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)

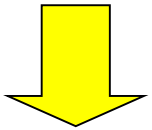
Light

- **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

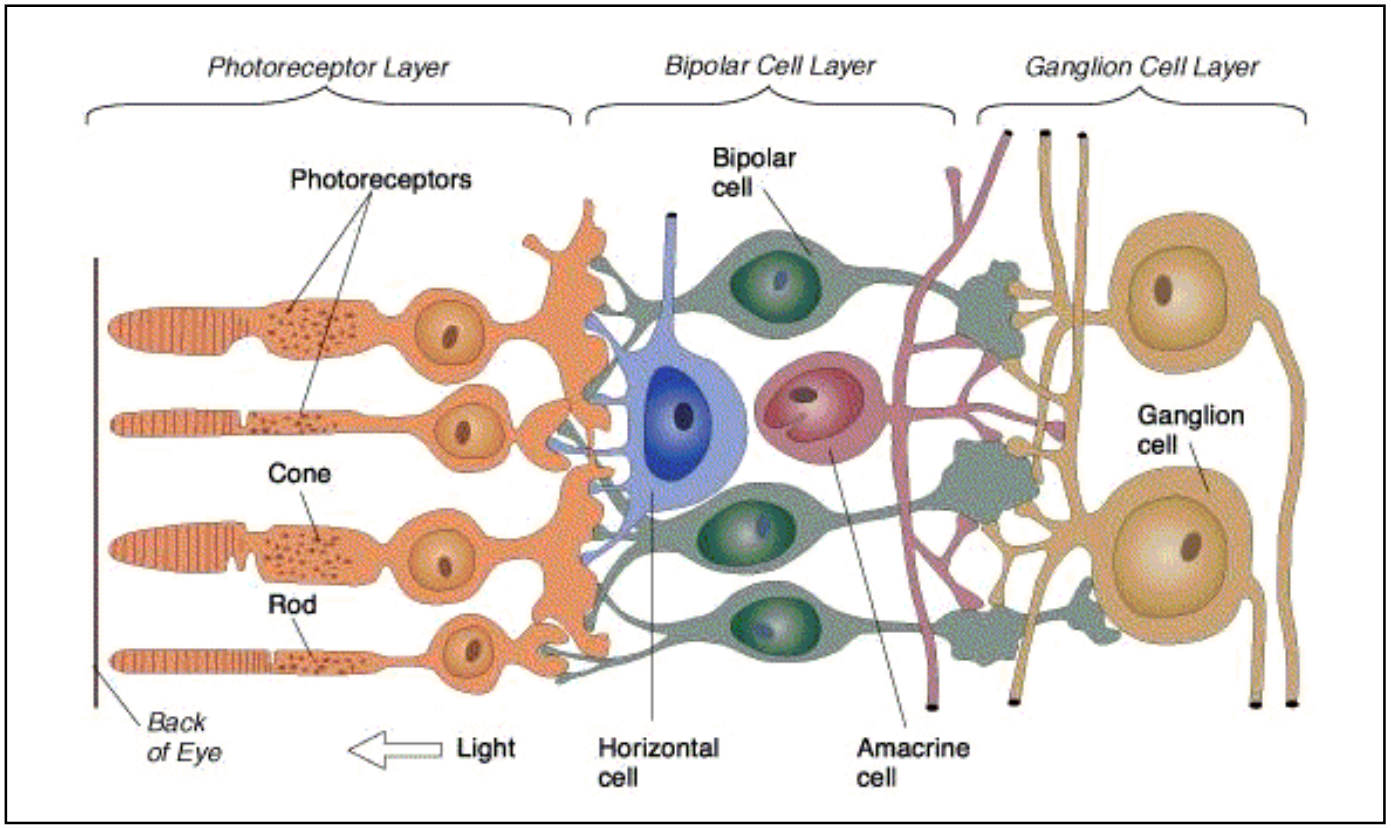
Photoreceptors
Rods & Cones

Morphology & Distribution

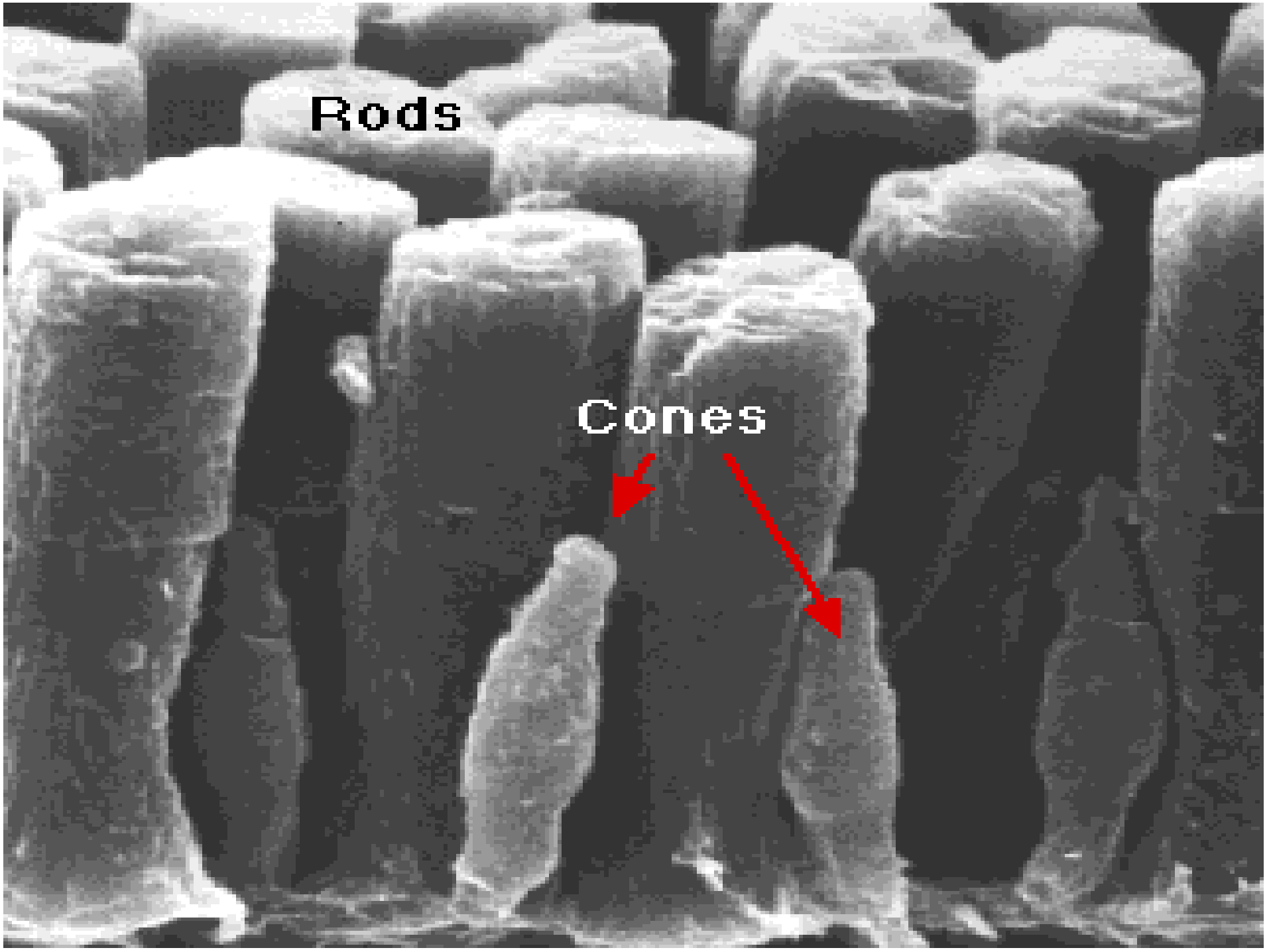
Retina

Back of retina, pigment epithelium

(Choroid)



