Physiology of vision_1

Neurophysiology

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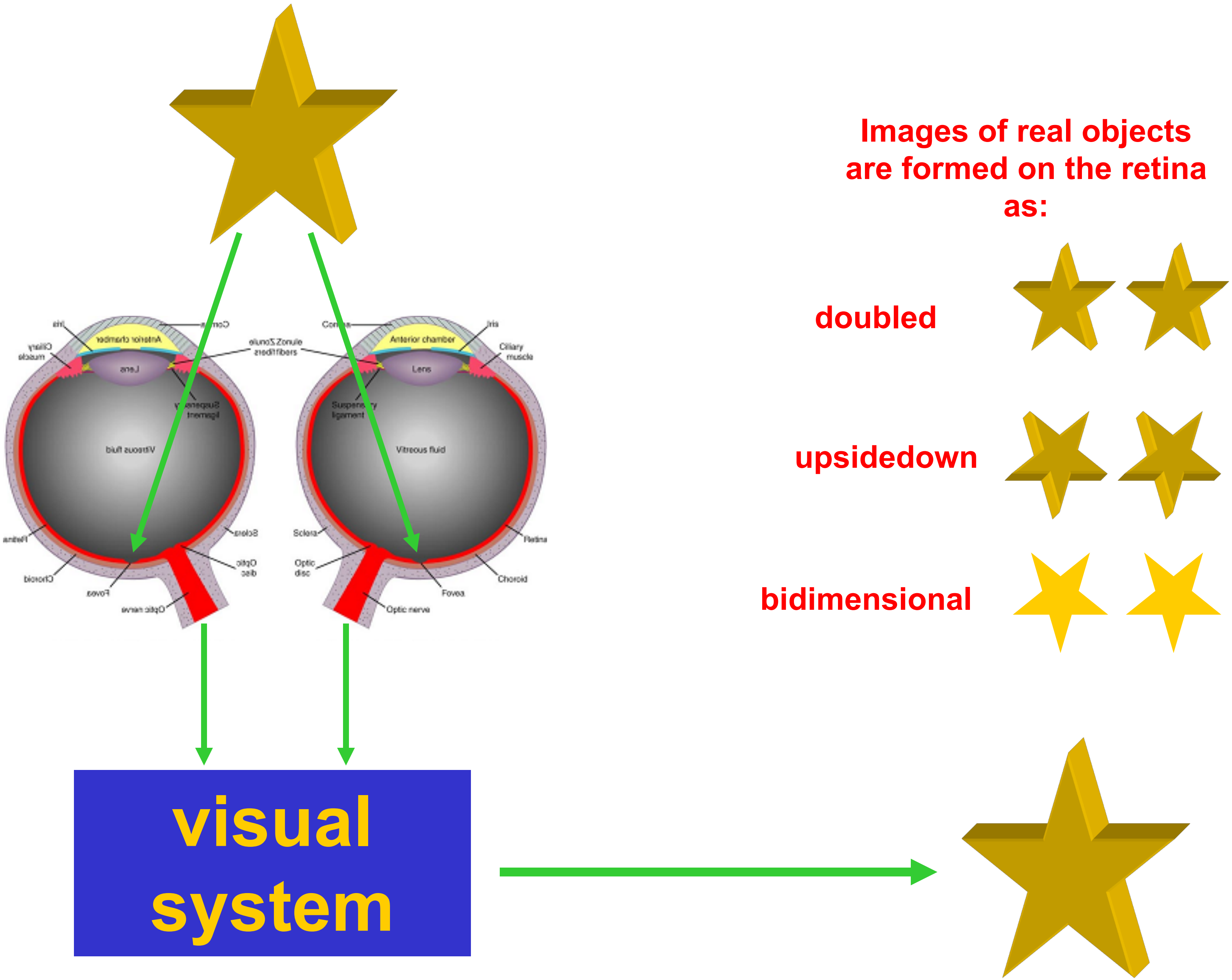
2018/2019

Slides on Moodle

Resources:
http://purveslab.net

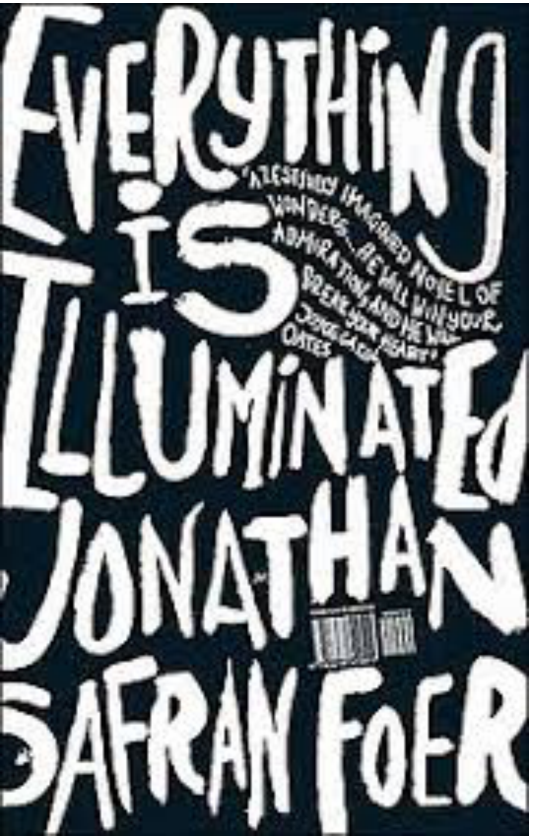
Neuroscience, Dale Purves, George Augustine et al Eds

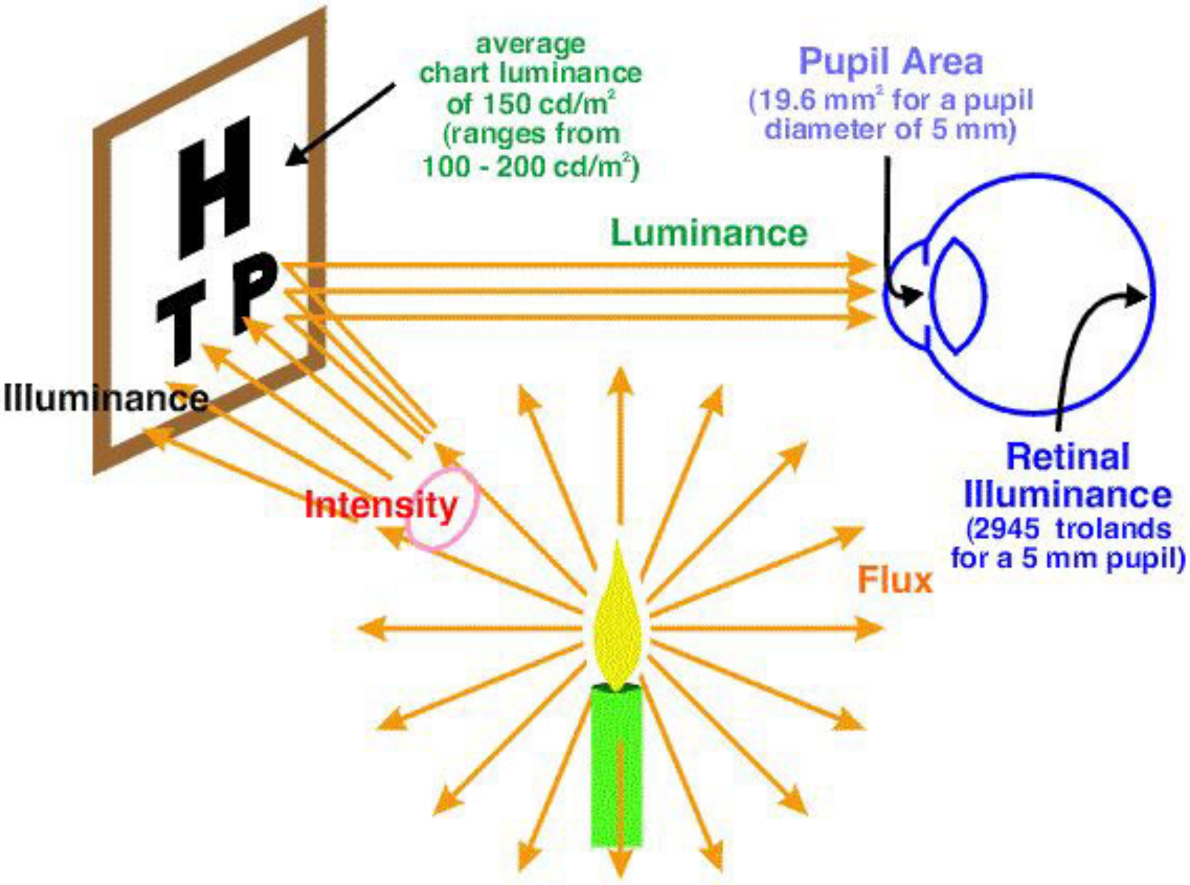


Images of real objects are formed on the retina as:
doubled
upsidedown
bidimensional
visual system
Cornea
Iris
Anterior chamber
Zonule fibers
Ciliary muscle
Lens
Suspensory ligament
Vitreous fluid
Sclera
Retina
Optic disc
Choroid
Fovea
Optic nerve

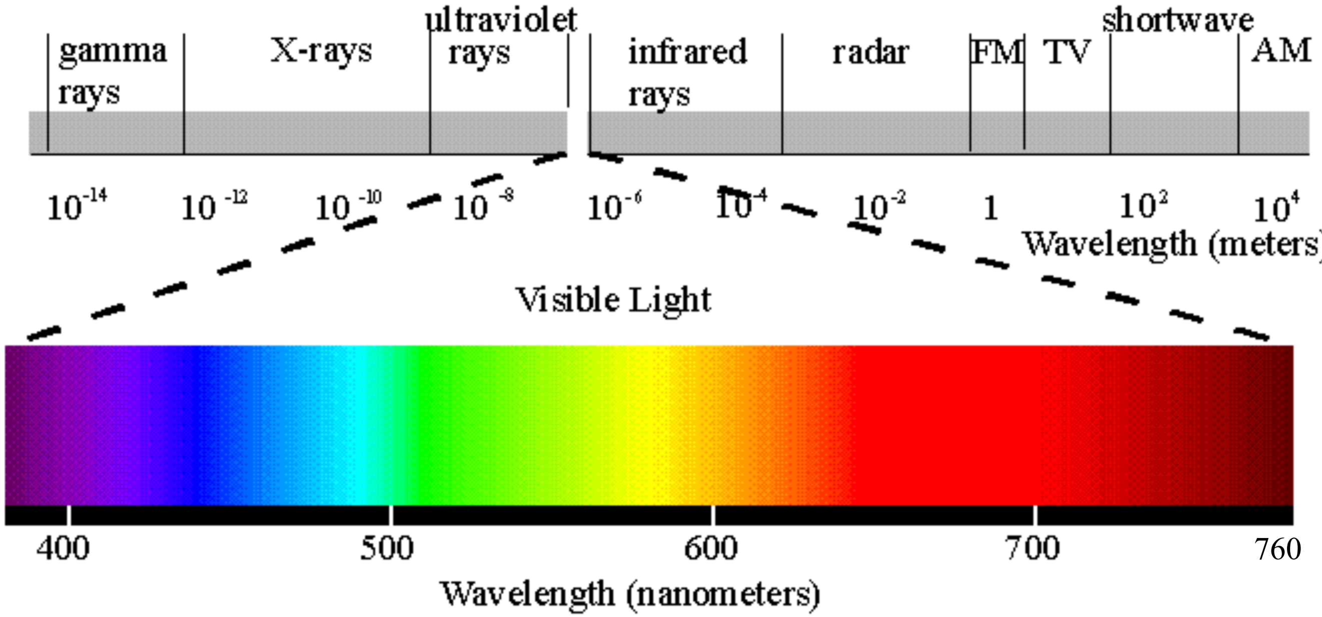
Reflection

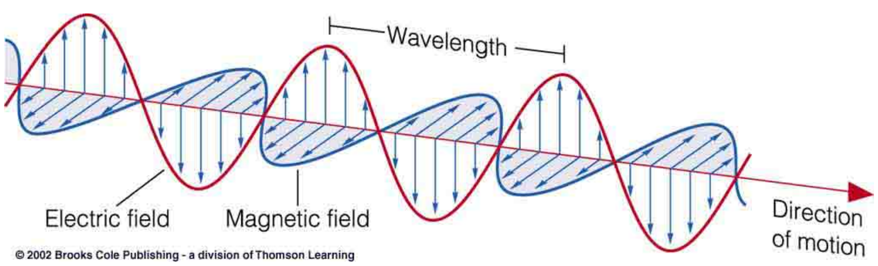
Luminous emittance (luminance)= intensity of luminous emitted flux





Illuminance = intensity of luminous flux incident on a surface


gamma rays
X-rays
ultraviolet rays
infrared rays
radar
FM
TV
shortwave
AM
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^{2}
10^{4}
Wavelength (meters)
Visible Light
400
500
600
700
760
Wavelength (nanometers)


Wavelength
Electric field
Magnetic field
Direction of motion
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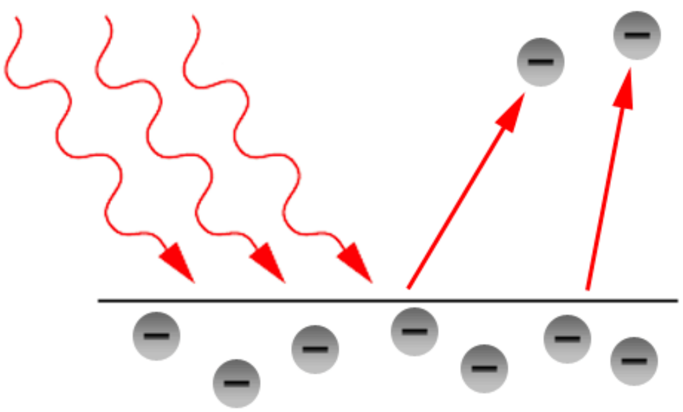
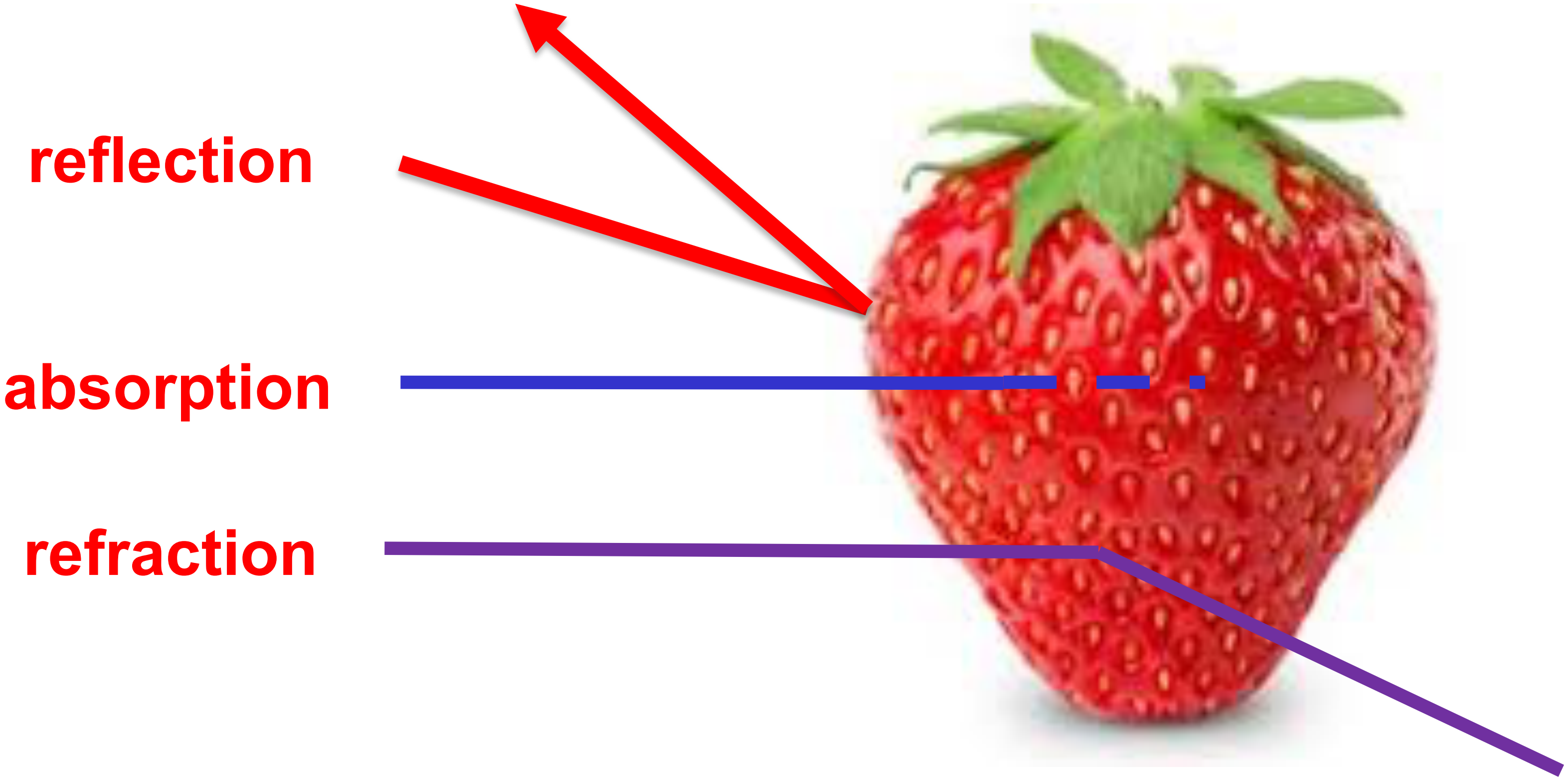
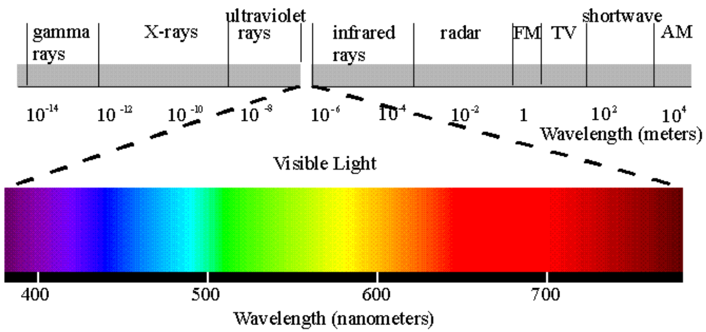



reflection
absorption
refraction


gamma rays
X-rays
ultraviolet rays
infrared rays
radar
FM
TV
shortwave
AM
10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1 10^{2} 10^{4}
Wavelength (meters)
Visible Light
400 500 600 700
Wavelength (nanometers)

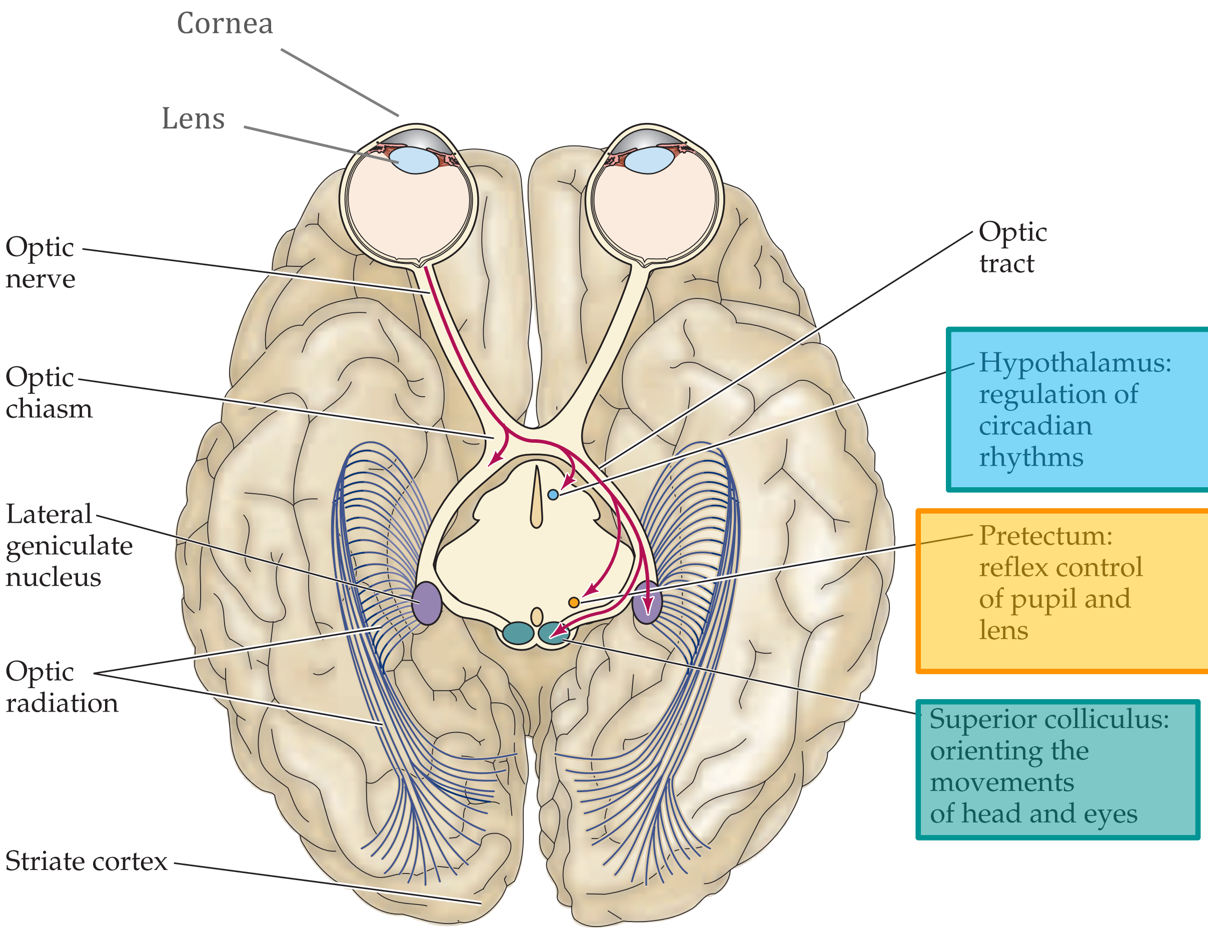
THE VISUAL SYSTEM

1. Images are formed on the retina thanks to the refraction of the cornea and lens

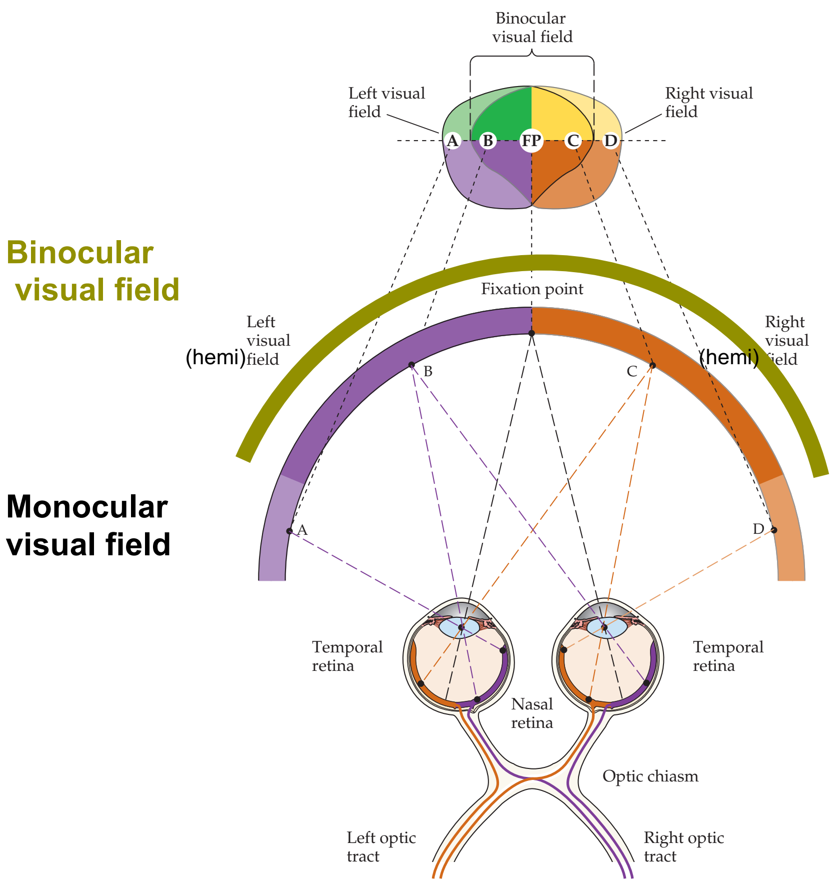
2. Light is transduced into electrical signals in the retina whose output are retinal ganglion cells

