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 of rhodopsine regeneration

To know the meaning of nyctalopia

Contrast the dark and light adaptation

To know the visual cycle and rhodopsine regeneration

Visual Receptors: Rods and Cones

Rods

-abundant in the periphery of the retina

-best for low light(dimlight) conditions

-see black/white and shades of gray

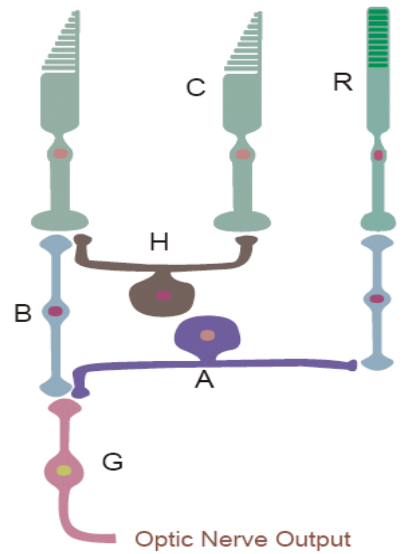
Cones

- abundant in & around fovea

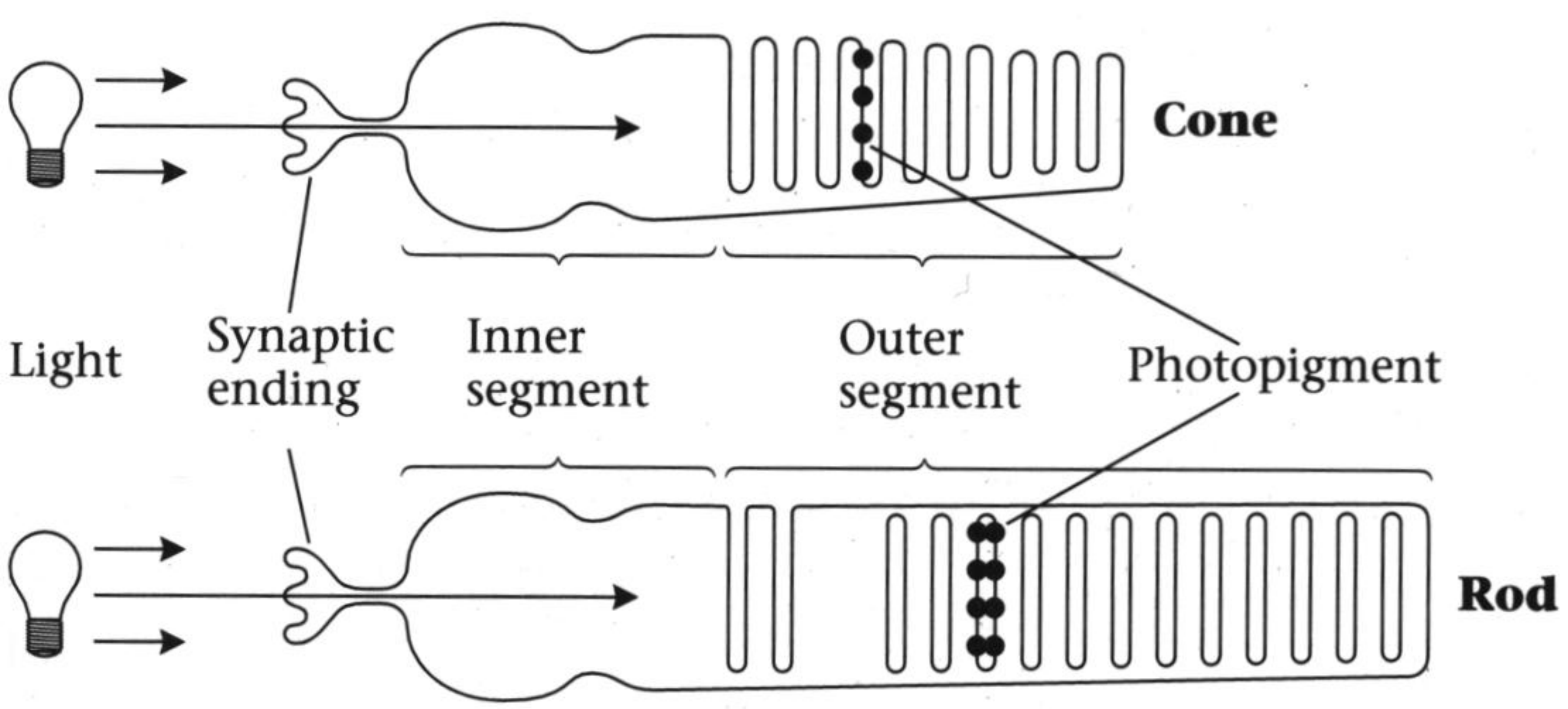
- best for bright light conditions

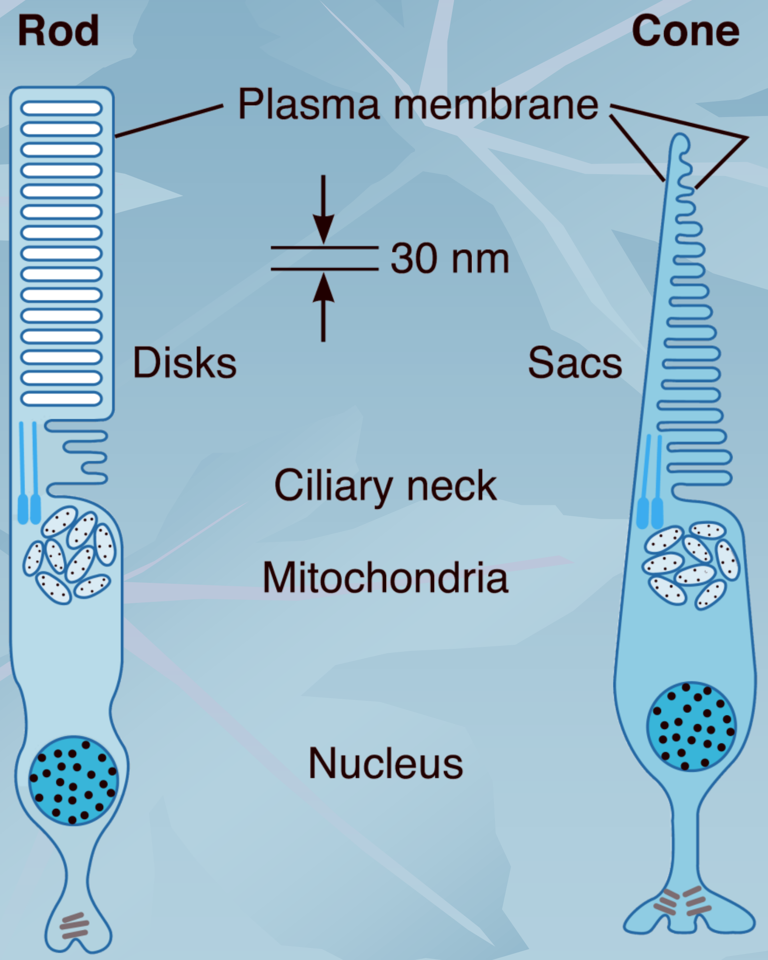
-see all colors

- <u>**Shape of rodes& cones (receptors of vision)**</u>
- **1- <u>Outer segment</u> (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- <u>Inner segment</u> full of mitochondria (source of energy for Na-K pump), it is thick in cones**
- **There is Na-K pump in inner segment**



