Vision

Phototransduction of light

By

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Objectives:

-List and compare functional properties of rods and cones in scotopic and photopic vision
-To know the convergence and its value
-To describe the photosensitive compounds
-To Contrast the phototransduction process for rods and cones in light and dark and the ionic basis of these responses
-To know the process visual cycle & rhodopsine regeneration
-To know the meaning of nyctalopia
-Contrast the dark and light adaptation
- To recognize types of ganglion cells

Ref/ Gyton& Hall

Visual Receptors (photoreceptors)

Rods	Cones
-abundant in the periphery of the retina	- abundant in & around fovea
-best for low light (dimlight) conditions	- best for bright light conditions
see black/white and shades of gray	-see all colors
-100,000,000	-5,000,000

Visible light Spectrum:

- **Extends from 397 to 723nm**
- **Eye functions under two 2 conditions of illumination:**

Duplicity theory of vision

-
  - **Bright light (Photopic vision)…Cones**
  - **Dim light (Scotopic vision) ..Rods**

Photoreceptors
Rods & Cones
Morphology & Distribution

Shape of rodes& cones (receptors of vision)

1- Outer segment (modified cilia) has disks full of photosensitive pigment (rhodopsin) react with light to initiate action potential

-In cones is conical , small and contain 3 types of rhodopsin

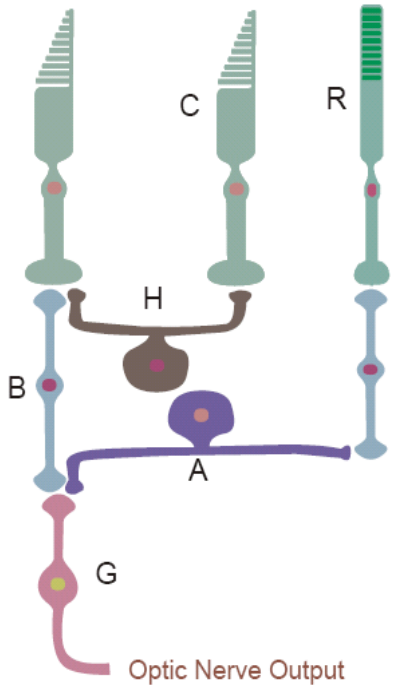
- in rods it is big, rode like and contain one type of rhodopsin

-There are Na channels in the outer segment

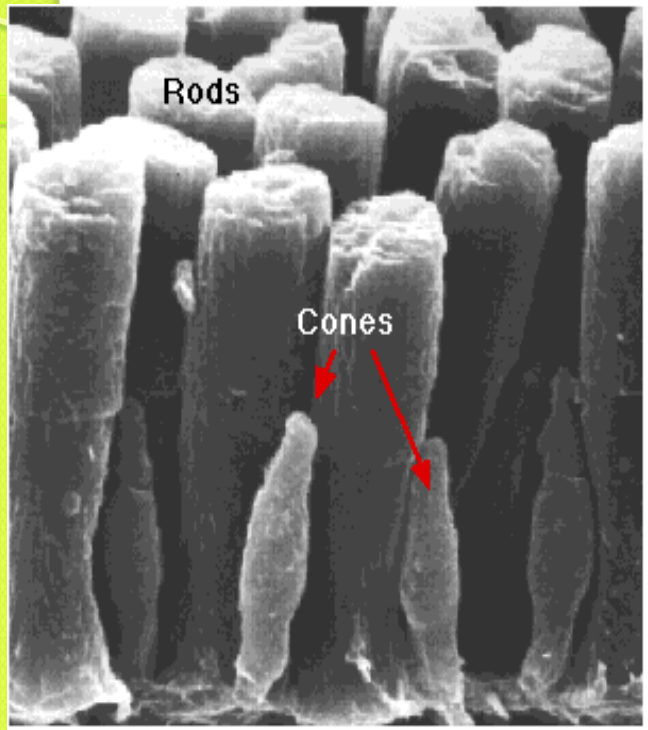
2- Inner segment

-full of mitochondria (source of energy for Na-K pump), it is thick in cones

-There is Na-K pump in inner segment



Photoreceptors



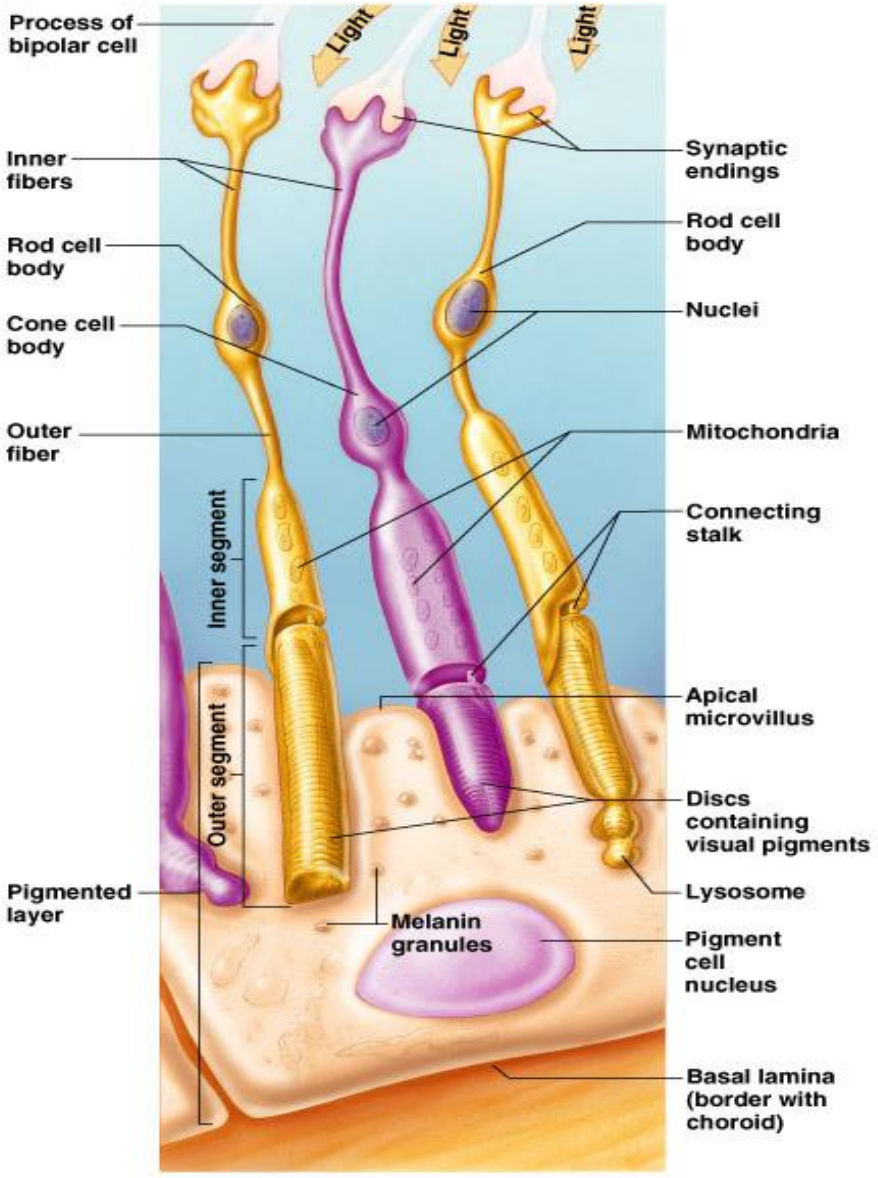
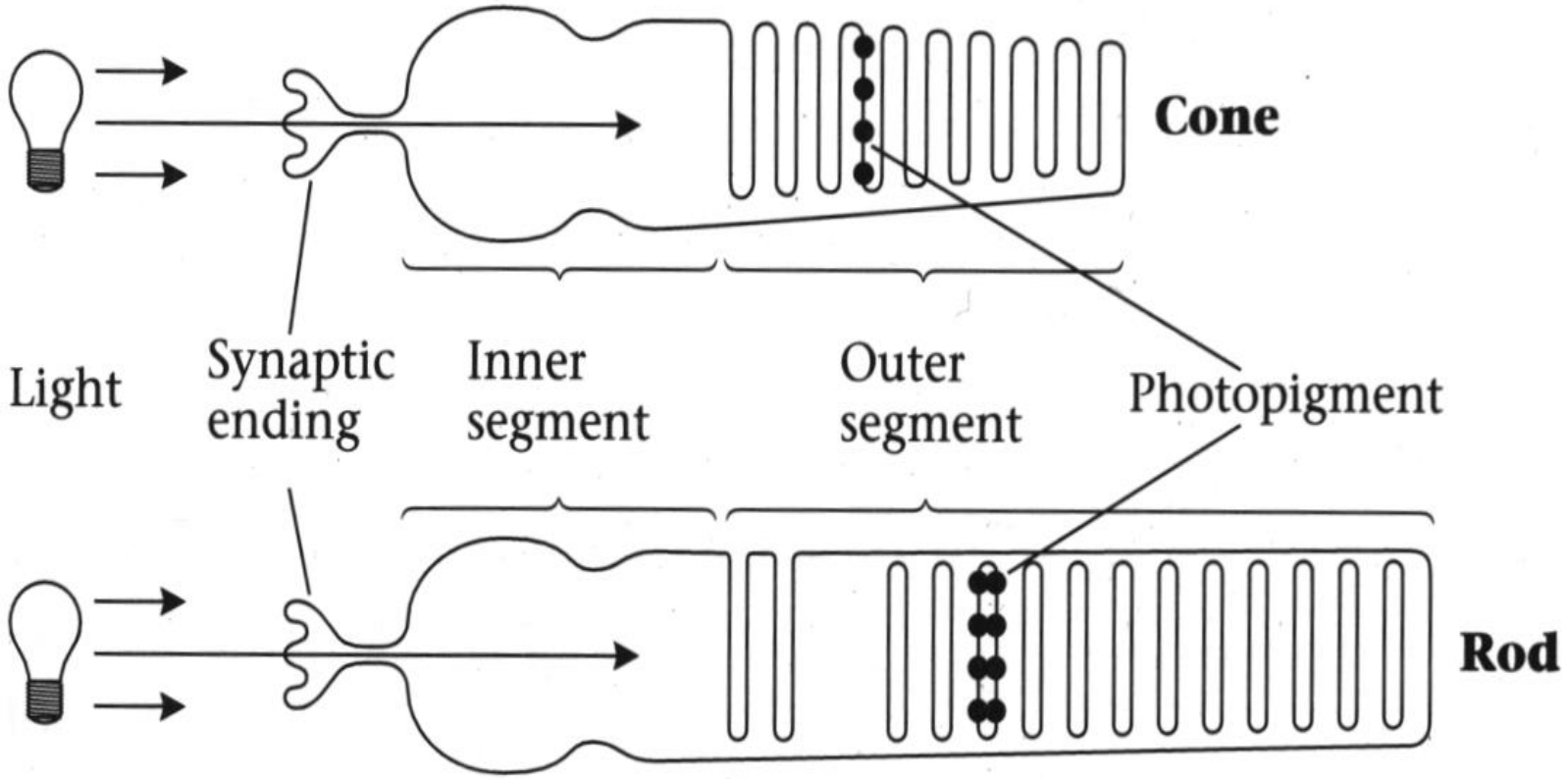
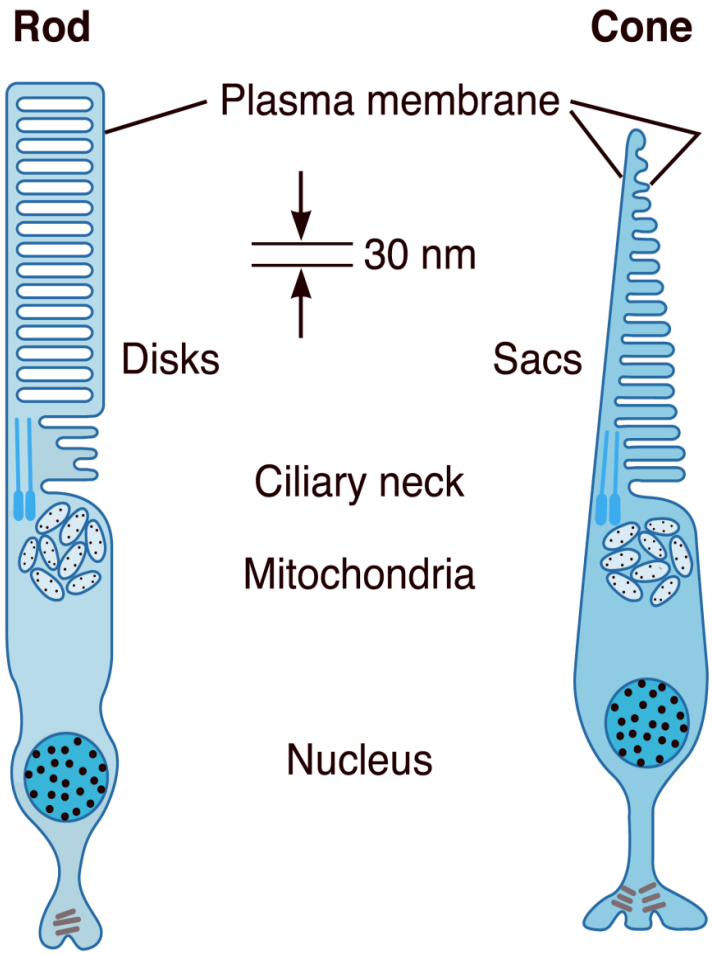


