

# The Eye: II. Receptor and Neural Function of the Retina



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# Objectives

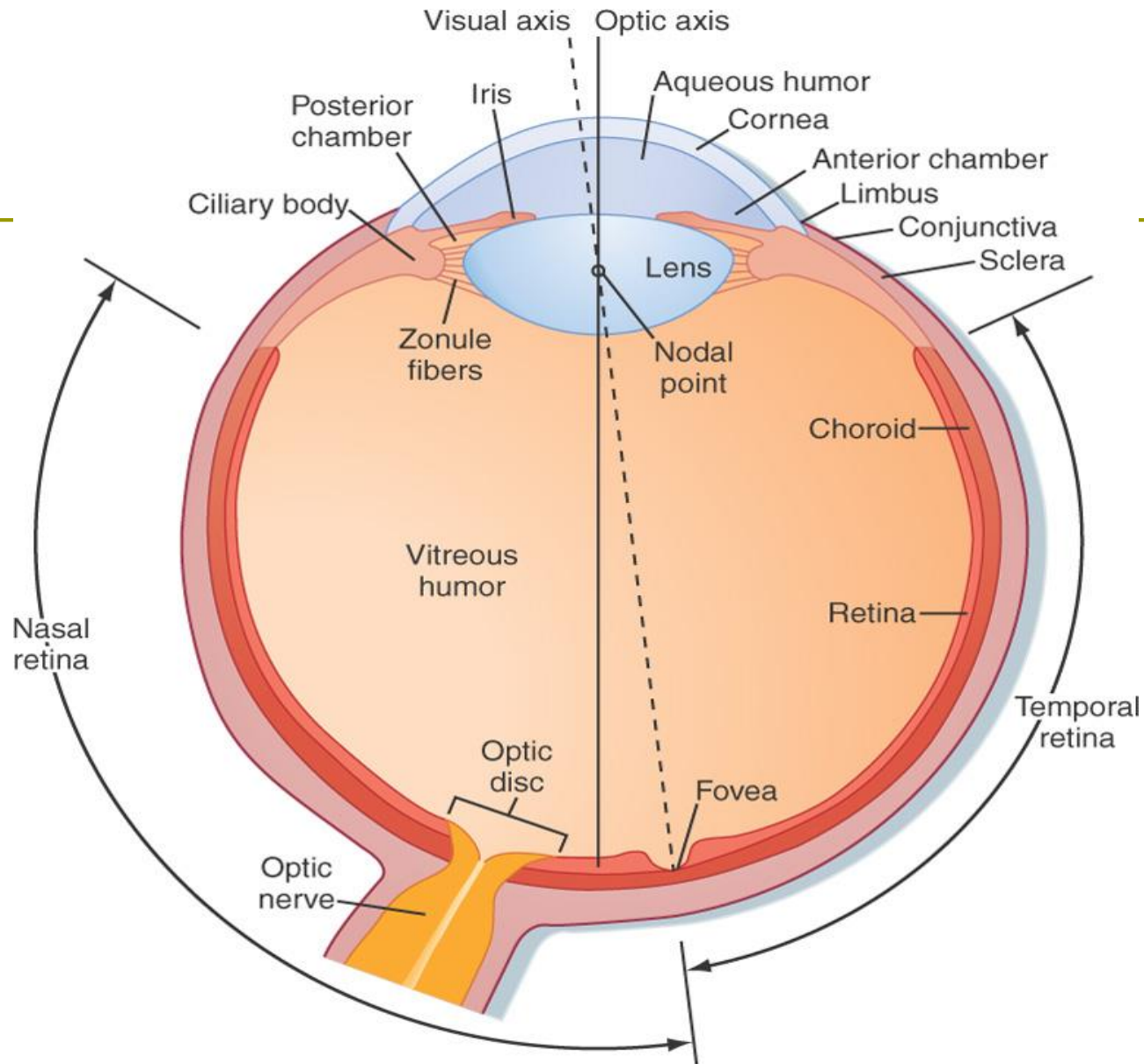
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- ❑ Describe visual receptors and characterize them
- ❑ List the layers of the retina and its cellular makeup
- ❑ Explain visual transduction mechanism
- ❑ Outline light and dark adaptation
- ❑ Describe vitamin A importance for vision
- ❑ Explain color blindness

