Vision

Phototransduction of light

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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

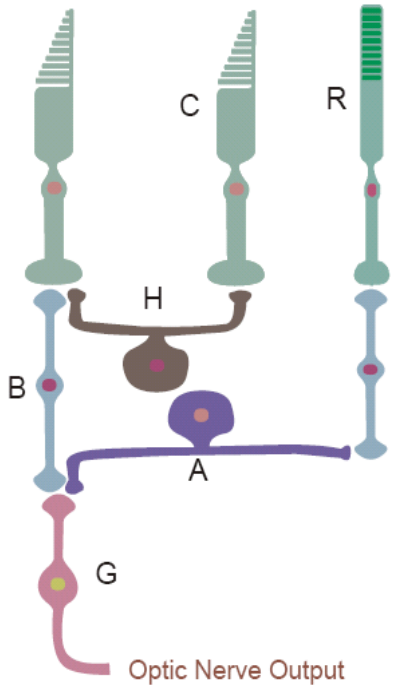
- in rods it is big, rode like and contain one type of rhodopsin

-There are Na channels in the outer segment

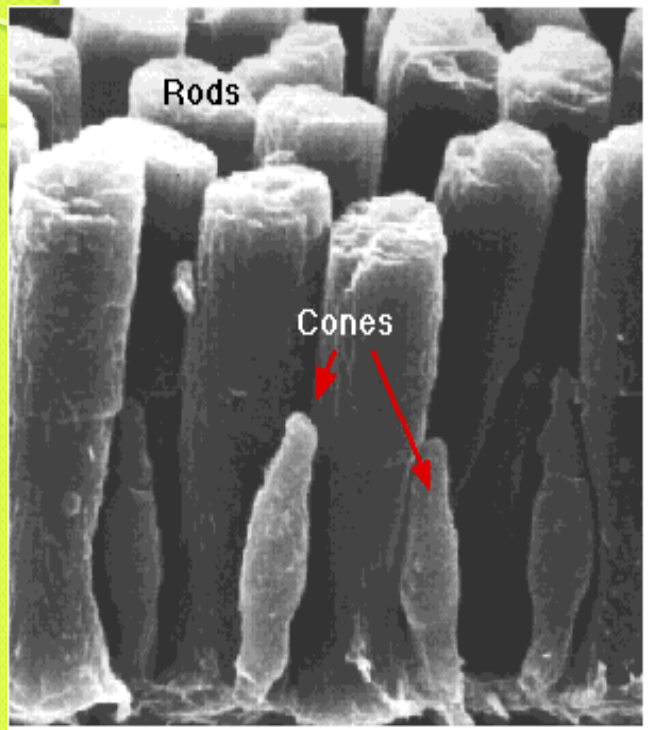
2- Inner segment

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

-There is Na-K pump in inner segment



Photoreceptors



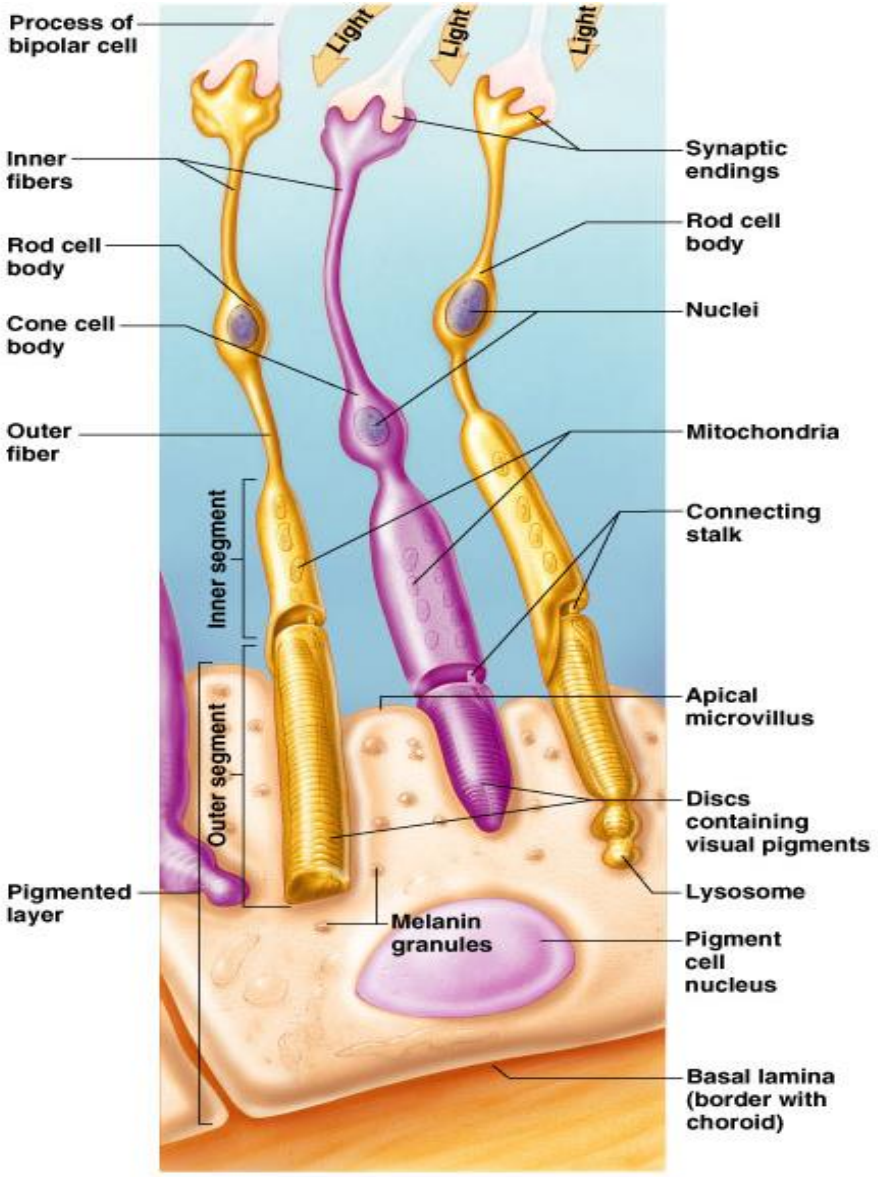
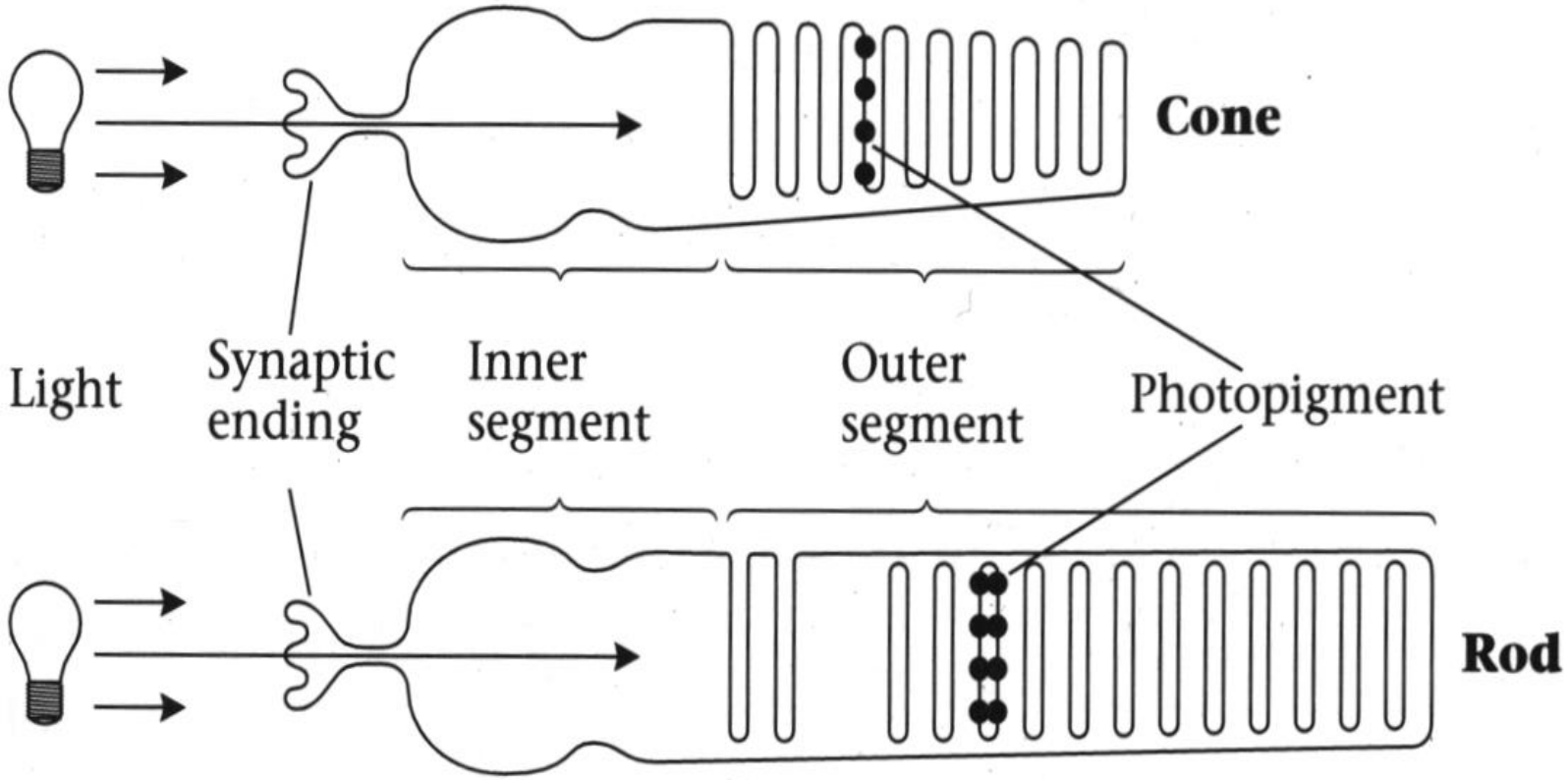
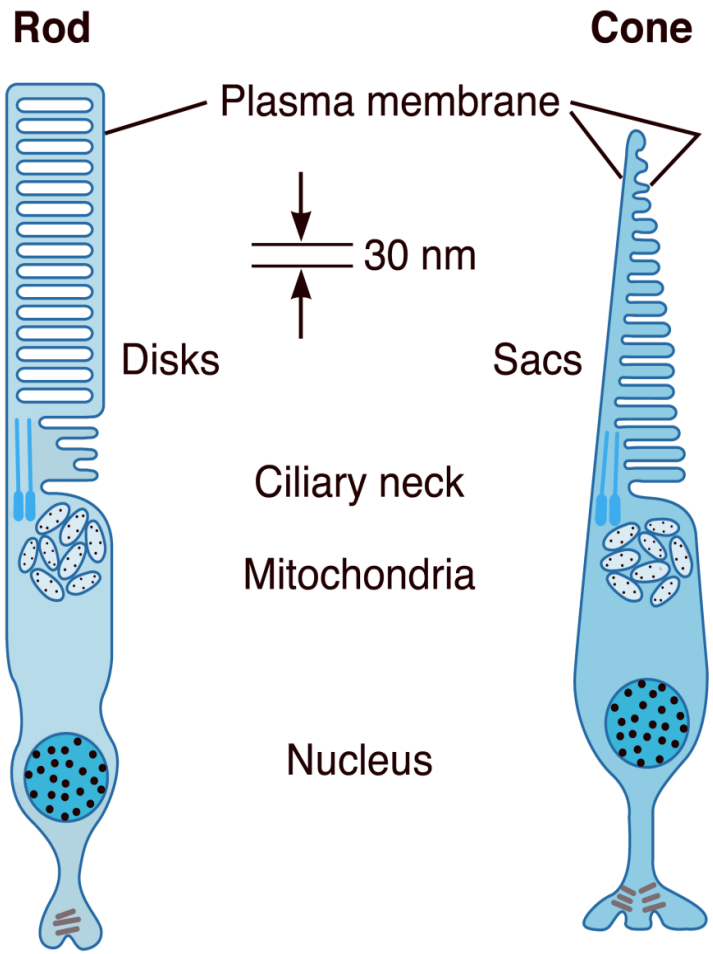


