# Vision

## Phototransduction of light

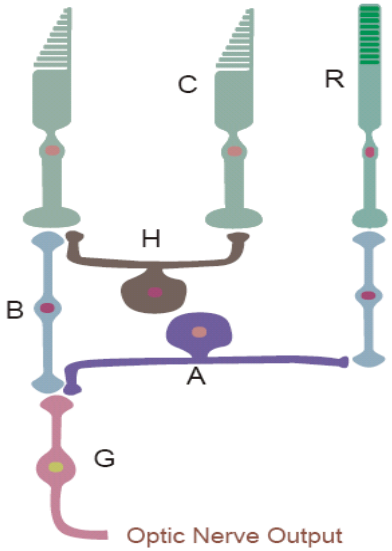
By

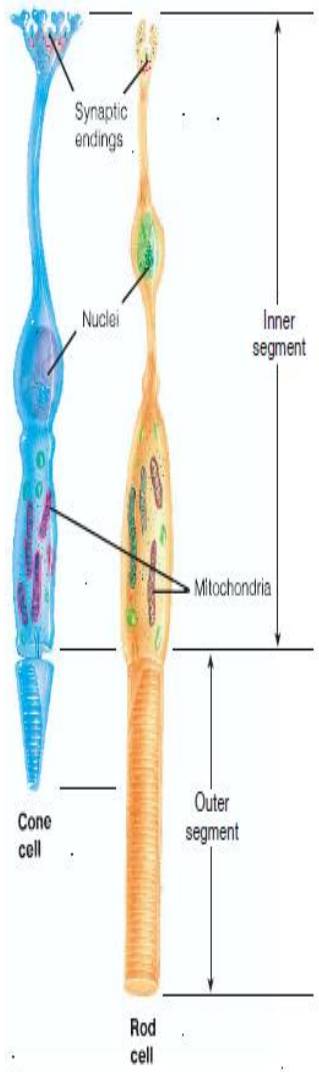
Prof/Faten zakareia
King Saud University
Physiology Dept

Objectives:

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

- **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**





(a)


(b)

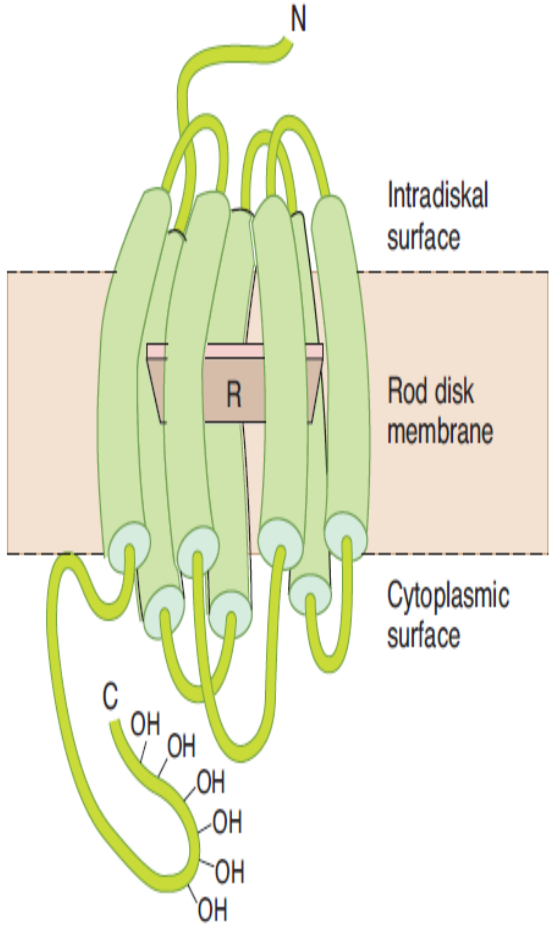
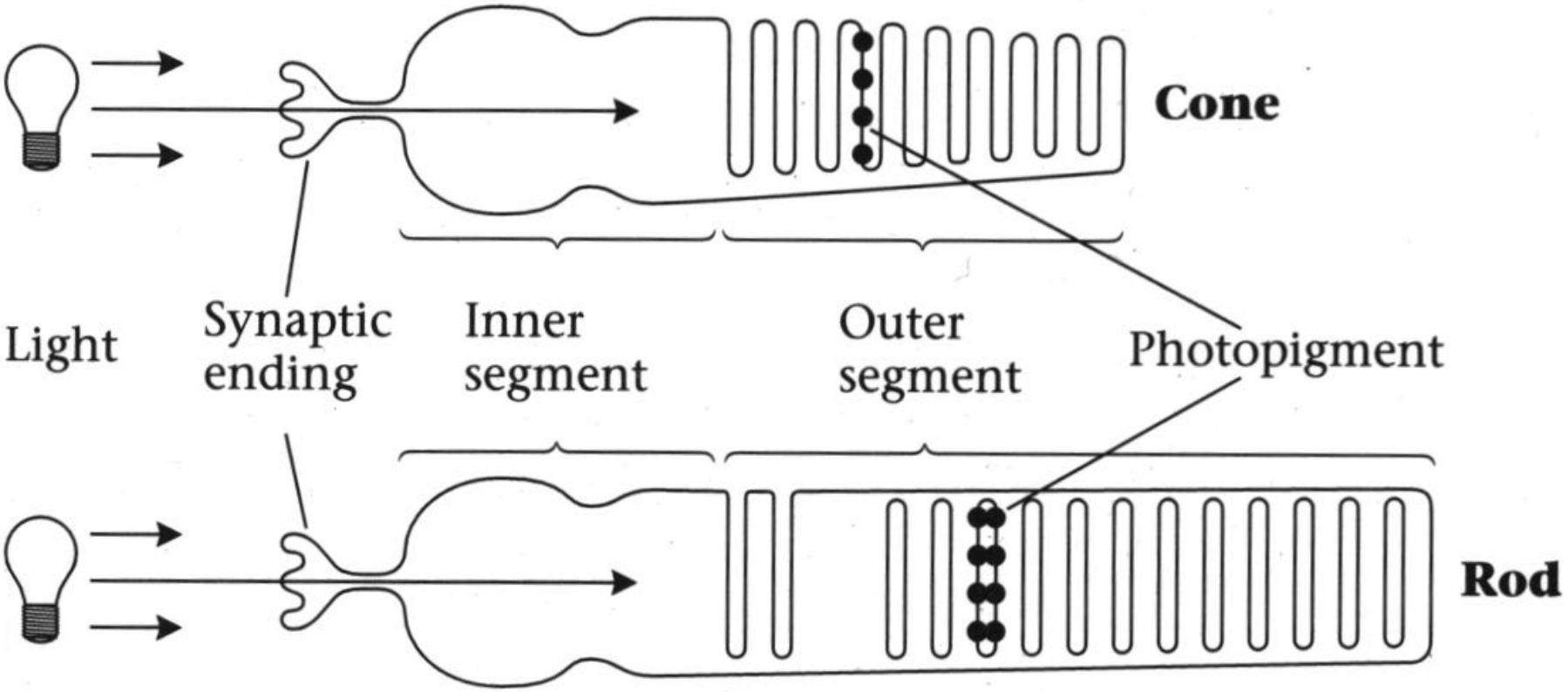



**FIGURE 12–13 Diagrammatic representation of the structure of rhodopsin, showing the position of retinene$_1$ (R) in the rod disk membrane.** Retinene$_1$ is parallel to the surface of the membrane and is attached to a lysine residue at position 296 in the seventh transmembrane domain.