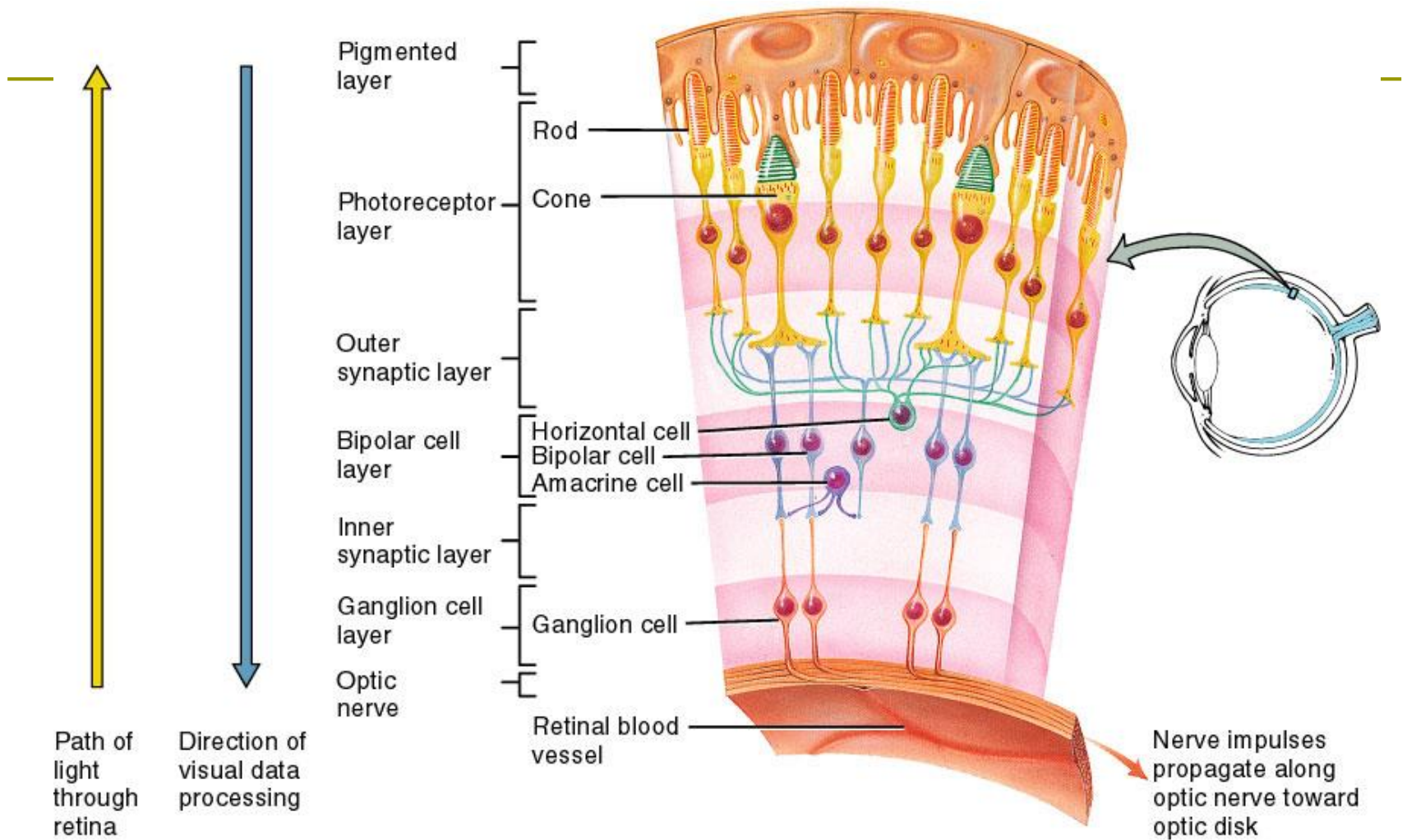
# Retina

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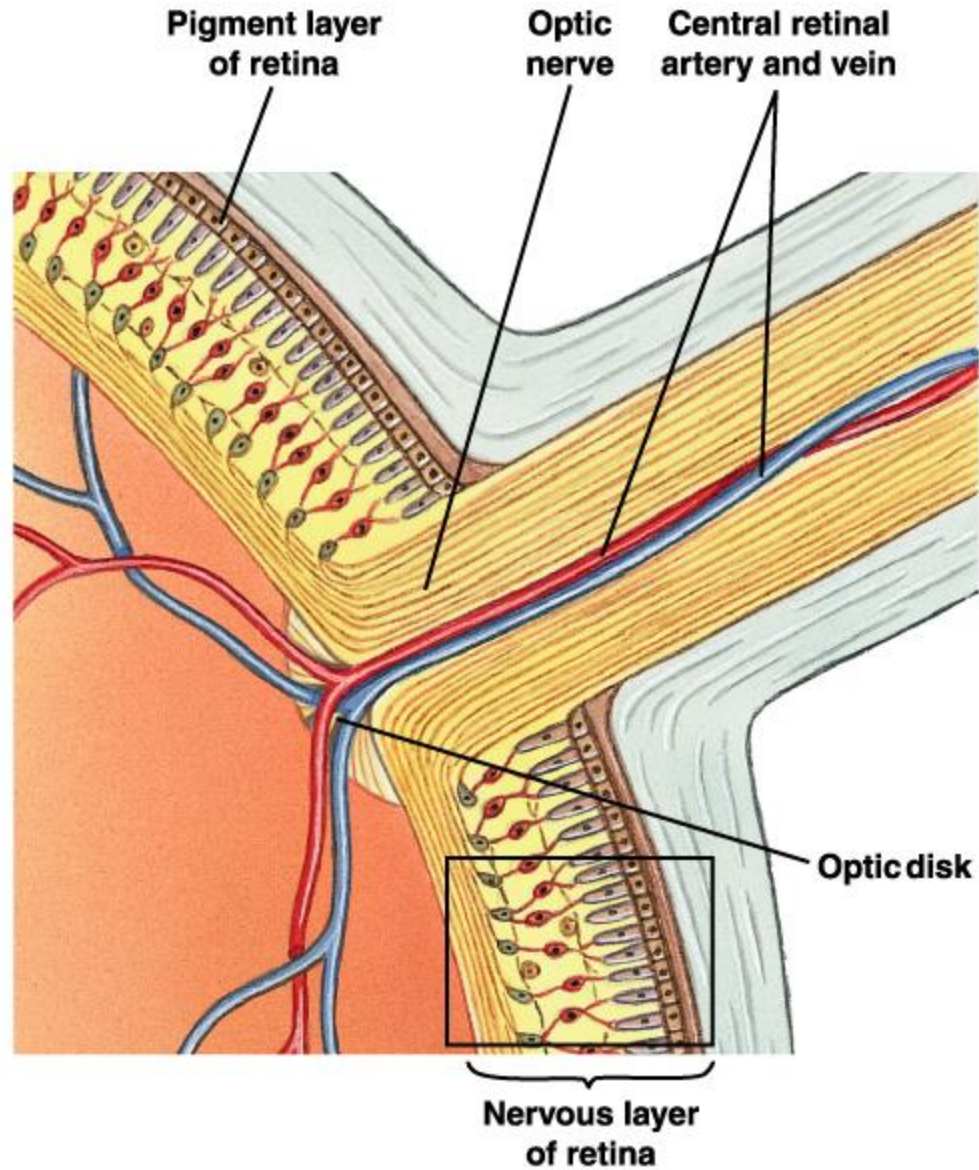
- ✍ light sensitive portion of the eye
- ✍ contains *cones* for day and color vision
- ✍ contains *rods* for night vision
- ✍ contains neural architecture
- ✍ light must pass through the neural elements to strike the light sensitive rods and cones