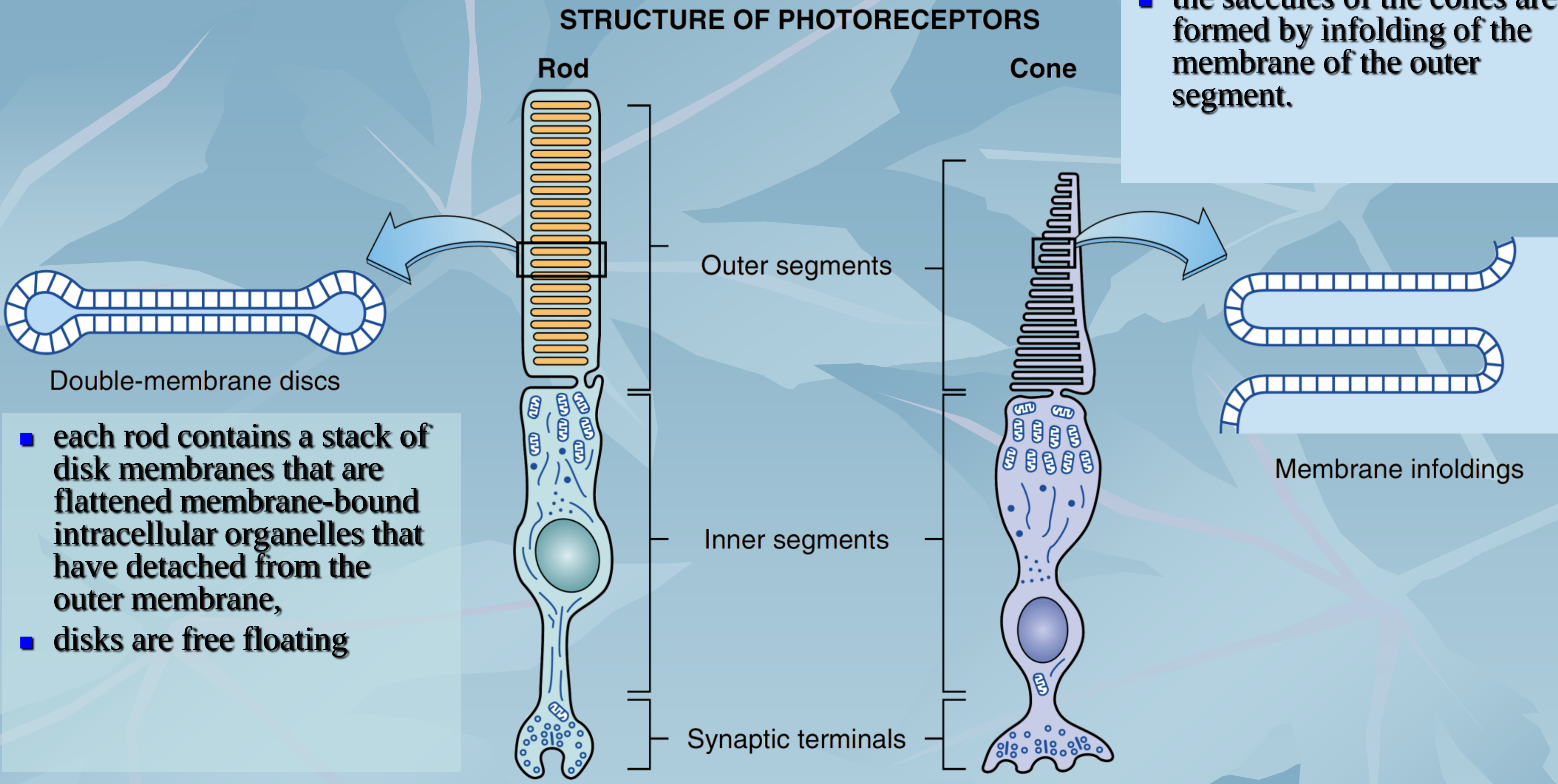
Inside the rod and the cone





-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.

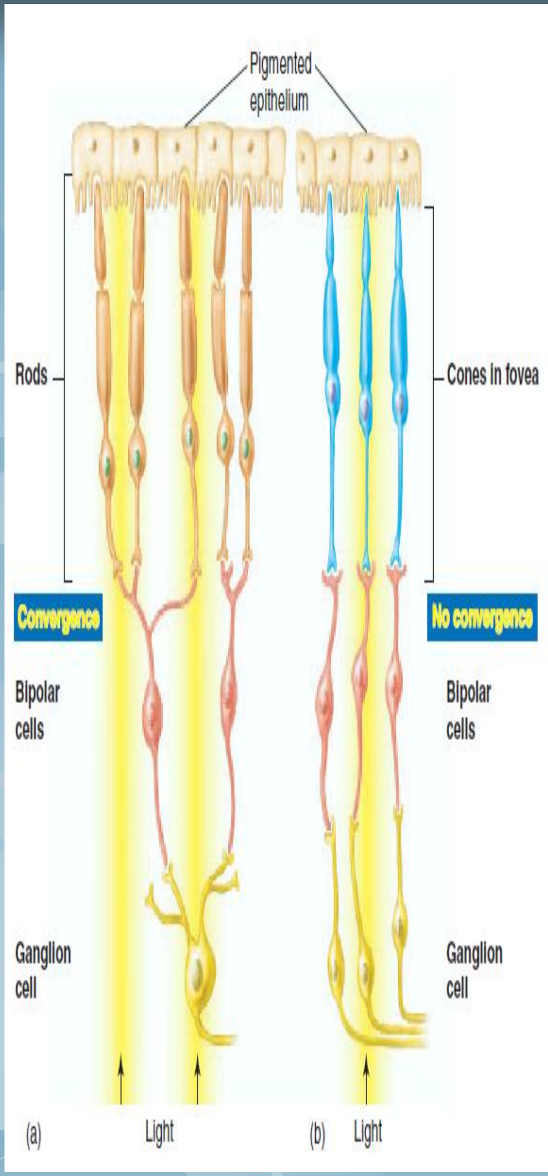


- each rod contains a stack of disk membranes that are flattened membrane-bound intracellular organelles that have detached from the outer membrane,
- disks are free floating

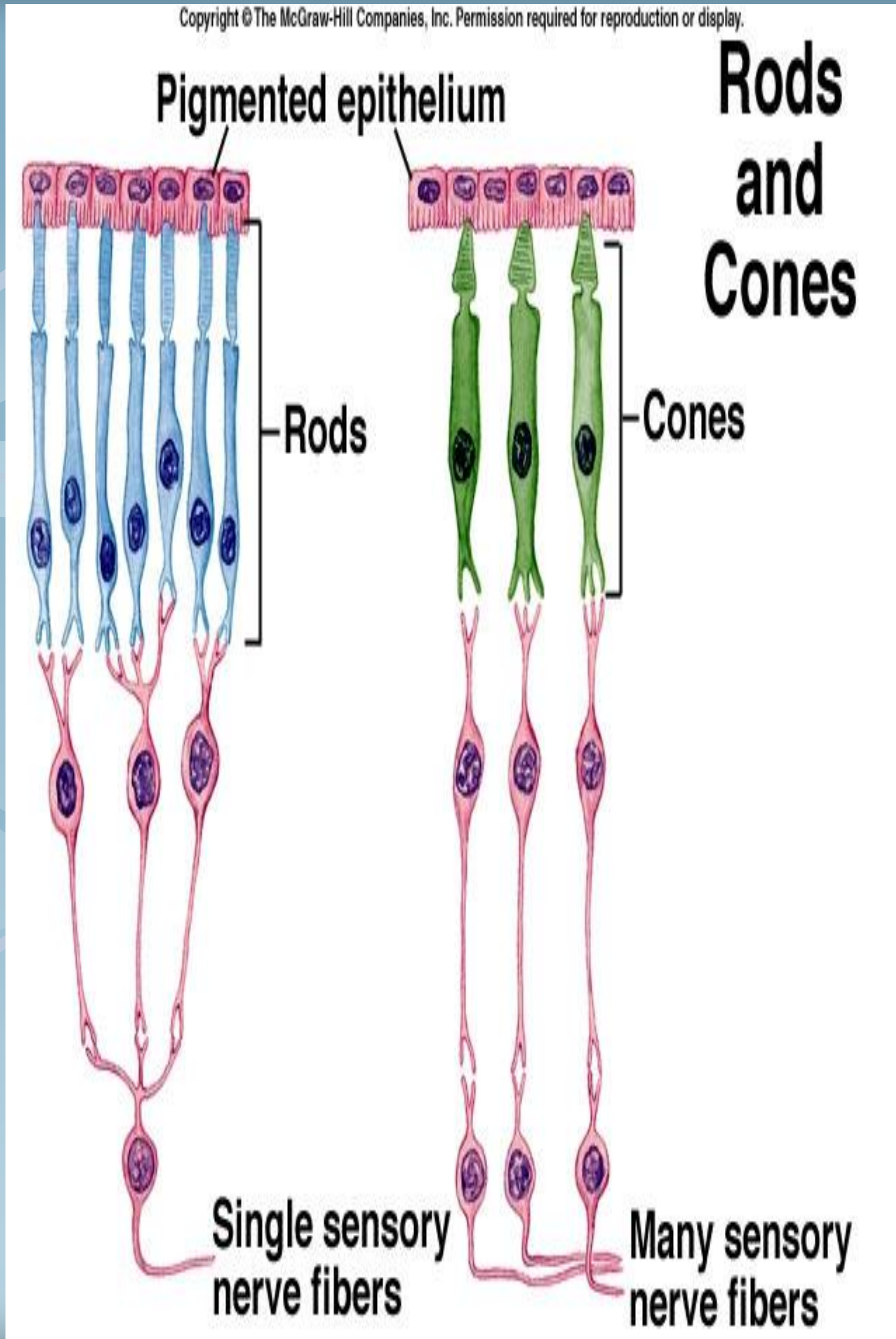
<u>**the saccules and disks contain the photosensitive compounds that react to light, initiating action potentials in the post synaptic cells**</u>

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



- **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 stimlate the rods)**
- **3- 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.**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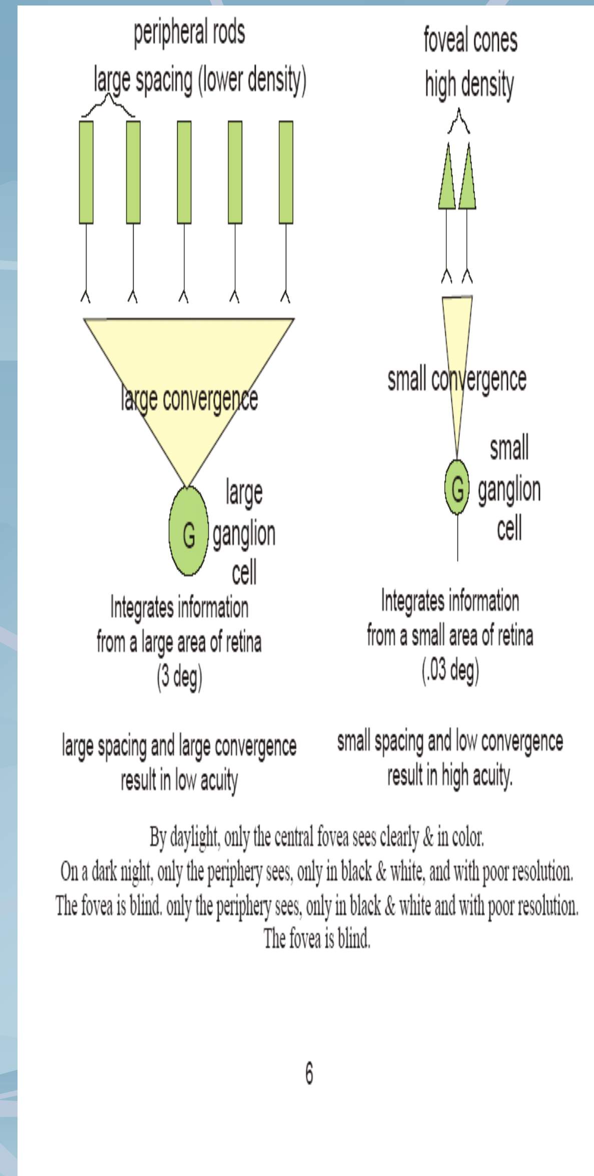
Rods and Cones
Pigmented epithelium
Rods
Cones
Single sensory nerve fibers
Many sensory nerve fibers


peripheral rods
large spacing (lower density)
foveal cones
high density
large convergence
small convergence
G
large ganglion cell
G
small ganglion cell
Integrates information from a large area of retina (3 deg)
Integrates information from a small area of retina (.03 deg)
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.
6