# Inside the rod and the cone



# 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**

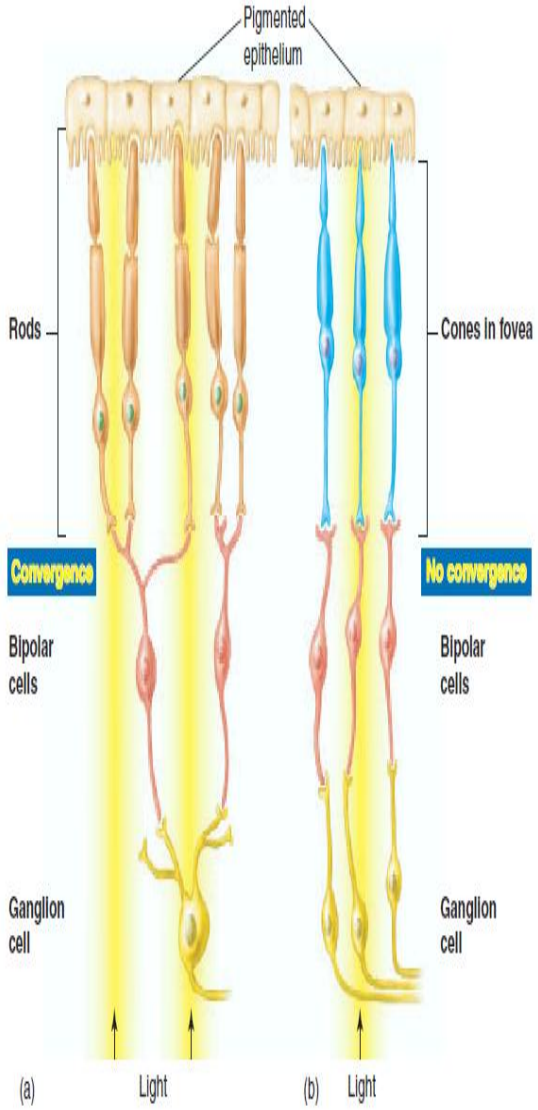
**- abundant in & around fovea**

**- best for bright light conditions**

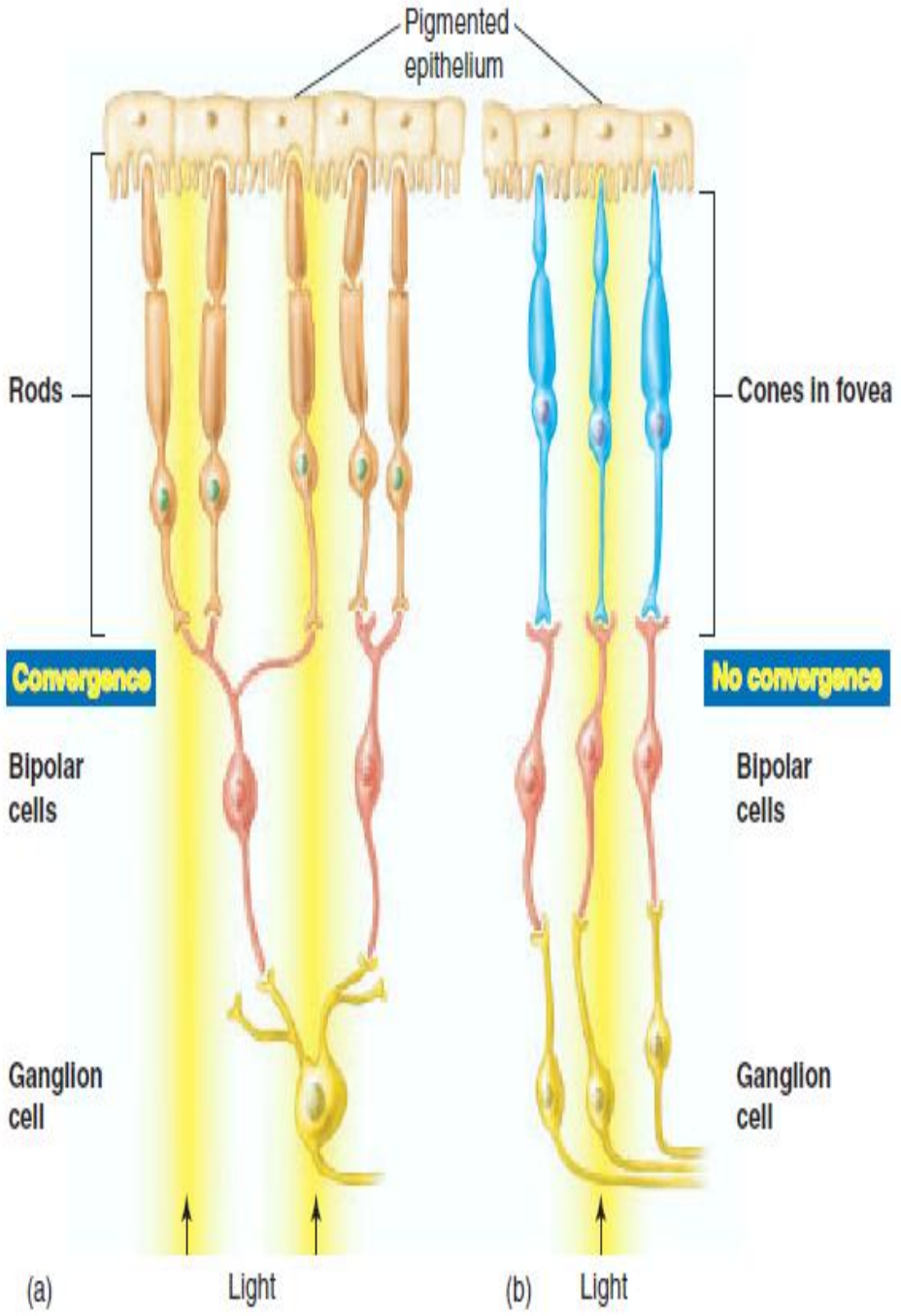
**-see all colors**

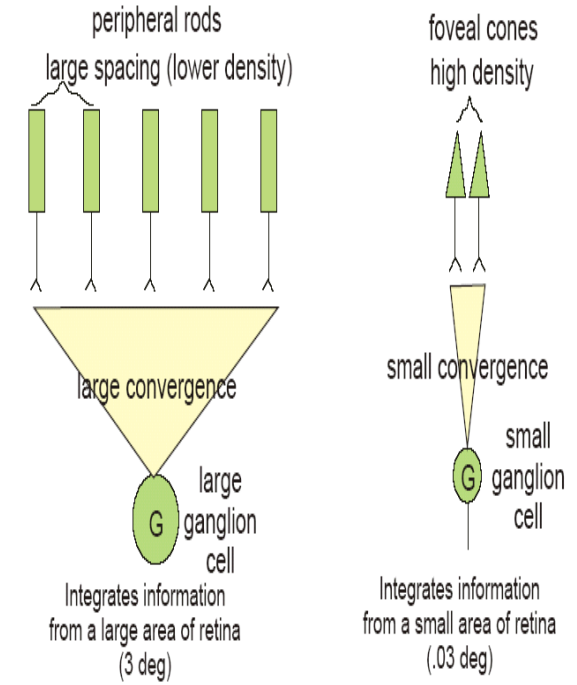
- **Convergence:-**
- **low convergence in cones / each foveal cone synapse with →one bipolar cell →one ganglion cell →single optic nerve fiber**
- **Value of low convergence /**
- **increases visual acuity → integrated information from small area of retina**

**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.



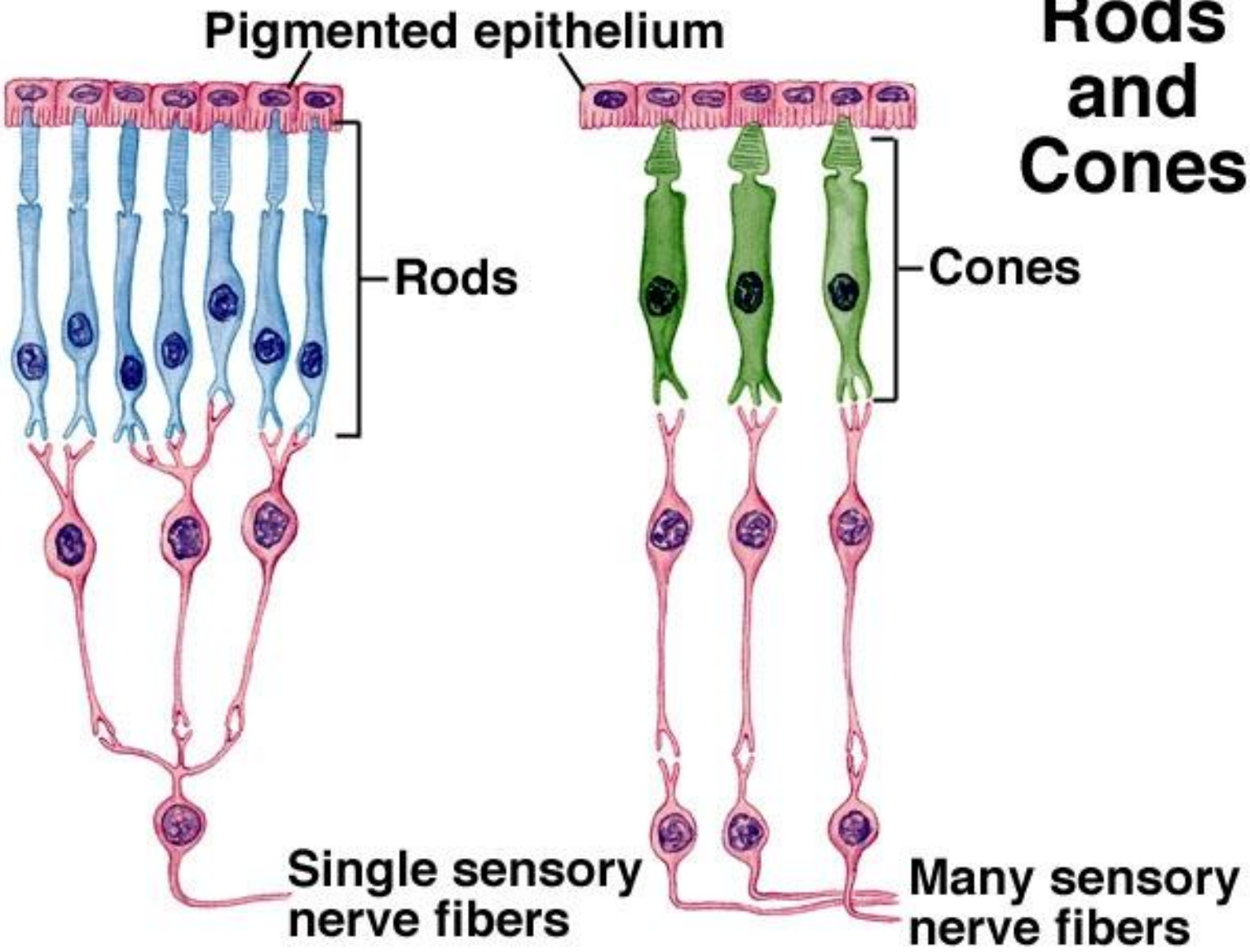




large spacing and large convergence result in low acuity

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.

