The Special Senses

Vision - 2

Photo-transduction

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The Physiology of Vision

Objectives:

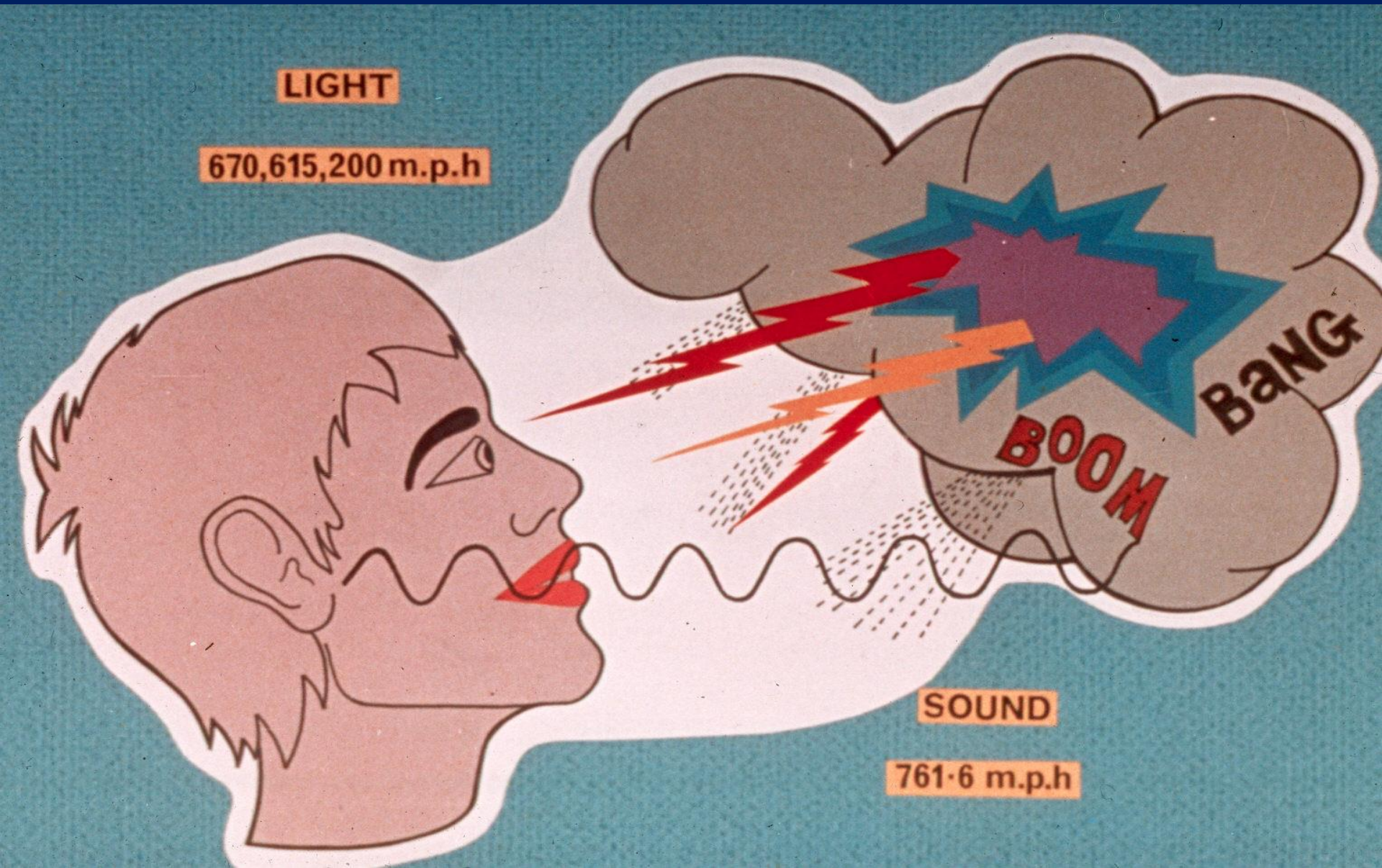
At the end of this lecture the student should be able to:

- **List and compare functional properties of rods and cones in scotopic and photopic vision**
- **To know the convergence and its value**
- **To know the photosensitive compounds Contrast the phototransduction process for rods and cones in light and dark and the ionic basis of these responses**
- **To know the synaptic mediators at retina**
- **To know the process of rhodopsine regeneration**
- **To know the meaning of nyctalopia Contrast the dark and light adaptation**
- **To know the visual cycle and rhodopsine regeneration**

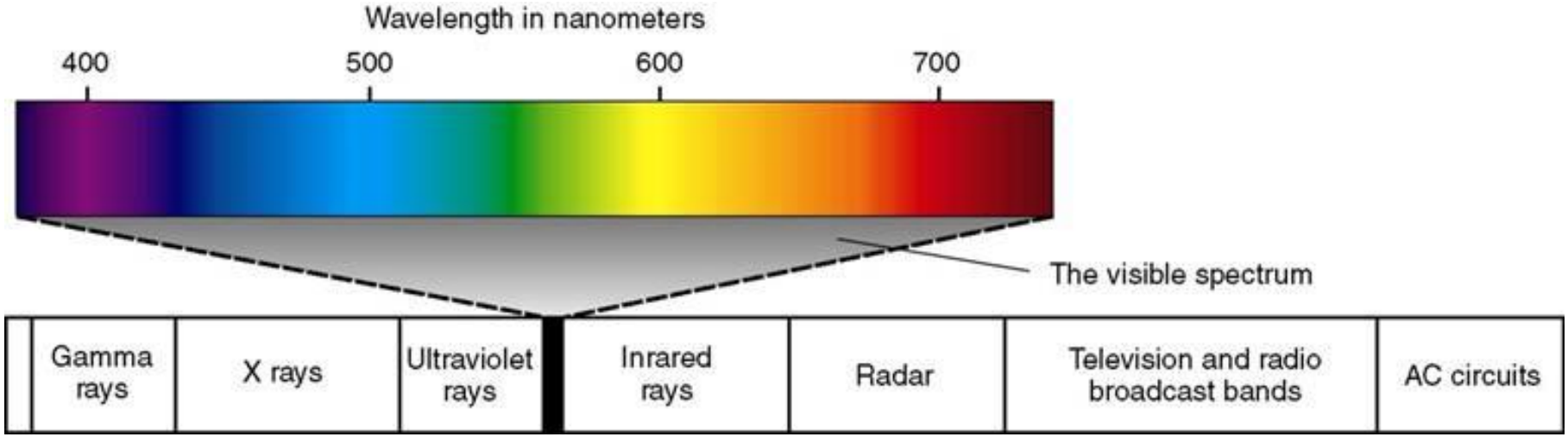
Physiology of Vision

- Stimulus: Light
- Receptor: Retina (Photoreceptors)

Which travels faster: light or sound?



The Electromagnetic Spectrum



Visible light & Duplicity Theory of vision

Visible light Spectrum

- Extends from 397 to 723nm

- Eye functions under two 2 conditions of illumination:
  - Bright light (Photopic vision)…Cones
  - Dim light (Scotopic vision) ..Rods

Duplicity theory of vision

Duplicity theory

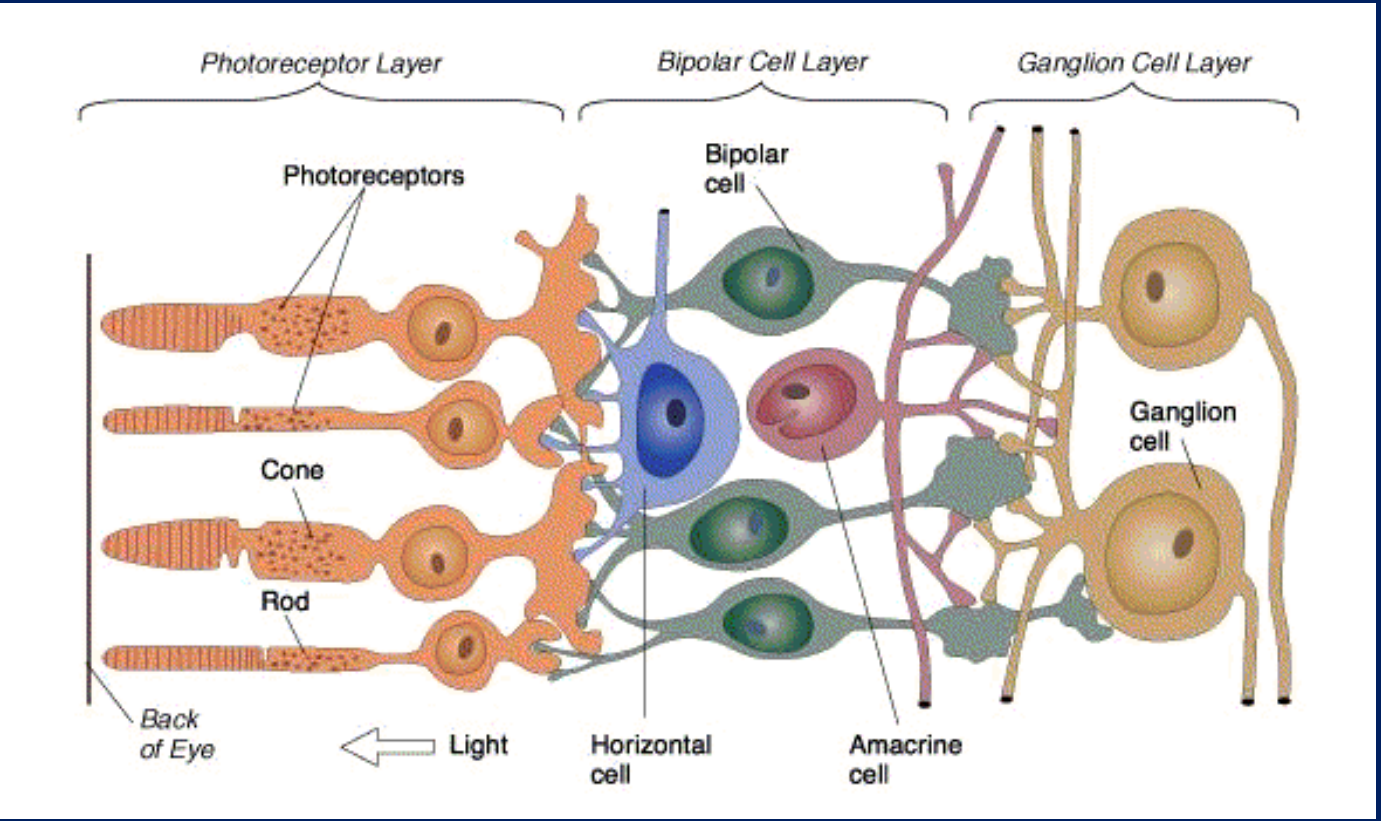
- Photopic visibilty curve peaks at 505nm
- Scotopic "" " " " 550nm