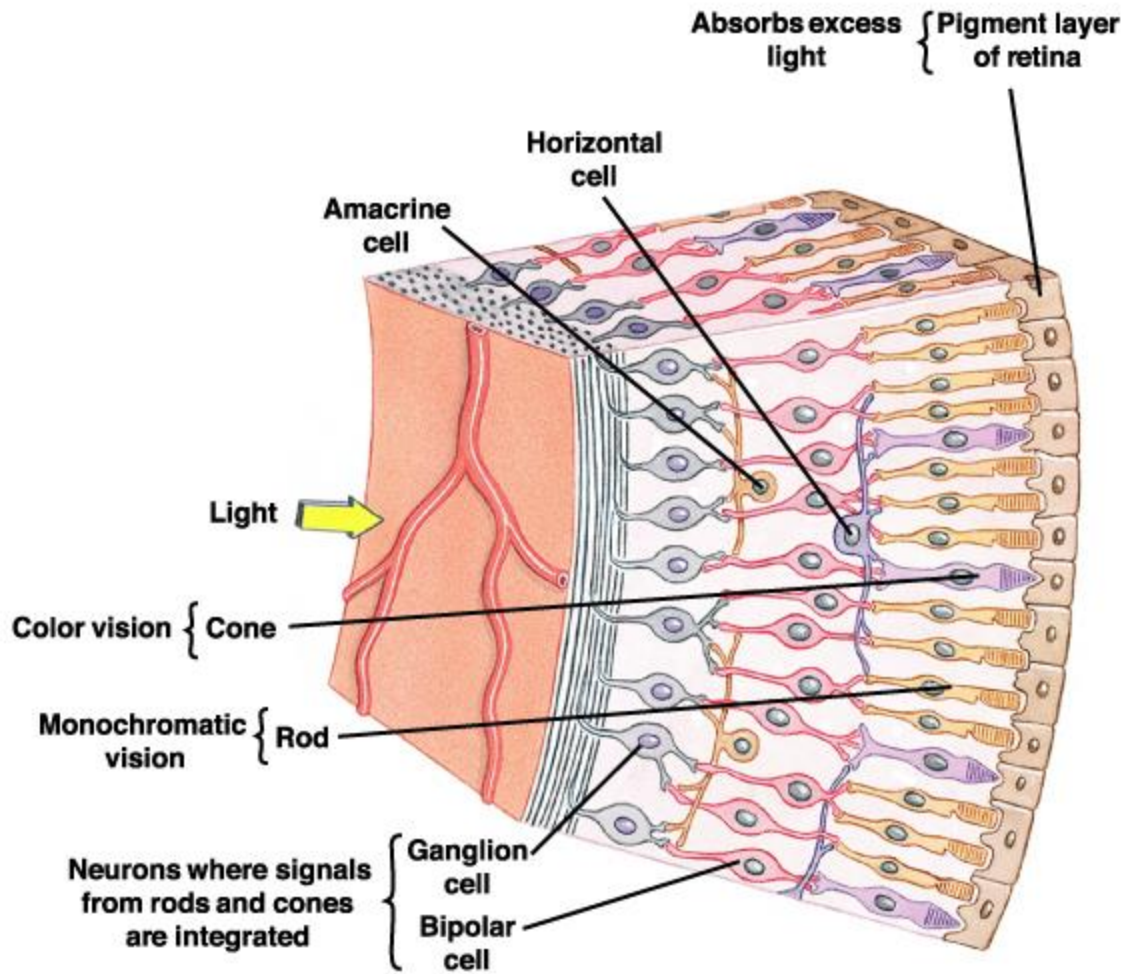
(Redrawn from Wall GL: The Vertebrate Eye and Its Adaptive Radiation. Bloomfield Hills, MI, Cranbrook Institute of Science, 1942.)



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**Layers of the retina, the light-sensitive layer lining the posterior chamber of the eye**



# The Fovea

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- ✍ A small area at the center of the retina about 1 sq millimeter
- ✍ The center of this area, “the central fovea,” contains only cones
  - ✍ these cones have a special structure
  - ✍ aid in detecting detail
- ✍ In the central fovea the neuronal cells and blood vessels are displaced to each side so that the light can strike the cones directly.
- ✍ This is the area of greatest visual acuity

# Rods, Cones and Ganglion Cells

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- ✍ Each retina has 100 million rods and 3 million cones and 1.6 million ganglion cells.
- ✍ 60 rods and 2 cones for each ganglion cell
- ✍ At the central fovea there are no rods and the ratio of cones to ganglion cells is 1:1.
- ✍ May explain the high degree of visual acuity in the central retina

# Rods

- ✎ high sensitivity; specialized for night vision
- ✎ more photopigment
- ✎ high amplification; single photon detection
- ✎ saturate in daylight
- ✎ slow response, long integration time
- ✎ more sensitive to scattered light

# Cones

- ✎ lower sensitivity; specialized for day vision
- ✎ less photopigment
- ✎ less amplification (less divergence 1:1 is more)
- ✎ saturate with intense light
- ✎ fast response, short integration time
- ✎ more sensitive to direct axial rays

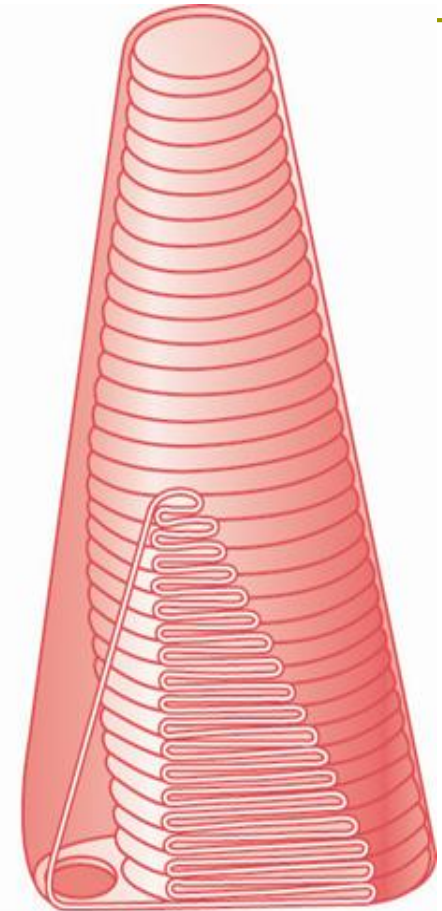
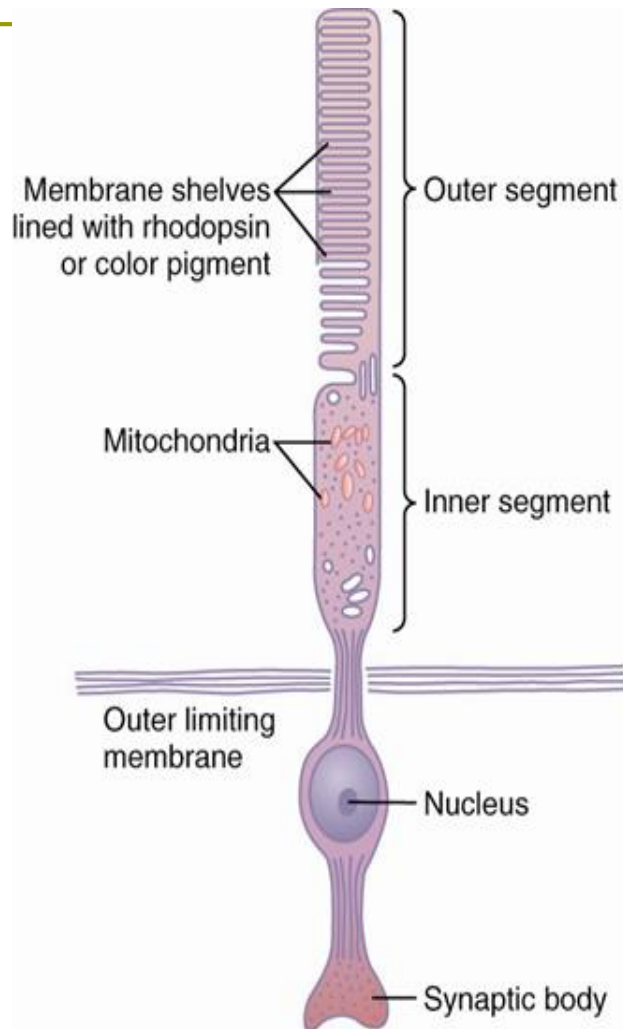
# Rods