# Rods and Cones



# 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.**
- **Rodes &cones & horizontal cells & Bipolar cell responses are depolarization at dark and hyperpolarization at light**

- **- 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**

- s

## Photosensitive compounds:-

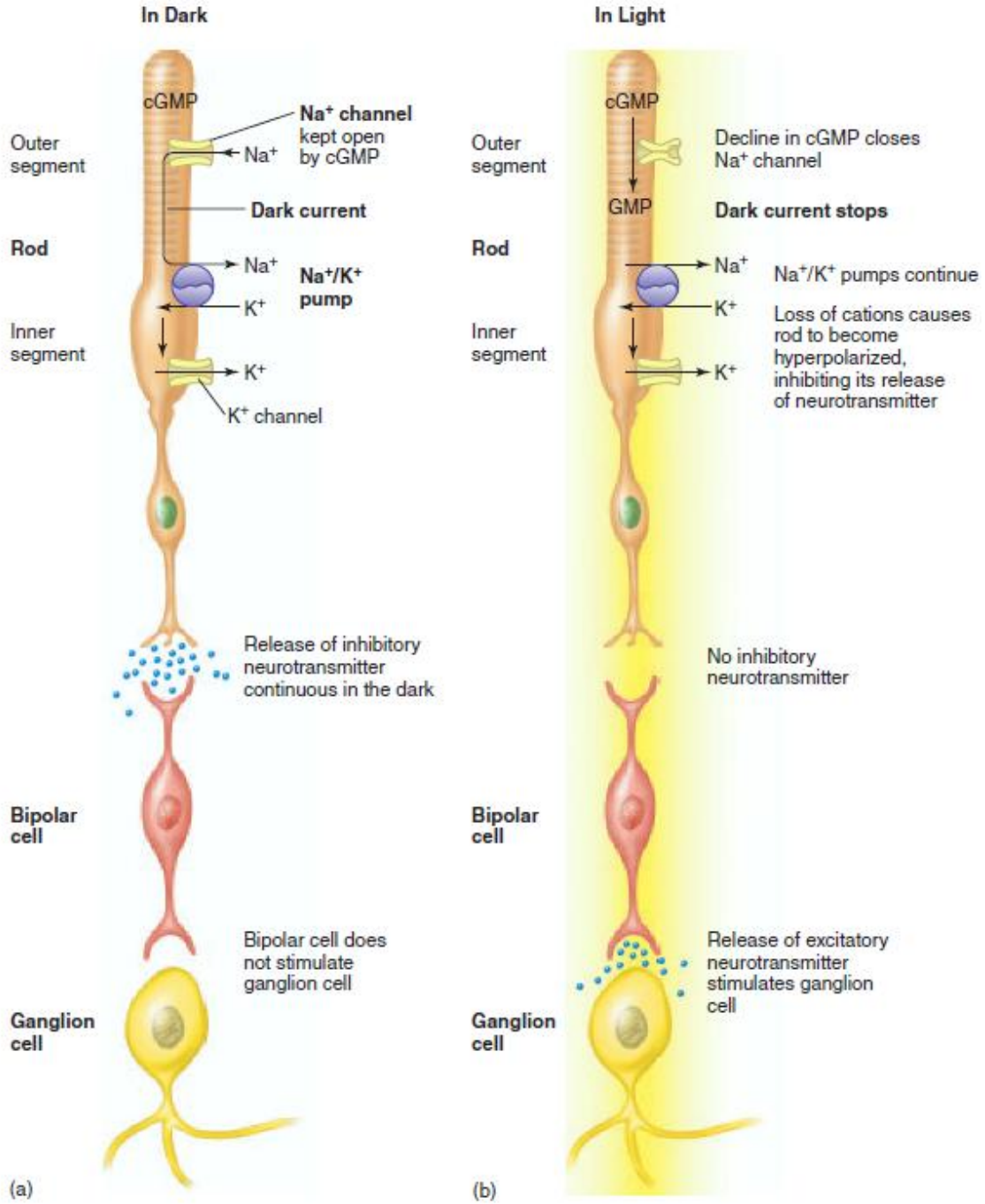
1- In cones it is rhodopsin (iodopsine) formed of :-
Opsin protein + retinal (retinene 1 = aldhyde form of Vit A)

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 is stored in disks of rods at outer segment
-It forms (90% of its protein )

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

- Ionic basis of photoreceptor potential at dark
- -In dark Na channels in rods outer segment are open by c-GMP
- -Na-K pump in inner segment pump Na
- -Na flow from inner to outer segmet ( called Na current) → Depolarization flow to synaptic endings → steady release of neurotransmitter at synapses with bipolar cells → which get depolarization potential **(depolarized bipolar cells)→ depolarize ganglion cells**


In Dark
In Light
cGMP
Na+ channel
kept open
by cGMP
Na+
Outer
segment
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)
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)

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) 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- → depolarization.**
- **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 ) .**

**4- A wave of depolarization spread to synaptic terminals.**

**5- Synaptic mediators are continuously (steadily) released ( mainly excitatory glutamate ( Ach + dopamine + GABA.)**

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

.

**N.B-at dark rhodopsin is regenerated from (retinal + scotopsin)**

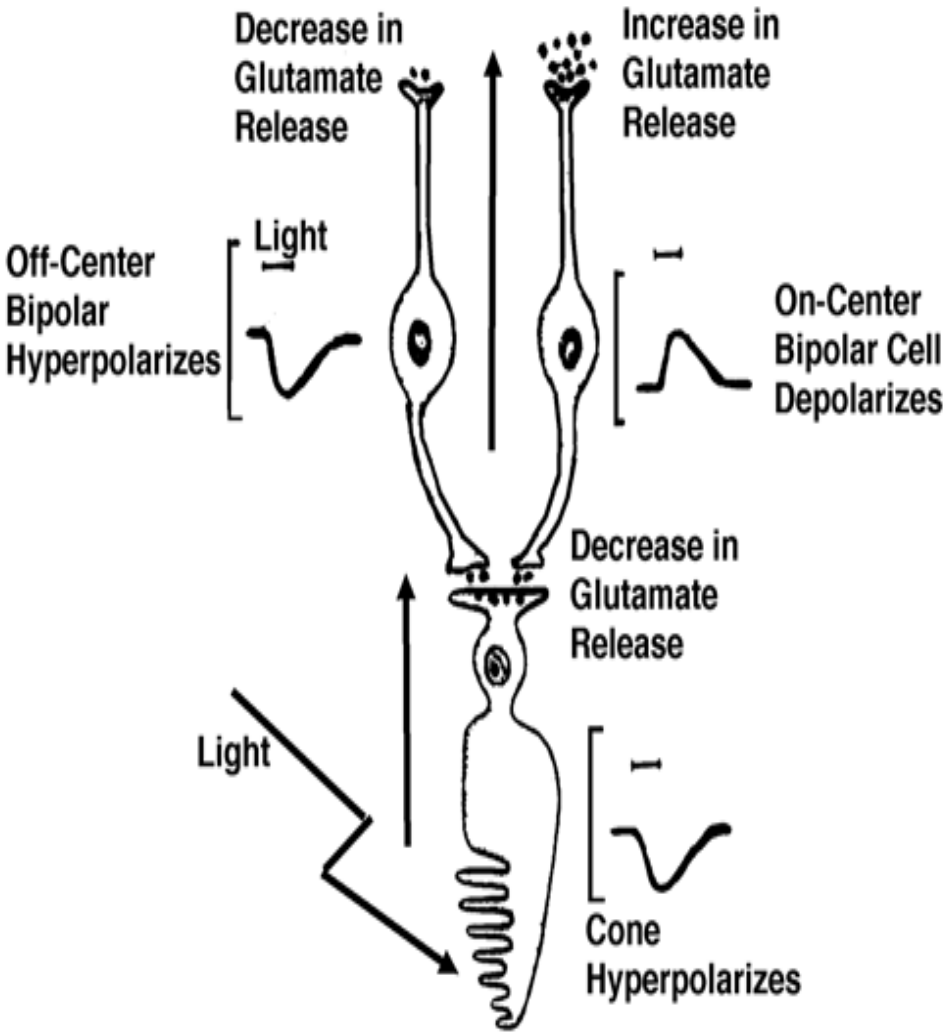
## B-Incident light ( PHOTOPIC VISION)