Figure 16.11

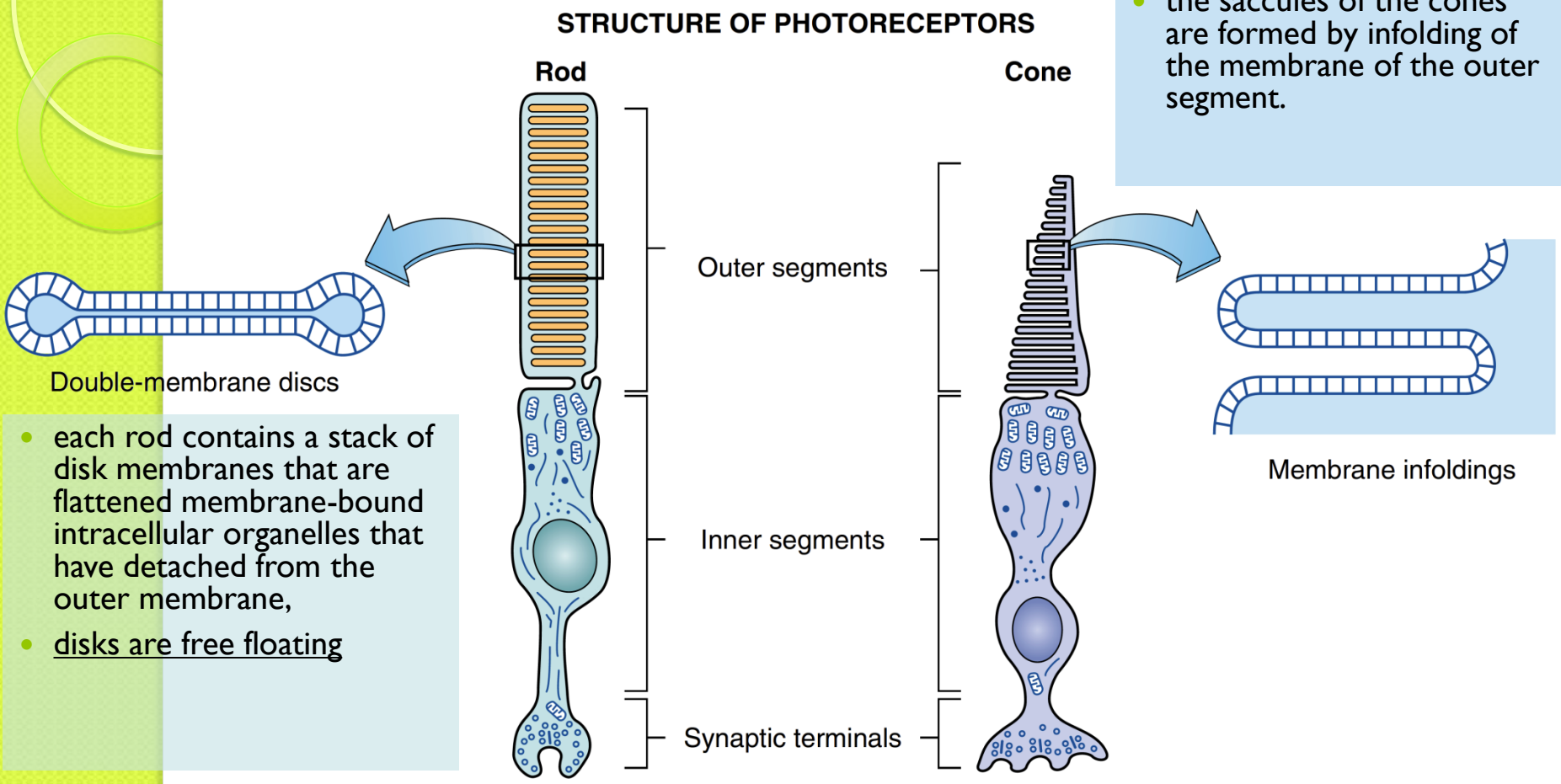
Inside the rod and the cone





-the inner and outer segments are connected by a ciliary stalk through which the photosensitive compounds travel from the inner segment (where they are manufactured) to the outer segment of the rods and cones (where they are used)

- the saccules of the cones are formed by infolding of the membrane of the outer segment.



- each rod contains a stack of disk membranes that are flattened membrane-bound intracellular organelles that have detached from the outer membrane,
- <u>disks are free floating</u>

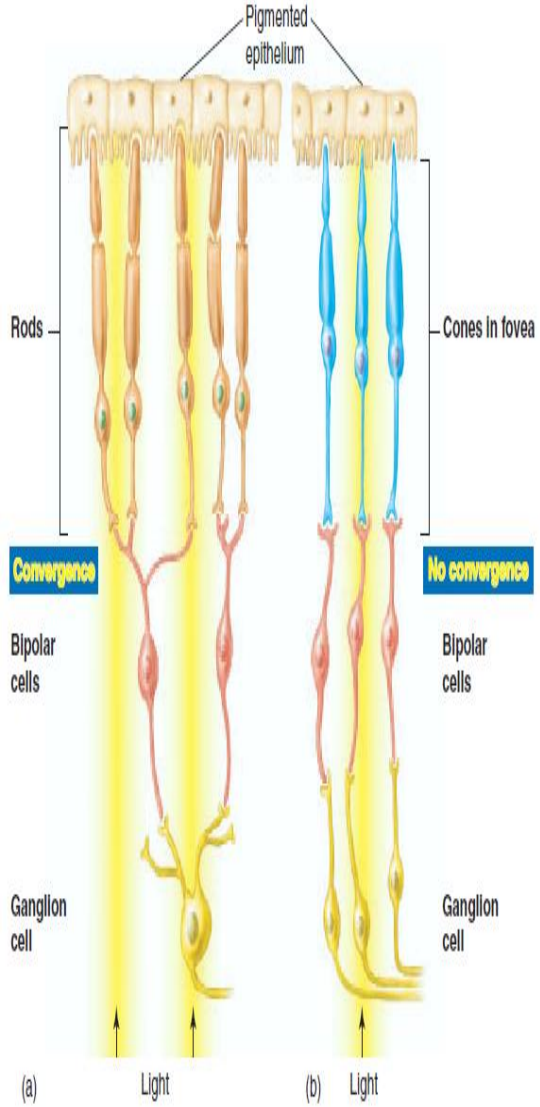
<u>the saccules and disks contain the photosensitive compounds that react to light, initiating action potentials in the post synaptic cells</u>

