



# **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 of rhodopsine regeneration
- To know the meaning of nyctalopia
- Contrast the dark and light adaptation
- To know the visual cycle and rhodopsine regeneration
- To recognize types of ganglion cells

Ref/ Gyton & Hall

## 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

# Shape of rods & 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

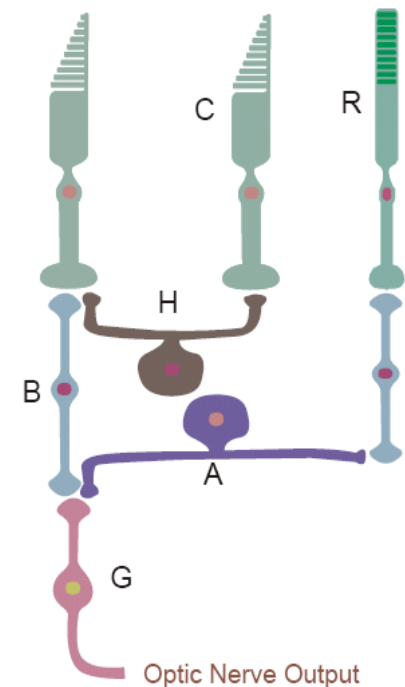
- In rods it is big, rod-like and contain one type of rhodopsin

