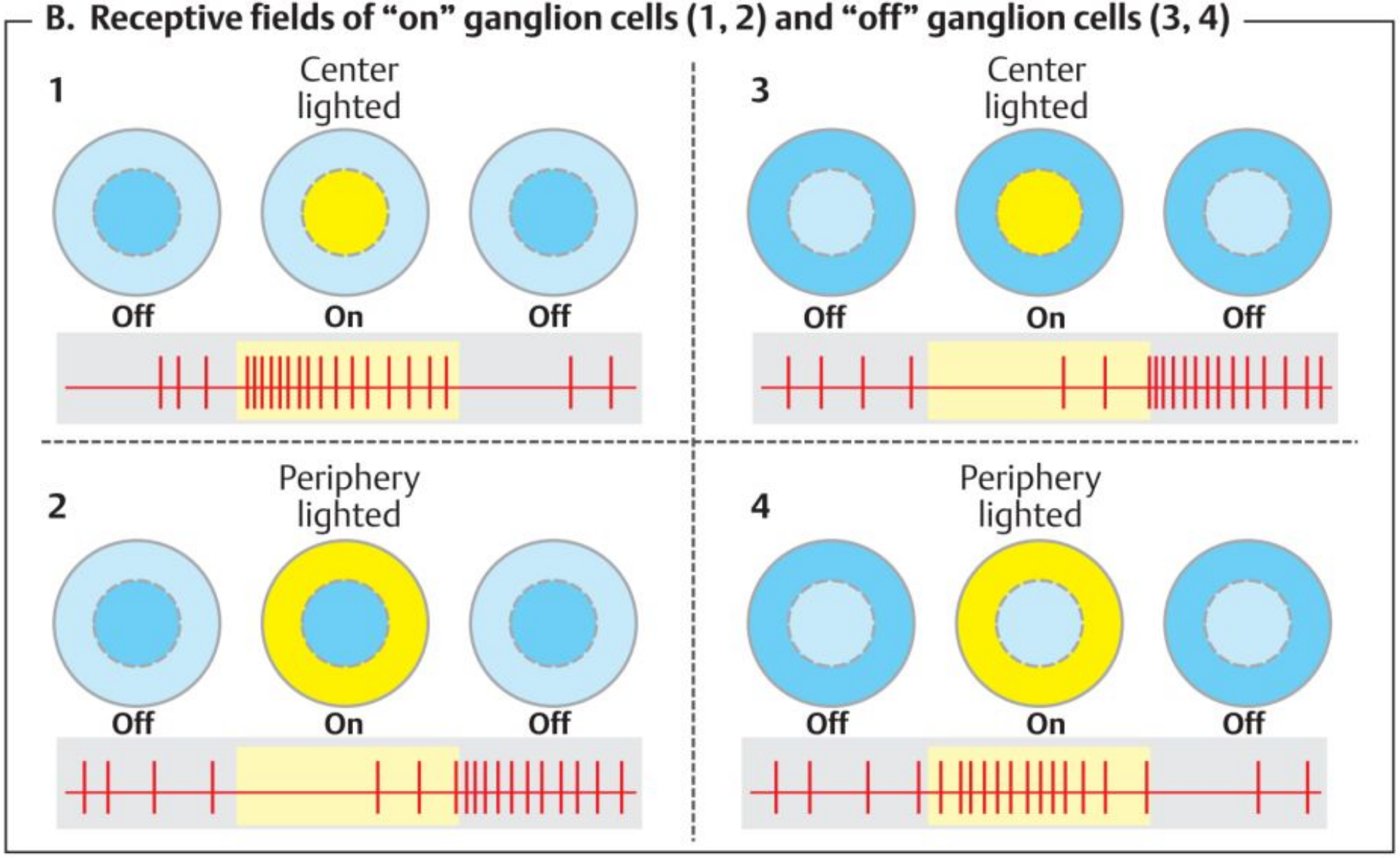

1
On absorbing light, retinal changes to a more linear shape. This change activates the opsin molecule.
2
Opsin activation changes the Na^+ permeability of the outer segment, and this changes the rate of neurotransmitter release by the inner segment at its synapse with a bipolar cell.
Na^+
Na^+
3
Changes in bipolar cell activity are detected by one or more ganglion cells. The location of the stimulated ganglion cell indicates the specific portion of the retina stimulated by the arriving photons.
Neuro-transmitter release
Bipolar cell
Ganglion cell
4
After absorbing a photon, the rhodopsin molecule begins to break down into retinal and opsin, a process known as **bleaching**.
5
The retinal is converted to its original shape. This conversion requires energy in the form of ATP.
6
Once the retinal has been converted, it can recombine with opsin. The rhodopsin molecule is now ready to repeat the cycle. The regeneration process takes time; after exposure to very bright light, photoreceptors are inactivated while pigment regeneration is under way.
Photon
11-*trans* retinal
11-*cis* retinal and opsin are reassembled to form rhodopsin.
ADP
ATP
enzyme
11-*cis* retinal
11-*trans* retinal
Opsin
Opsin


C VISUAL TRANSDUCTION
Visual pigment (rhodopsin)
Disk membrane
Disk
Light
Disk interior
Phosphodiesterase
Cytosol
Transducin
γ
β
α
α
GTP
GDP
GTP
GMP
cGMP
Guanylyl cyclase
Rod outer segment membrane
GTP
cGMP
cGMP
Ca2+
Na+
Ca2+
Extracellular space
Na+
Nonselective cation channel

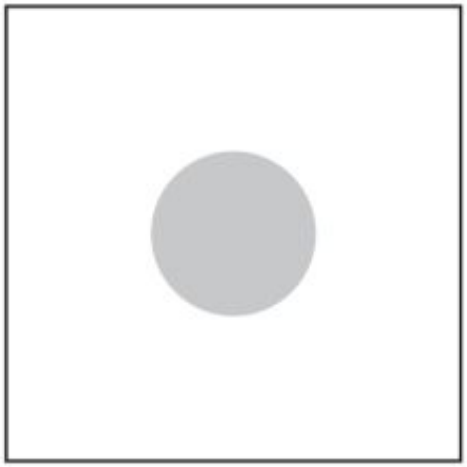

1 Rhodopsin absorbs no light
Rod cell
2 Rod cell releases glutamate
3 Bipolar cell inhibited
Bipolar cell
4 No synaptic activity here
Ganglion cell
5 No signal in optic nerve fiber
1 Rhodopsin absorbs light
2 Glutamate secretion ceases
3 Bipolar cell no longer inhibited
4 Bipolar cell releases neurotransmitter
5 Signal in optic nerve fiber

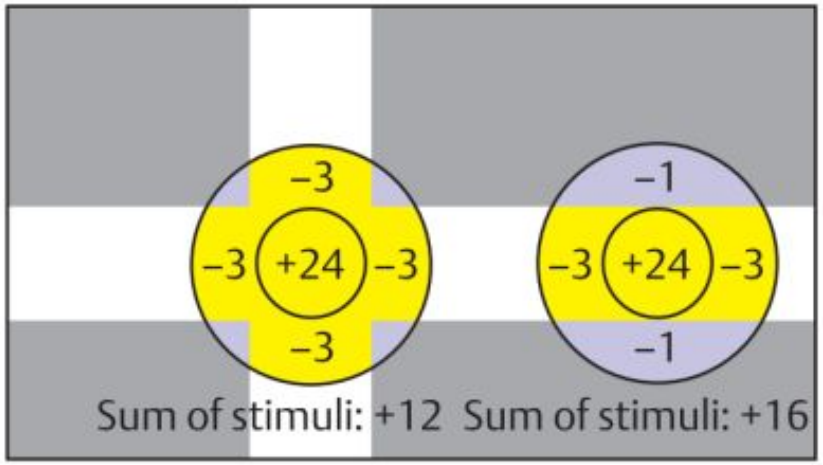


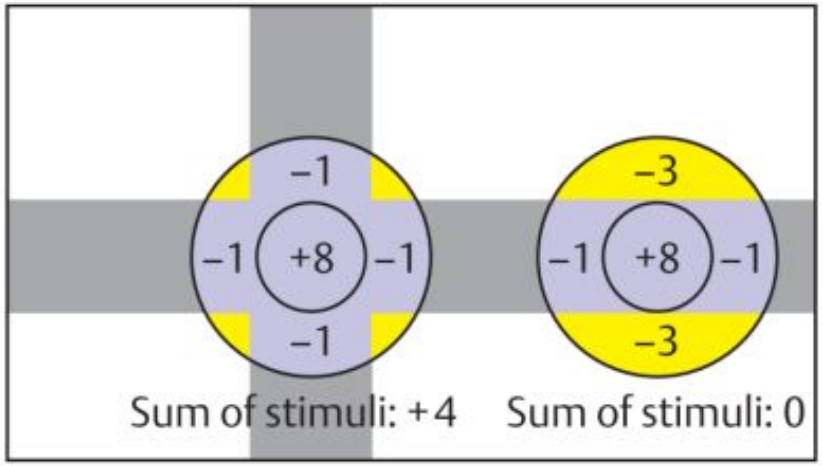

A On-center field
F Off-center field
Light
Central spot of light
Peripheral spot
B On-center cell responses
G Off-center cell responses
C Central illumination
H Central illumination
D Annular illumination
I Annular illumination
0
0.5
1.0
1.5
Sec
E Diffuse illumination
J Diffuse illumination

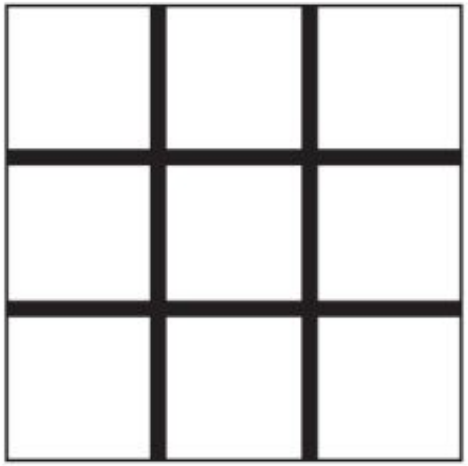

B. Receptive fields of "on" ganglion cells (1, 2) and "off" ganglion cells (3, 4)
1
Center lighted
Off
On
Off
3
Center lighted
Off
On
Off
2
Periphery lighted
Off
On
Off
4
Periphery lighted
Off
On
Off

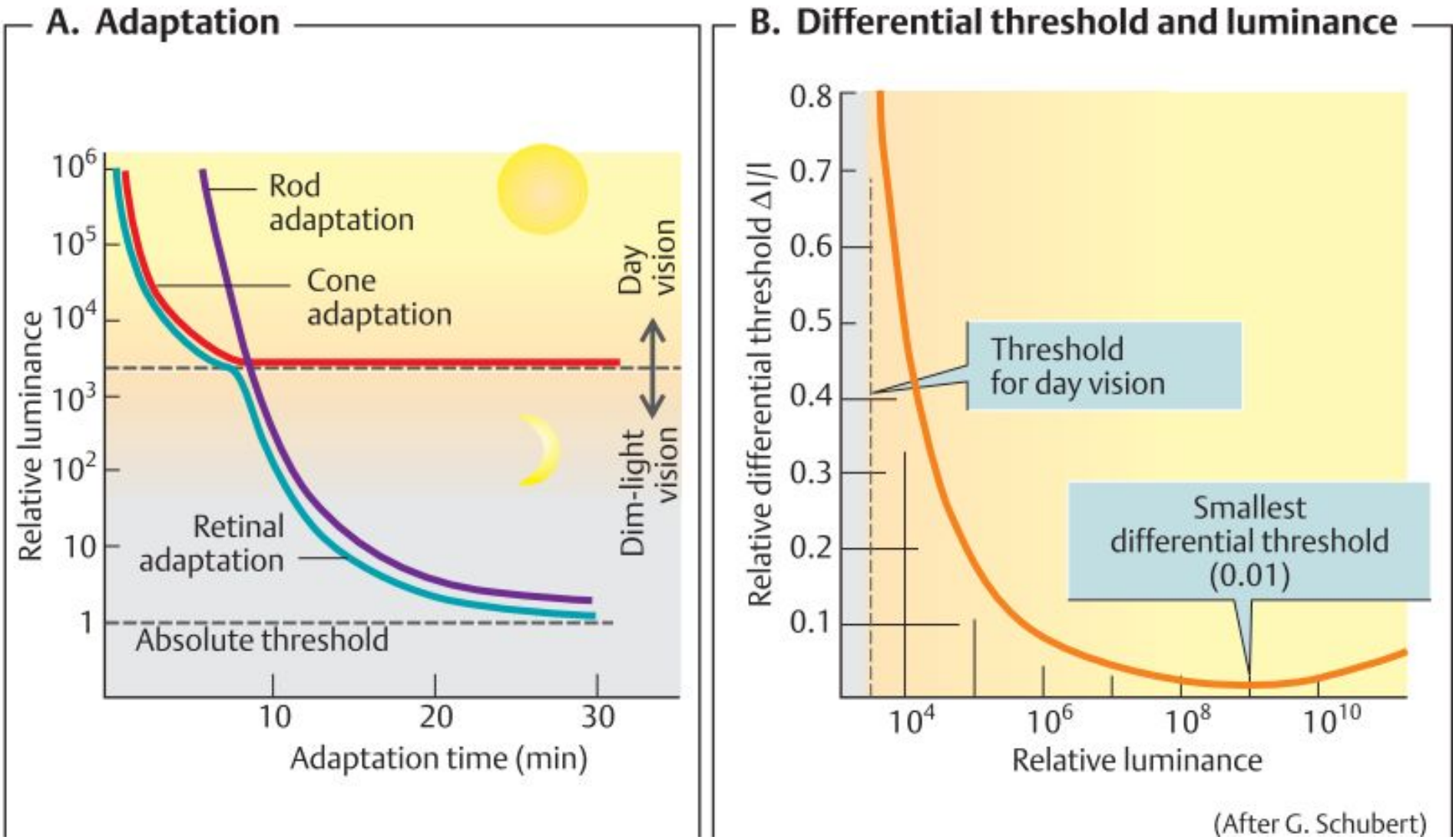
C. Receptive field-related contrast (on ganglion cells)