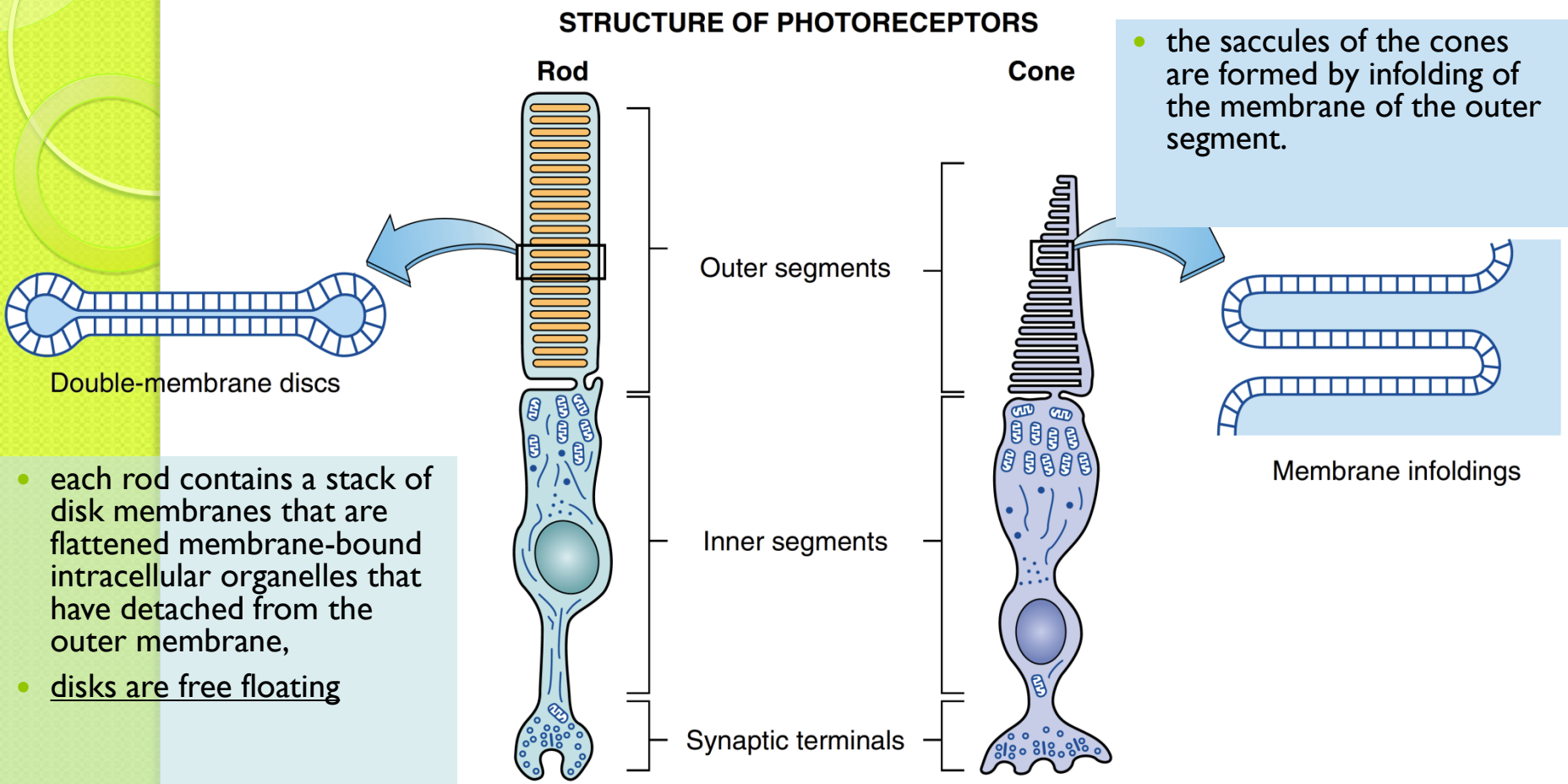
Figure 16.11

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)



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

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

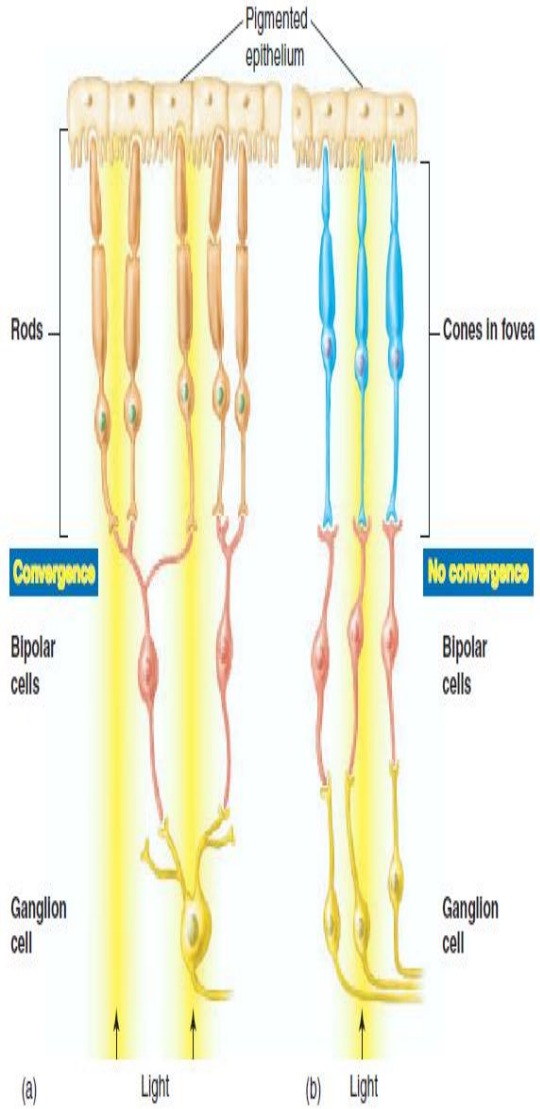
the saccules and disks contain the photosensitive compounds that react to light, initiating action potentials in the post synaptic cells

