

**The Special Senses**  
**Vision - 3**  
**Photo-transduction**

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# Objectives

At the end of this lecture the student should be able to:

- List and compare functional properties of rods and cones in scotopic and photopic vision
- Know the convergence and its value
- To describe the photosensitive compounds
- Contrast the phototransduction process for rods and cones in light and dark and the ionic basis of these responses
- Know the meaning of nyctalopia
- Contrast the dark and light adaptation

# Physiology of Vision

- Stimulus: **Light**
- Receptor: **Retina** (Photoreceptors)

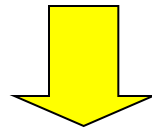
# Light

- **Definition:**
- 'Electromagnetic' radiation that is capable of exciting the human eye'
- **Extremely fast**

# Visible light & Duplicity Theory of vision

## Visible light Spectrum:

- Extends from 397 to 723nm
- Eye functions under two 2 conditions of illumination:
  - Bright light (Photopic) vision .. Cones
  - Dim light (Scotopic vision) ..Rods



Duplicity theory  
of vision

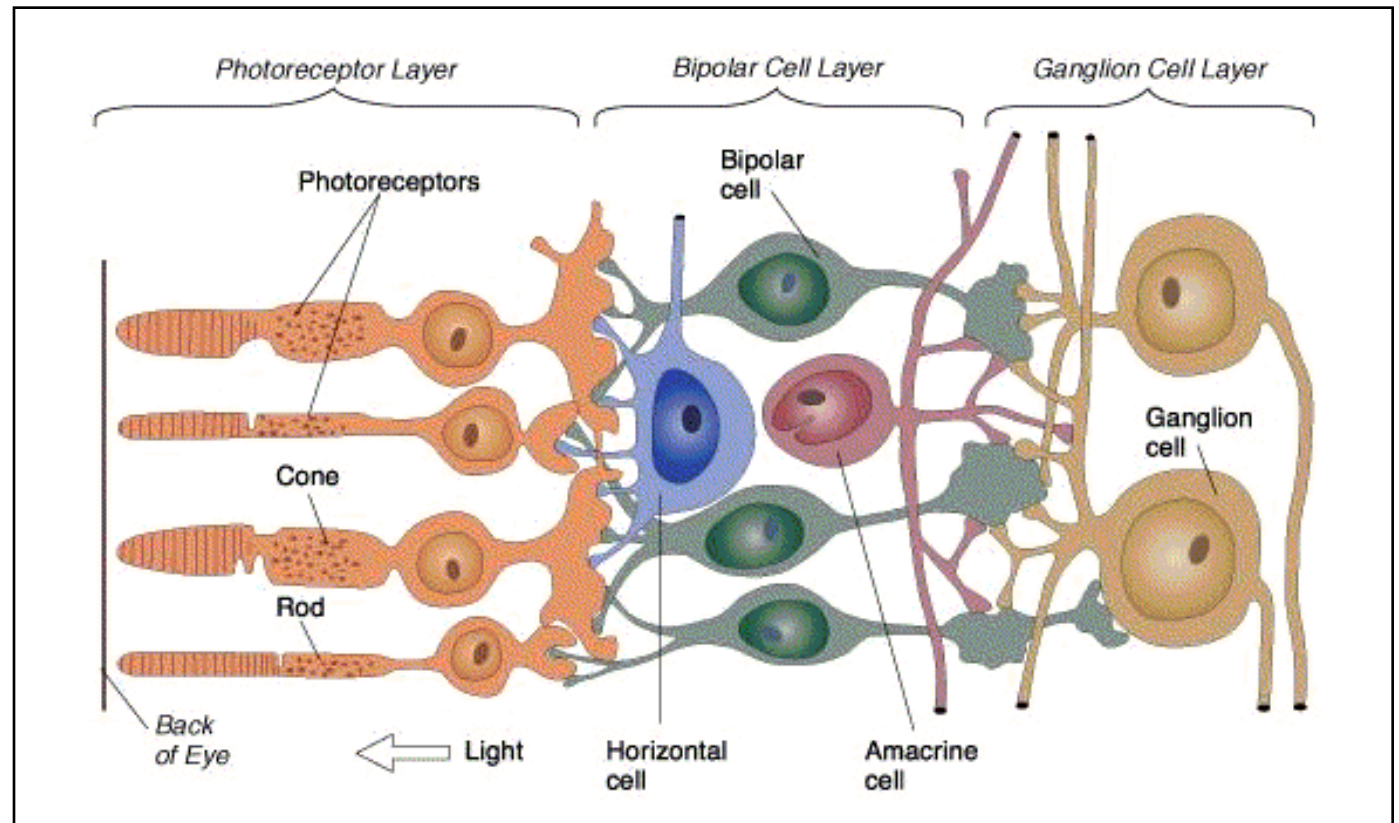


# Photoreceptors Rods & Cones

## Morphology & Distribution

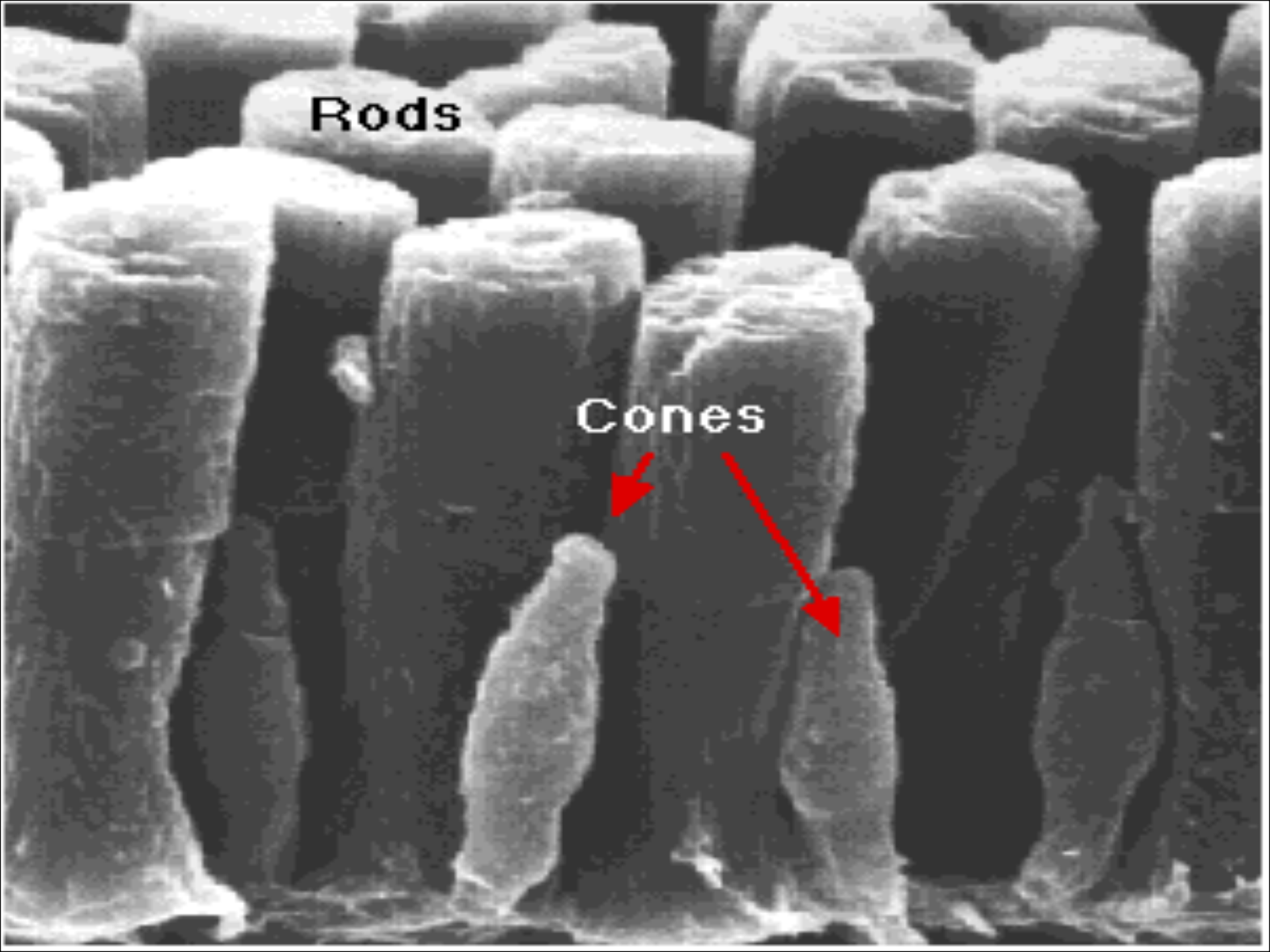
# Retina

Back of retina,  
pigment  
epithelium  
(Choroid)



← Light





Rods

Cones

# Photoreceptors

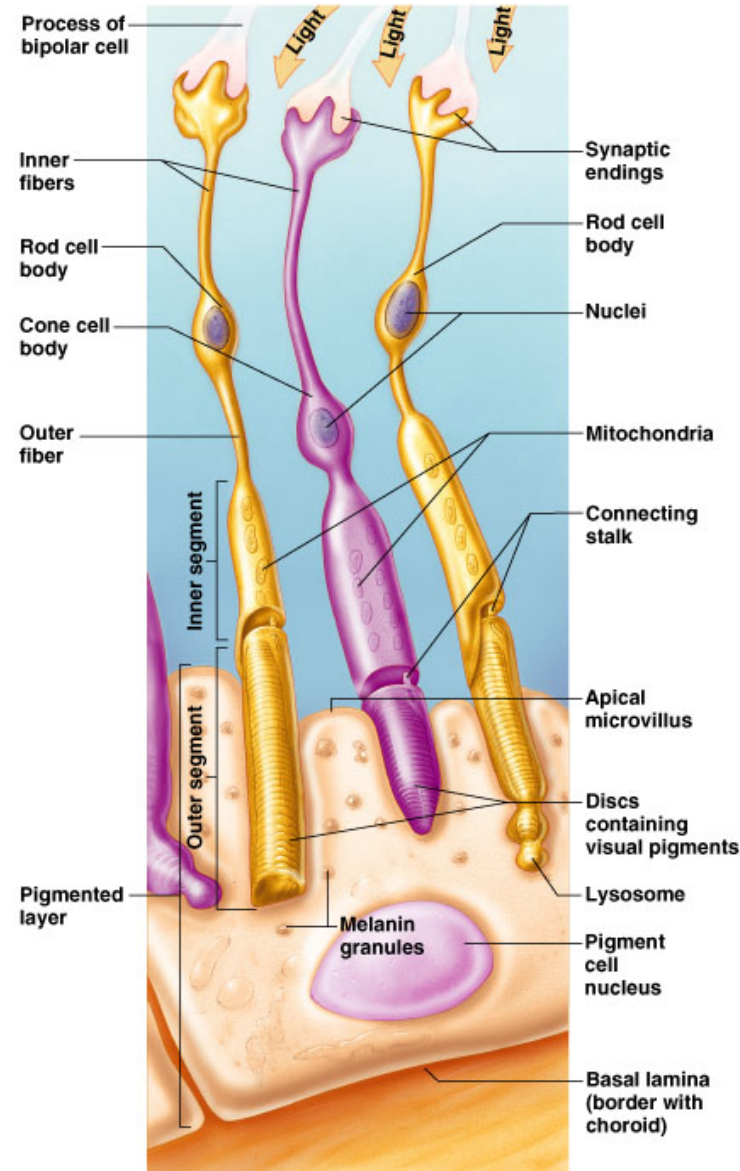


Figure 16.11

# Retina: photoreceptors

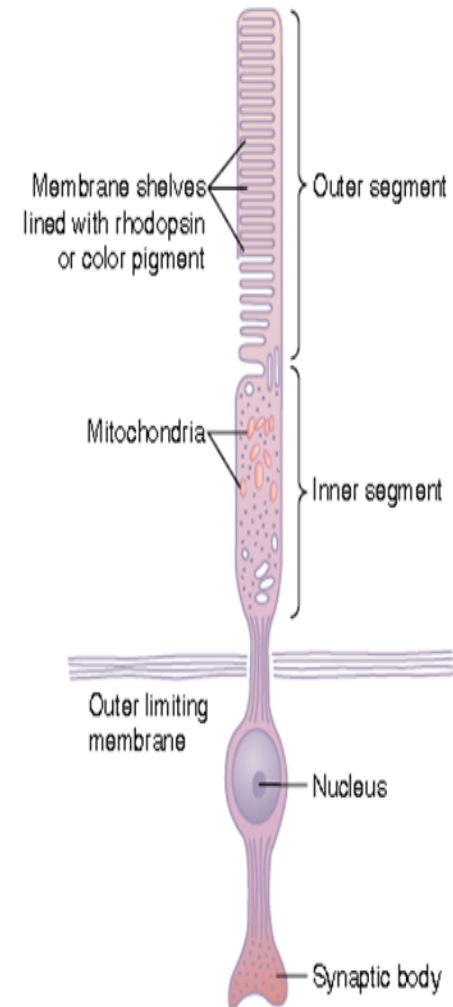
- 120,000,000 rods
- 6,000,000 cones

<b>Cones</b>	<b>Rods</b>
<b>Fovea</b>	<b>Periphery</b>
<b>High light levels</b>	<b>Low light levels</b>
<b>Color</b>	<b>Monochromatic</b>
<b>Good acuity</b>	<b>Poor acuity</b>