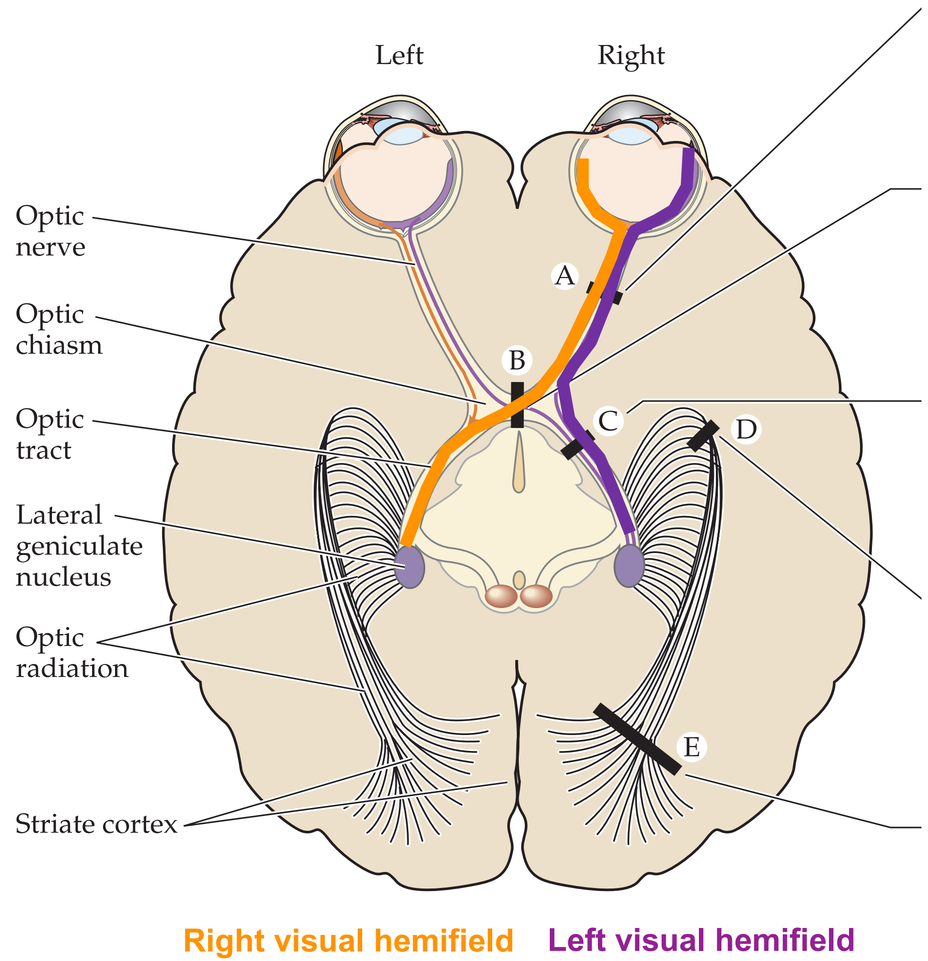
3. AP of ganglion cells relay info to the thalamus (geniculate nucleus) via the optic nerve

4. The optical radiation conveys info from the thalamus to the primary visual cortex (visual representation - perception)

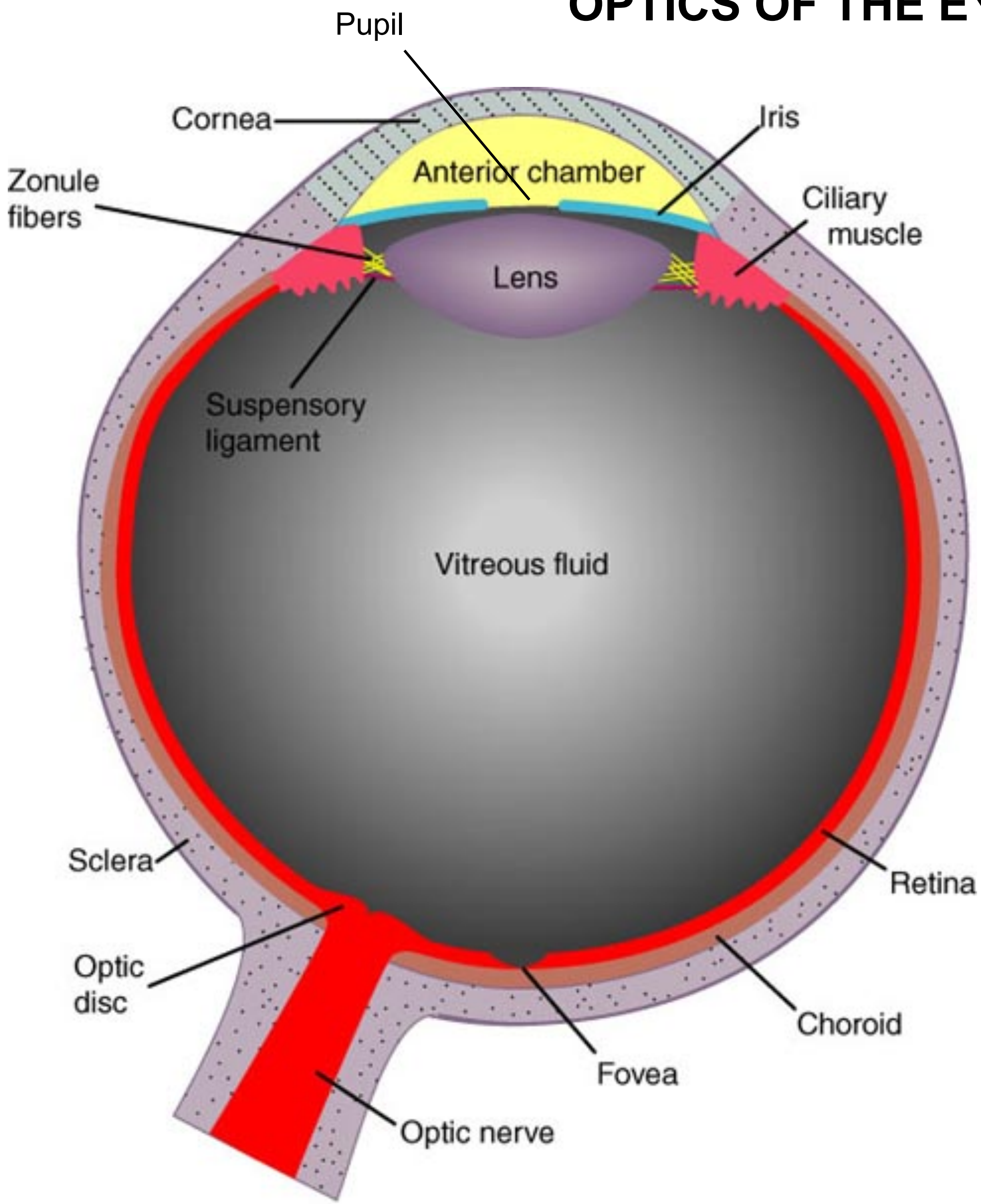


THE VISUAL PATH PARTLY CROSSES IN THE OPTIC CHIASMA





OPTICS OF THE EYE



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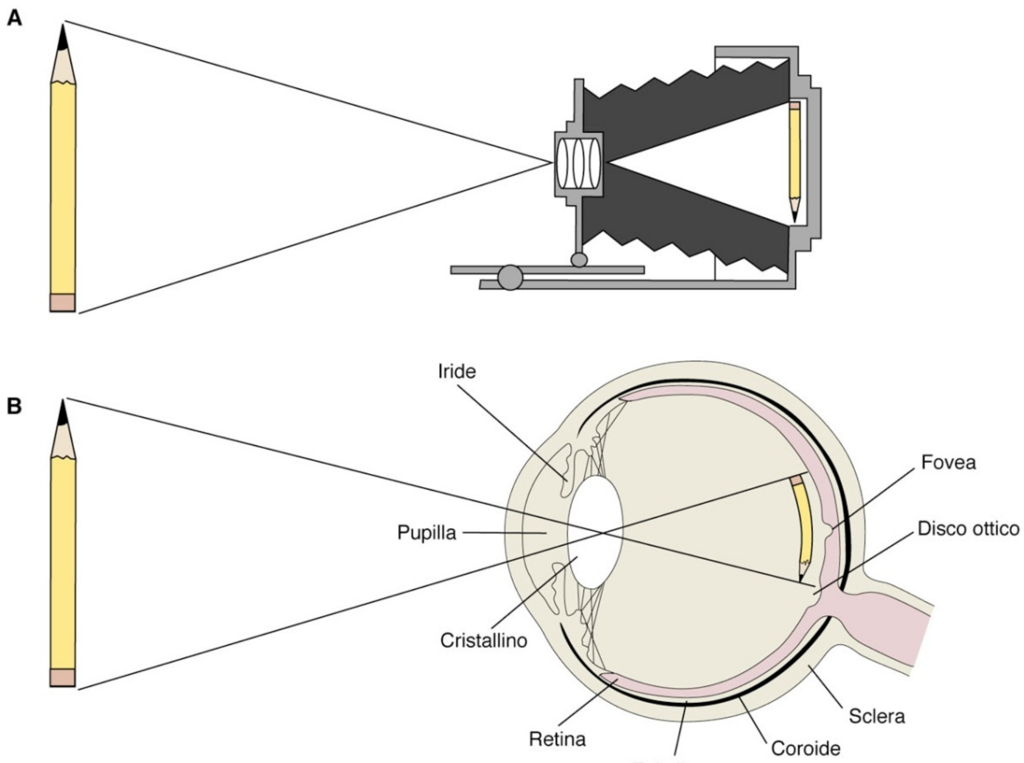
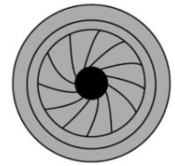
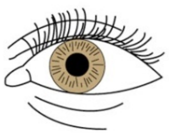
Dioptric system

Filter for non visible radiations

Formation of images 'on focus' on the retina - point by point

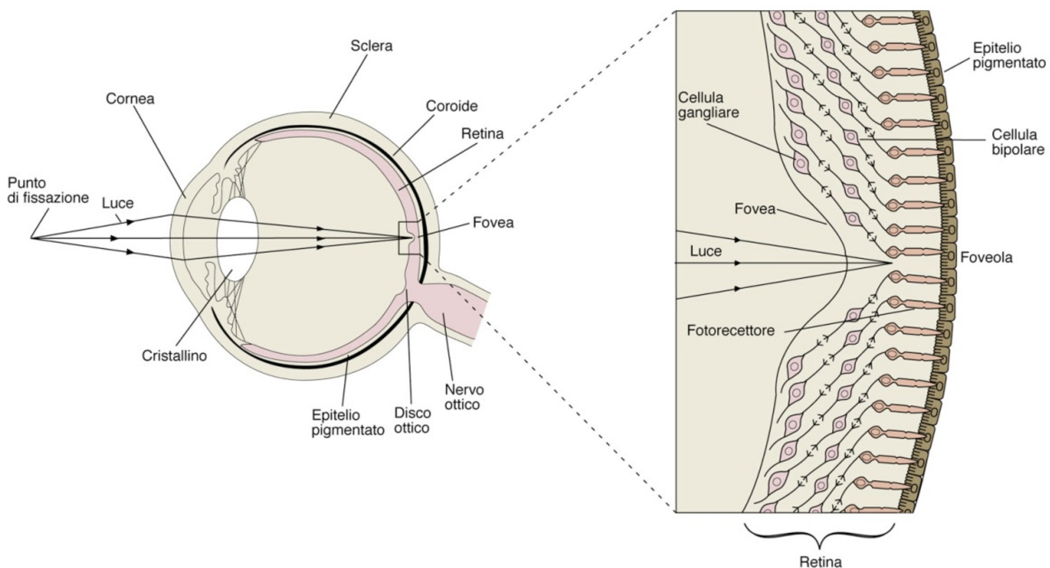






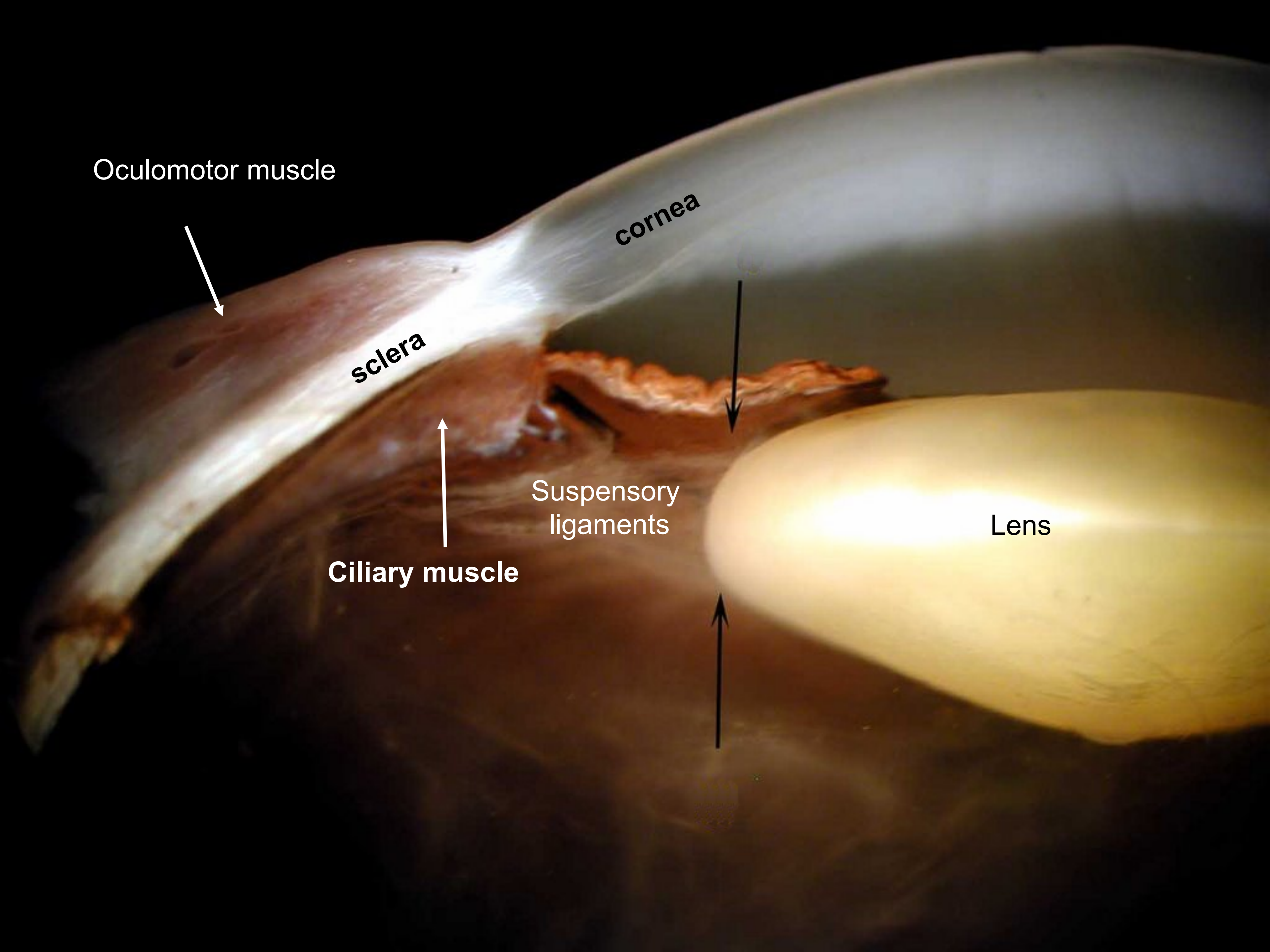
FOCUS on RETINA
(sensitive sensory surface)