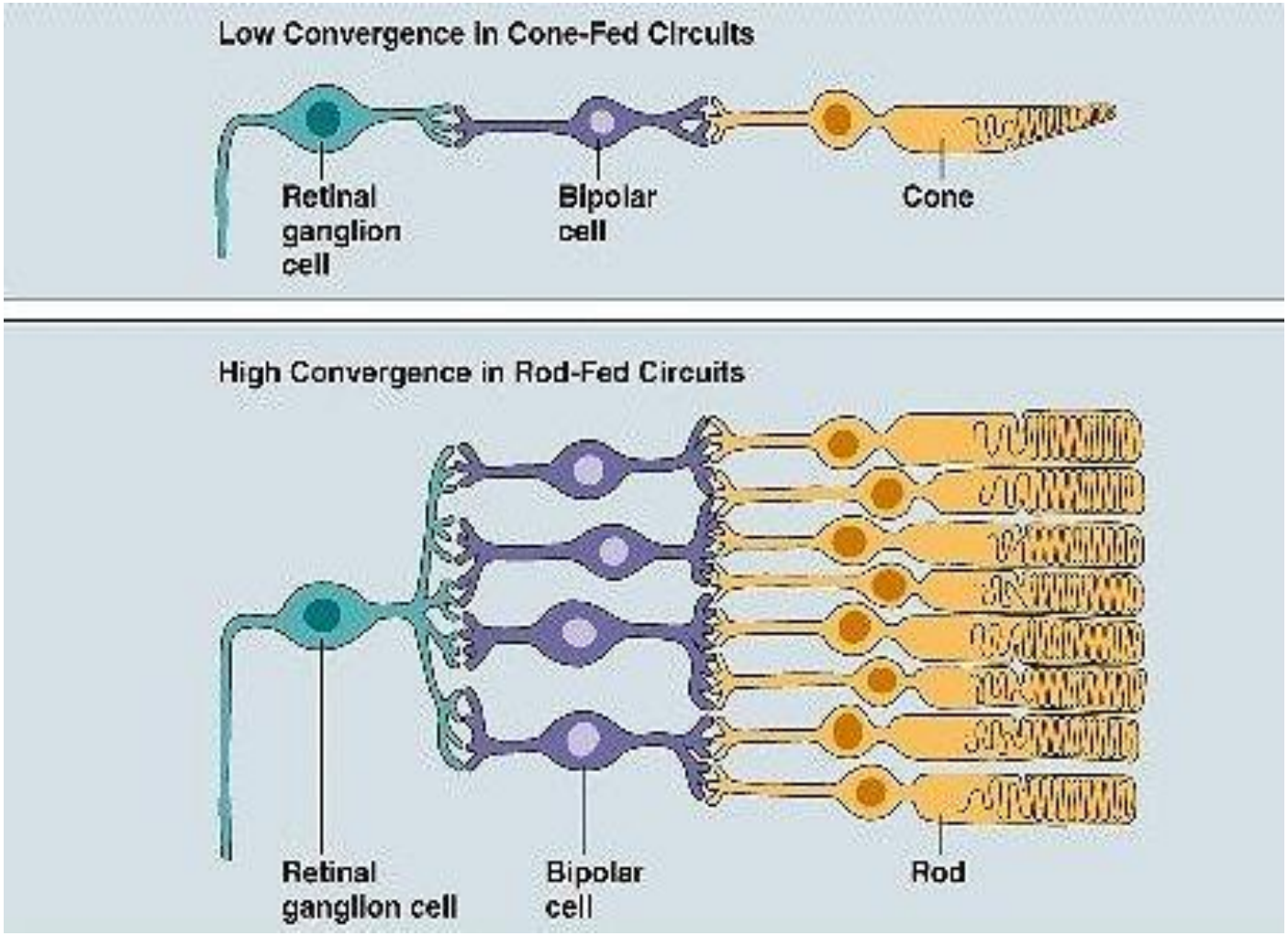
- **Convergence:-**

- low convergence in cones / each foveal cone synapse with →one bipolar cell →one ganglion cell →single optic nerve fiber

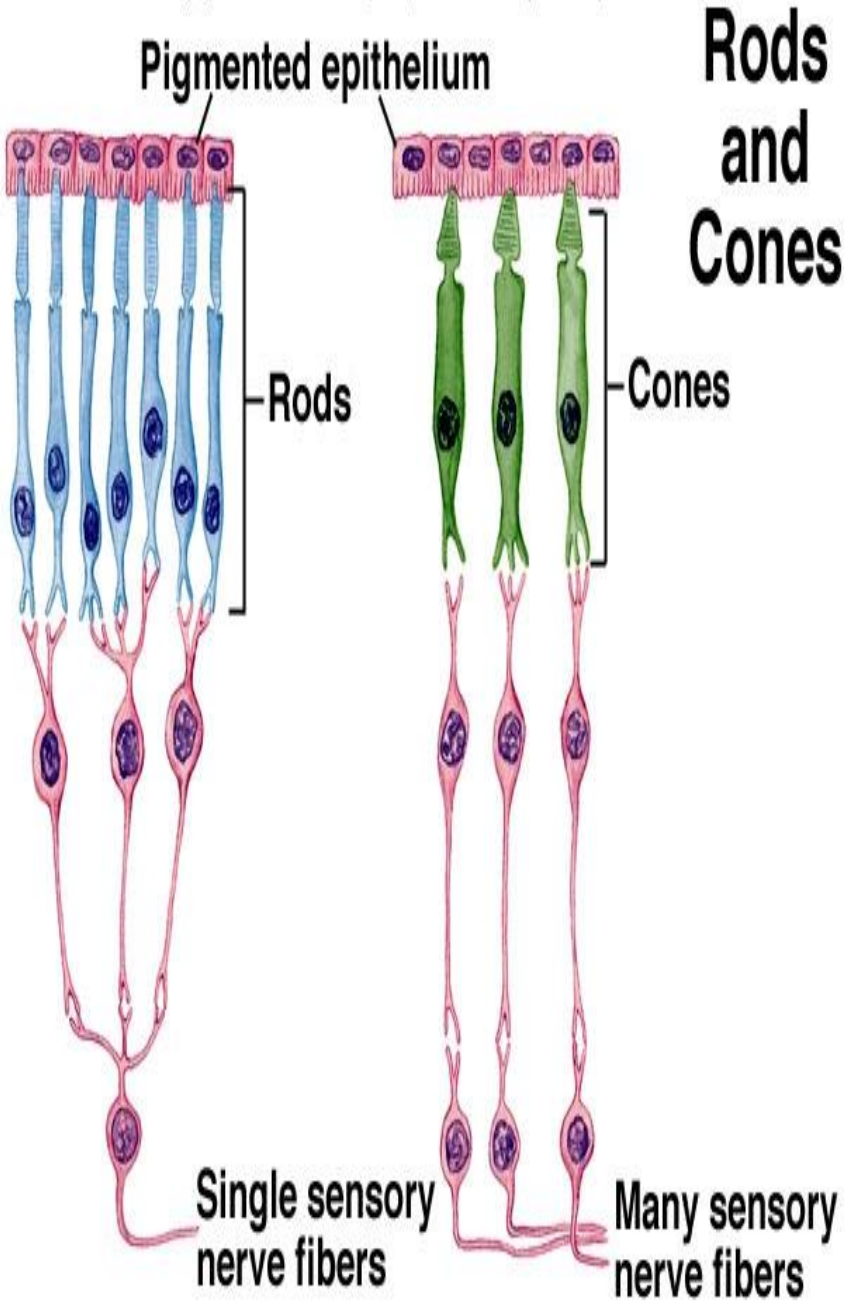
- Advantage of low convergence /
- increases visual acuity → integrated information from small area of retina

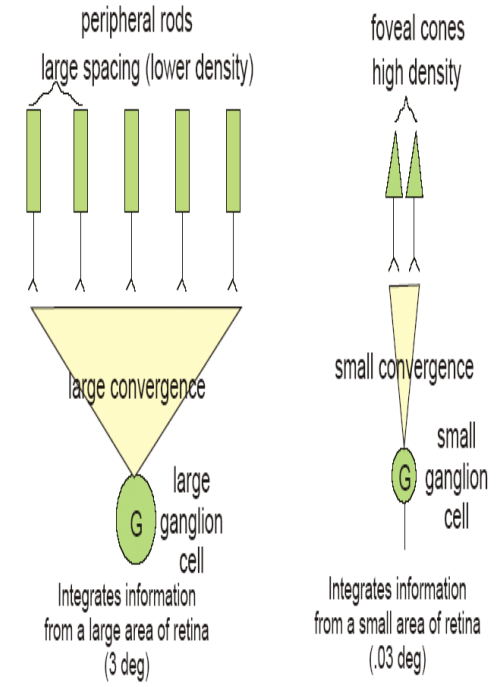
Disadvantage/ decreases sensitivity to light i.e need high threshold of illumination to stimulate cones)




Low Convergence in Cone-Fed Circuits
Retinal ganglion cell
Bipolar cell
Cone
High Convergence in Rod-Fed Circuits
Retinal ganglion cell
Bipolar cell
Rod

- 2- high convergence of rods
- several rodes about 300 synapse with one bipolar cell& one ganglion cell
- -high convergence/// decreases visual acuity acuity = integrated information from large area of retina
- - but increases sensitivity to light i.e so low light threshold stimlates the rods)
- - 120 million rode& 6 million cone converge on 1.2 million optic nerve fibers , (126 million recepton on 1.2 million nerve fiber)so convergence is 105 receptor : 1 fiber.





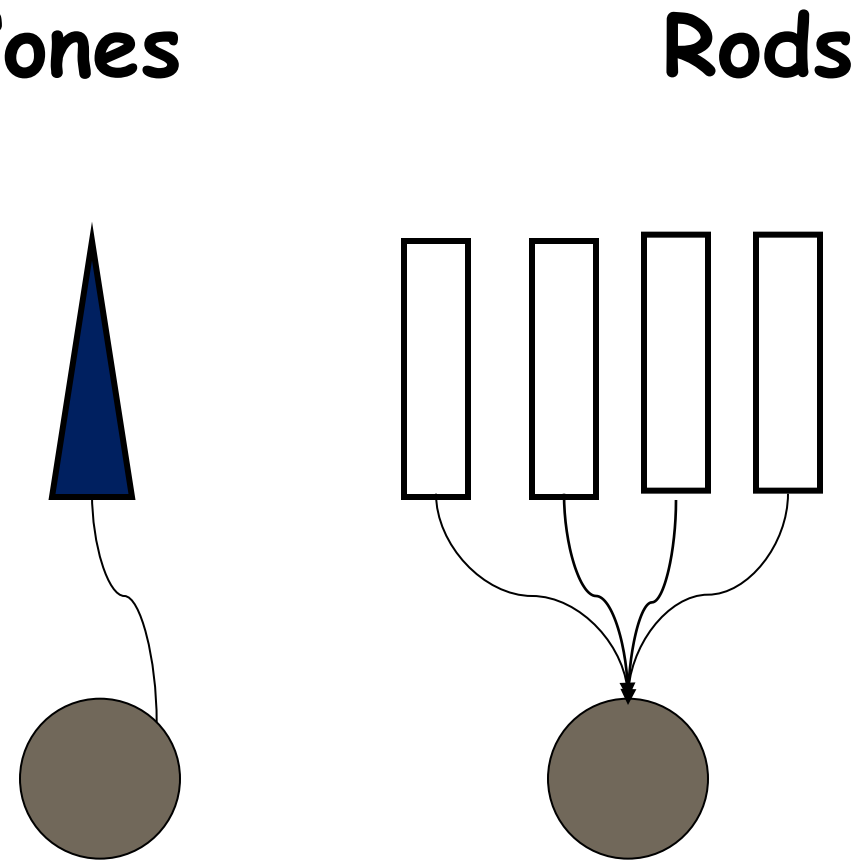
large spacing and large convergence result in low acuity

small spacing and low convergence result in high acuity.

By daylight, only the central fovea sees clearly & in color.
On a dark night, only the periphery sees, only in black & white, and with poor resolution.
The fovea is blind. only the periphery sees, only in black & white and with poor resolution.
The fovea is blind.

Convergence

- Photoreceptors
- Ganglion cells



Genesis of photoreceptor potential

- -Rodes & cones potentials are graded, local potential (generator potential) propagated as A.P in ganglion cells.
- -Ganglion cell action potential transmitted to optic nerve.
- - Cones respond to high levels of light intensity (illumination)
- -Rods respond to levels of light intensity (illumination) below threshold levels for cones, so rods are more sensitive

Electric recording in Retinal cells:

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

Photosensitive compound (rhodopsin):-

1- In cones rhodopsin (iodopsine) formed of :-
Opsin protein + retinal (retinene 1 = aldhyde form of Vit A)

2-There are 3 types of rhodopsin in cones (photopsine I,II,III) each respond to a certain wave length of light for color vision.