Photoreceptors
Rods & Cones

Morphology & Distribution

Retina

Back of retina, pigment epithelium



Light

Rods and Cones

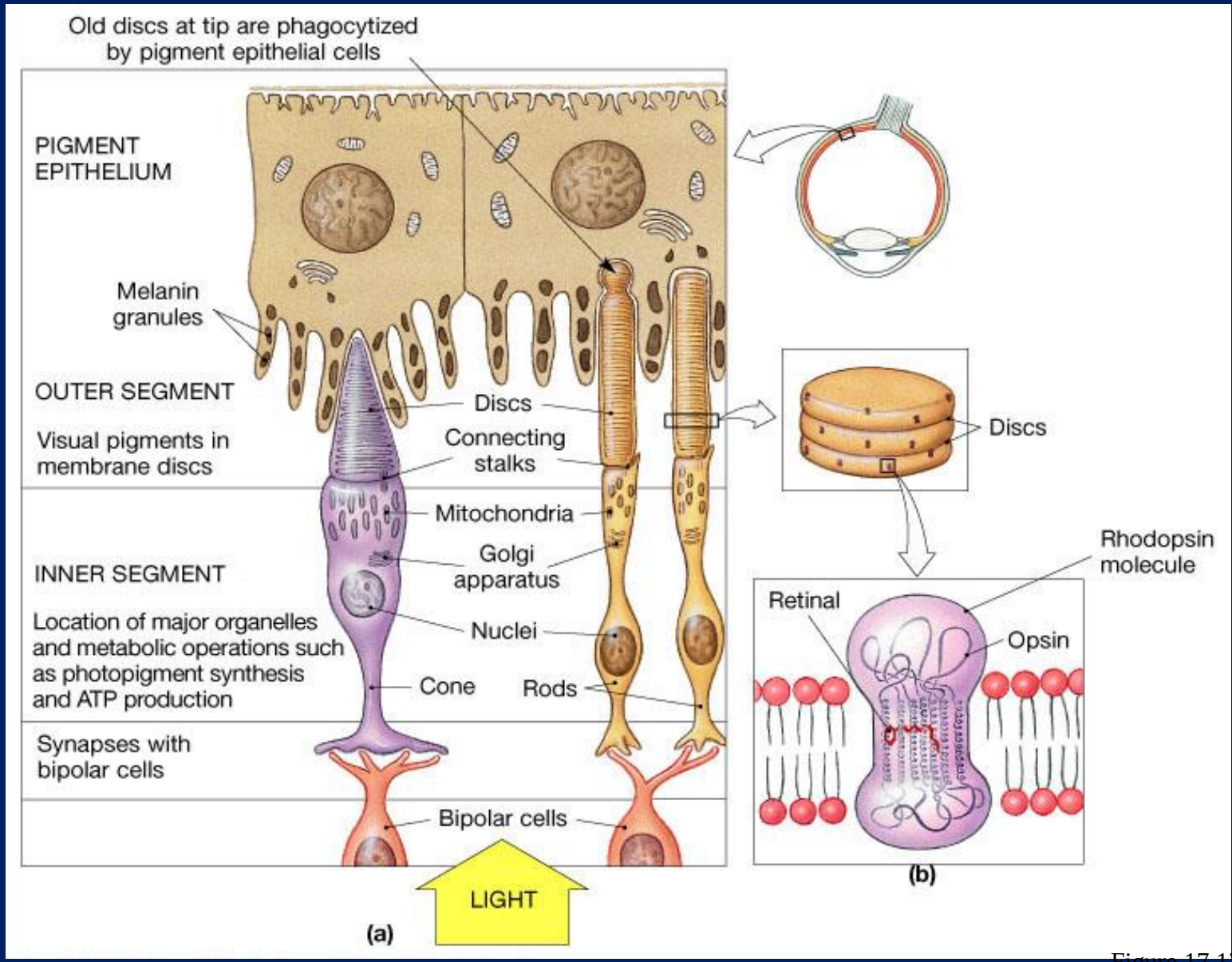
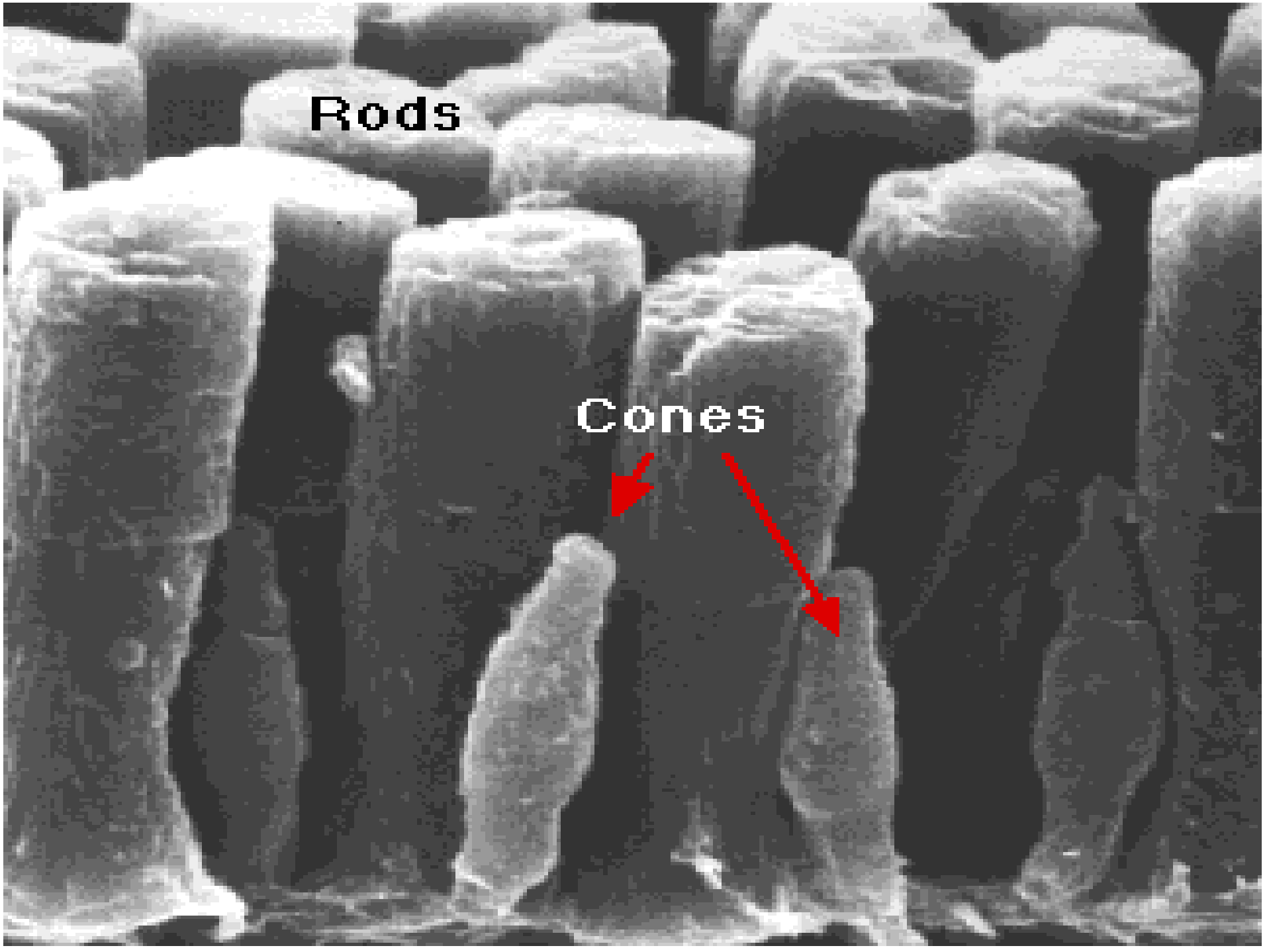
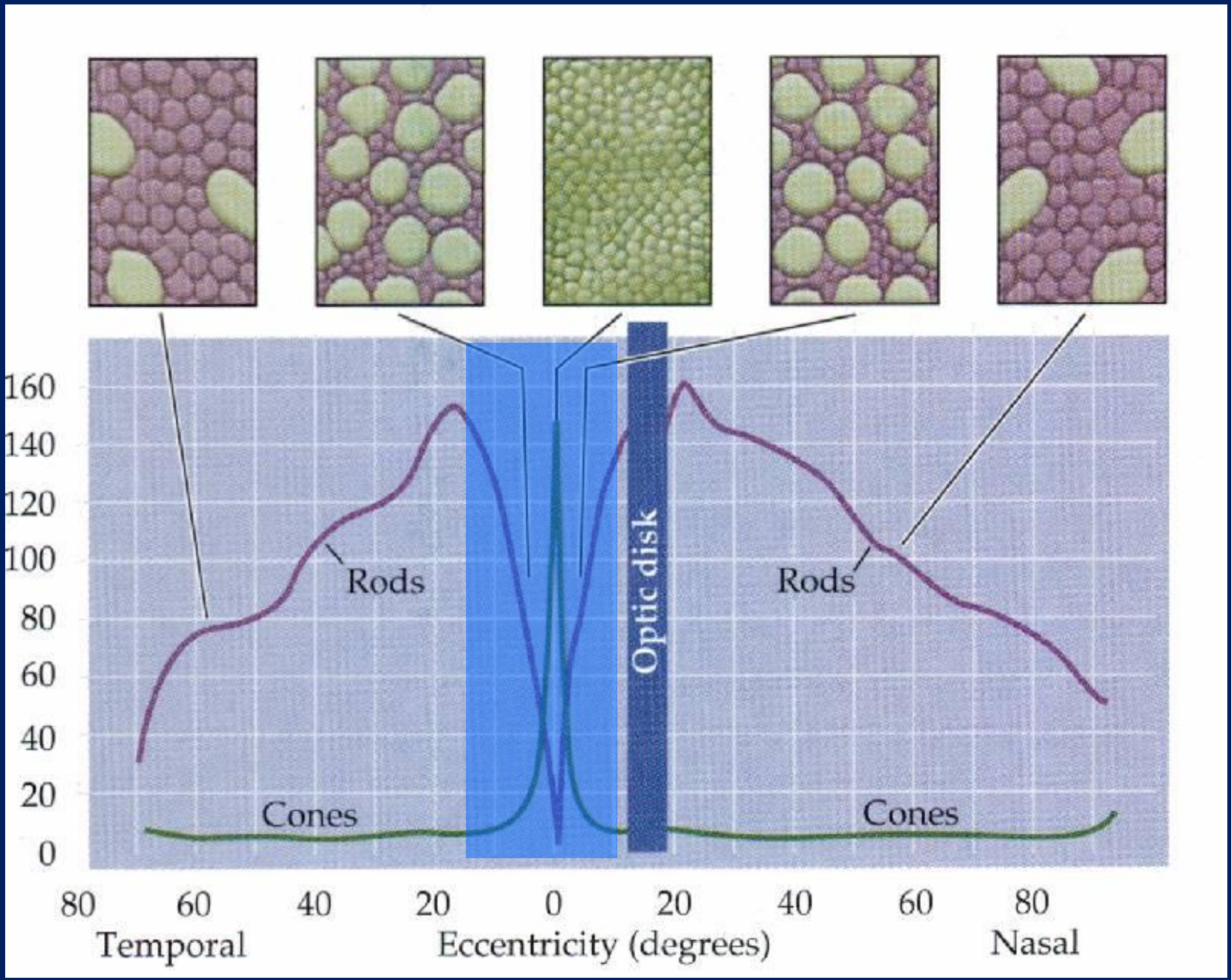