# Shape of rods & cones

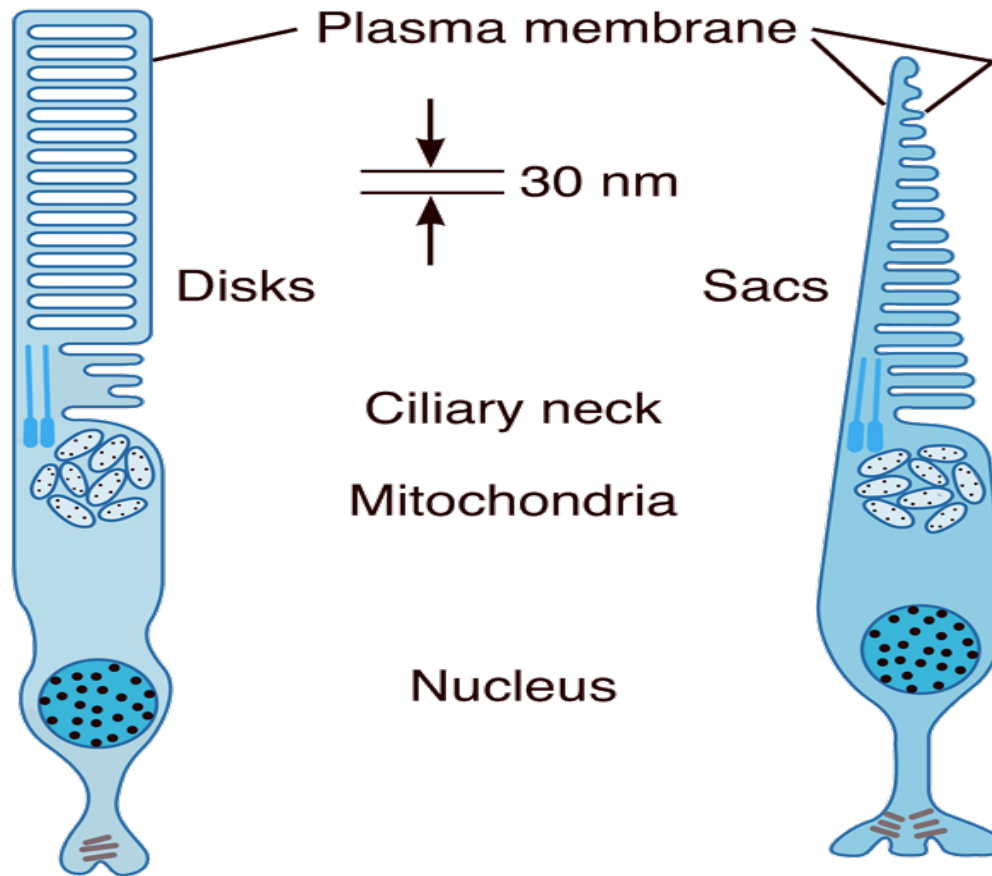
## (receptors of vision)

- 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 photosensitive pigments
- In rods it is big, rod like and contain one type of rhodopsin
- There are Na channels in the outer segment
- 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