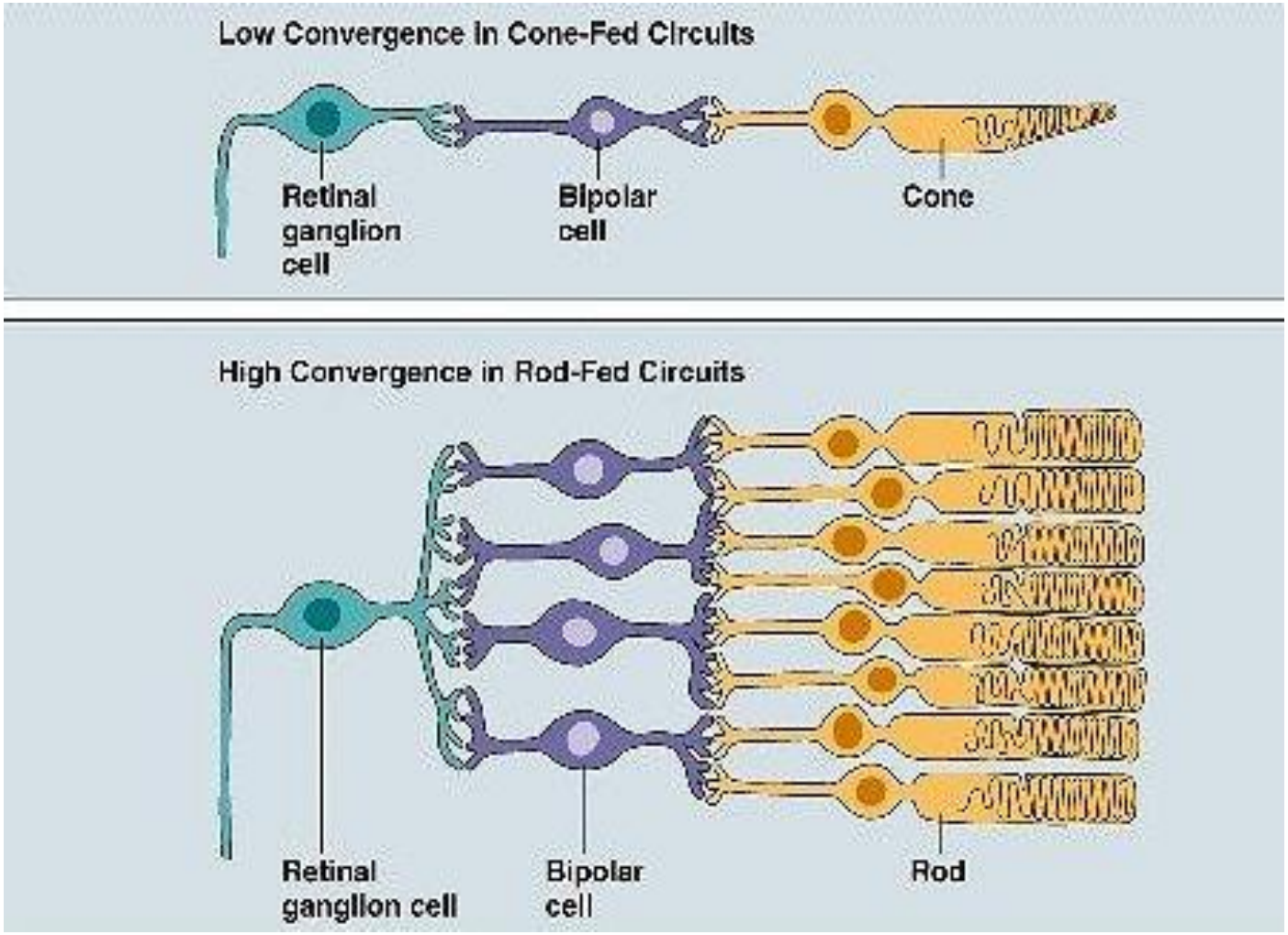
- **Convergence:-**

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

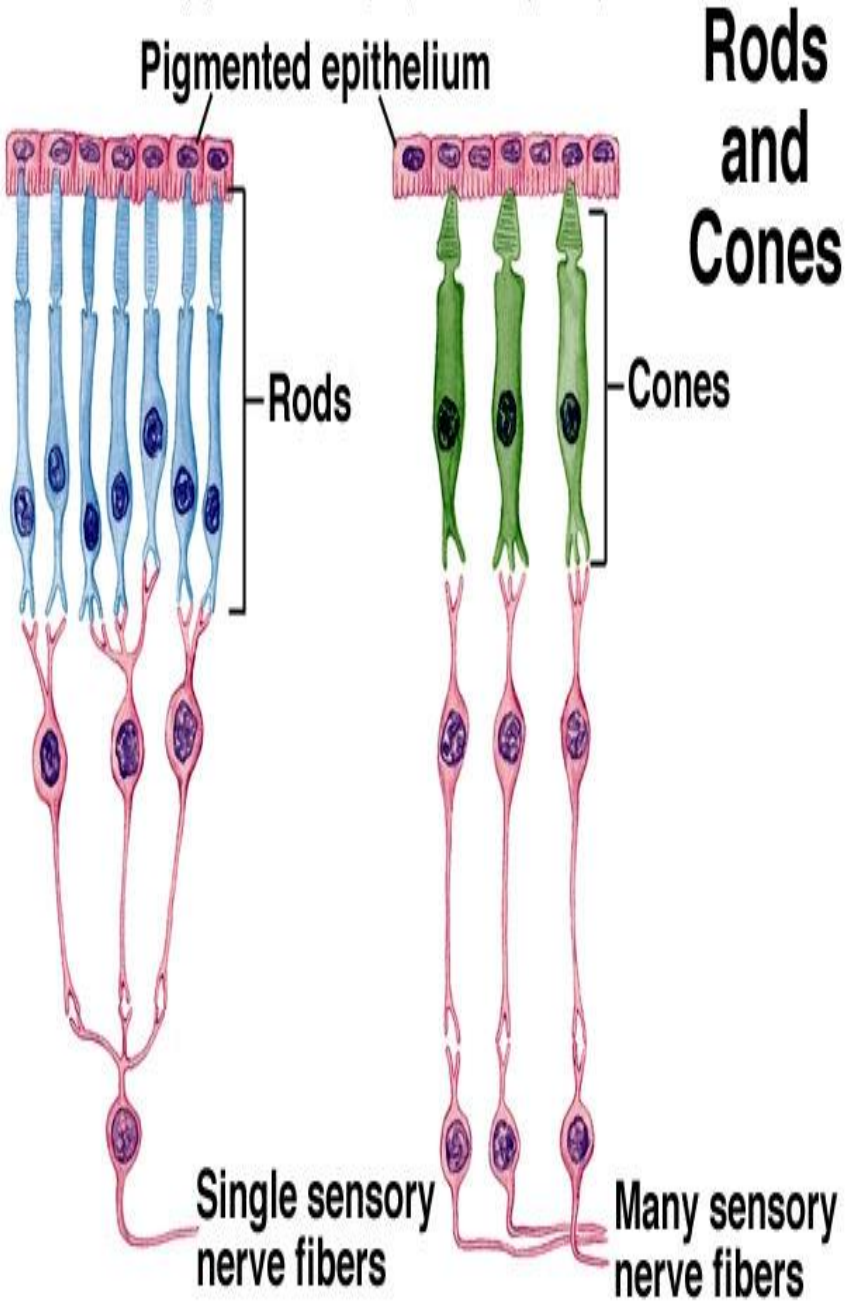
- Advantage of low convergence /
- increases visual acuity → integrated information from small area of retina

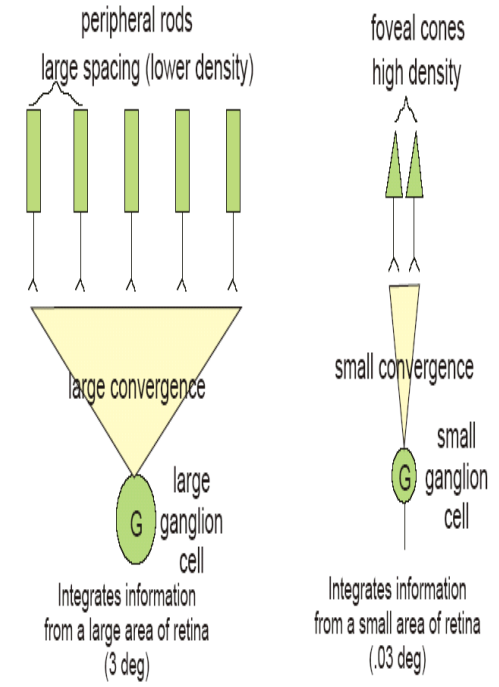
Disadvantage/ decreases sensitivity to light i.e need high threshold of illumination to stimulate cones)




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.