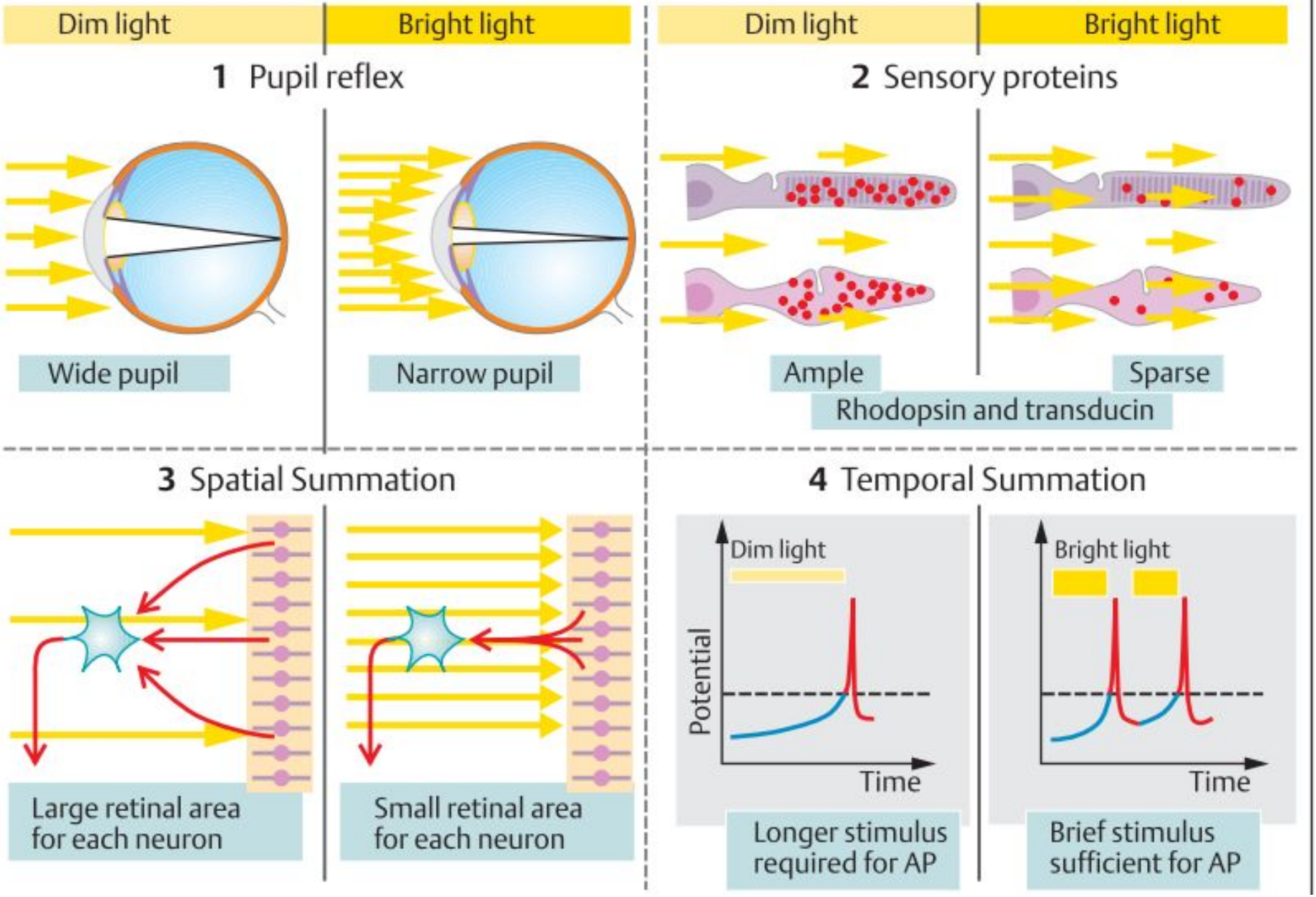







A. Adaptation
Relative luminance
10^6
10^5
10^4
10^3
10^2
10
1
Rod adaptation
Cone adaptation
Retinal adaptation
Absolute threshold
Day vision
Dim-light vision
10
20
30
Adaptation time (min)
B. Differential threshold and luminance
Relative differential threshold ΔI/I
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Threshold for day vision
Smallest differential threshold (0.01)
10^4
10^6
10^8
10^{10}
Relative luminance
(After G. Schubert)

C. Mechanisms for adaptation



при тусклом свете

постганглионарное симпатическое волокно

← из верхнего шейного ганглия

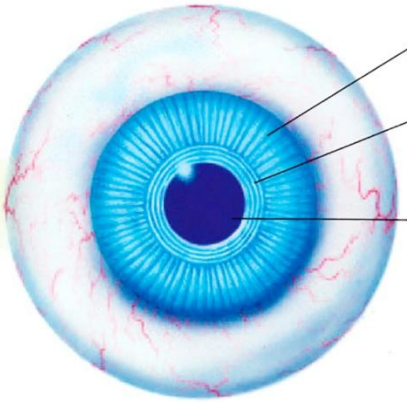
расширение зрачка

при обычном свете

радиальные гладкомышечные волокна радужки

циркулярные гладкомышечные волокна радужки

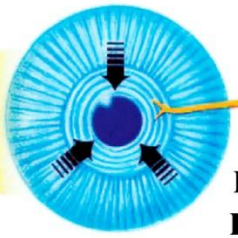
зрачок



при ярком свете

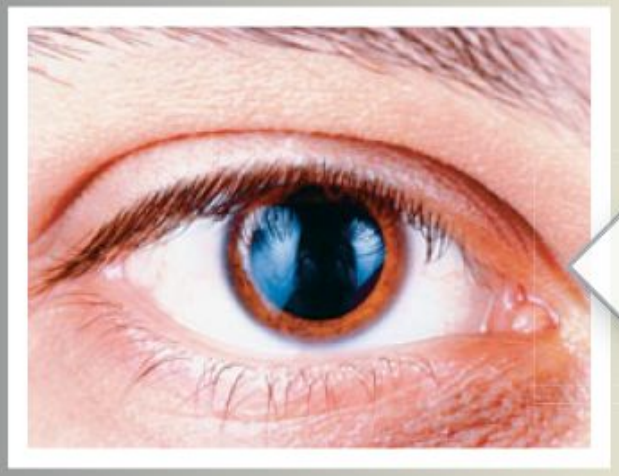
ресничный ганглий

← из глазодвигательного нерва



постганглионарное парасимпатическое волокно

сужение зрачка



Pupillary constrictor (sphincter)

Pupil

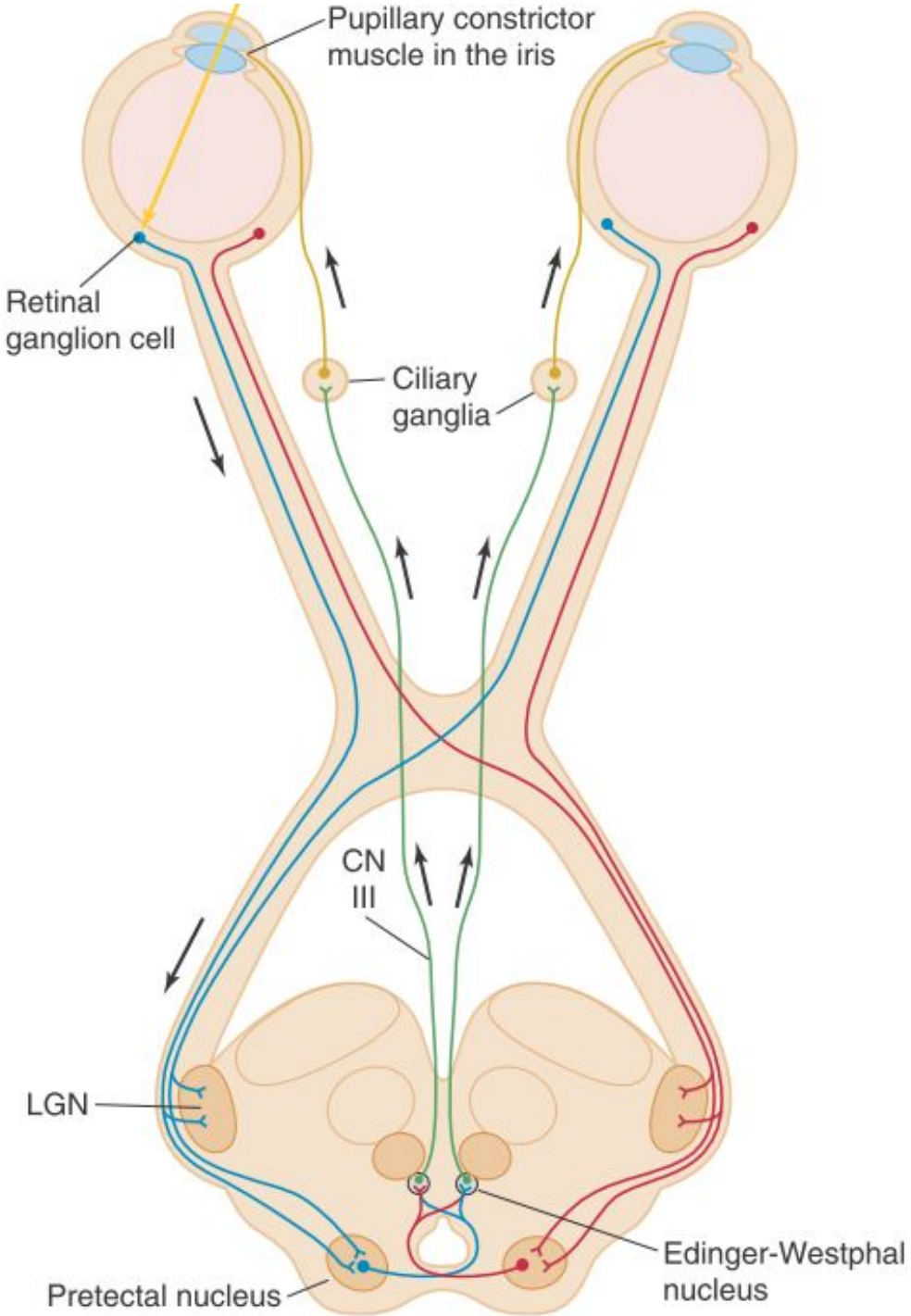
Pupillary dilator (radial)