3-In Rods its rhodopsin formed of /
Scotopsin protein(opsin) + retinal (retinene 1 = aldhyde form of Vit A) = visual purple
(Rhodopsin of the rods most strongly absorbs green-blue light and, therefore, appears reddish-purple, so called "visual purple)

-It forms 90% of rods protein ,stored in disks of rods at outer segment

-At dark rhodopsin is in **11-cisretinal form (inactive)** but light sensitive form which increase sensitivity of rods to light

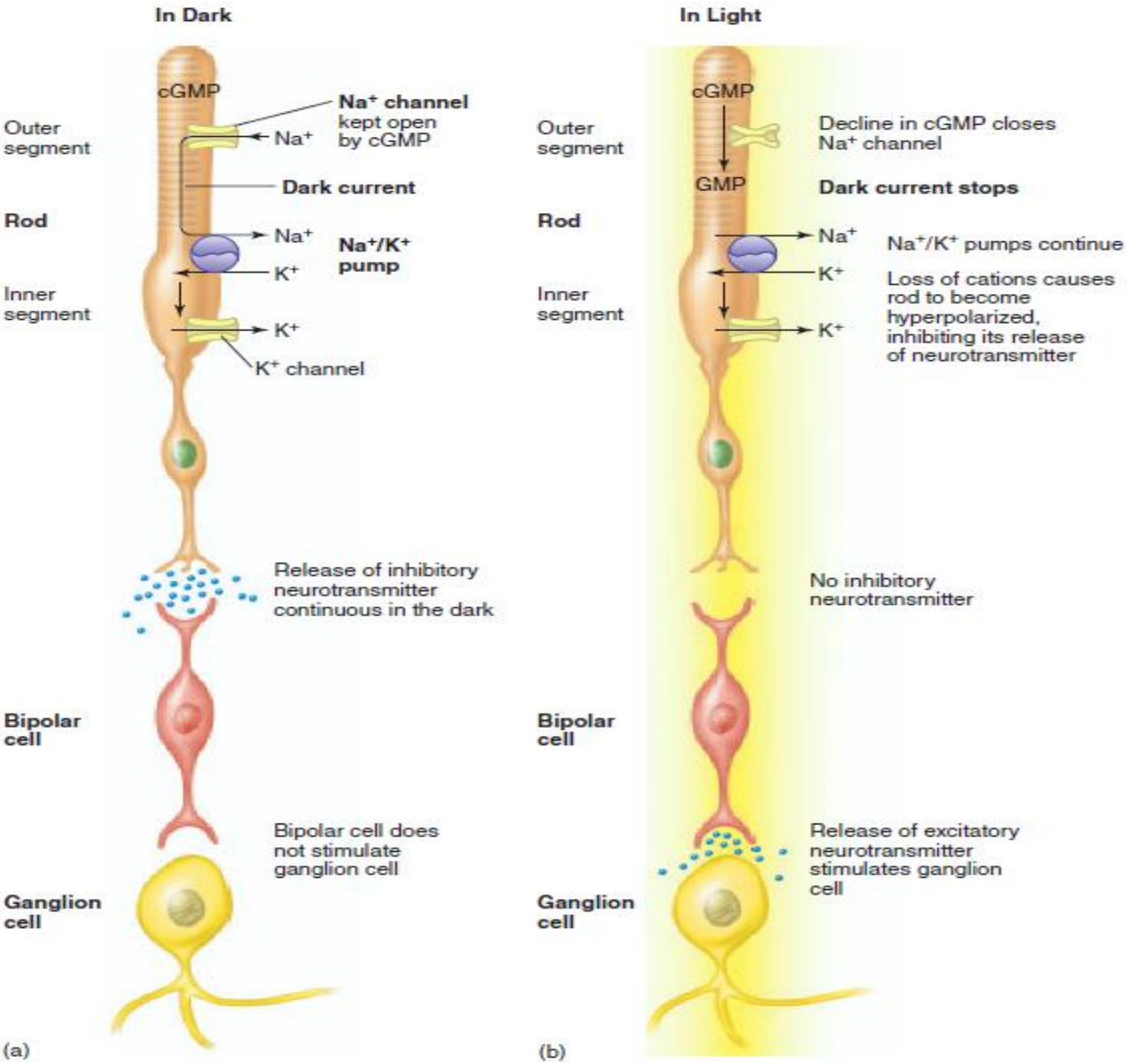
ELECTROPHYSIOLOGY OF VISION (PHOTOTRANSDUCTION)

A-At Dark (scotopic vision, dimlight vision):

1-Rhodopsin in 11-cisretinal (inactive form-light sensitive form which increase sensitivity of rods to light)

2- (5 –GMP) of the outer segment Na channels is in the c-GMP form -c-GMP at c-GMP gated Na channels of the outer segment , it bound to proteins at Na channel membrane & keep them open) → opening of Na channels at outer segment → allow Na influx after its is pumped out from Na –K pump of the inner segment→ depolarization.
(-40mvolt , instead of -80 mvolt in most receptors)

3- Dark current (Na current):- At the inner segment Na pumped by Na- K pump to outside & re-entered through Na channels (at outer segment) → Depolarization flow to synaptic endings → steady increased release of glutamate at synapses with bipolar cells → which get depolarization potential (off-center bipolar cells)→ depolarize ganglion cells


In Dark
cGMP
Na+ channel kept open by cGMP
Outer segment
Na+
Dark current
Rod
Na+
Na+/K+ pump
K+
Inner segment
K+
K+ channel
Release of inhibitory neurotransmitter continuous in the dark
Bipolar cell
Bipolar cell does not stimulate ganglion cell
Ganglion cell
(a)
In Light
cGMP
Decline in cGMP closes Na+ channel
Outer segment
GMP
Dark current stops
Rod
Na+
Na+/K+ pumps continue
K+
Loss of cations causes rod to become hyperpolarized, inhibiting its release of neurotransmitter
Inner segment
K+
No inhibitory neurotransmitter
Bipolar cell
Release of excitatory neurotransmitter stimulates ganglion cell
Ganglion cell
(b)

- Response in bipolar cells(OFF –center bipolar cells)(depolarization) → ganglion cells- → AP in optic nerve- → vision at dark.

NB/

-At dark rhodopsin is inactive (l l cis-retinal needs light for its activation) / inactive rhodopsin is essential for depolarization

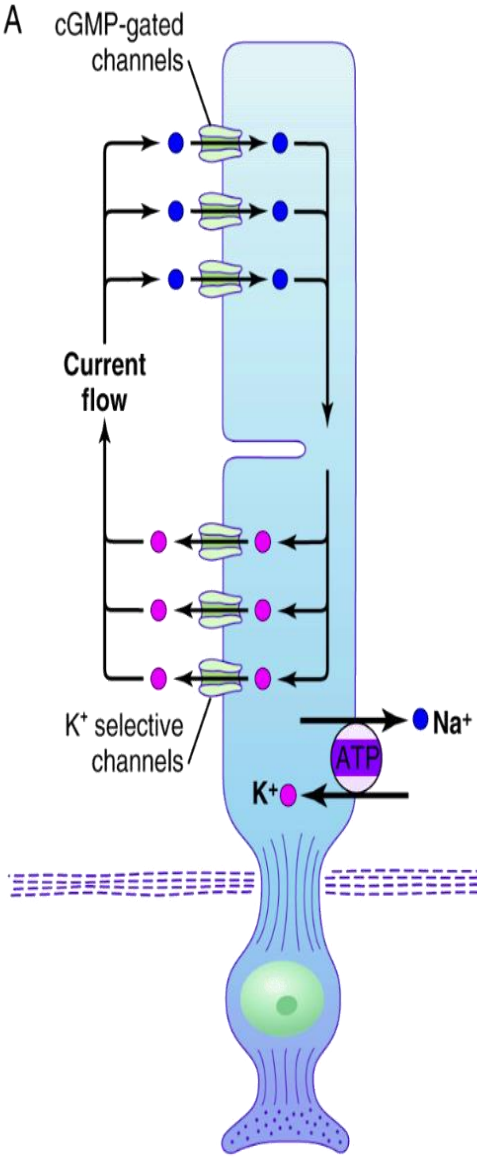
- its inactivation keeps Na channels open & Na current occurs

B-Incident light (PHOTOPIC VISION)

- - Light- → Conformational change of photopigment retinine-1 in rhodopsin (11-cisretinal form changed to → all-trans isomer called metarhodopsin II which is an active rhodopsin) →Activation of G – protein (transducin) → activation of phosphodiestrase enzyme → conversion of c-GMP to 5- GMP →

- - Decreased intracellular c-GMP → closure of Na channels in outer segment .
- -but still Na pump out of inner segment → Hyperpolarization of photoreceptors (-70 ~ -80 millivolts)

- Hyperpolarization → Decreased release of synaptic transmitter → Response in bipolar cells
- - off-center bipolar cells get hyperpolarized(this cause decreased release of glutamate → gradually depolarize on center bipolar cells leads to Generator potential in amakrine cells & ganglion cells (depolarize) → AP → optic nerve → optic pathway
- NB/
- -these reactions occur in both rods &cones but in rods occur at low illumination as in dimlight & in cones at high illumination.
- - in cones 4 times faster



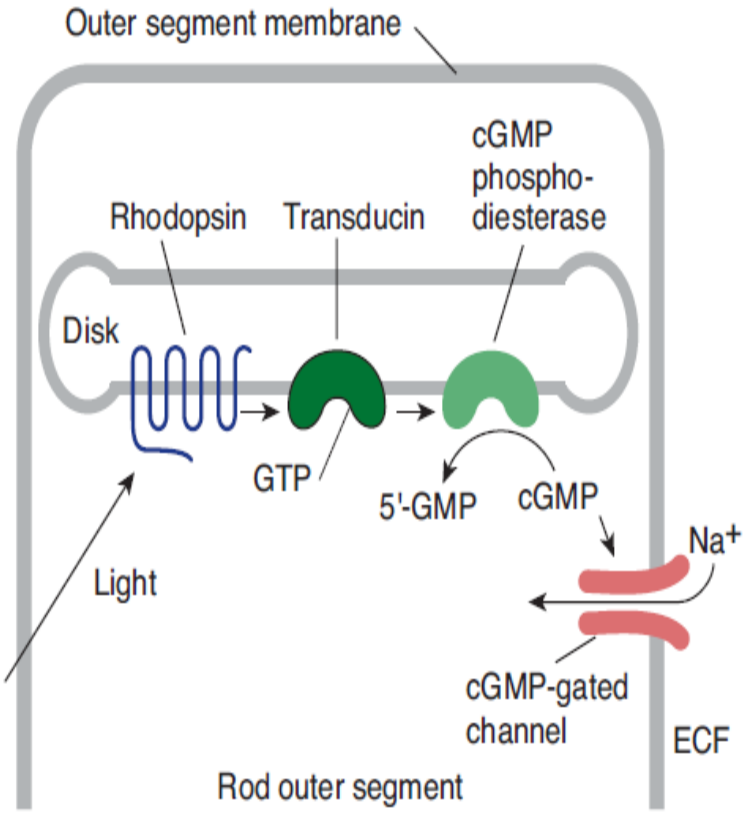


FIGURE 12–14 **Initial steps in phototransduction in rods.** Light activates rhodopsin, which activates transducin to bind GTP. This activates phosphodiesterase, which catalyzes the conversion of cGMP to 5'-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels to close.