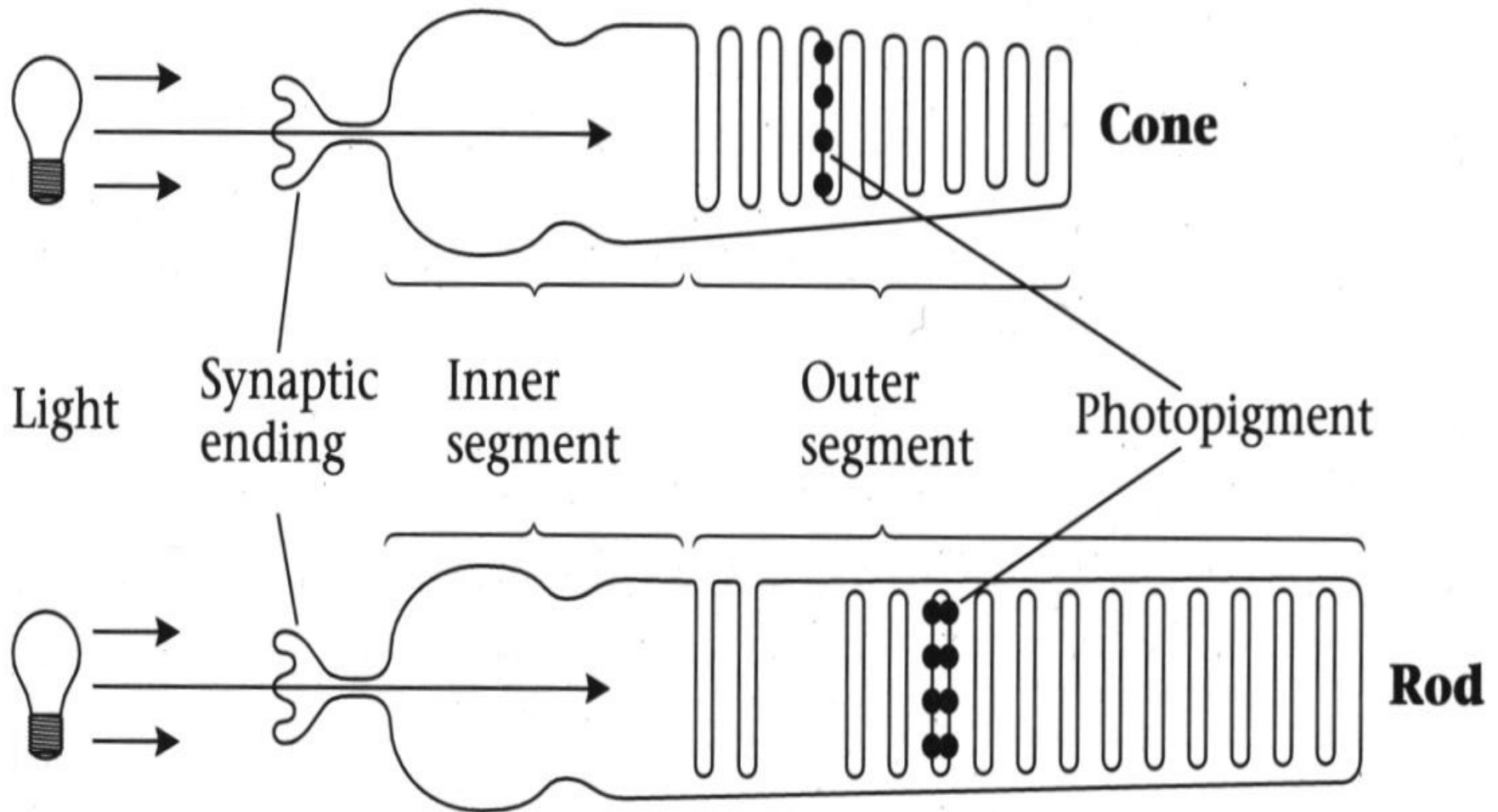


**Rod**

**Cone**

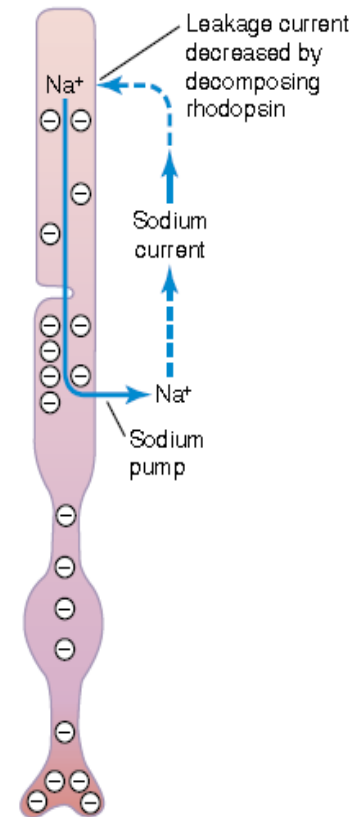


# Inside the rod and the cone



# Shape of rods & cones cont.

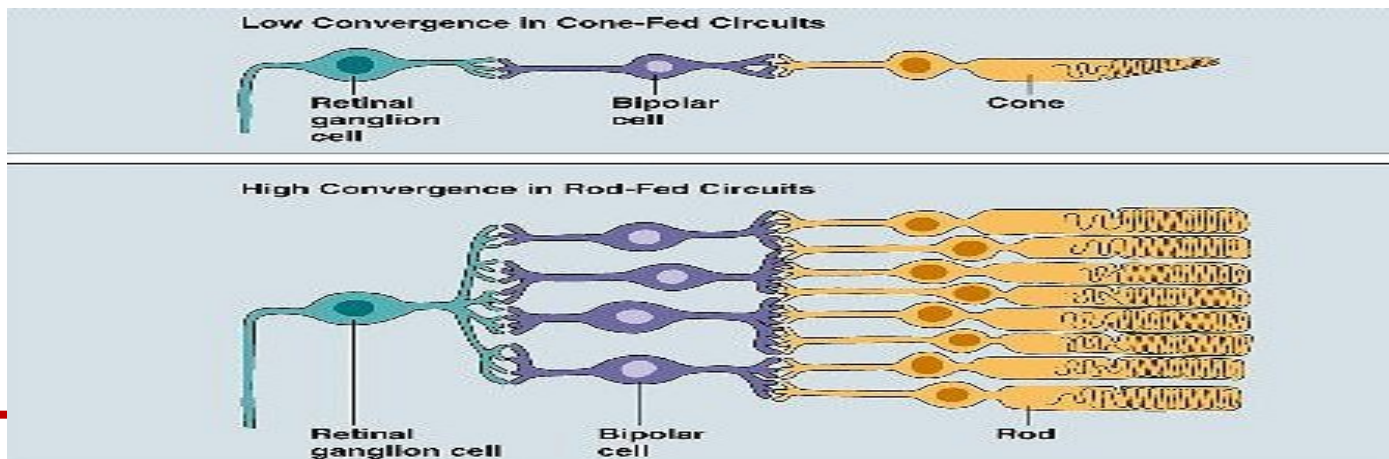
- The inner and outer segments are connected by a ciliary stalk through which the photosensitive compounds travel from the inner segment (where they are manufactured) to the outer segment of the rods and cones (where they are used)



# 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)





# Convergence *Cont.*

## High convergence of rods:

- several rods about 300 synapse with one bipolar cell & one ganglion cell
- high convergence/ decreases visual acuity = integrated information from large area of retina
- - but increases sensitivity to light i.e so low light threshold stimulate the rods.
- - 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.

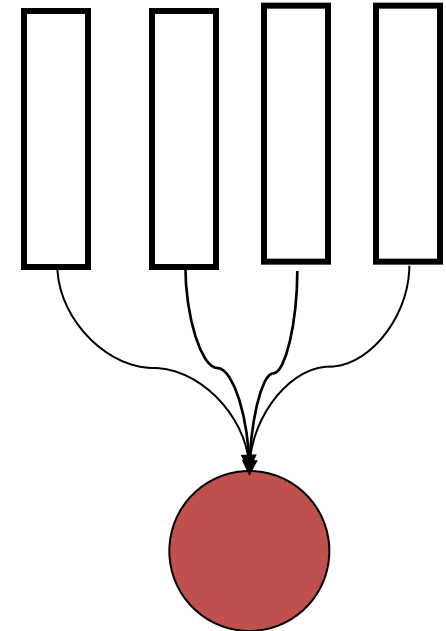
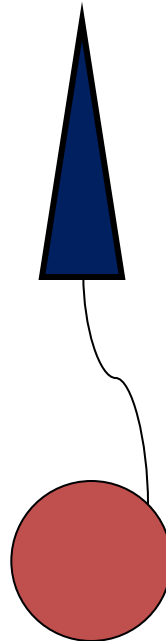
# Convergence

**Cones**

**Rods**

- **Photoreceptors**

- **Ganglion cells**



# **Electrophysiology of Vision**

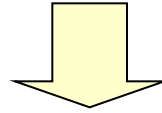
## **Genesis of electrical responses**

# Photosensitive Compounds

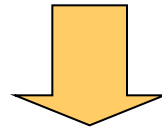
- 1. photosensitive pigment of cones (iodopsin) formed of :- Opsin protein(photopsin) + retinal (retinene 1 = aldehyde form of Vit A)
- 2-There are 3 types of iodopsin in cones (I,II,III ) each respond to a certain wave length of light for color vision.
- 3-In Rods its rhodopsin formed of Scotopsin protein+ retinal (retinene 1 = aldehyde form of Vit A)
- 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