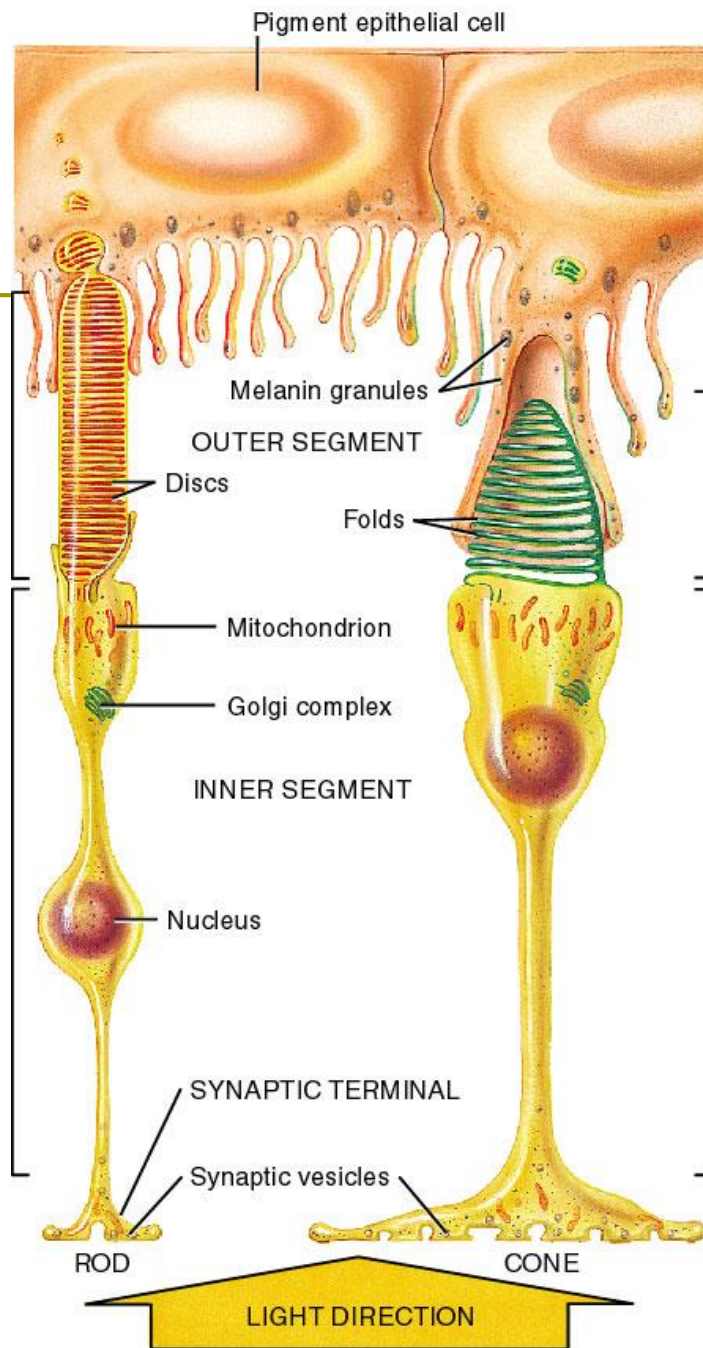
# Cones

- ✍ low acuity; highly convergent retinal pathways, not present in central fovea
- ✍ achromatic; one type of rod pigment

- ✍ high acuity; less convergent retinal pathways, concentrated in central fovea
- ✍ trichromatic; three types of cones, each with a different pigment that is sensitive to a different part of the visible spectrum, **Red**, **Green** and **Blue**

# Structure of the Rods and Cones





# Pigment Layer of Retina

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- ✎ Pigment layer of the retina is very important
- ✎ Contains the black pigment *melanin*
- ✎ Prevents light reflection in the globe of the eye
- ✎ Without the pigment there would be diffuse scattering of light rather than the normal contrast between dark and light.
- ✎ This is what happens in *albinos* (***genetic absence of melanocyte activity***)
  - ✎ poor visual acuity because of the scattering of light