- - 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)

- **Hyperpolarization → Decreased release of synaptic transmitter → Response in bipolar cells (hyperpolarization) ( off-center bipolar cells get hyperpolarized)(this cause decreased release of synaptic transmitter) → 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**

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



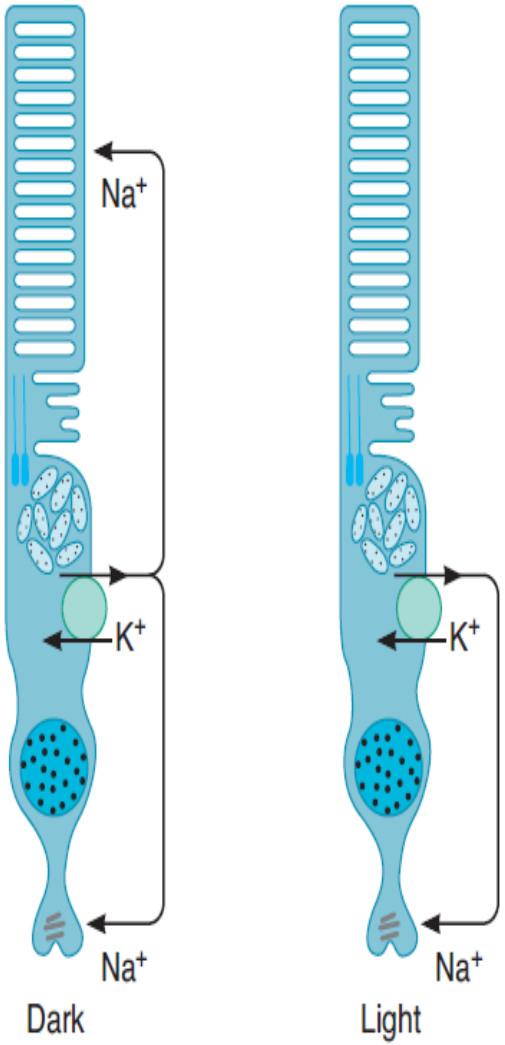
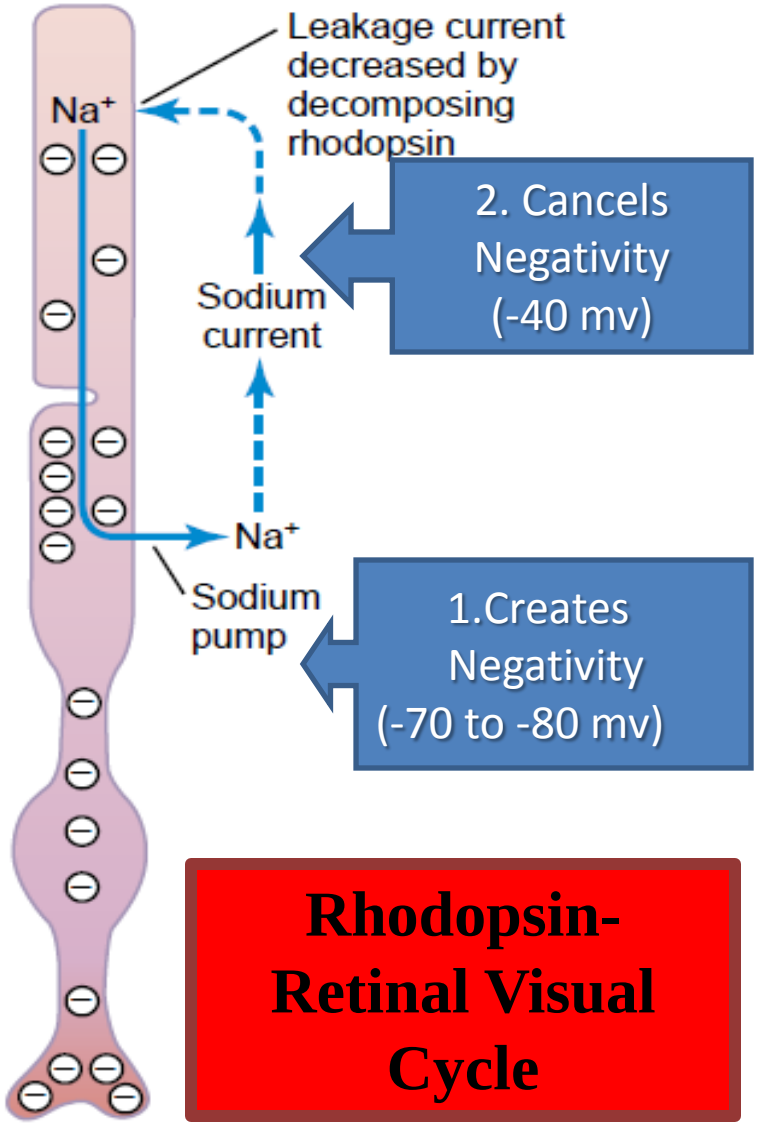


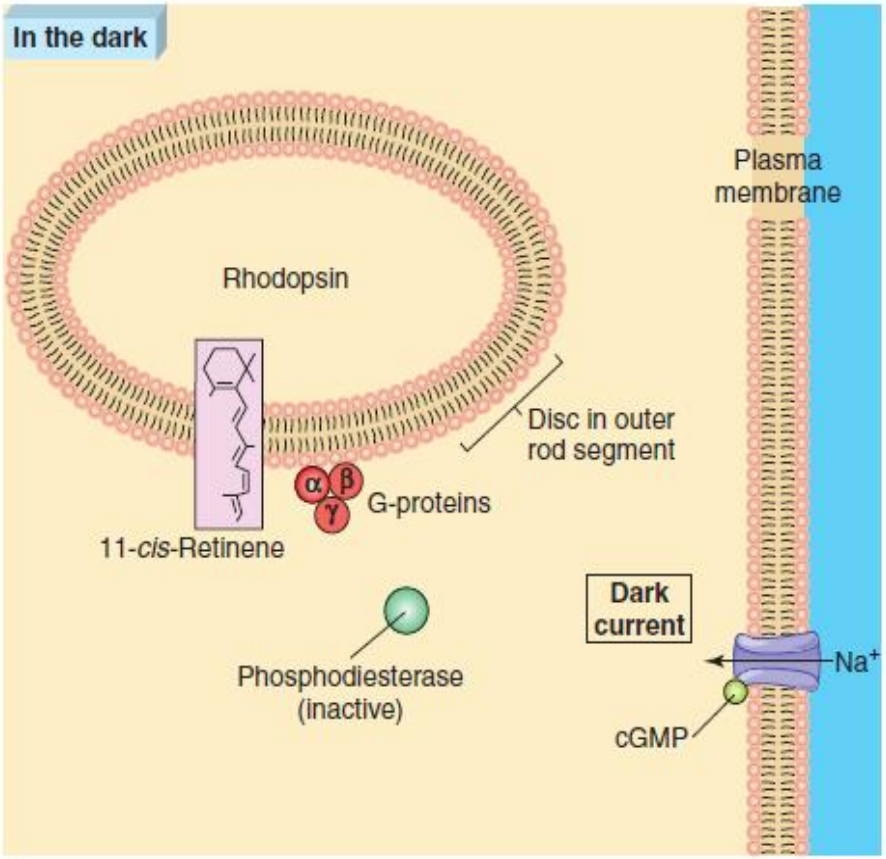

**FIGURE 12–12 Effect of light on current flow in visual receptors.** In the dark, $Na^+$ channels in the outer segment are held open by cGMP. Light leads to increased conversion of cGMP to 5'-GMP, and some of the channels close. This produces hyperpolarization of the synaptic terminal of the photoreceptor.