Ordered and consistent point to point image formation

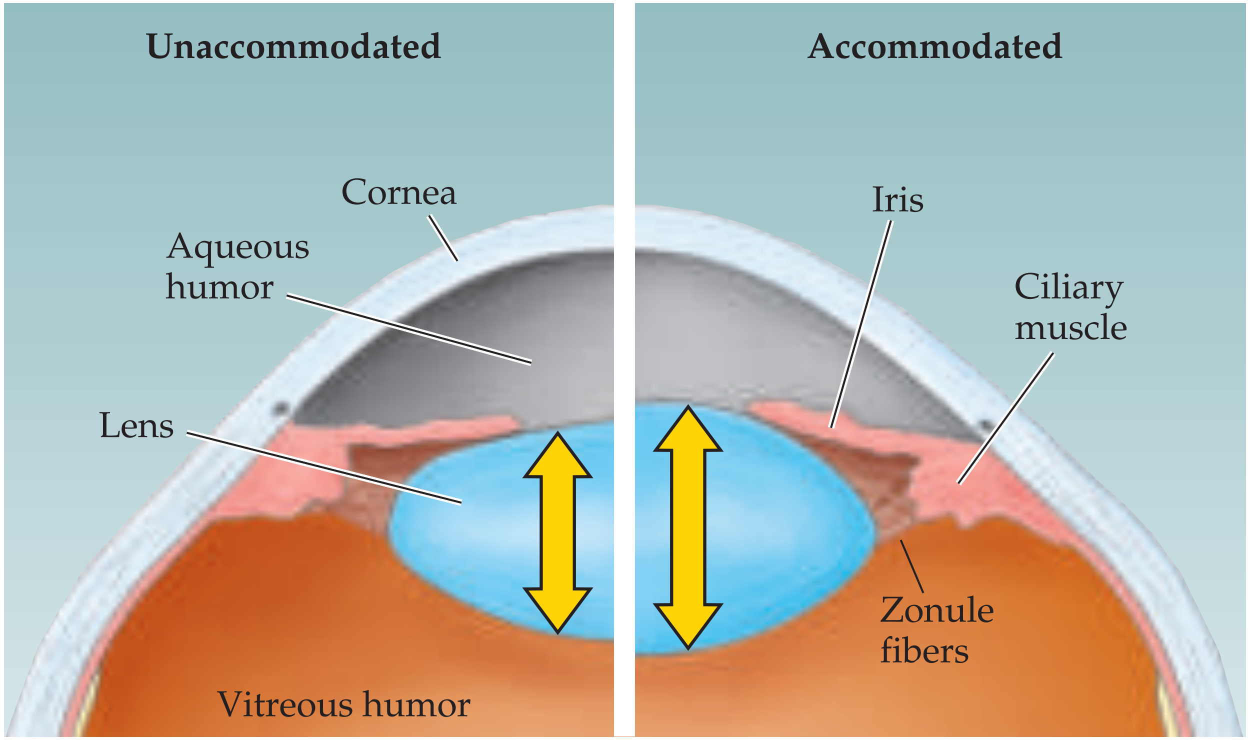


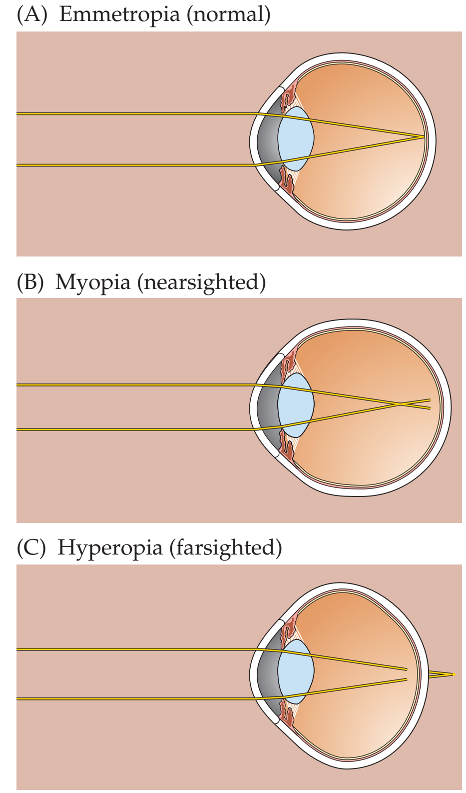
STATIC REFRACTION

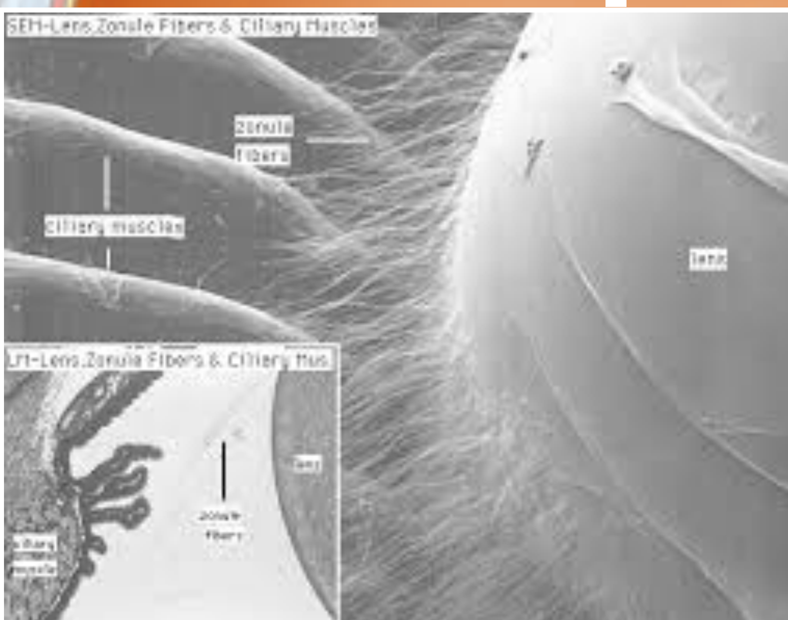
DINAMIC REFRACTION

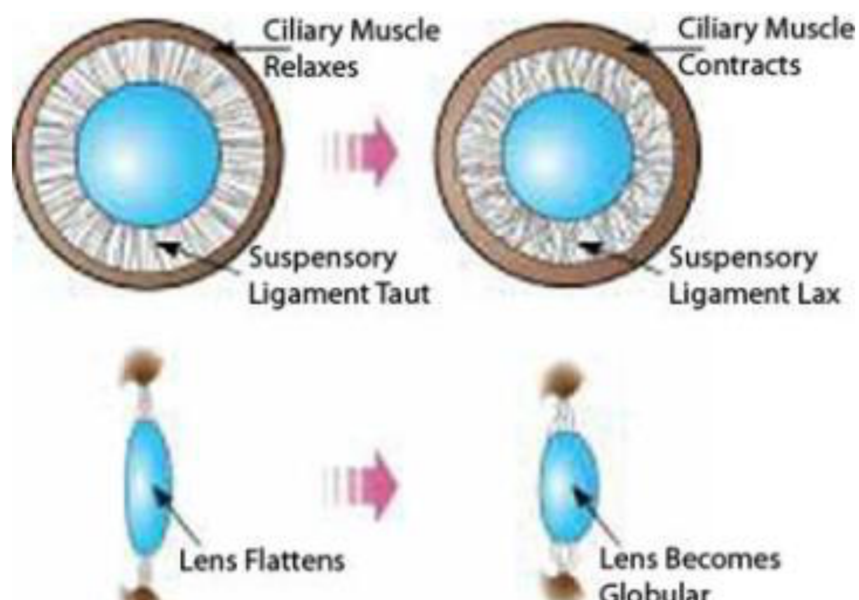

Oculomotor muscle
cornea
sclera
Suspensory
ligaments
Lens
Ciliary muscle

ACCOMODATION

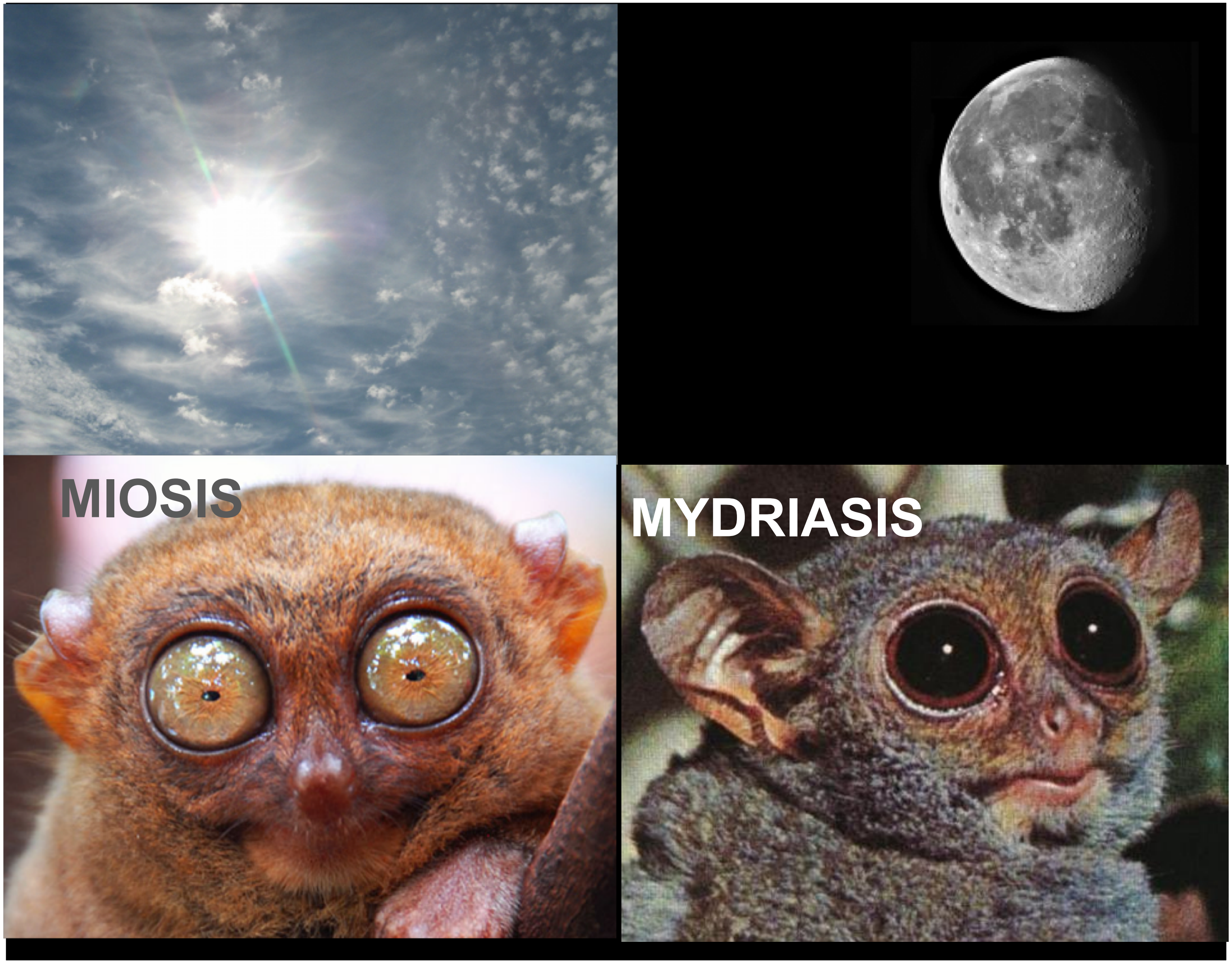






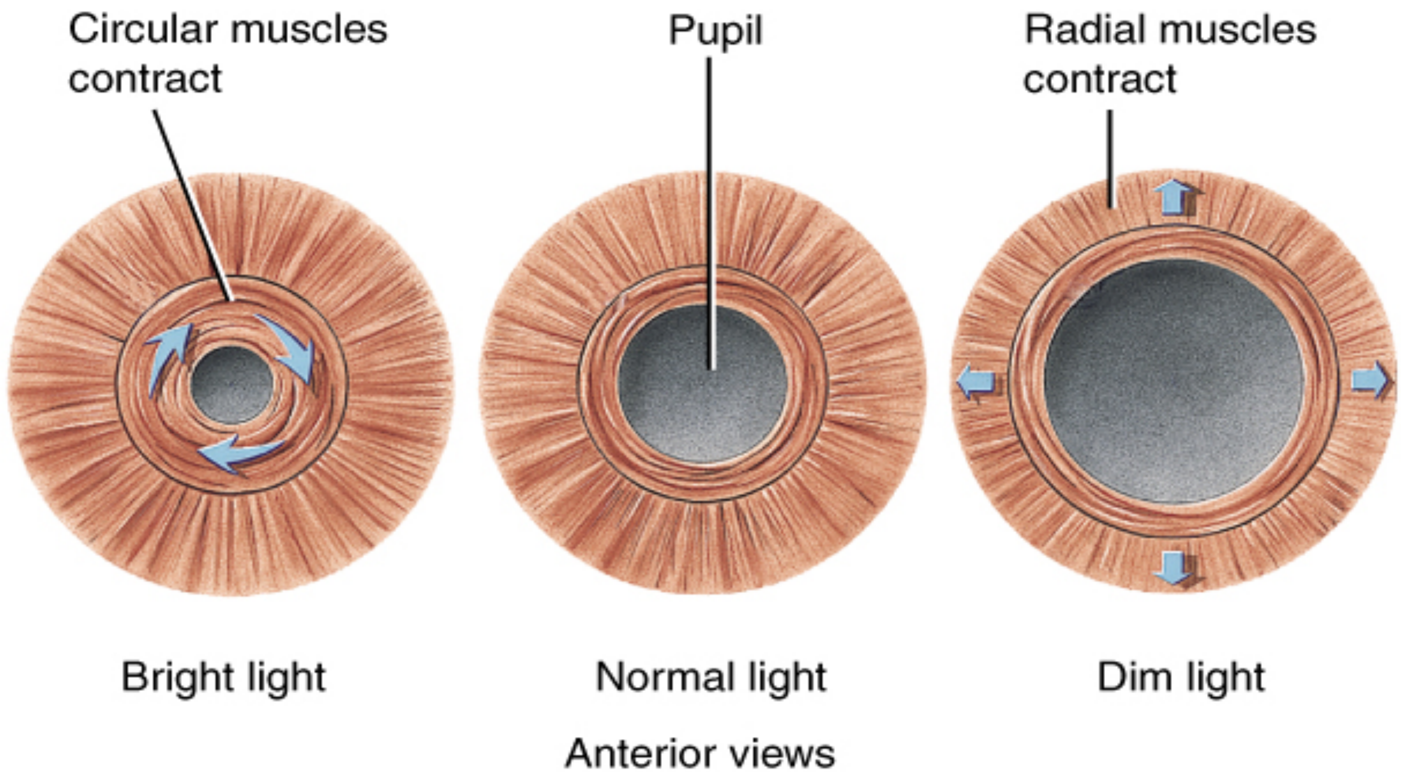


PUPILLARY REFLEXES



TARSIUS

Smooth muscle



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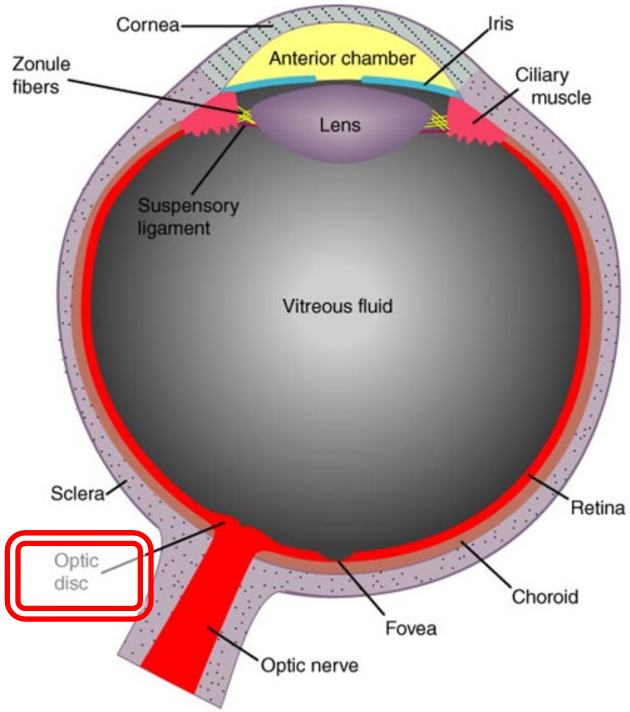
Blind spot



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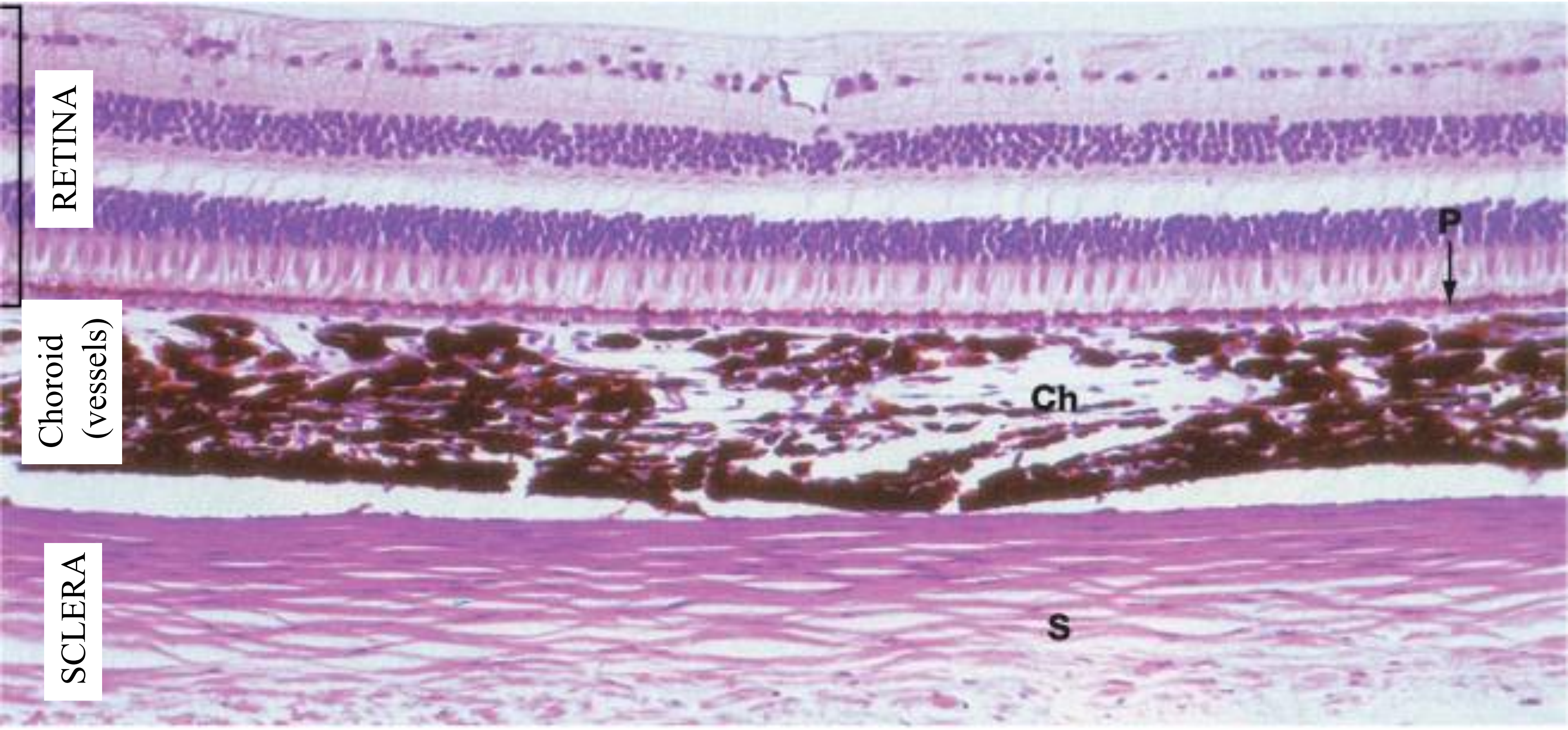
Neural portion of the eye: the retina

10 layers of cells/processes



10) Limitans membrane

9) Axons of ganglion cells
8) Ganglion cells

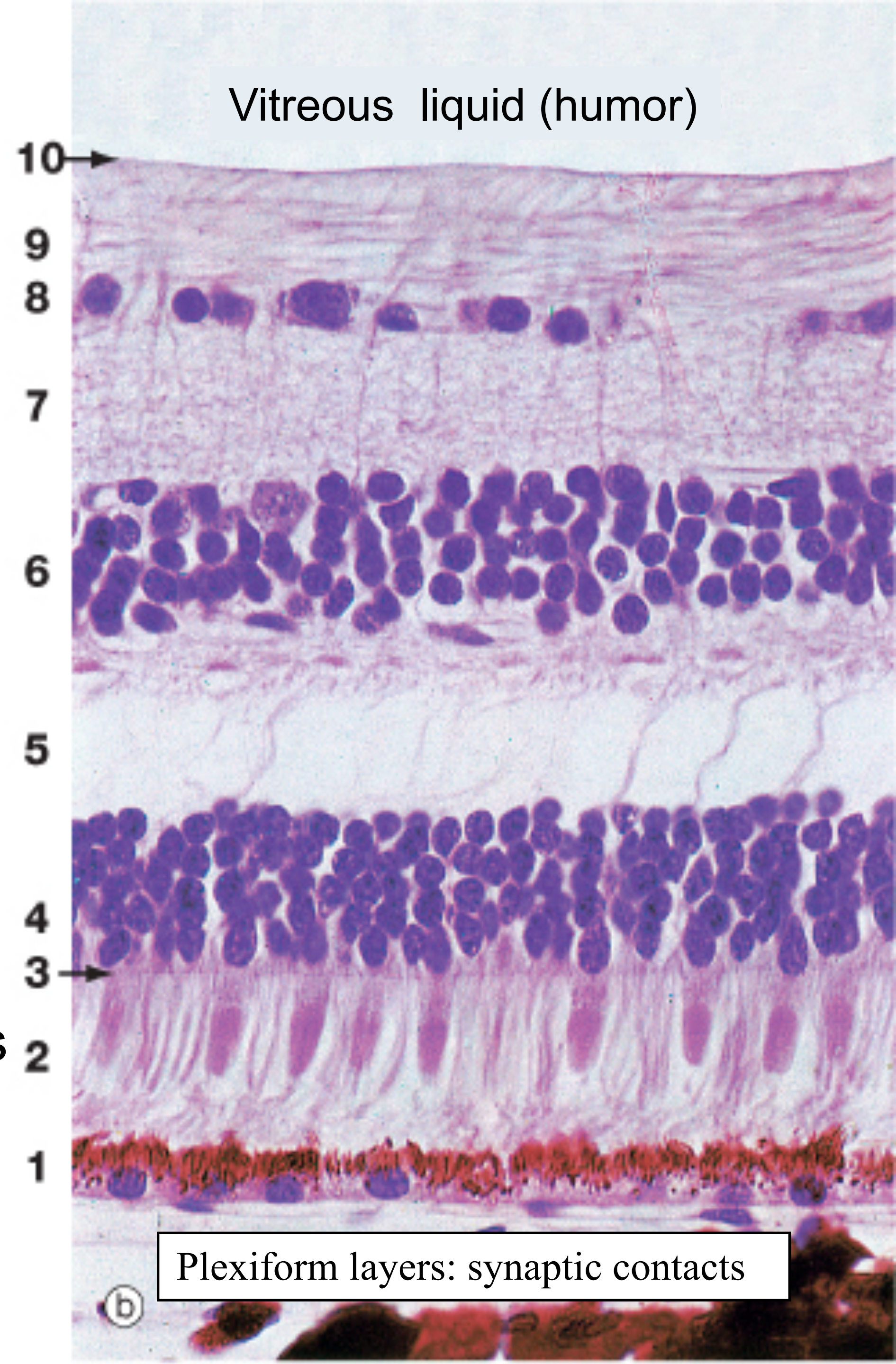
7) Inner Plexiform layer

6) Inner nuclear layers

5) Outer Plexiform layer

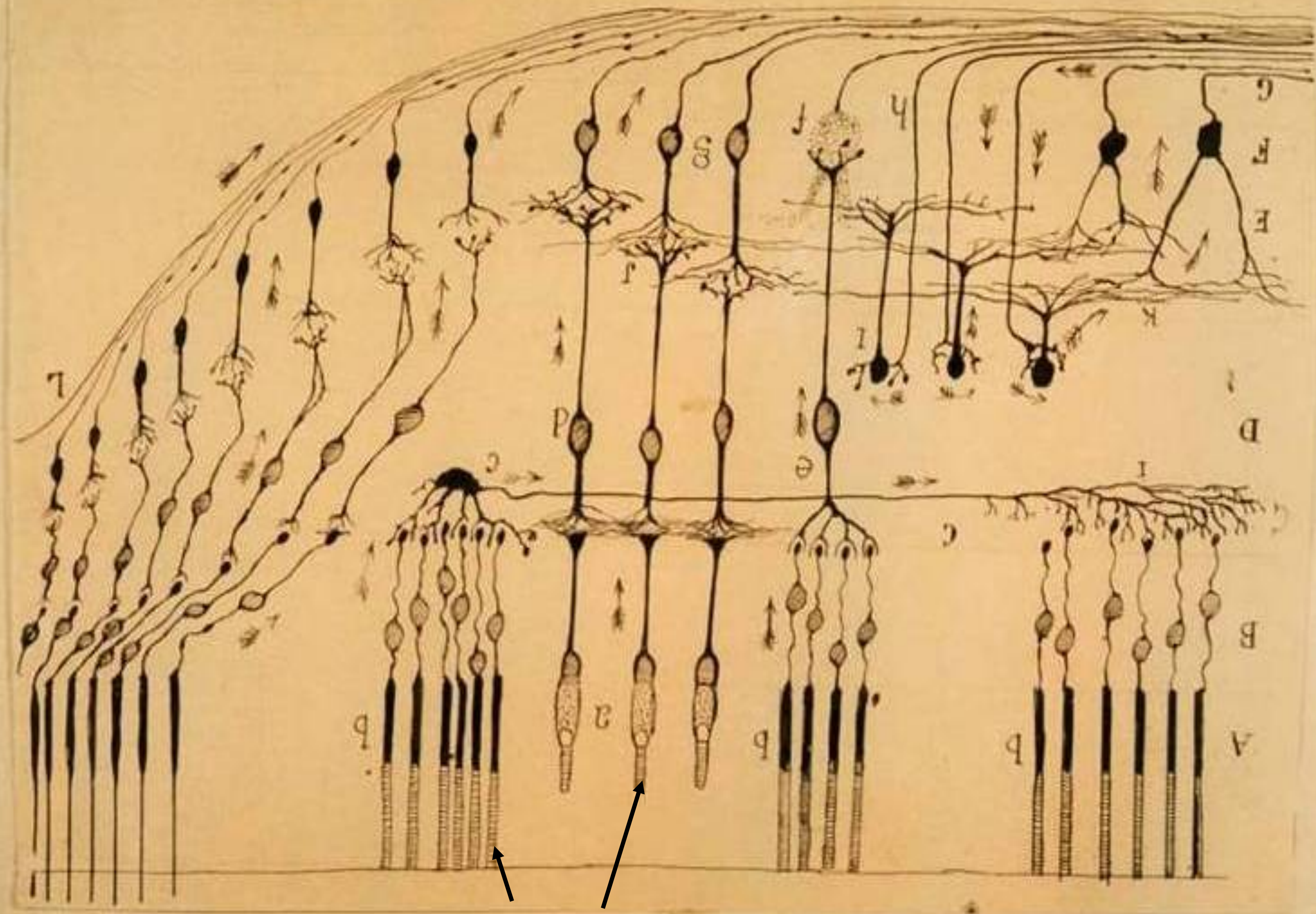
4) Outer nuclear layer
3) Limitans membrane