Light


Rods
Cones

Photoreceptors

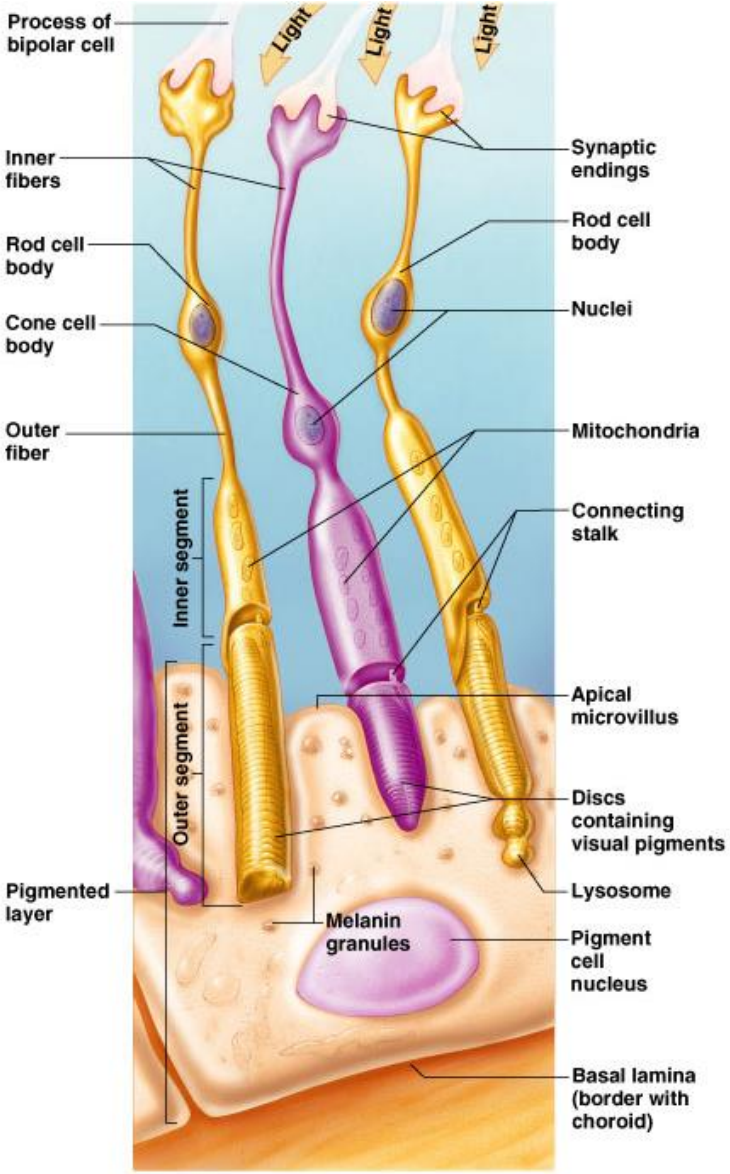


Figure 16.11

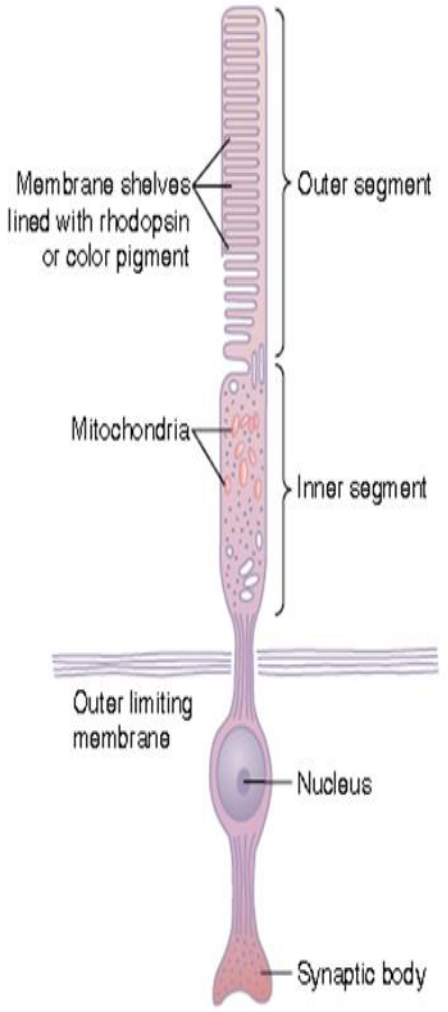
Retina: photoreceptors

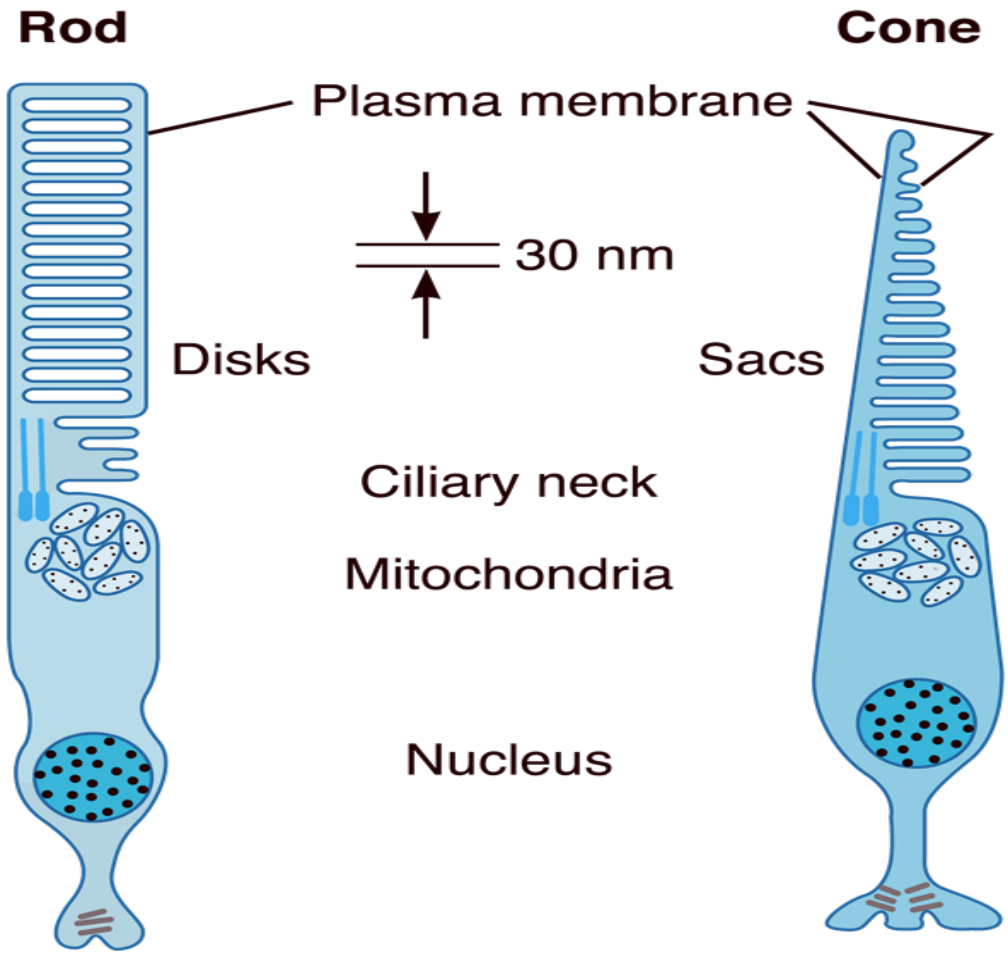
- 120,000,000 rods
- 6,000,000 cones

Cones	Rods
Fovea	Periphery
High light levels	Low light levels
Color	Monochromatic
Good acuity	Poor acuity