- There are Na channels in the outer segment

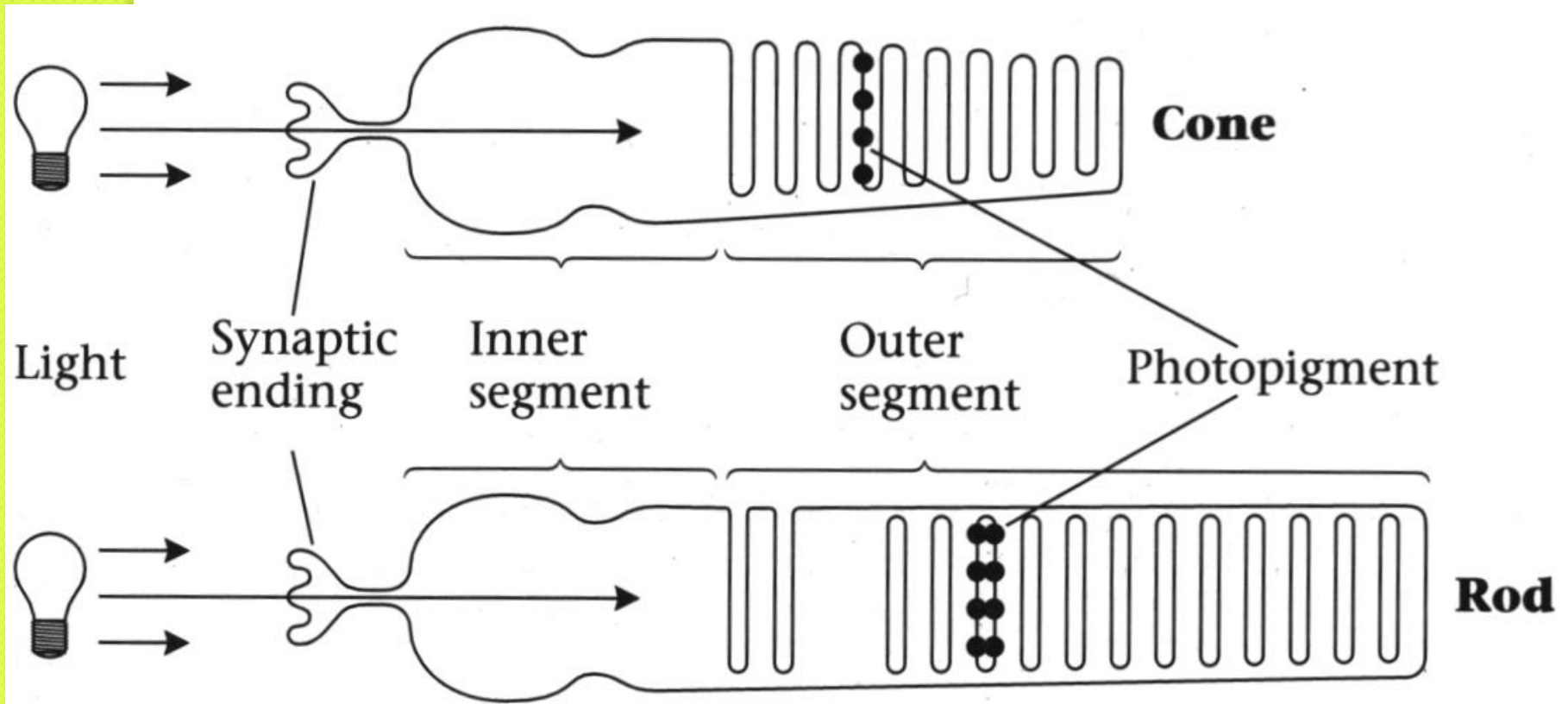
## 2- Inner segment

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

- There is Na-K pump in inner segment

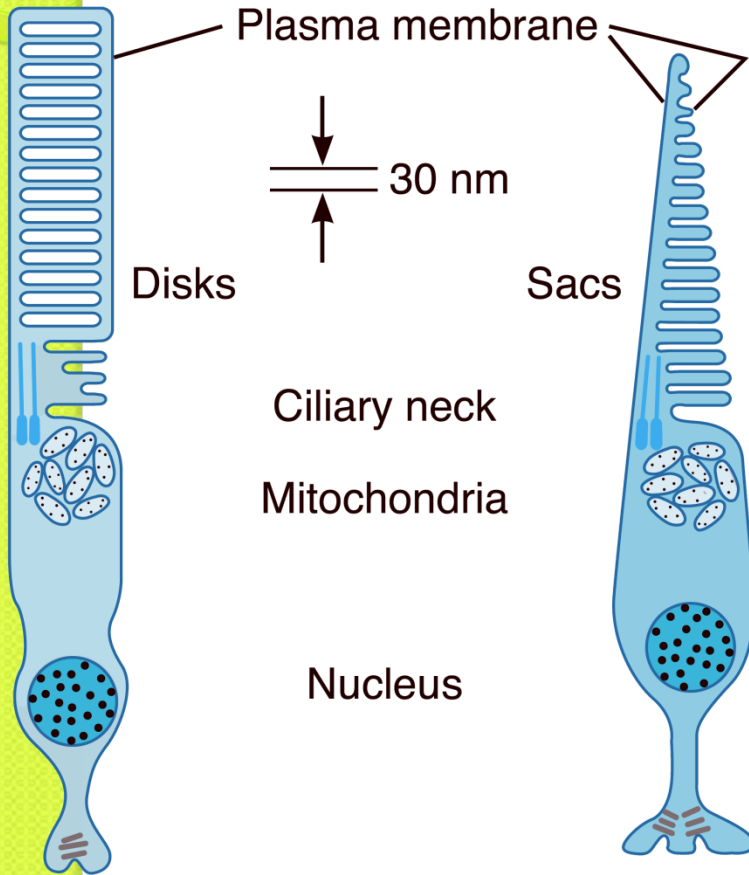


## Inside the rod and the cone



Rod

Cone



Plasma membrane

30 nm

Disks

Sacs

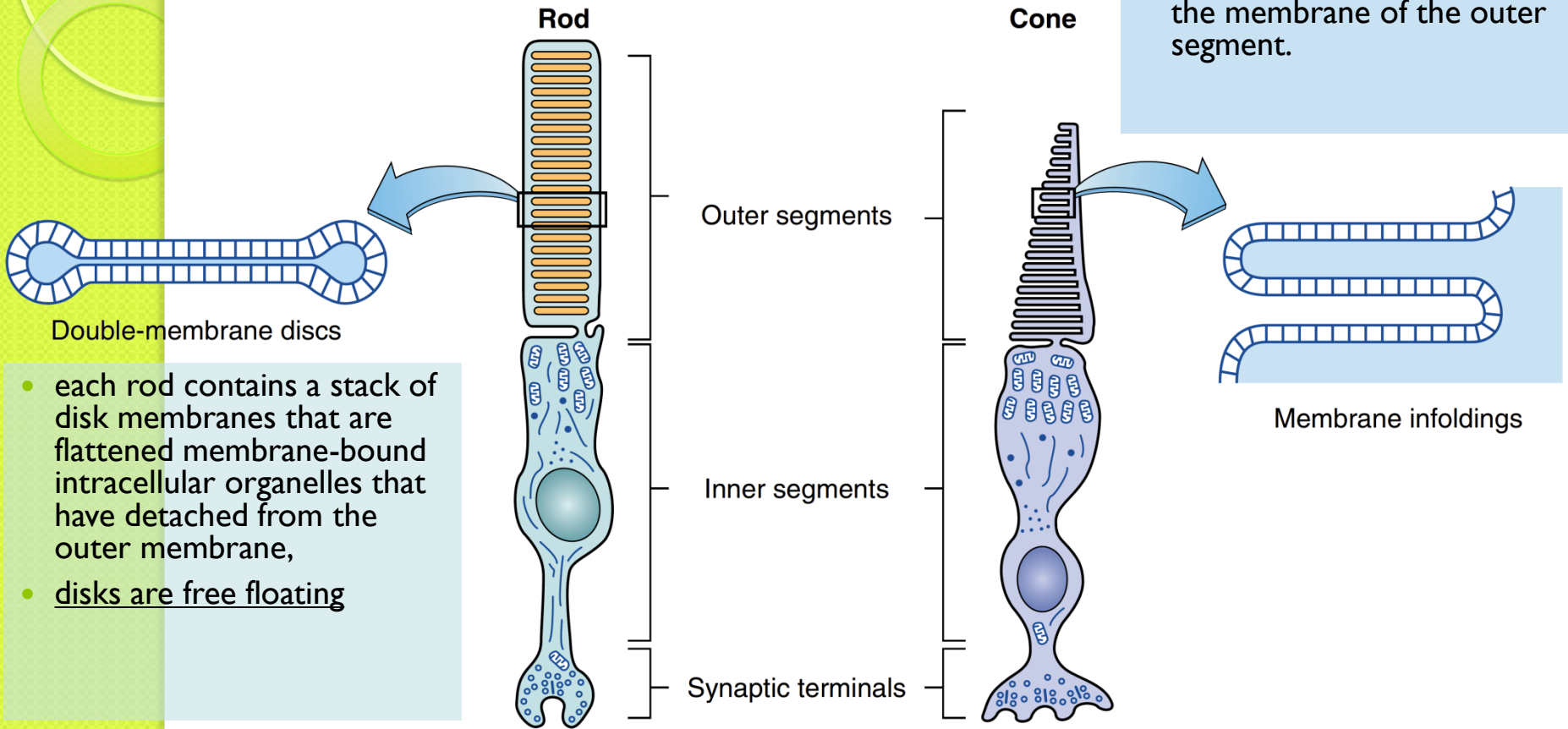
Ciliary neck

Mitochondria

Nucleus

**-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)**

## STRUCTURE OF PHOTORECEPTORS



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

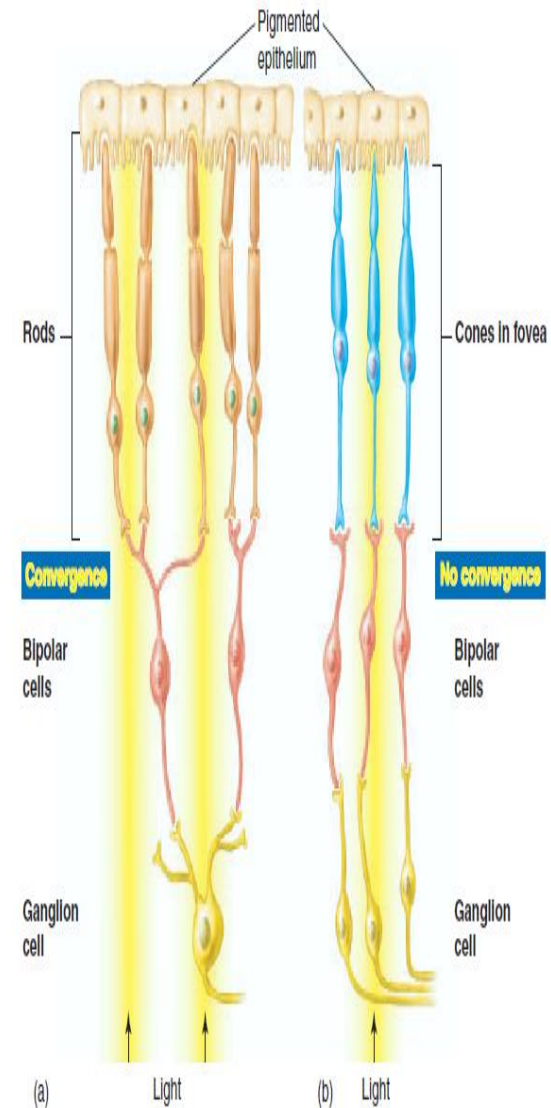
- each rod contains a stack of disk membranes that are flattened membrane-bound intracellular organelles that have detached from the outer membrane,
- disks are free floating

**the sacculi 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

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

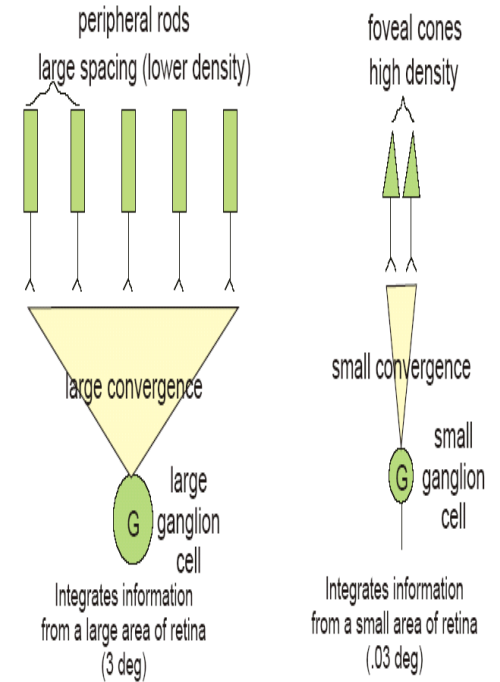
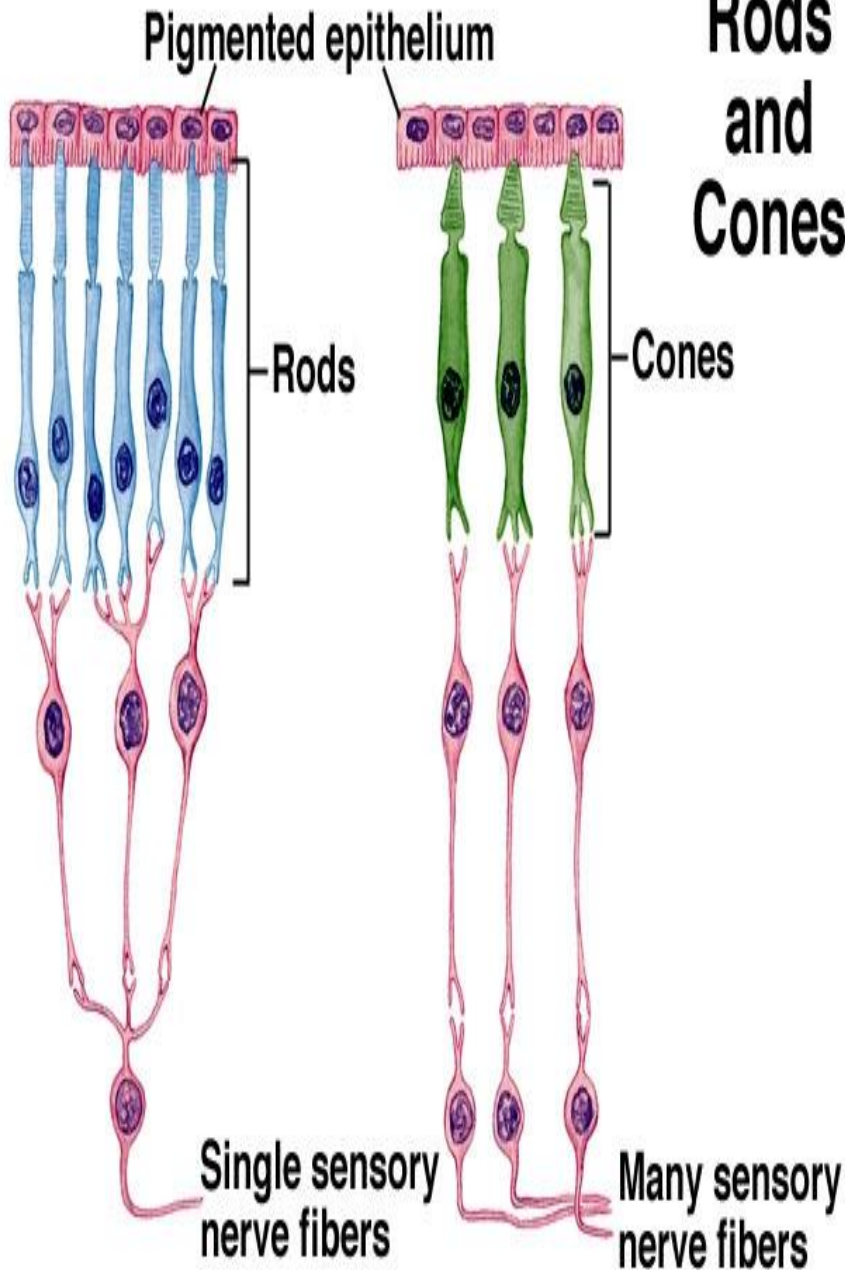
Disadvantage// decreases sensitivity to light i.e need high threshold of illumination to stimulate cones)