Genesis of photoreceptor potential

- -Rodes &cones potentials are graded, local potential (generator potential) propagated as A.P in ganglion cells.
- -Ganglion cell action potential (all or none A.P) 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

Photosensitive compounds:-

1- In cones it is 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, which is why it is also called "visual purple)

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

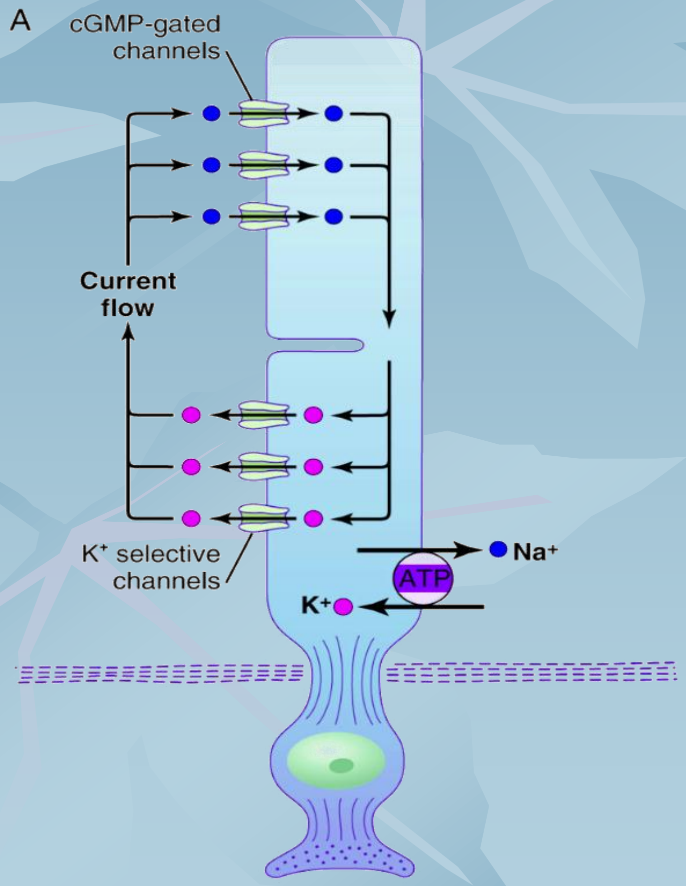
-At dark rhodopsin is in 11-cisretinal form (inactive) but light sensitive form which increase sensitivity of rods to light

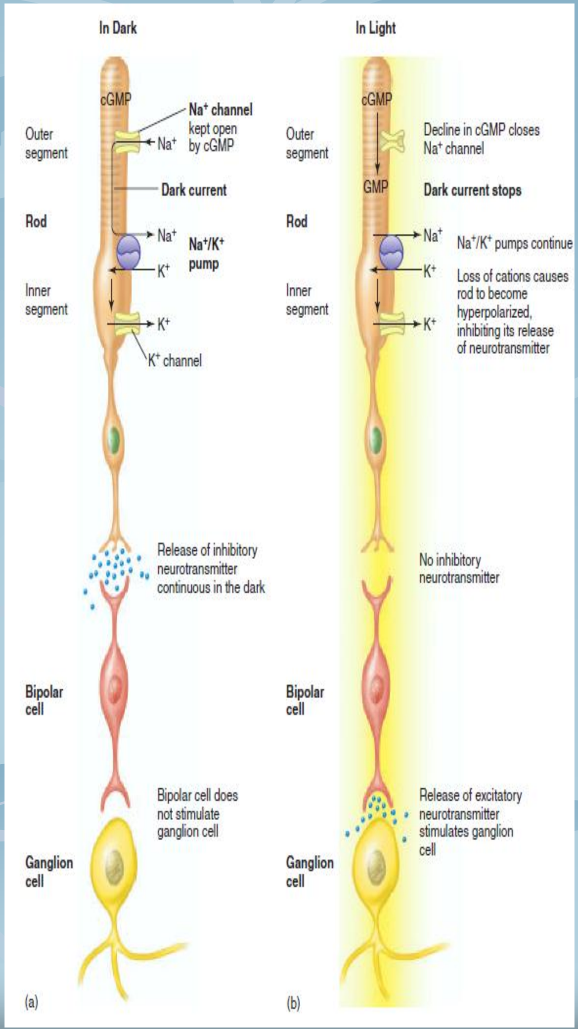
LECTROPHYSIOLOGY OF VISION (PHOTOTRANSDUCTION

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) in the c-GMP form
c-GMP at c-GMP gated Na channels, 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→ 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 → depolarize ganglion cells**
- **-electronegativity inside the membrane of the rod, measuring about −40 millivolts rather than the usual −70 to −80 millivolts found in most sensory receptors.**


A
cGMP-gated channels
Current flow
K+ selective channels
ATP
Na+
K+


In Dark
In Light
Outer segment
Rod
Inner segment
cGMP
Na+ channel kept open by cGMP
Na+
Dark current
Na+/K+ pump
K+
K+ channel
Release of inhibitory neurotransmitter continuous in the dark
Bipolar cell
Bipolar cell does not stimulate ganglion cell
Ganglion cell
(a)
Outer segment
Rod
Inner segment
cGMP
GMP
Decline in cGMP closes Na+ channel
Dark current stops
Na+/K+ pumps continue
Loss of cations causes rod to become hyperpolarized, inhibiting its release of neurotransmitter
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/

1-at dark rhodopsin is inactive (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 (hyperpolarization) (off-center bipolar cells get hyperpolarized)(this cause decreased release of glutamate → 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**

-
-

IN THE LIGHT

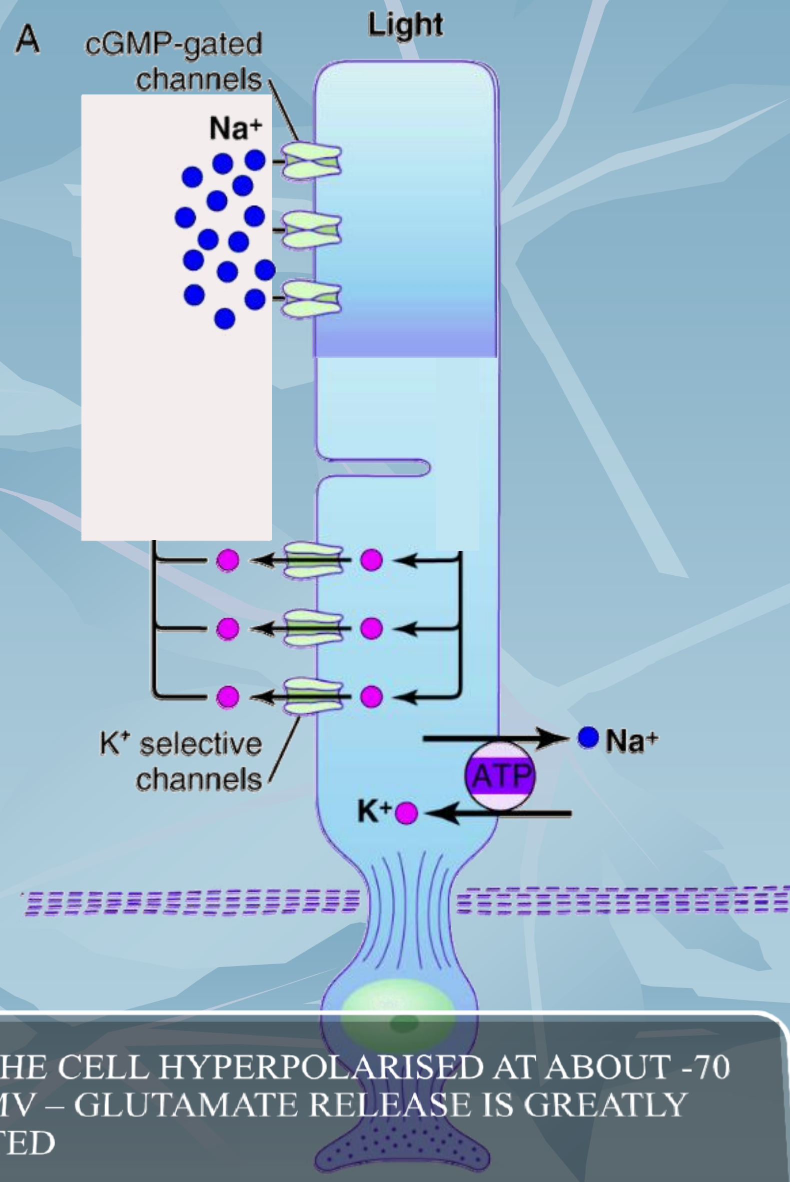
LIGHT EXPOSURE WILL LEAD TO CLOSURE OF THE CGMP GATED NA+ CHANNELS

HOWEVER, THE INNER SEGMENT STILL IS CONTINUALLY PUMPING SODIUM FROM INSIDE THE ROD TO THE OUTSIDE

DESPITE POTASSIUM IONS BEING PUMPED TO THE INSIDE OF THE CELL.