# Photochemistry of Vision

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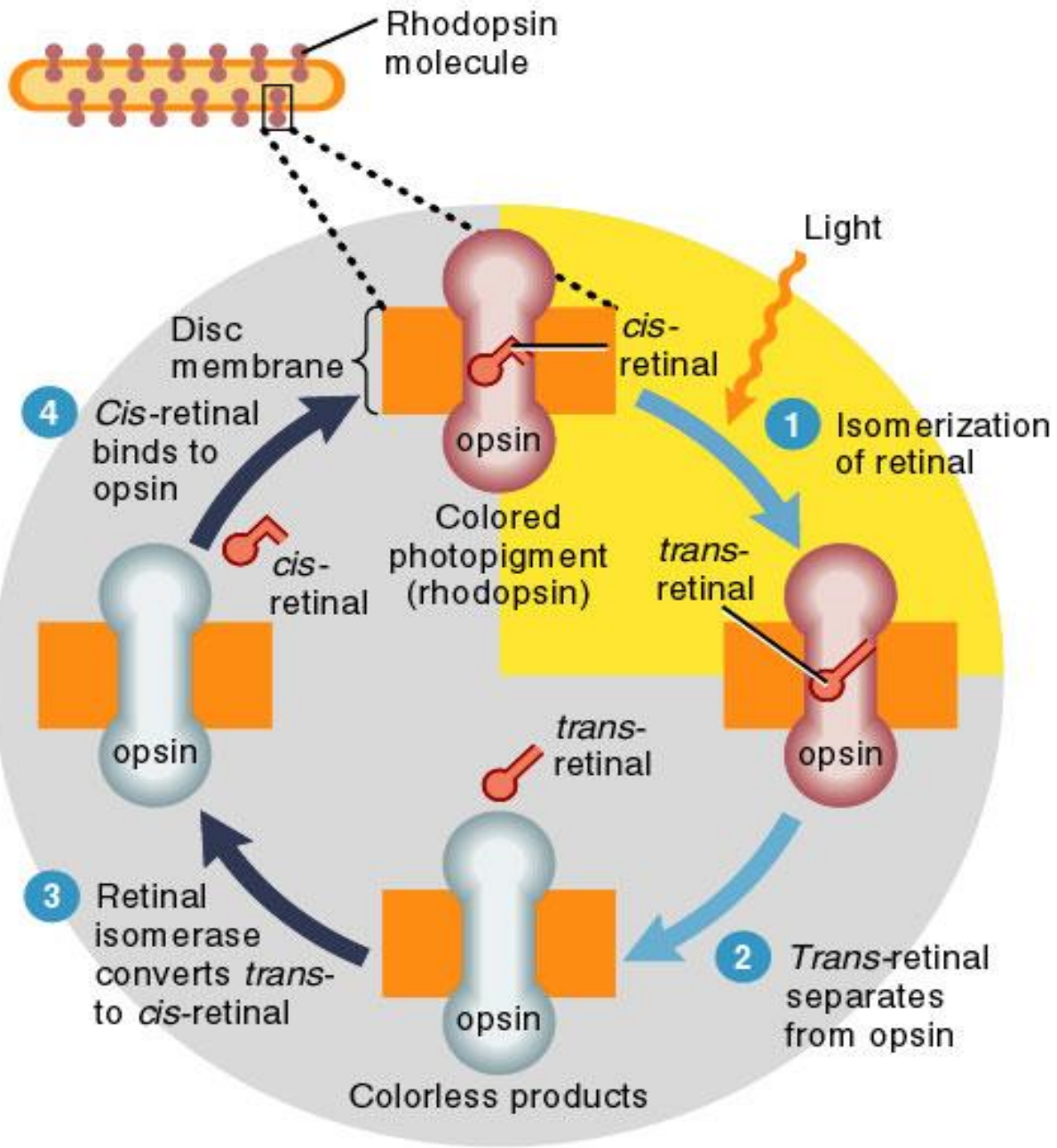
- ✎ Rods and cones contain chemicals that decompose on exposure to light.
- ✎ This excites the nerve fibers leading from the eye.
- ✎ The membranes of the outer-segment of the rods contain *rhodopsin* or *visual purple*.
- ✎ Rhodopsin is a combination of a protein called *scotopsin* and a pigment, *retinal* (*Vitamin A derivative*)
- ✎ The retinal is in the *cis* configuration.
- ✎ Only the *cis* configuration can bind with scotopsin to form rhodopsin.