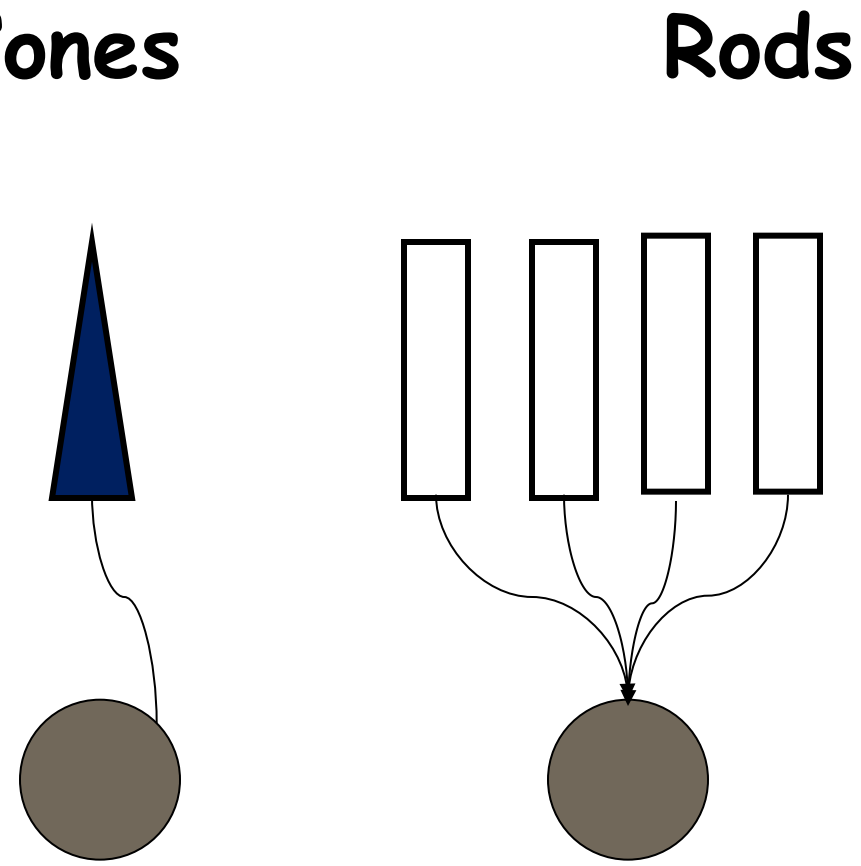
large spacing and large convergence result in low acuity

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(generator potential)
- Bipolar cells: Hyper- & Depolarization
- Horizental cells: Hyperpolarization
- Amacrine cells: Depolarizing potential
- Ganglion cells: Depolarizing action potential(AP)

Photosensitive compound (rhodopsin):-

1- In cones rhodopsin (iodopsine) formed of :-
Opsin protein + retinal (retinene I = 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 I = 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

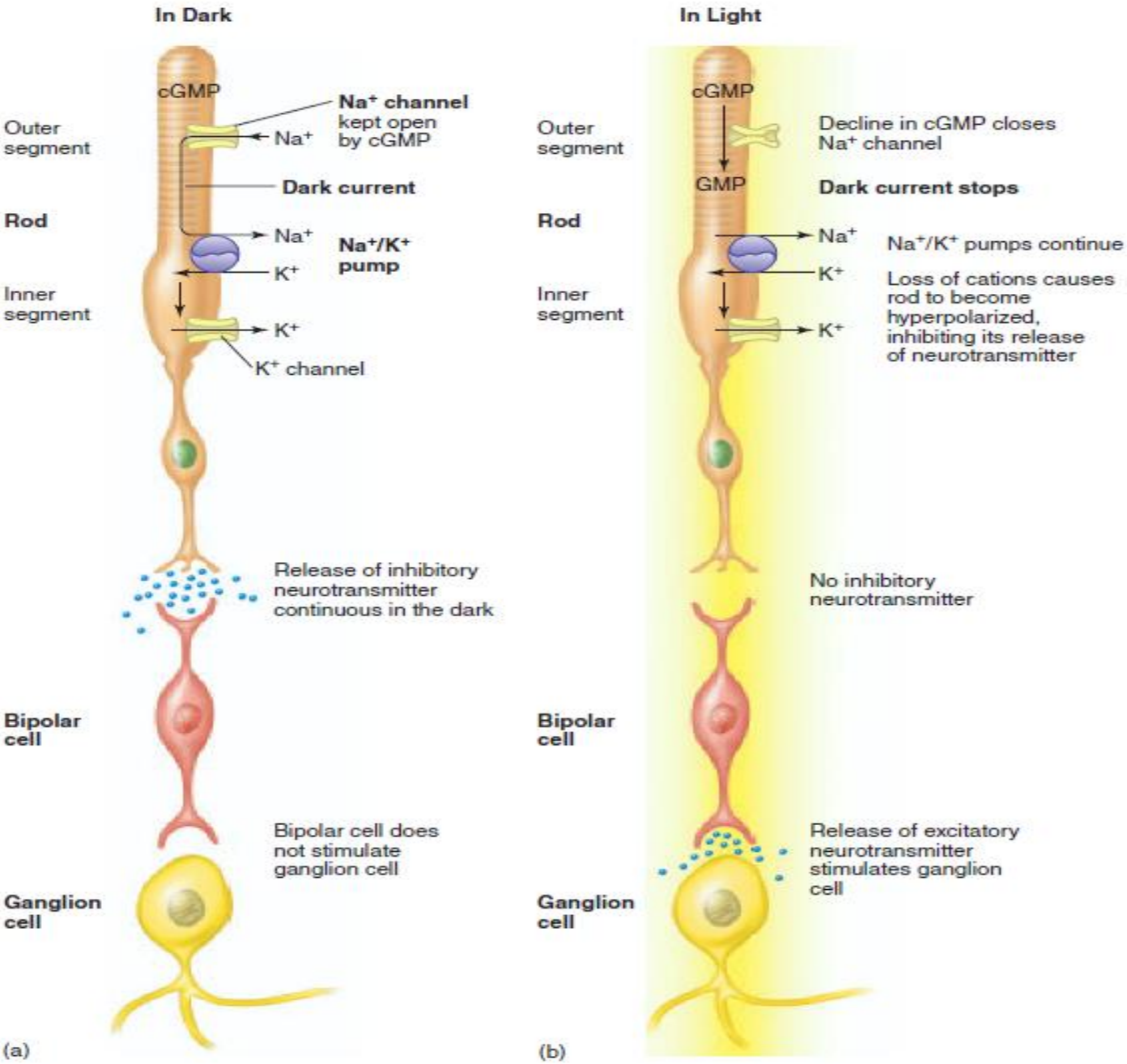
ELECTROPHYSIOLOGY OF VISION (PHOTOTRANSDUCTION)

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

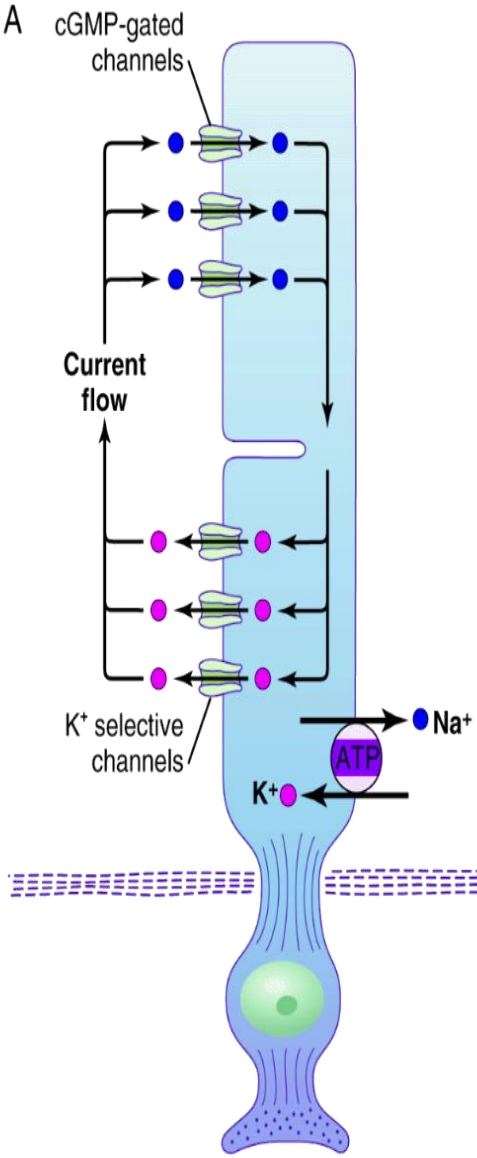
- its inactivation keeps Na channels open & Na current occurs