2) Photoreceptors outer segments
1) Pigmented epithelium



Back of the eye ball

Retina neurons, Ramon y Cajal

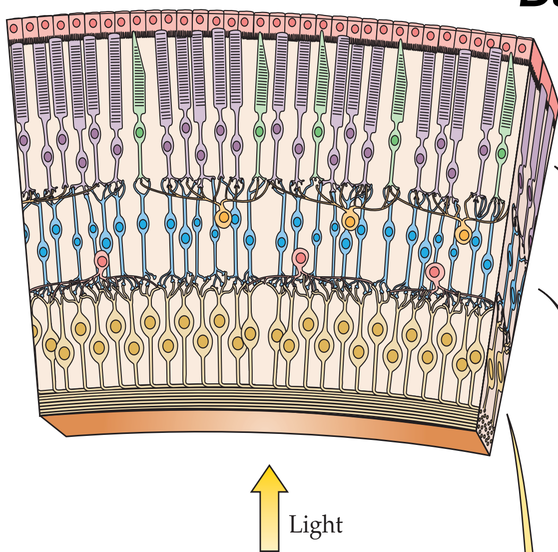


Photoreceptors

Back of the eye ball

Back of the eye ball

(A) Section of retina



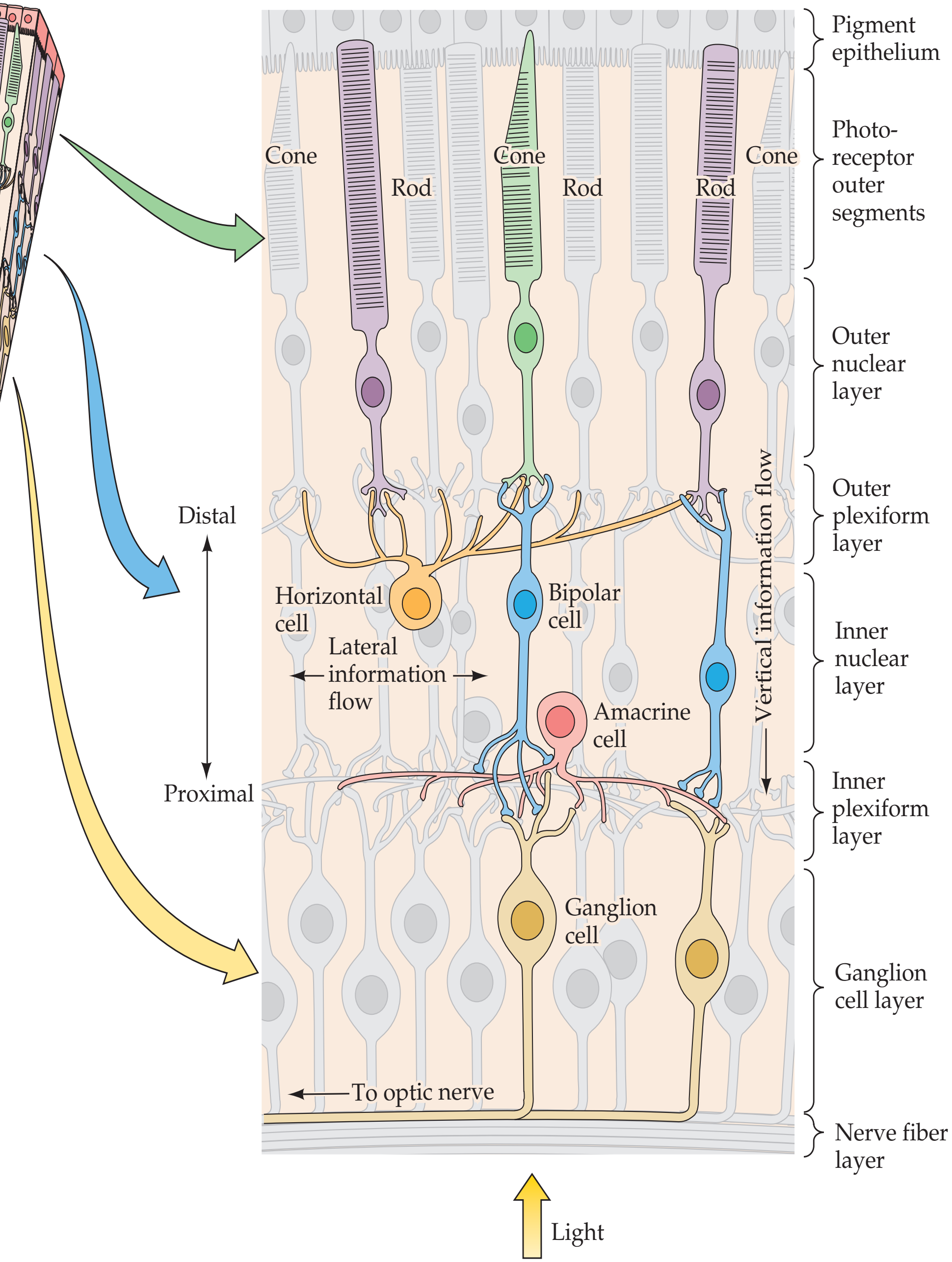
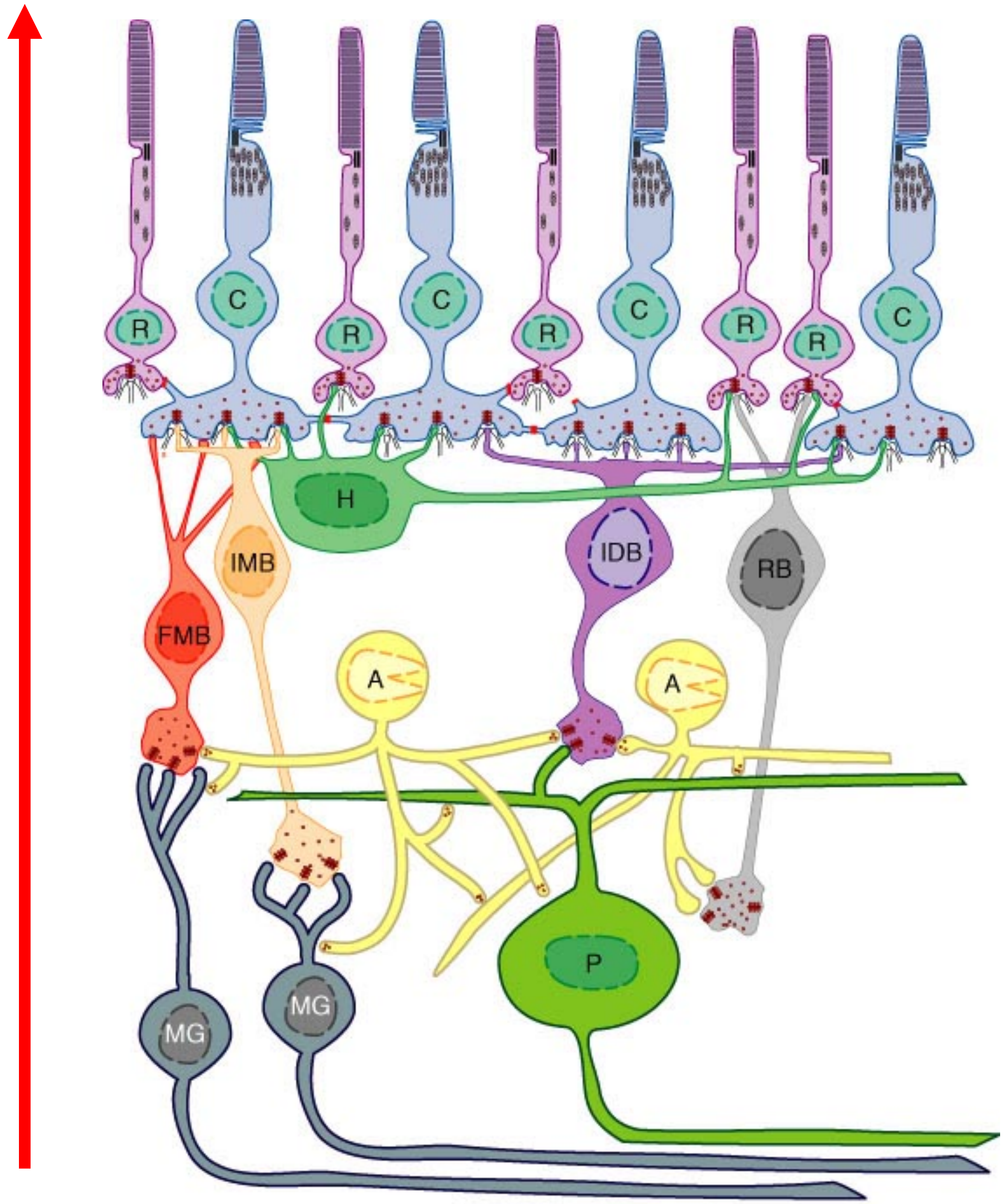


Figure 10.4 Structure of the retina. (A) Section of the retina showing overall arrangement of retinal layers. (B) Diagram of the basic circuitry of the retina. A three-neuron chain—photoreceptor, bipolar cell, and ganglion cell—provides the most direct route for transmitting visual information to the brain. Horizontal cells and amacrine cells mediate lateral interactions in the outer and inner plexiform layers, respectively. The terms *inner* and *outer* designate relative distances from the center of the eye (inner, near the center of the eye; outer, away from the center, or toward the pigment epithelium).



light

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photoreceptor

↓

Bipolar cells
Amacrine cells
Horizontal cells

↓

Ganglionic cells

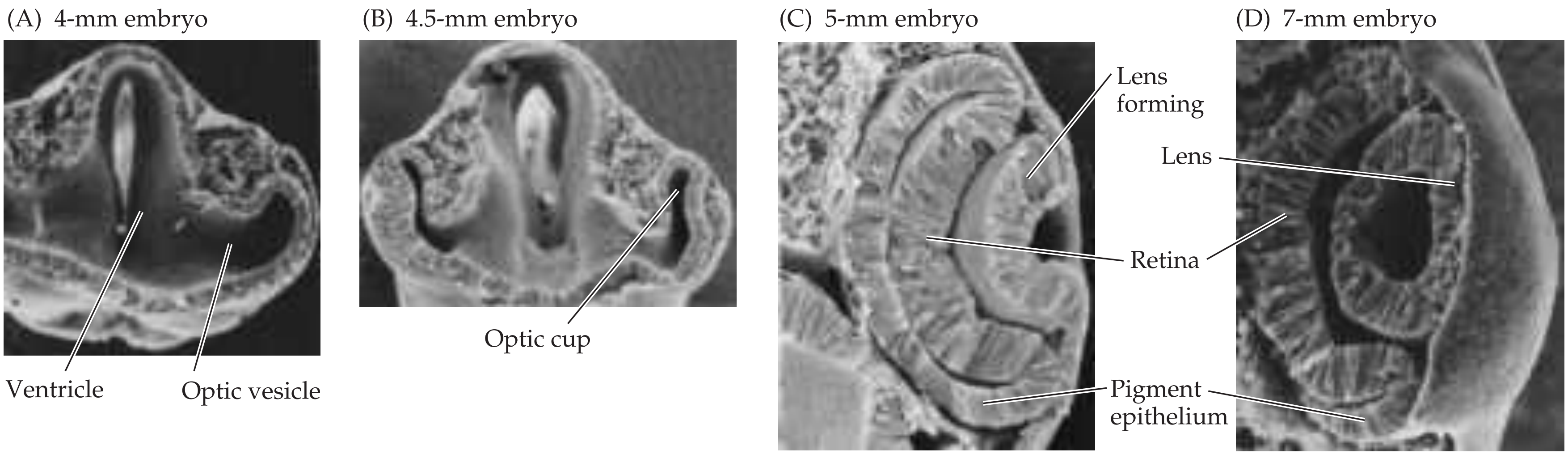
↓

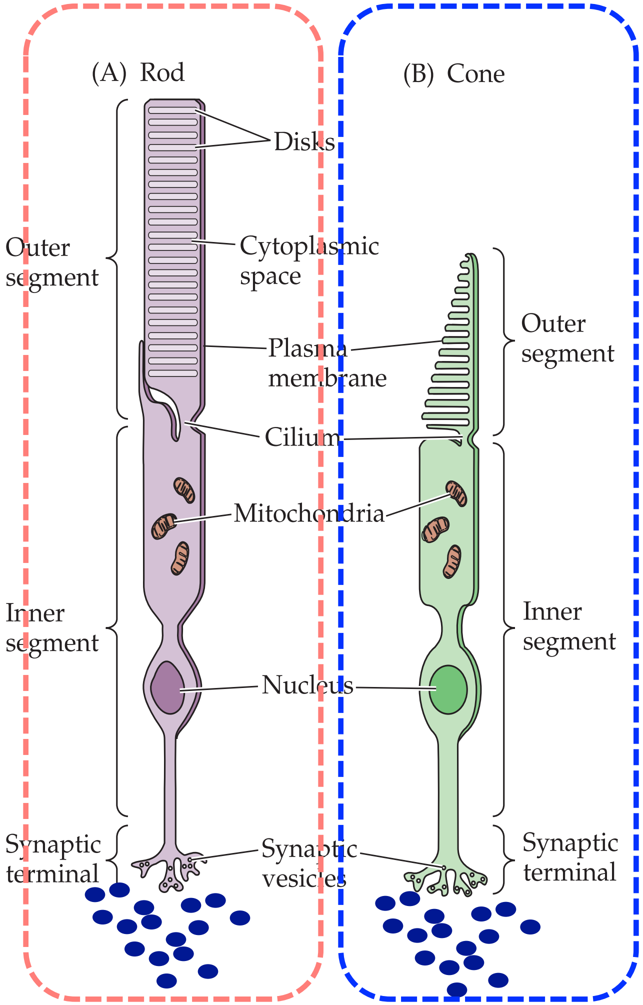
Optic nerve

↓

CNS

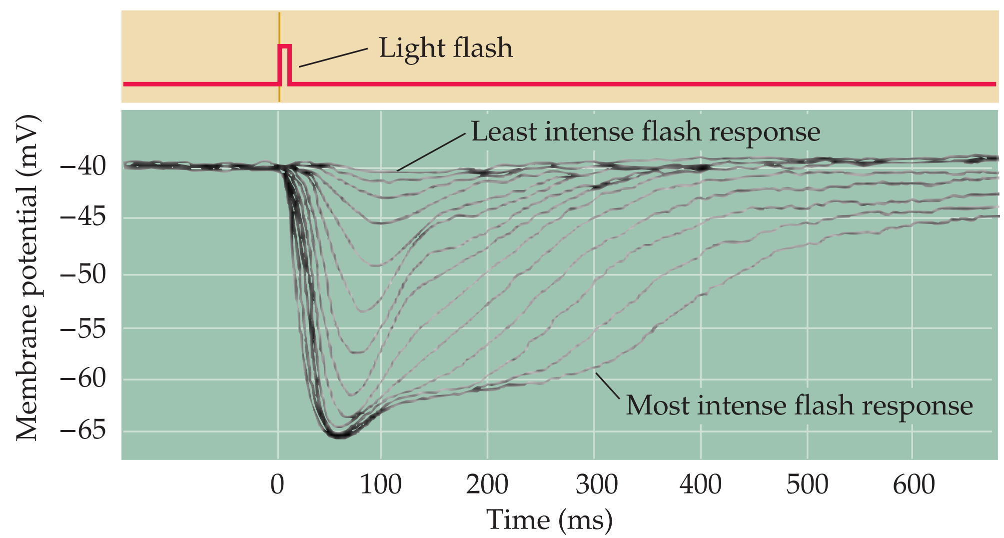
Retina + optic nerve are CNS!



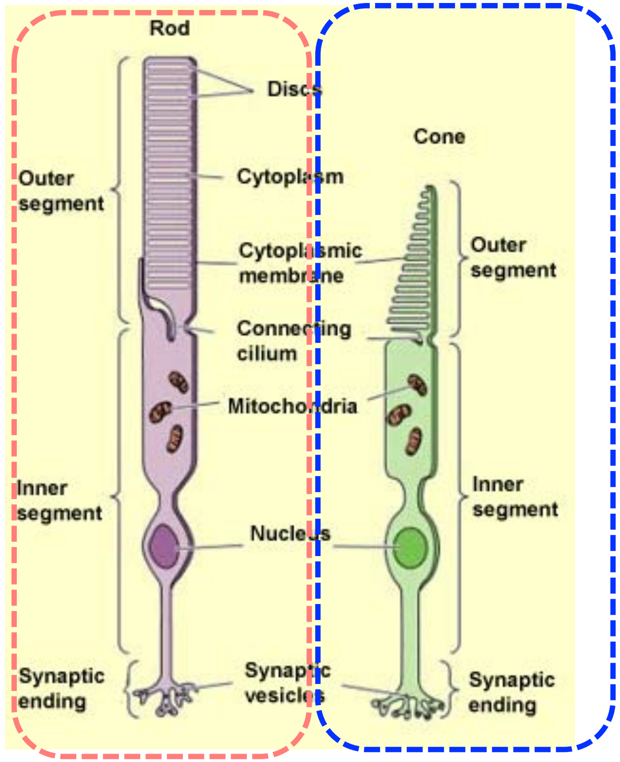


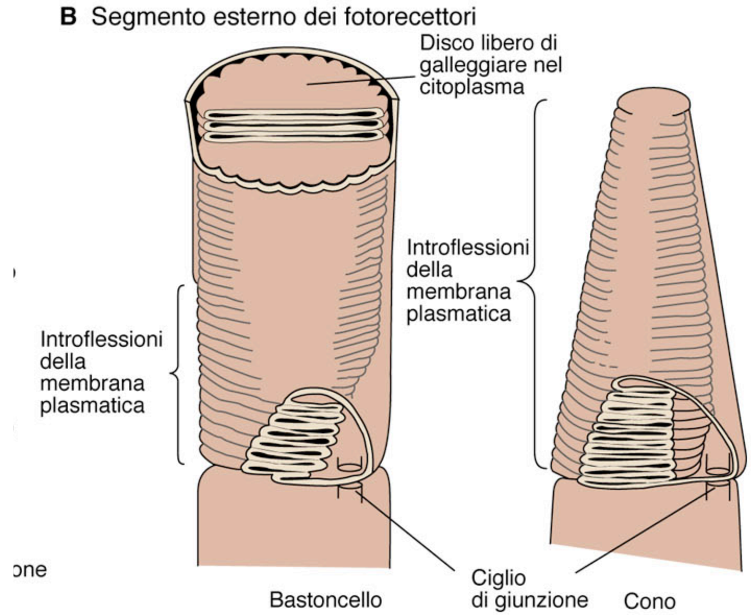
glutammate

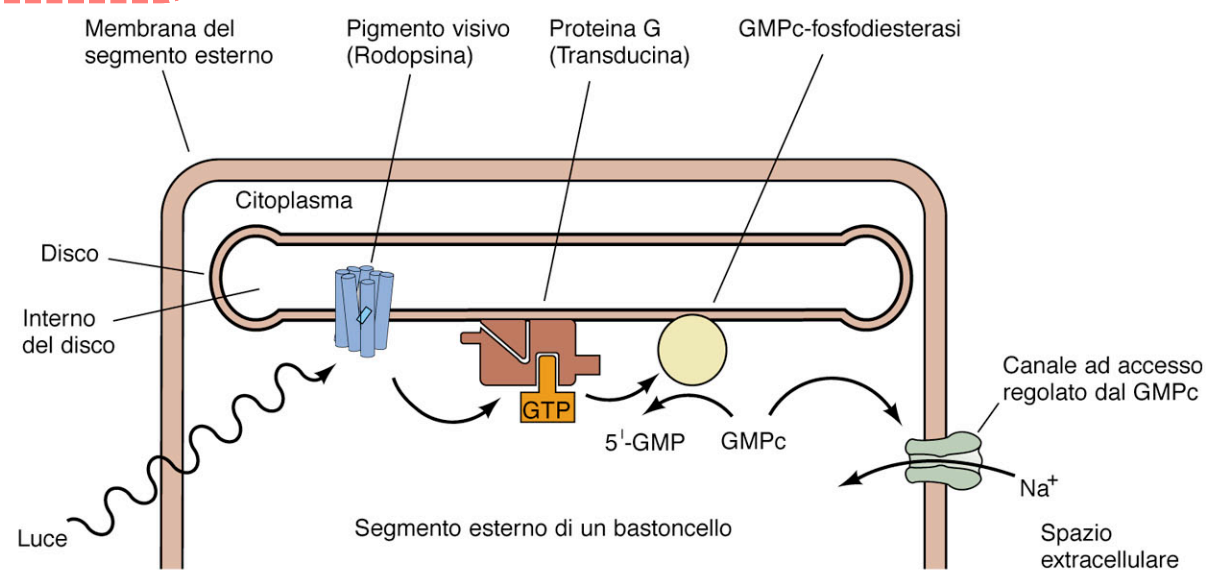
Hyperpolarization in response to light

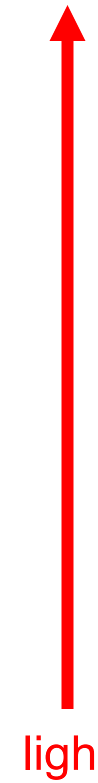


(Dark current)

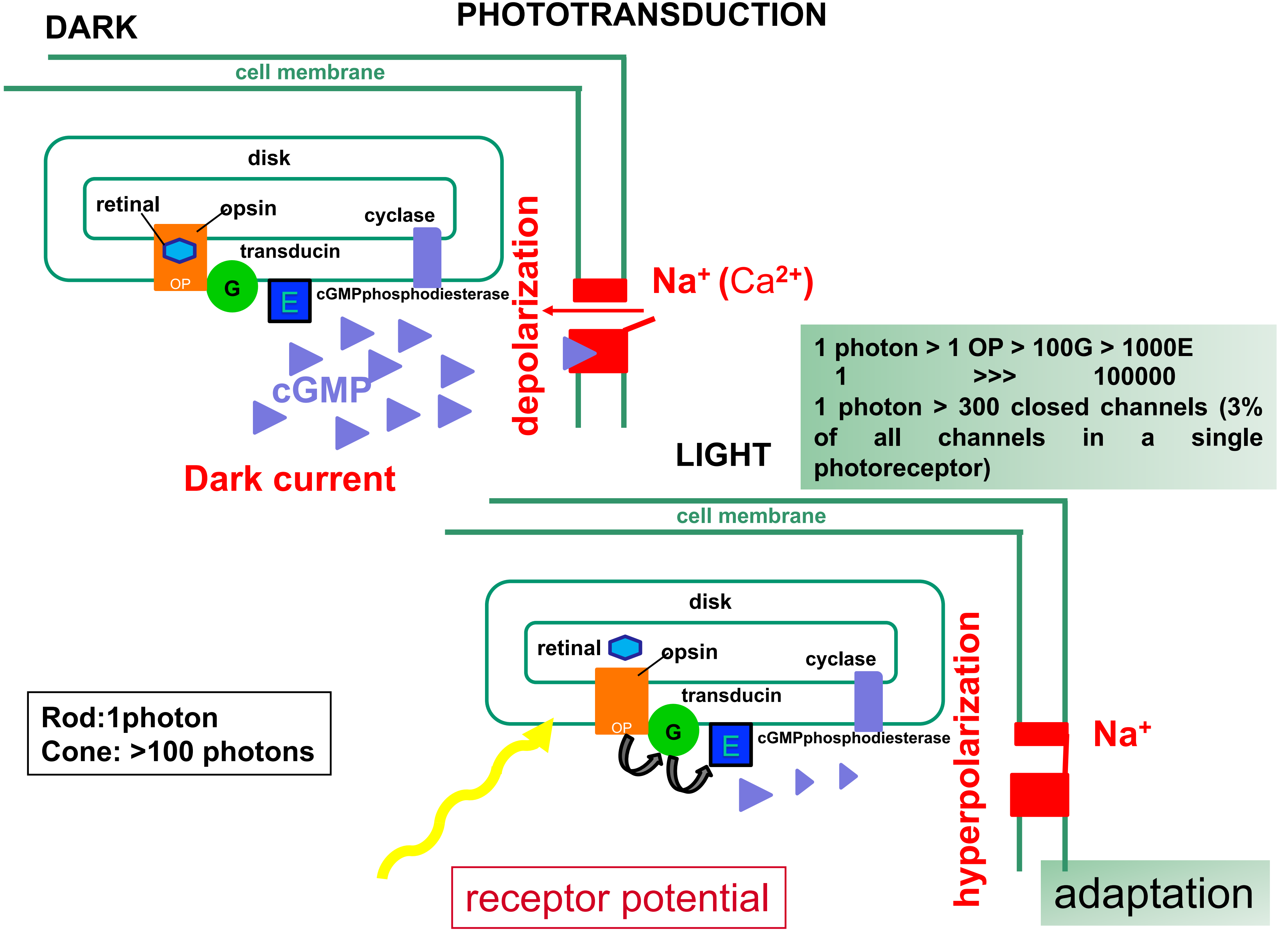

Rod
Discs
Outer segment
Cytoplasm
Cytoplasmic membrane
Connecting cilium
Mitochondria
Inner segment
Nucleus
Synaptic ending
Synaptic vesicles
Cone
Outer segment
Inner segment
Synaptic ending