- 2- high convergence of rods/
- several rods 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 stimulates the rods)
- -3- 120 million rods & 6 million cones converge on 1.2 million optic nerve fibers, (126 million receptors on 1.2 million nerve fibers) so convergence is 105 receptors : 1 fiber.

# Rods and Cones



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.

# 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 compound (rhodopsin ):-

1- In cones rhodopsin (iodopsine) formed of :-

Opsin protein + retinal (retinene I = aldehyde 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 = aldehyde 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)

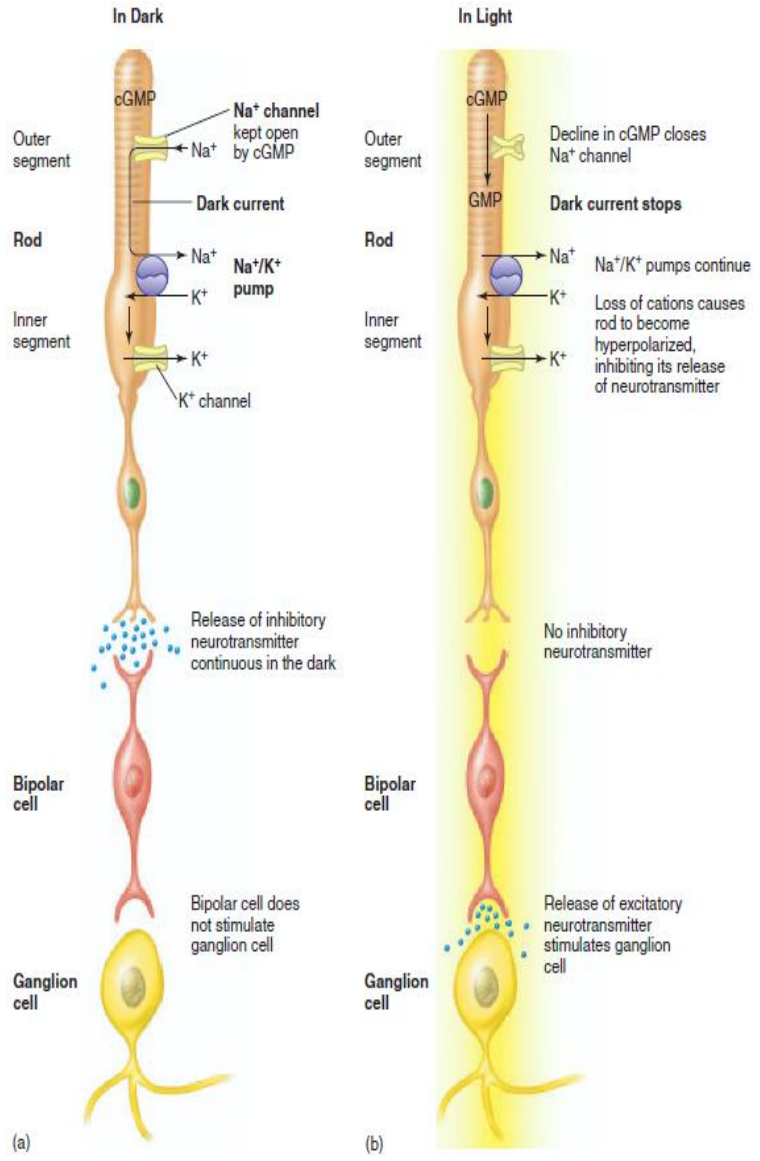
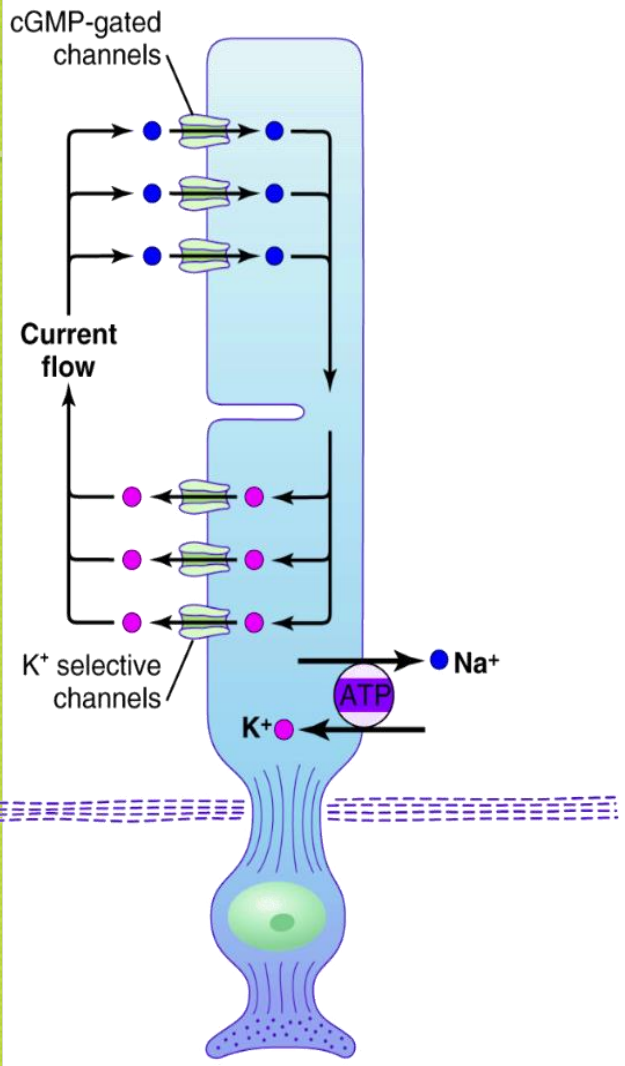
2- (5 -GMP) in the c-GMP form