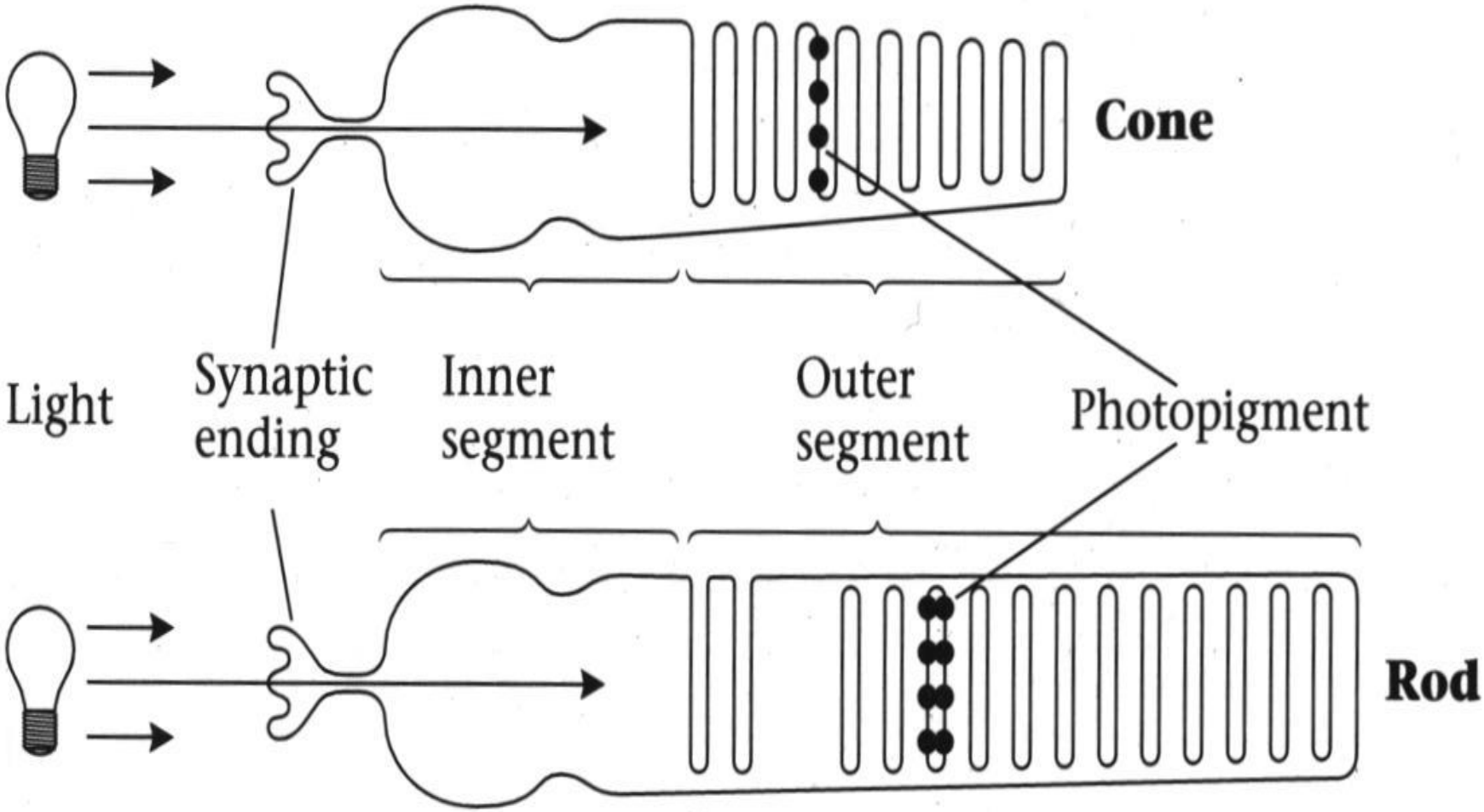
Shape of rods & cones
(receptors of vision)

- 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, rode 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



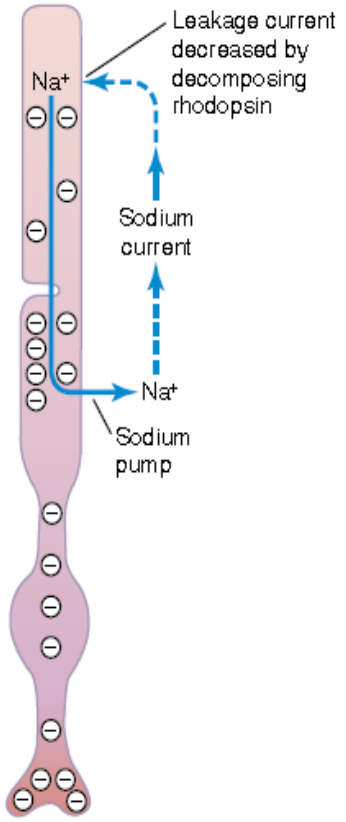

Rod
Cone
Plasma membrane
30 nm
Disks
Sacs
Ciliary neck
Mitochondria
Nucleus

Inside the rod and the cone



Shape of rods & cones cont.