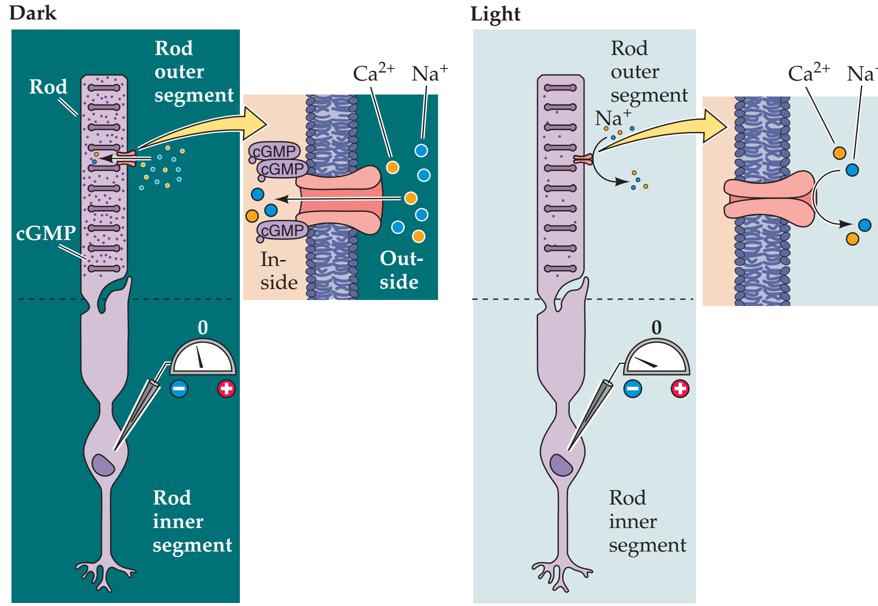

B Segmento esterno dei fotorecettori
Disco libero di galleggiare nel citoplasma
Introflessioni della membrana plasmatica
Introflessioni della membrana plasmatica
Bastoncello
Ciglio di giunzione
Cono


Membrana del segmento esterno
Pigmento visivo (Rodopsina)
Proteina G (Transducina)
GMPc-fosfodiesterasi
Citoplasma
Disco
Interno del disco
GTP
5'-GMP
GMPc
Canale ad accesso regolato dal GMPc
Na+
Luce
Segmento esterno di un bastoncello
Spazio extracellulare

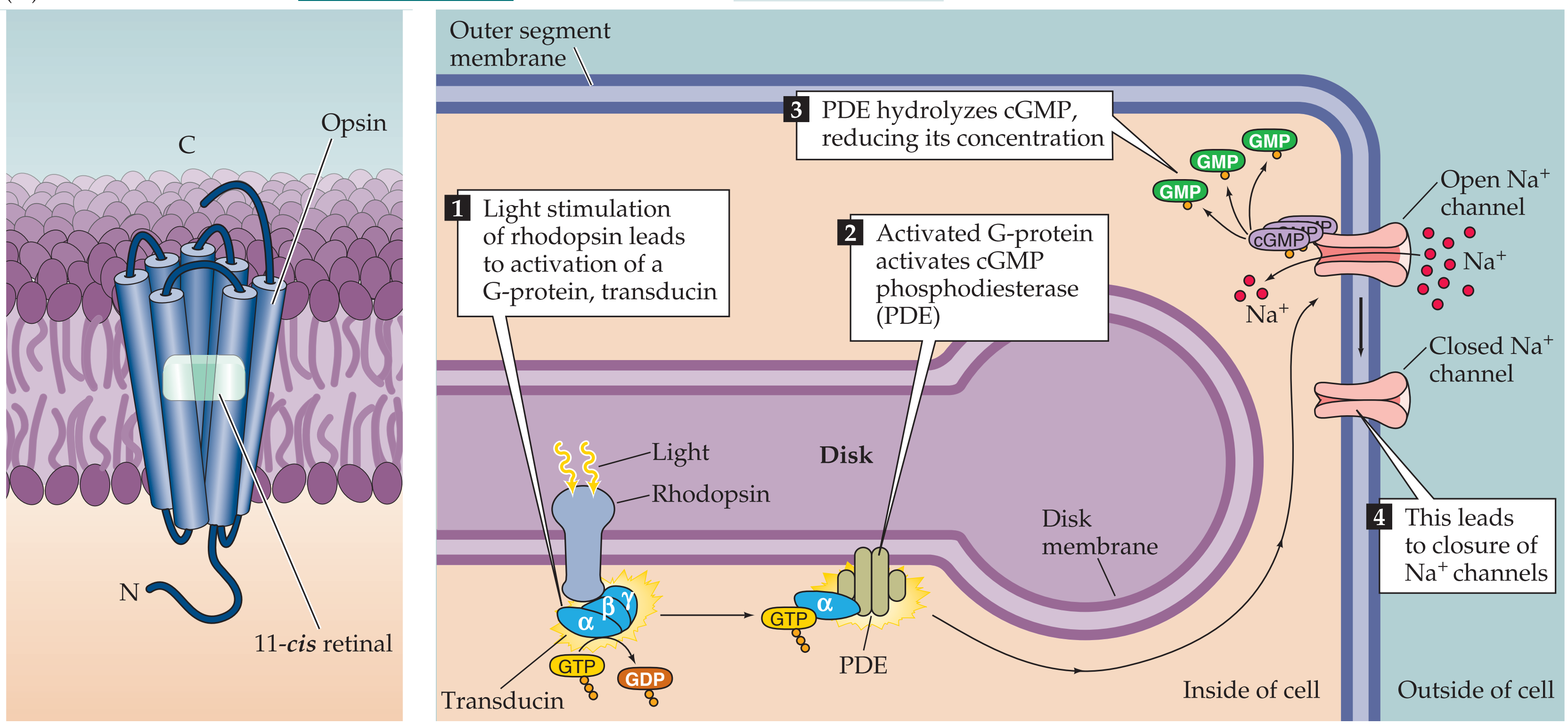

light

PHOTOTRANSDUCTION




Dark
Rod
Rod outer segment
cGMP
cGMP
cGMP
cGMP
Ca^{2+}
Na^{+}
In-side
Out-side
0
Rod inner segment
Light
Rod outer segment
Na^{+}
Ca^{2+}
Na^{+}
0
Rod inner segment

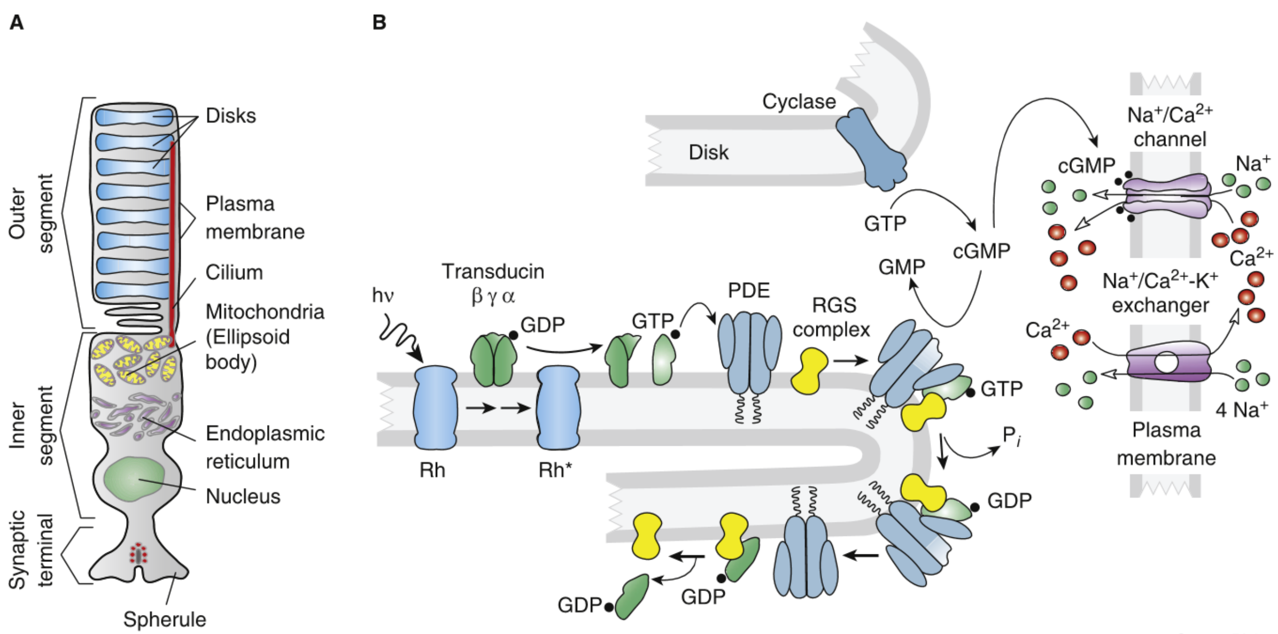
(A)


C
Opsin
N
11-*cis* retinal
Outer segment membrane
3 PDE hydrolyzes cGMP, reducing its concentration
GMP
GMP
GMP
GMP
cGMP
Open Na^{+} channel
Na^{+}
Na^{+}
1 Light stimulation of rhodopsin leads to activation of a G-protein, transducin
2 Activated G-protein activates cGMP phosphodiesterase (PDE)
Closed Na^{+} channel
Light
Rhodopsin
Disk
Disk membrane
4 This leads to closure of Na^{+} channels
α
β
γ
GTP
GDP
Transducin
α
GTP
PDE
Inside of cell
Outside of cell

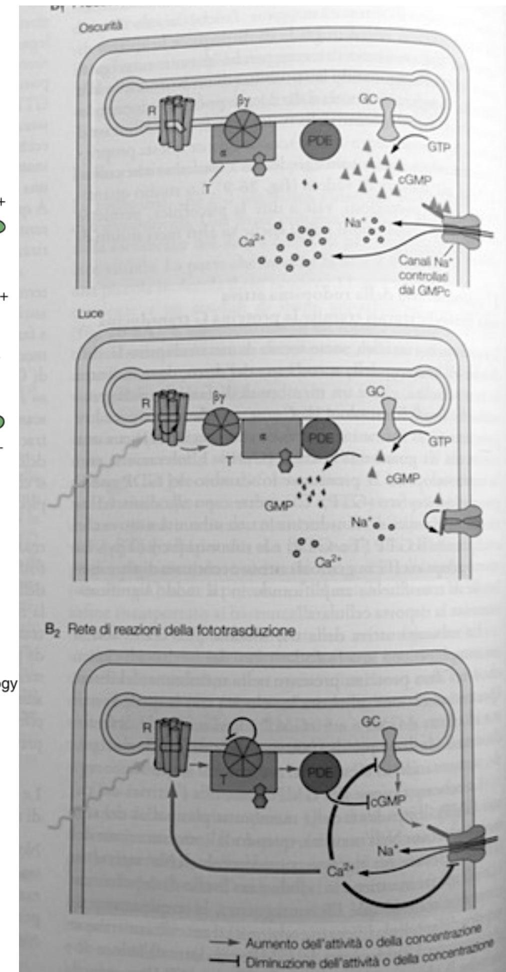
Photoreceptors need to stop the activated response to allow responses to another incoming photon

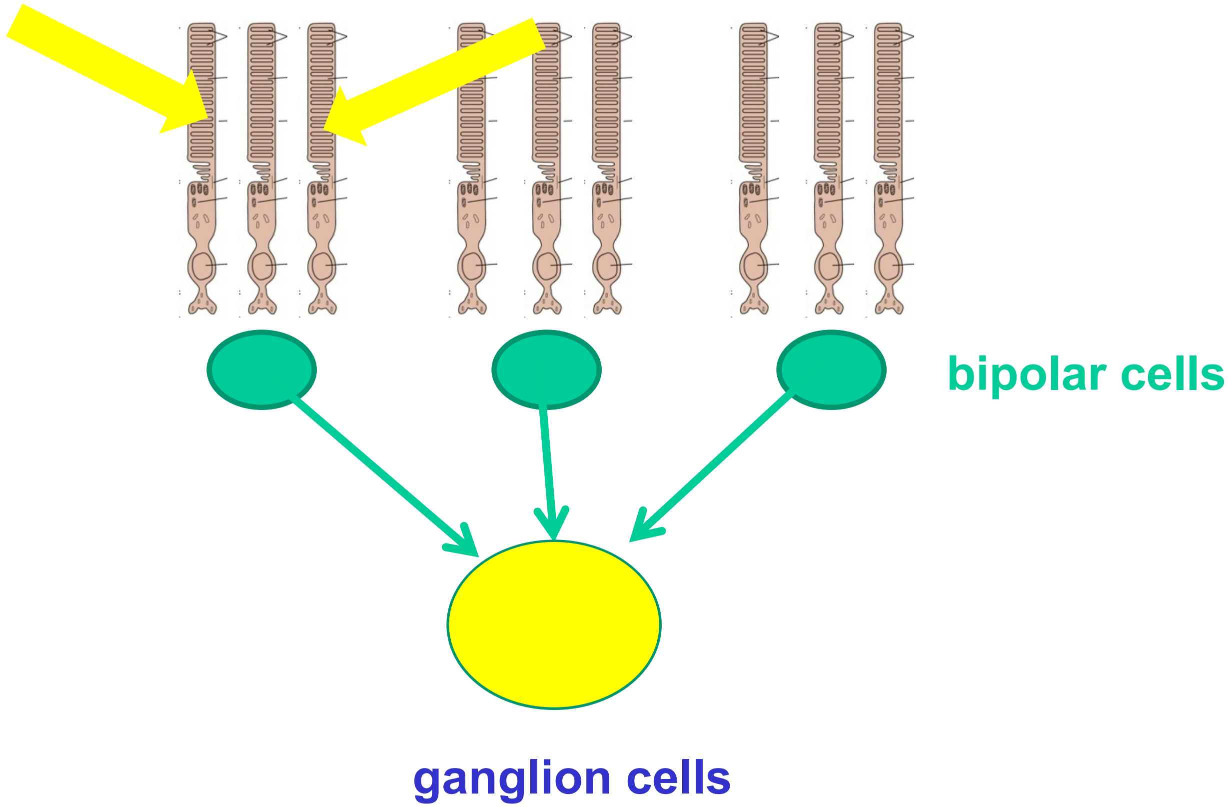
- Phosphorylation of rhodopsin+ inhibition of PDE
- Adaptation: calcium inhibits cGMP cyclase, decreases affinity of Na^+ch for cGMP, inhibits rhodopsin phosphorylation

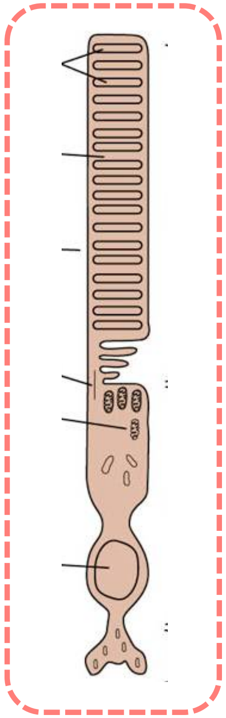
Light decreases calcium, which reactivates the cyclase that re-opens the channels