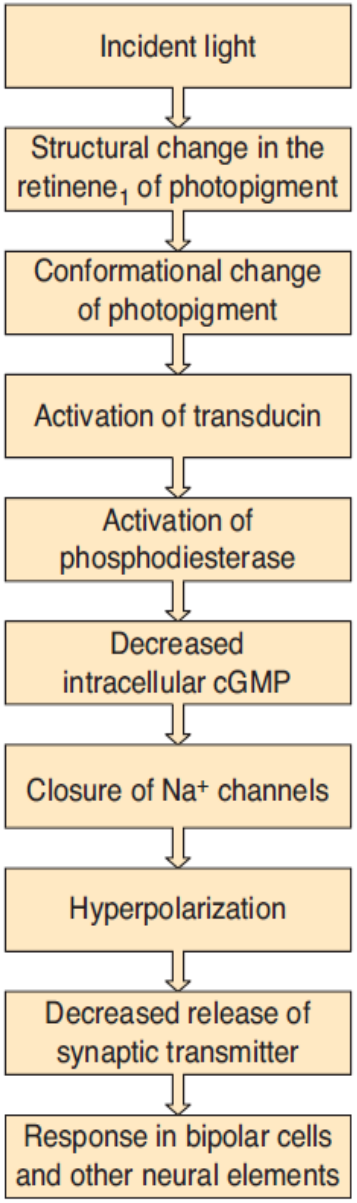


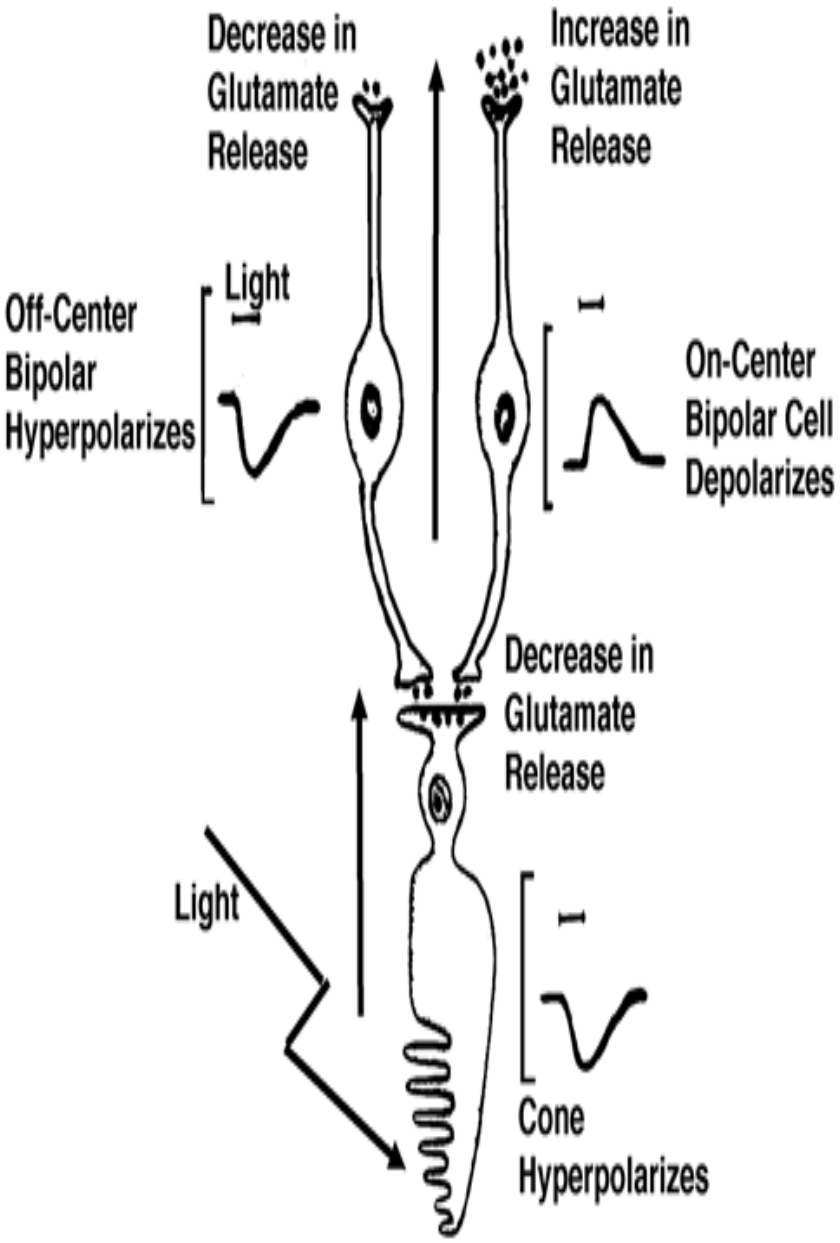
FIGURE 12–15 **Sequence of events involved in phototransduction in rods and cones.**

We have 10 types of cones bipolar cells & one type of rod bipolar cell

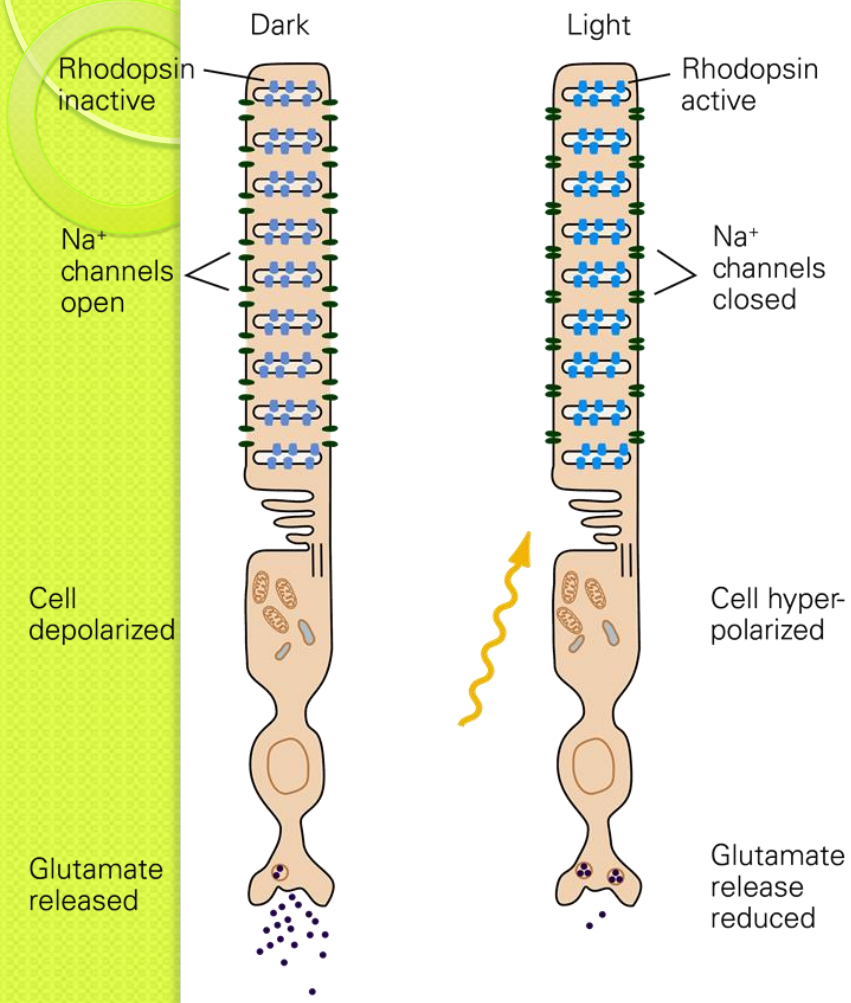
-Dark>> depolarize receptors >>> increase glutamate at photoreceptor ends>>
1-hyperpolarize ON- center bipolar cells
2-depolarize OFF-center bipolar cells

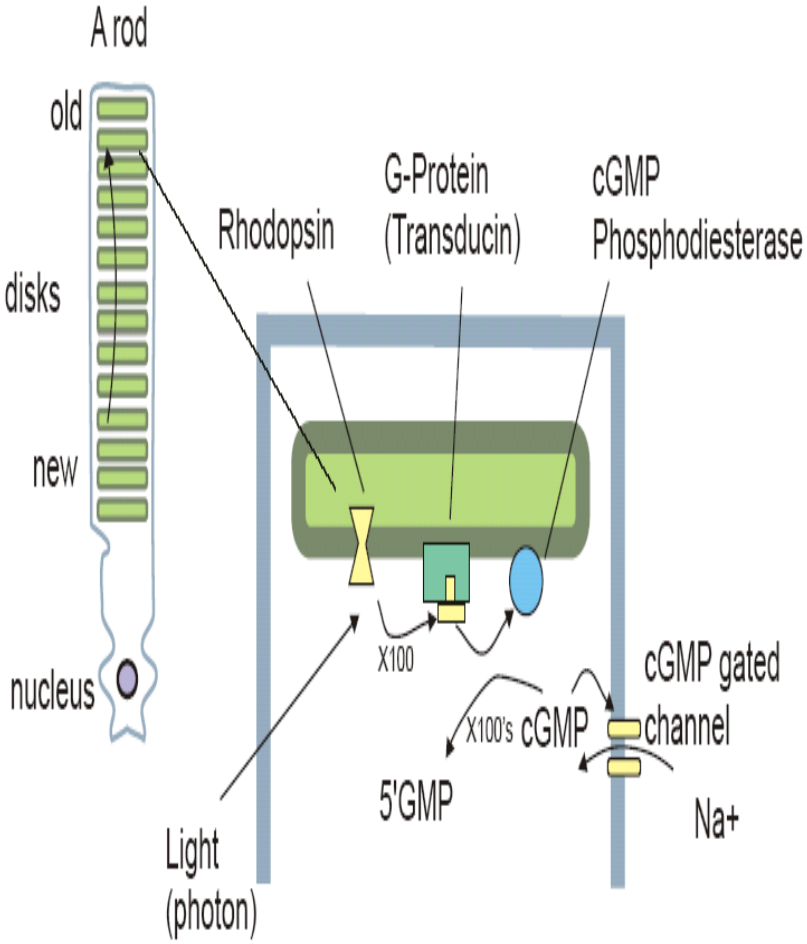
Light>> hyperpolarize the receptors>>>> decrease glutamate release at photoreceptor ends>>.
1- depolarize ON- center bipolar cells
2- hyperpolarize OFF-center bipolar cells (inactive)