POTASSIUM IONS STILL LEAK OUT OF THE CELL THROUGH NONGATED POTASSIUM CHANNELS IN THE INNER SEGMENT OF THE ROD.

THEREFORE WITH LOSS OF POSITIVELY CHARGED NA+ AND K+ THIS CREATES A NEGATIVE POTENTIAL ON THE INSIDE OF THE ENTIRE CELL OF ABOUT -70 TO -80MV



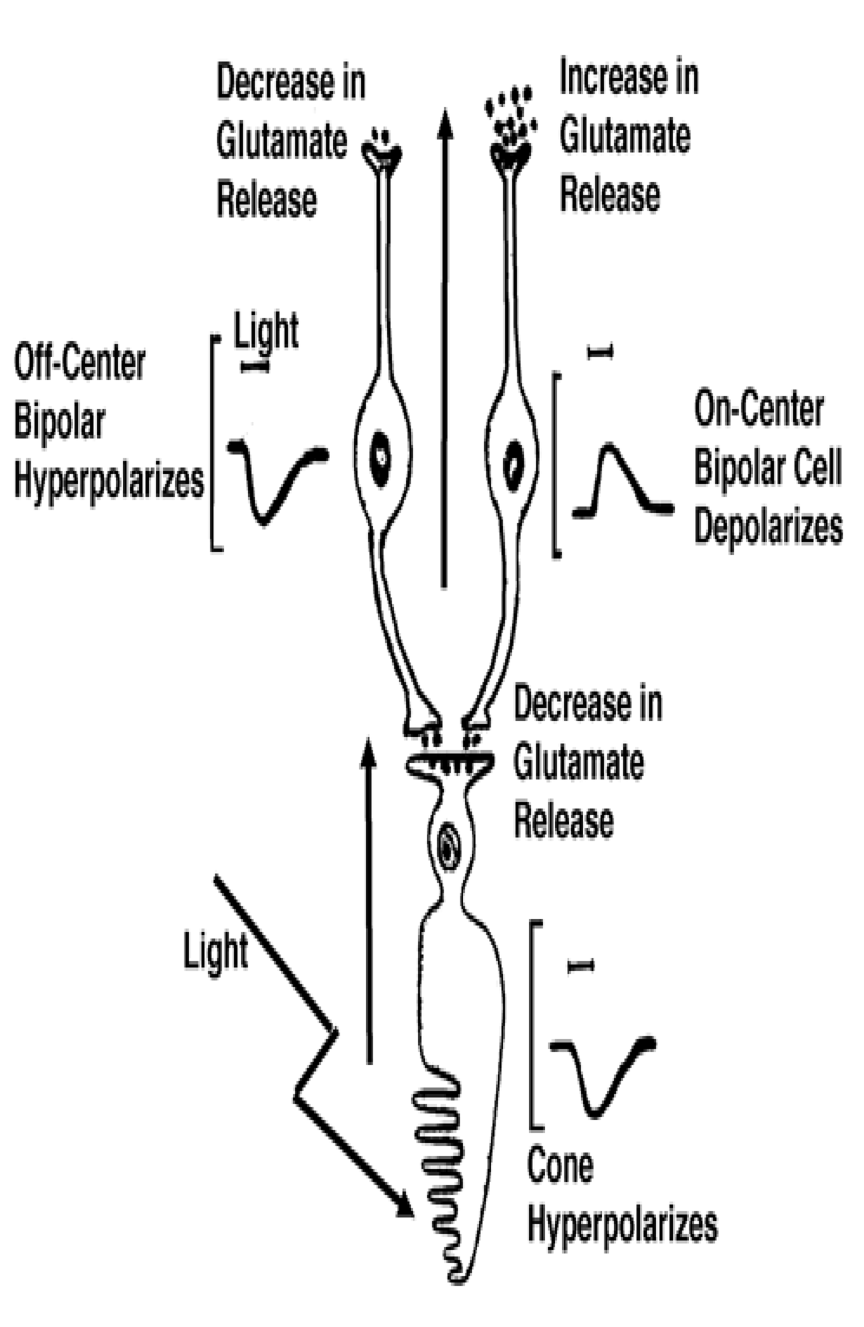
WITH THE CELL HYPERPOLARISED AT ABOUT -70 TO -80MV – GLUTAMATE RELEASE IS GREATLY INHIBITED

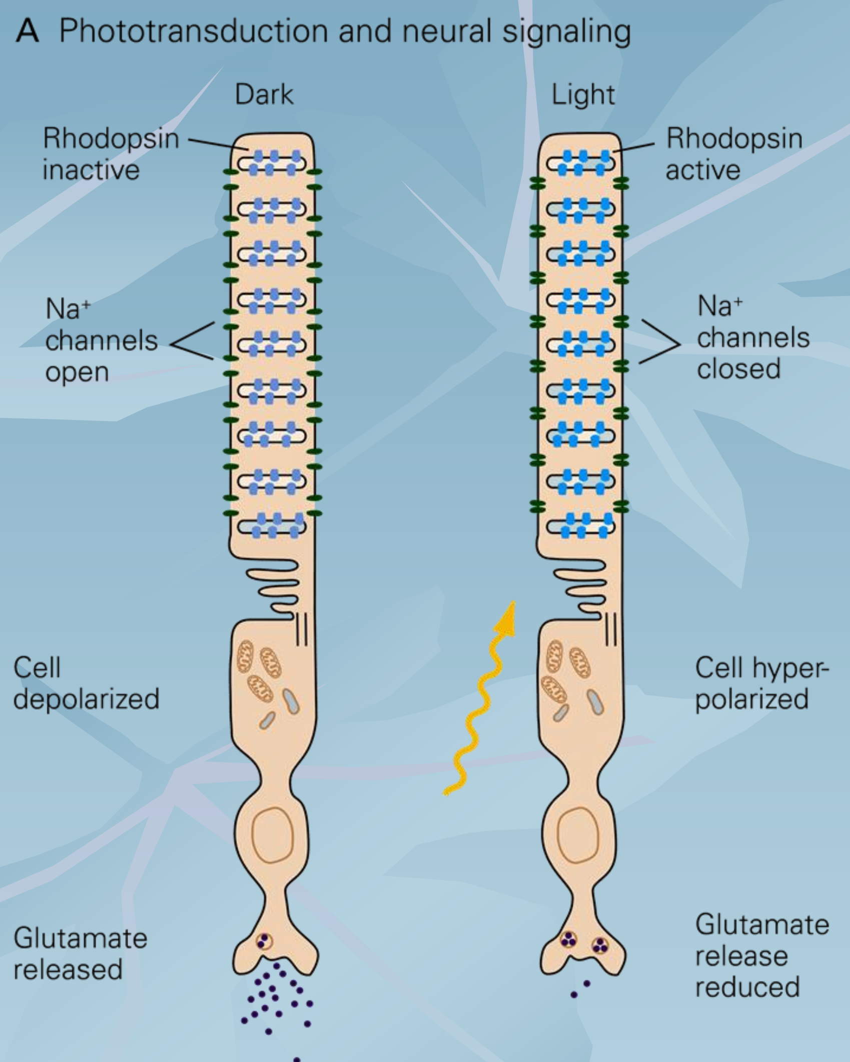
We have 10 types of cones bipolar cells & one type of rod bipolar cell

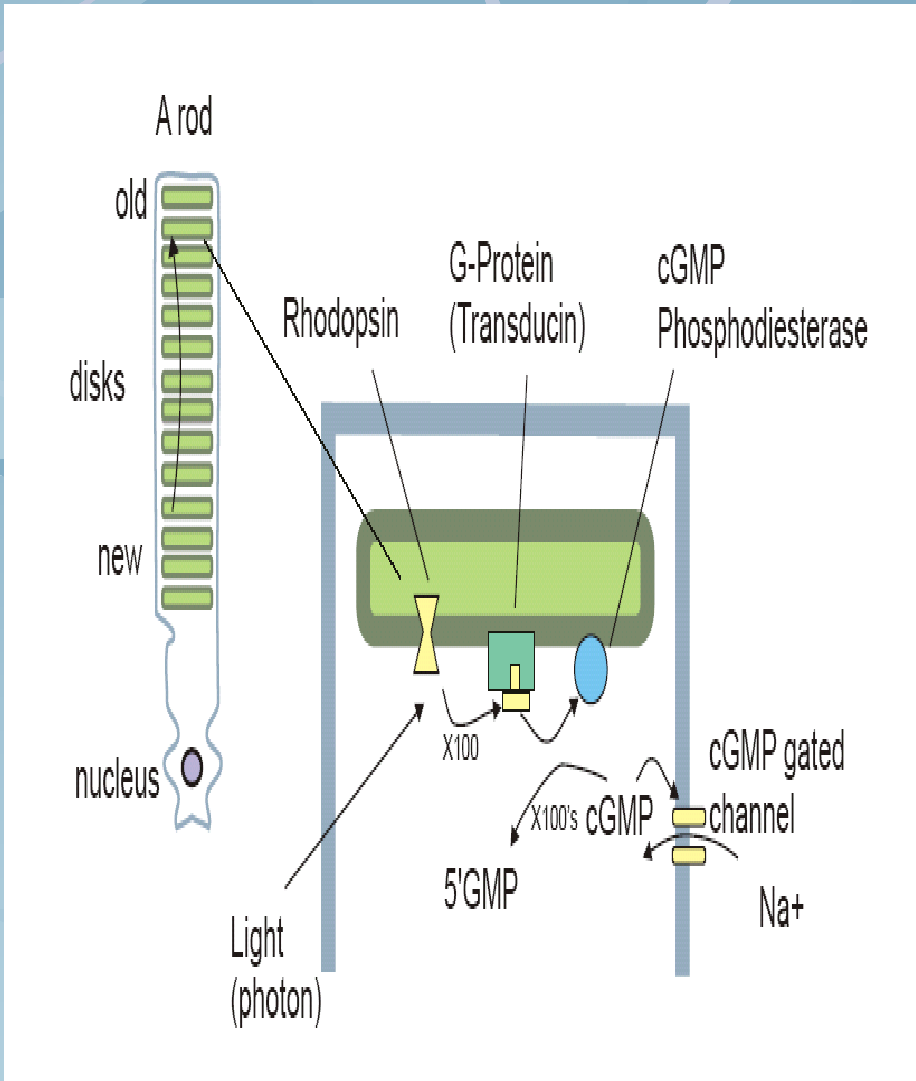
-Dark>> depolarize receptors >>> increase glutamate at photoreceptor ends>>
1-hyperpolarize ON- center bipolar cells
2-depolarize OFF-center bipolar cells