# Light and Rhodopsin

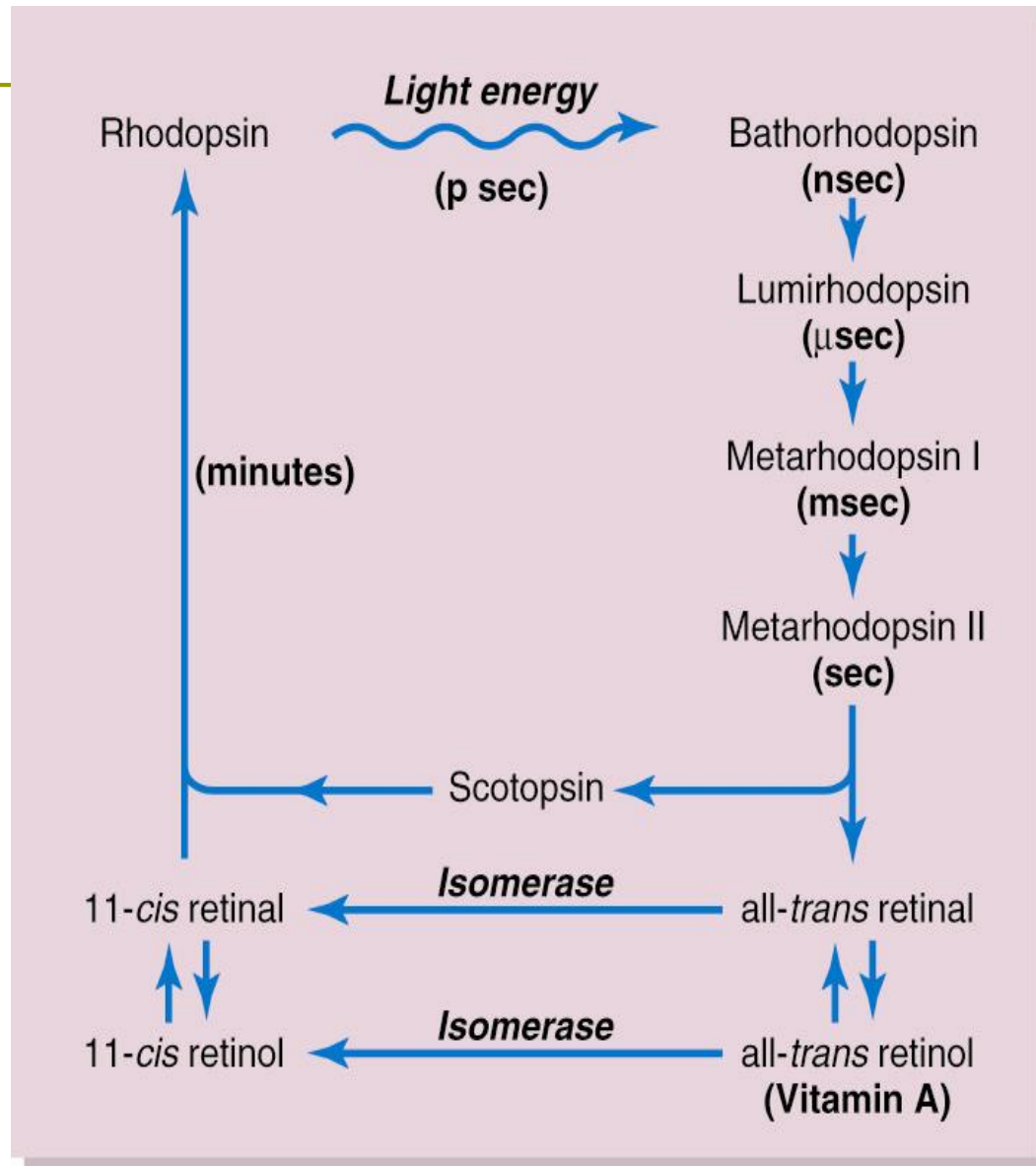
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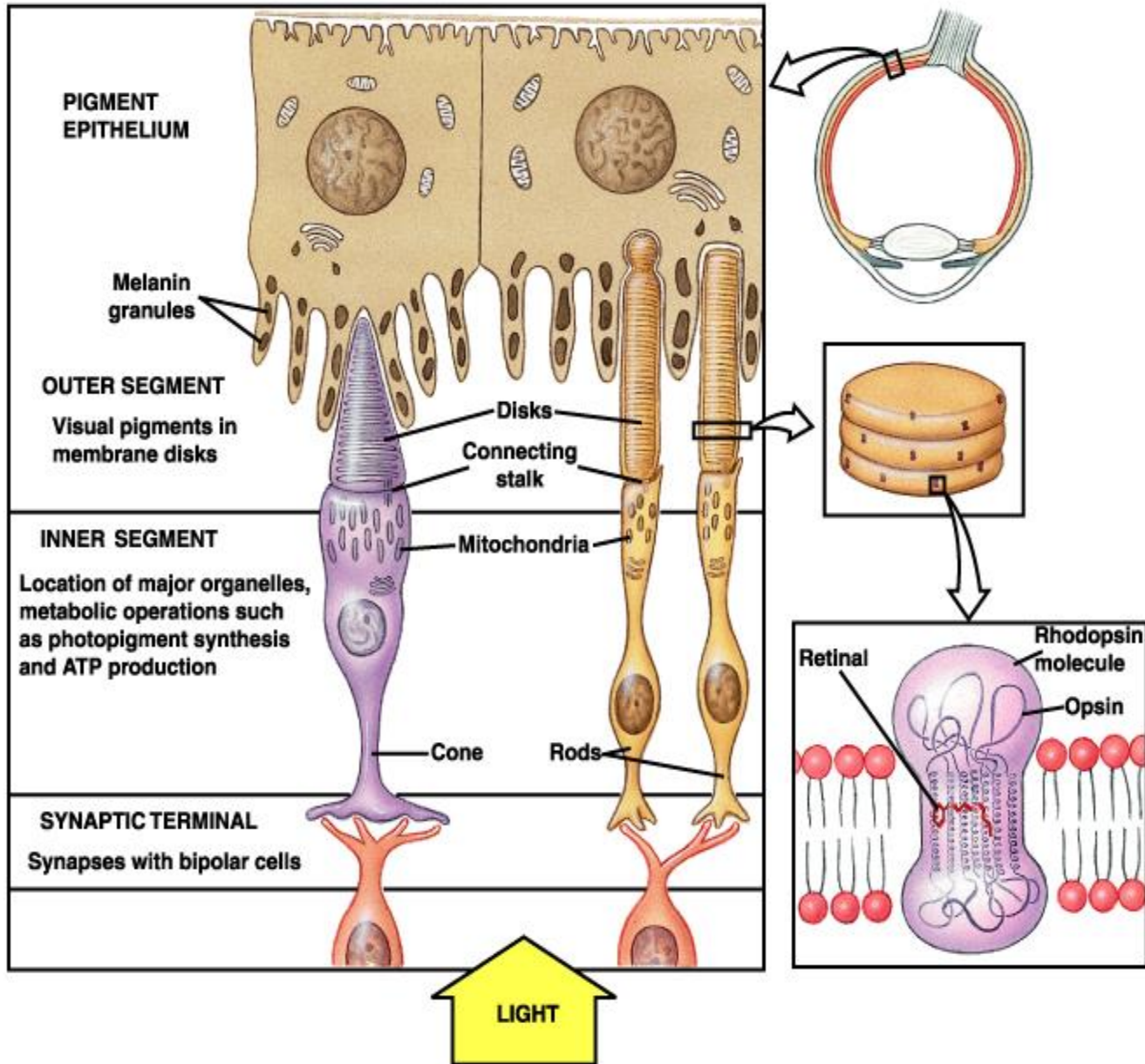
- ✍ When light is absorbed by rhodopsin it immediately begins to decompose.
- ✍ Decomposition is the result of photoactivation of electrons in the *retinal portion* of rhodopsin which leads to a change from the *cis form* of the retinal to the *trans form* of the molecule.
  - ✍ *Trans* retinal has the same chemical structure but is a straight molecule rather than an angulated molecule.
  - ✍ This configuration does not fit with the binding site on the scotopsin and the retinal begins to split away.
  - ✍ In the process of splitting away a number of intermediary compounds are formed.