N.B/
-ON- center bipolar(synaptic connection with center photoreceptors= cones , so light depolarize them to see in bright light)
-OFF- center bipolar(synaptic connection with peripheral photoreceptors= rods , so dark depolarize them to see in dark)
-All these help to sharpen signal from rods in dark and from cones in light



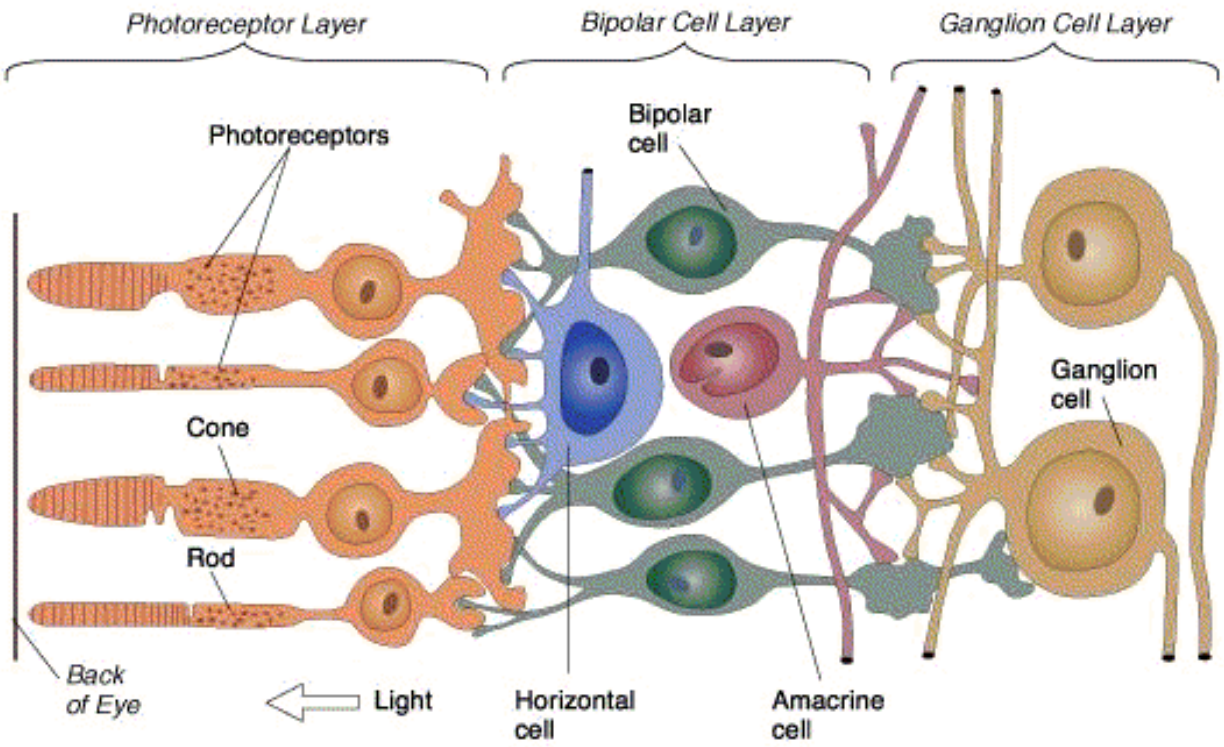
A Phototransduction and neural signaling





- **Synaptic mediators in retina:-**
- **Ach, glutamate, dopamine, serotonine,GABA, substance P,somatomedin, VIP, enkephalins, glucagons,neurotensin.**
- **In dark:- depolarization of receptors >>>>glutamate is continuously (steadily) released by depolarization of rods depolarize bipolar cell (OFF-center)→generator potential → AP in ganglion cells**
- **In light:- hyperpolarization of the receptors >>decrease glutamate release → hyperpolarize bipolar cells (OFF-center)gradual depolarize (on –center cells),depolarize amacrine cell →generator potential → AP in ganglion cells.**

Retina


Photoreceptor Layer
Bipolar Cell Layer
Ganglion Cell Layer
Photoreceptors
Bipolar cell
Cone
Rod
Ganglion cell
Back of Eye
Light
Horizontal cell
Amacrine cell

VISUAL CYCLE(bleaching& regeneration)

Retinal is produced in the retina from Vitamin A, from dietary beta-carotene.

light induces Isomerization of 11-*cis*-retinal into metarhodopsin I then into metarhodopsin II ,then into all-*trans*-retinal by a conformational change **(bleaching)** and all trans-retinal separate from opsin by light and opsin remains alone.

In dark/// trans-retinal is enzymatically re-converted to the 11-cis-retinal form via an retinal isomerase enzyme. Since the scotopsin is present alone (having been removed from the rhodopsin) it immediately will combine with 11-cis-retinal to regenerate new rhodopsin

-*At dark // 11cis-Retinal in rods + scotopcin → → rhodopsin regeneration

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

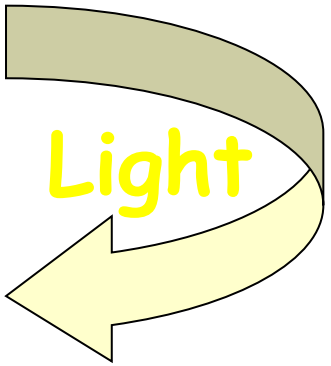
Photoreceptor compounds-cont

Rhodopsin (visual purple, scotopsin):

Activation of rhodopsin:

- **In the dark:**

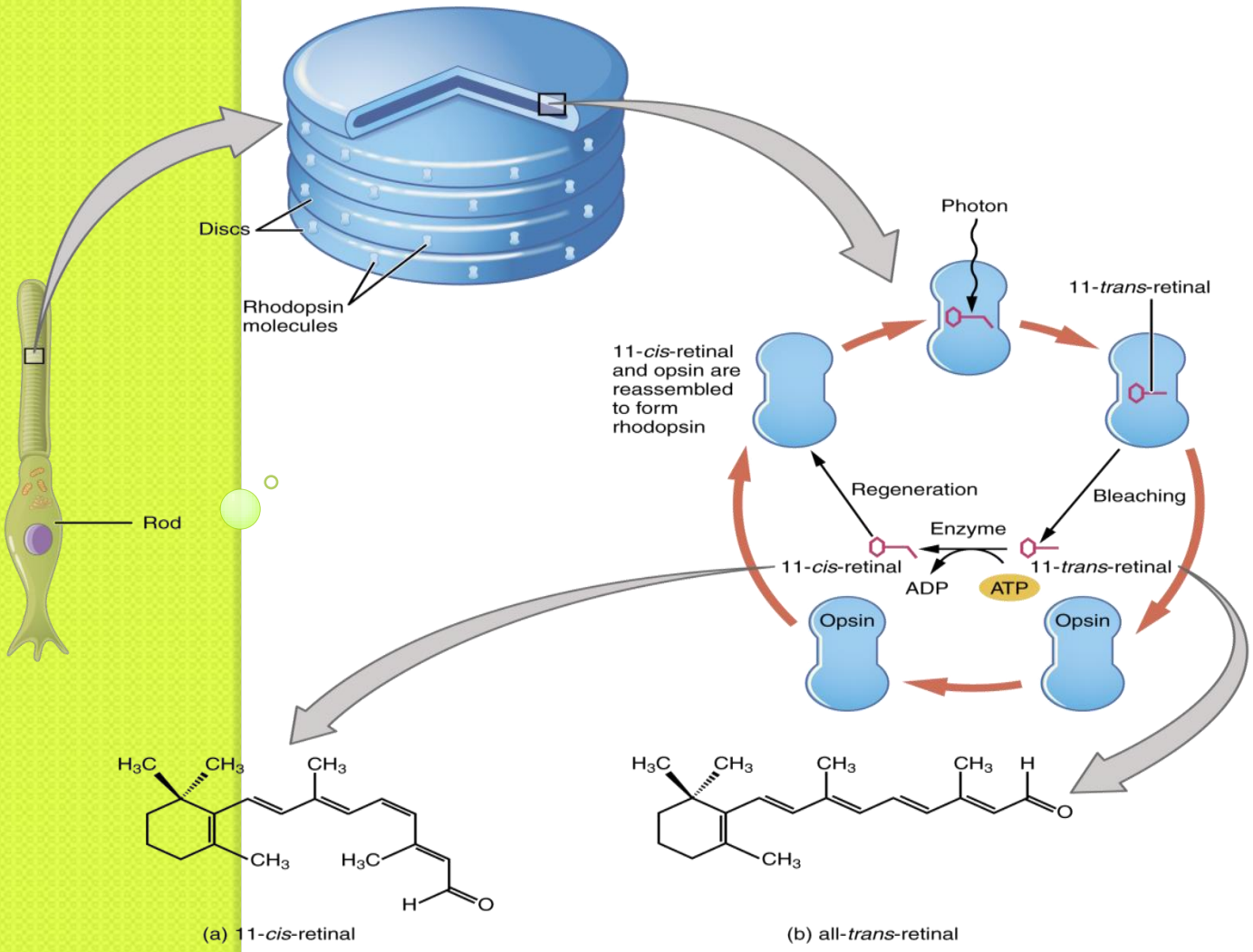
retinine1 in the 11-*cis* configuration



All-*trans* isomer

Metarhodopsin II

Closure of Na channels

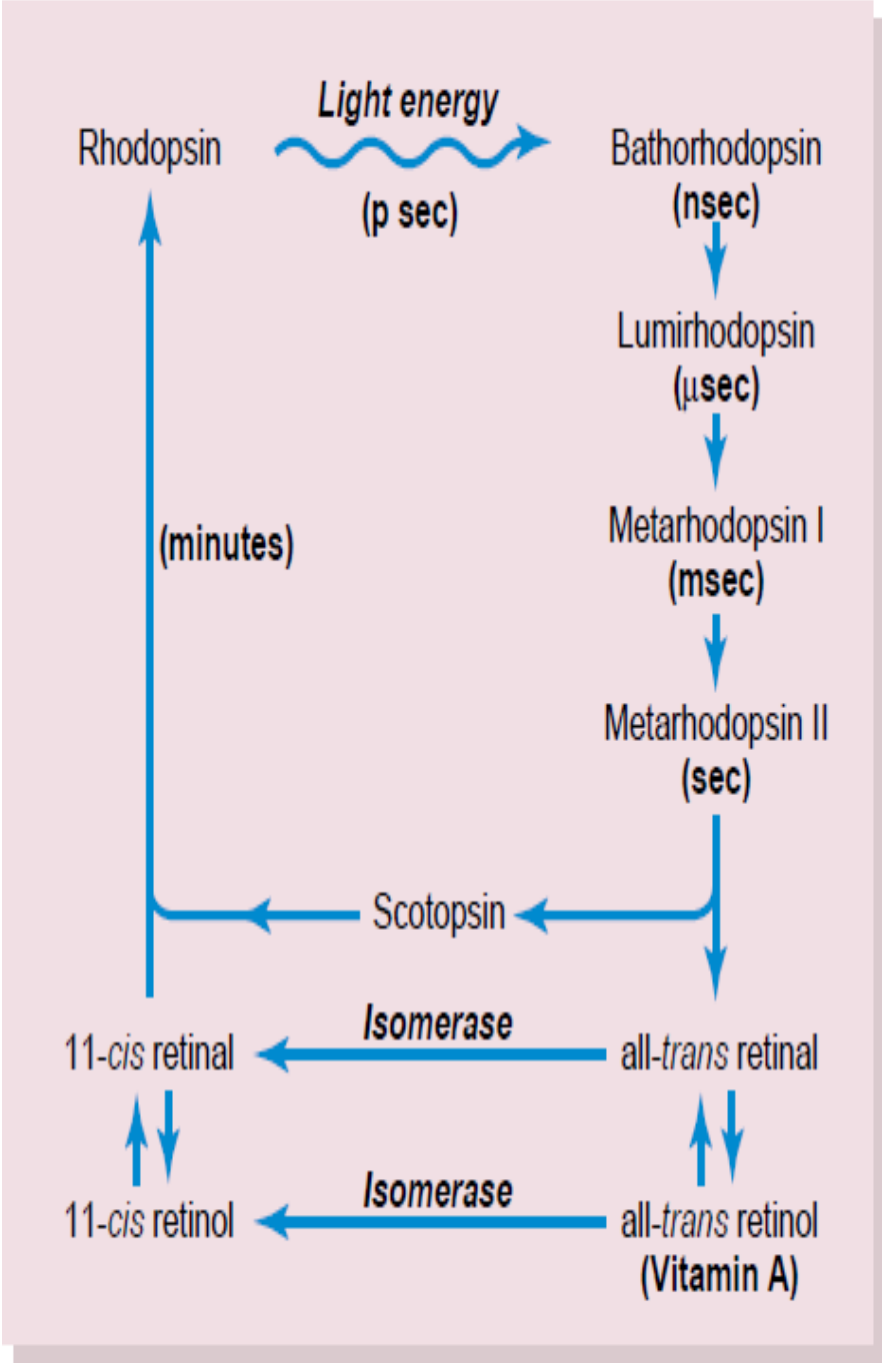


RHODOPSIN CYCLING

-scotopsin retinal visual cycle

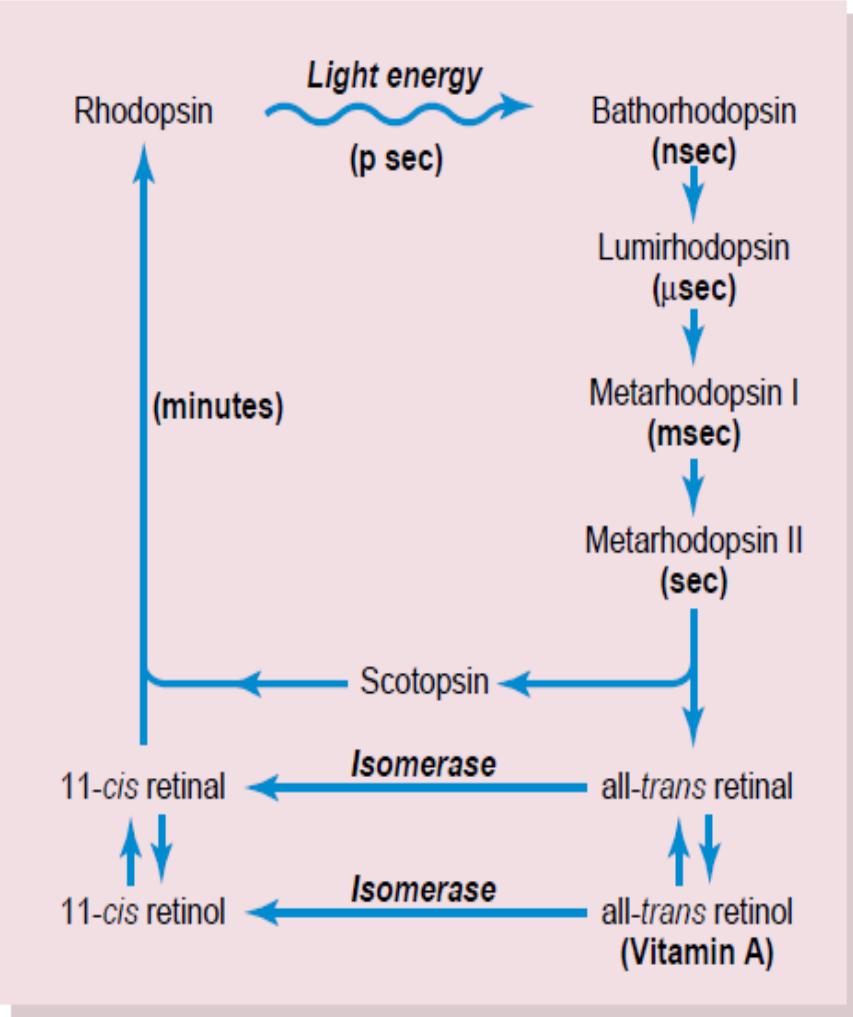
-The amount of rhodopsin in the receptors varies inversely with the incident light level.(decreases with light)

- **when there is excess retinal in the retina, it is converted back into vitamin A, thus reducing the amount of light-sensitive pigment in the retina.**



Photochemistry of Color Vision by the Cones

- **Photopsins Retinal Visual Cycle**
- The cones are about 30 to 300 times less sensitive than rods to light



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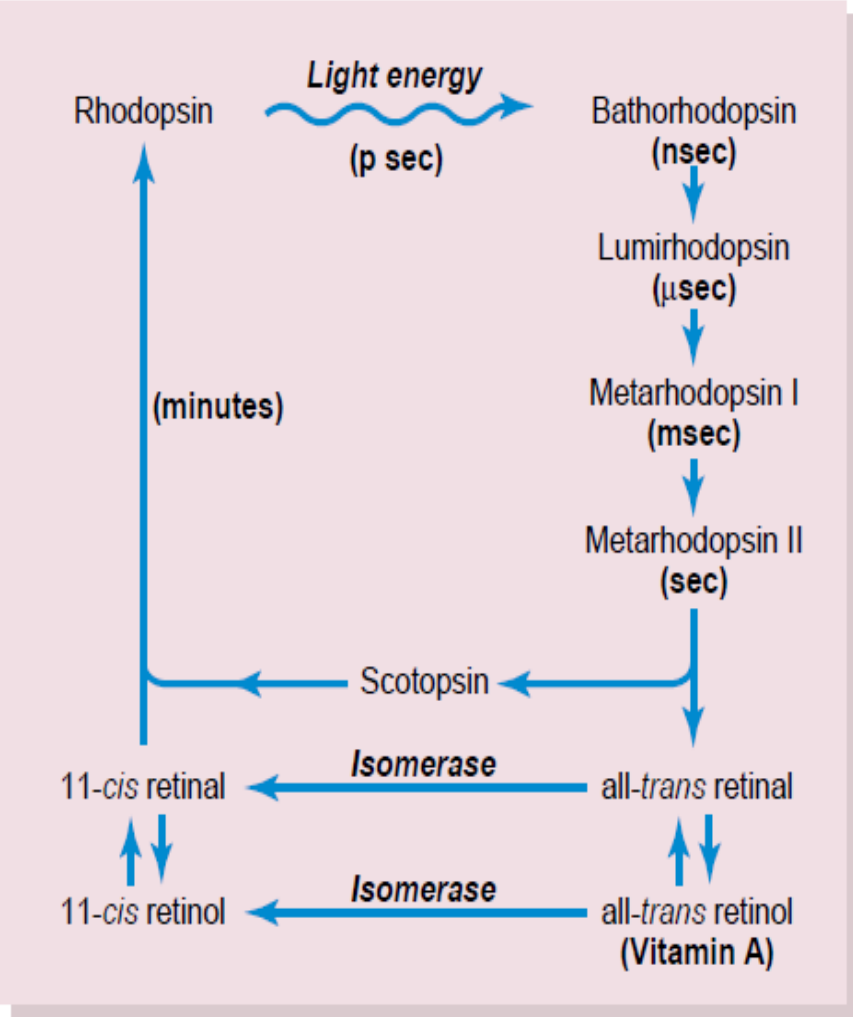
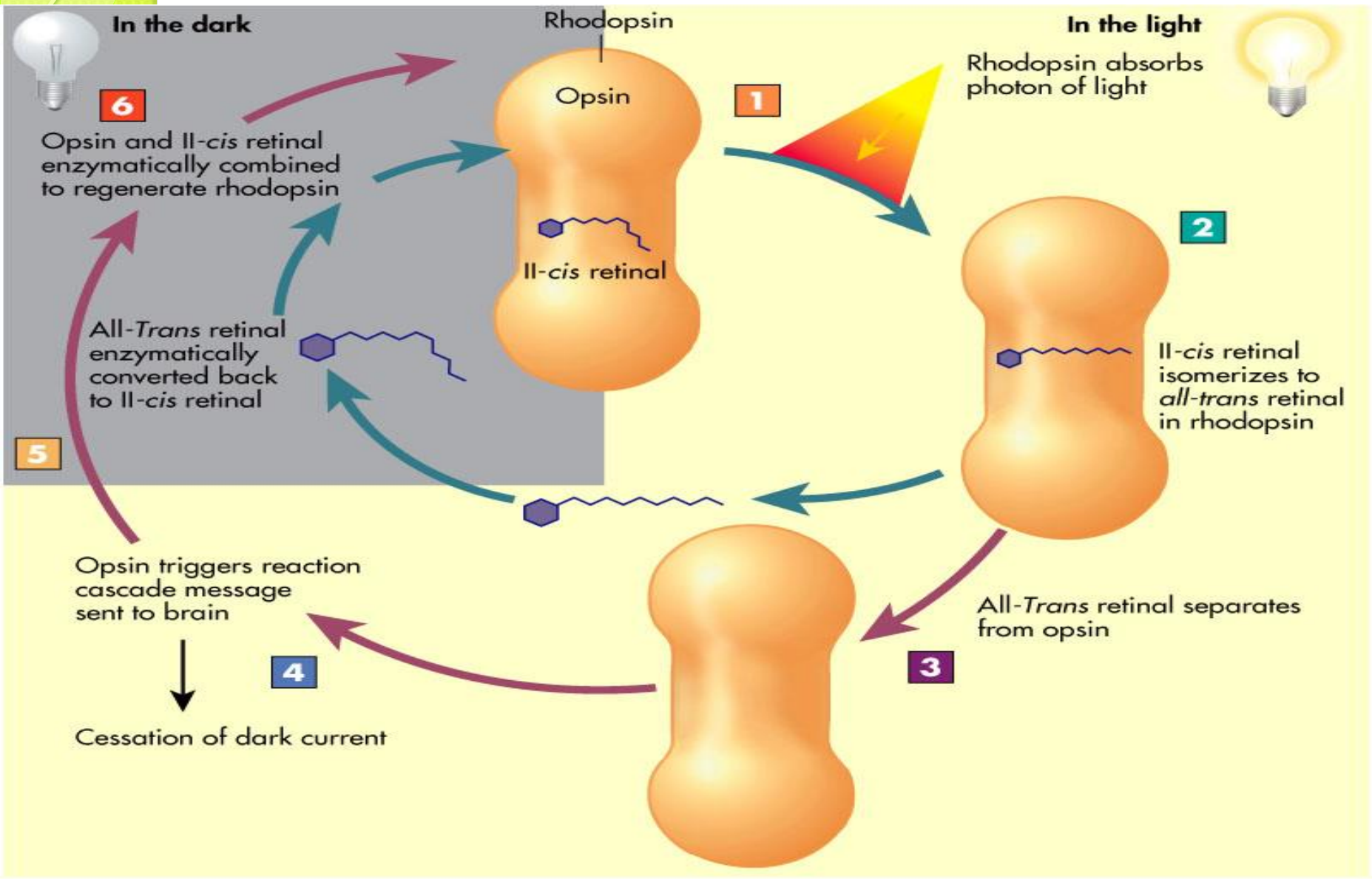