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
Dark
Light
Rhodopsin inactive
Rhodopsin active
Na+ channels open
Na+ channels closed
Cell depolarized
Cell hyper-polarized
Glutamate released
Glutamate release reduced


A rod
old
disks
new
nucleus
Rhodopsin
G-Protein (Transducin)
cGMP Phosphodiesterase
X100
X100's cGMP
5'GMP
cGMP gated channel
Na+
Light (photon)

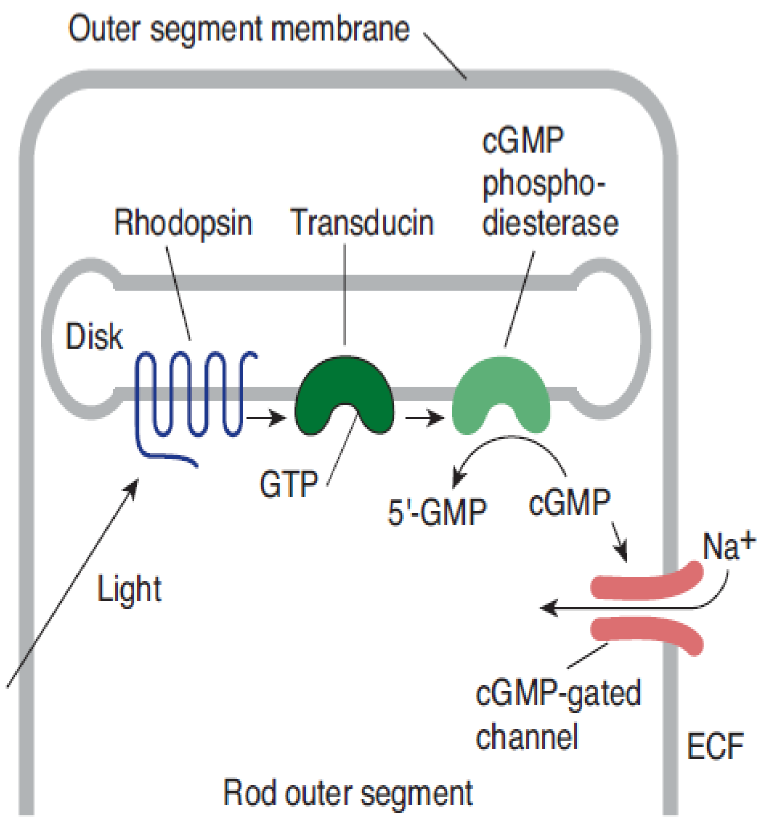


FIGURE 12–14 Initial steps in phototransduction in rods. Light activates rhodopsin, which activates transducin to bind GTP. This activates phosphodiesterase, which catalyzes the conversion of cGMP to 5'-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels to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

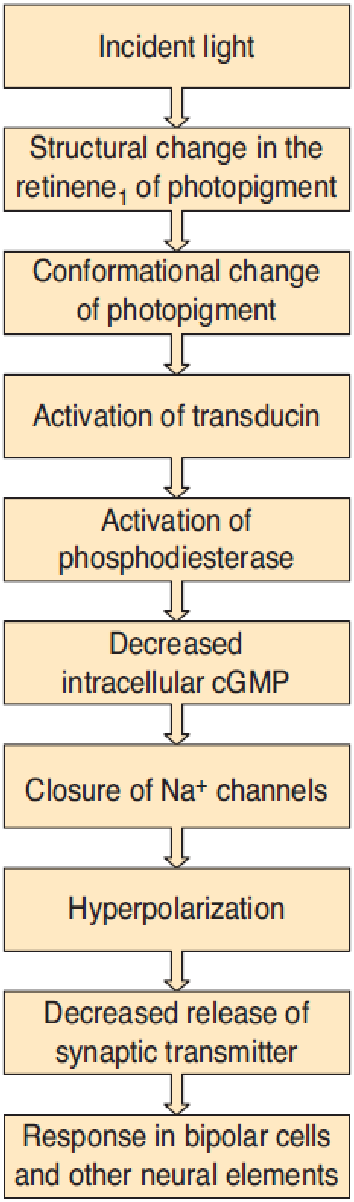


FIGURE 12–15 Sequence of events involved in phototransduction in rods and cones.