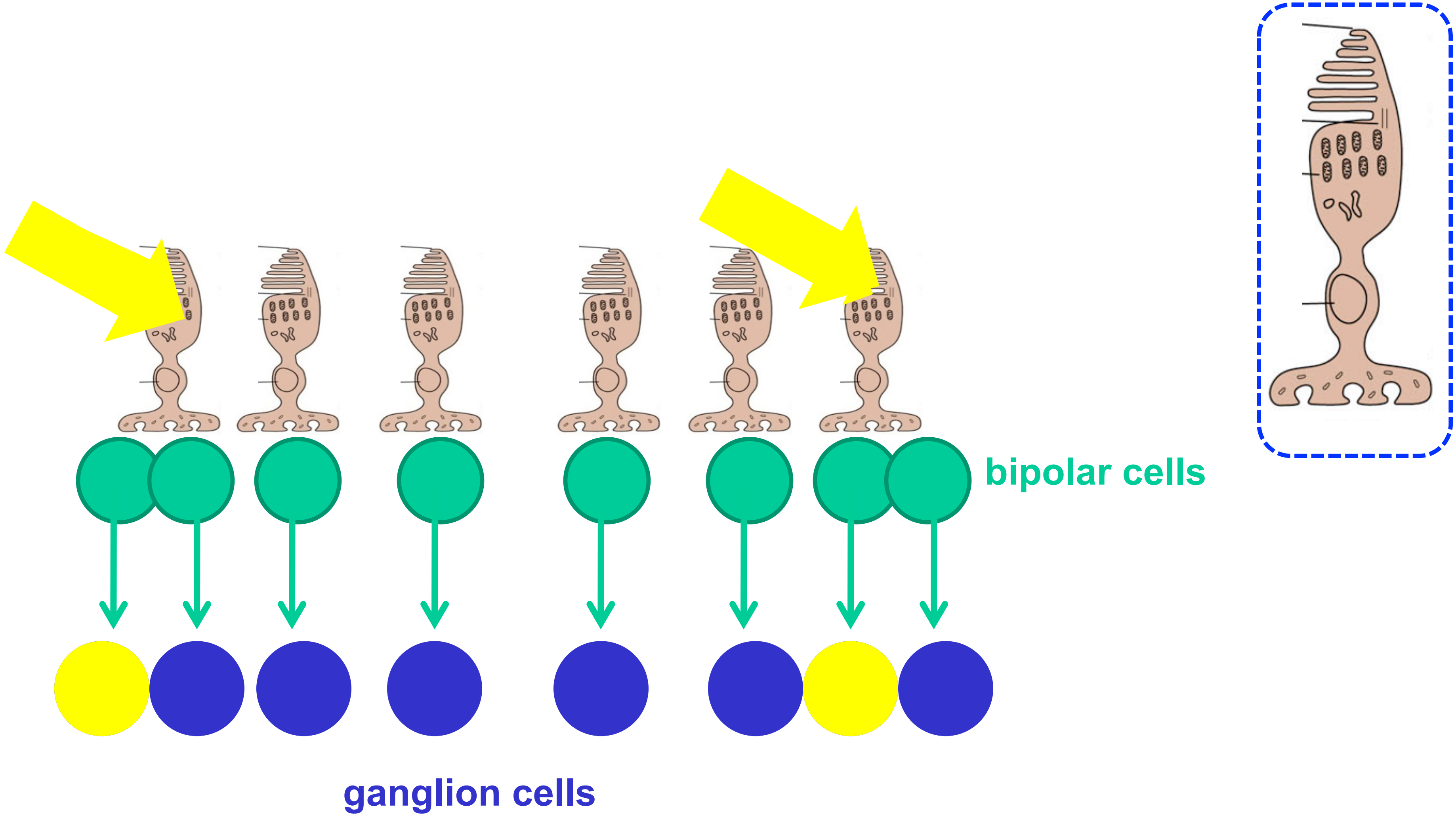
Current Biology







high sensibility
low spatial and temporal resolution



Low sensibility
High temporal and spatial resolution

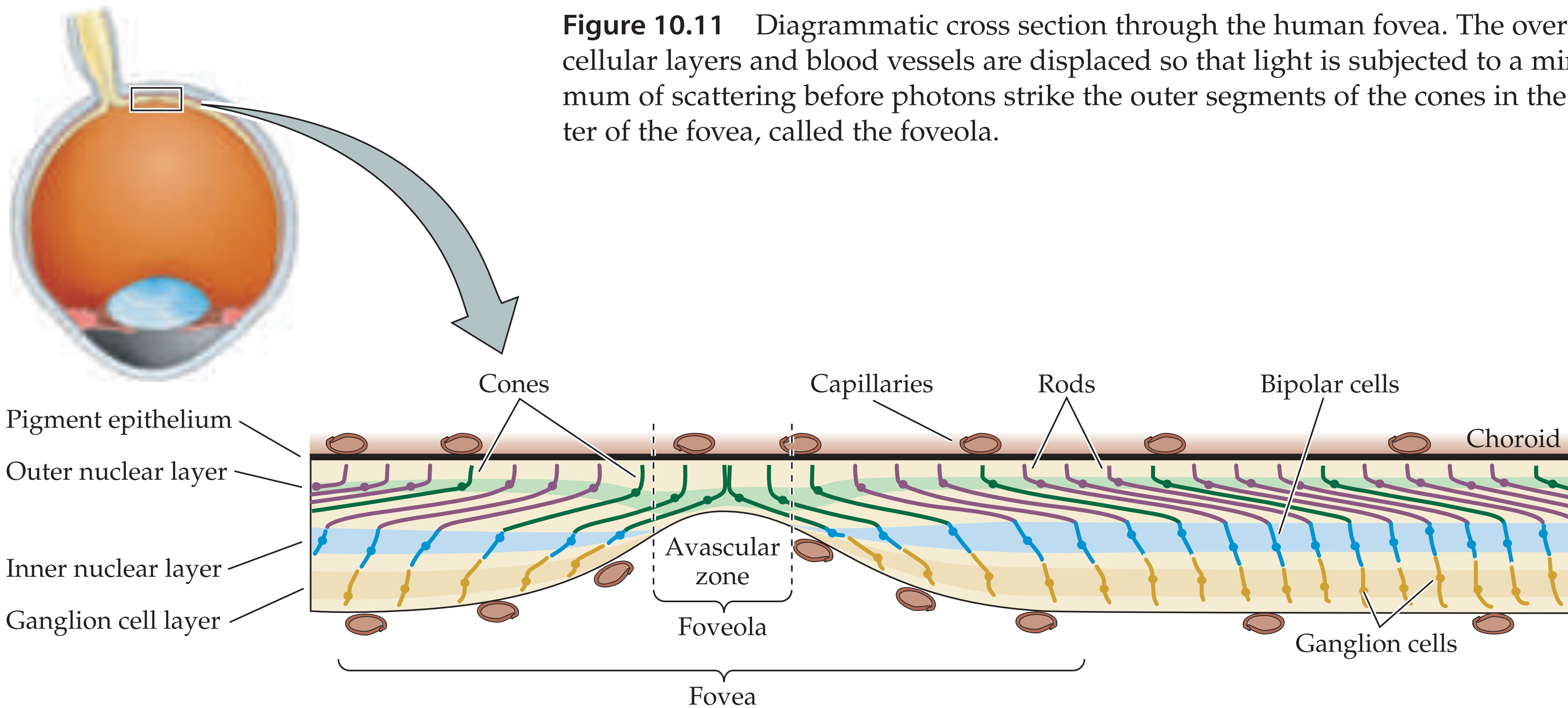
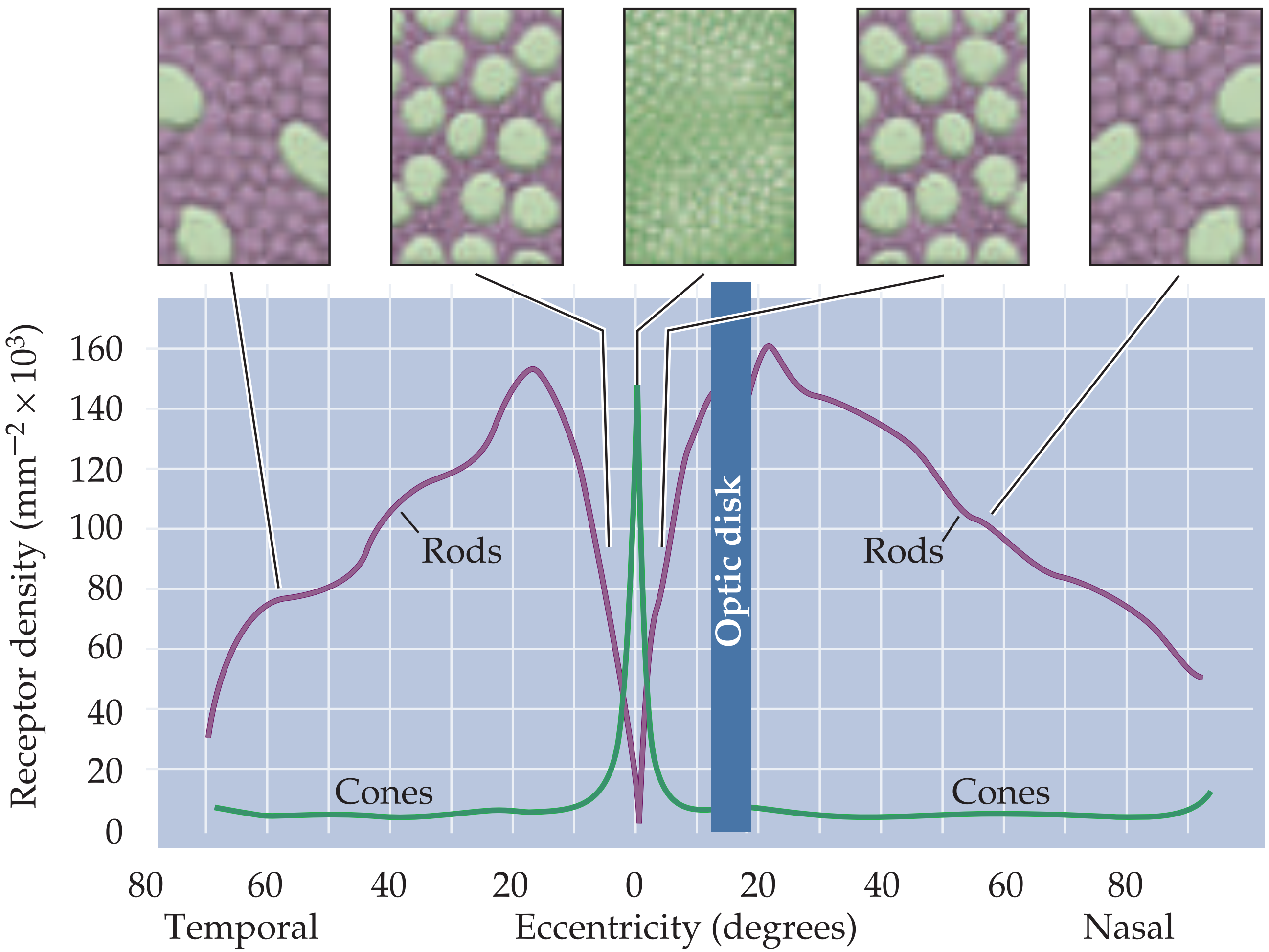


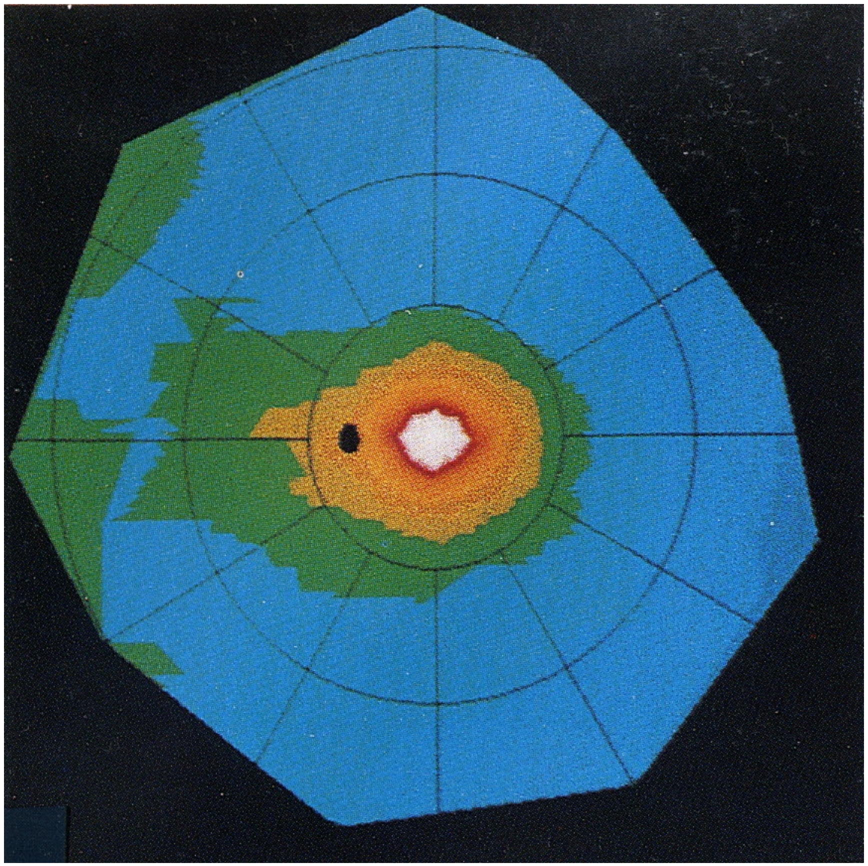
Figure 10.11 Diagrammatic cross section through the human fovea. The overlying cellular layers and blood vessels are displaced so that light is subjected to a minimum of scattering before photons strike the outer segments of the cones in the center of the fovea, called the foveola.

1:1:1 cone: bipolar cell: ganglion cell

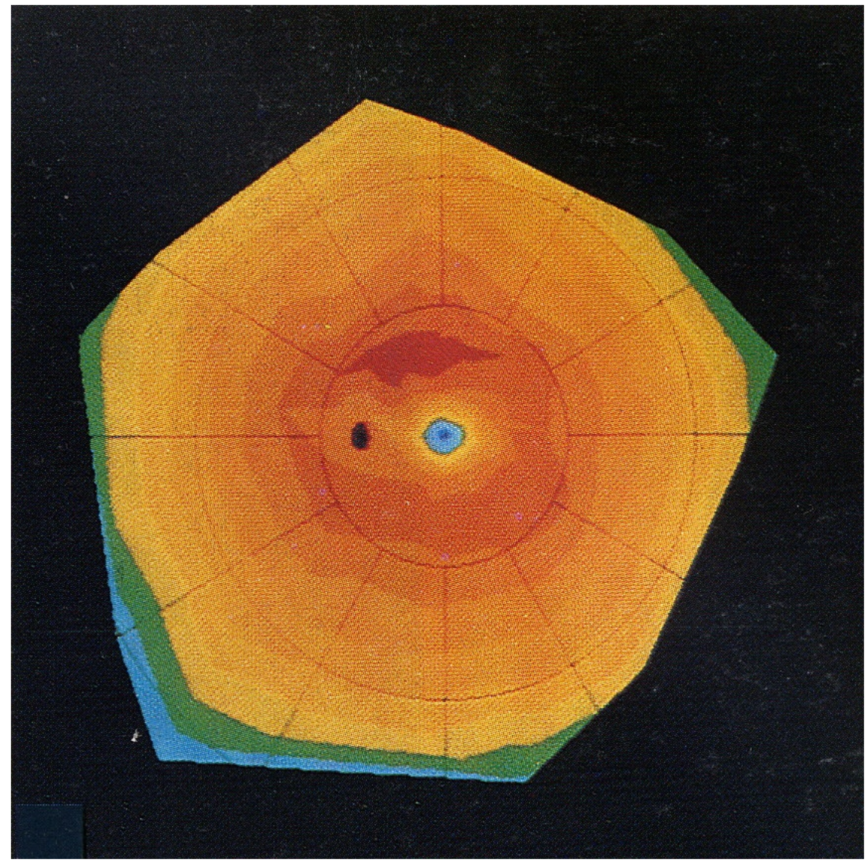


Receptor density (mm^{-2} × 10^3)
160
140
120
100
80
60
40
20
0
Rods
Rods
Cones
Cones
Optic disk
80
60
40
20
0
20
40
60
80
Temporal
Eccentricity (degrees)
Nasal

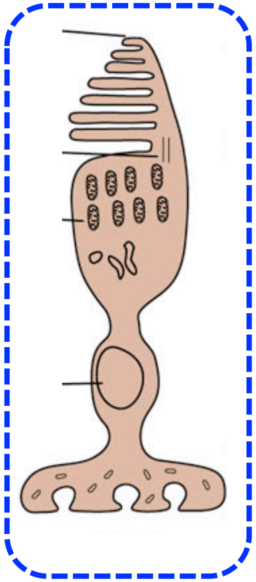
CONES



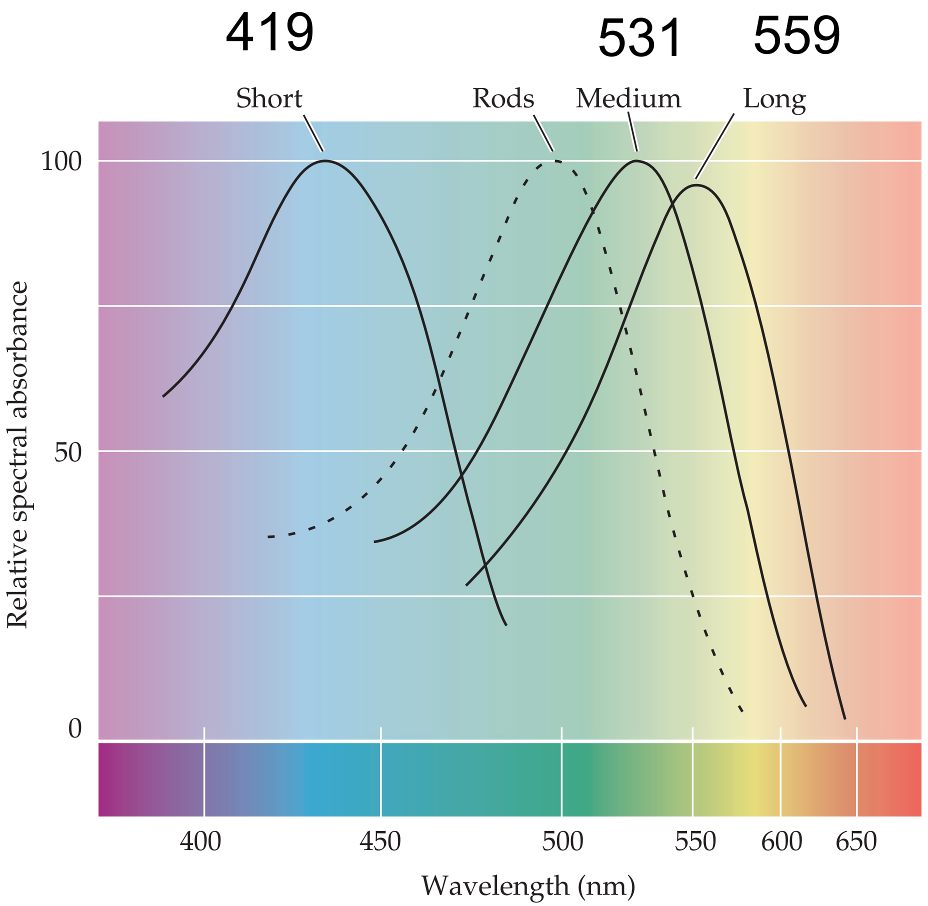
RODS




CORTICAL
MAGNIFIC
ATIONFIX
ESACUITY



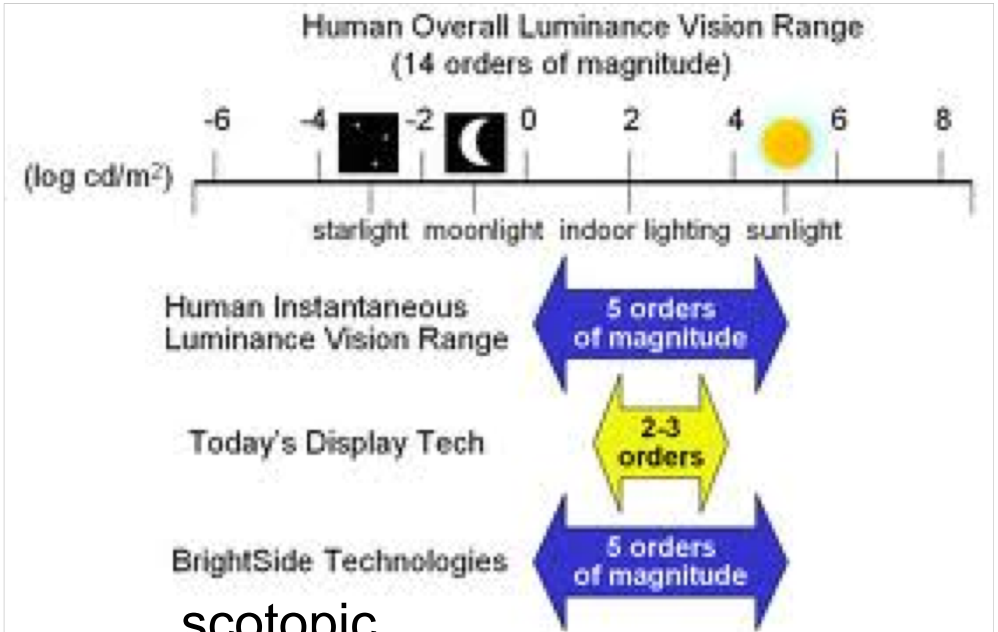
Photopigments

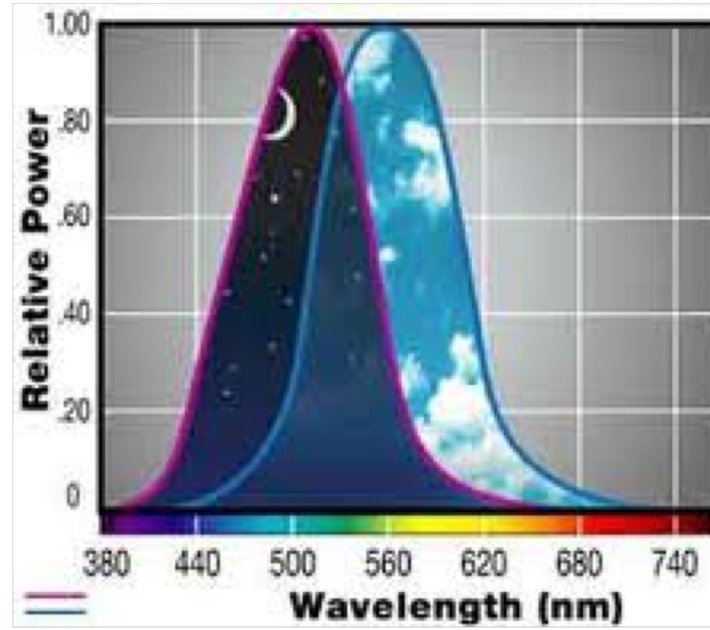


3 sets of cones with different but overlapping absorption spectra

Color vision is thrichromatic

Contribution of rodes and cones to vision

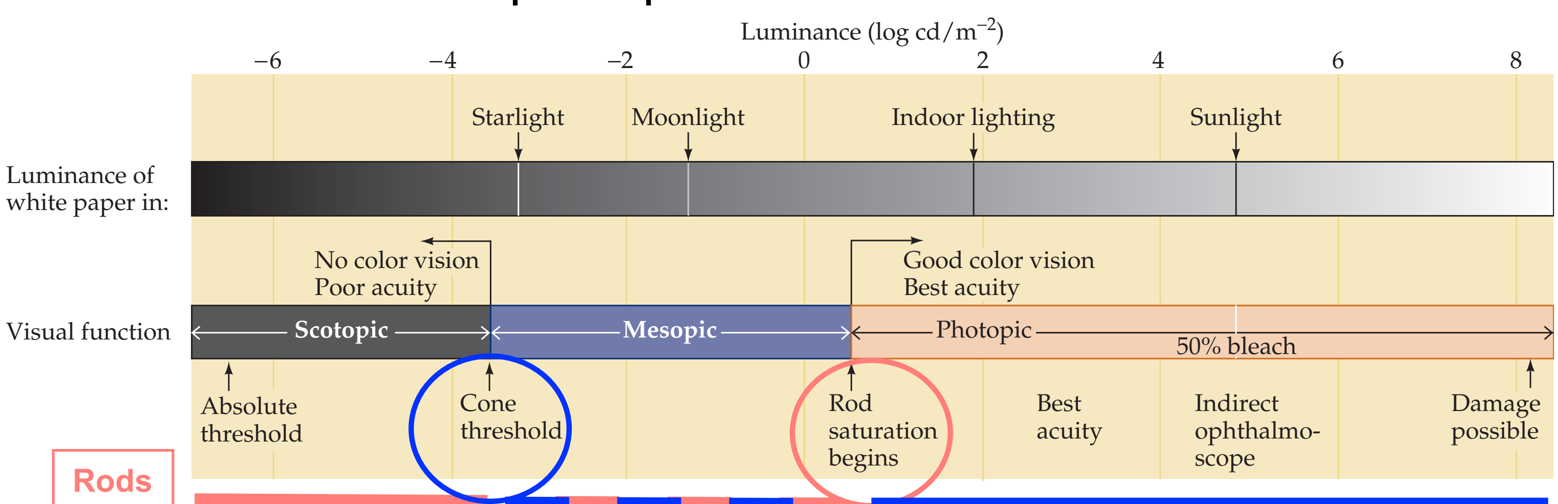




scotopic

mesopic

photopic

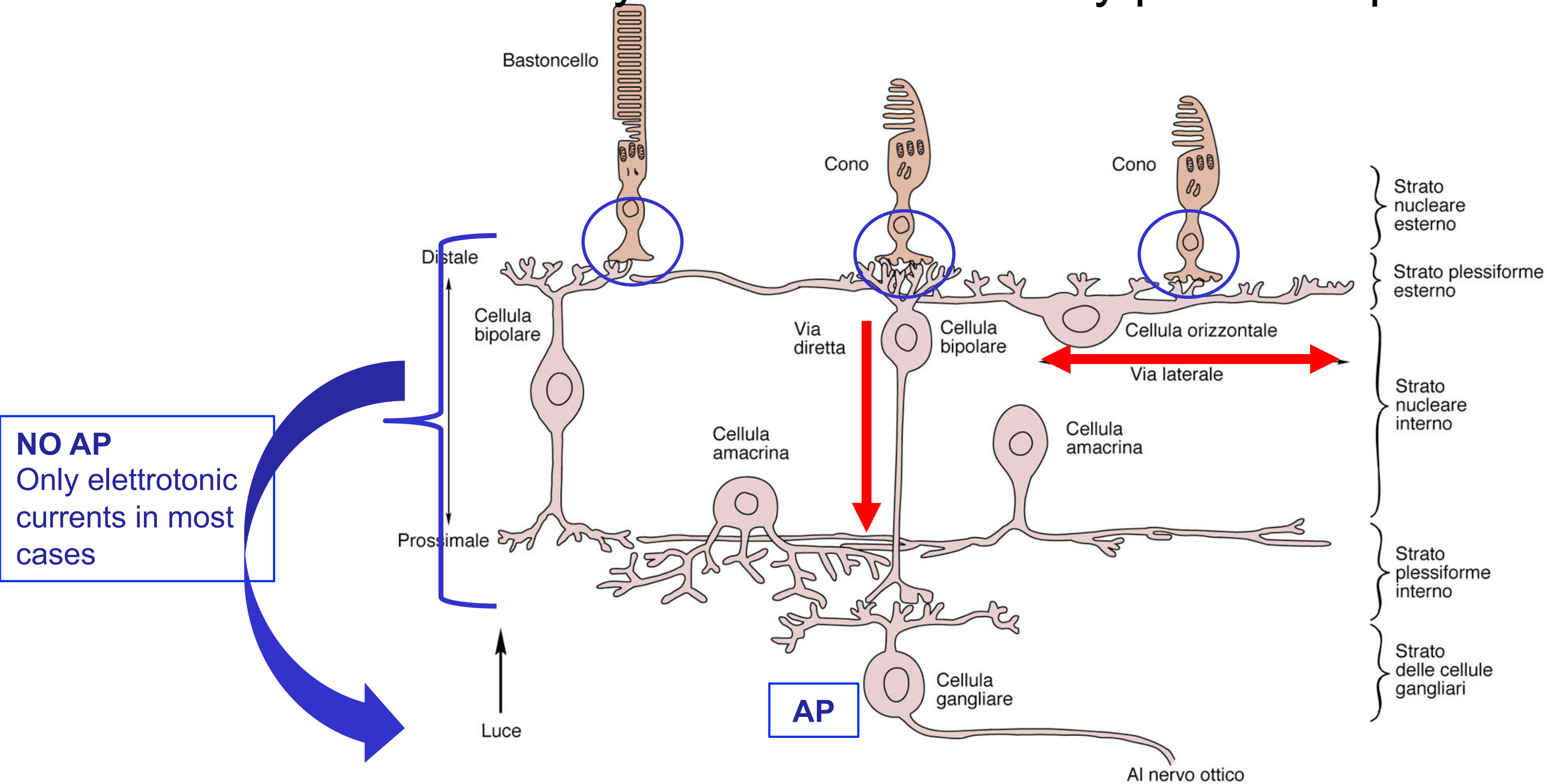


Rods

Cones

Rods	Cones
High sensibility (nocturnal vision) - more pigments - more intense signal amplification - Low temporal resolution (summation)	Low sensibility (day vision) - less pigment - less intense amplification - high temporal resolution
Achromatic vision (only one type of pigment)	Chromatic vision (3 types of pigments)
Convergent connections (low visual acuity)	Non convergent (high visual acuity)
Not in the fovea	High density in the fovea, absent in peripheral retina