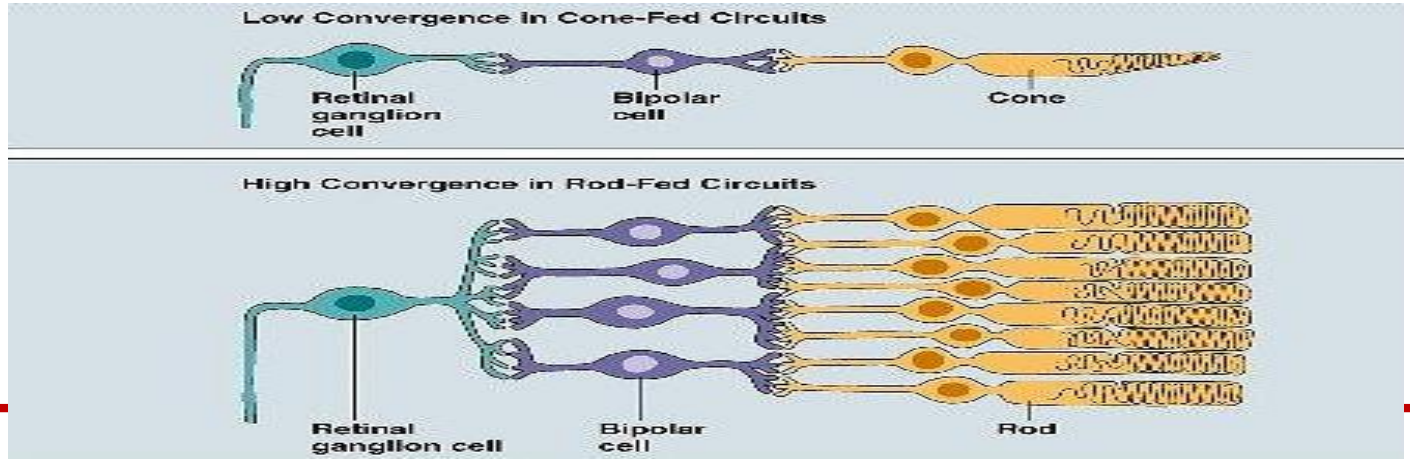
- The inner and outer segments are connected by a ciliary stalk through which the photosensitive compounds travel from the inner segment (where they are manufactured) to the outer segment of the rods and cones (where they are used)



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.

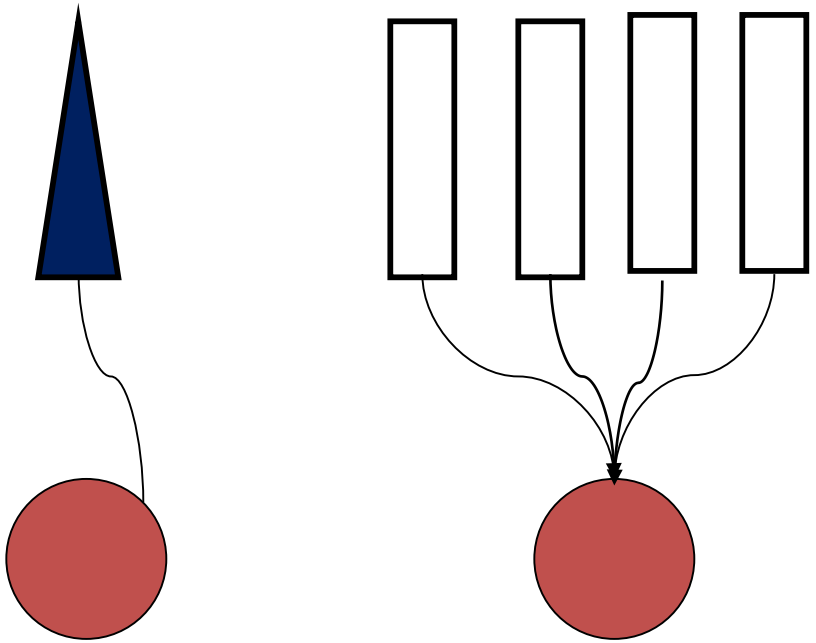
High convergence of rods:

- 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 rode& 6 million cone converge on 1.2 million optic nerve fibers , (126 million receptors on 1.2 million nerve fiber)so convergence is 105 receptor : 1 fiber.

Convergence

Cones Rods

- Photoreceptors
- Ganglion cells



Electrophysiology of Vision

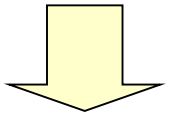
Genesis of electrical responses

Photosensitive Compounds

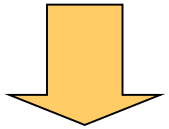
- 1. photosensitive pigment of cones (iodopsine) formed of :- Opsin protein(photopsin) + retinal (retinene 1 = aldhyde form of Vit A)
- 2-There are 3 types of iodopsin in cones (I,II,III) each respond to a certain wave length of light for color vision.
- 3-In Rods its rhodopsin formed of Scotopsin protein+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