- **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.**

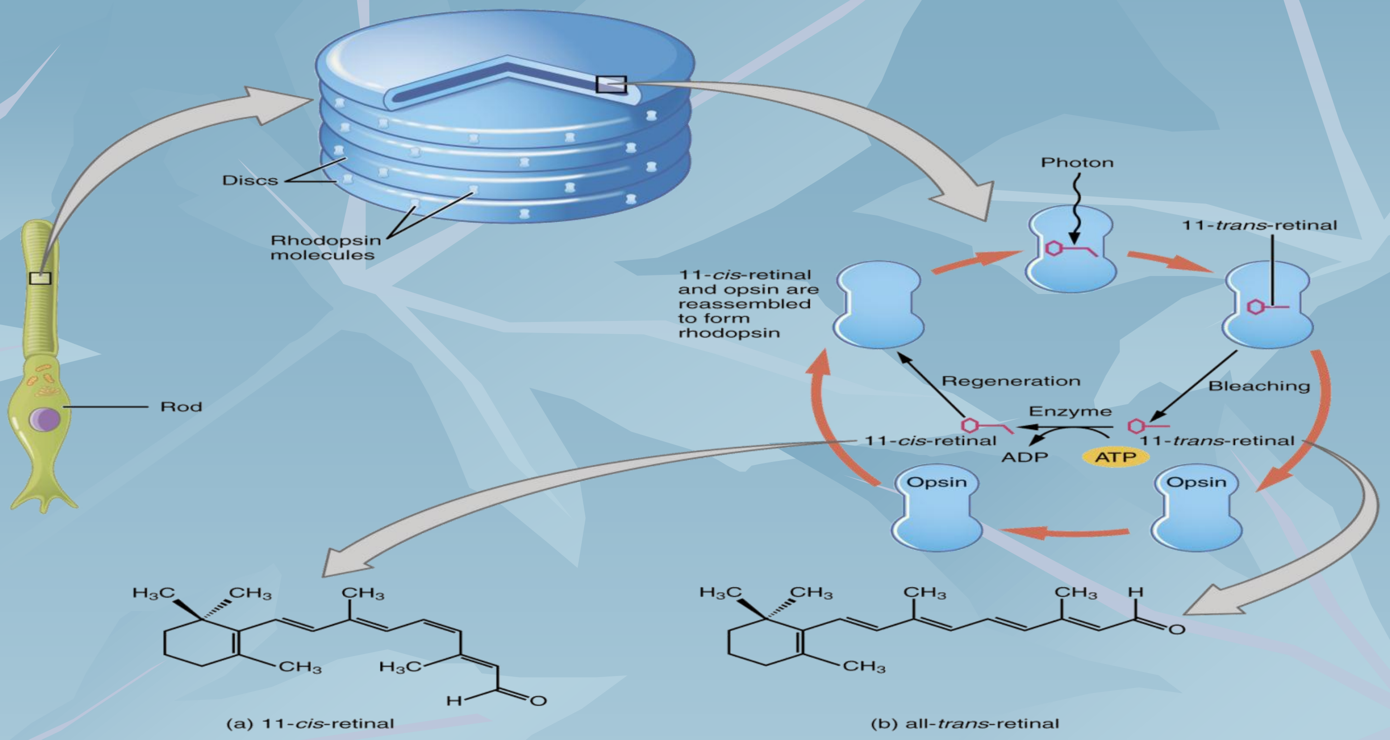
VISUAL CYCLE:-

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

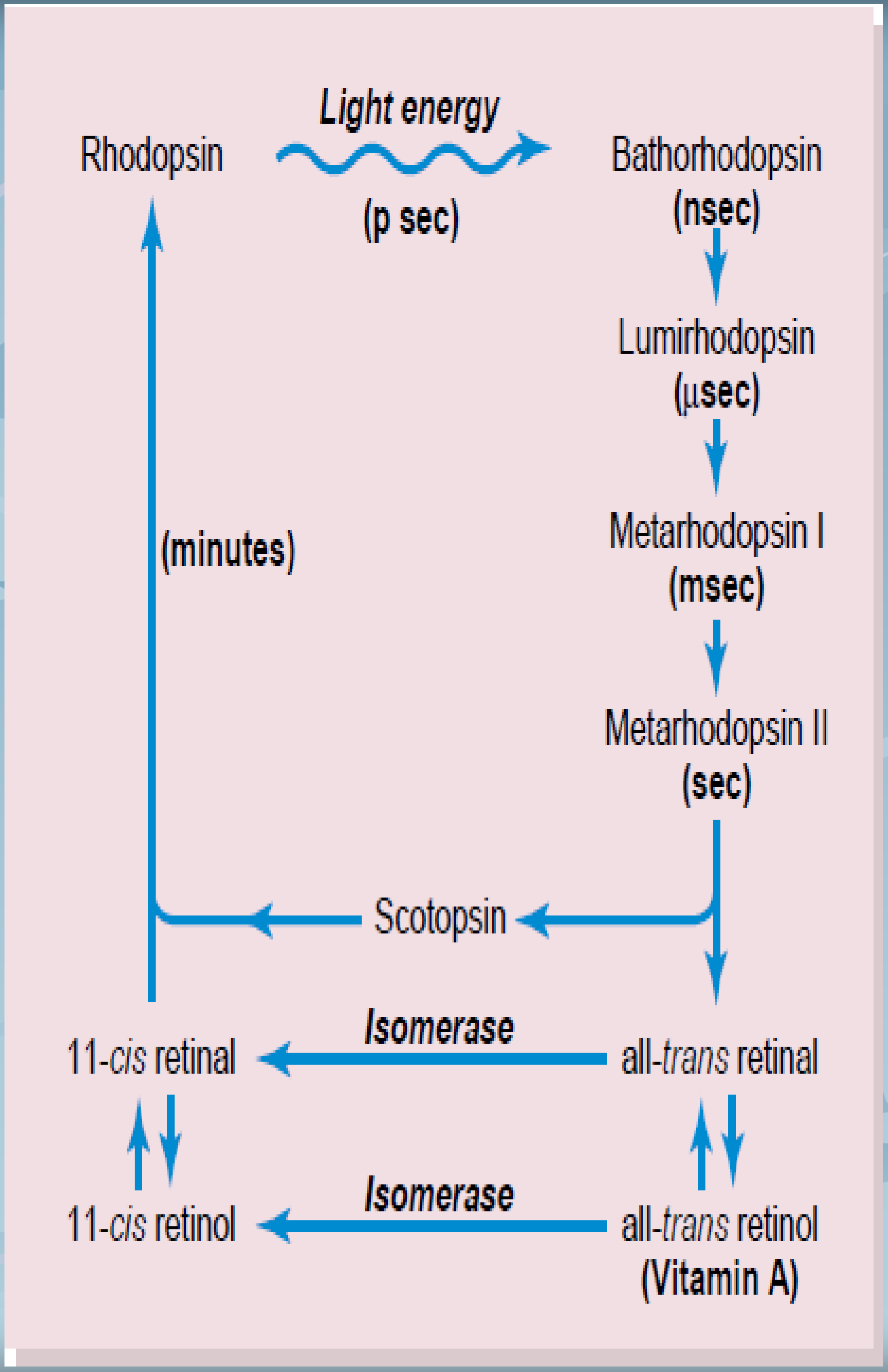


RHODOPSIN CYCLING

-scotopsin retinal visual cycle

Th amount of rhodopsin in the receptors therefore varies inversely with the incident light level.

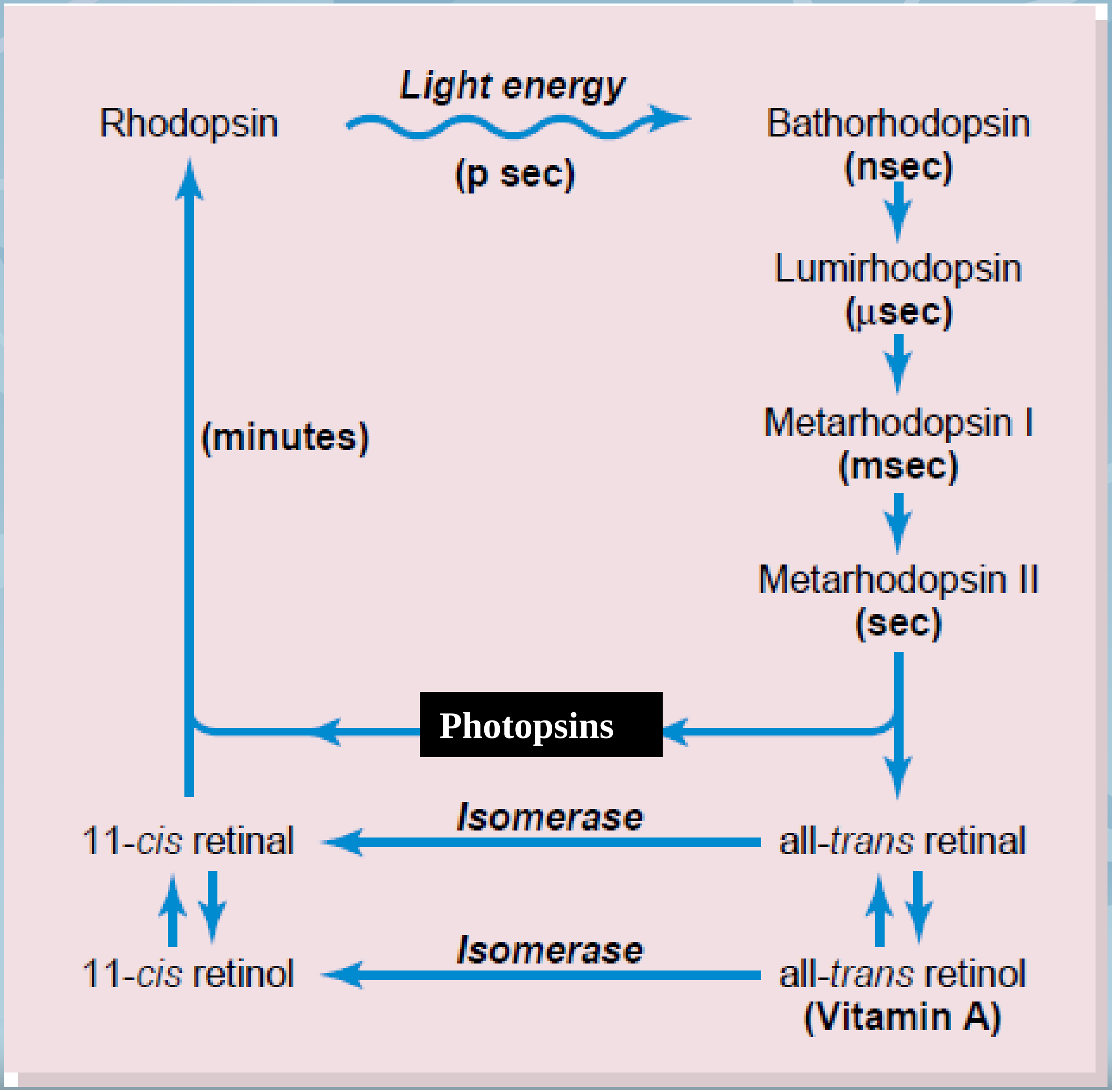
- when there is excess retinal in the retina, it is converted back into vitamin A, thus reducing the amount of light-sensitive pigment in the retina.