# Retinal photoreceptors mechanism

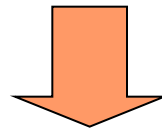
Light



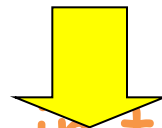
Absorption by photosensitive substances



Structural change in photosensitive substances

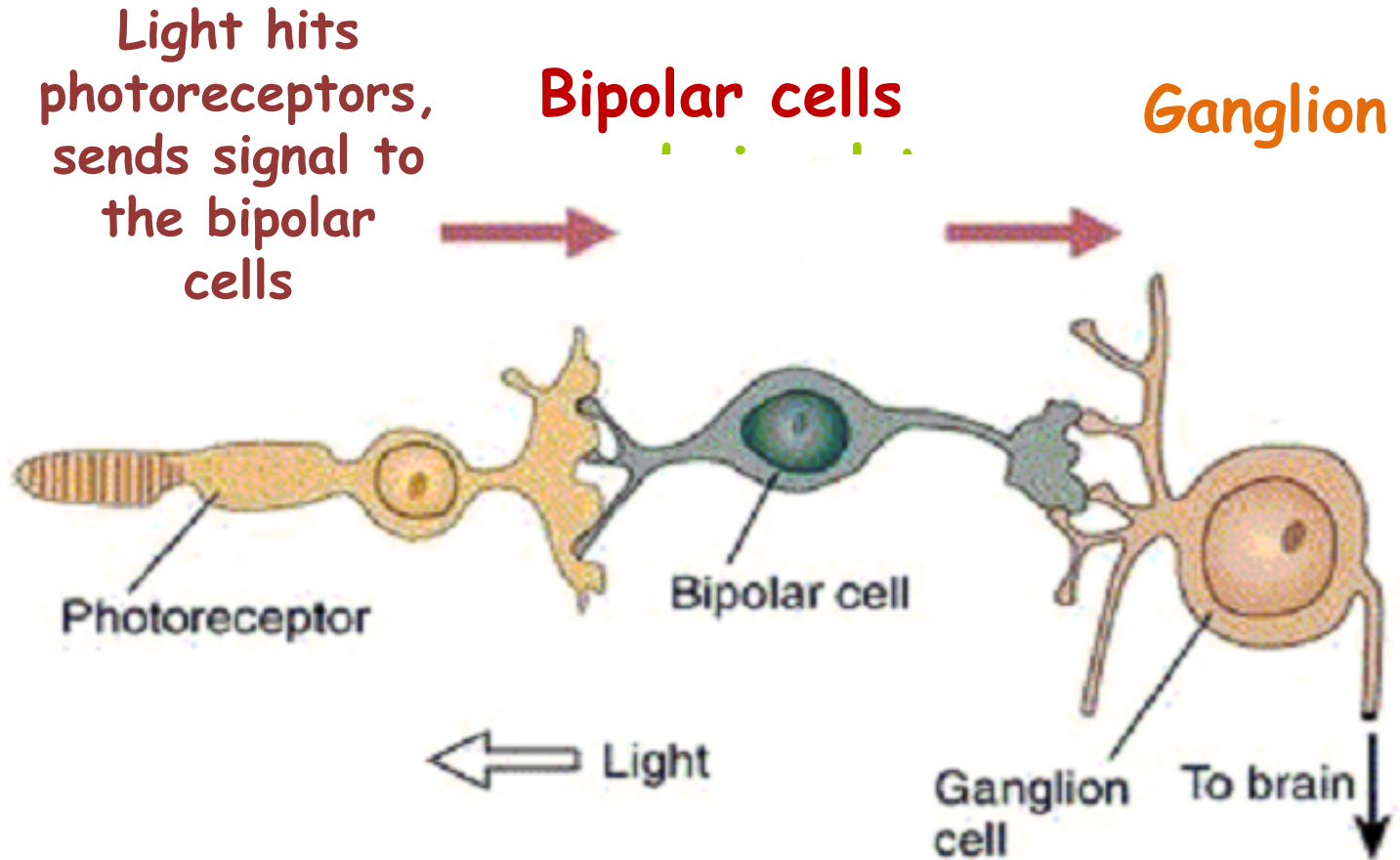


Phototransduction

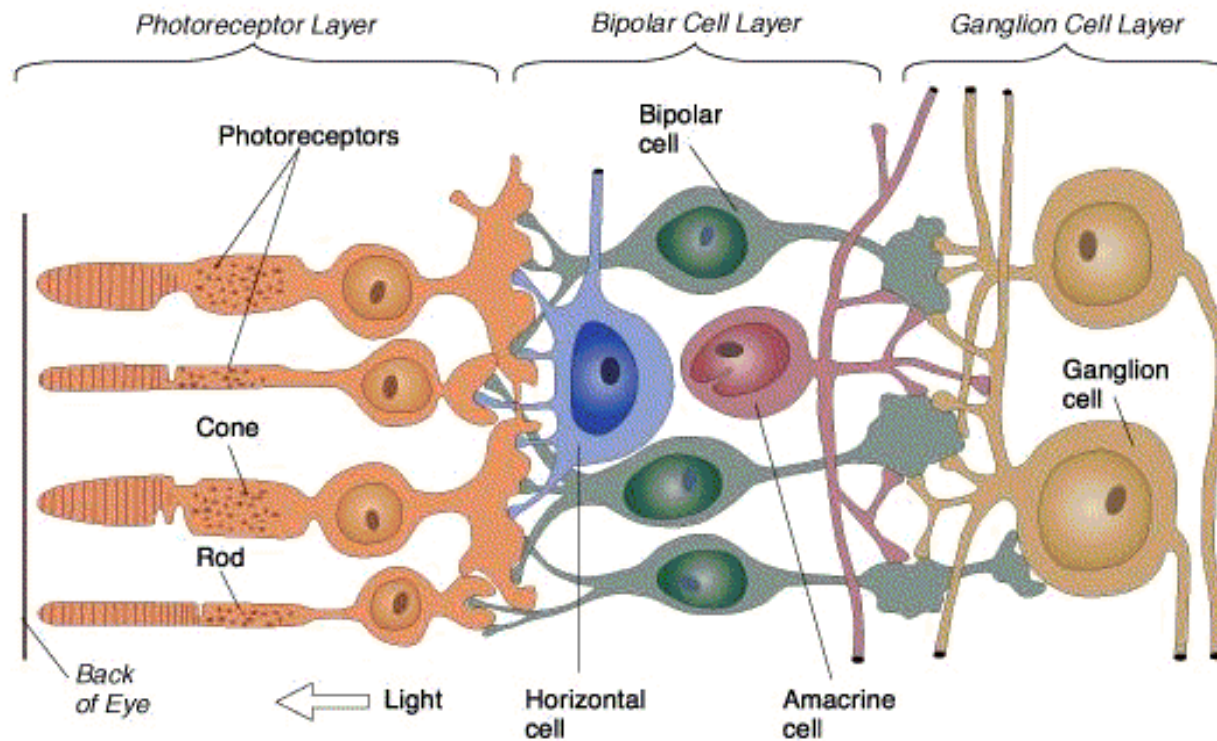


Action potential in the optic nerve

# Retina: Neural Circuitry



# Retina



# Genesis of photoreceptor potential -1

- Rods & 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



# Genesis of photoreceptor potential -2

## Electric recording in Retinal cells:

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

# Photoreceptor pigments

# Photoreceptor pigments

- **Composition:**
  - **Retinene1 (Aldehyde of vitamin A)**
    - Same in all pigments
  - **Opsin (protein)**
    - Different amino acid sequence in different pigments
- **Rhodopsin (Rod pigment):**
  - **Retinene + scotopsin**

## Photoreceptor compounds<sup>-cont</sup>

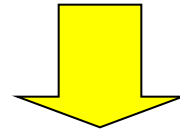
### Rhodopsin (visual purple, scotopsin):

#### Activation of rhodopsin:

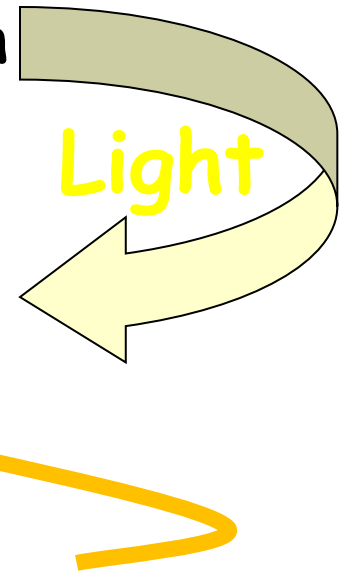
- In the dark:

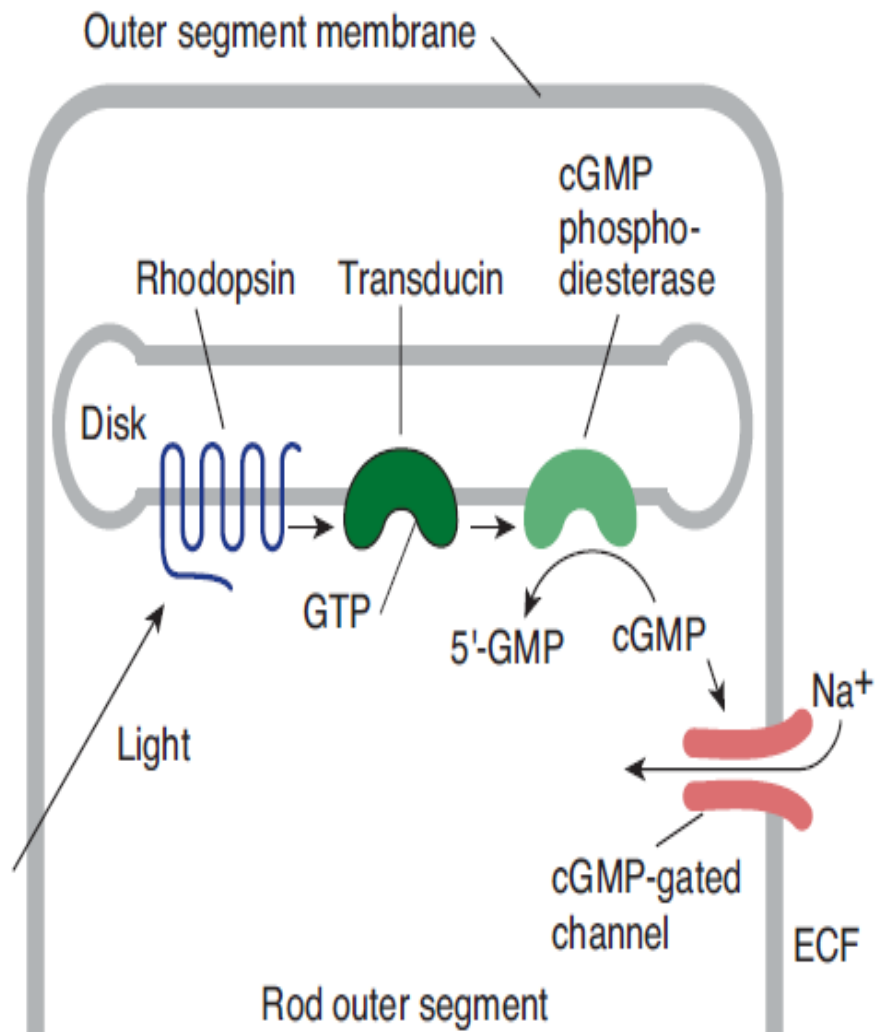
retinene1 in the 11-*cis* configuration

Metarhodopsin II



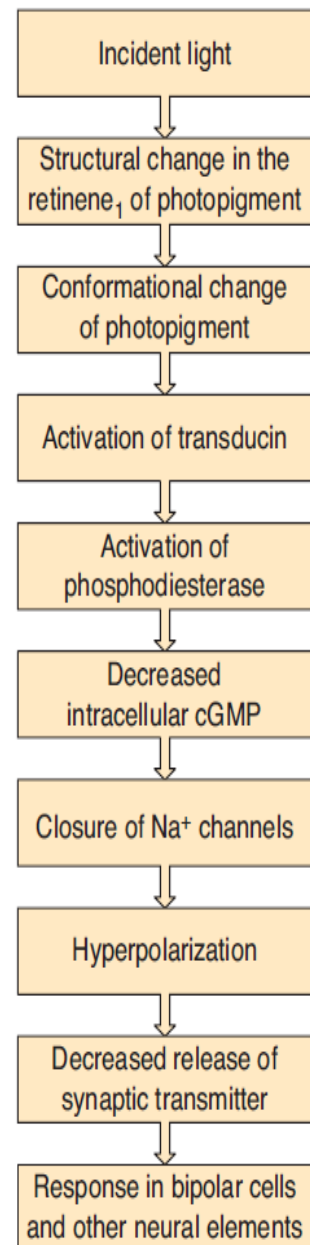
Closure of Na channels





**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.



Change in photopigment



Metarhodopsin II



Activation of transducin



Activation of phosphodiesterase



Decrease IC cyclic GMP



Closure of Na channels



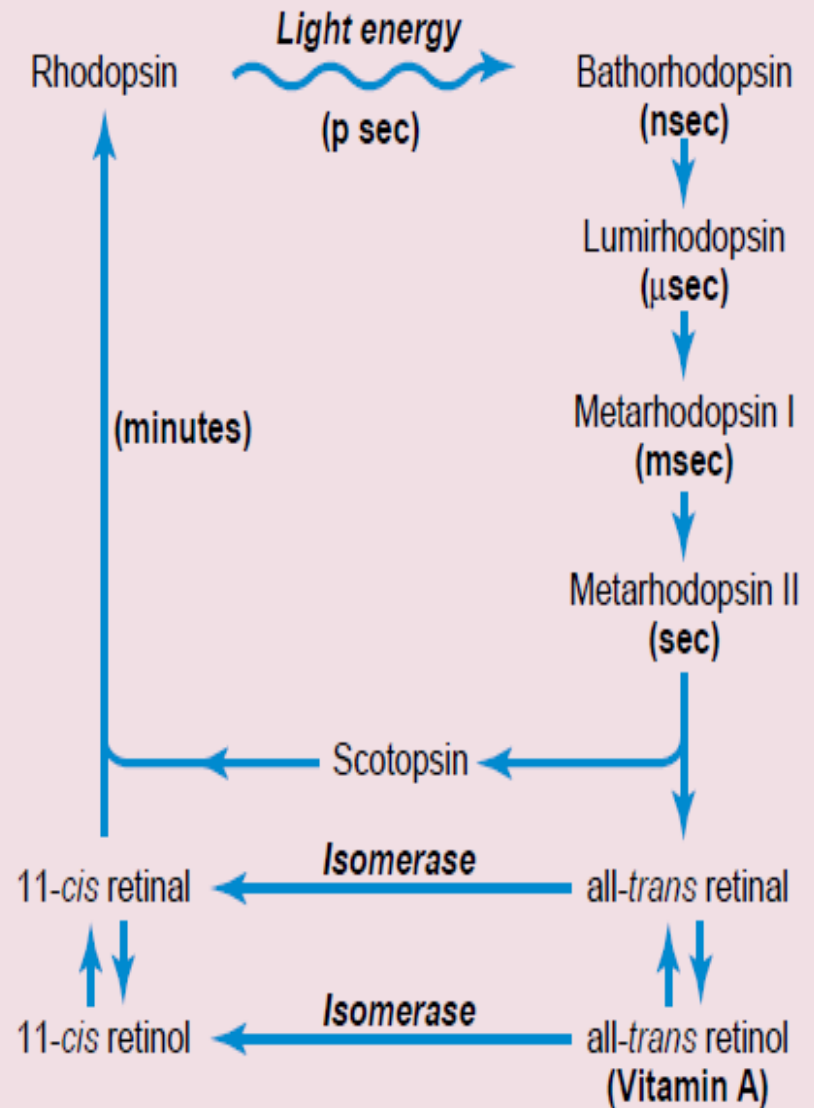
Hyperpolarization of receptor  
Decrease release of synaptic transmitter  
Action potential in optic nerve fibres

# 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*

# Scotopsin Retinal Visual Cycle

- ❑ The 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.