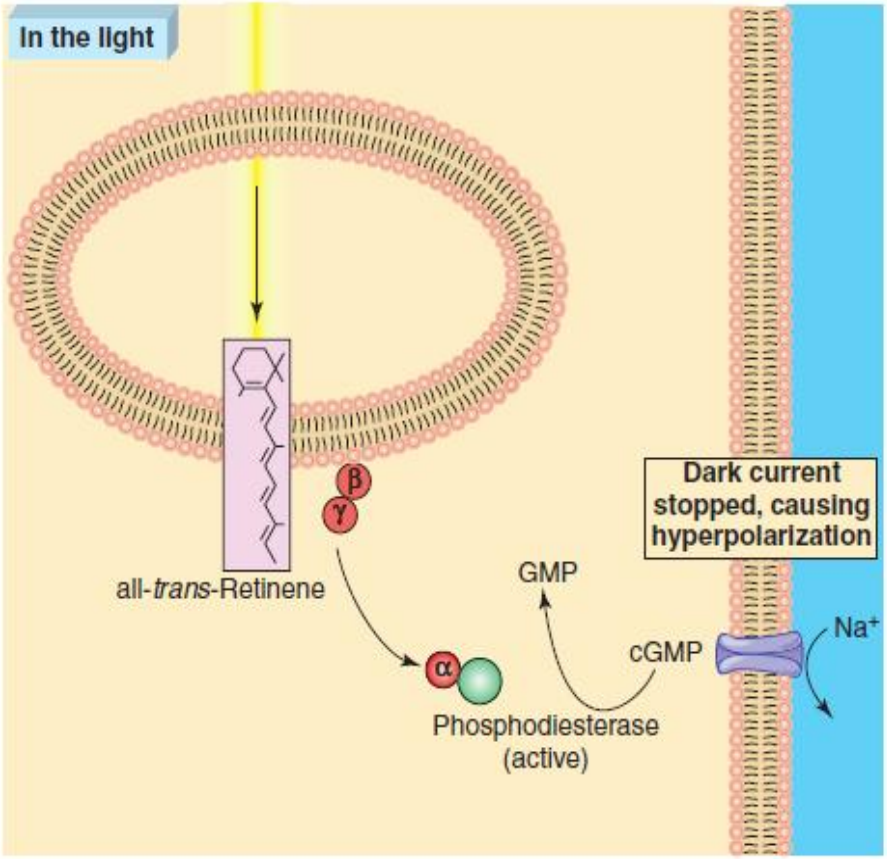
## Excitation of the Rod when Rhodopsin Is Activated by Light

- **When the rhodopsin in the outer segment of the rod is exposed to light, it begins to decompose, and this decreases the outer segment membrane conductance of sodium thus causing hyperpolarization**

- **The Rod Receptor Potential Is Hyperpolarizing (increased negativity), Not Depolarizing**




In the dark
Plasma membrane
Rhodopsin
Disc in outer rod segment
α
β
γ
G-proteins
11-cis-Retinene
Dark current
Phosphodiesterase (inactive)
Na+
cGMP


In the light
β
γ
all-trans-Retinene
Dark current stopped, causing hyperpolarization
GMP
cGMP
Na+
α
Phosphodiesterase (active)

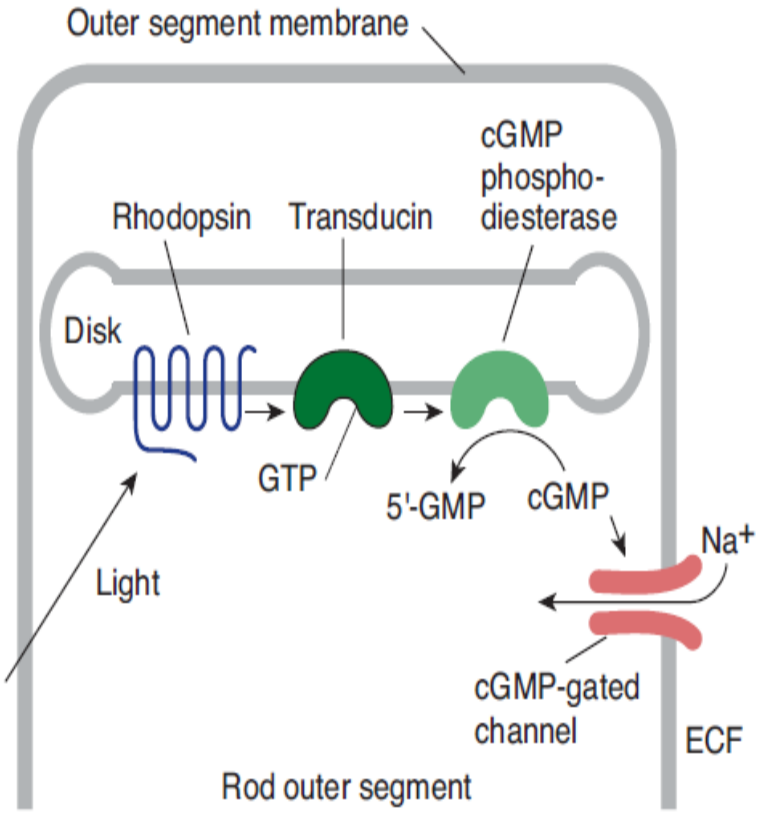



**FIGURE 12–14** **Initial steps in phototransduction in rods.** Light activates rhodopsin, which activates transducin to bind GTP. This activates phosphodiesterase, which catalyzes the conversion of cGMP to 5'-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels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

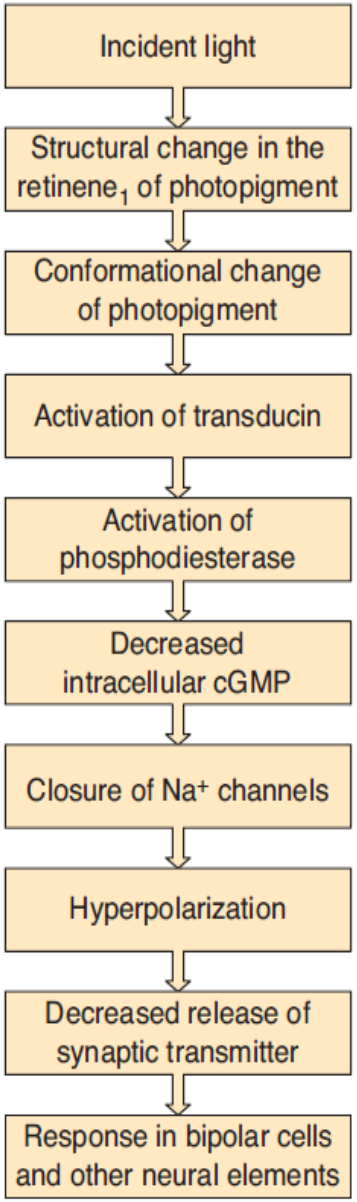



**FIGURE 12–15** **Sequence of events involved in phototransduction in rods and cones.**

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

**VISUAL CYCLE:-**

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

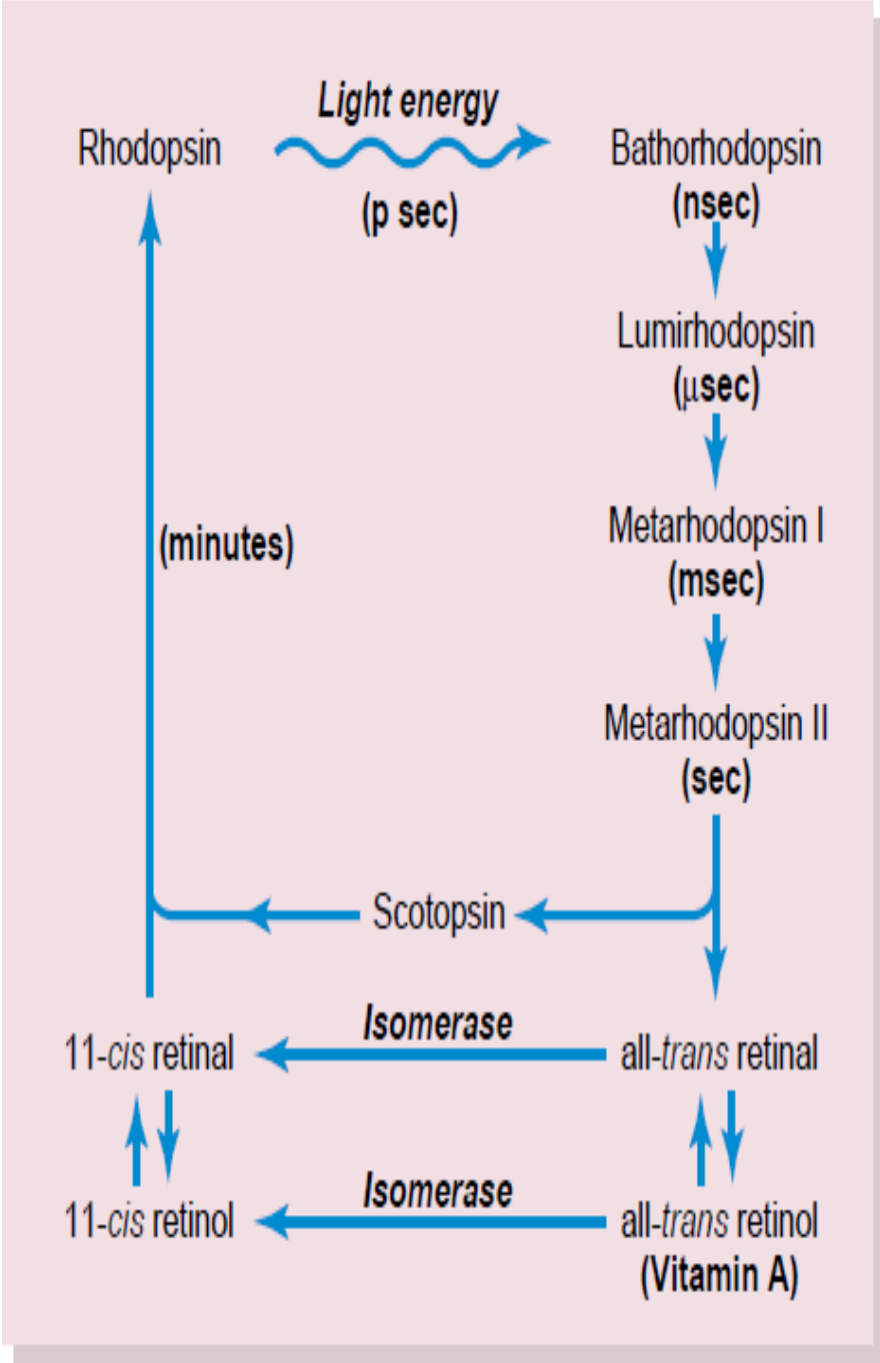
**light induces Isomerization of 11-*cis*-retinal into all-*trans*-retinal by a conformational change (bleaching) in opsin and all trans-retinal separate from opsin by light and opsin remains alone.**