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

A



(a)

(b)

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

**NB/**

- I-at dark rhodopsin is inactive (I I 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 retinene-I in rhodopsin ( **I I-cisretinal** form changed to → **all-trans isomer** called **metarhodopsin II** which is an active rhodopsin) → Activation of **G – protein (transducin)** → activation of **phosphodiesterase** 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

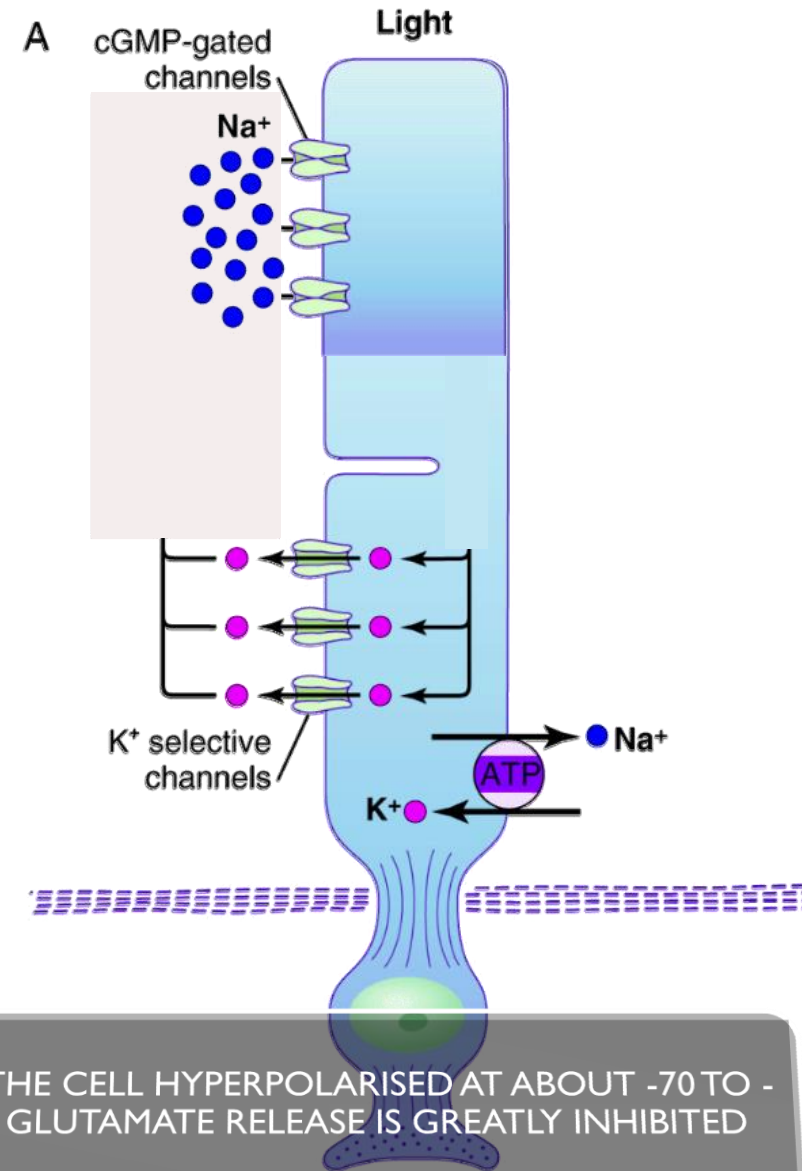
LIGHT EXPOSURE WILL LEAD TO CLOSURE OF THE CGMP GATED  $\text{Na}^+$  CHANNELS

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  $\text{Na}^+$  AND  $\text{K}^+$  THIS CREATES A NEGATIVE POTENTIAL ON THE INSIDE OF THE ENTIRE CELL OF ABOUT -70 TO -80MV



**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**

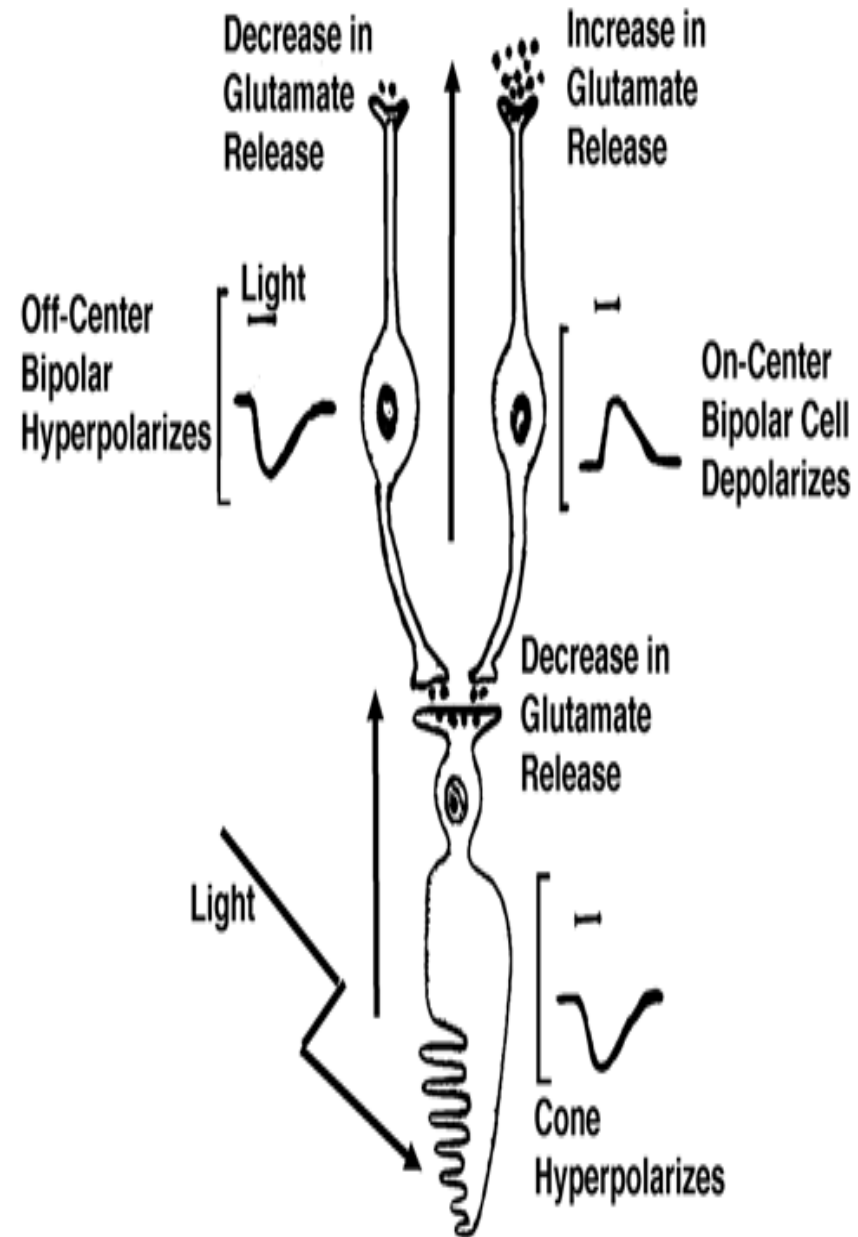
**2- hyperpolarize OFF-center bipolar cells (inactive)**