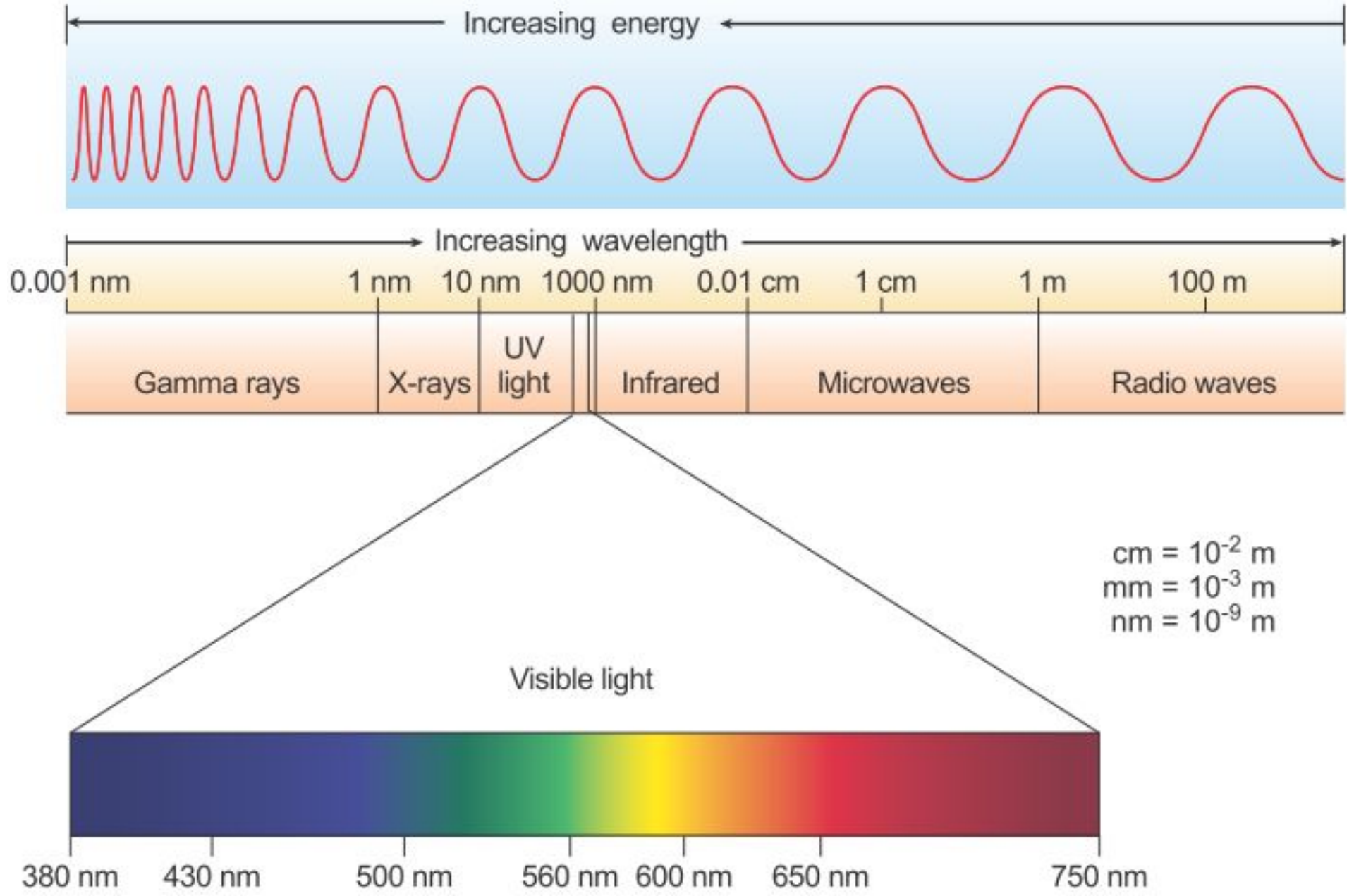
The **pupillary dilator muscles** extend radially away from the edge of the pupil. Contraction of these muscles enlarges the pupil.

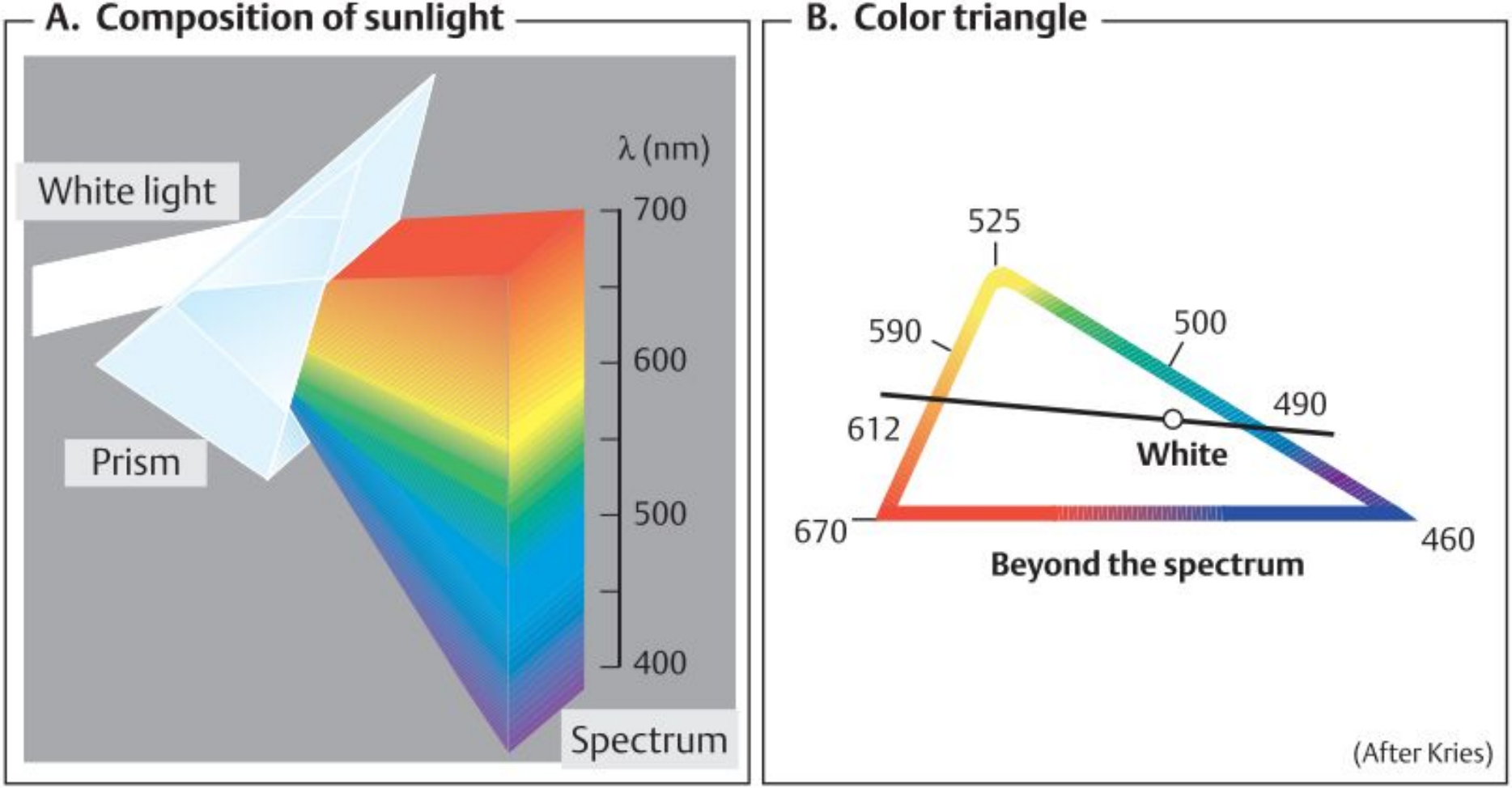
The **pupillary constrictor muscles** form a series of concentric circles around the pupil. When these sphincter muscles contract, the diameter of the pupil decreases.

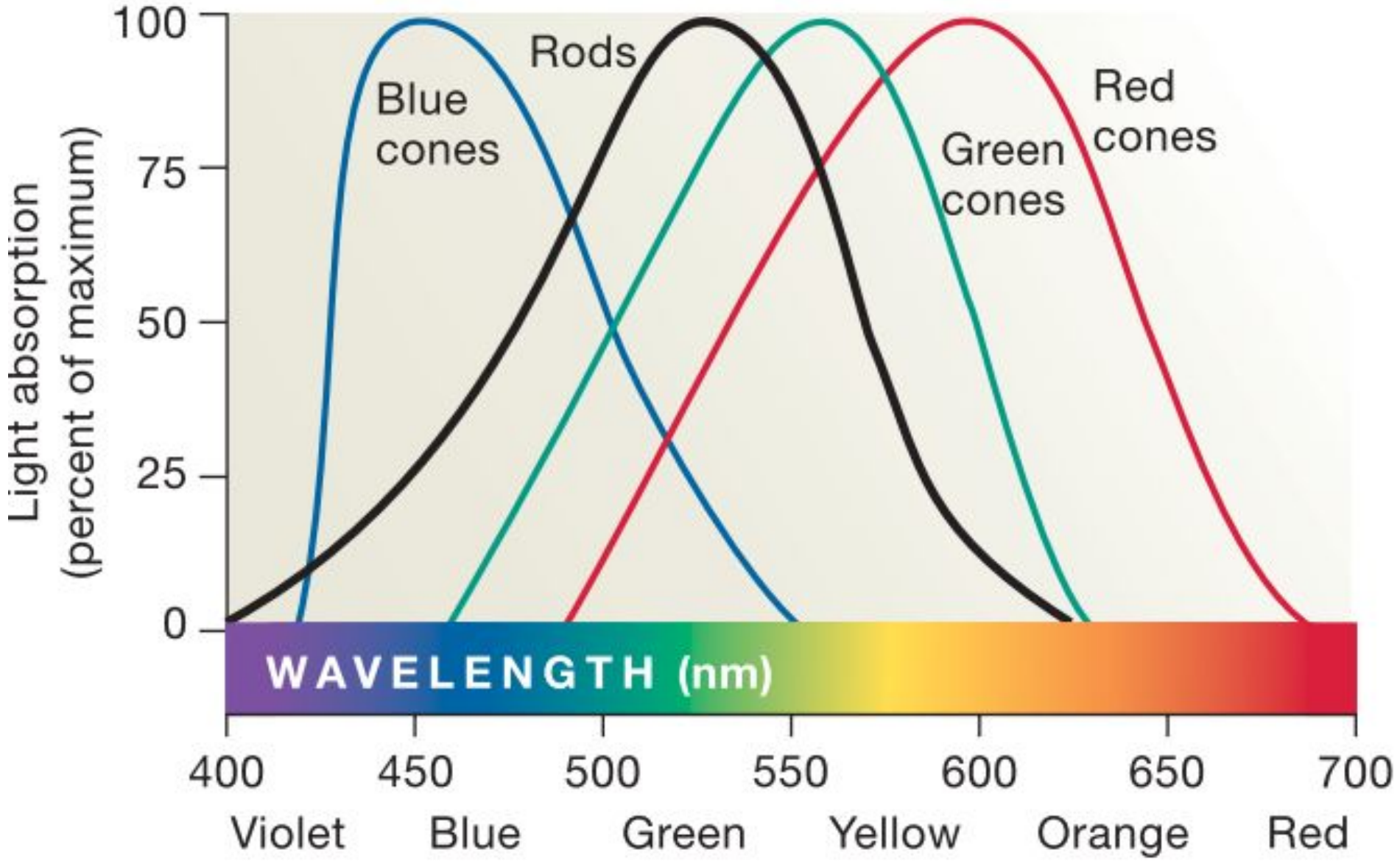
Decreased light intensity
Increased sympathetic stimulation