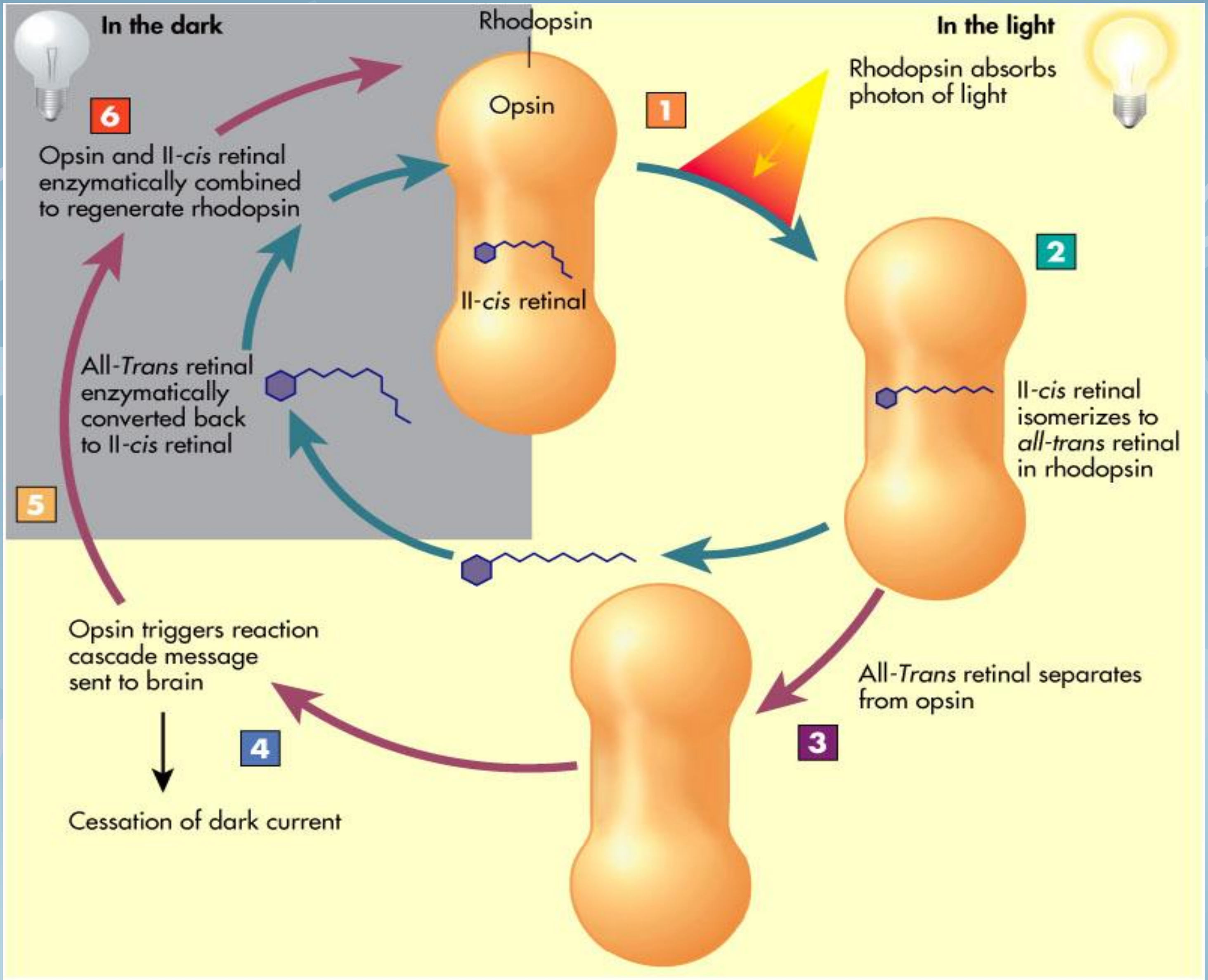


Photochemistry of Color Vision by the Cones

Photopsins Retinal Visual Cycle

The cones are about 30 to 300 times less sensitive than rods to light





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

- **NYCTALOPIA:- (night blindness)**

-- Vitamine A (main source of retinal of rhodopsin) deficiency cause rods , cones & retinal degeneration & loss of rods

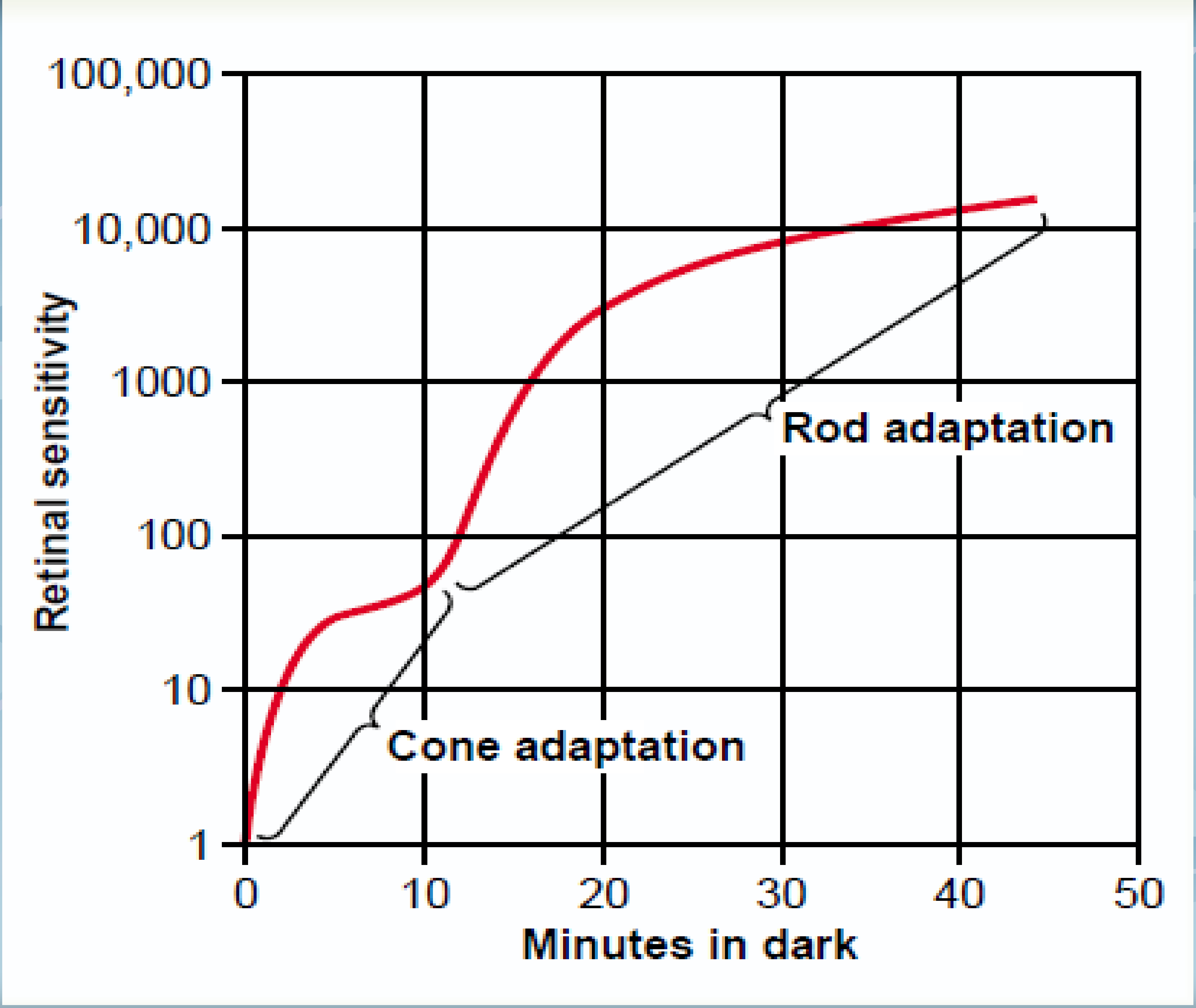
-- R /   Intravenous vit A if receptors are well.

Dark adaptation:-

-
- -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
- (Na channels to open & for dark adaptation)

- 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 .
- - dark adaptation of rodes in the peripheral retina
- - sensitivity of rodes to light increase, in 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 of rods to light)


100,000
10,000
1000
100
10
1
Retinal sensitivity
0
10
20
30
40
50
Minutes in dark
Rod adaptation
Cone adaptation

- **N.B (20 min for dark adaptation are for regeneration of rhodopsin → increase sensitivity of rodes to light → 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 andTheir Respective Fields