**N.B/**

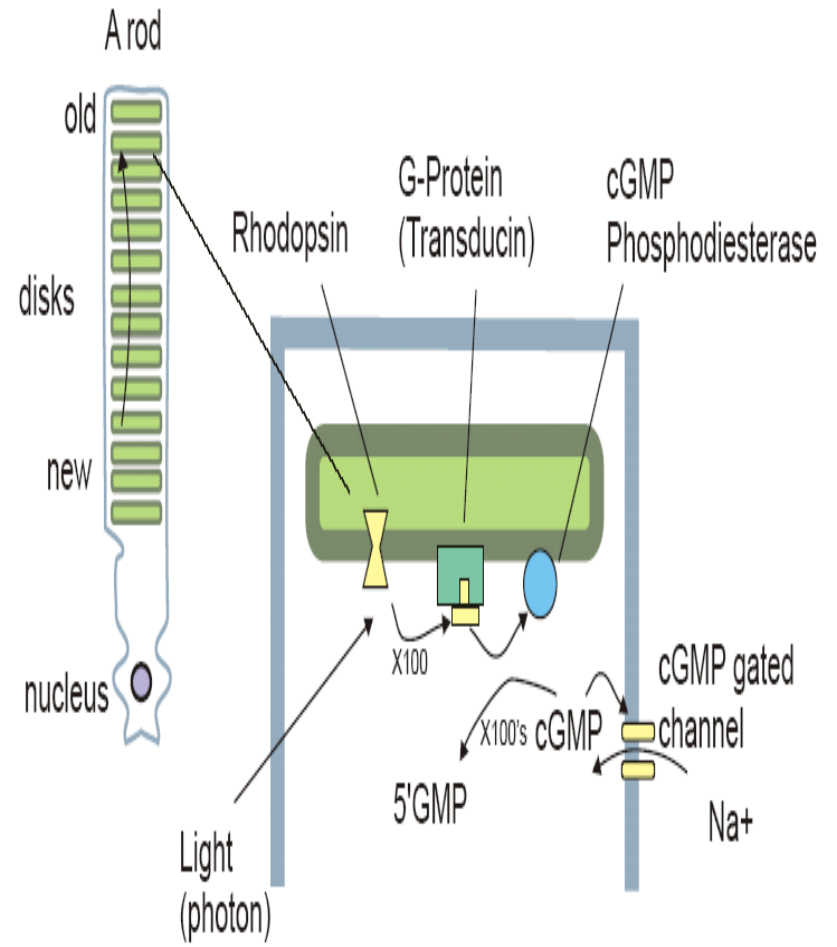
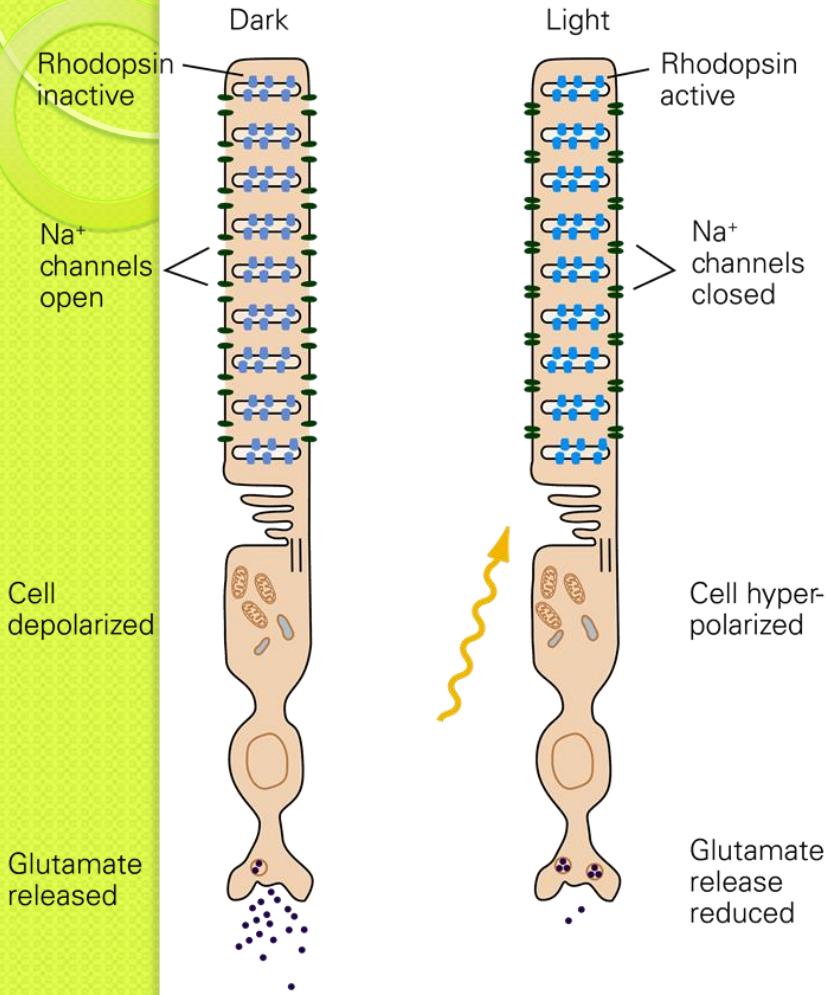
**-ON- center bipolar( synaptic connection with center photoreceptors= cones , so light depolarize them to see in bright light)**

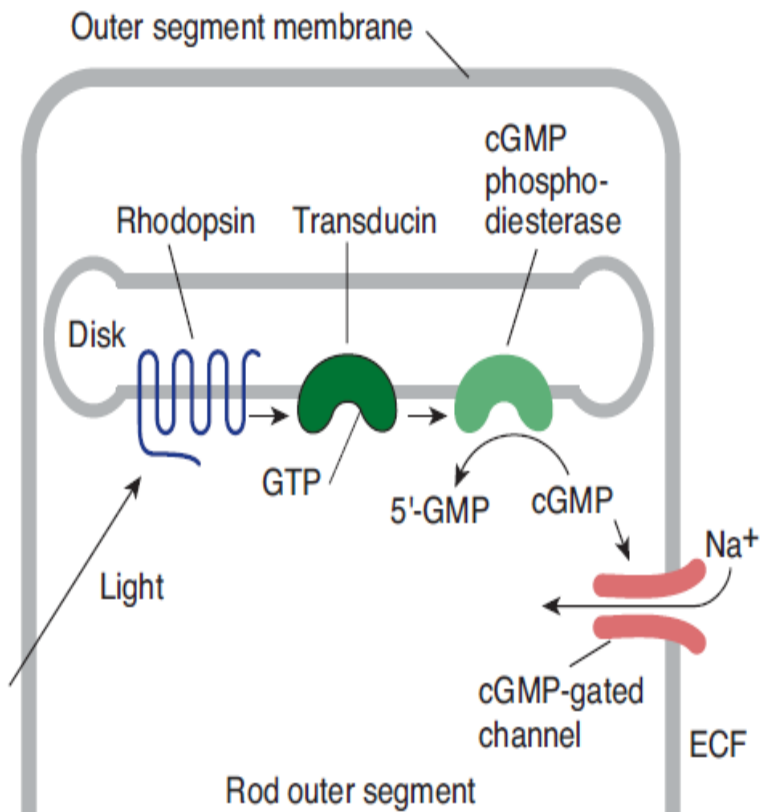
**-OFF- center bipolar( synaptic connection with peripheral photoreceptors= rods , so dark depolarize them to see in dark)**

**-All these help to sharpen signal from rods in dark and from cones in light**

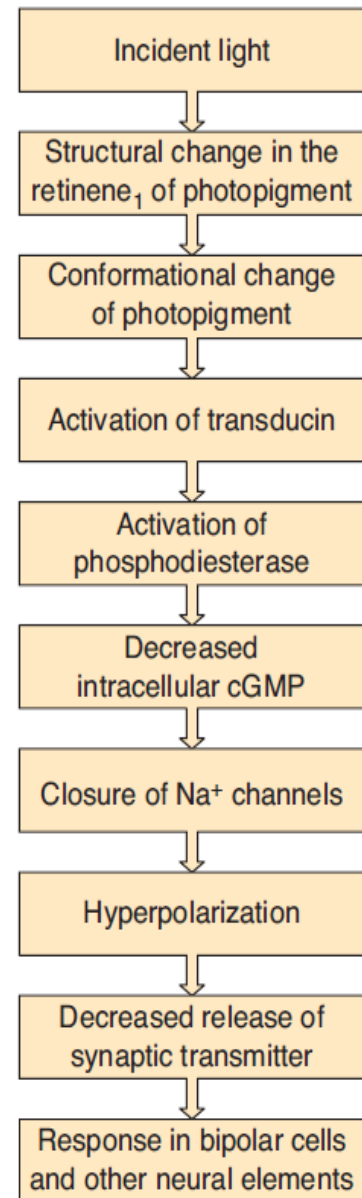


# A Phototransduction and neural signaling





**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, serotonin, GABA, substance P, somatostatin, 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.