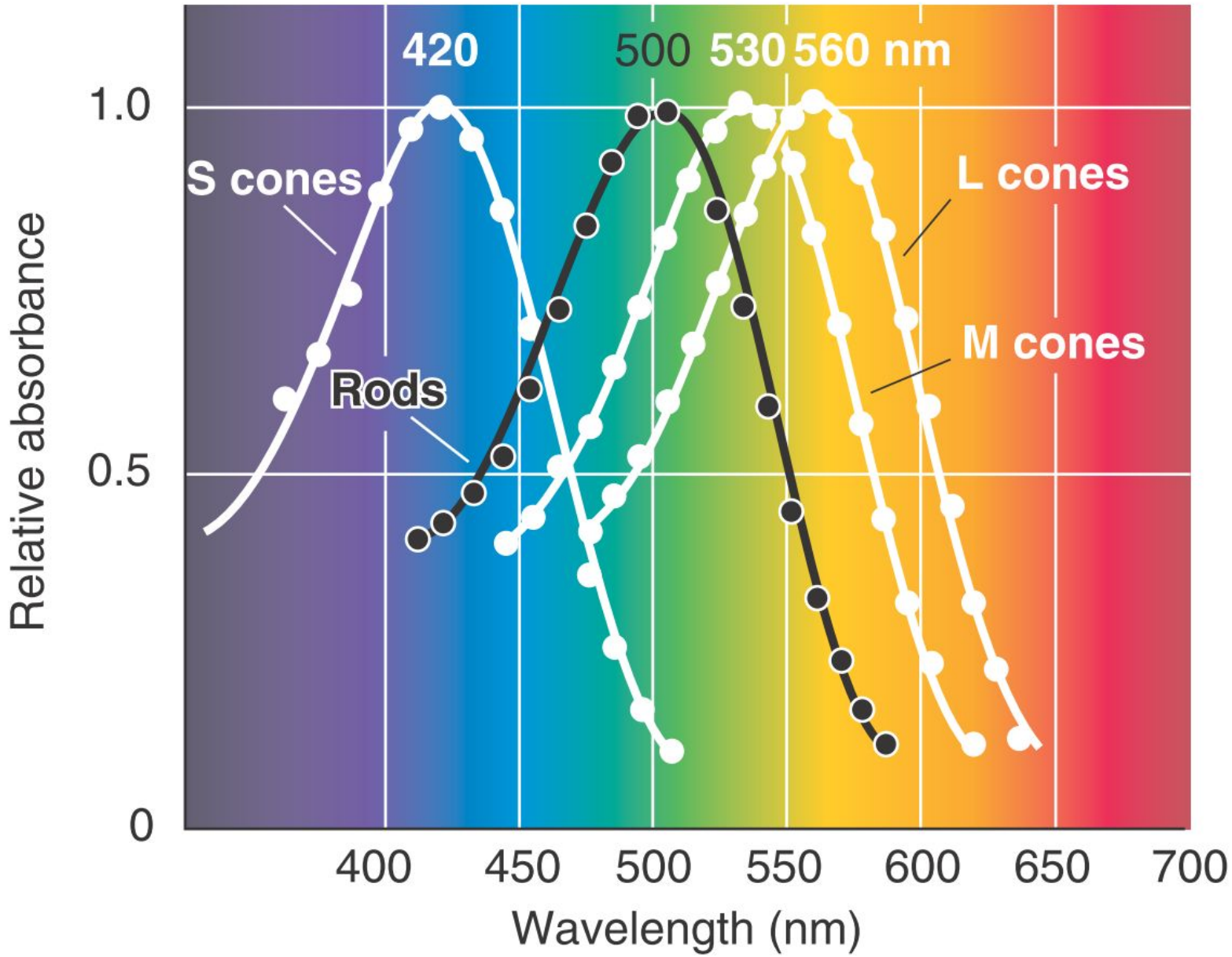
Increased light intensity
Increased parasympathetic stimulation

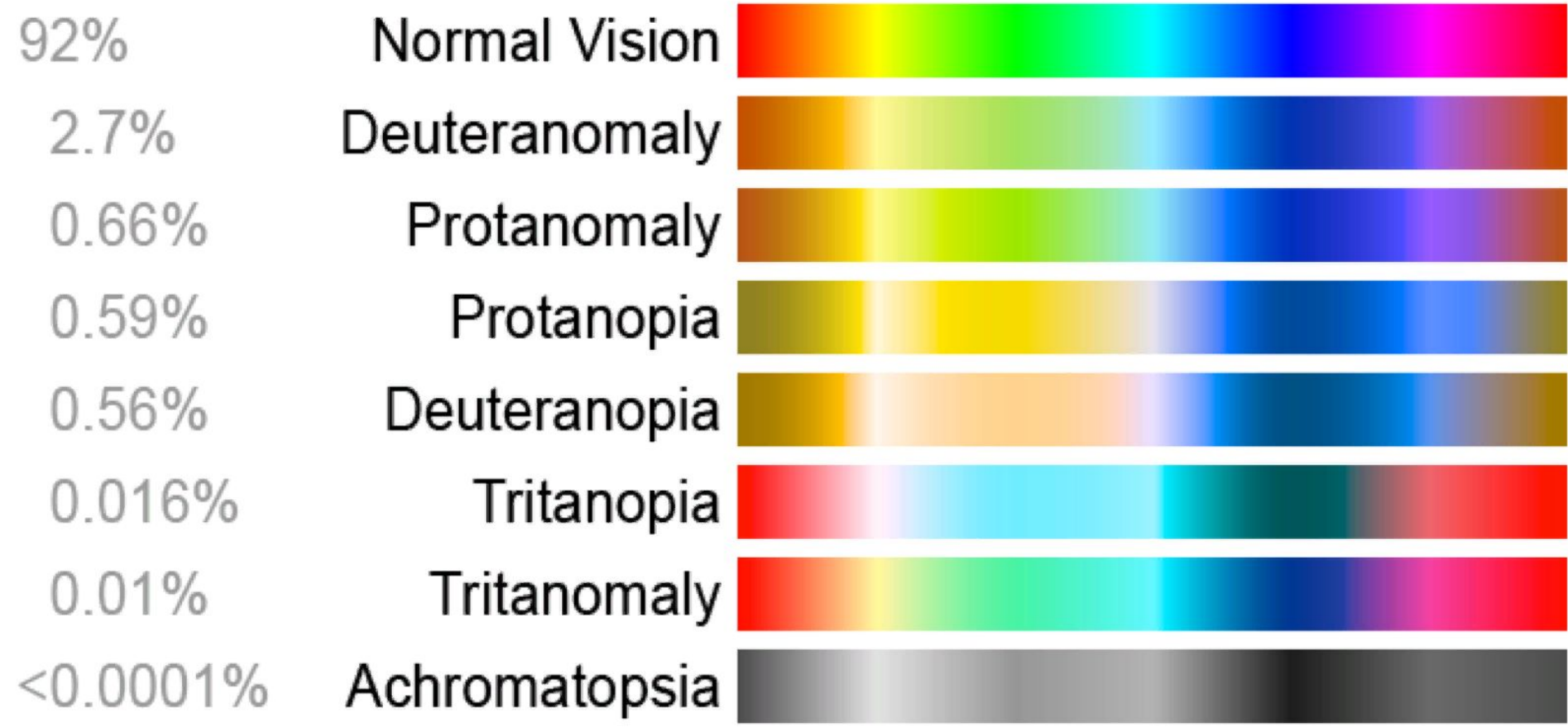

Pupillary constrictor muscle in the iris
Retinal ganglion cell
Ciliary ganglia
CN III
LGN
Pretectal nucleus
Edinger-Westphal nucleus


Increasing energy
Increasing wavelength
0.001 nm
1 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
UV light
Infrared
Microwaves
Radio waves
cm = 10-2 m
mm = 10-3 m
nm = 10-9 m
Visible light
380 nm
430 nm
500 nm
560 nm
600 nm
650 nm
750 nm

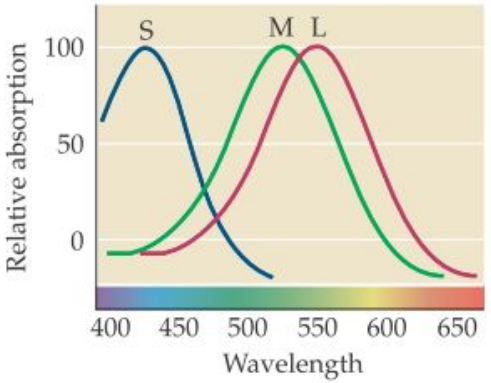

A. Composition of sunlight
White light
Prism
λ (nm)
700
600
500
400
Spectrum
B. Color triangle
525
590
500
490
612
White
670
460
Beyond the spectrum
(After Kries)


Light absorption
(percent of maximum)
100
75
50
25
0
Blue
cones
Rods
Green
cones
Red
cones
WAVELENGTH (nm)
400
450
500
550
600
650
700
Violet
Blue
Green
Yellow
Orange
Red

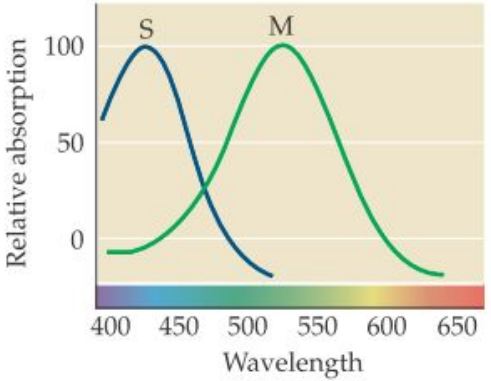

B ABSORBANCE SPECTRA OF THE HUMAN ROD AND CONE RHODOPSINS
420
500
530
560 nm
S cones
Rods
L cones
M cones
Relative absorbance
1.0
0.5
0
400
450
500
550
600
650
700
Wavelength (nm)


92%
Normal Vision
2.7%
Deuteranomaly
0.66%
Protanomaly
0.59%
Protanopia
0.56%
Deuteranopia
0.016%
Tritanopia
0.01%
Tritanomaly
<0.0001%
Achromatopsia

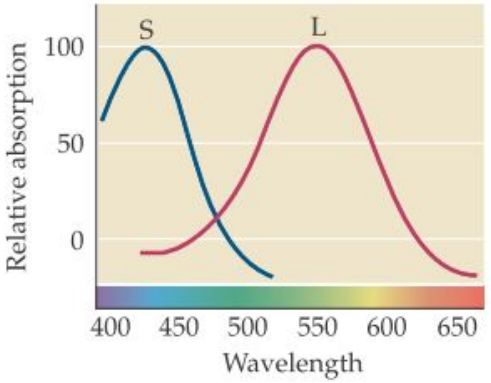
(A) Normal (trichromat)