**In dark,11-trans-retinal(meta-rhodopsin) is enzymatically re-converted to the 11-cis-retinal form via an isomerase enzyme. Since the opsin moiety 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**

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

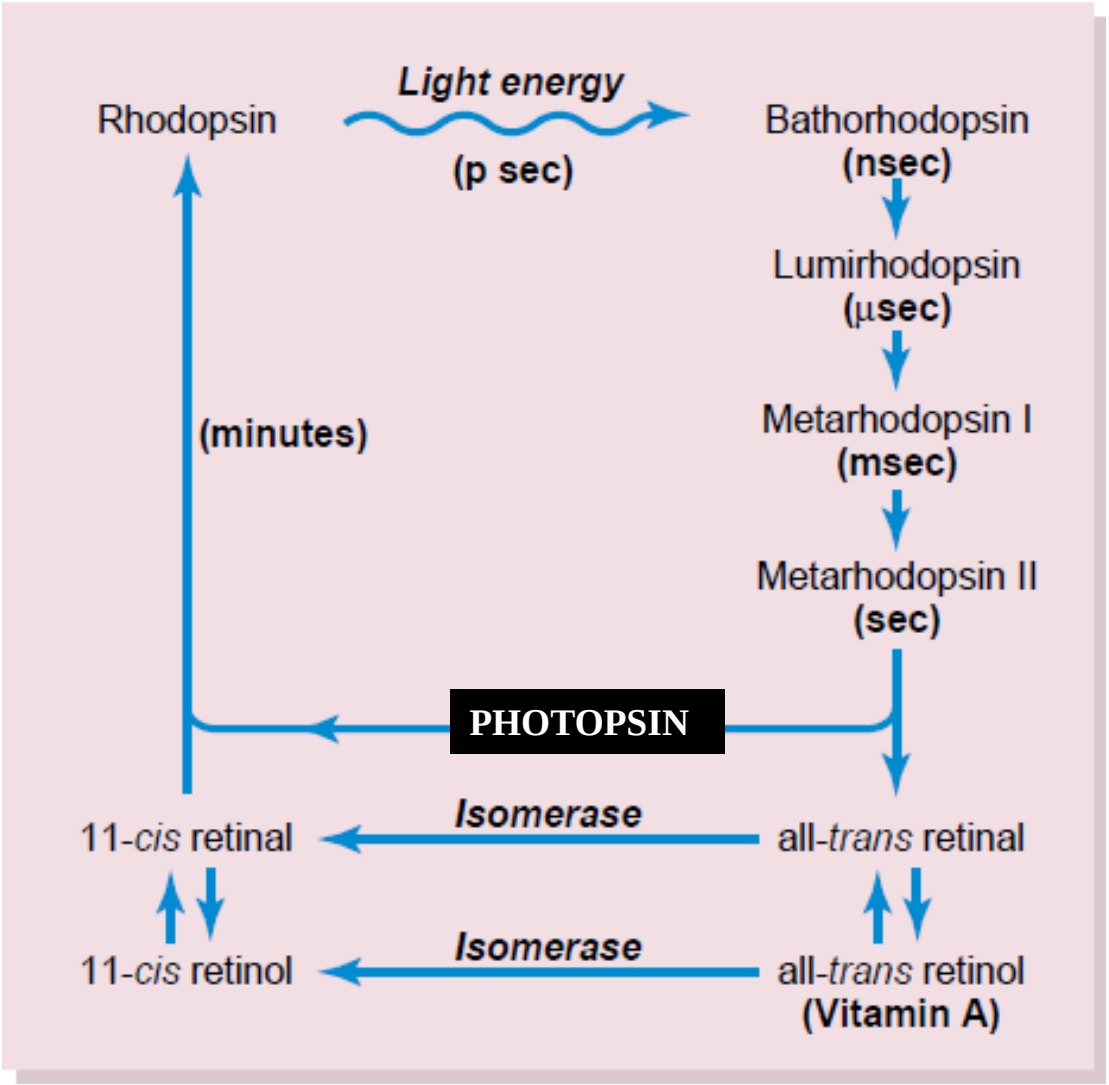
**<u>Rhodopsin-retinal visual cycle in the rod</u>, showing decomposition of rhodopsin during exposure to light and subsequent slow reformation of rhodopsin by the chemical processes**