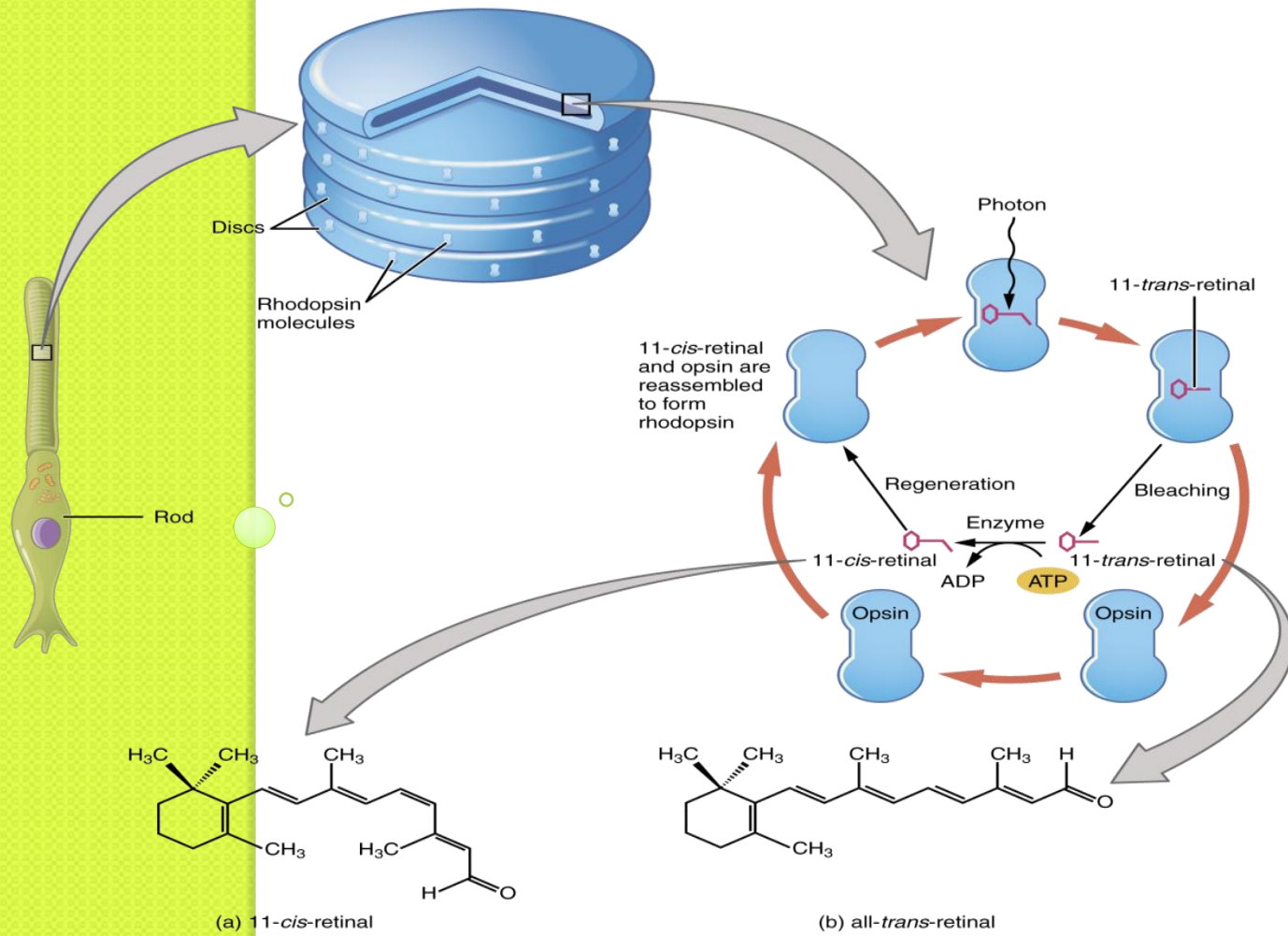
## VISUAL CYCLE(bleaching& regeneration)

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 + scotopsin → → rhodopsin  
regeneration