(B) Protanopia



(C) Deuteranopia



NORMAL VISION

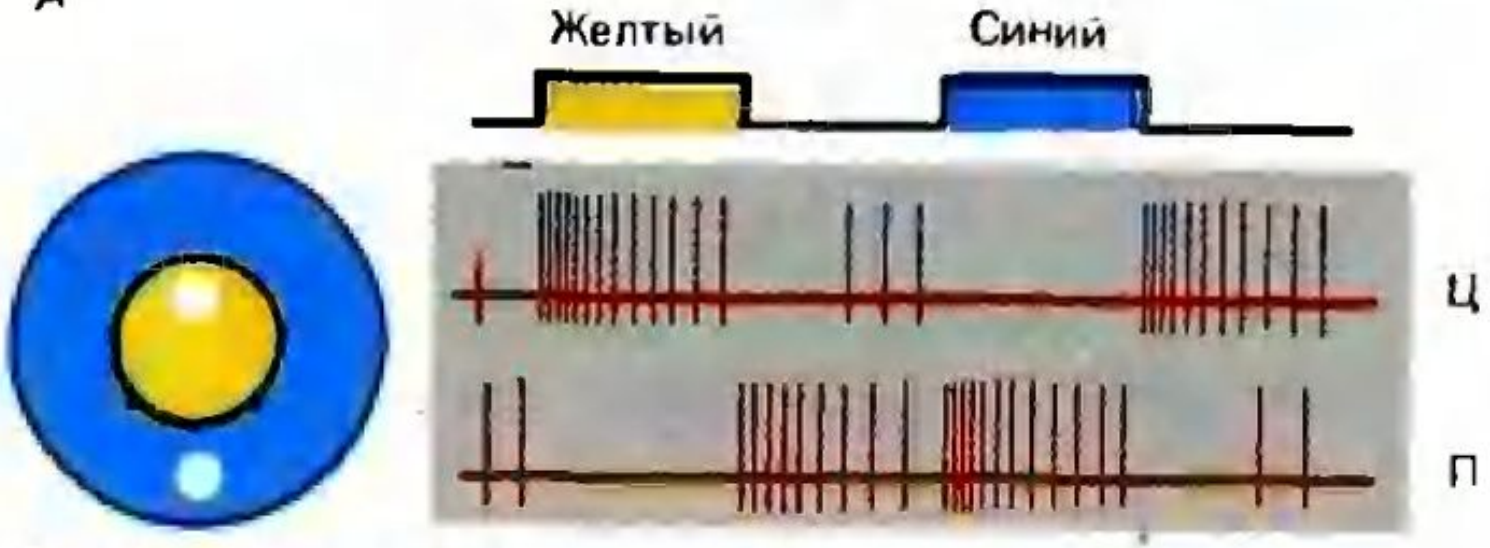
DEUTERANOMALY

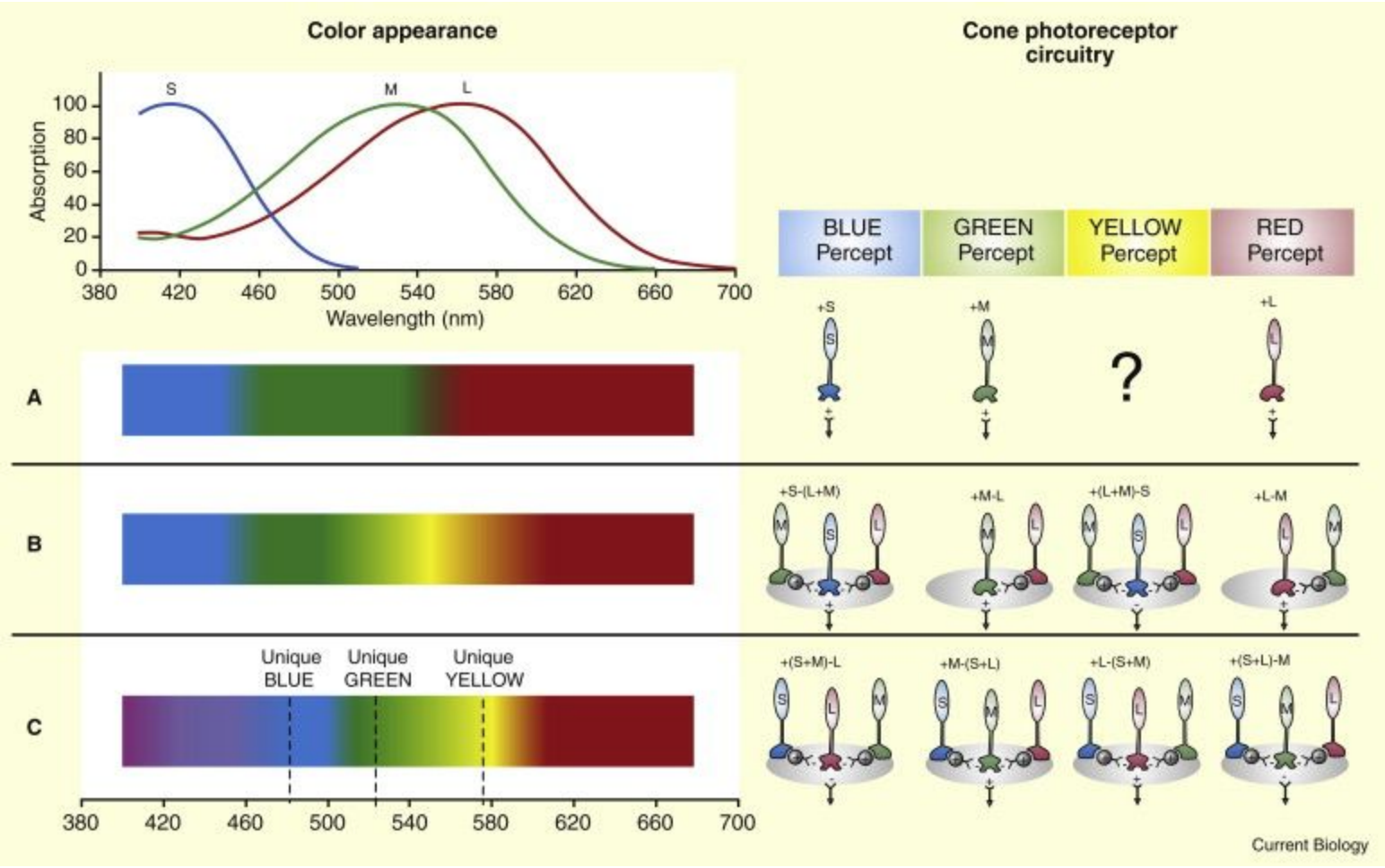
PROTANOPIA

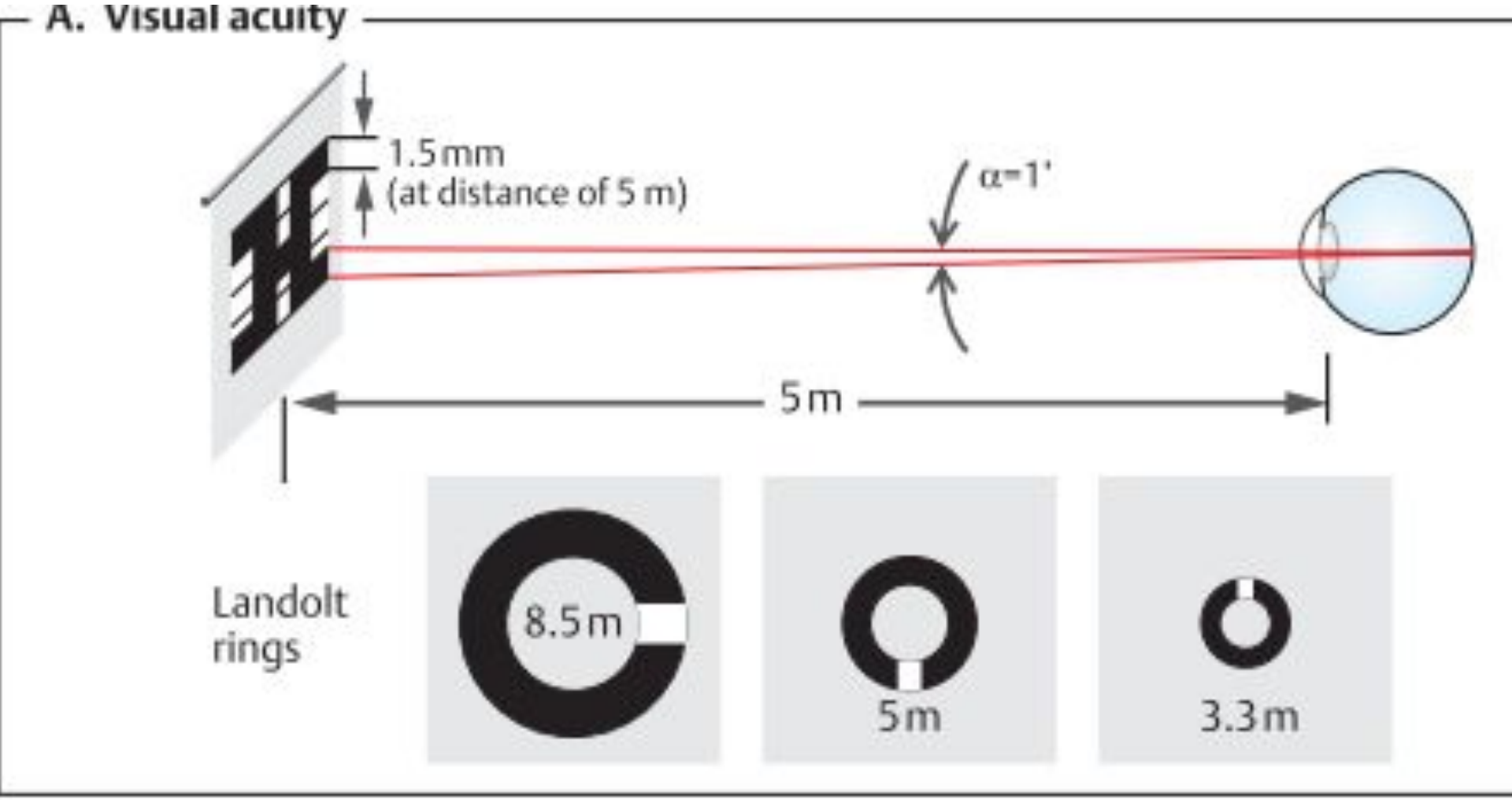
TRITANOPIA

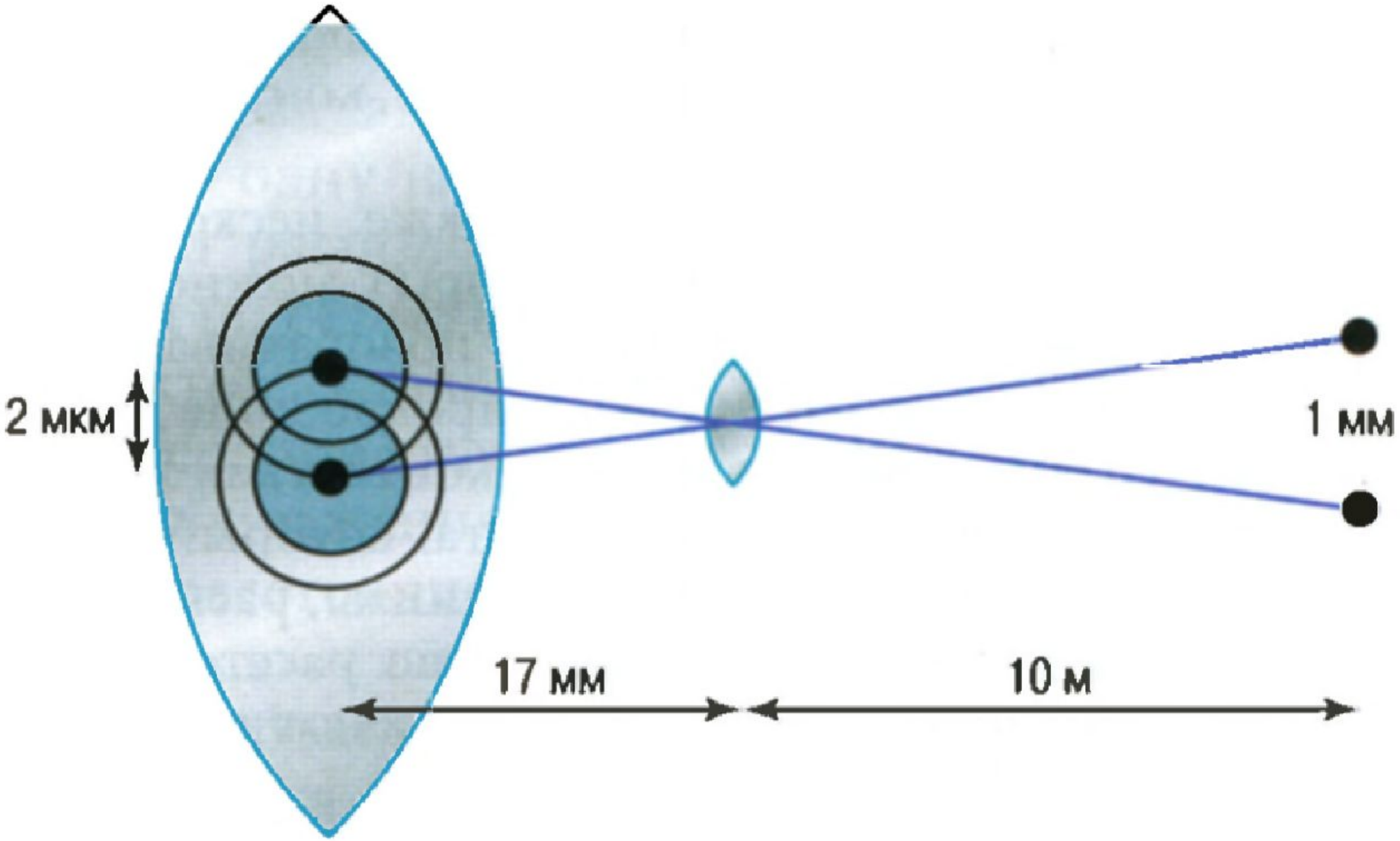
Рецептивное поле нейрона красно-зеленой системы