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**



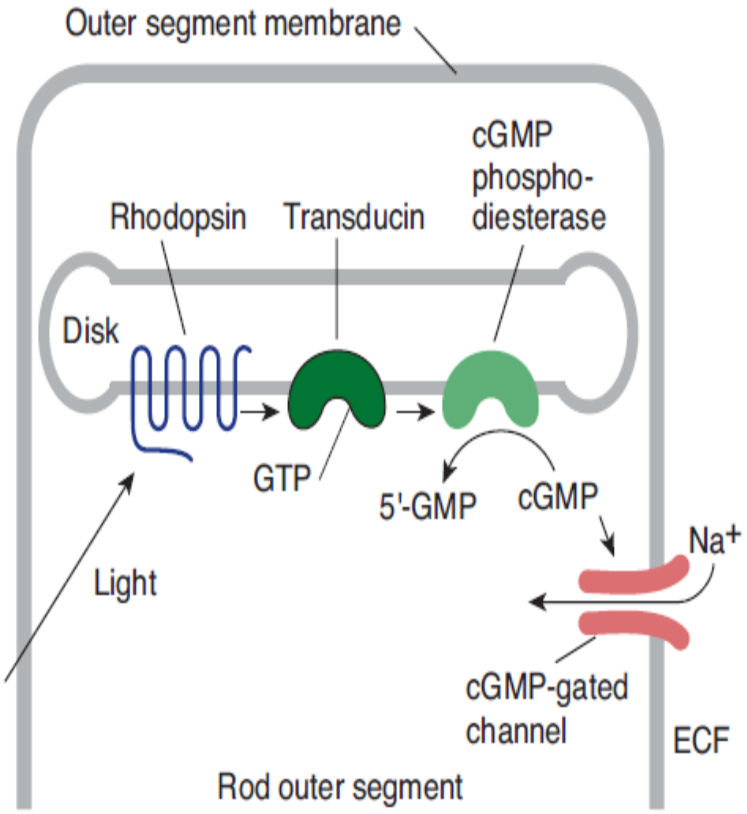


FIGURE 12–14 **Initial steps in phototransduction in rods.** Light activates rhodopsin, which activates transducin to bind GTP. This activates phosphodiesterase, which catalyzes the conversion of cGMP to 5'-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels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

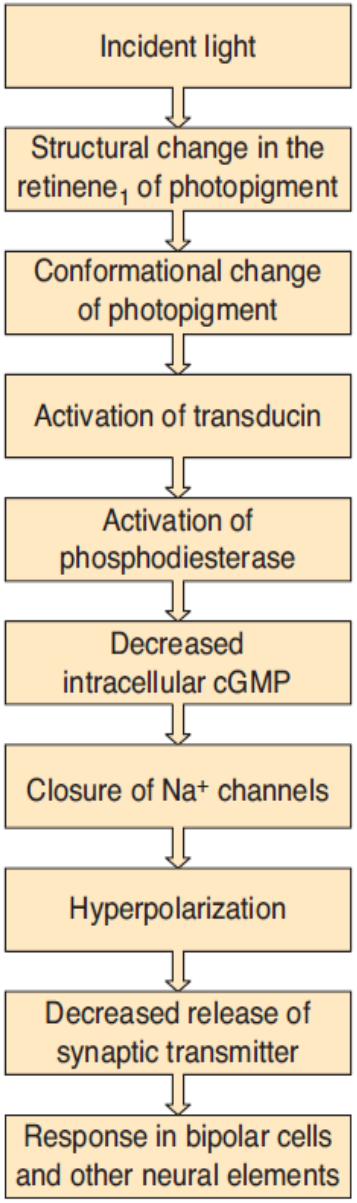


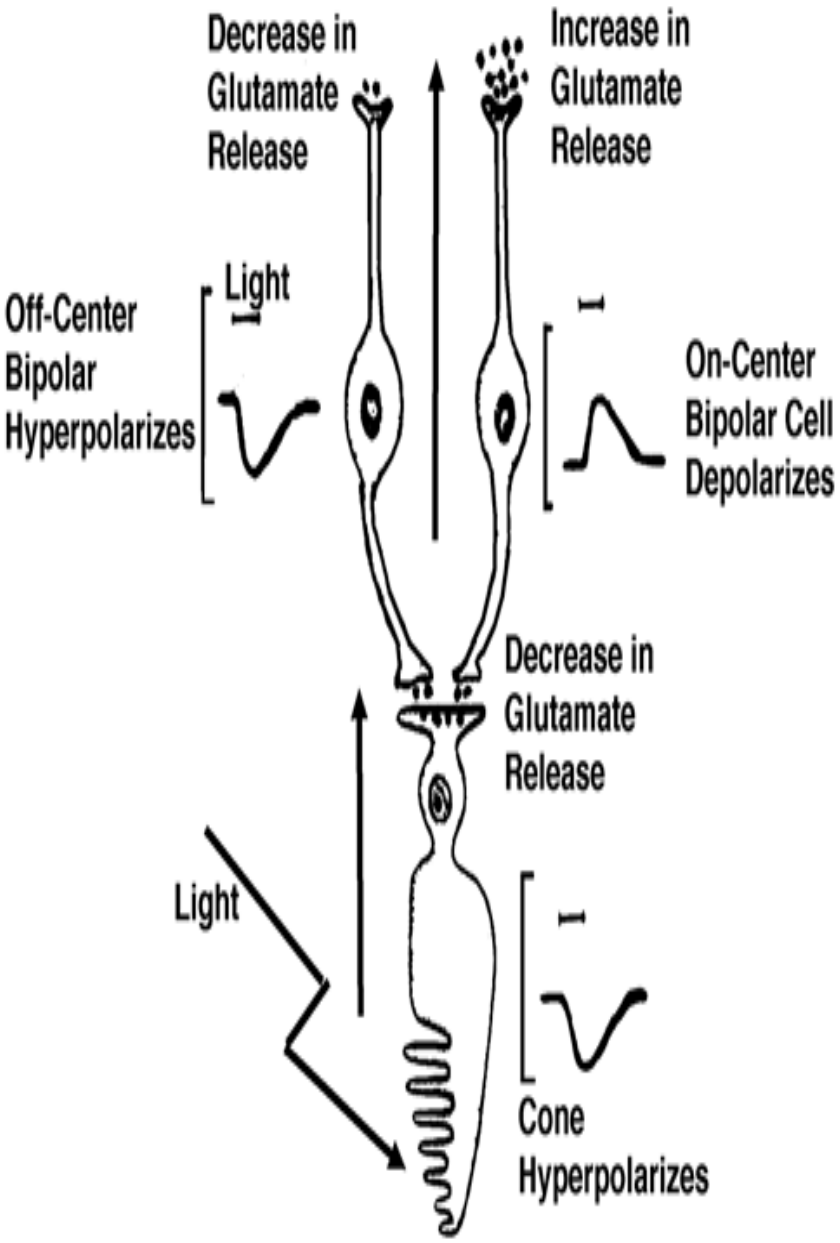
FIGURE 12–15 **Sequence of events involved in phototransduction in rods and cones.**

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

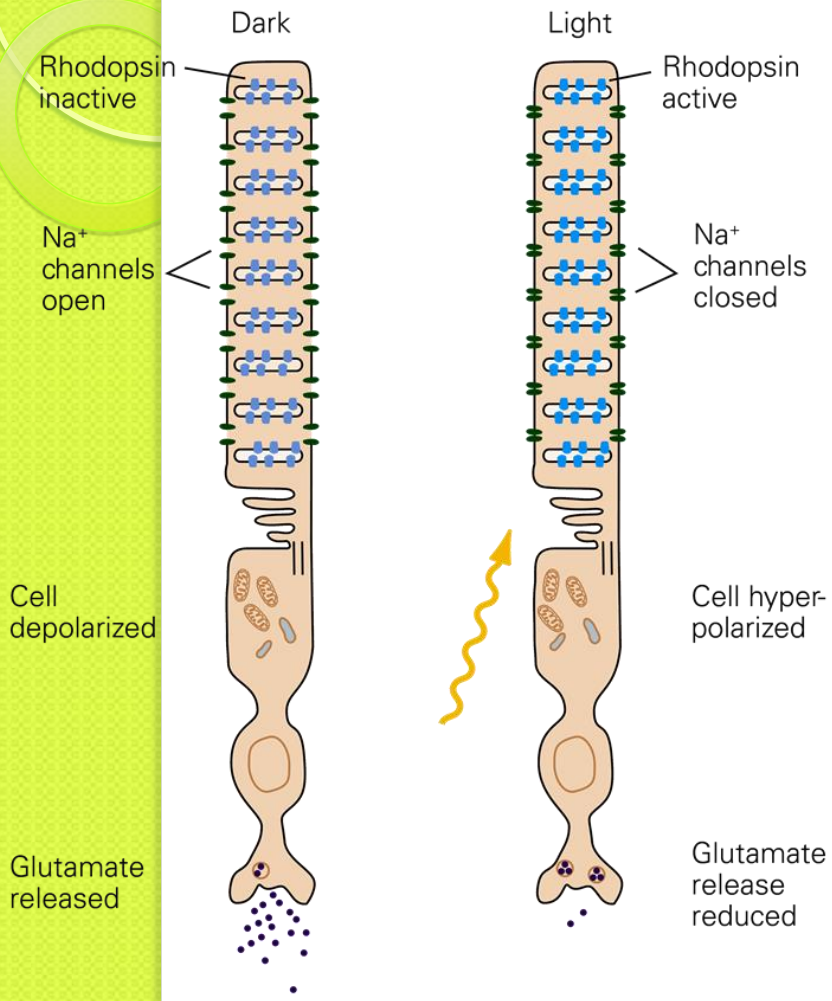
-Dark>> depolarize receptors >>> increase glutamate at photoreceptor ends>>
1-hyperpolarize ON- center bipolar cells
2-depolarize OFF-center bipolar cells