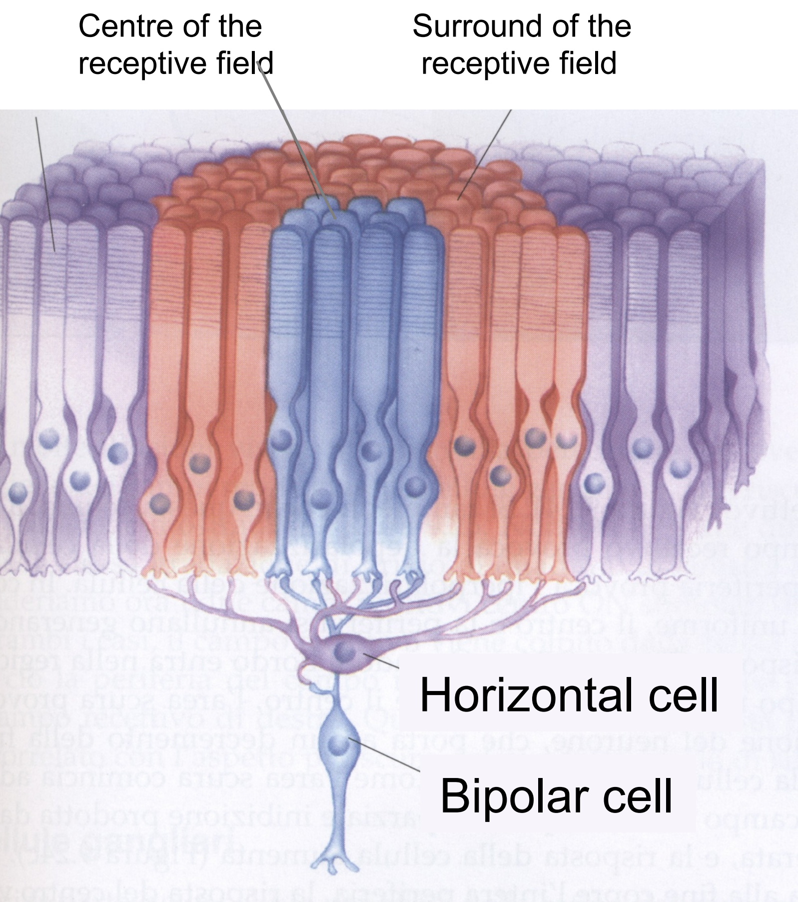
GC axons: 1% of photoreceptors
The retina circuits modify the info collected by photoreceptors

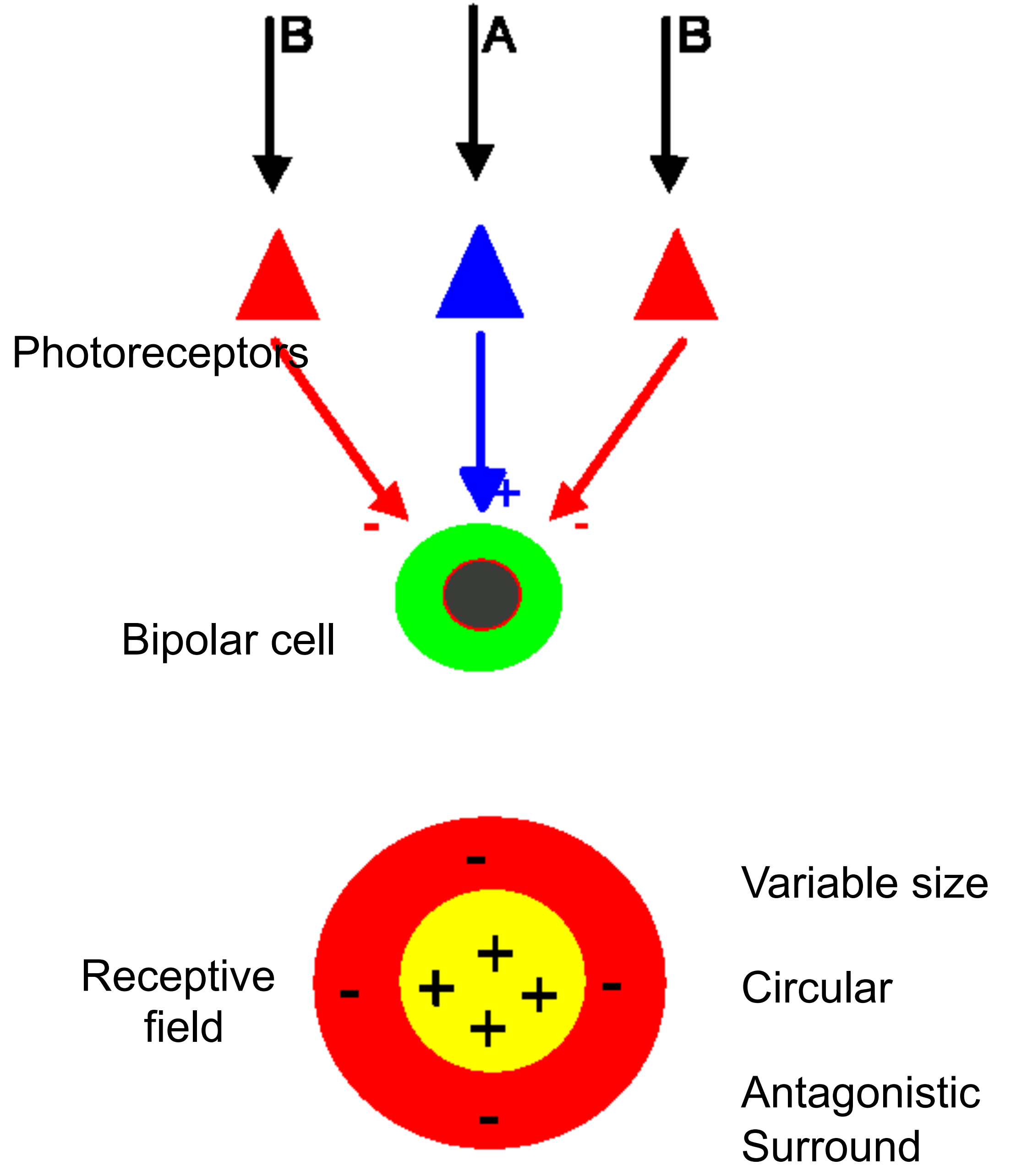


Bipolar cells, amacrine cells, horizontal cells elaborate the signals transmitted by rod and cones and **extract spatial and temporal features of visual stimuli**

Spatial and temporal filters based on inhibitory circuits

Receptive field: area of the <u>retina</u> (retina patch) where light stimulation excites the cells

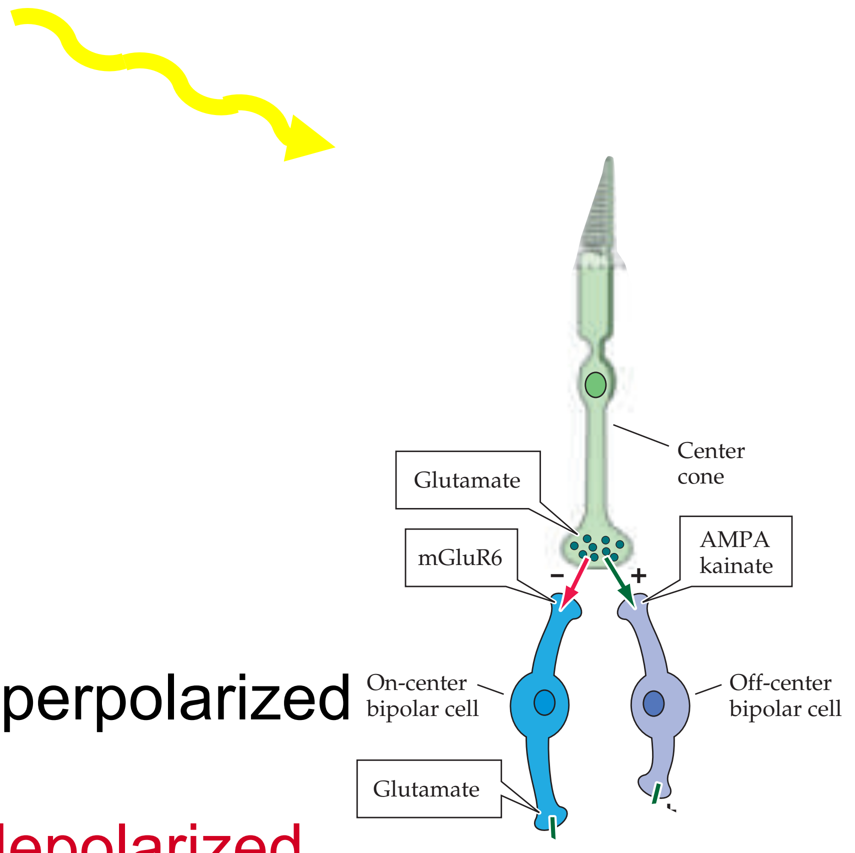




On/off center-surround receptive fields also for ganglion cells:

- **Circular**
- **2 regions: central spot + surround (concentric)**
- **cell types: on center, off center cells**

- On/off center cells are about equal in numbers
- Receptive fields have overlapping distributions
- Every point on the retina (each point of the visual field is analyzed by several ganglion cells)



hyperpolarized

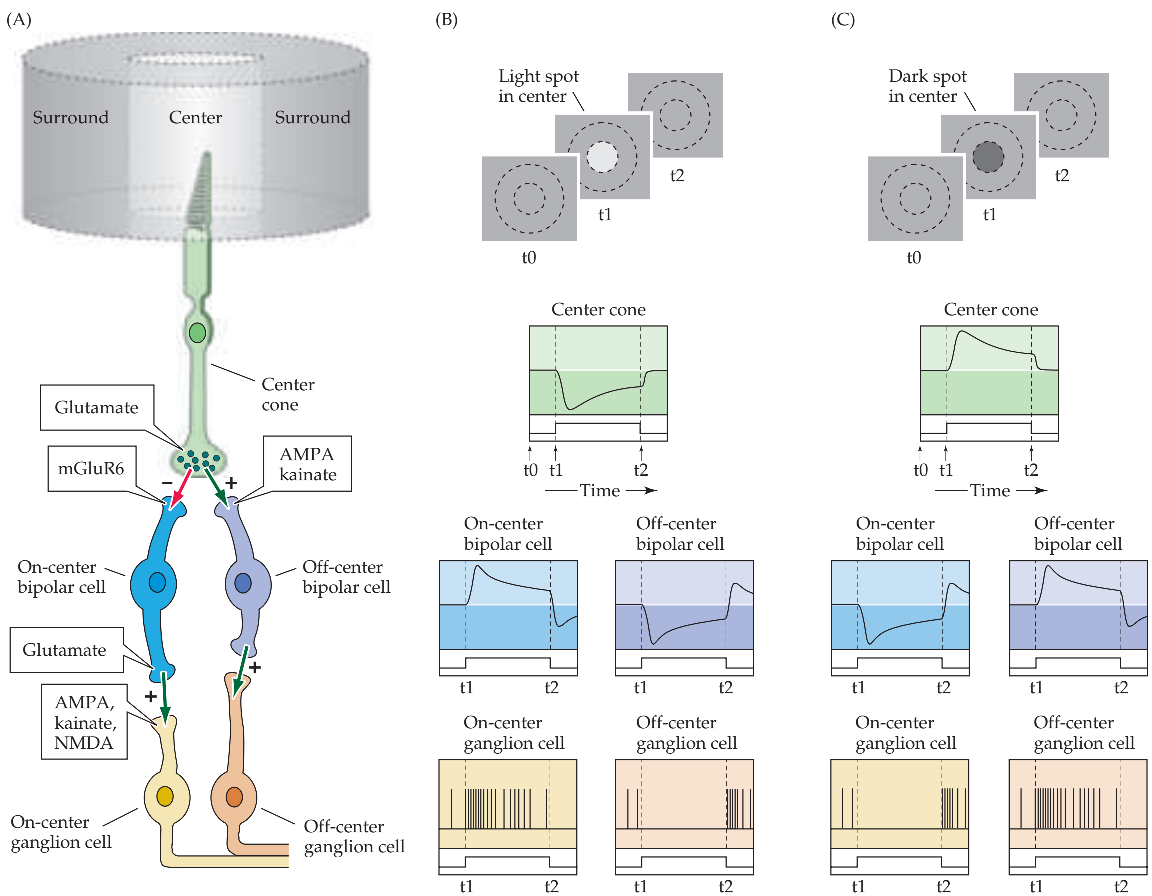
depolarized

depolarized

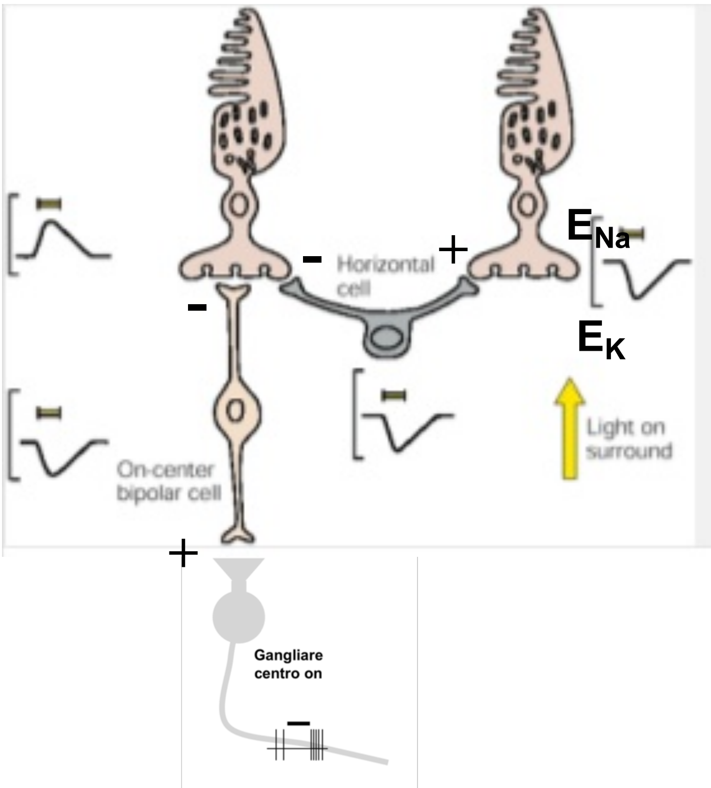
hyperpolarized

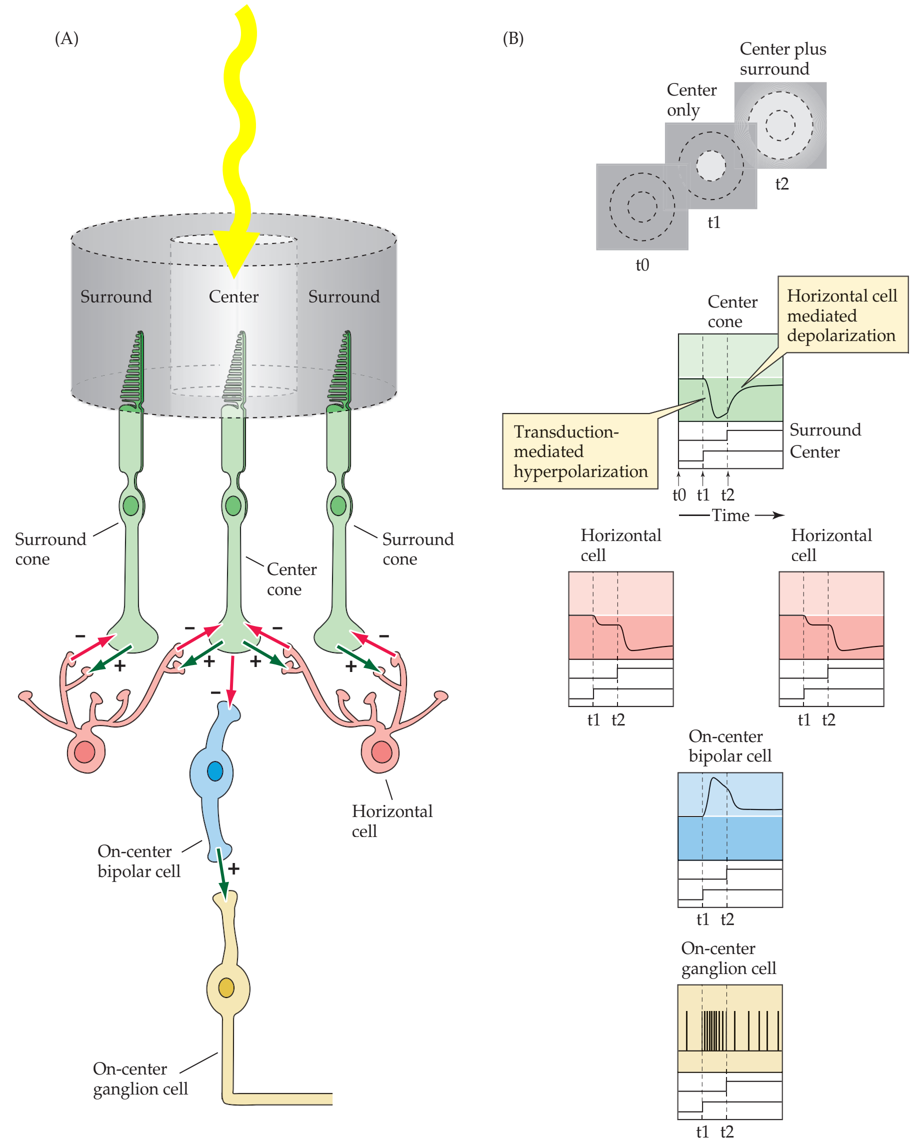
Impact on function of retinal ganglion cells and on the structure of their receptive fields

Effects of circuit integration:
on-center, off-center receptive fields
on-center, off-center bipolar cells and ganglion cells



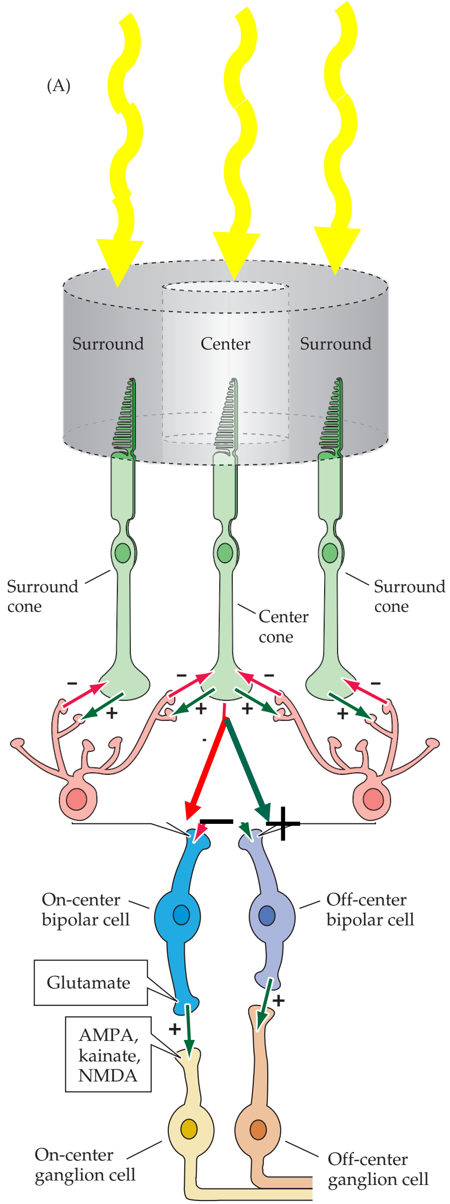
How opponent center surround zones are generated

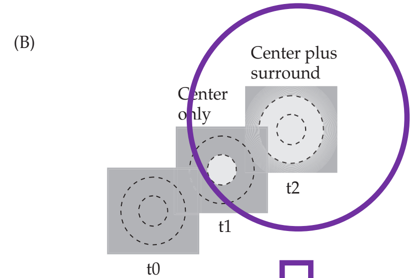




Lateral inhibition

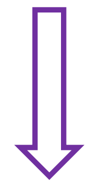
Horizontal cells: antagonize receptors' responses to light

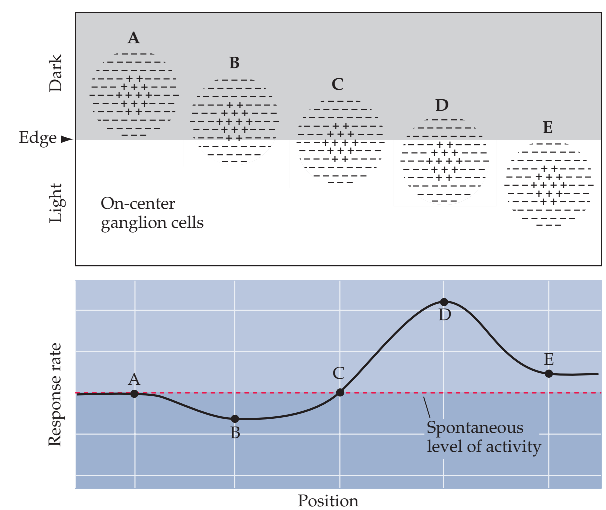




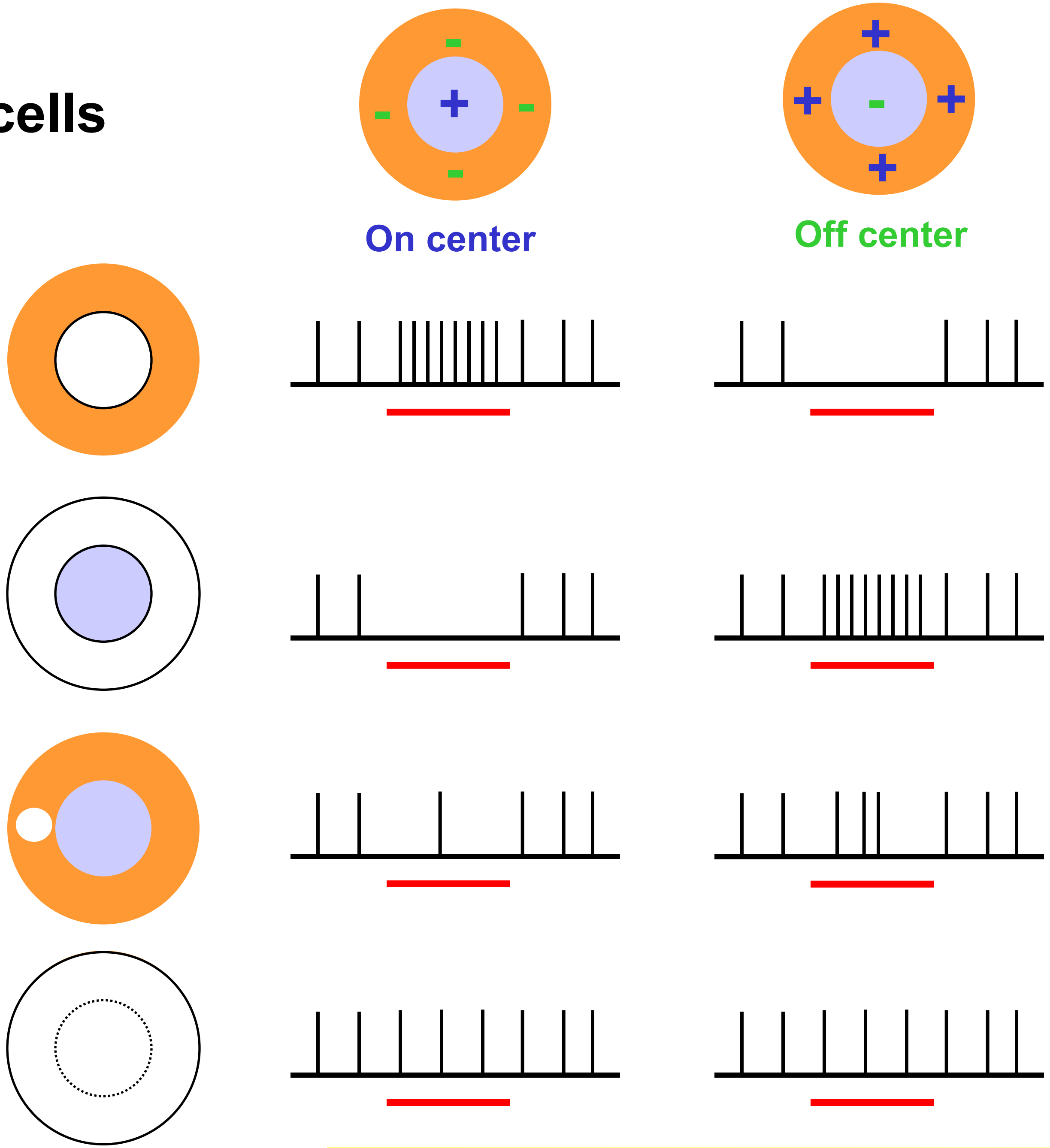
Ganglion cells do not signal diffuse illumination