А

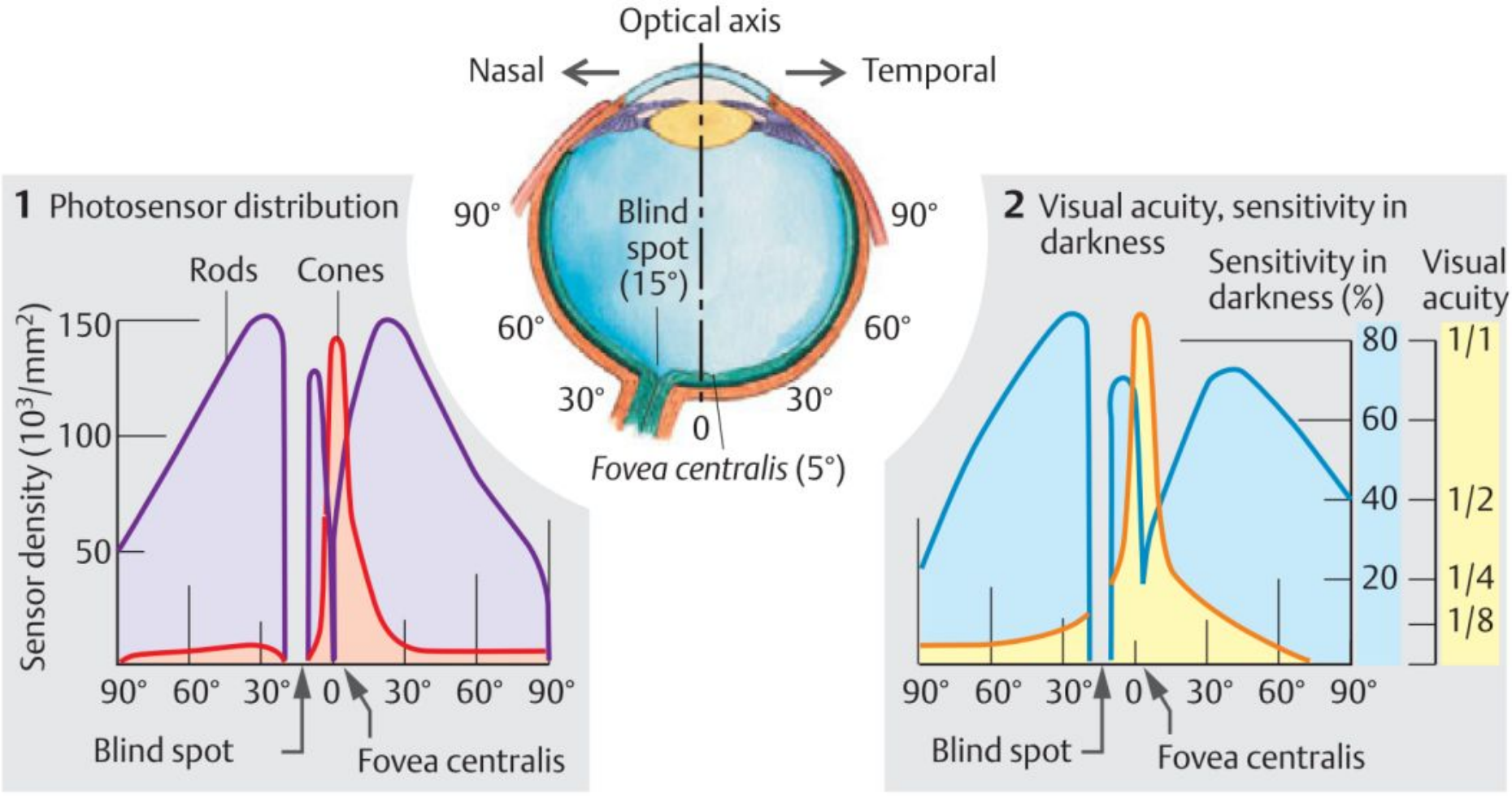


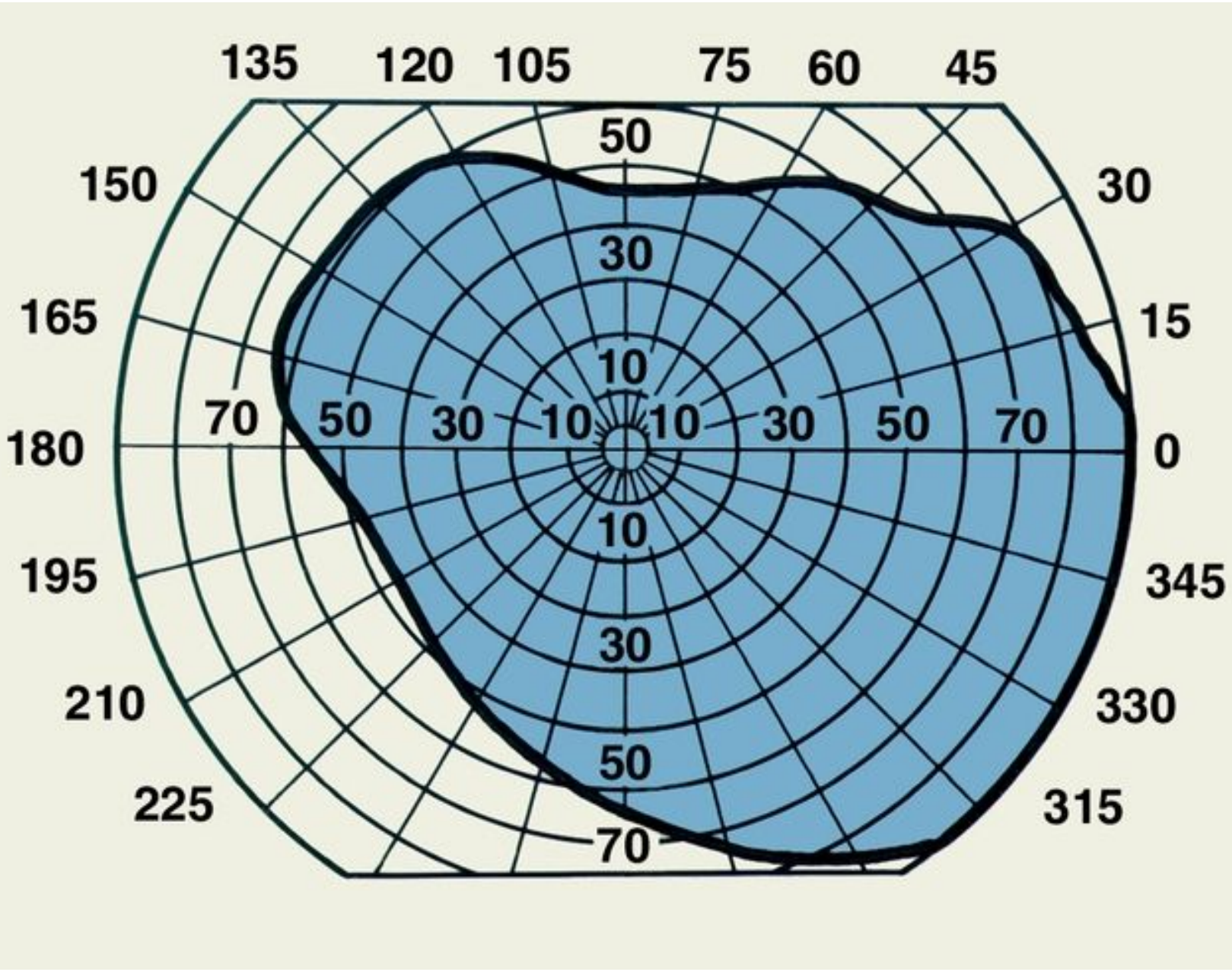

Color appearance
Cone photoreceptor circuitry
S
M
L
Absorption
100
80
60
40
20
0
380
420
460
500
540
580
620
660
700
Wavelength (nm)
A
B
C
Unique BLUE
Unique GREEN
Unique YELLOW
BLUE Percept
GREEN Percept
YELLOW Percept
RED Percept
+S
+M
?
+L
+S-(L+M)
+M-L
+(L+M)-S
+L-M
+(S+M)-L
+M-(S+L)
+L-(S+M)
+(S+L)-M
Current Biology