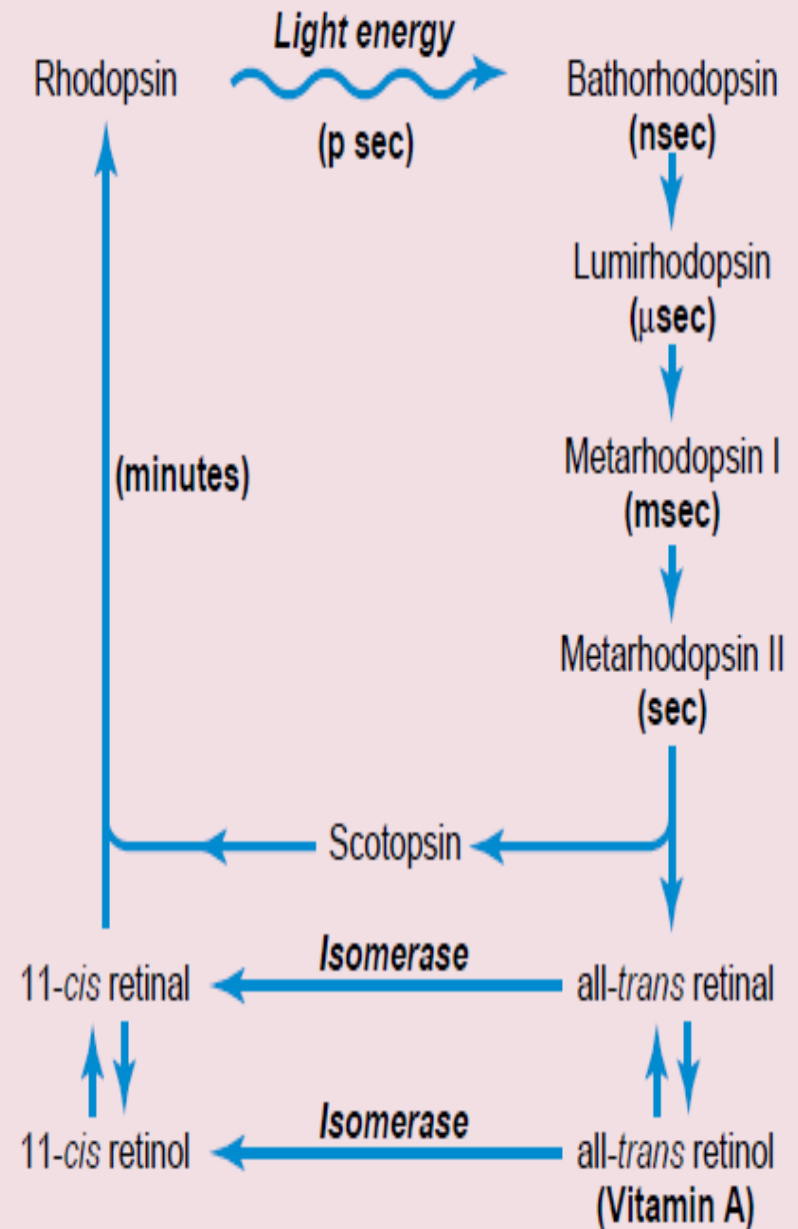
# RHODOPSIN CYCLING

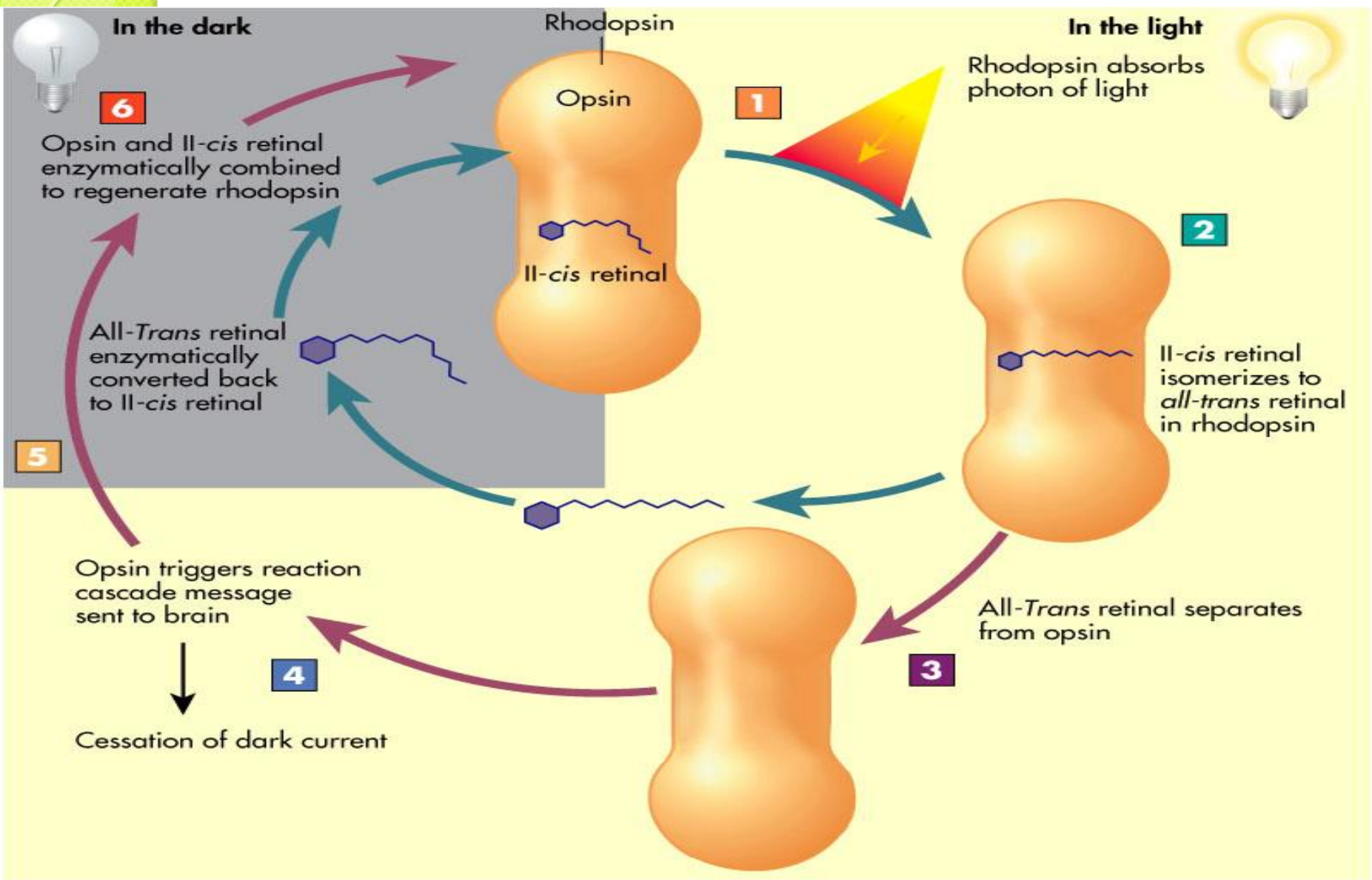


## -scotopsin retinal visual cycle

-The amount of rhodopsin in the receptors therefore 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.





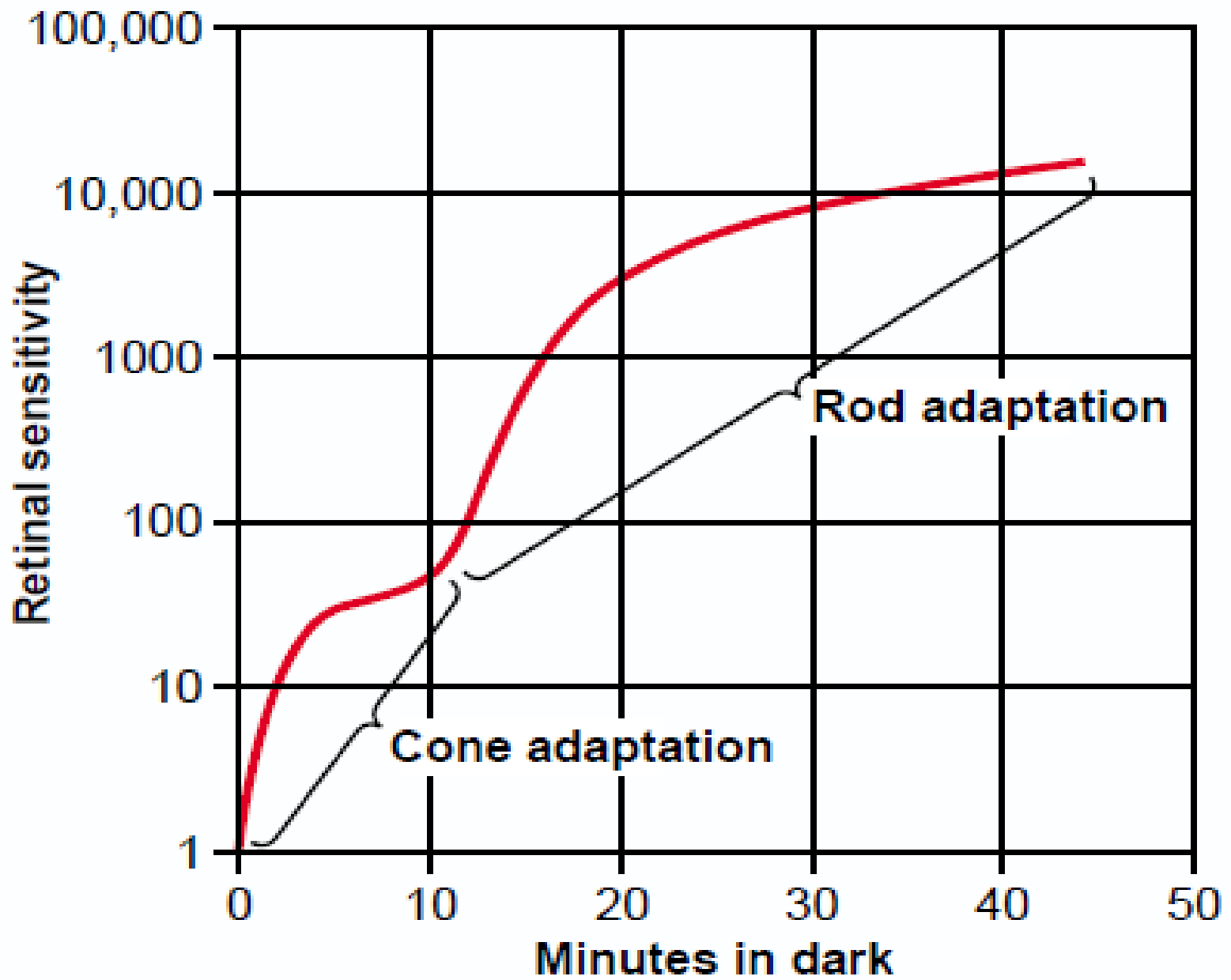
## **NYCTALOPIA:- ( night blindness)**

- 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:-

- - 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 rods to see in dark
- & 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 stimulates 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 to light)**