Rod disc in outer segment



# Rhodopsin Cycle

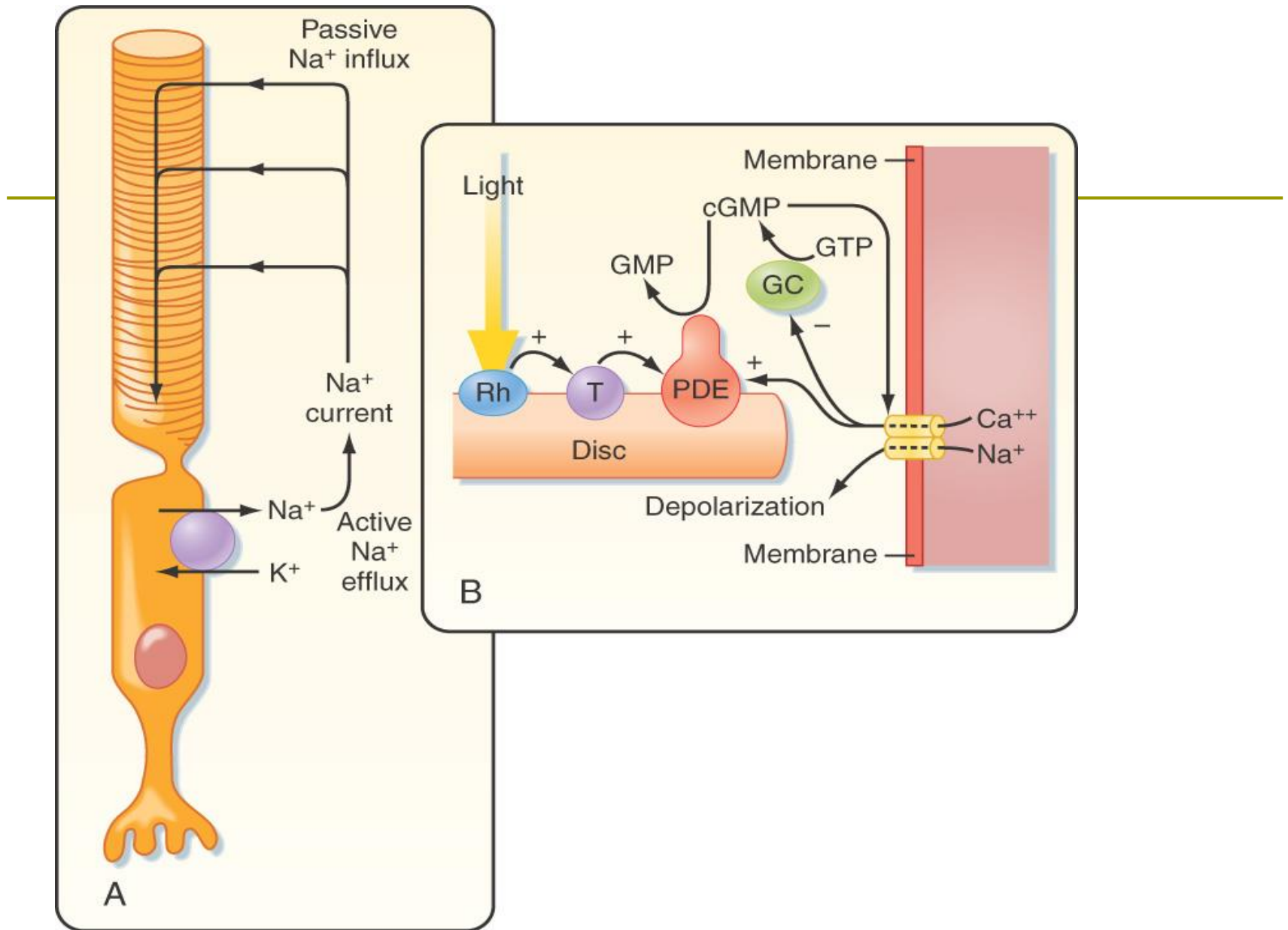




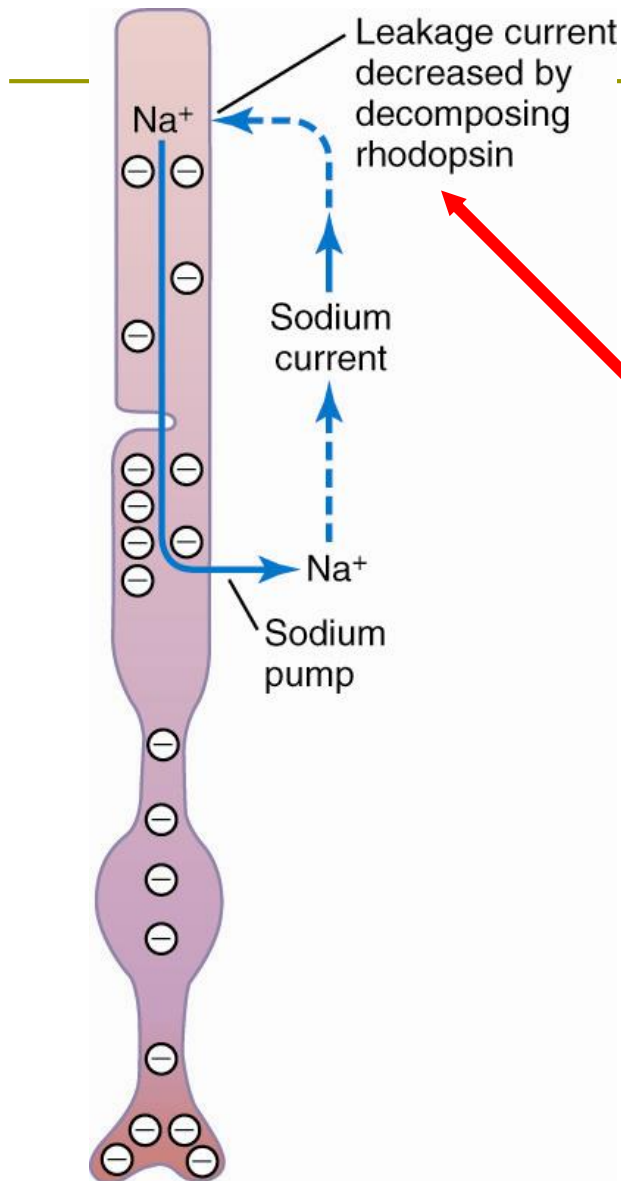
# Mechanism for Light to Decrease Sodium Conductance

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- ✍ cGMP is responsible for keeping Na<sup>+</sup> channel in the outer segment of the rods open.
- ✍ Light activated rhodopsin (metarhodopsin II) activates a G-protein, *transducin*.
- ✍ Transducin activates *cGMP phosphodiesterase* which destroys cGMP.
- ✍ *Rhodopsin kinase* deactivates the activated rhodopsin (which began the cascade) and cGMP is regenerated re-opening the Na<sup>+</sup> channels.