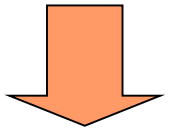
Light



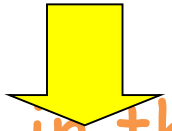
Absorption by photosensitive substances



Structural change in photosensitive substances



Phototransduction



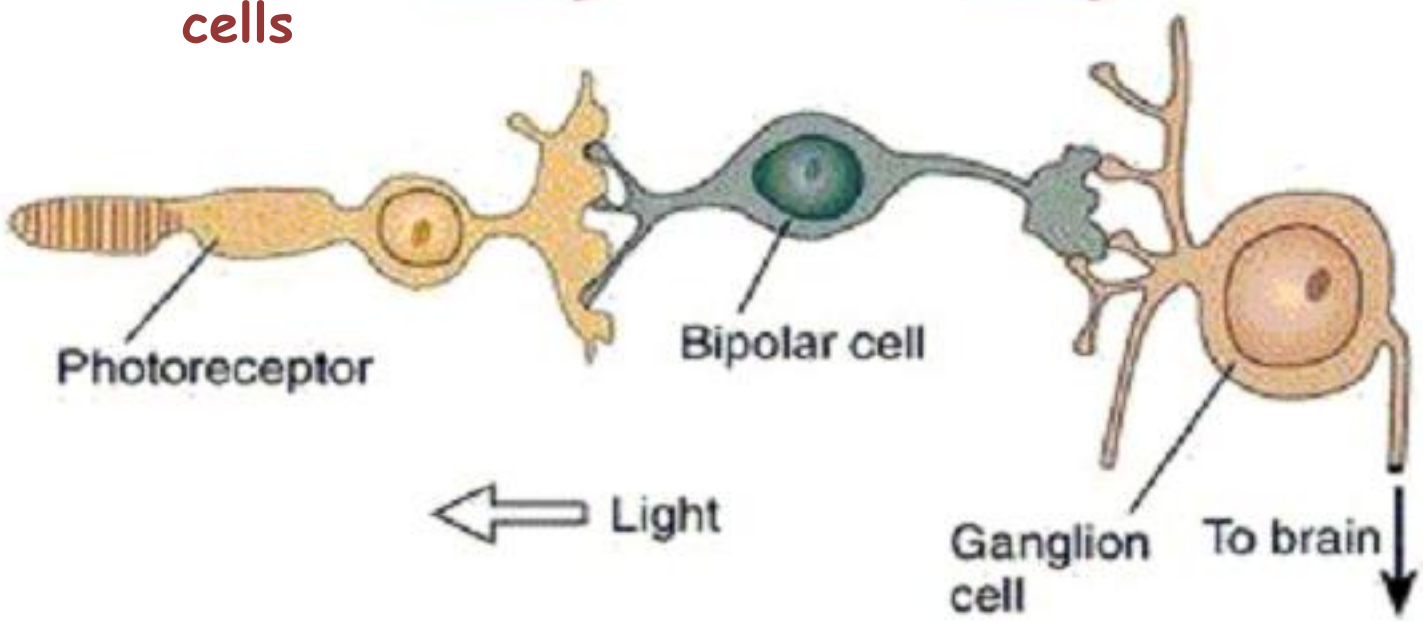
Action potential in the optic nerve

Retina: Neural Circuitry

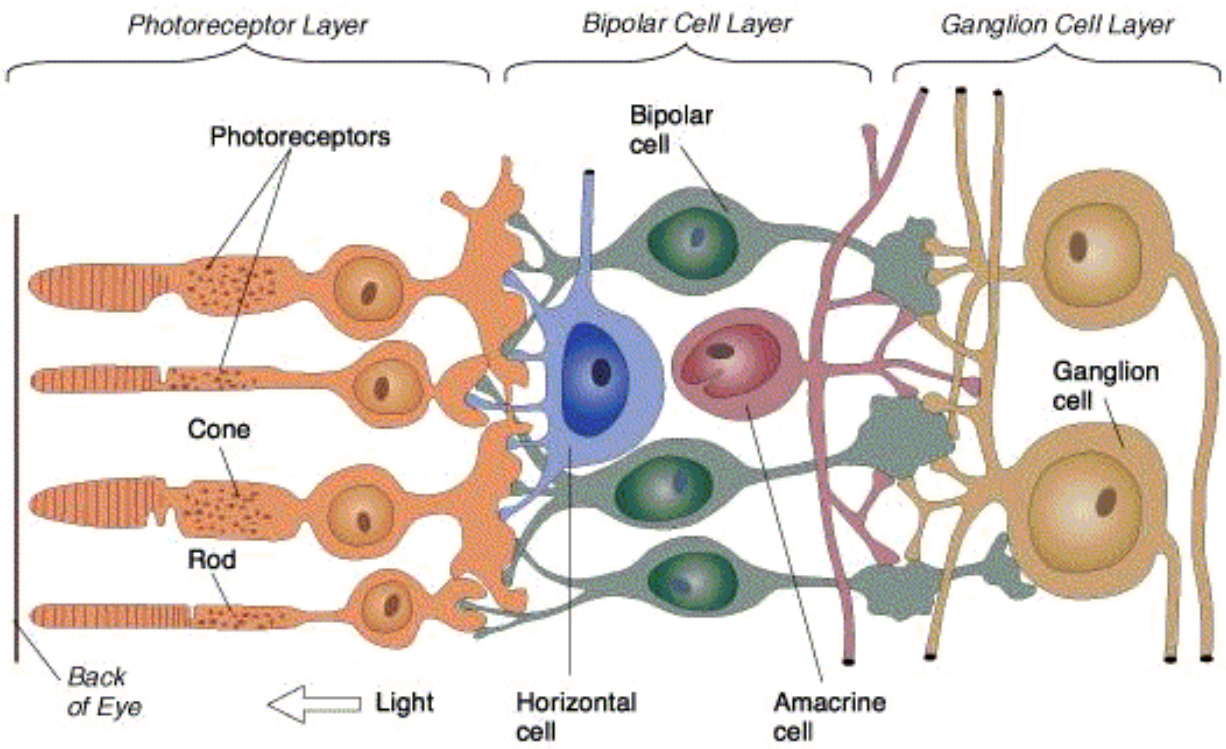
Light hits photoreceptors, sends signal to the bipolar cells

Bipolar cells

Ganglion



Retina


Photoreceptor Layer
Bipolar Cell Layer
Ganglion Cell Layer
Photoreceptors
Bipolar cell
Cone
Rod
Ganglion cell
Back of Eye
Light
Horizontal cell
Amacrine cell

Electrophysiology of Vision

Electric recording in Retinal cells:

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

Photoreceptor pigments

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**

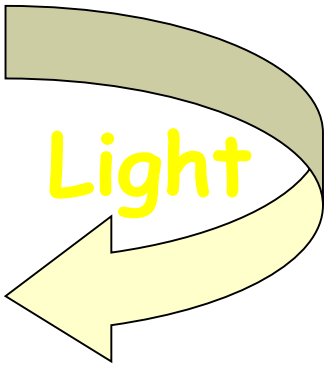
Photoreceptor compounds-cont

Rhodopsin (visual purple, scotopsin):

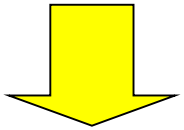
Activation of rhodopsin:

- **In the dark:**

retinine1 in the 11-*cis* configuration



All-*trans* isomer



Metarhodopsin II

Closure of Na channels

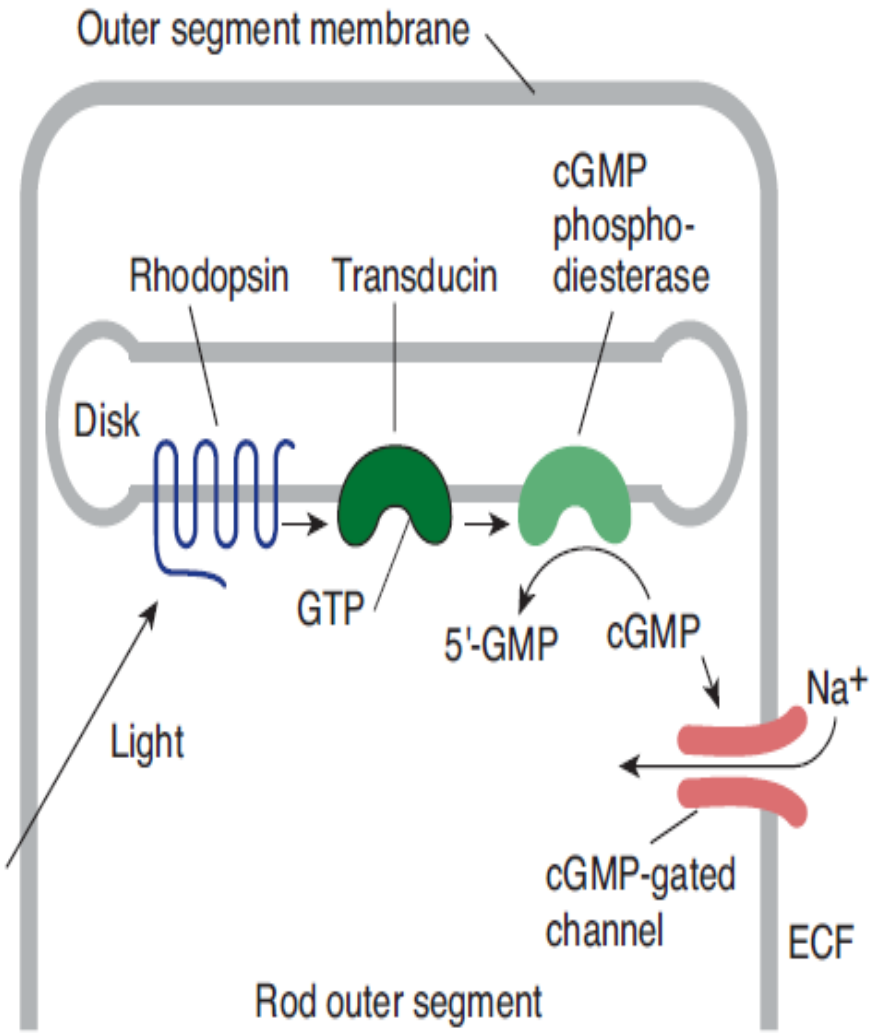


FIGURE 12–14 **Initial steps in phototransduction in rods.**
Light activates rhodopsin, which activates transducin to bind GTP. This activates phosphodiesterase, which catalyzes the conversion of cGMP to 5'-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels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

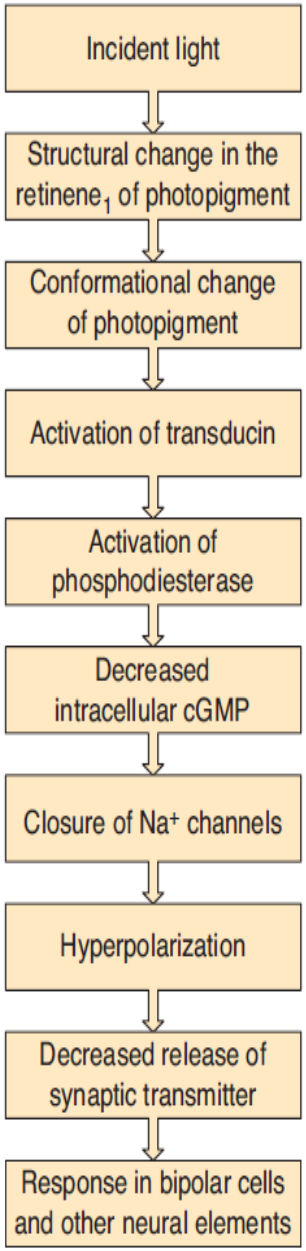


FIGURE 12–15 **Sequence of events involved in phototransduction in rods and cones.**

Change in photopigment

Metarhodopsin II

Activation of transducin

Activation of phophodiesterase

Decrease IC cyclic GMP

Closure of Na channels

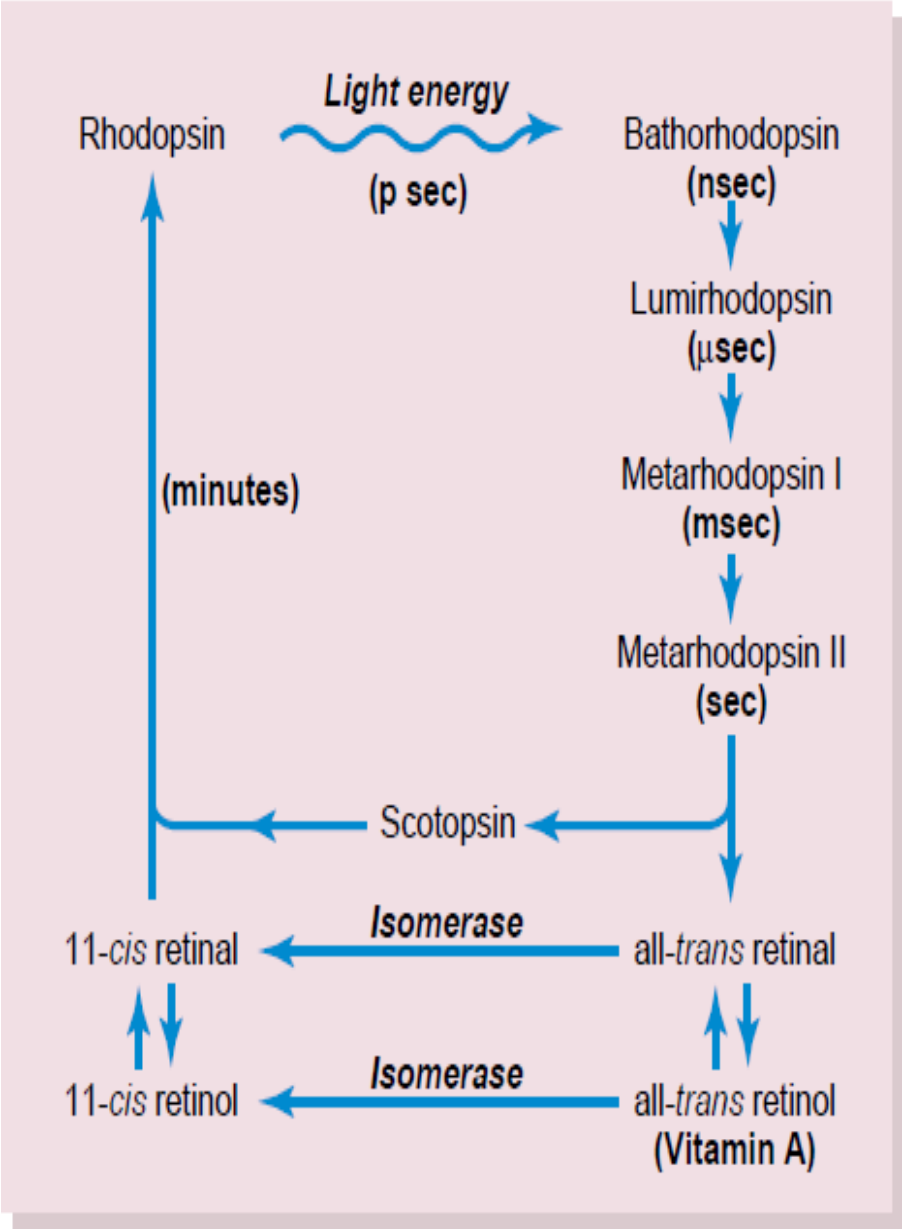
Hyperpolarization of receptor
Decrease release of synaptic transmitter
Action potential in optic nerve fibres