Not simple photodetectors





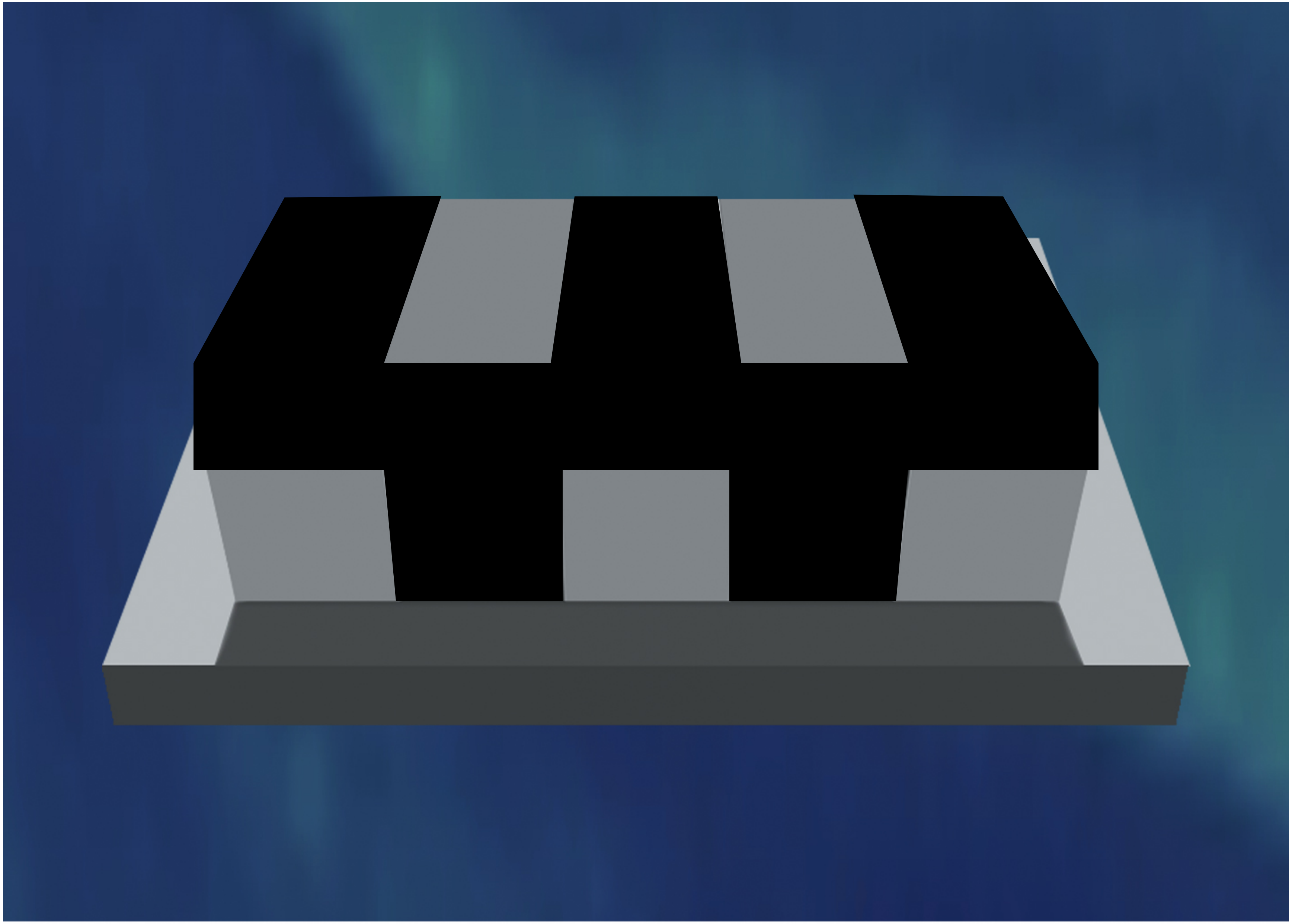
Ganglion cells



Response to luminance contrast

The perceived brightness of objects depends on that of the background (luminance contrast):

Ganglion cells are not photoreceptors – they code contrast - not the absolute intensity of stimuli



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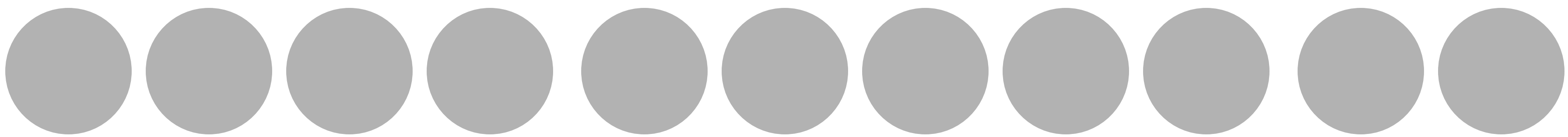
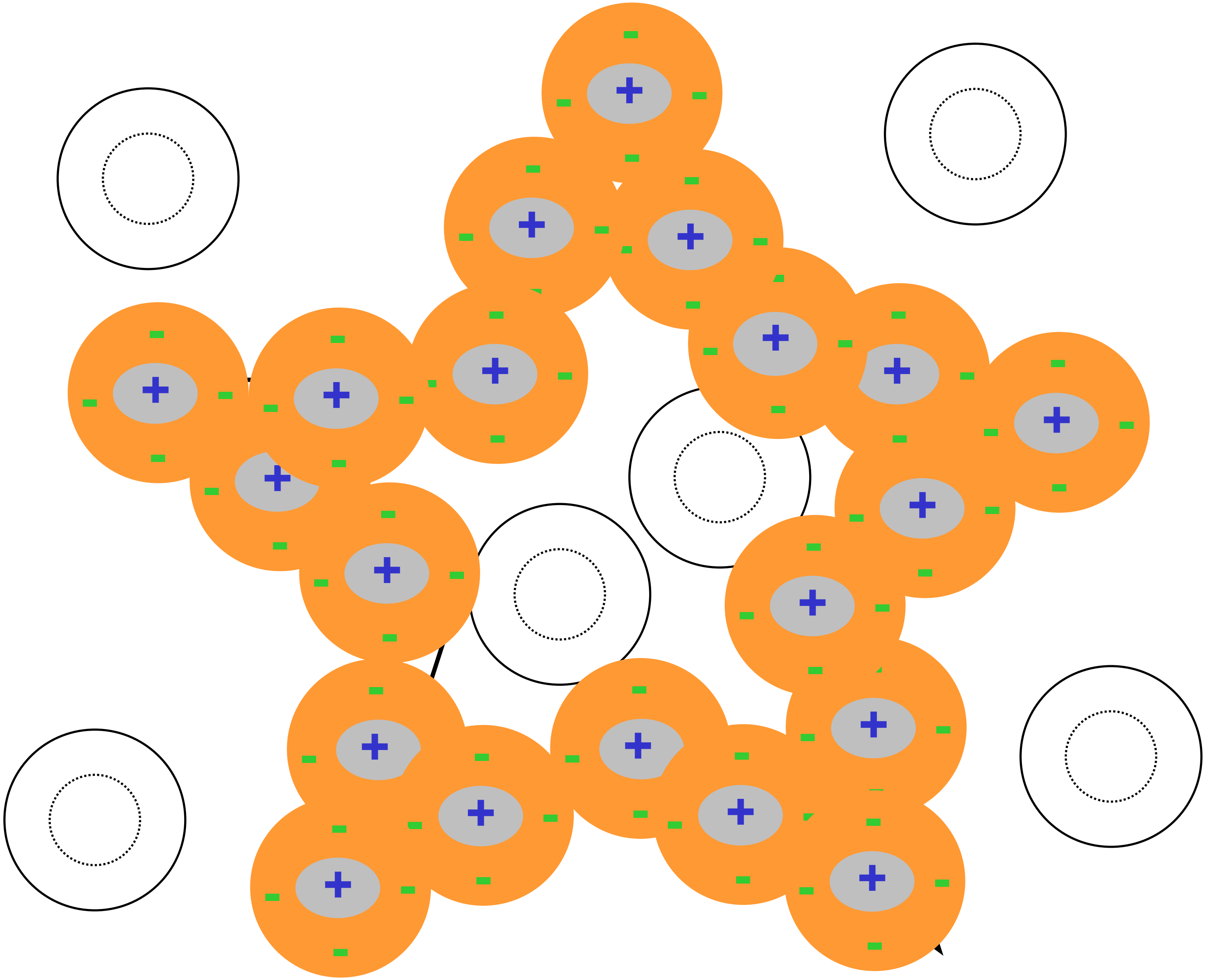


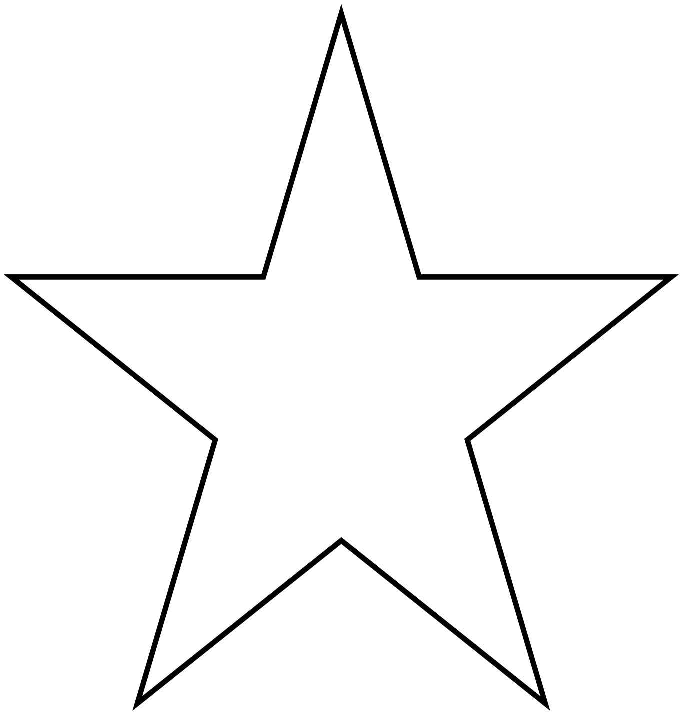
Ganglion cells

Ganglion cells are never silent

Small light spots are more effective than uniform illumination

The discarge frequency of ganglion cells does not reflect the absolute intensity of the stimulus but the diference of intensities of the stimuli applied in the center vs the surround

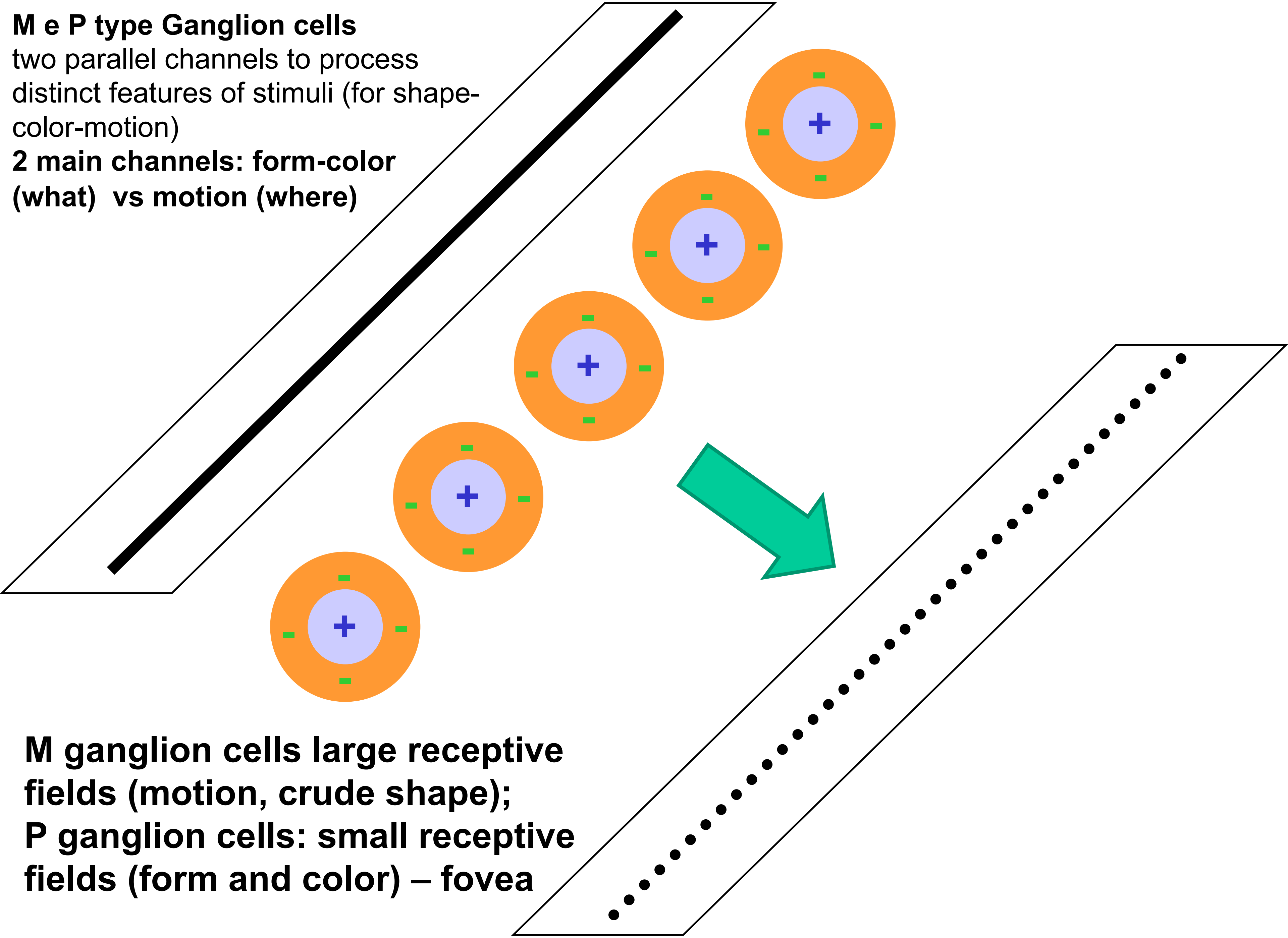




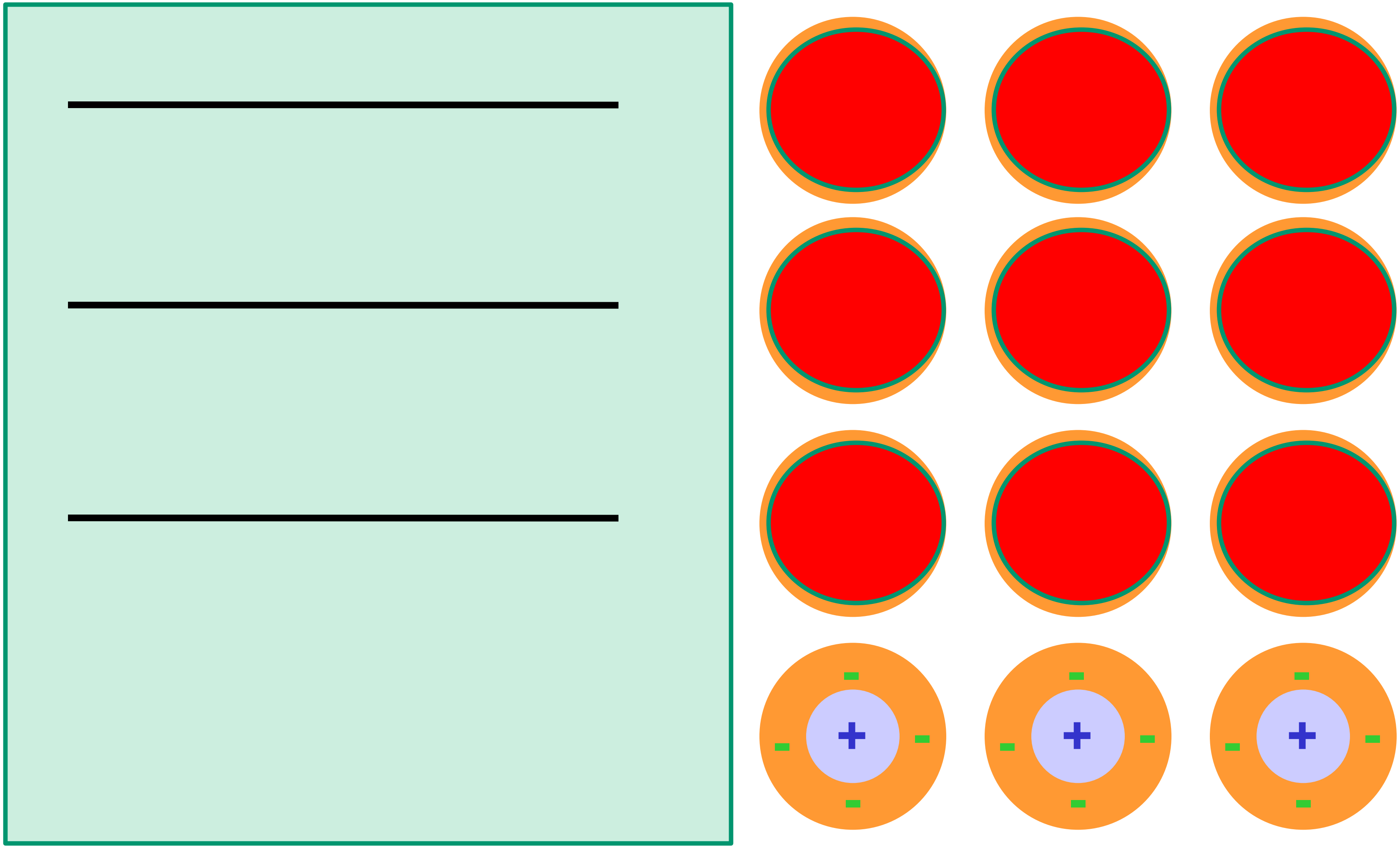
Most informative: regions where there are differences in luminance


N2321R

M e P type Ganglion cells
two parallel channels to process distinct features of stimuli (for shape-color-motion)
2 main channels: form-color (what) vs motion (where)

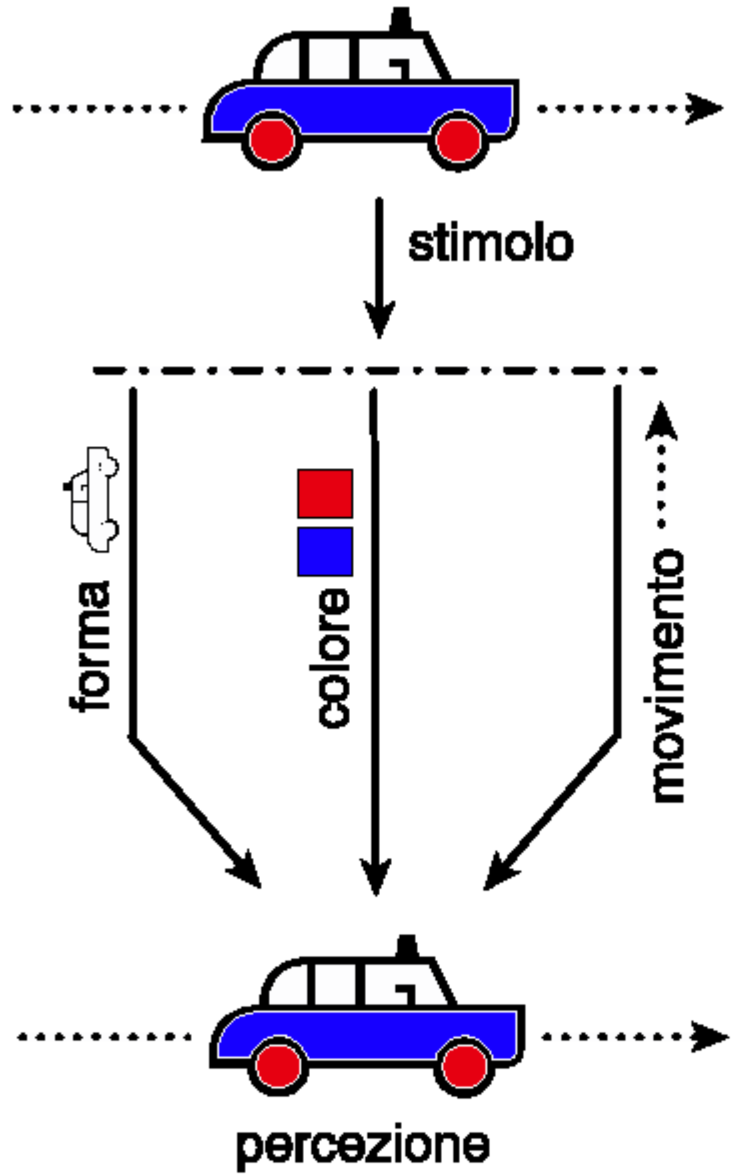


M ganglion cells large receptive fields (motion, crude shape); P ganglion cells: small receptive fields (form and color) – fovea



Field of view

Spatial localization


stimolo
forma
colore
movimento
percezione