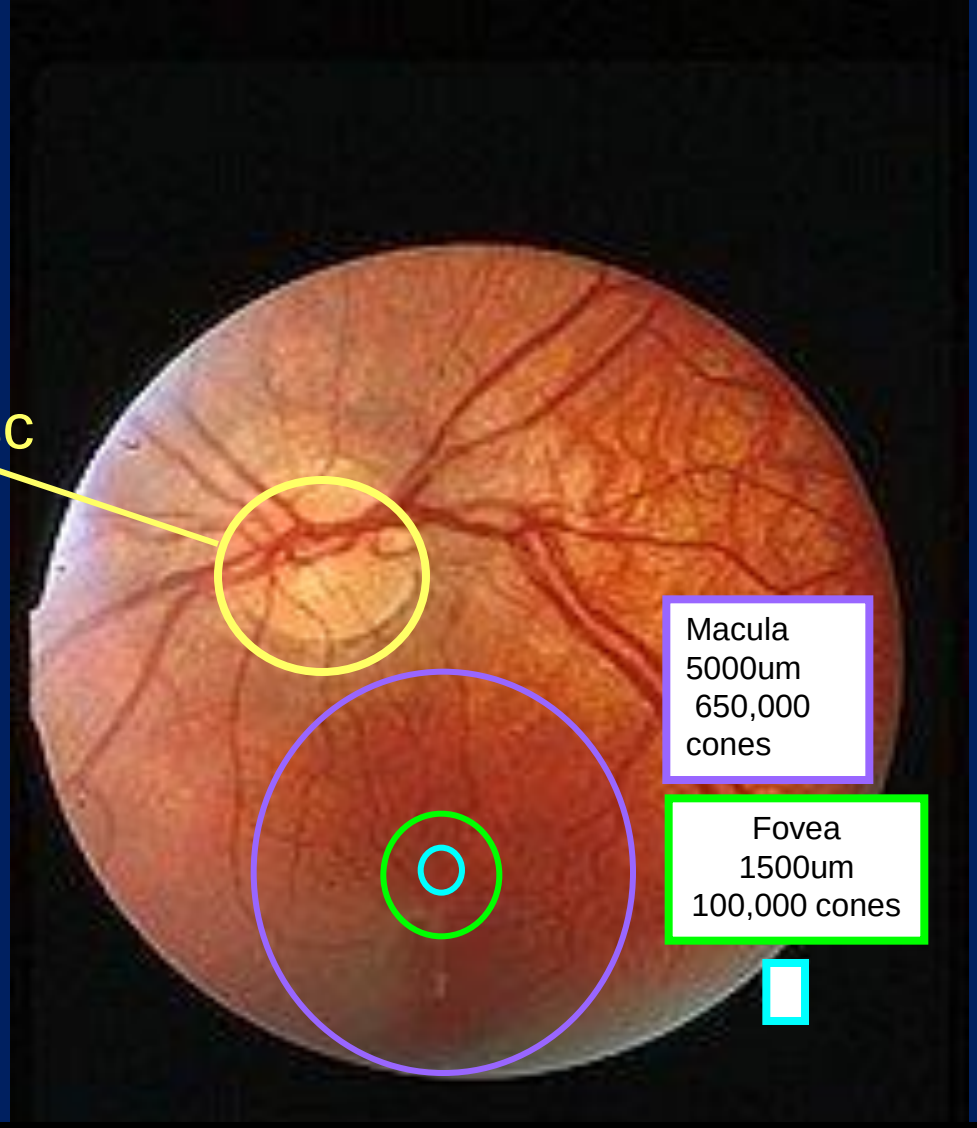
Figure 17.13


Rods
Cones

Distribution of

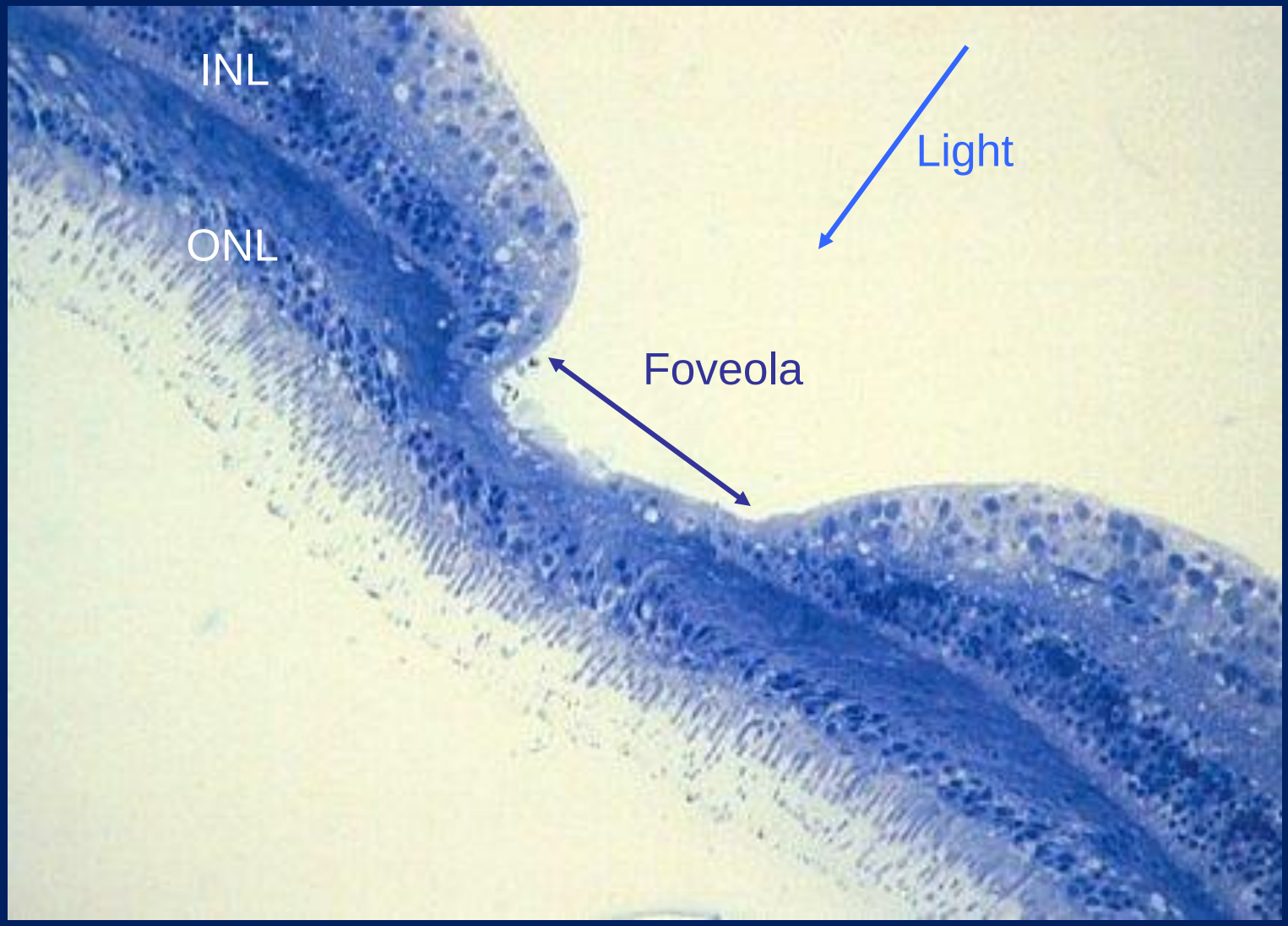


Normal Fundus



Photoreceptors are not distributed uniformly across the retina

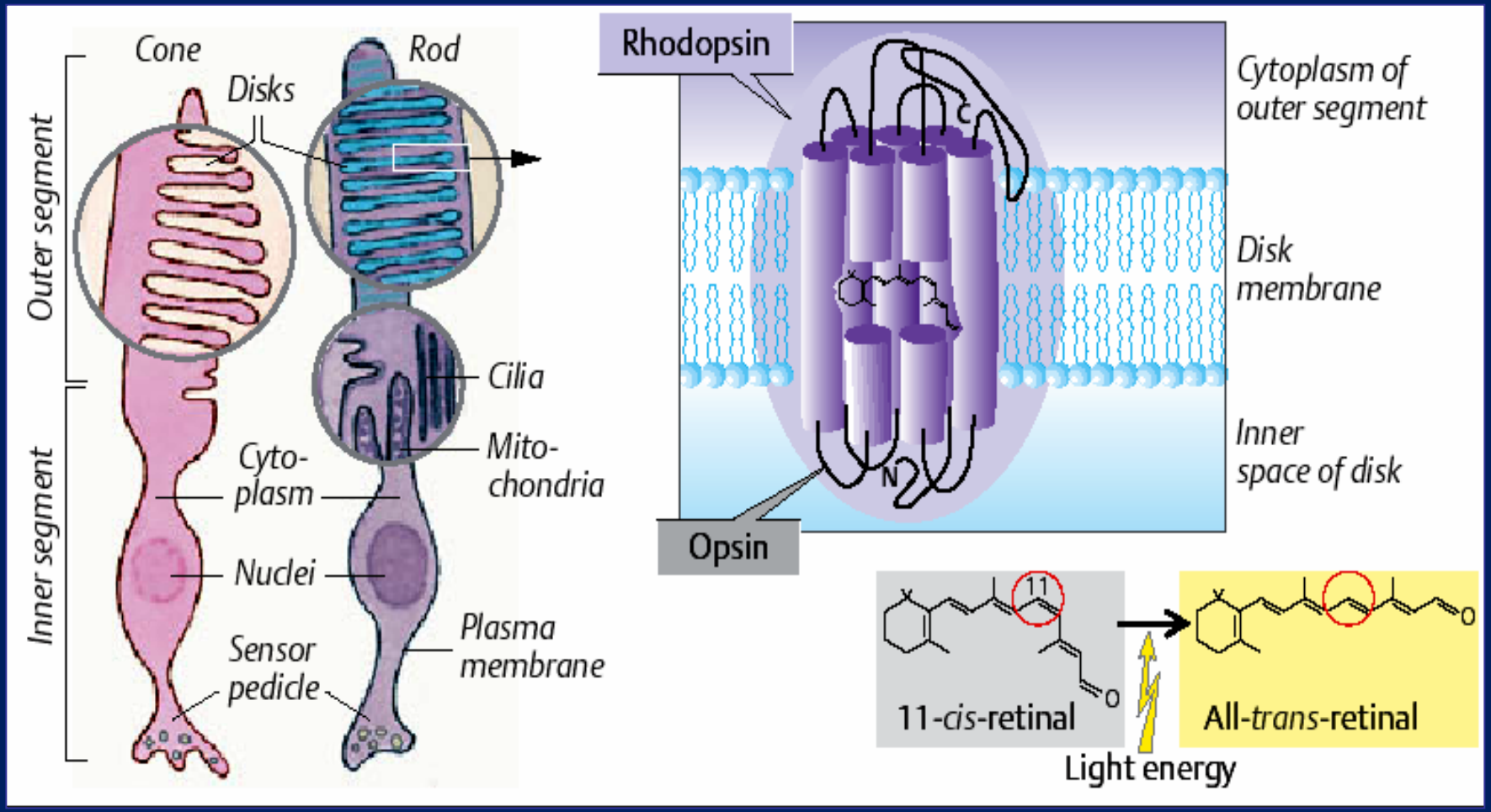
Human foveal pit



1)- Retinal Pigmented Epithelium

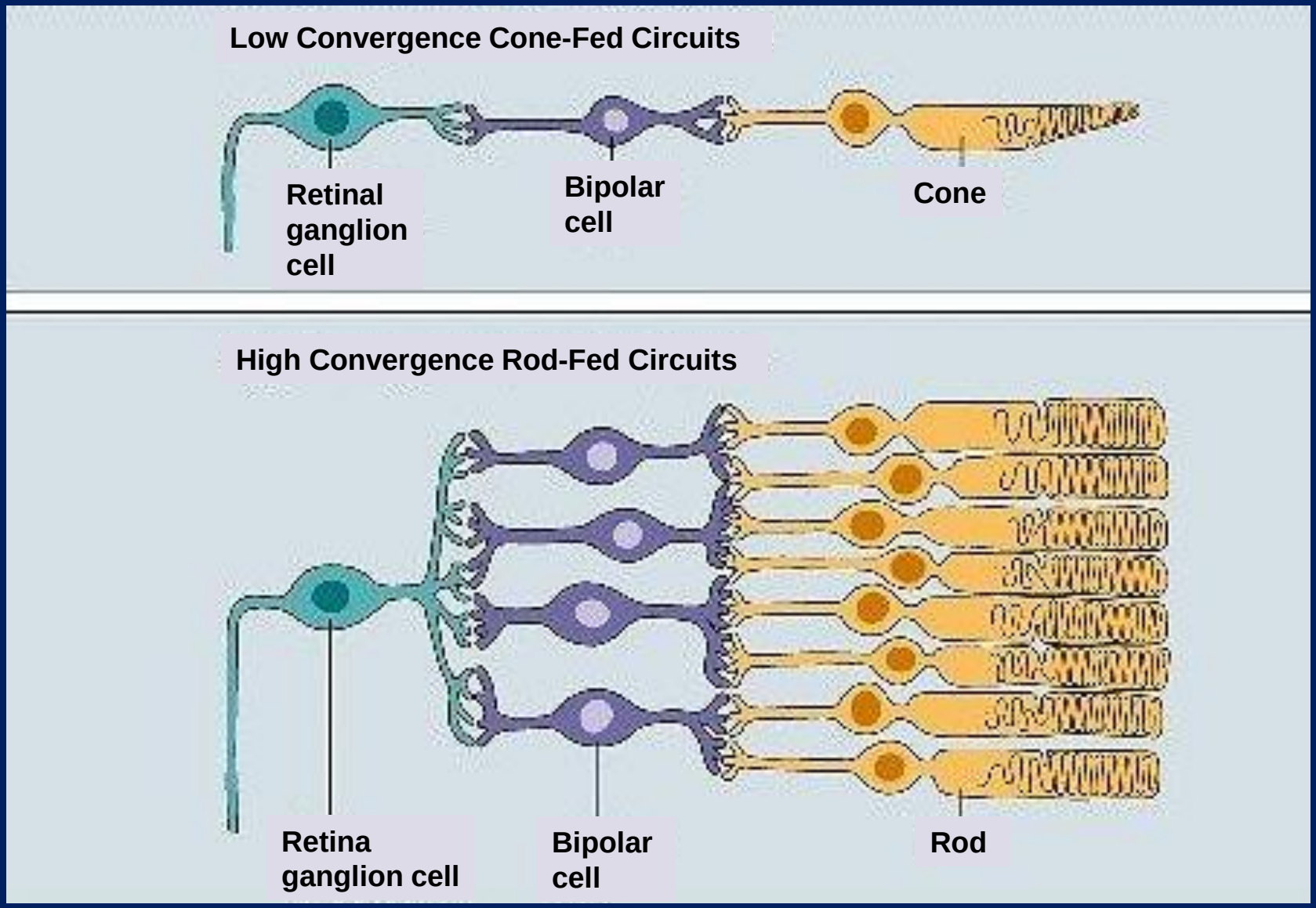
- **Absorption of light (due to presence of black pigment melanin) → reduction of glare**
- **Production of extracellular matrix**
- **Storage of vitamin A (precursor of 11-cis retinal) for regeneration of photosensitive pigments**
- **Phagocytosis of the tips of outer segments after their shedding off by the photoreceptors → continual renewal of outer segments**

2- Photoreceptors; Rods & Cones



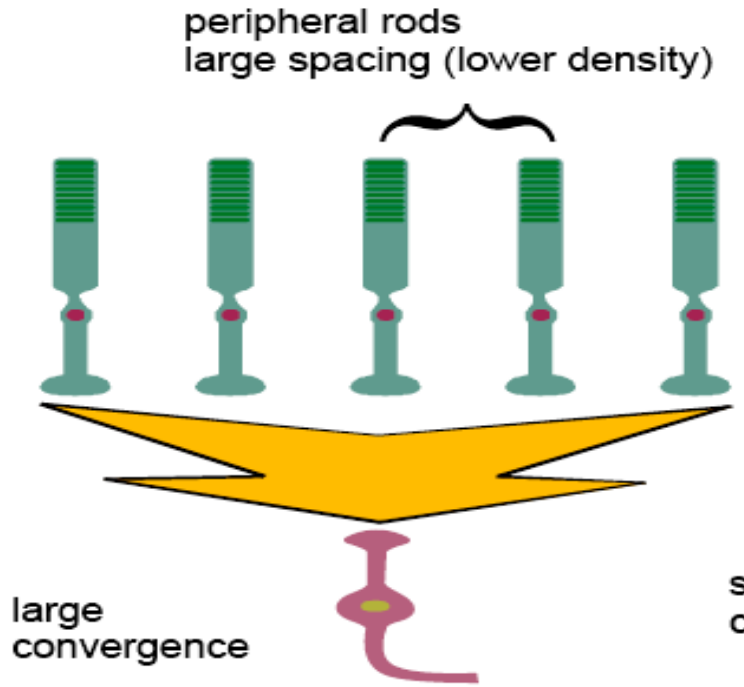
The 1st order neuron in visual pathway

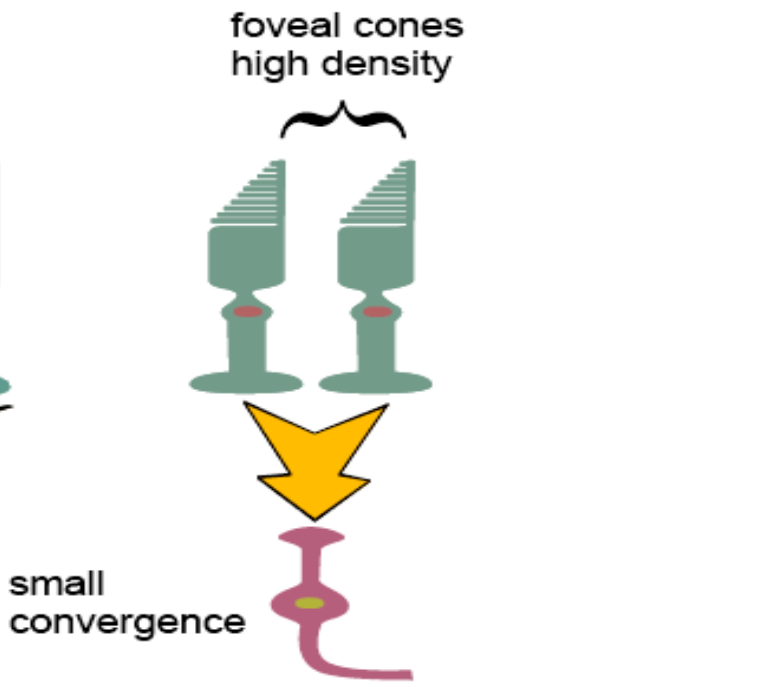
	Rods	Cones
Number	~ 120 millions in each retina	~ 6 millions in each retina
Distribution	More in periphery Non in Fovea	More in centre Present
Photosensitive pigment	Rhodopsin	3 types (iodopsin)
Connection	Convergence (300:1 connection)	No convergence (1:1; direct private line)
Function	▪↑light sensitivity ▪↓ visual acuity ▪- colour vision ▪Night vision	▪↓ light sensitivity ▪↑ visual acuity ▪+ colour vision ▪Day vision