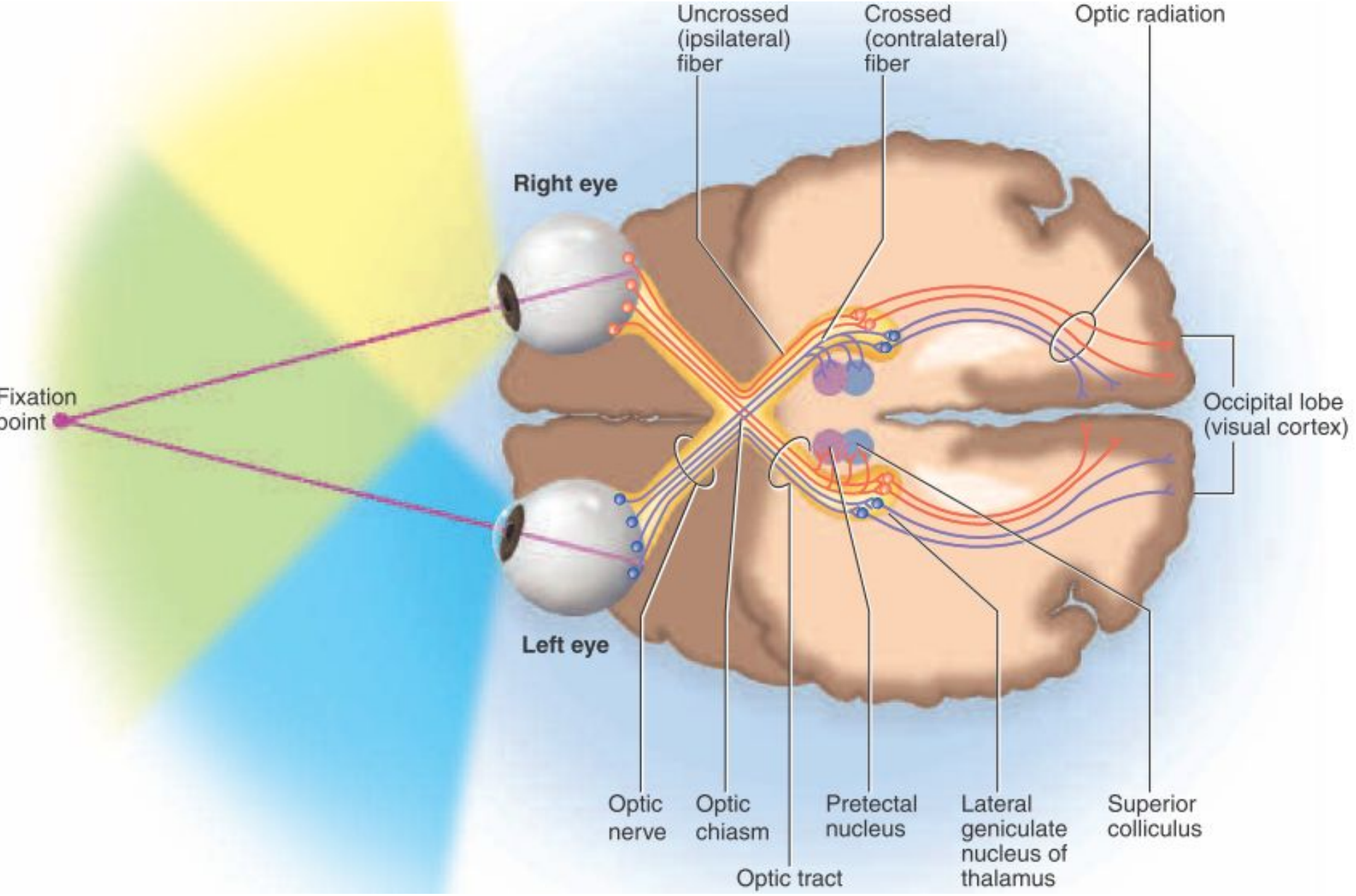

A. Visual acuity
1.5 mm
(at distance of 5 m)
α=1'
5 m
Landolt rings
8.5 m
5 m
3.3 m

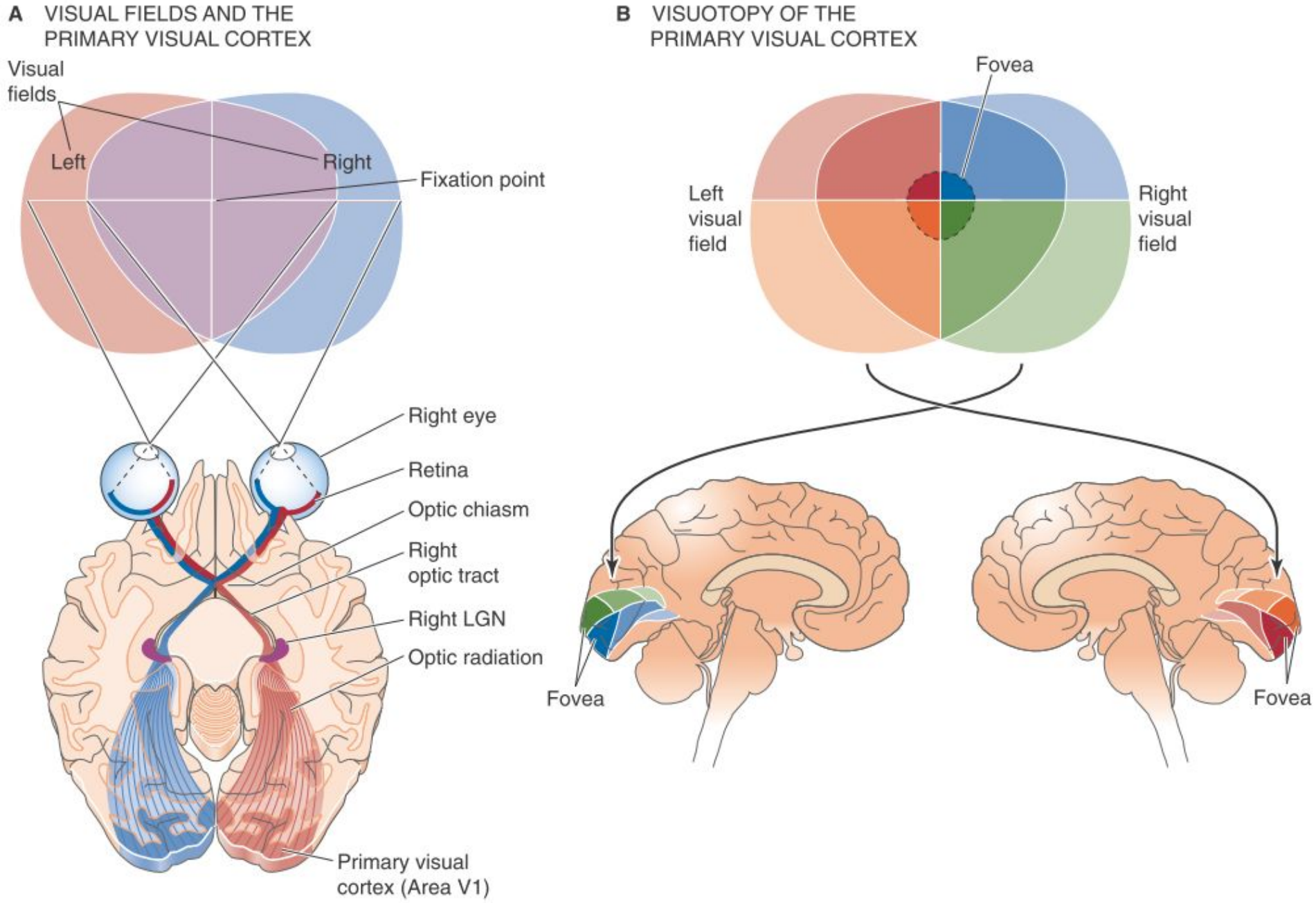

2 мкм
1 мм
17 мм
10 м

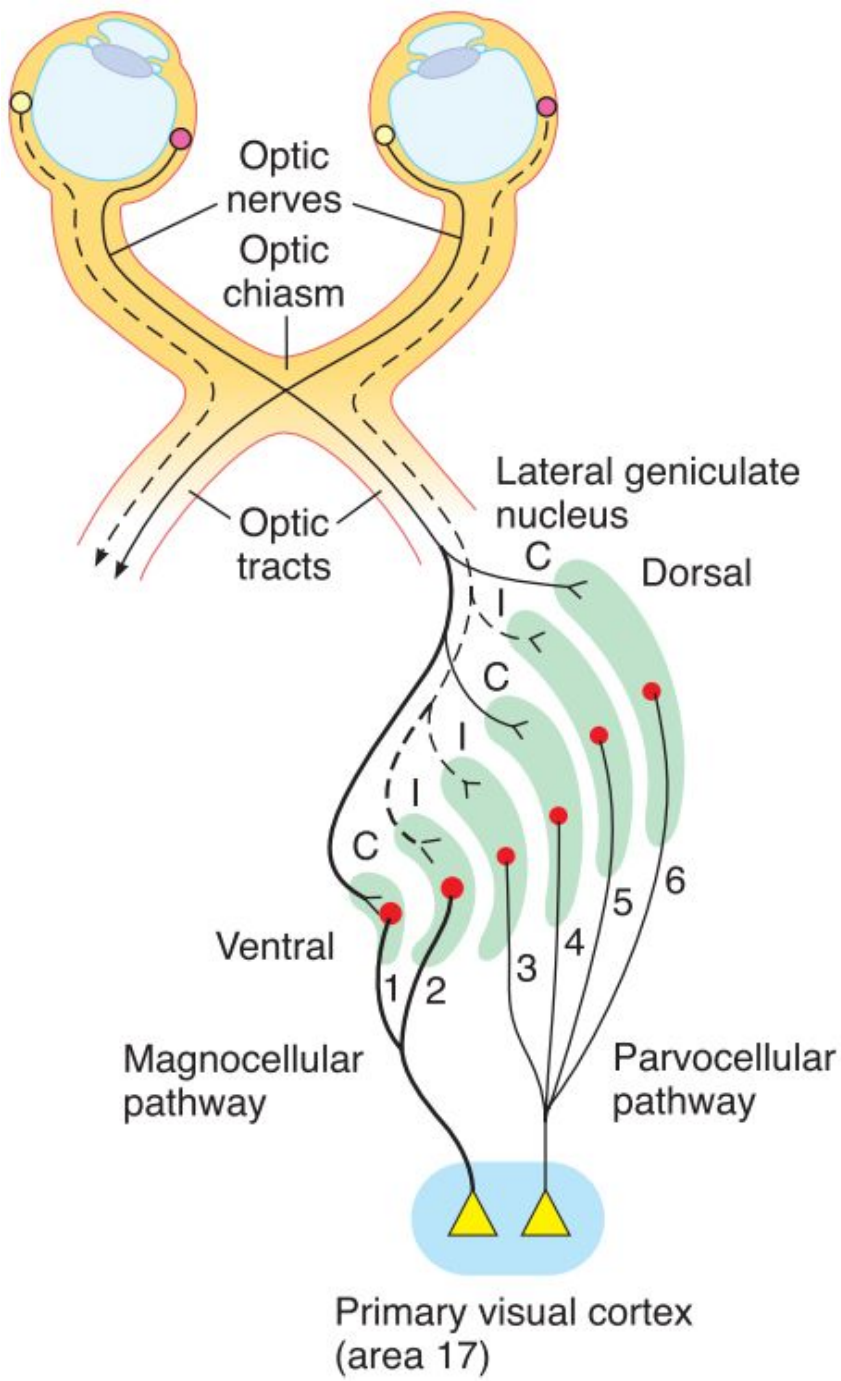
B. Retina: Photosensor distribution, sensitivity in darkness and visual acuity

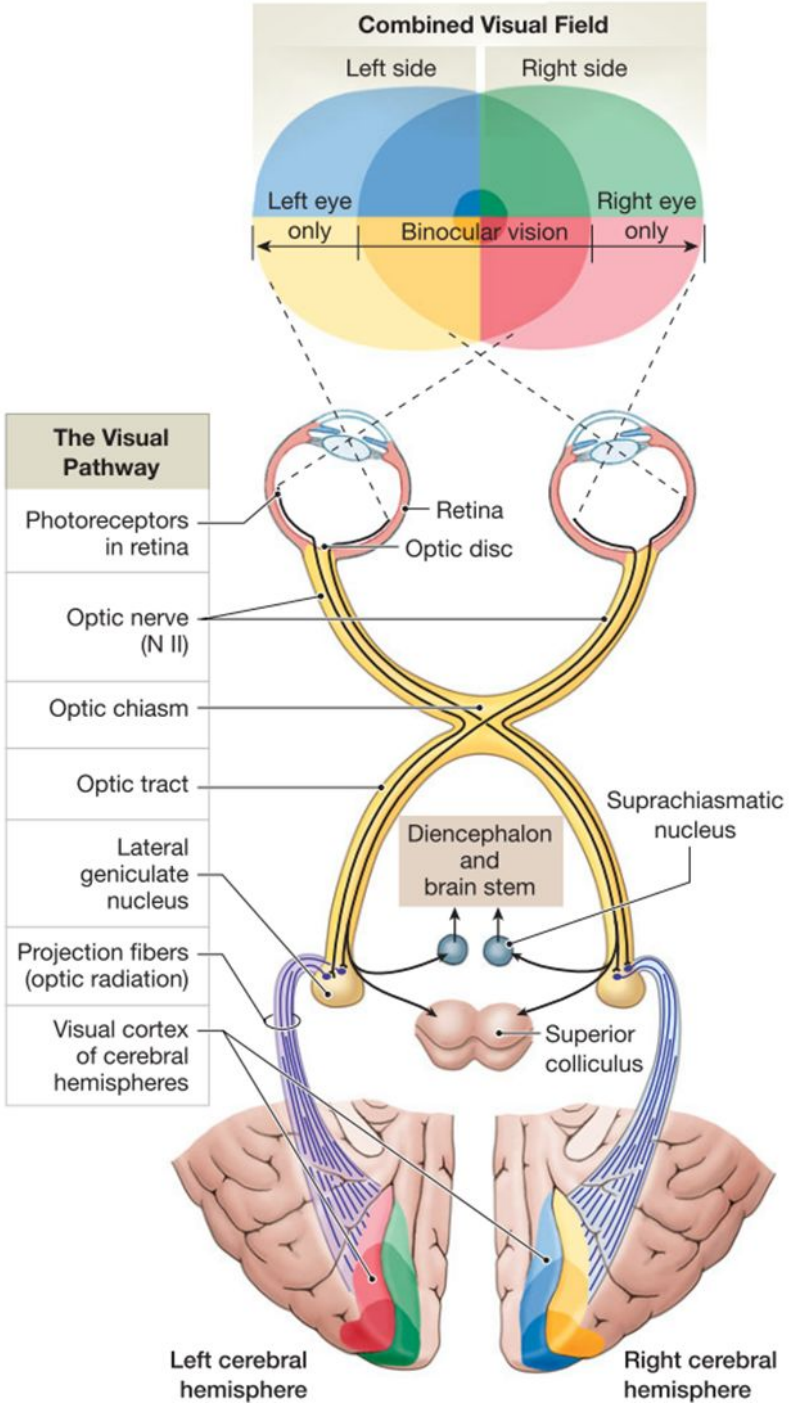


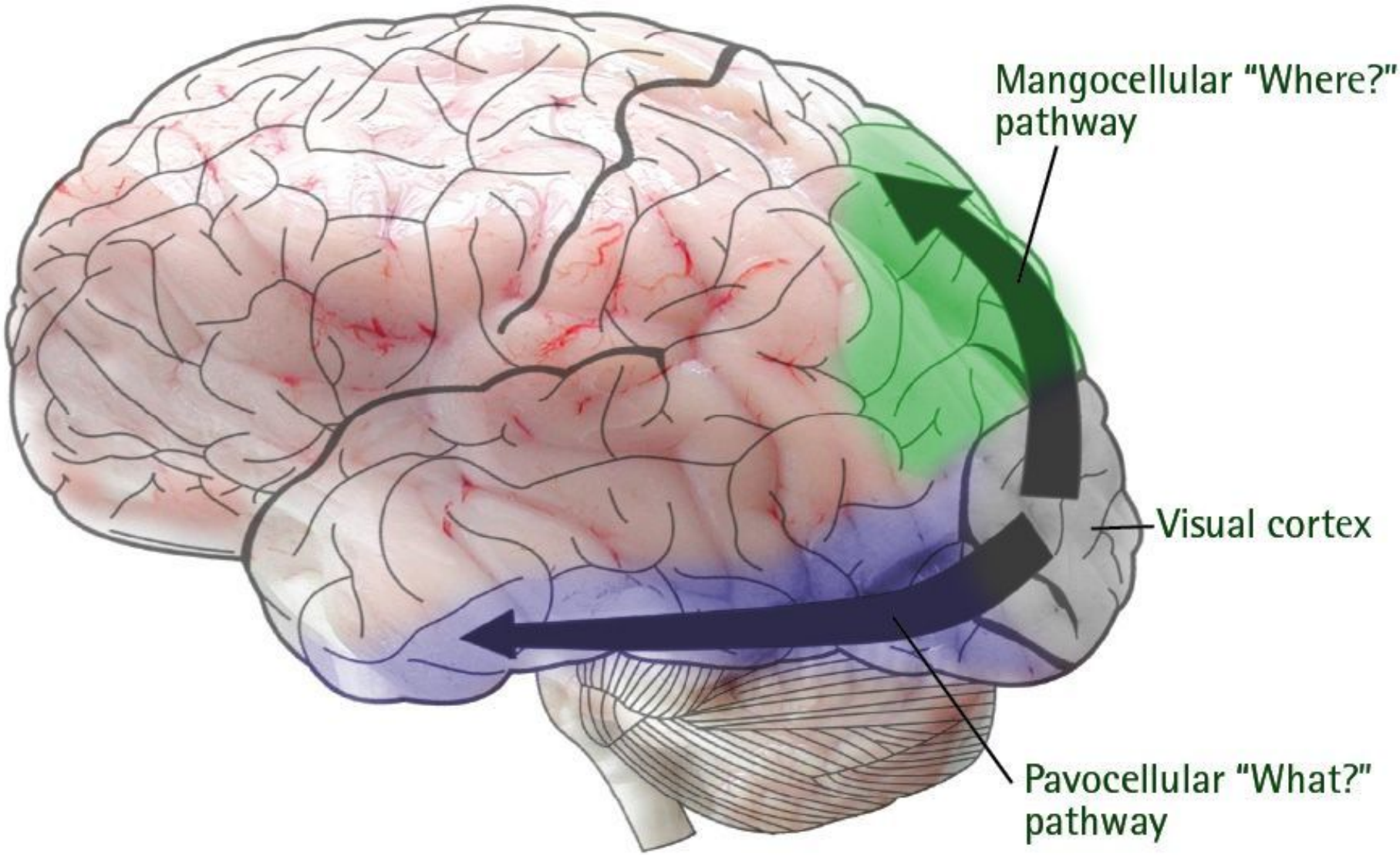

135
120
105
75
60
45
150
30
165
15
180
0
195
345
210
330
225
315
50
30
10
10
30
50
70
70
50
30
10
10
30
50
70