- **N.B** ( 20 min for dark adaptation are for regeneration of rhodopsin → increase sensitivity of rods 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 rods 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

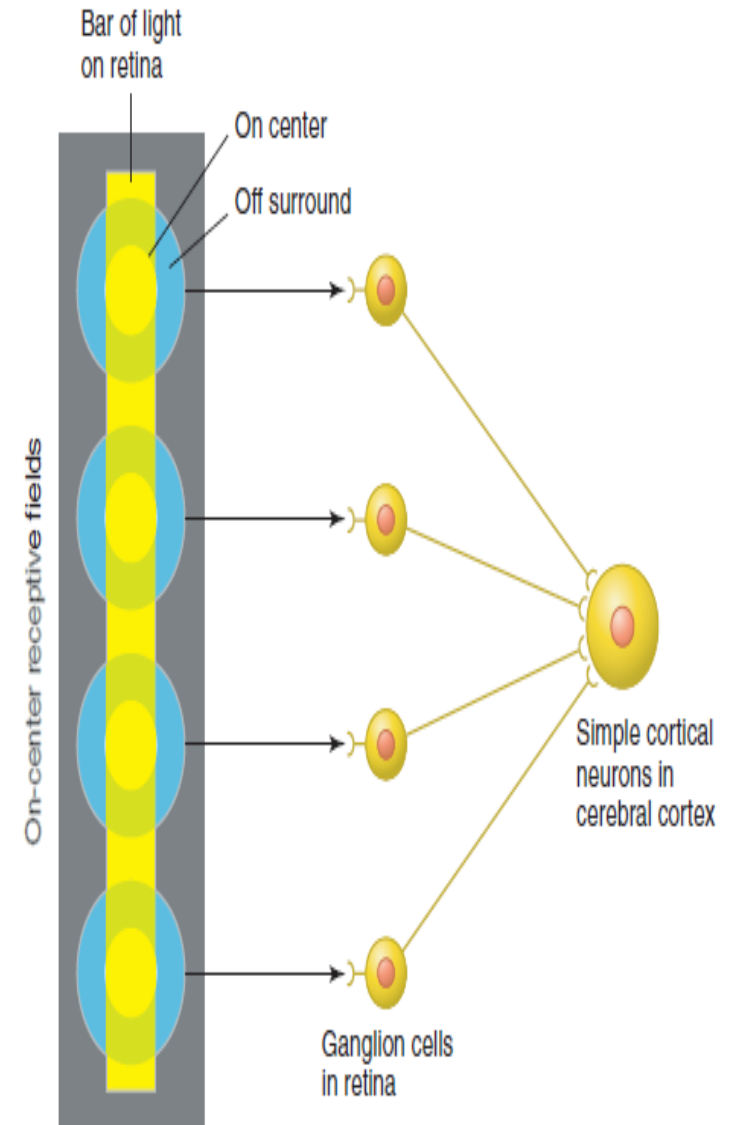
3-Y Cells // to Transmit Instantaneous & rapid Changes in the Visual Image , either rapid movement or rapid change in light intensity

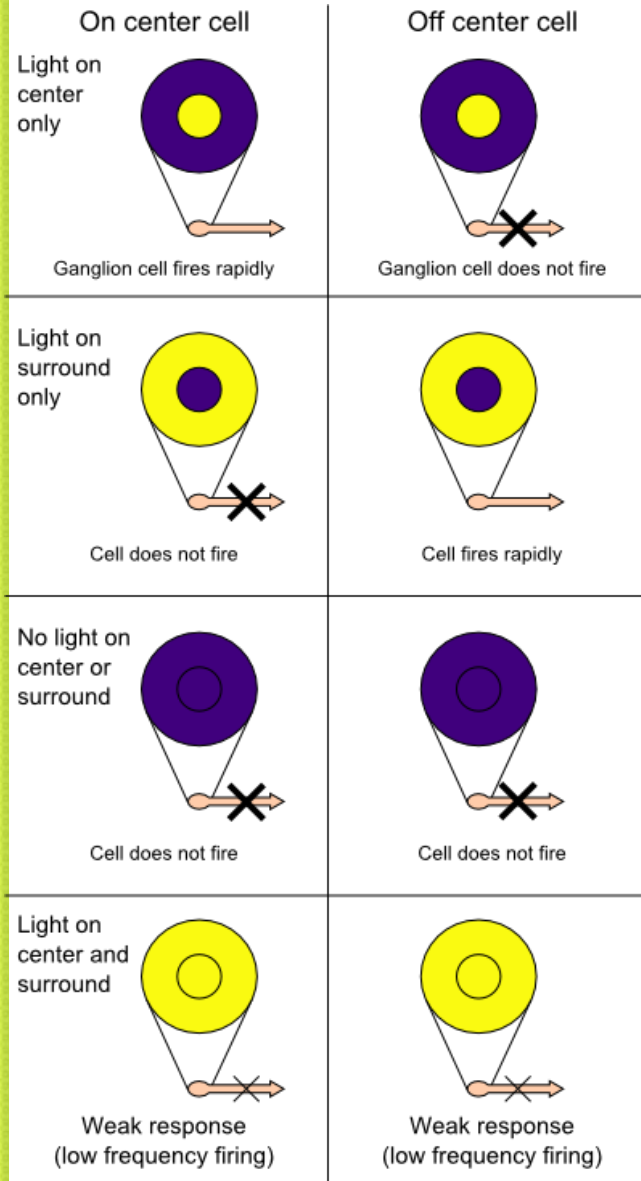


## Convergence of ganglion cells

-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



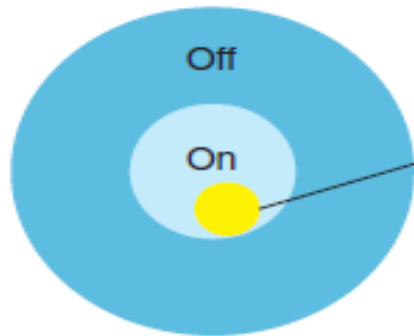


There are two types of retinal ganglion cells: "on-center" and "off-center".

- \*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 is stimulated by activation of the surround and inhibited by stimulation of the center
- \*Stimulation of 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
- \*-stimulation of both the center and surround produces only a mild response (due to mutual inhibition of center and surround).

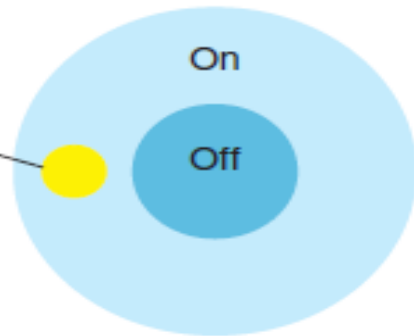
# Ganglion Cell Receptive Fields

**On-center Field**

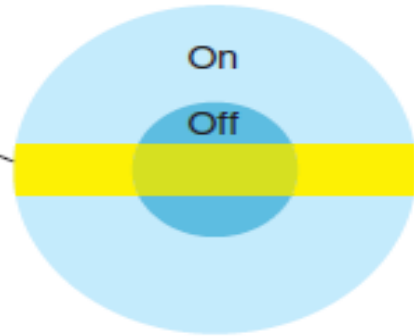
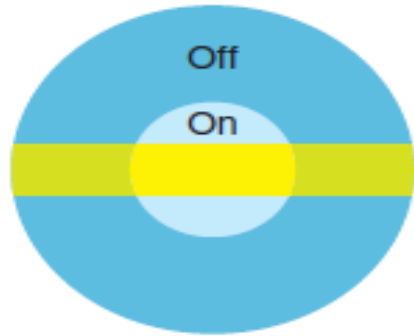


Light on center stimulates, light on surround inhibits, ganglion cell

**Off-center Field**



Light on center inhibits, light on surround stimulates, ganglion cell



Light across both center and surround is less effective at stimulating ganglion cell

*Thank you for  
listening*