Convergence rod/cone cells

Convergence vs. No Convergence





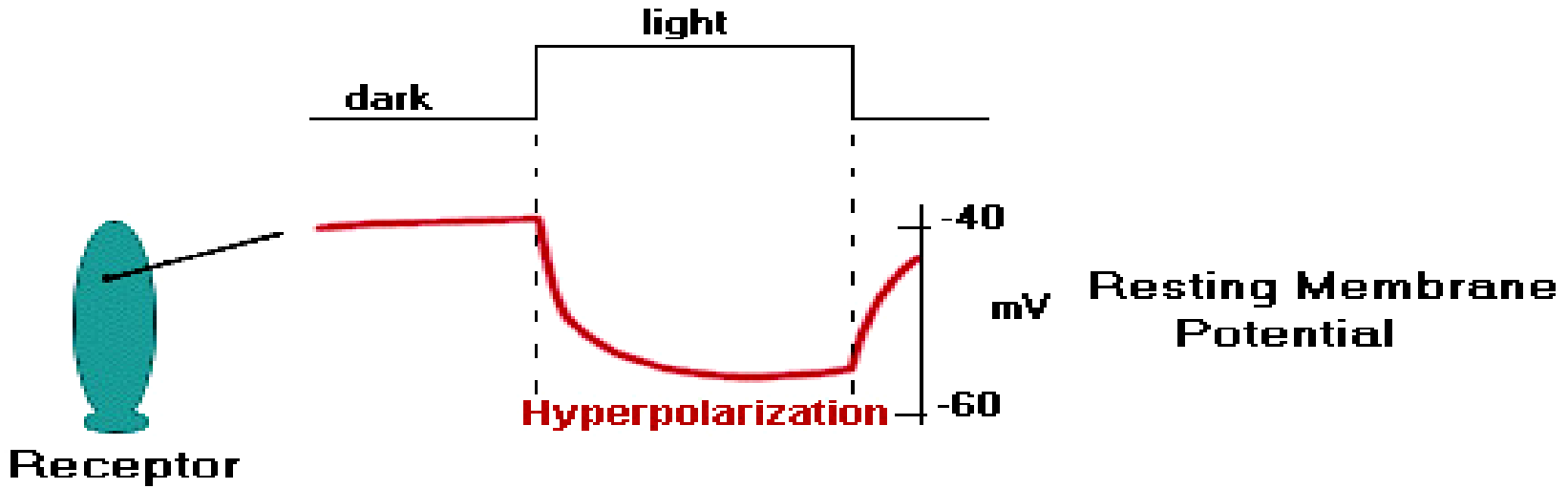
1. Ganglion cells integrate information from a large area of retina (3 deg)

2. Large spacing and large convergence results in low acuity

1. Ganglion cells integrate information from a small area of retina (.03 deg)

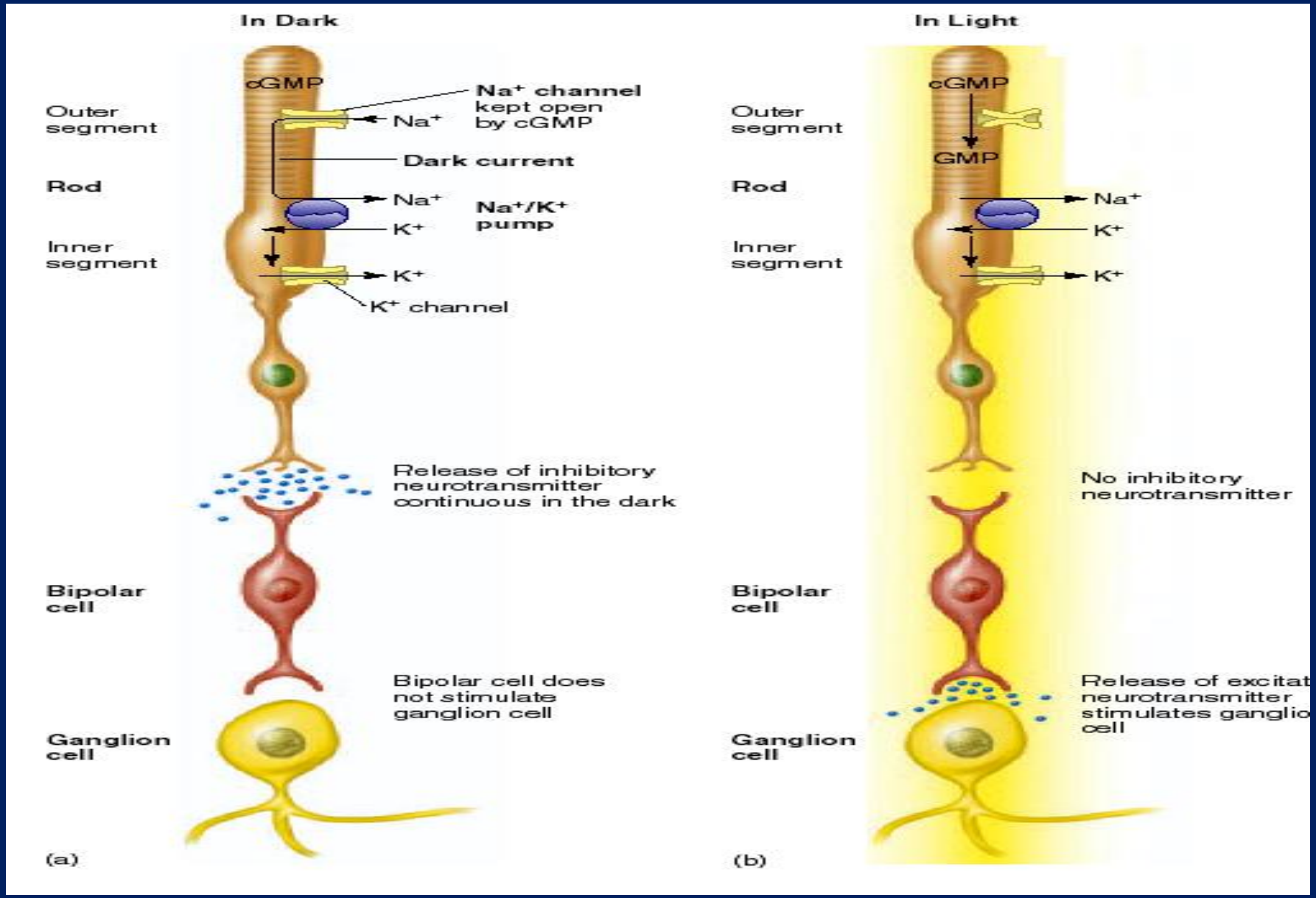
2. Small spacing and low convergence results in high acuity.

Membrane Potentials of Photoreceptors



- **In darkness, RMP of photoreceptors is ~ - 40mV (Dark Na current)**
- **Light → certain reactions → blockage of Dark current → hyperpolarization (MP of -60:-70 mV)**

Effect of Light on Retinal Neurons



3)- Bipolar Cells

- **The 2nd order neuron in visual pathway**
- **All bipolar cells secrete excitatory transmitter**
- **2 types:**
- **On-bipolar cells; Light →↓ release of inhibitory transmitter from the ends of photoreceptors→ disinhibition of BC [depolarized] → ↑release of excitatory transmitter → facilitation of GC .**
- **Off-bipolar cells; darkness →↑ release of glutamate from ends of photoreceptors → inhibition of BC [hyperpolarized] → ↓release of excitatory transmitter → disfacilitation of GC**

4)- Ganglion cells

- **The 3nd order neuron in visual pathway.**
- **~ 1.6 million in number.**

- **The only retinal neuron that respond to stimulation by a full regenerative action potential; depolarization**

4- Ganglion cells

- There are 3 Types of Ganglion cells:

1- Magnocellular (M)

- Less common (10%)
- of large receptive field corresponding to 100s of BC
- gross analysis of visual image & location of objects in visual field

2- Parvocellular (P)

- Numerous (80%)
- of small receptive field corresponding to 1 or few BC
- Responsible for fine detailed vision (shape & texture)

3- Coniocellular

- Few (10%)
- Medium in size
- Controlling pupillary reflexes.

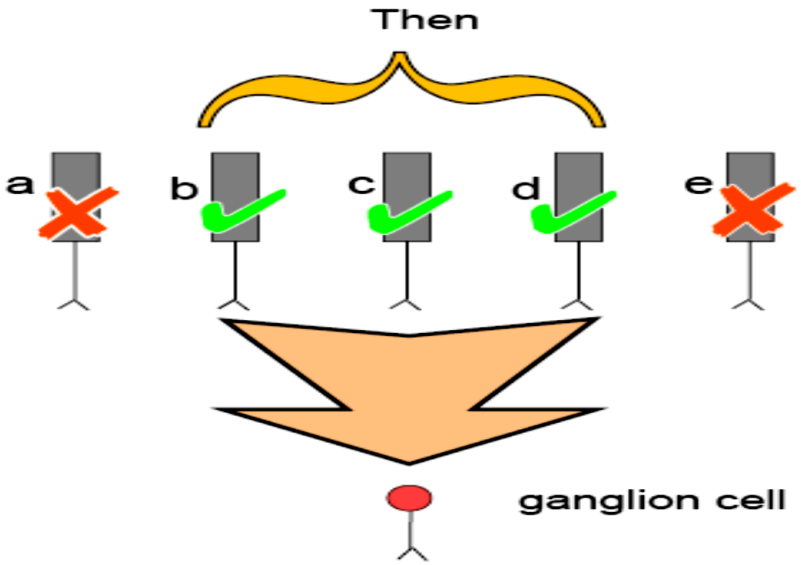
The Receptive Field (RF) of Ganglion Cells

- Is the part of the retina it sees through its photoreceptor input
- In fovea, the RF of ganglion cell is ~ 2µm; corresponding to width of 1 cone (one line connection)
- In peripheral retina, the RF of ganglion cell is ~ 1mm; (connected to hundreds of photoreceptors).

The Receptive Field (RF) of Ganglion Cells

When light shone is on rods b, c, or d,
a change is seen
in the ganglion cell's firing rate.

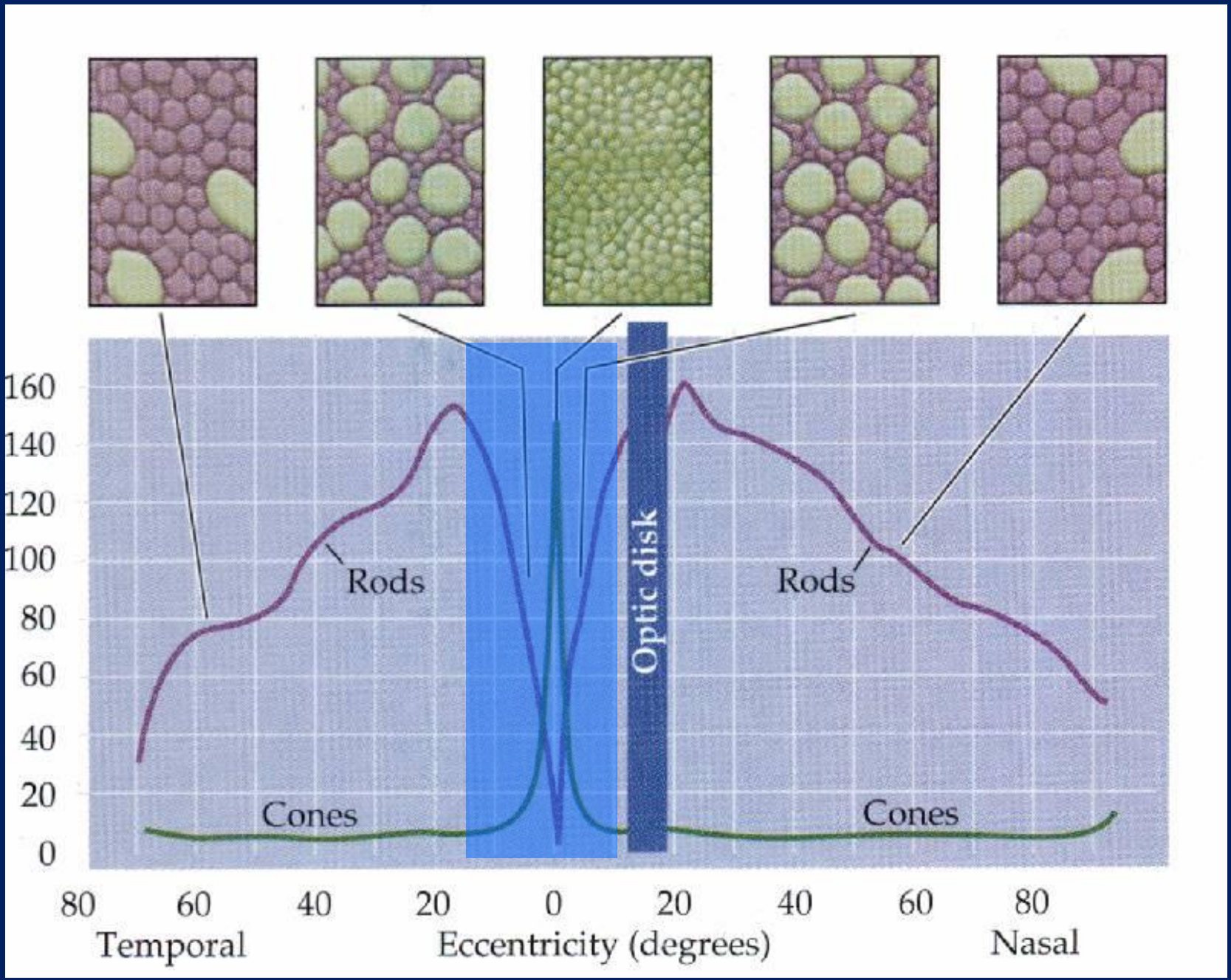
When light is shone on a or e
no change is seen
in the ganglion cell.