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

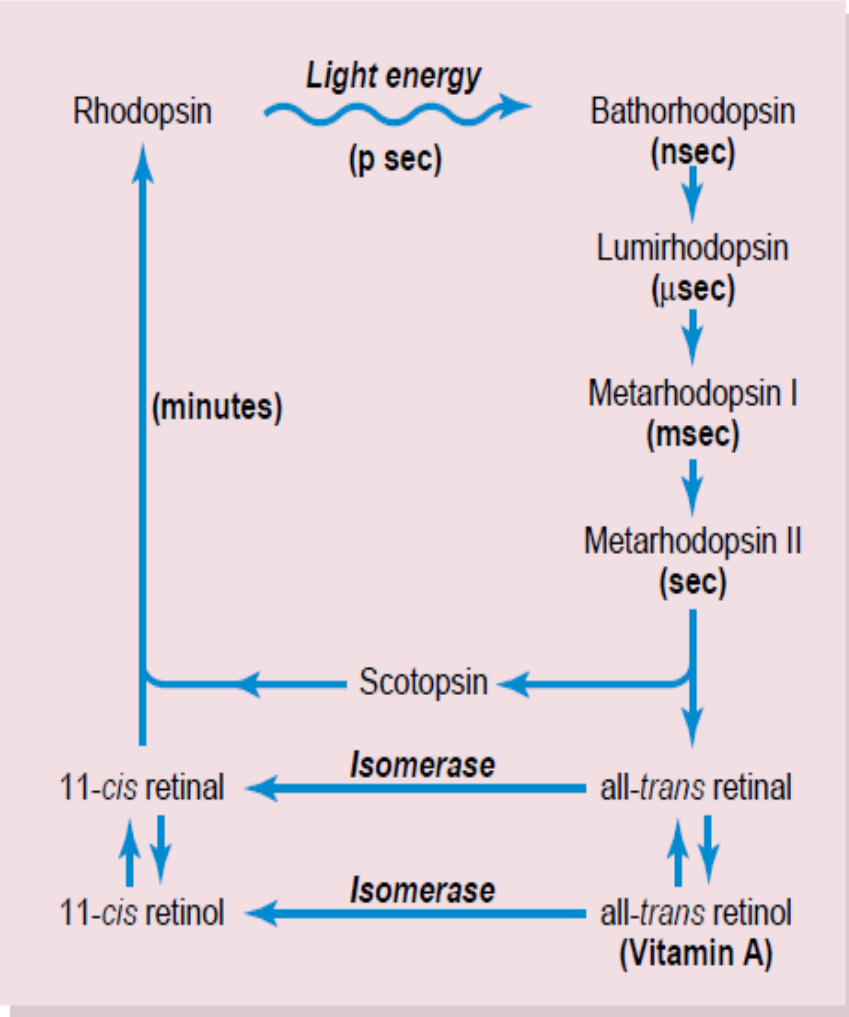
- The amount of rhodopsin in the receptors therefore varies inversely with the incident light level.
- When there is excess retinal in the retina, it is converted back into vitamin A, thus reducing the amount of light-sensitive pigment in the retina.



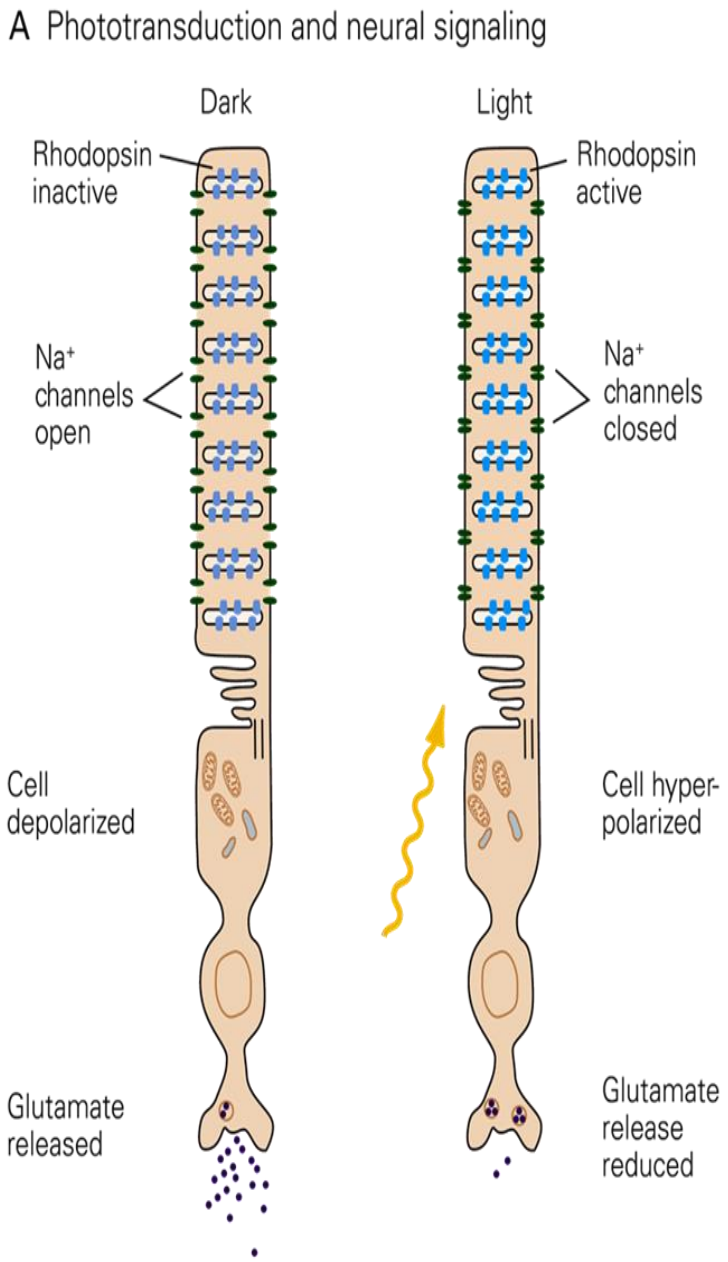
Photochemistry of Color Vision by the Cones