W, X, and Y cells

1-W cells/ ➔ sensitivef or 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

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

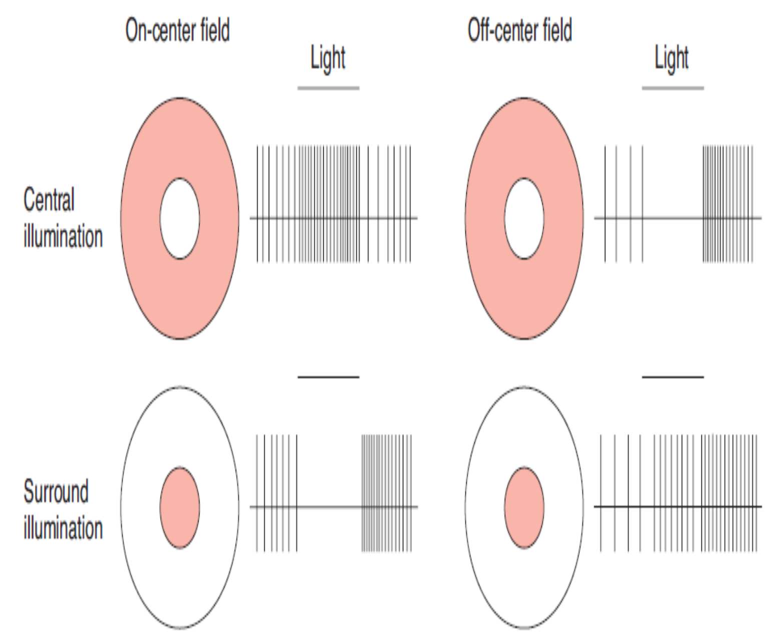
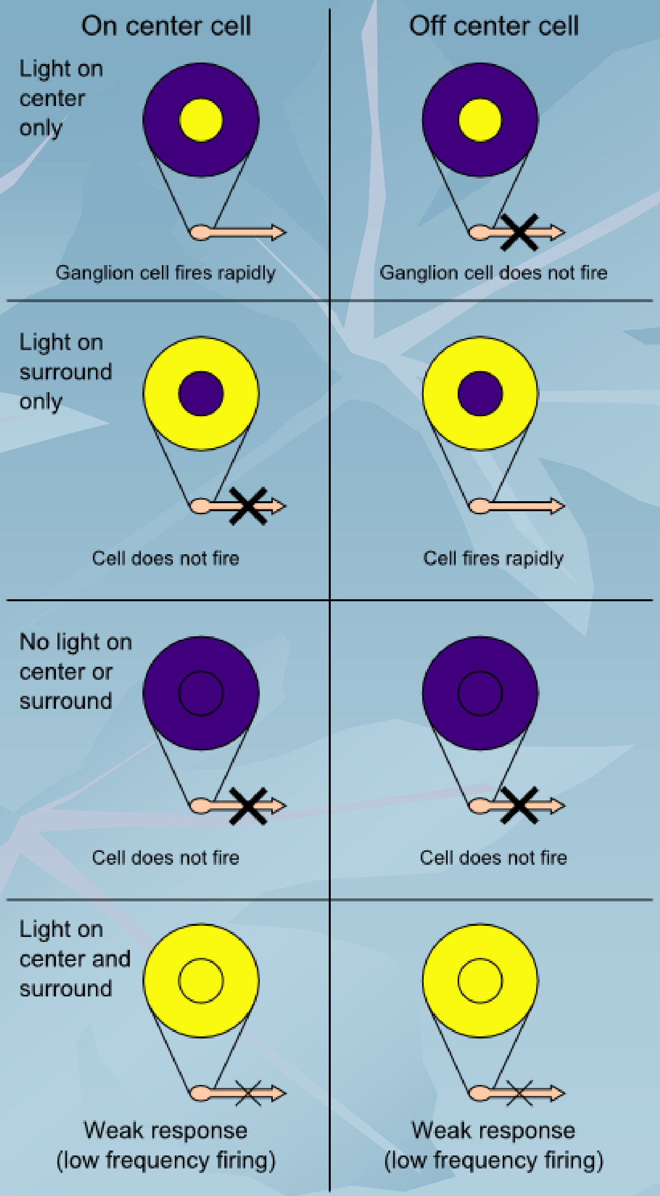
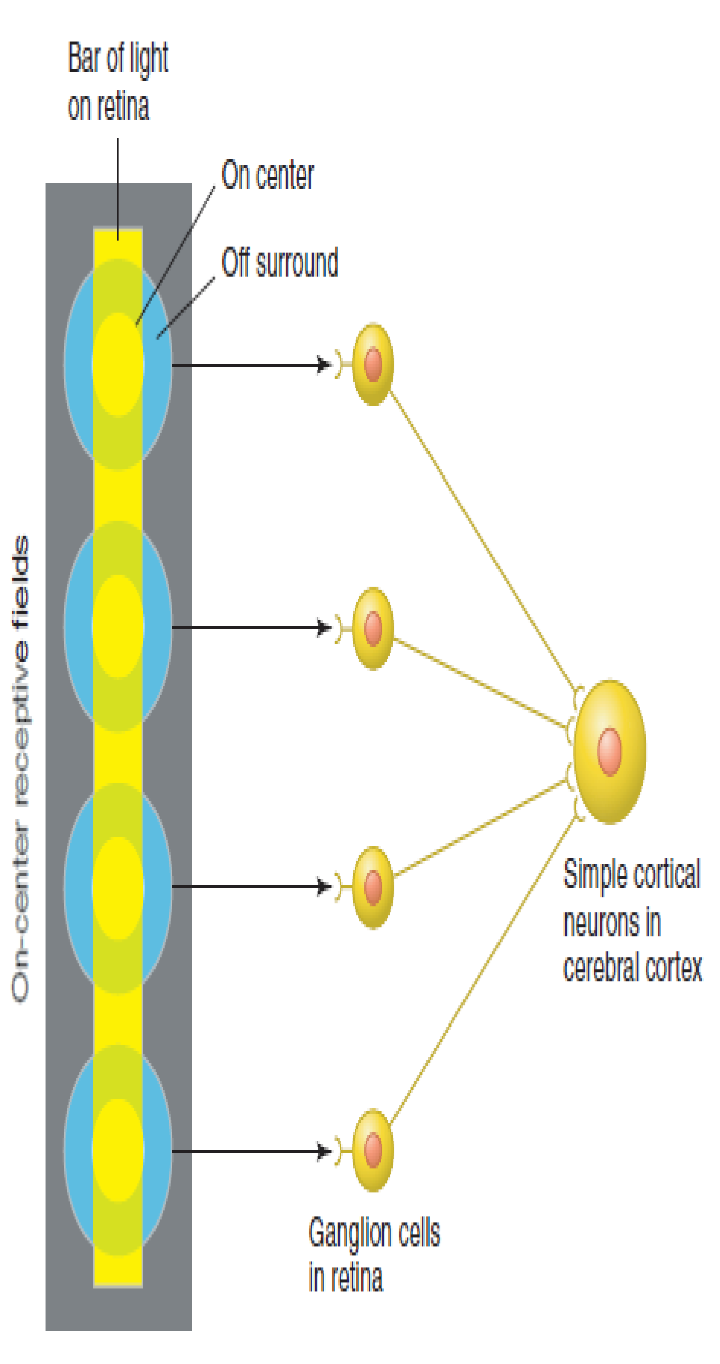


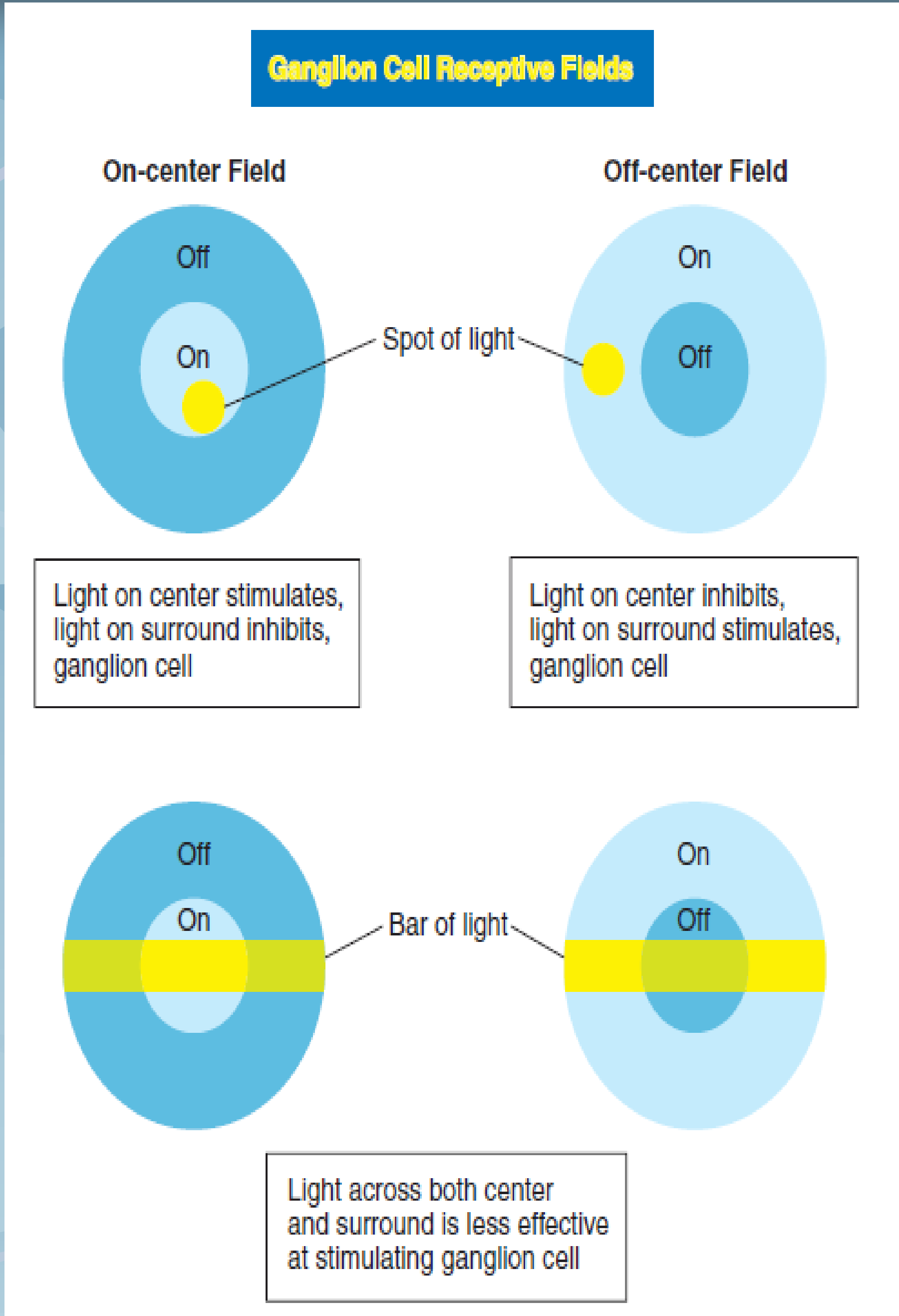
FIGURE 12-16 Responses of retinal ganglion cells to light on the portions of their receptive fields indicated in white. Beside each receptive field diagram is a diagram of the ganglion cell response, indicated by extracellularly recorded action potentials. Note that in three of the four situations, there is increased discharge when the light is turned off. (Modified from Kandel E, Schwartz JH, Jessell TM [editors]: *Principles of Neural Science*, 4th ed. McGraw-Hill, 2000.)



There are two types of retinal ganglion cells: "on-center" and "off-center". An on-center cell is stimulated when the center of its receptive field is exposed to light, and is inhibited when the surround is exposed to light. Off-center cells have just the opposite reaction. Stimulation of the center of an on-center cell's receptive field produces *depolarization* and an increase in the firing of the ganglion cell, stimulation of the surround produces a *Hyperpolarization* and a decrease in the firing of the cell, and stimulation of both the center and surround produces only a mild response (due to mutual inhibition of center and surround).

-An off-center cell is stimulated by activation of the surround and inhibited by stimulation of the center


Bar of light on retina
On center
Off surround
On-center receptive fields
Simple cortical neurons in cerebral cortex
Ganglion cells in retina


Ganglion Cell Receptive Fields
On-center Field
Off-center Field
Off
On
Spot of light
On
Off
Light on center stimulates, light on surround inhibits, ganglion cell
Light on center inhibits, light on surround stimulates, ganglion cell
Off
On
Bar of light
On
Off
Light across both center and surround is less effective at stimulating ganglion cell

Thank you for listening