b, c, and d are
in the
receptive field
of this ganglion cell

a and e are
out of the
receptive field
of this ganglion cell

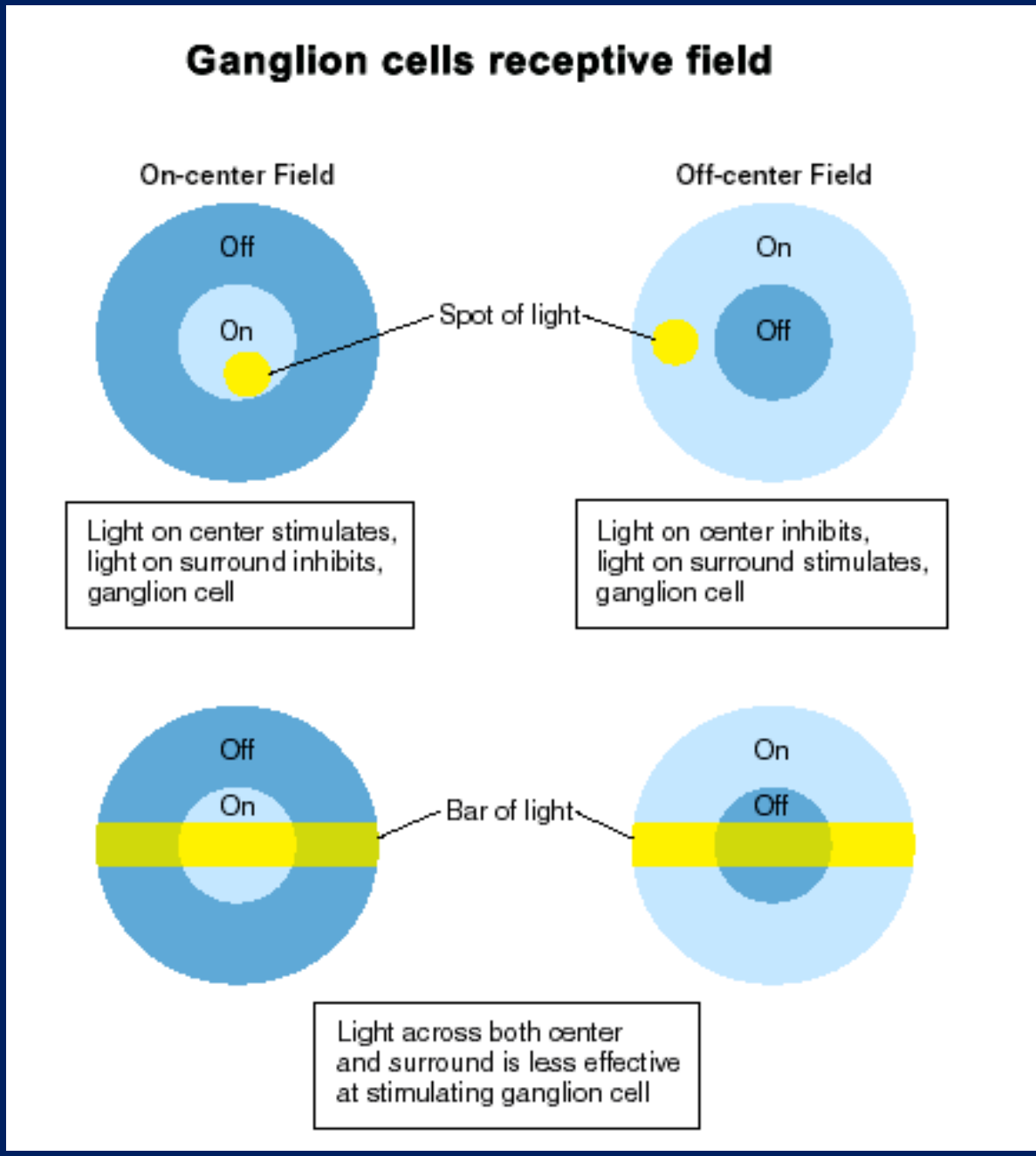
Distribution of



- **2 types of ganglion cells**

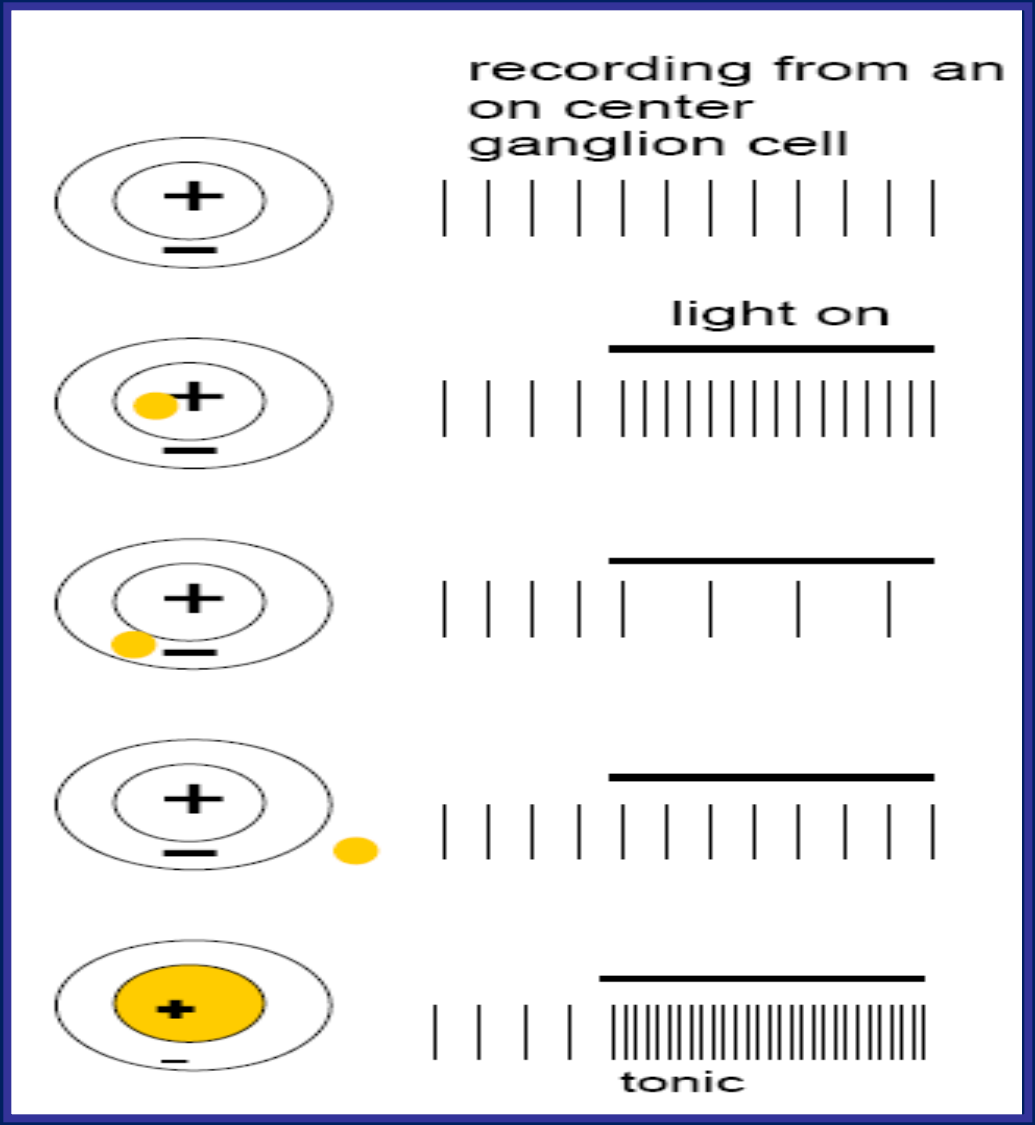
  : According to the effect exerted by the receptive field on them:

- **On-centre GC**
- **Off-centre GC**



The Receptive Field (RF) of Ganglion Cells

Response of ON-centre Ganglion cell to Light



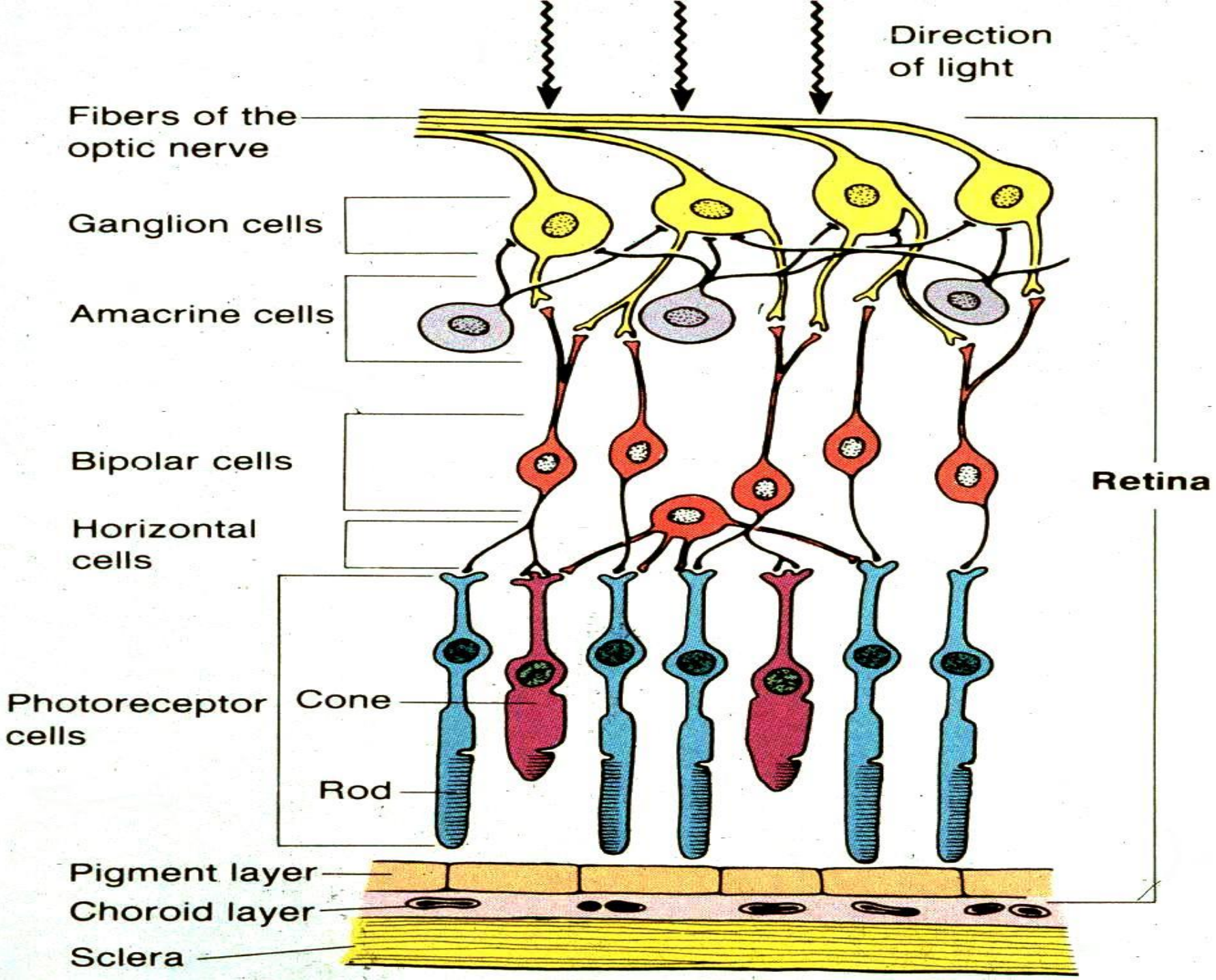
What is the role of Lateral Cells?