Photopsins Retinal Visual Cycle

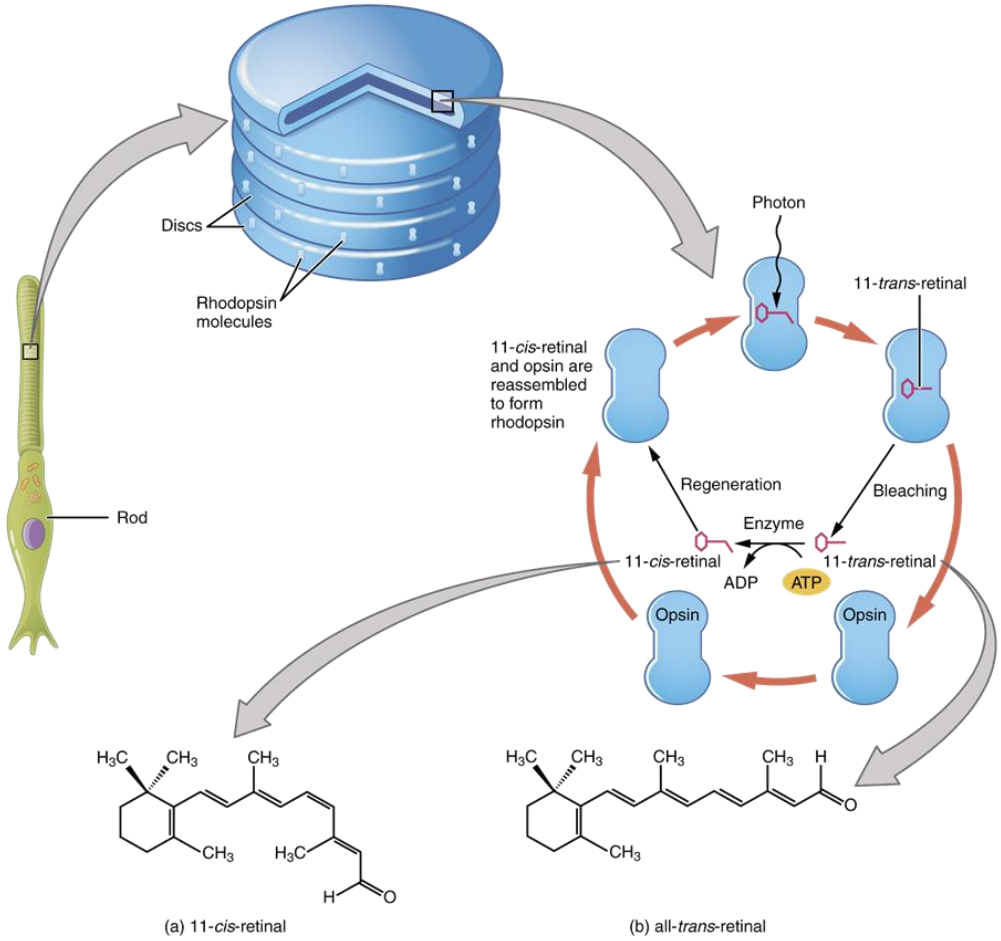
- The cones are about 30 to 300 times less sensitive than rods to light



- In the dark, there is an increase in cyclic GMP levels, which produces an NA+ inward current (or "dark current") and depolarization of the photoreceptor membrane (the cell remains at about -40mv), which leads to steady release of glutamate at dark
- In the light, there is a decrease in cyclic GMP levels, which closes NA+ channels in the photoreceptor membrane, reduces inward 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 -80mv)



Rhodopsin Cycling



Dark adaptation

Dark adaptation:

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

Dark Adaptation

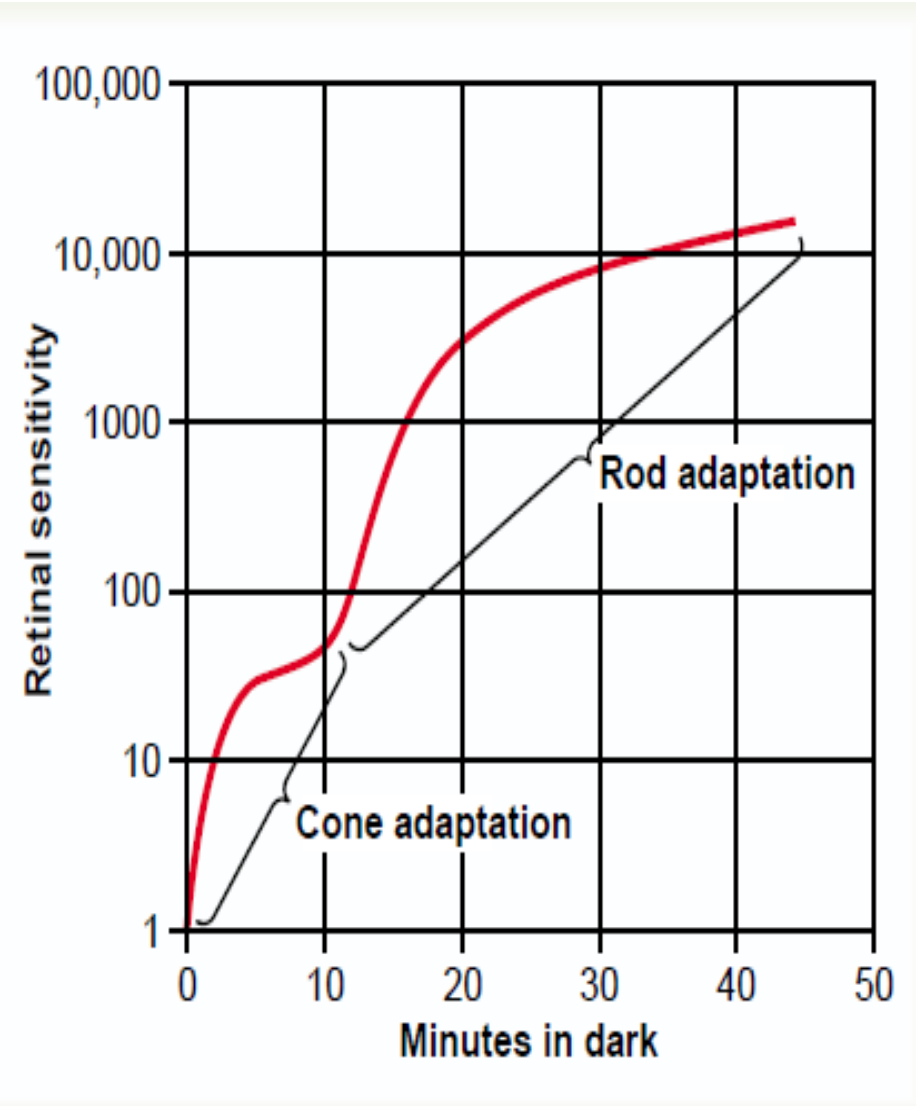
- Reaches max in 20 minutes
- First 5 minutes …… threshold of cones ↓
- 5 to 20 mins ……. ↑ Sensitivity of rods

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 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.

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