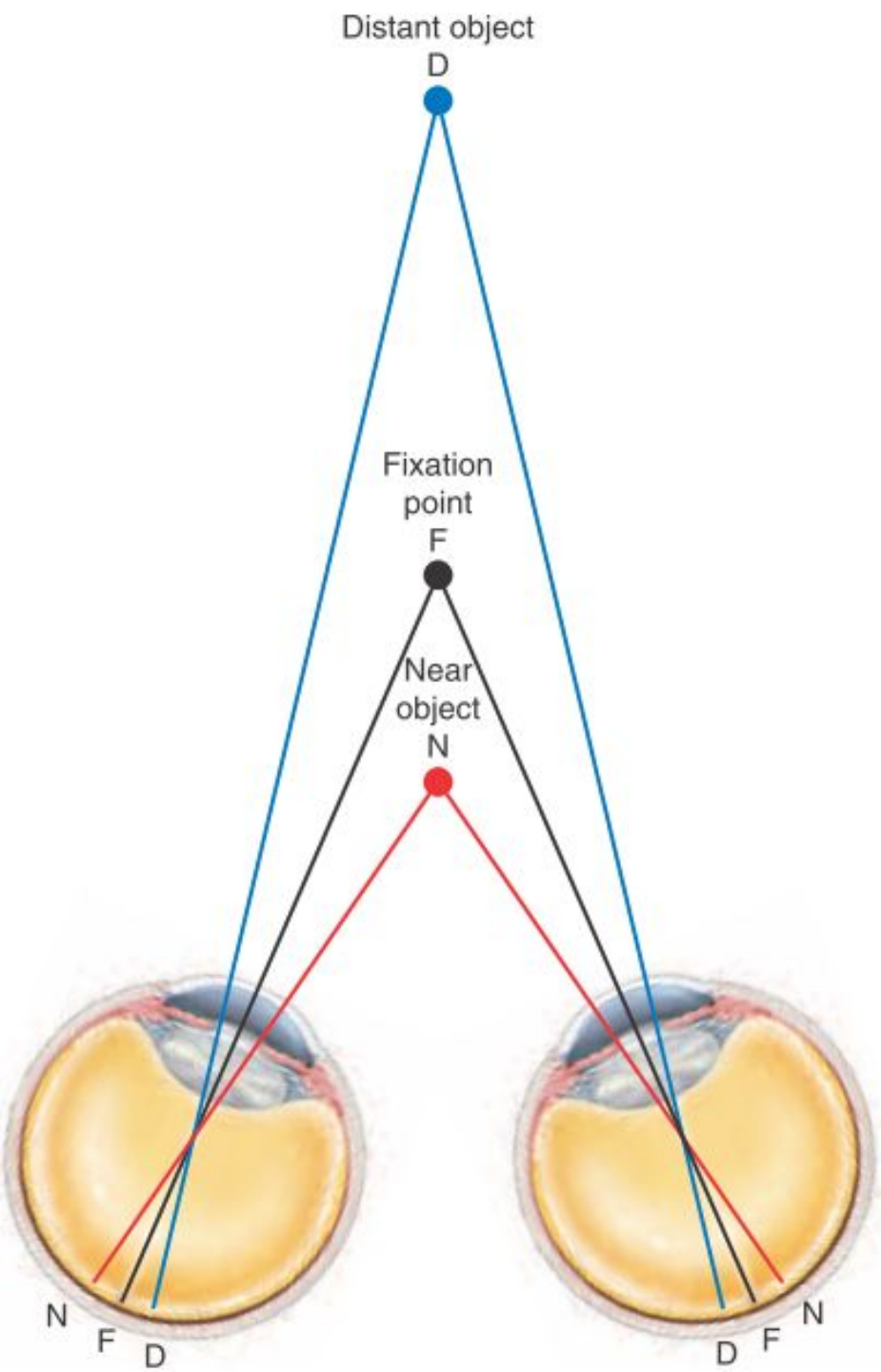

Uncrossed (ipsilateral) fiber
Crossed (contralateral) fiber
Optic radiation
Right eye
Fixation point
Occipital lobe (visual cortex)
Left eye
Optic nerve
Optic chiasm
Optic tract
Pretectal nucleus
Lateral geniculate nucleus of thalamus
Superior colliculus

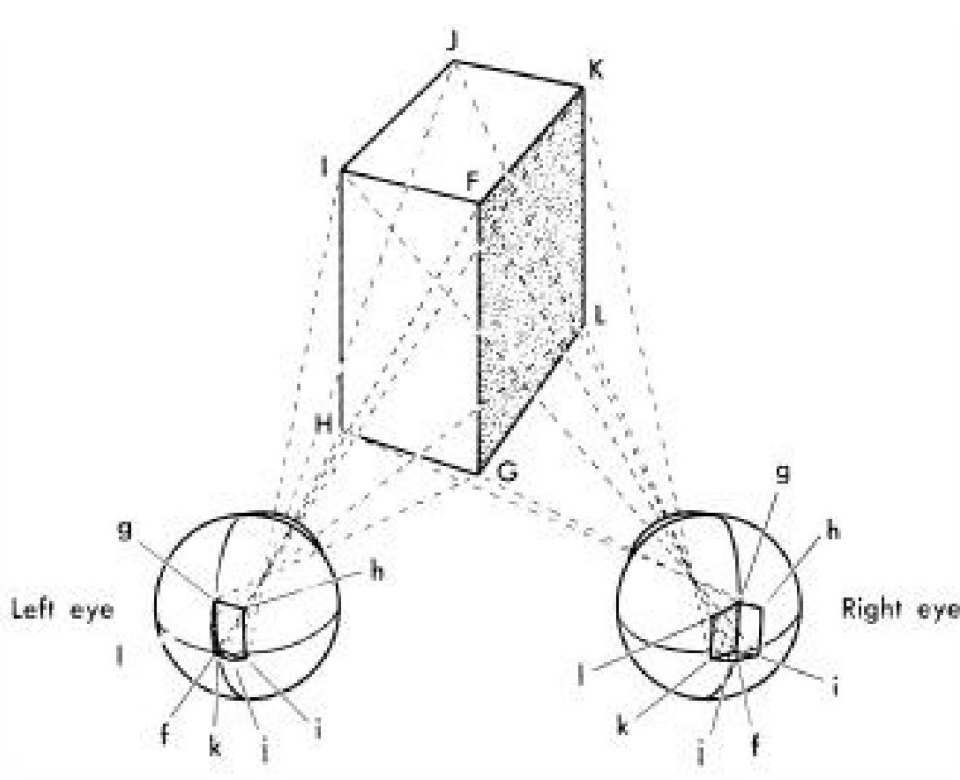

A VISUAL FIELDS AND THE PRIMARY VISUAL CORTEX
Visual fields
Left
Right
Fixation point
Right eye
Retina
Optic chiasm
Right optic tract
Right LGN
Optic radiation
Primary visual cortex (Area V1)
B VISUOTOPY OF THE PRIMARY VISUAL CORTEX
Fovea
Left visual field
Right visual field
Fovea
Fovea

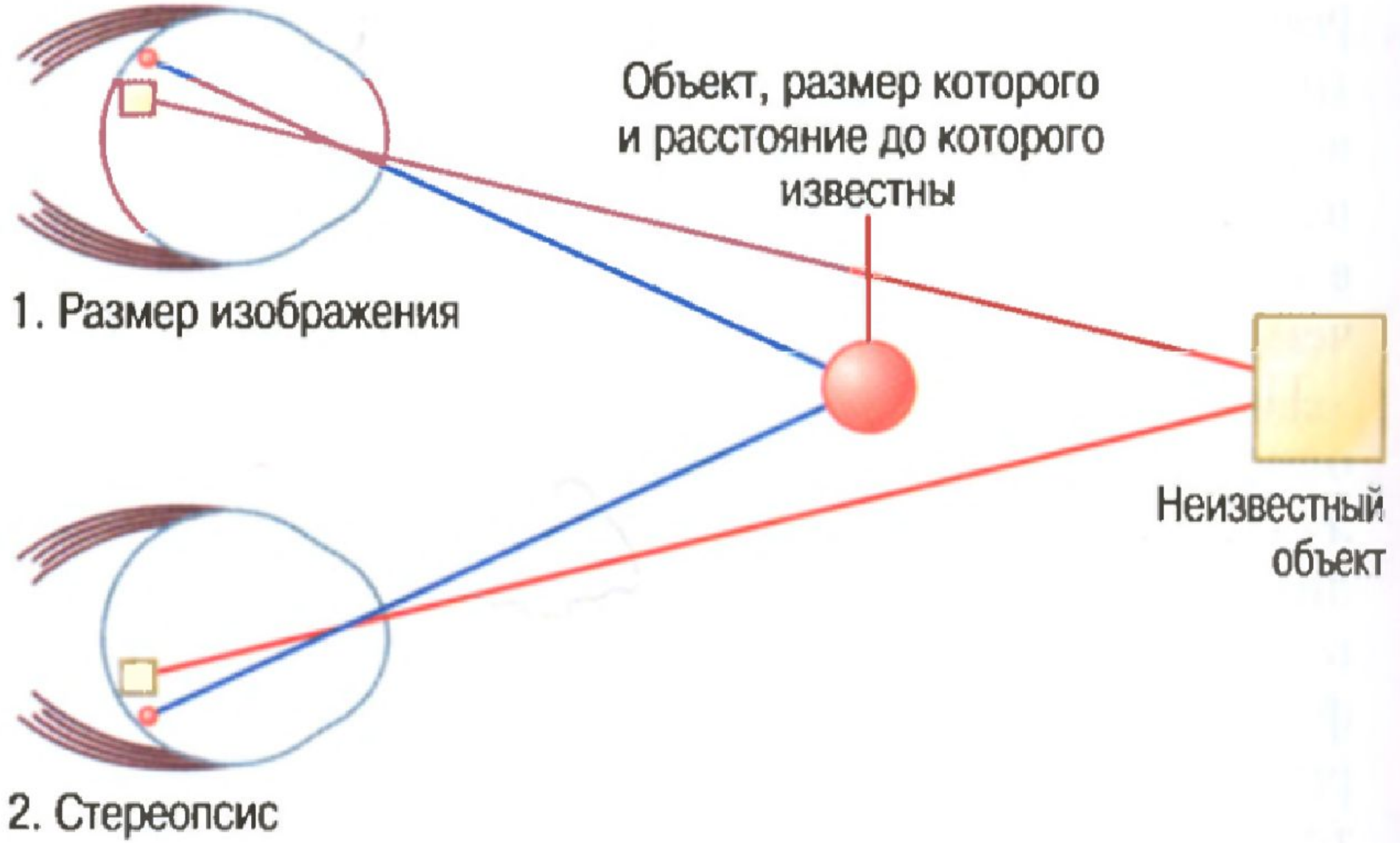

Optic nerves
Optic chiasm
Optic tracts
Lateral geniculate nucleus
C
I
Dorsal
C
I
I
C
Ventral
1
2
3
4
5
6
Magnocellular pathway
Parvocellular pathway
Primary visual cortex (area 17)


Combined Visual Field
Left side
Right side
Left eye only
Binocular vision
Right eye only
The Visual Pathway
Photoreceptors in retina
Retina
Optic disc
Optic nerve (N II)
Optic chiasm
Optic tract
Lateral geniculate nucleus
Projection fibers (optic radiation)
Visual cortex of cerebral hemispheres
Diencephalon and brain stem
Suprachiasmatic nucleus
Superior colliculus
Left cerebral hemisphere
Right cerebral hemisphere


Mangocellular "Where?" pathway
Visual cortex
Pavocellular "What?" pathway


Distant object
D
Fixation point
F
Near object
N
N
F
D
D
F
N


J
K
I
F
L
H
G
g
h
Left eye
l
f
k
j
i
g
h
Right eye
l
i
k
j
f


Объект, размер которого
и расстояние до которого
известны
1. Размер изображения
Неизвестный
объект
2. Стереопсис