Horizontal Cells

- Lateral connection between rods & cones, between bipolar cells
- Responsible for lateral inhibition giving a stop to lateral spread of excitation →↑visual accuracy

Amacrine Cells

- Lateral connection between BC & GC
- ~ 30 types
- Helping to analyse visual signals


Direction of light
Fibers of the optic nerve
Ganglion cells
Amacrine cells
Bipolar cells
Horizontal cells
Photoreceptor cells
Cone
Rod
Retina
Pigment layer
Choroid layer
Sclera

Electrophysiology of Vision

Genesis of electrical responses

Retinal photoreceptors mechanism

Light

Absorption by photosensitive substances

Structural change in photosensitive substances

Phototransduction

Action potential in the optic nerve

Action Potential

Propagated and obeys
"All-or-None"

Receptor Potential

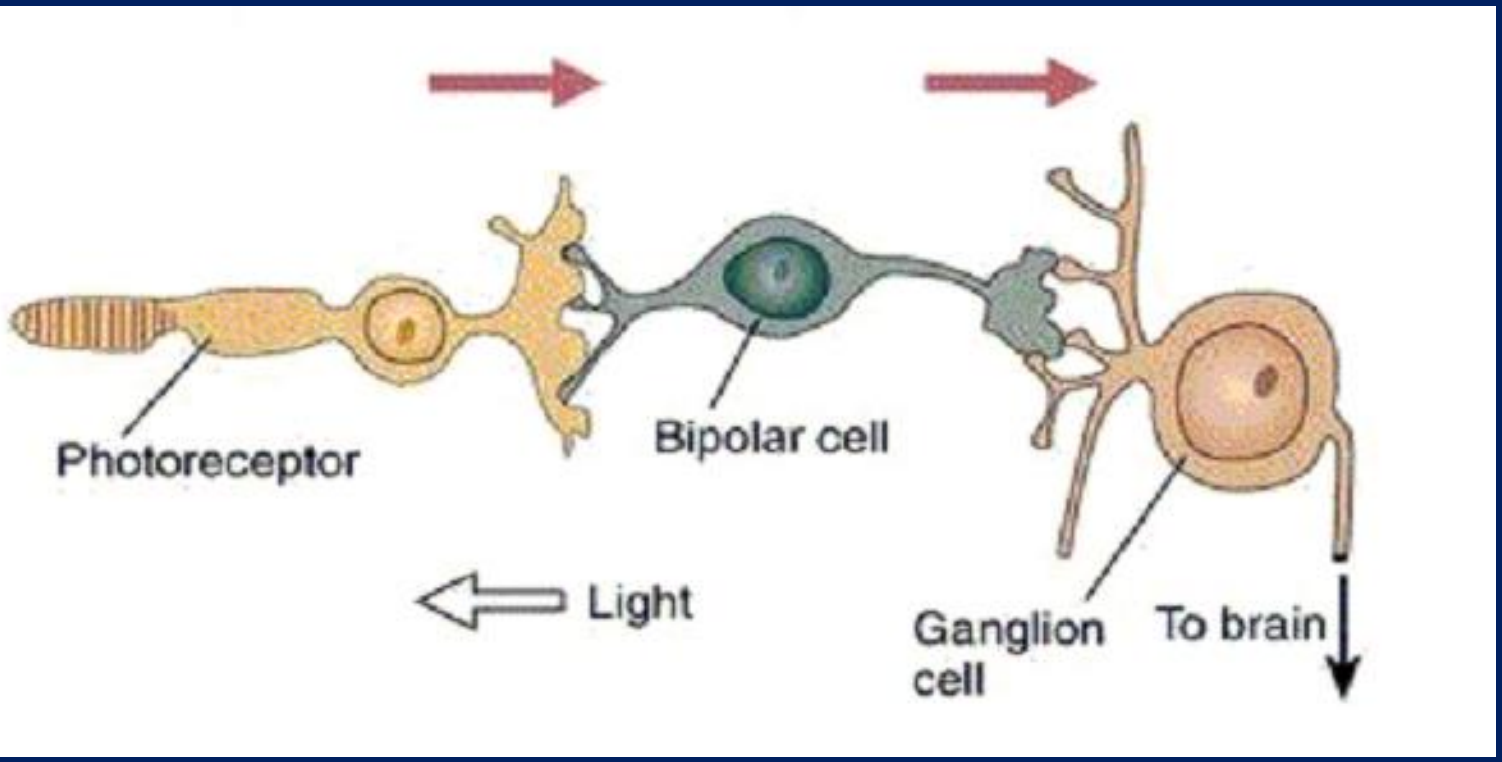
Local & Graded

Retina: Neural Circuitry

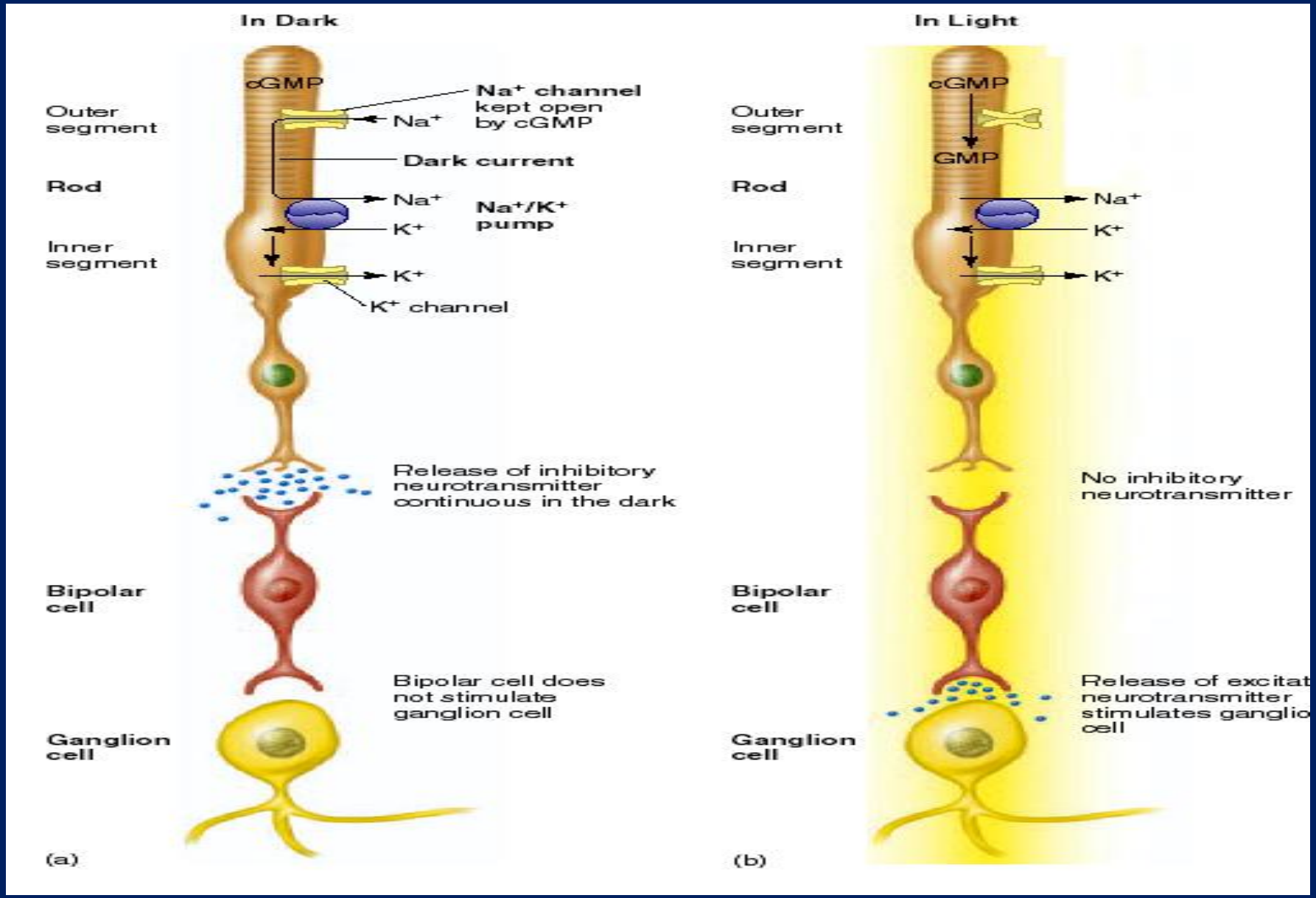
Light hits photoreceptors, sends signal to the bipolar cells

Bipolar cells send signal to ganglion cells

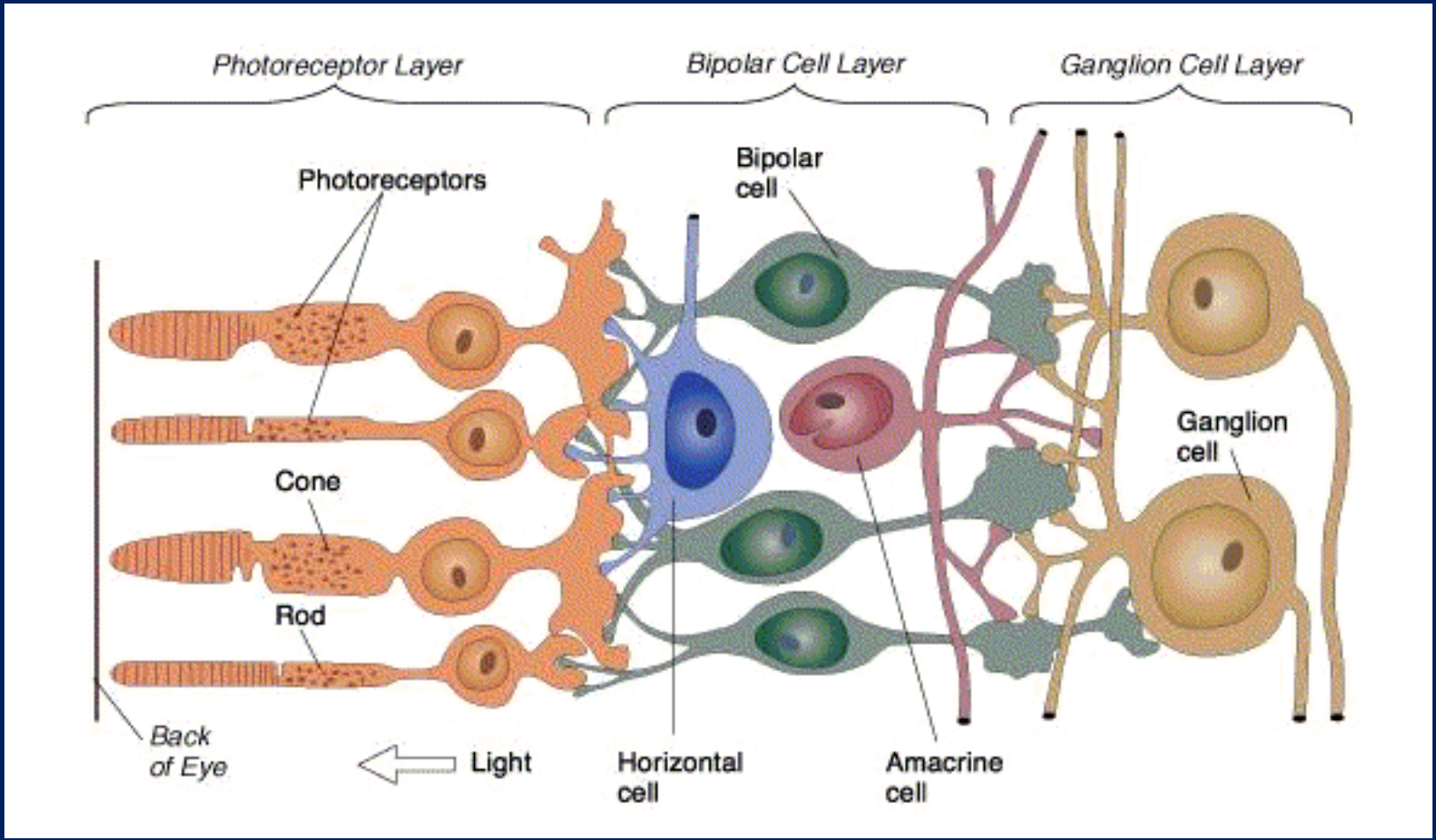
Ganglion cells send signal to the brain



Effect of Light on Retinal Neurons



Retina

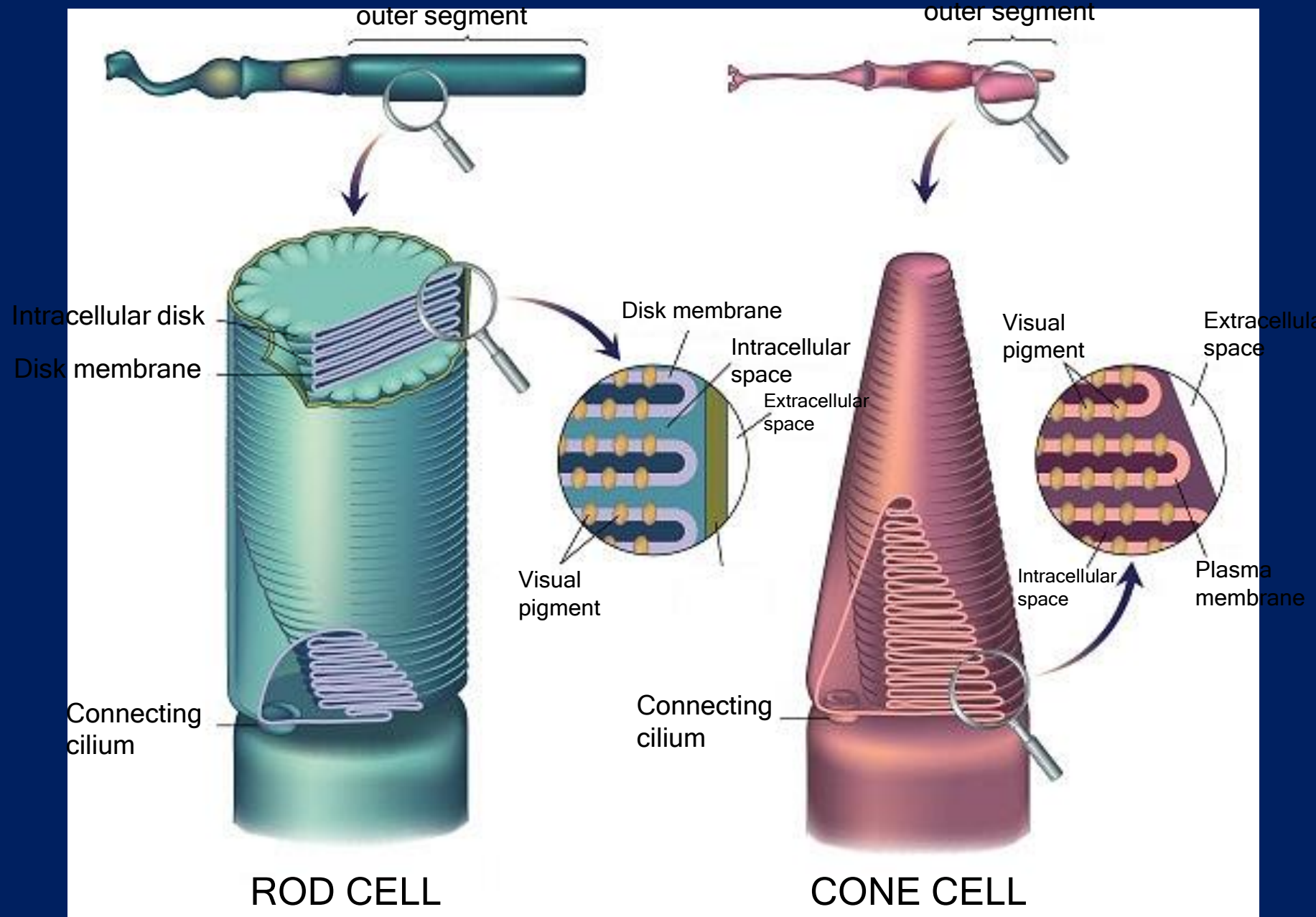


Light

Electrophysiology of Vision

Electric recording in Retinal cells:

- Rods & Cones: Hyperpolarization
- Bipolar cells: Hyper- & Depolarization
- Horizental cells: Hyperpolarization
- Amacrine cells: Depolarizing potential
- Ganglion cells:Depolarizing potential


outer segment
outer segment
Intracellular disk
Disk membrane
Connecting cilium
Disk membrane
Intracellular space
Extracellular space
Visual pigment
Visual pigment
Extracellular space
Intracellular space
Plasma membrane
Connecting cilium
ROD CELL
CONE CELL

Photoreceptor pigments

Photoreceptor pigments

- **Composition:**
  - Retinine1 (Aldehyde of vitamin A)
    - Same in all pigments
  - Opsin (protein)
    - Different amino acid sequence in different pigments

Rhodopsin (Rod pigment):

Retinine + scotopsin

Photosensitive compounds:-

- 2-There are 3 types of **Photopsin** in cones
  - **Iodopsins** (I,II,III) + Retinine

Photoreceptor compounds-cont

Rhodopsin (visual purple, scotopsin):

Activation of rhodopsin:

- In the dark:

retinine1 in the 11-*cis* configuration

All-*trans* isomer

Metarhodopsin II

Closure of Na channels

Light

↓

Change in photopigment

↓

Metarhodopsin II

↓

Activation of transducin

↓

Activation of phophodiesterase

↓

Decrease IC cyclic GMP

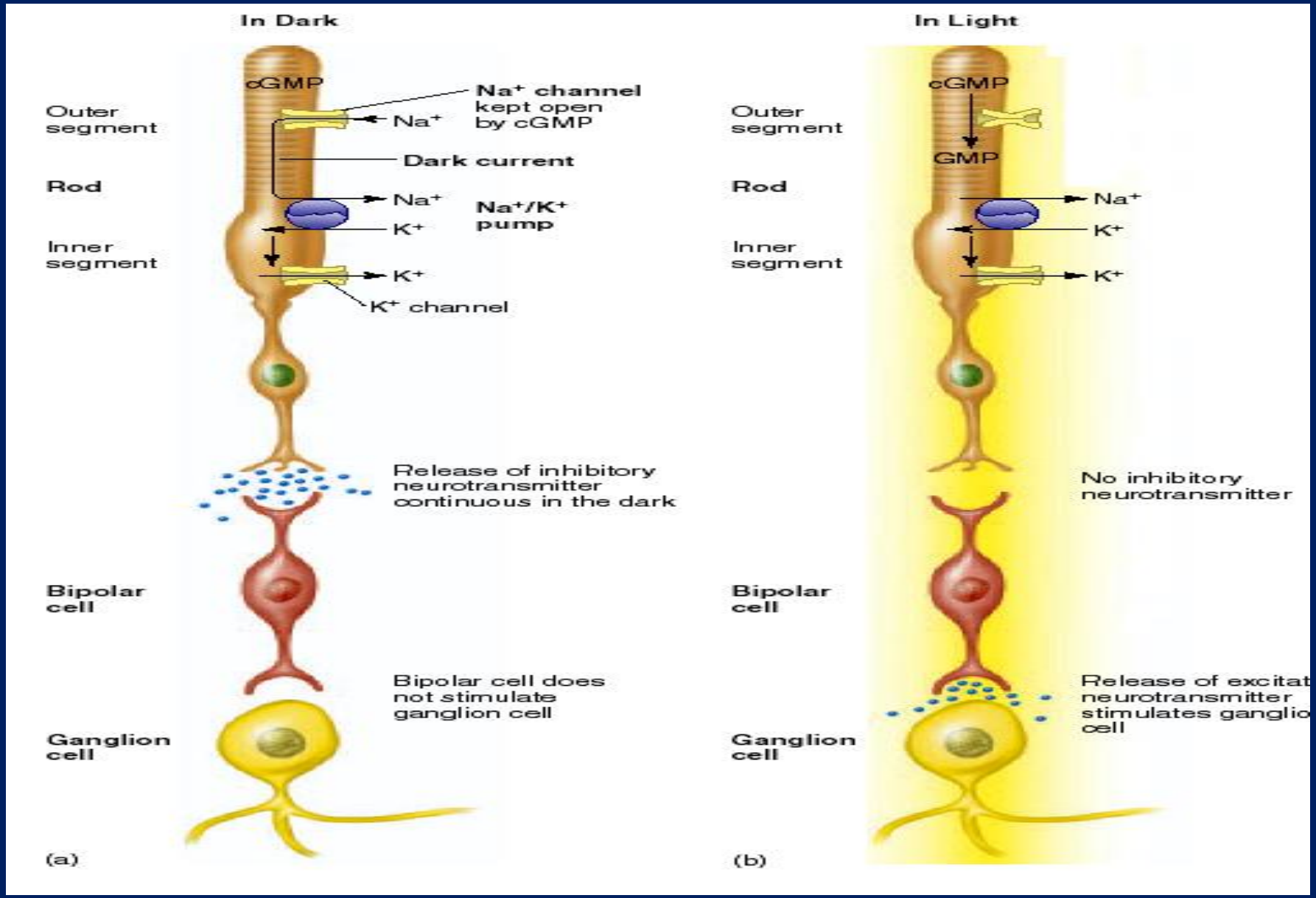
↓

Closure of Na channels

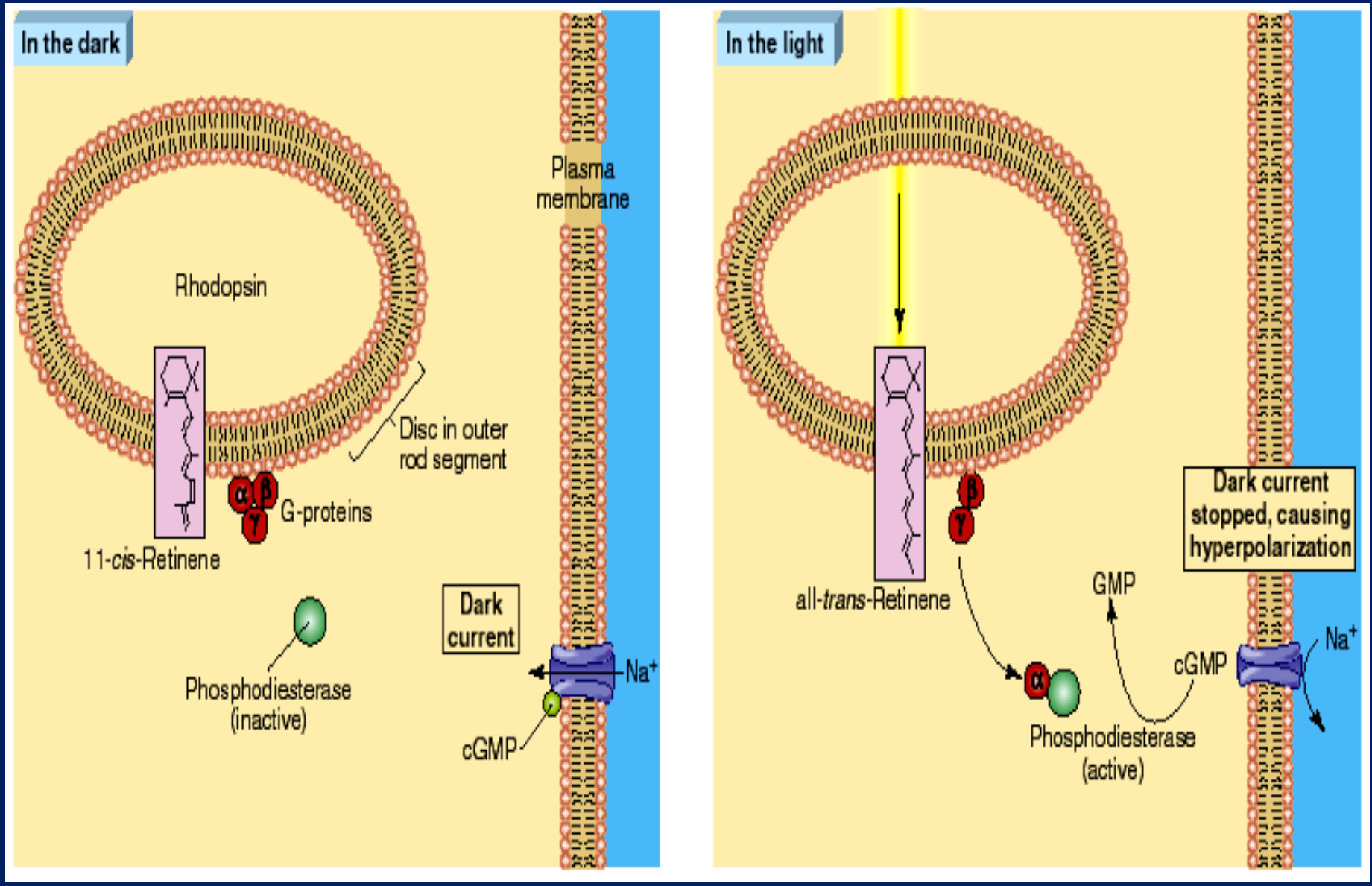
↓

Hyperpolarization of receptor
Decrease release of synaptic tramitter
Action potential in optic nerve fibres