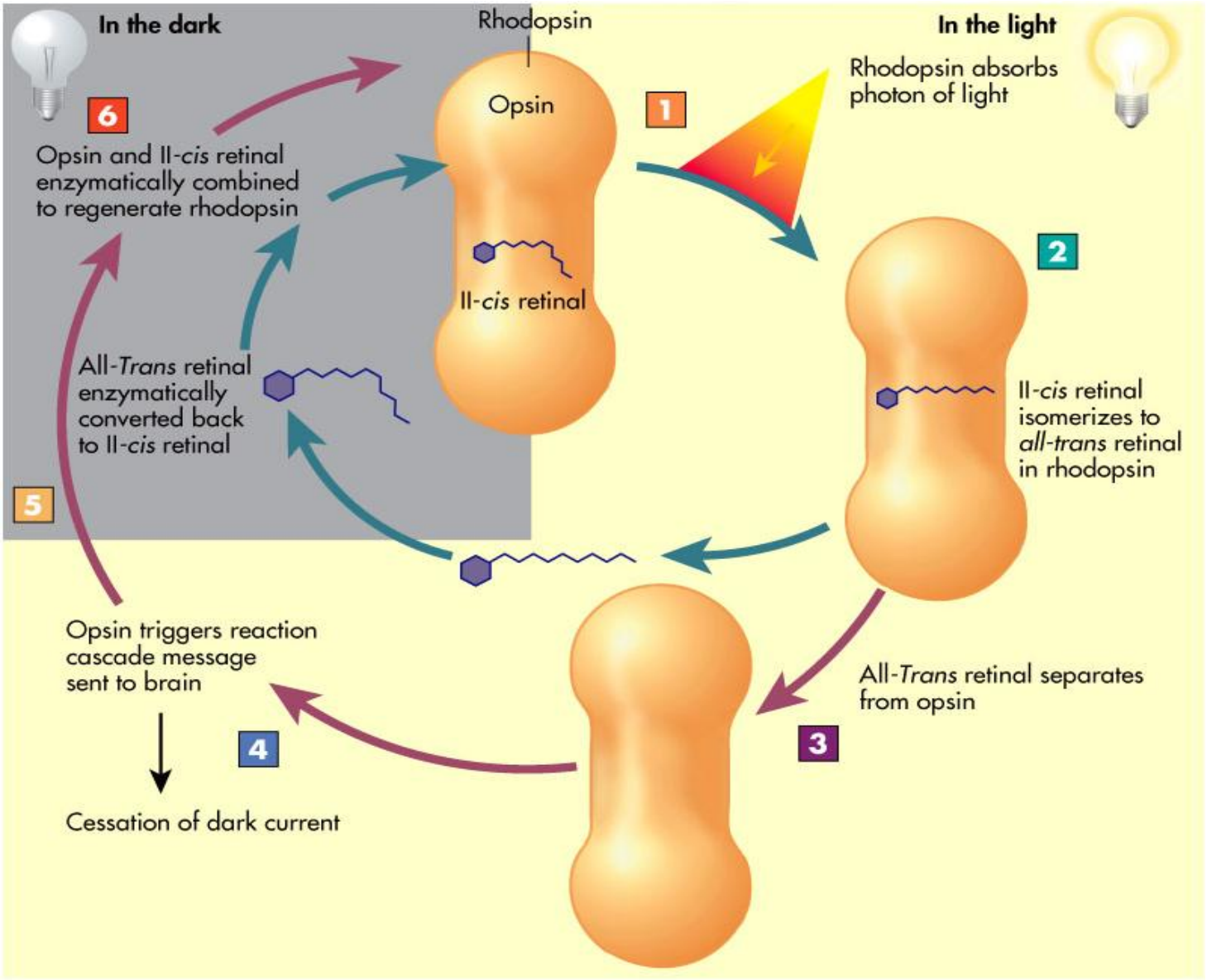


# Photochemistry of Color Vision by the Cones

## 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
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

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

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

-- R / vit A if receptors are well.

## Dark adaptation:-

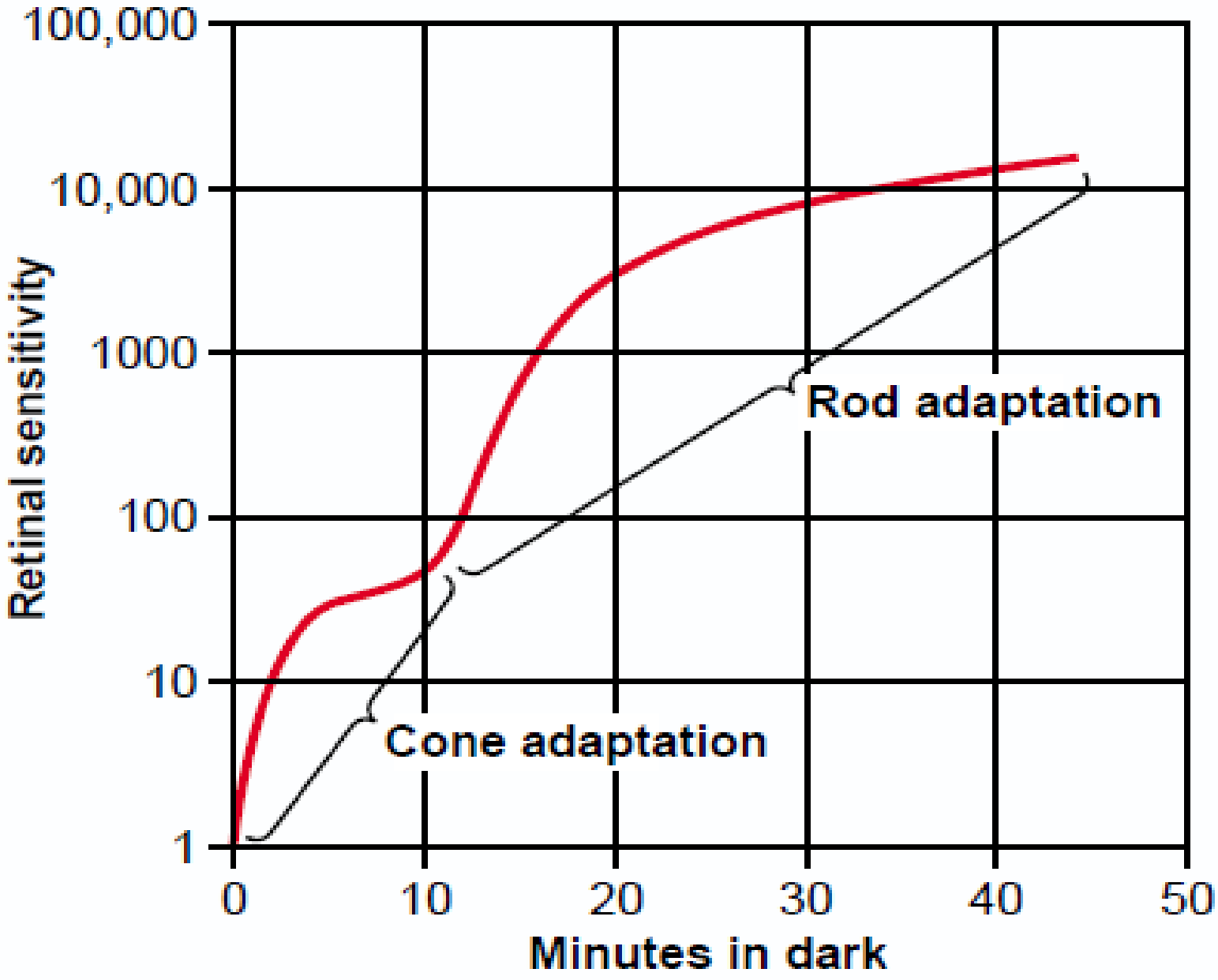
- 
- -When a person moves from lighted environment → a dimly lighted environment, the retina becomes more sensitive to light & the person will see at dark ( accustomed to dark ) in about 20 min.( only gross features but no details or colors) .
- - Rhodopsin in darkness is essential for depolarization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

- -

- **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**


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

- **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/ ➔ especially sensitivef or detecting directional movement in the field of vision, and they are probably important for much of our crude rod vision under dark conditions**

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

**3-Y Cells // to Transmit Instantaneous & rapid Changes in the Visual Image like many of the amacrine cells, either rapid movement or rapid change in light intensity**