In the dark
Rhodopsin
In the light
Rhodopsin absorbs photon of light
6
Opsin and 11-cis retinal enzymatically combined to regenerate rhodopsin
Opsin
1
11-cis retinal
2
All-Trans retinal enzymatically converted back to 11-cis retinal
11-cis retinal isomerizes to all-trans retinal in rhodopsin
5
Opsin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

NYCTALOPIA:- (night blindness)

-- Vitamine A (main source of retinal of rhodopsin)

- Vitamine A deficiency cause rods , cones & retinal degeneration & loss of rods

- R / Intravenous vit A if receptors are well.

Dark adaptation:-

- -It means increased sensitivity of the photoreceptors when vision shifts from **bright** to **dim light**

- **-When a person moves from lighted environment → a dimly lighted environment, the retina becomes more sensitive to light & the person will see at dark (accustomed to dark) in about 20 min.(only gross features but no details or colors) .**
- **- Rhodopsin in darkness is essential for depolarization of rodes to see in dark**
- **& for dark adaptation)**

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

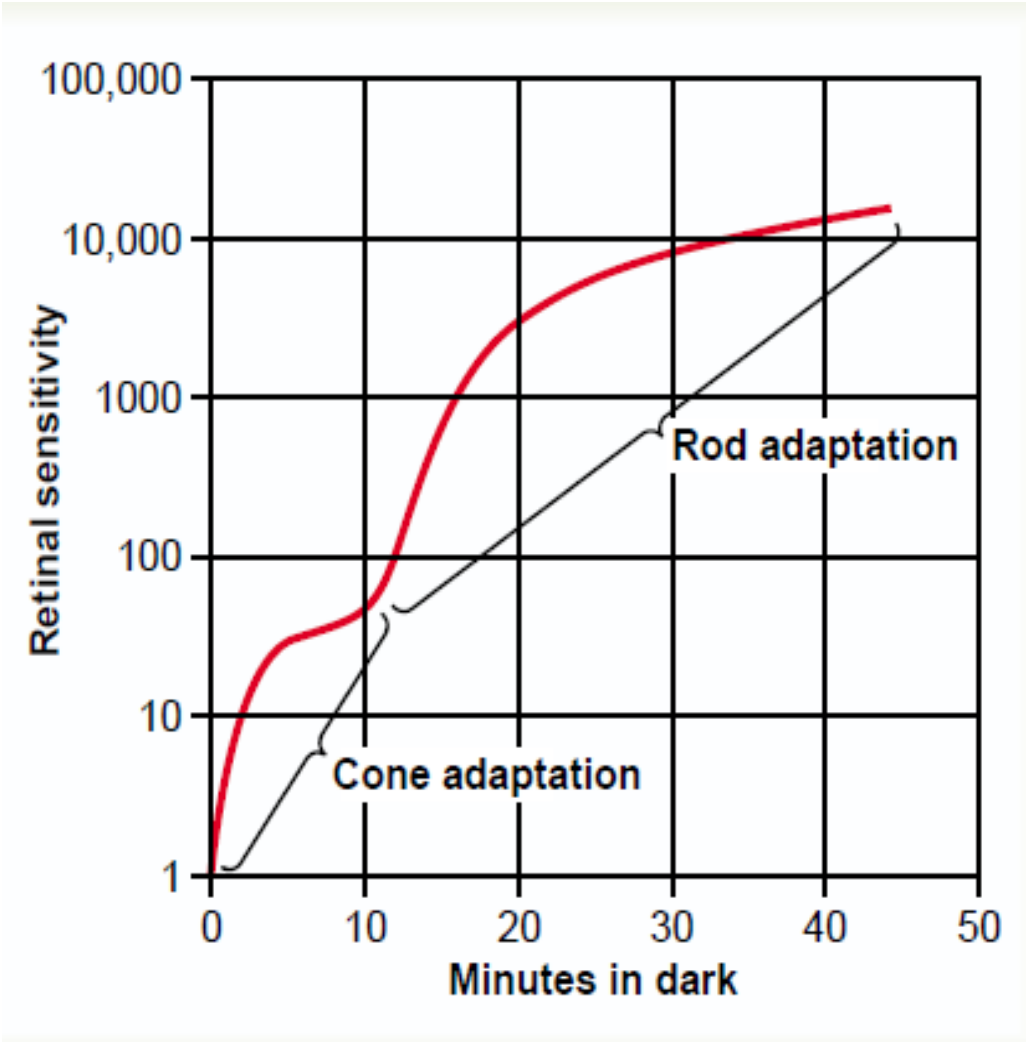
- **Dark adaptation has 2 components:-**

- **1- rapid (about 5 minutes) drop in visual threshold .**
- **Fast dark adaptation of cones , only in fovea**
- **-half of the cone rhodopsin regenerate in only 90 seconds**
- -
- **2- less rapid (till 20 min) drop in visual threshold stimulates dark adaptation of rodes in the peripheral retina**
- **- sensitivity of rodes to light increases in each 1 min increase 10 folds**
- **(rodes increase their sensitivity to light by convergence 300:1 ganglion cell , so summation at ganglion cells potential will increase sensitivity to light)**

N.B (20 min for dark adaptation are for regeneration of rhodopsin → increase sensitivity of rodes to light due to a drop in visual threshold

Q- Why radiologists & aircraft pilots wear red goggles in bright light?

A- Light wavelength of the red stimulate the cones & stimulates rods to some extent, so red goggles for rods act as dimlight, so with it rods are adapted to darkness & form large amounts of rhodopsin while the person in bright light & when person enter dark places he can see well & not remain 20 minutes.



- **2-Light adaptation**

- **-When light switched on again, the rodes are knocked out of action (they stop sending AP at high levels of light) & cones start to function to adjust & adapt to the level of brightness in 5 min this is called Light adaptation**

Three Types of Retinal Ganglion Cells and Their Respective Fields (W, X, and Y cells)

1-W cells/ ➔ sensitive for detecting directional movement in the field of vision, and they are probably important for much of our rod vision under dark conditions

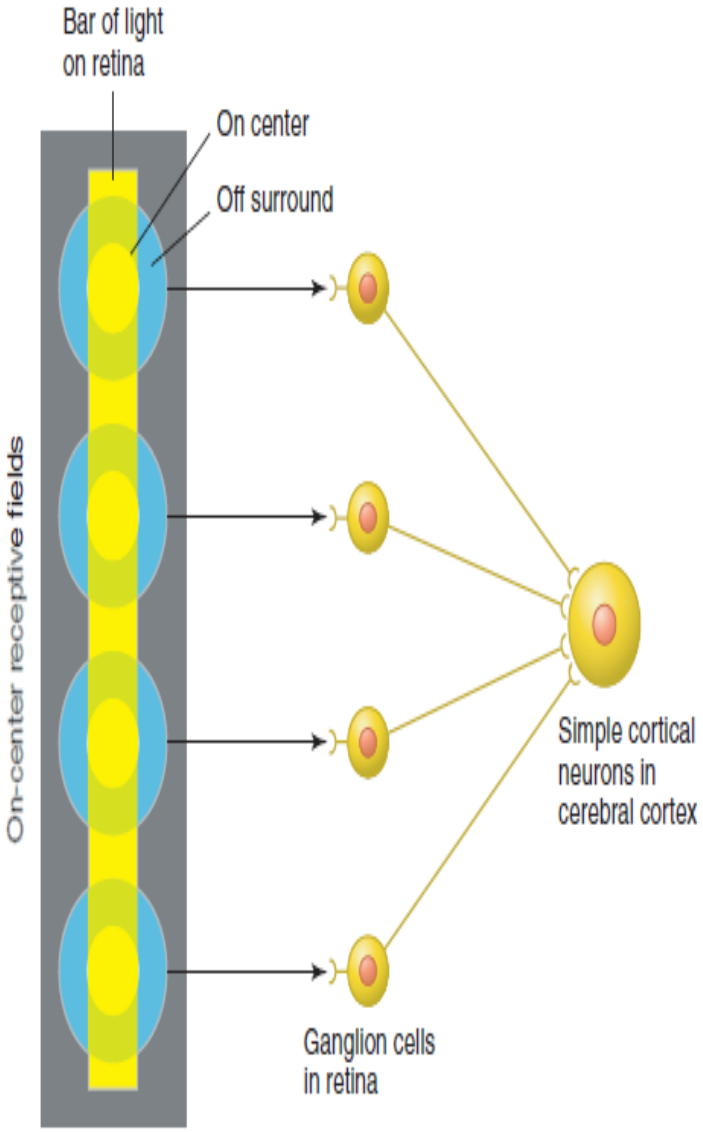
2- X Cells / Transmission of the Visual Image and Color ➔ Color Vision

3-Y Cells // to Transmit Instantaneous & rapid Changes in the Visual Image , either rapid movement or rapid change in light intensity

Convergence of ganglion cells

-The receptive field of a ganglion cell in the retina of the eye is composed of input from all of the photoreceptors which synapse with it

- A group of ganglion cells in turn forms the receptive field for a cell in the brain. This process is called convergence



Thank you for listening