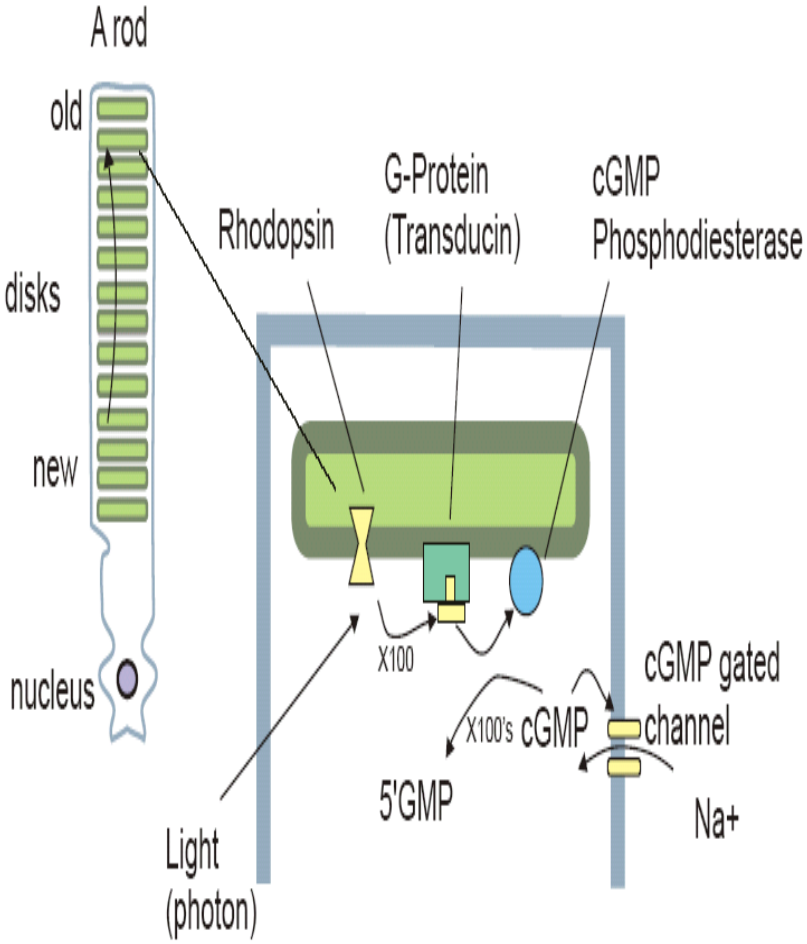
Light>> hyperpolarize the receptors>>>> decrease glutamate release at photoreceptor ends>>.
1- depolarize ON- center bipolar cells
2- hyperpolarize OFF-center bipolar cells (inactive)

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



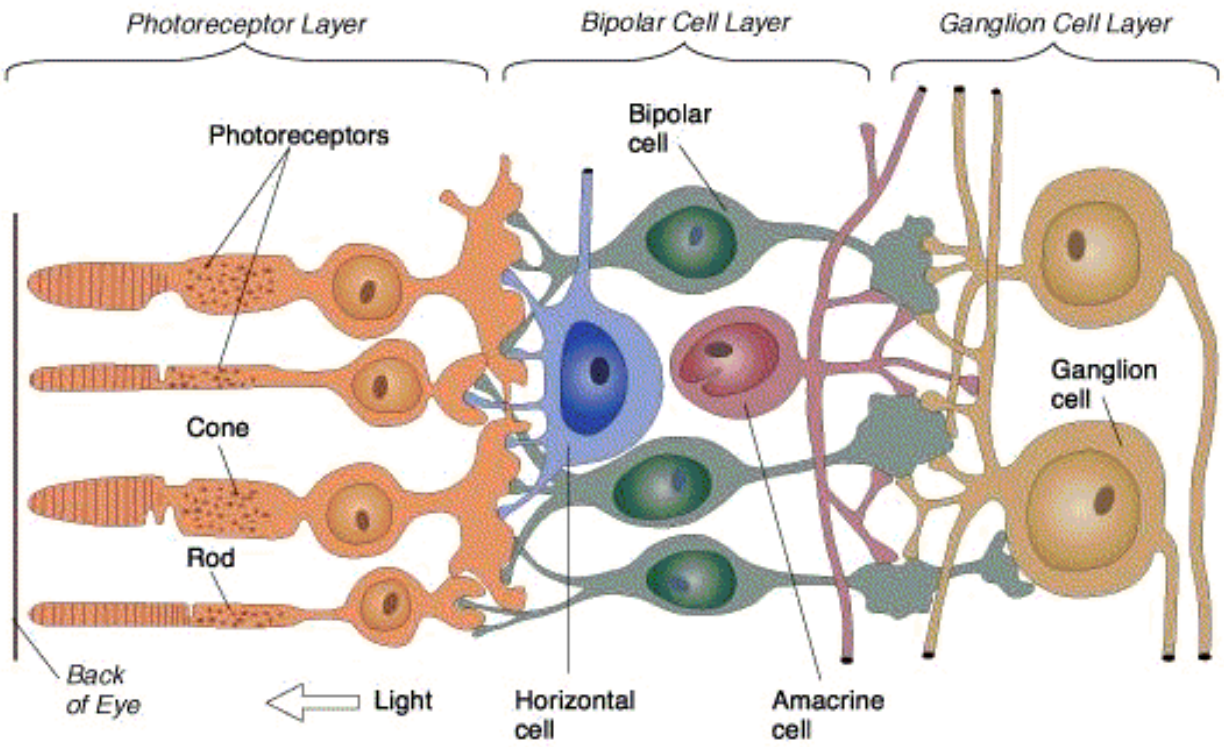
A Phototransduction and neural signaling





- **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

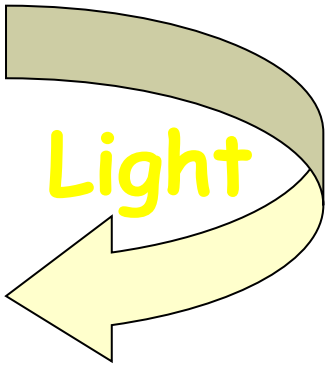
Photoreceptor compounds-cont

Rhodopsin (visual purple, scotopsin):

Activation of rhodopsin:

- **In the dark:**

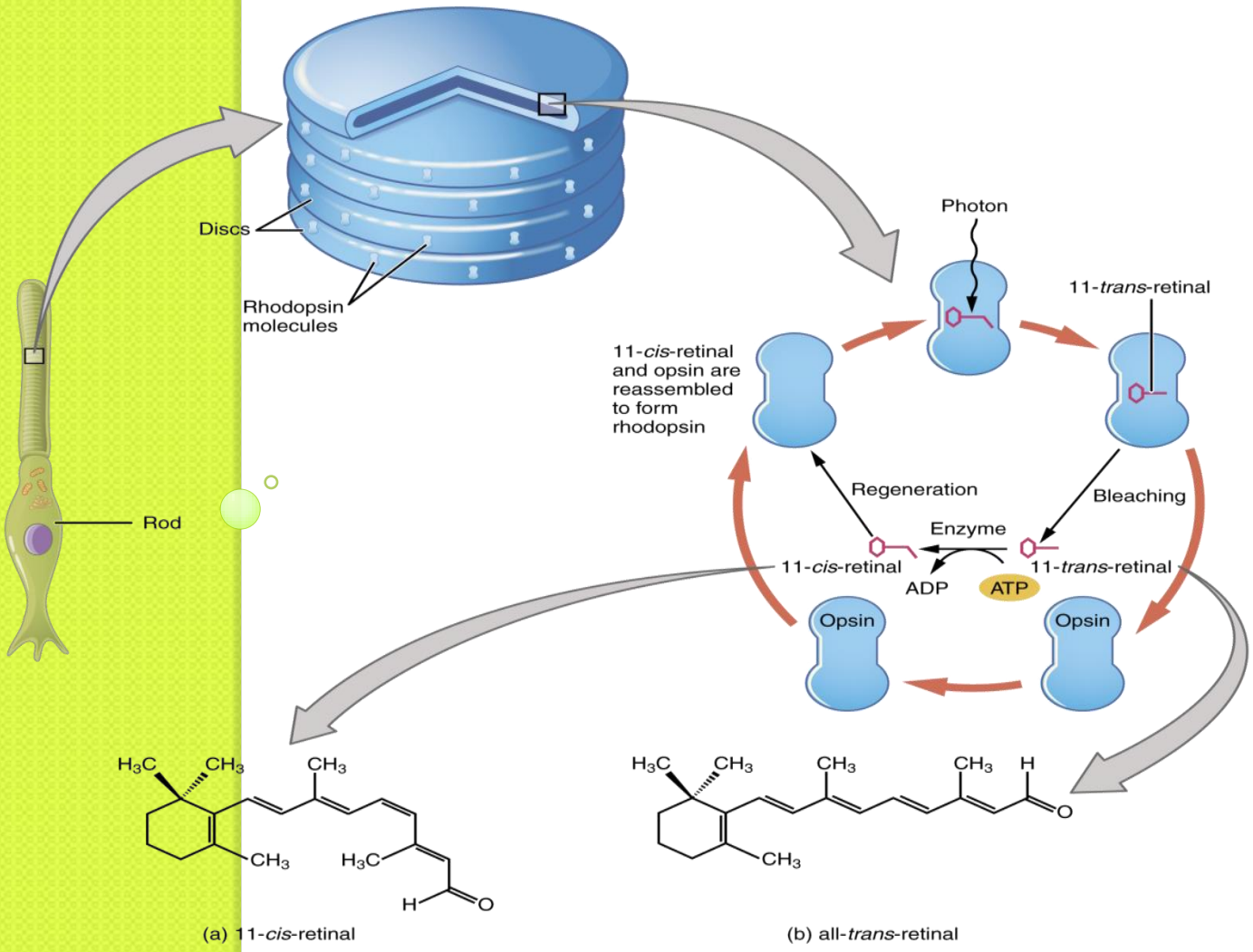
retinine1 in the 11-*cis* configuration



All-*trans* isomer

Metarhodopsin II

Closure of Na channels

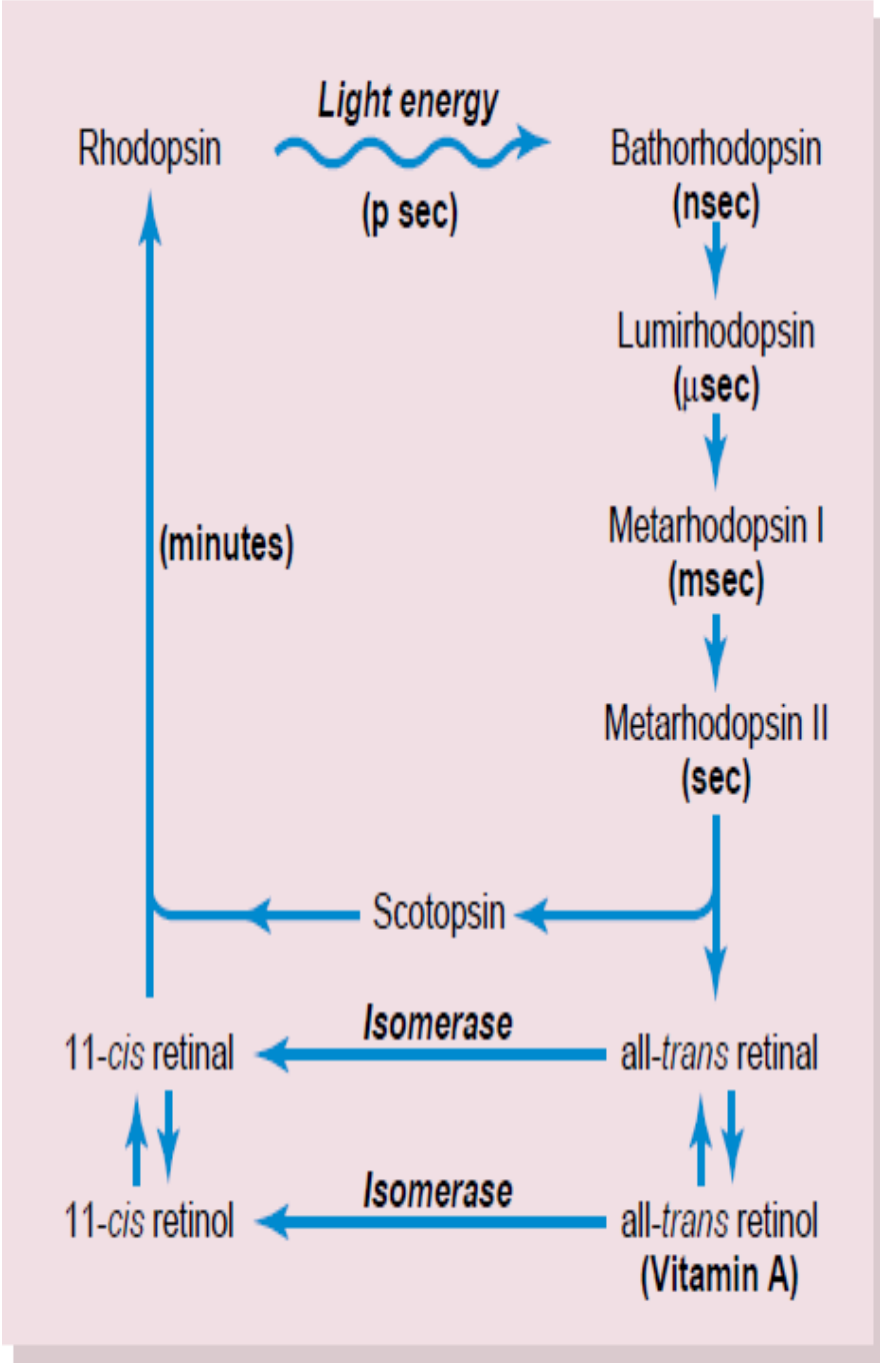


RHODOPSIN CYCLING

-scotopsin retinal visual cycle

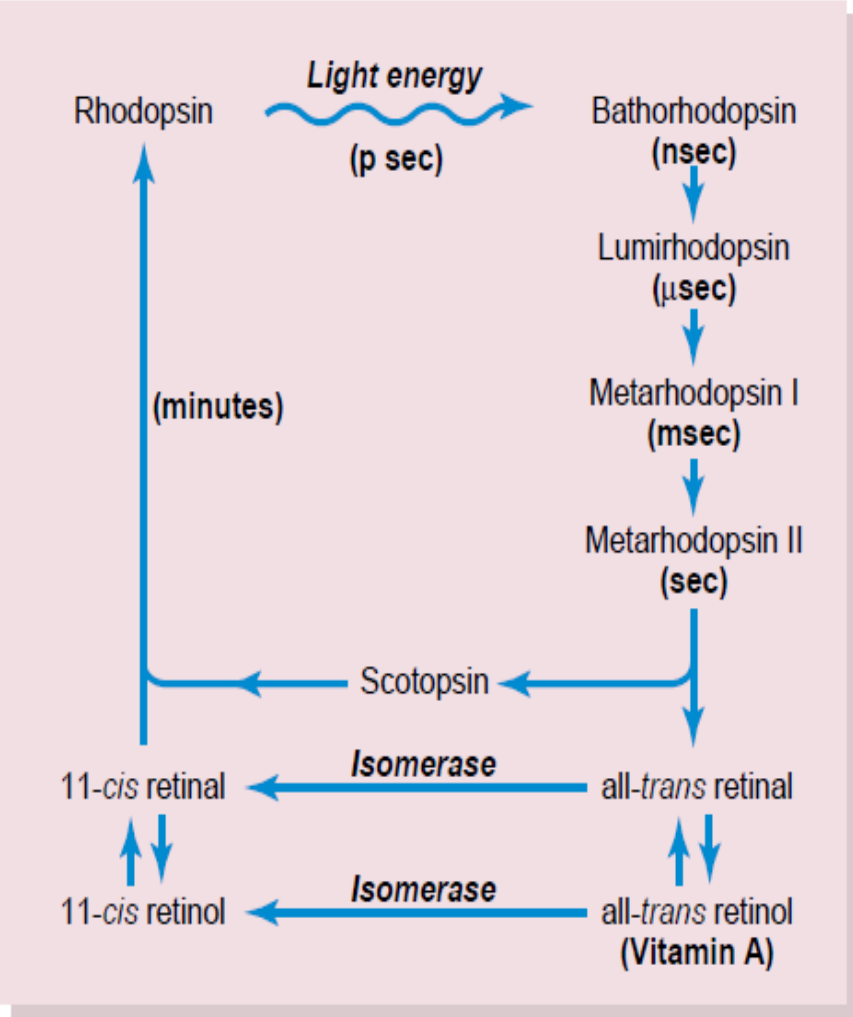
-The amount of rhodopsin in the receptors varies inversely with the incident light level.(decreases with light)