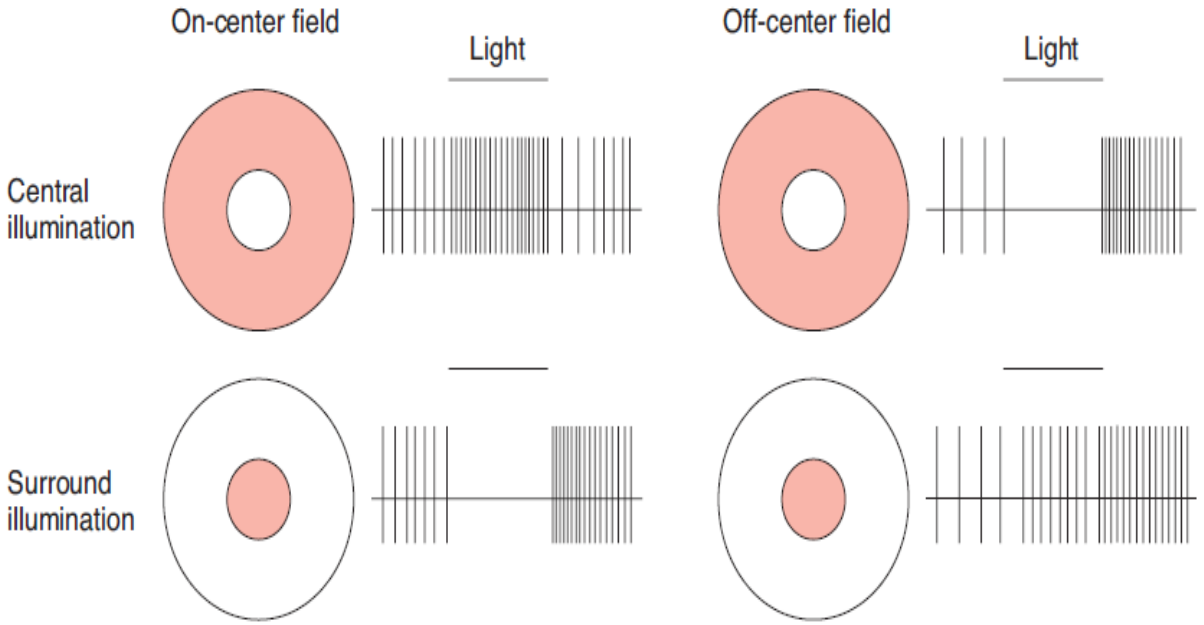
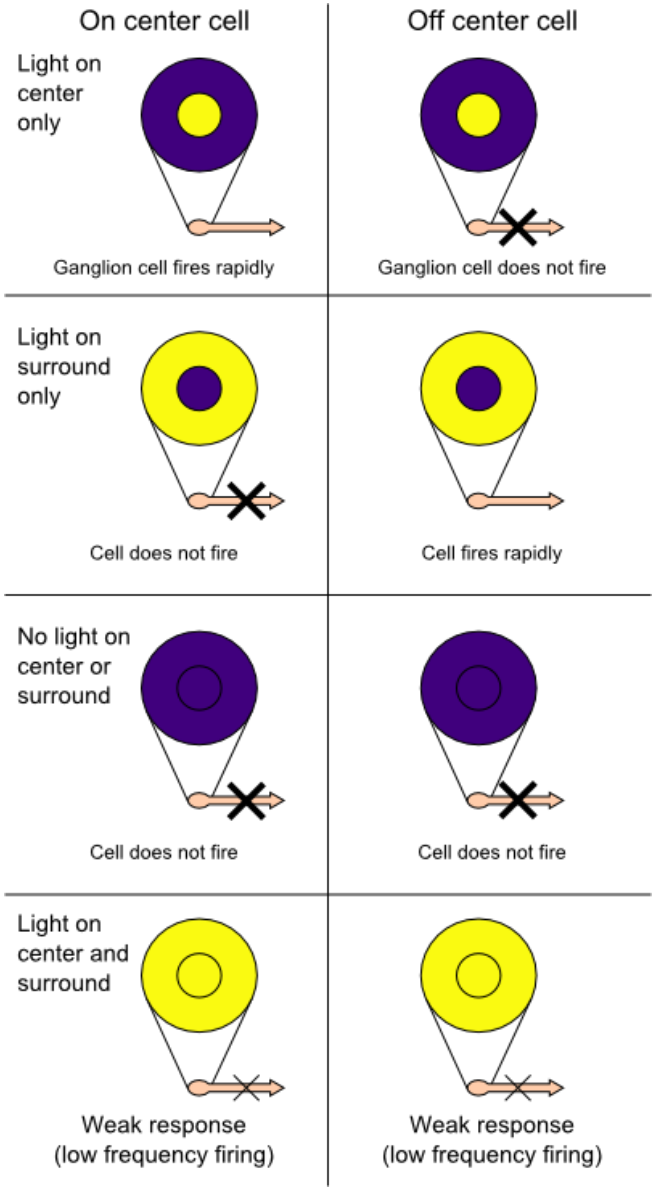
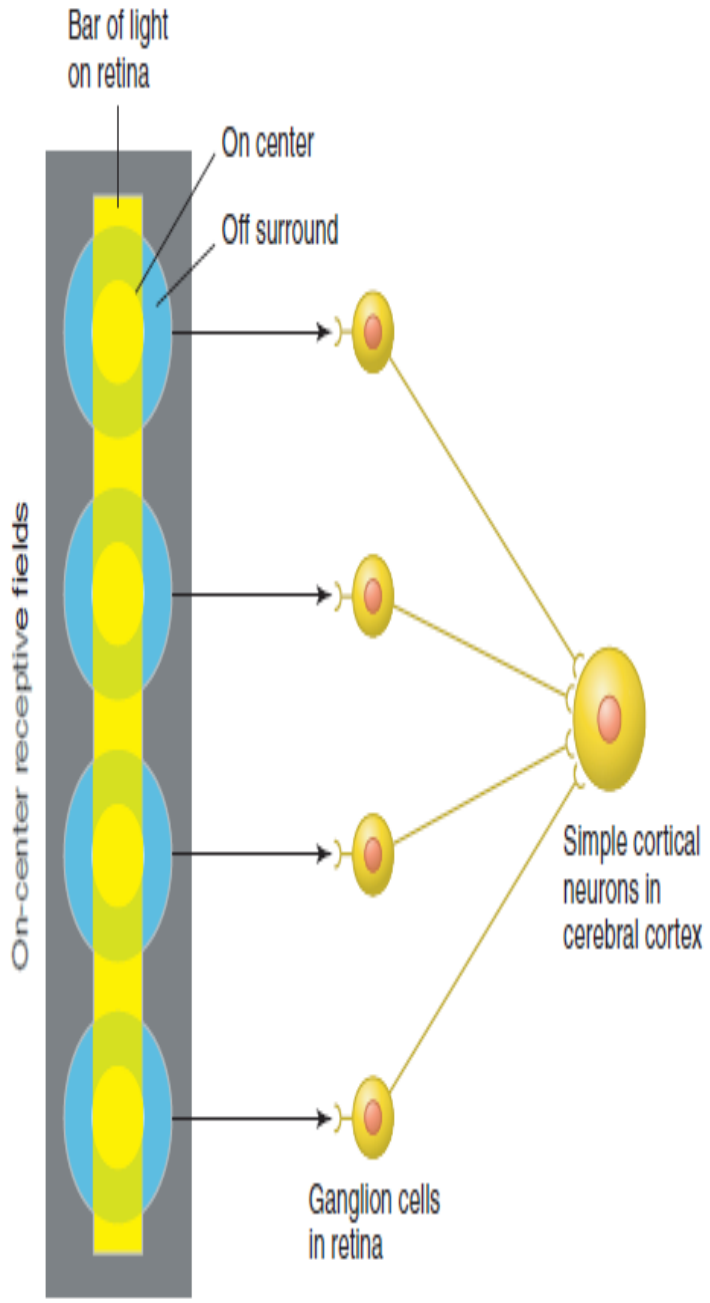
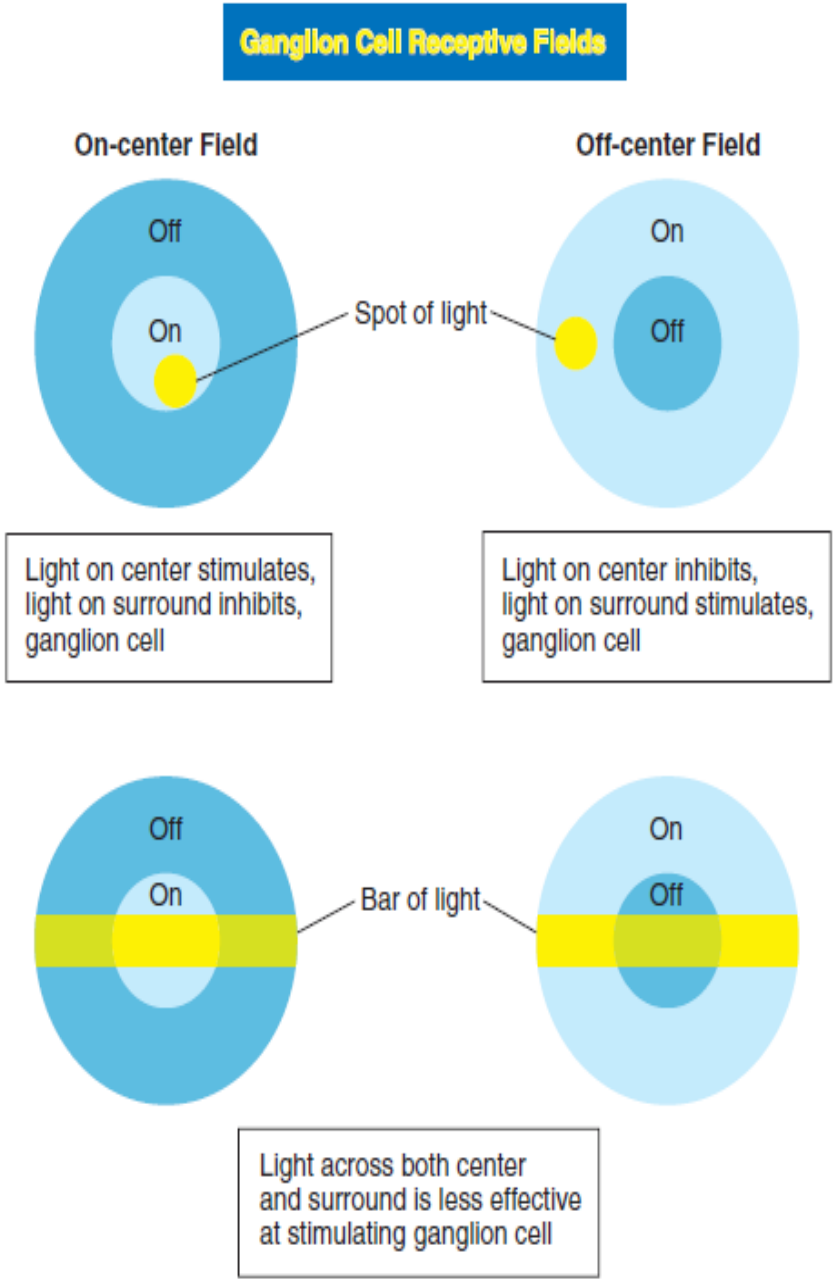



**FIGURE 12–16** **Responses of retinal ganglion cells to light on the portions of their receptive fields indicated in white.** Beside each receptive field diagram is a diagram of the ganglion cell response, indicated by extracellularly recorded action potentials. Note that in three of the four situations, 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.)




**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).**


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