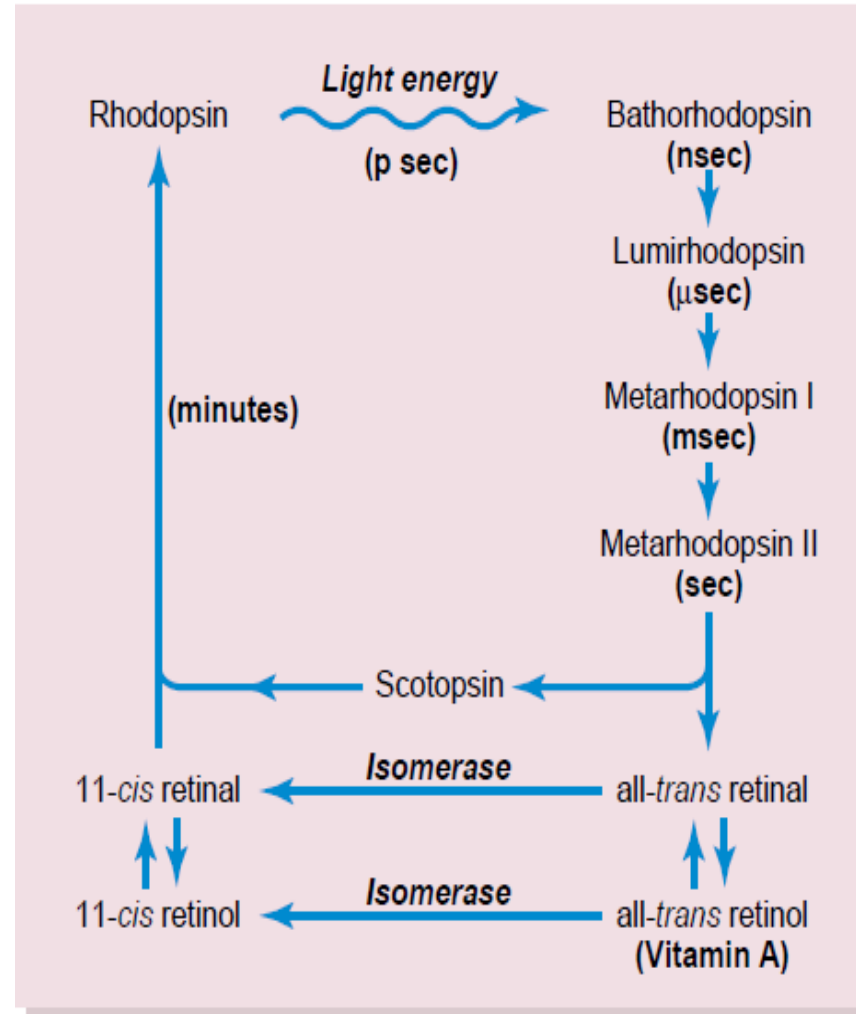




# Photochemistry of Color Vision by the Cones

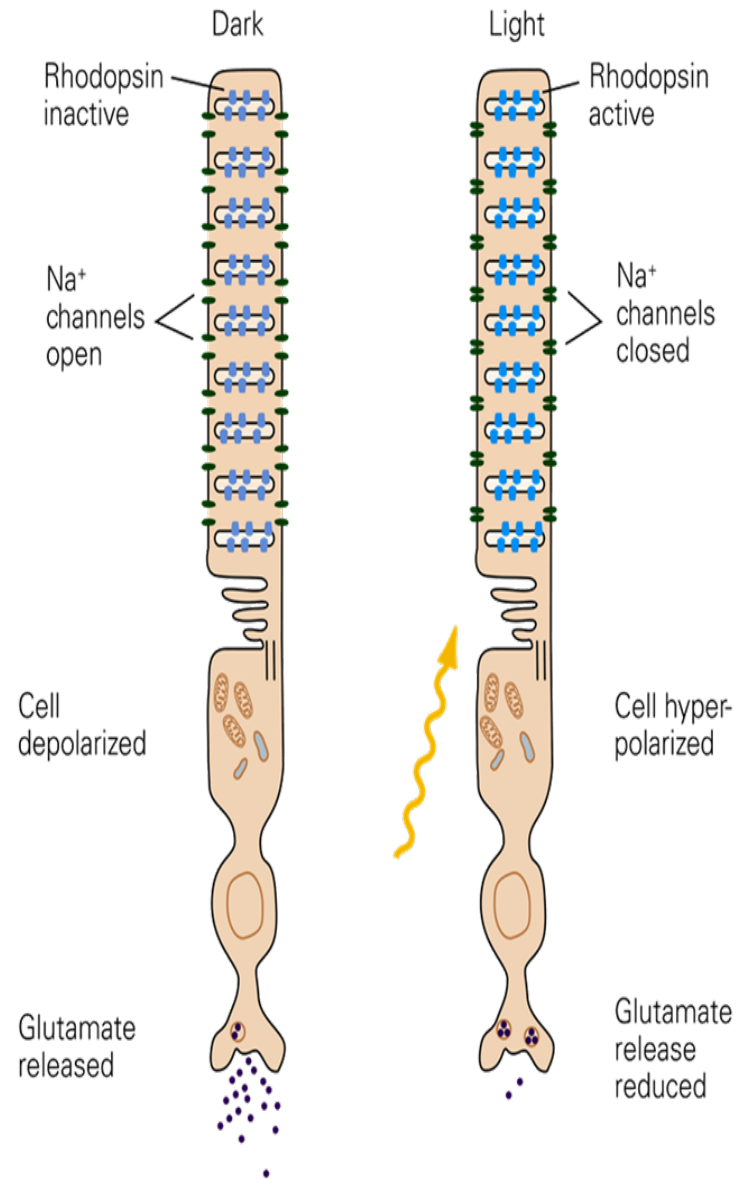
## Photopsins Retinal Visual Cycle

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

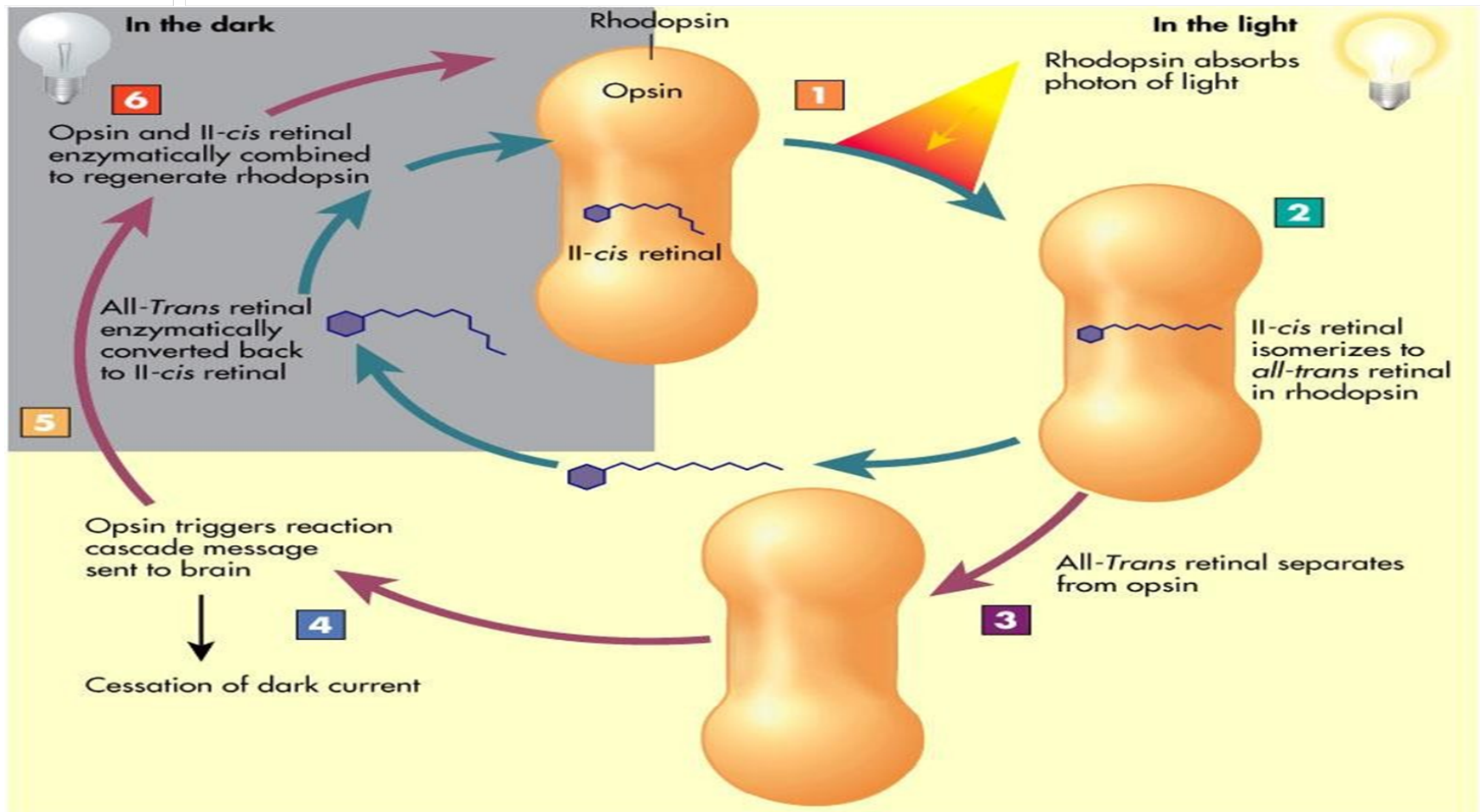


- In the dark, there is an increase in cyclic *GMP* levels, which produces an  $\text{Na}^+$  inward current (or "dark current") and depolarization of the photoreceptor membrane (the cell remains at about  $-40\text{mV}$ ), which leads to steady release of glutamate at dark
- In the light, there is a decrease in cyclic *GMP* levels, which closes  $\text{Na}^+$  channels in the photoreceptor membrane, reduces inward  $\text{Na}^+$  current, and produces hyperpolarization.
- Hyperpolarization of the photoreceptor membrane decreases the release of glutamate, from the synaptic terminals of the photoreceptor (this creates a negative potential on the inside of the entire cell of about  $-70$  to  $-80\text{mV}$ )

A Phototransduction and neural signaling



# Rhodopsin Cycling



# Dark adaptation

# Dark adaptation

□ Increased sensitivity of the photoreceptors when vision shifts from **bright** to dim light

# Dark Adaptation

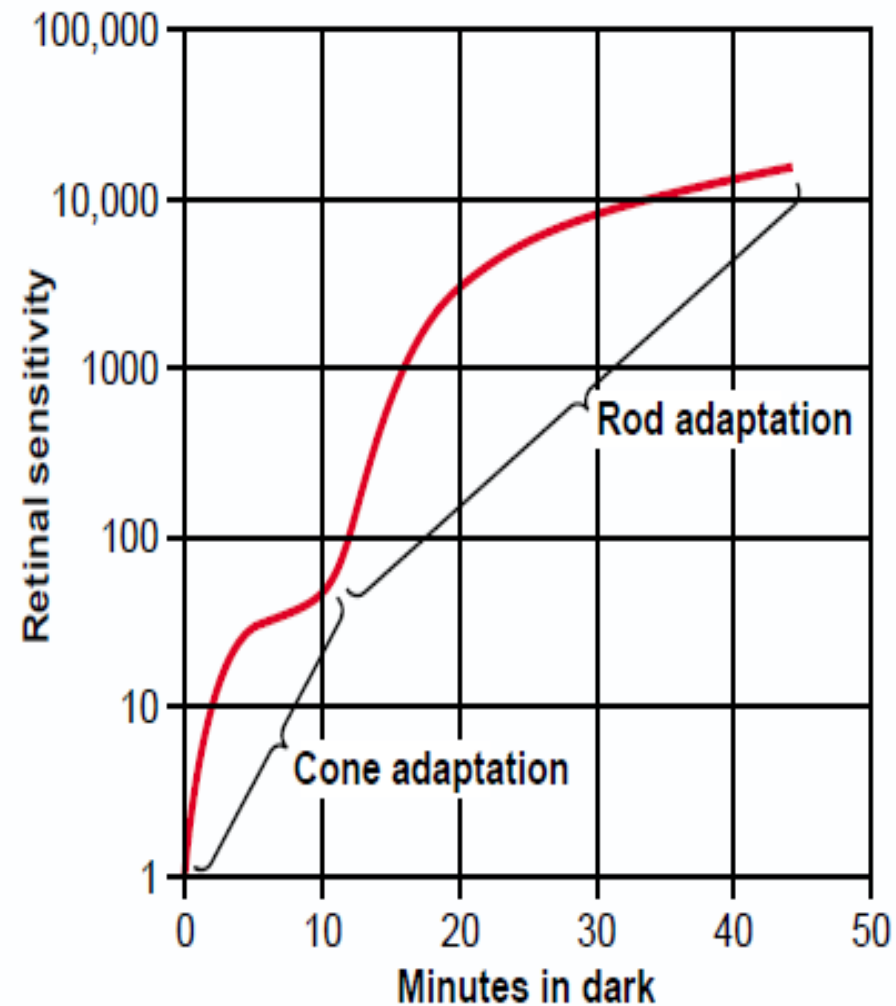
- ❑ Reaches max in 20 minutes
- ❑ First 5 minutes ..... threshold of cones ↓
- ❑ 5 to 20 mins ..... ↑ Sensitivity of rods

Mechanism of dark adaptation:

↑ Regeneration of rhodopsin

# Adaptation Curve

- This chart shows the course of dark adaptation when a person is exposed to total darkness after having been exposed to bright light for several hours.
- Note that the sensitivity of the retina is very low upon first entering the darkness, but within 1 minute, the sensitivity has already increased 10-fold