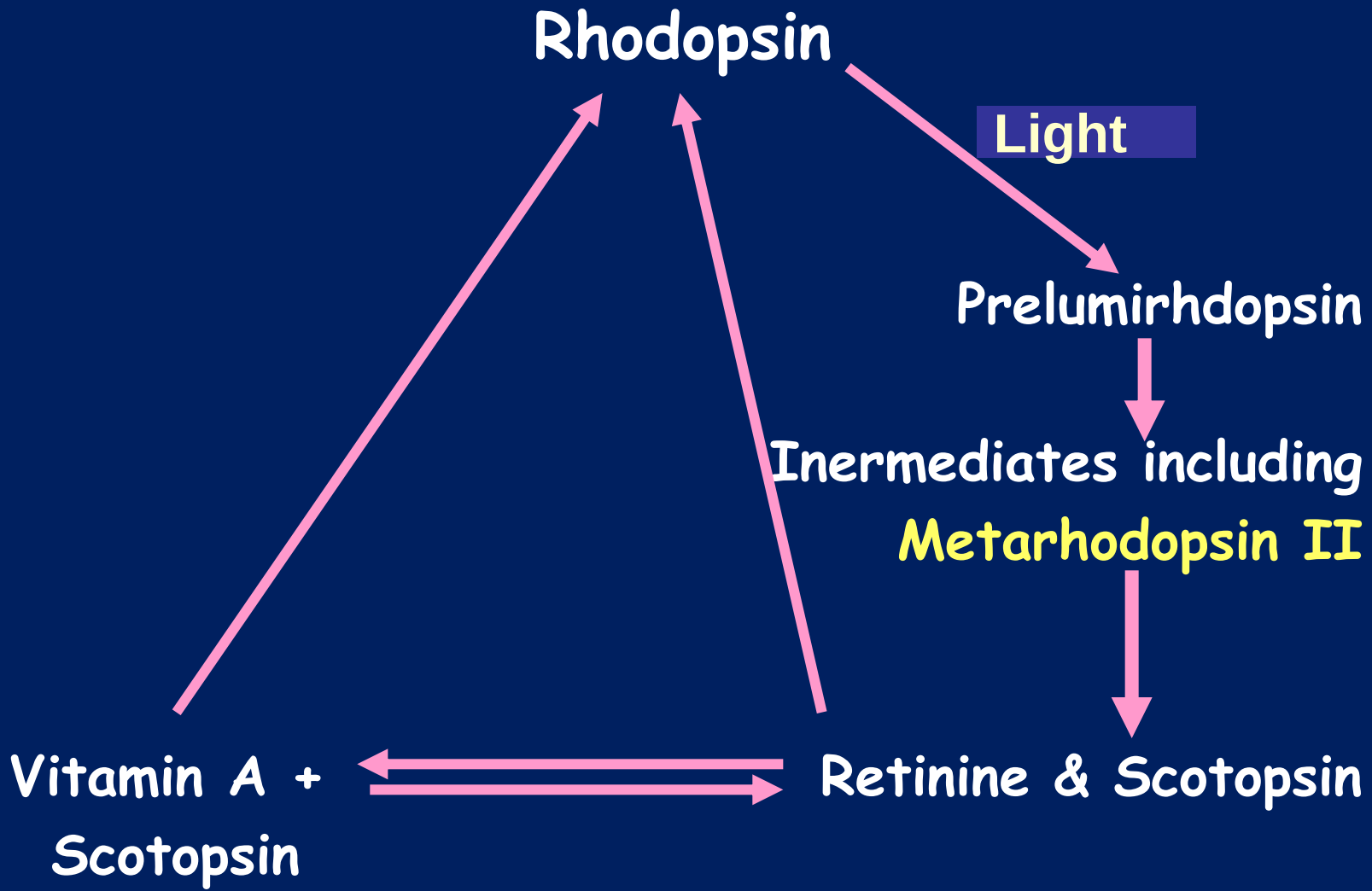
Effect of Light on Retinal Neurons

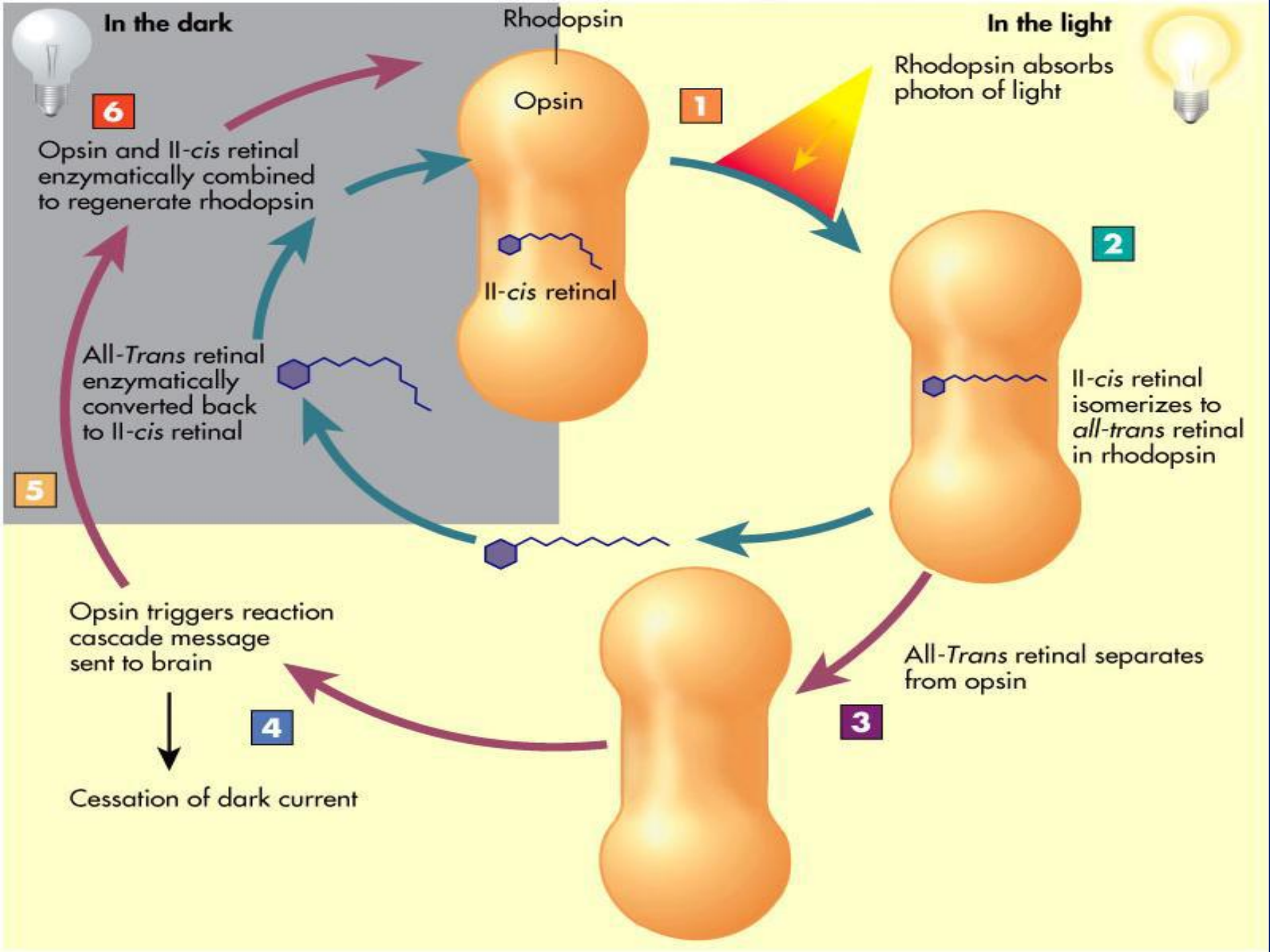


Ionic Basis of Light-evoked Hyperpolarization in Photoreceptors



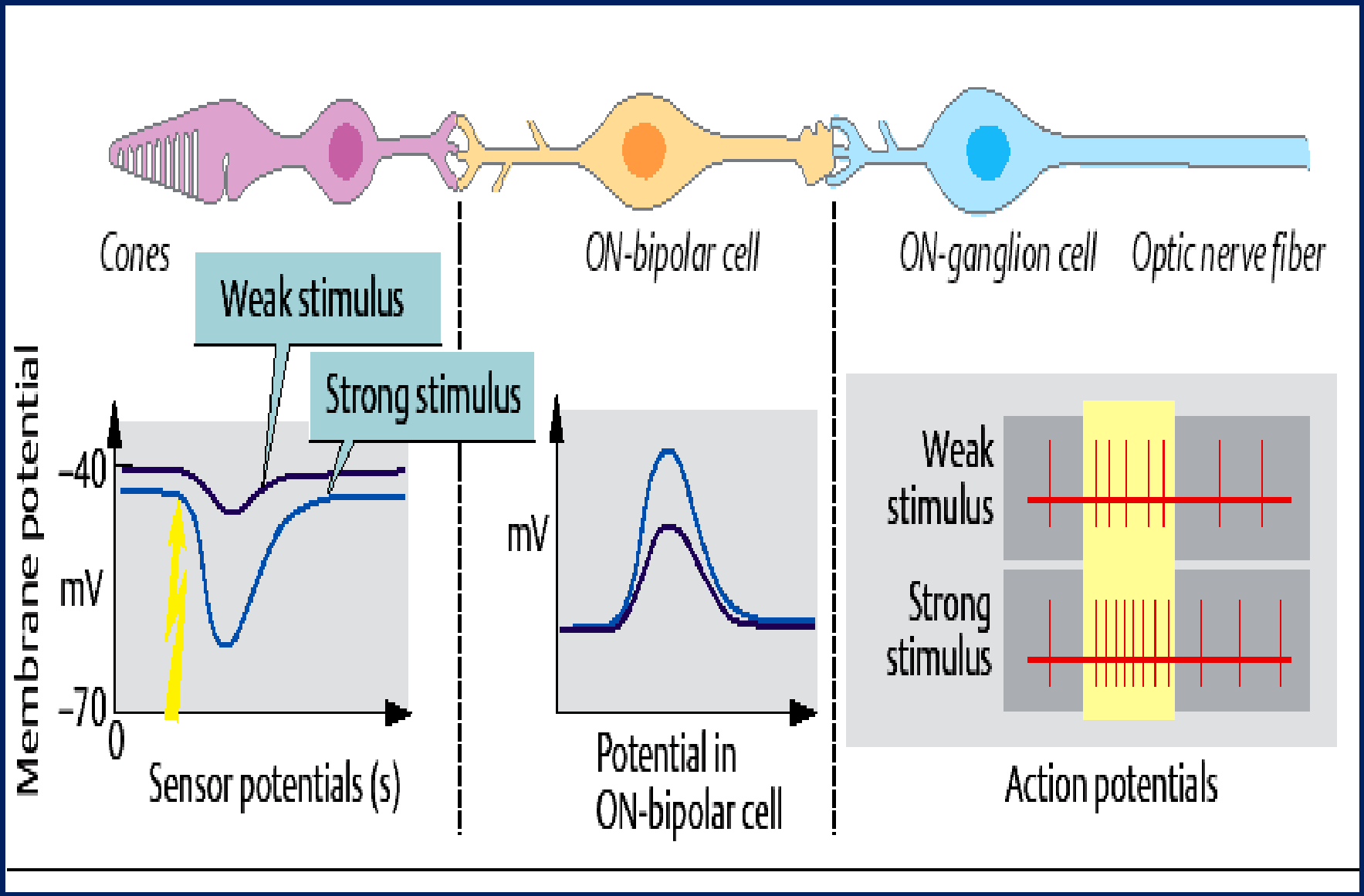
Visual cycle




In the dark
Rhodopsin
In the light
Opsin
Rhodopsin absorbs photon of light
1
6
Opsin and 11-cis retinal enzymatically combined to regenerate rhodopsin
11-cis retinal
2
All-Trans retinal enzymatically converted back to 11-cis retinal
11-cis retinal isomerizes to all-trans retinal in rhodopsin
5
Opsin triggers reaction cascade message sent to brain
All-Trans retinal separates from opsin
3
4
Cessation of dark current

- **Regeneration of photopigment**
- **All-trans retinal is taken up by RPE which contain isomeraze enzyme that converts it again into 11-cis retinal sent back to rods to recombine with opsin**

Retinal on pathway



Synaptic mediators in retina:-

- Ach, glutamate, dopamine, serotonine,GABA, substance P,somatomedin, VIP, enkephalins, glucagons,neurotensin.

Dark adaptation

Dark adaptation:

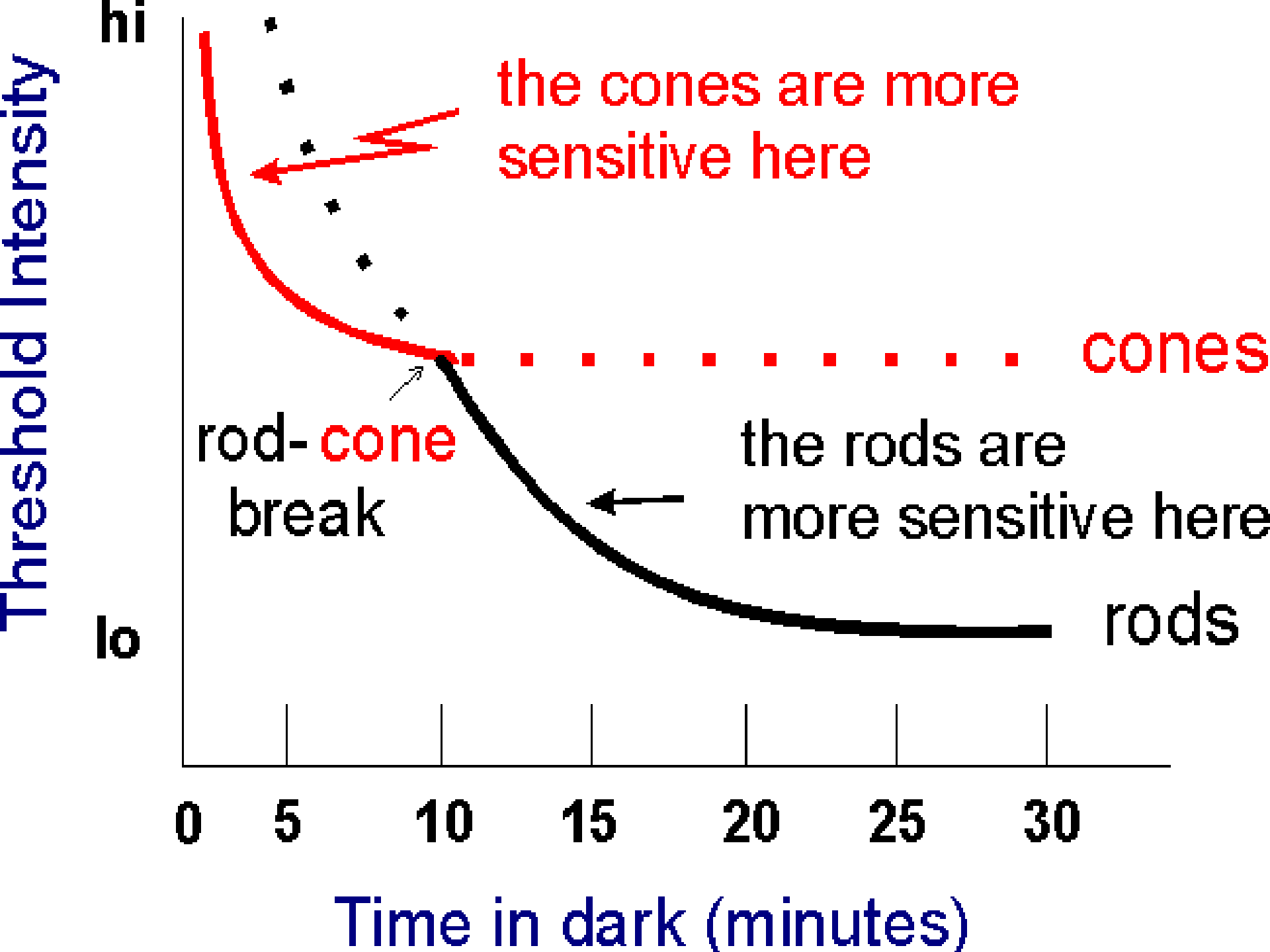
Increased sensitivity of the photoreceptors when vision shifts from bright to dim light

Dark adaptation

- Reaches max in 20 minutes
- First 5 minutes …… threshold of cones ↓
- 5 to 20 mins ……. ↑ Sensitvity of rods

Mechanism of dark adaptation:

↑ Regeneration of rhodopsin


hi
lo
Threshold Intensity
the cones are more sensitive here
cones
rod- cone break
the rods are more sensitive here
rods
0
5
10
15
20
25
30
Time in dark (minutes)

Dark adaptation-cont.

In vitamin A deficiency
What happens to Dark adaptation?

Night blindness
(Nyctalopia)