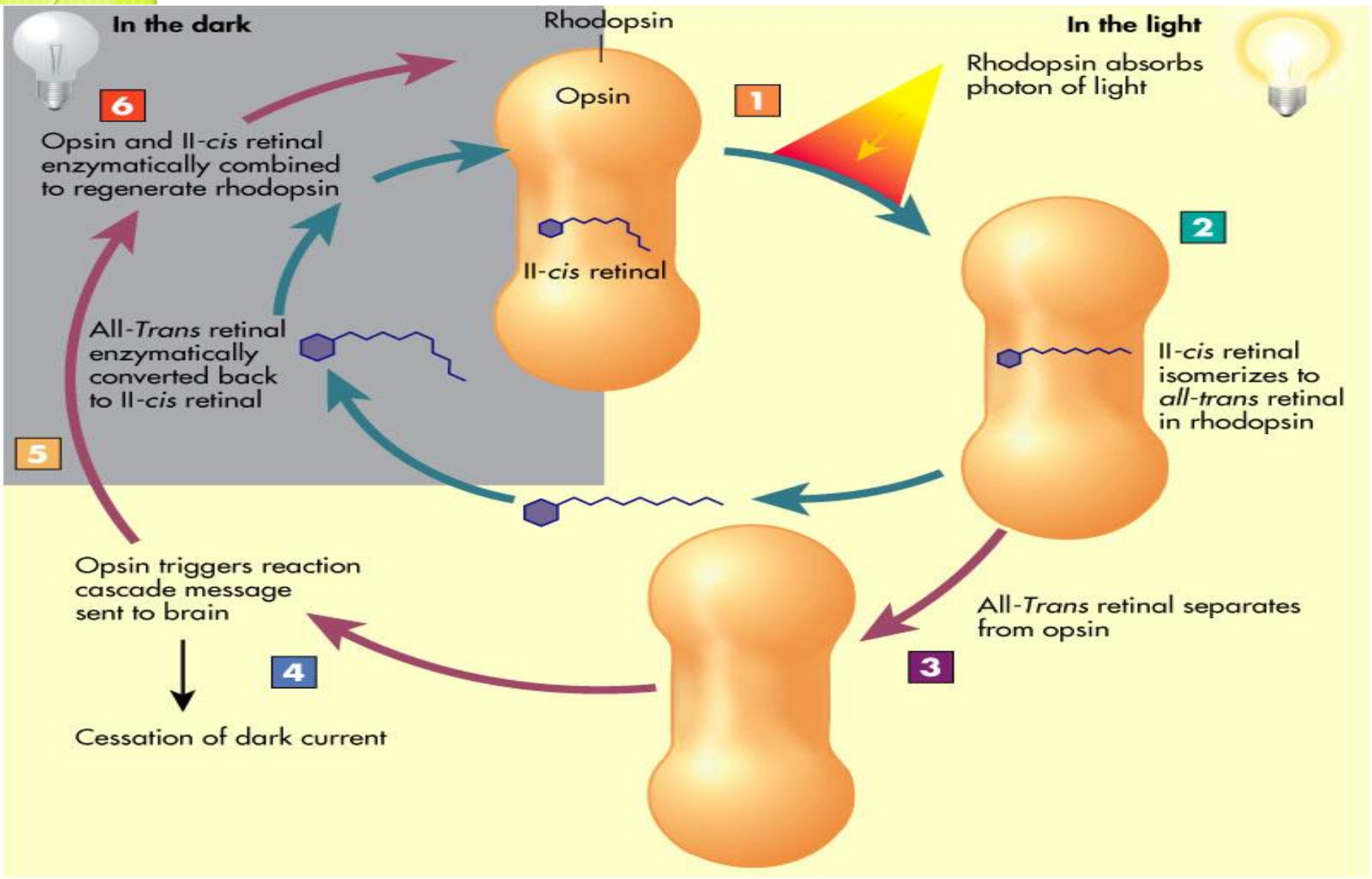
- **when there is excess retinal in the retina, it is converted in light back into vitamin A, thus reducing the amount of light-sensitive pigment in the retina.**



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




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

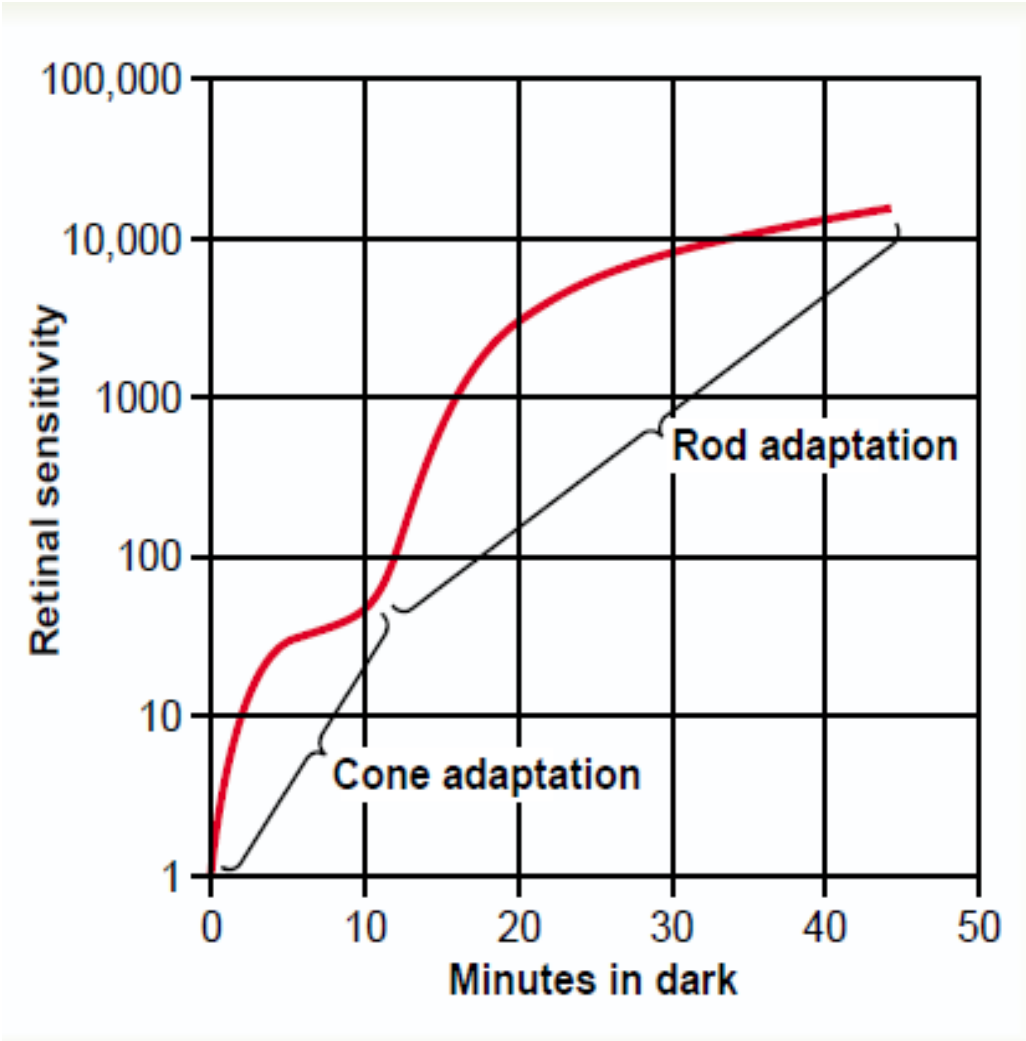
- **Dark adaptation has 2 components:-**

- **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.



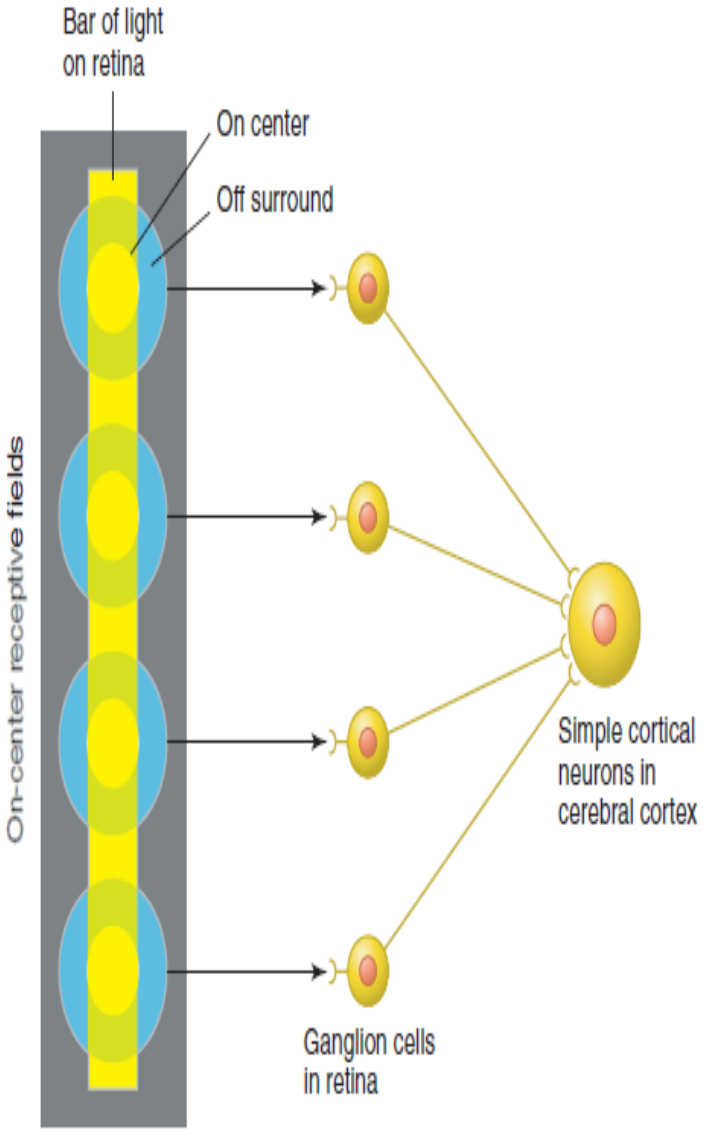
- **2-Light adaptation**

- **-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**

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