- That is, the retina can respond to light of one tenth the previously required intensity.
- At the end of 20 minutes, the sensitivity has increased about 6000-fold, and at the end of 40 minutes, it has increased about 25,000-fold.



# Dark Adaptation

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 dim light, 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.



# 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

# Other mechanisms of Light and Dark Adaptation

- in addition to adaptation caused by changes in concentrations of rhodopsin or colour photochemicals, the eye has two other mechanisms for light and dark adaptation:

## 1. A change in pupillary size:

- This change can cause adaptation of approximately 30-fold within a fraction of a second because of changes in the amount of light allowed through the pupillary opening

## 2. Neural adaptation:

- Involving the neurons in the successive stages of the visual chain in the retina itself and in the brain. That is, when light intensity first increases, the signals transmitted by the bipolar cells, horizontal cells, amacrine cells, and ganglion cells are all intense. However, most of these signals decrease rapidly at different stages of transmission in the neural circuit

# NYCTALOPIA:- ( night blindness)

- Vitamin A (main source of retinal of rhodopsin), deficiency cause rods , cones degeneration & loss of rods
- This condition is called night blindness because the amount of light available at night is too little to permit adequate vision in vitamin A-deficient persons.
- *-- R / Intravenous vit A if receptors are well.*



THANK YOU