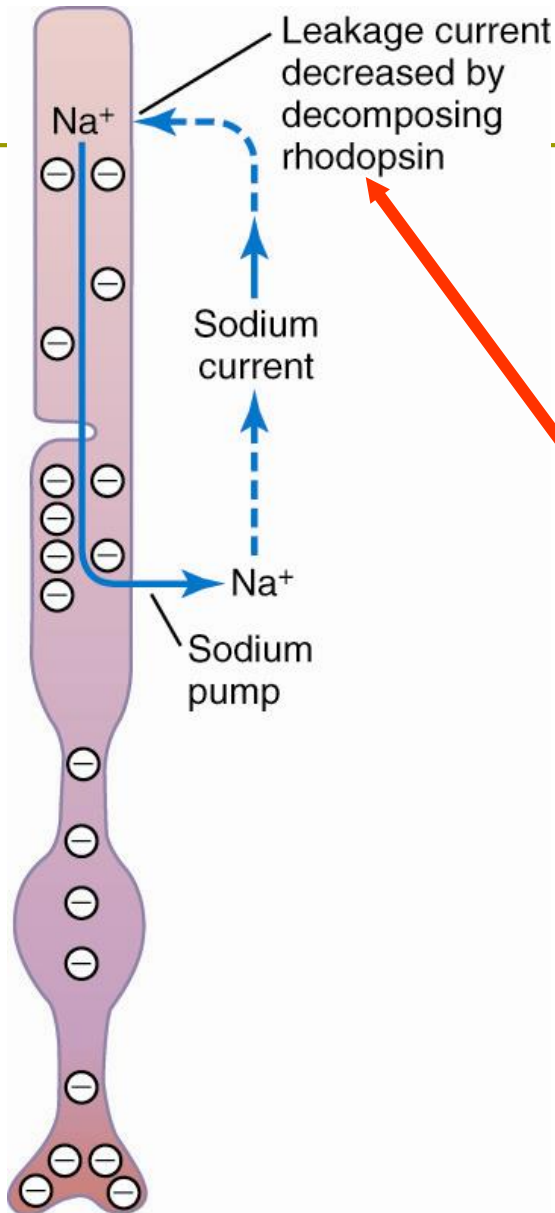


# The Dark Current

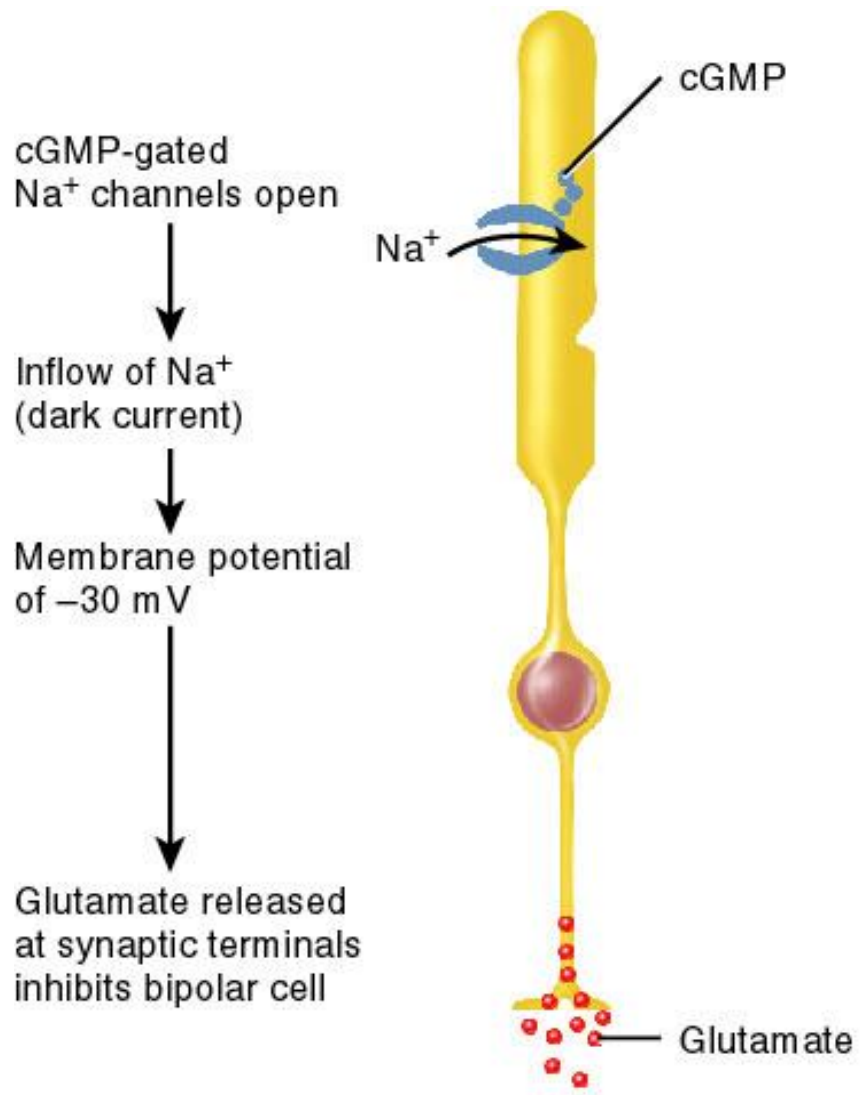


In the dark an inward current (*the dark current*) carried by the  $\text{Na}^+$  ions flows into the outer segment of the rod.

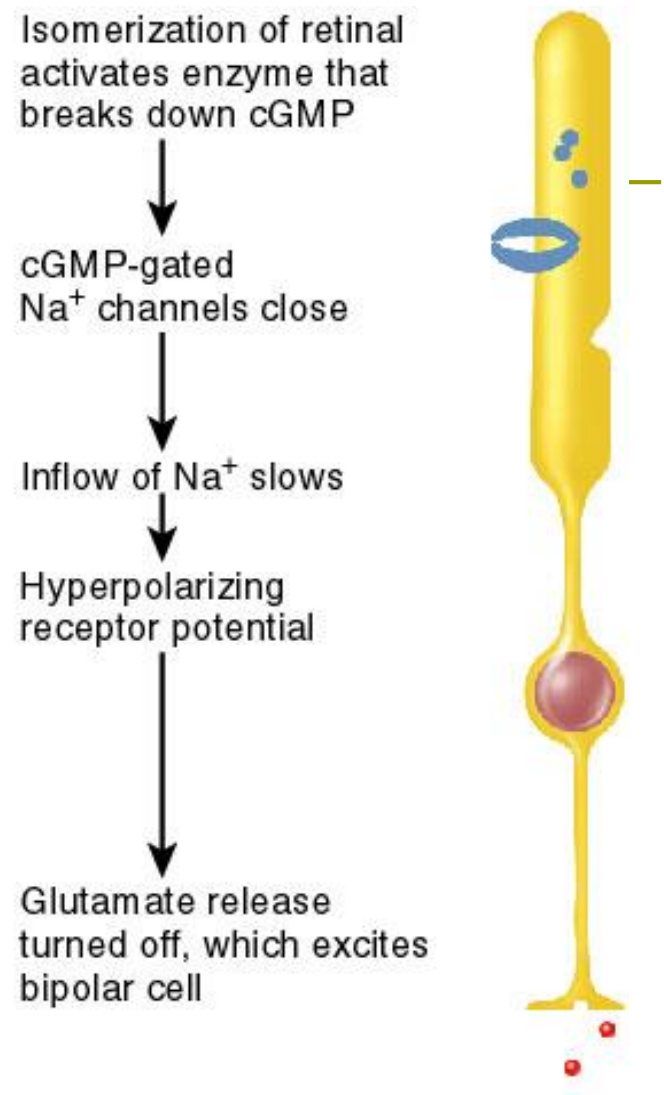
# The Dark Current



When rhodopsin decomposes in response to light it causes a **hyperpolarization** of the rod by decreasing  $\text{Na}^+$  permeability of the outer segment.



(a) In darkness



(b) In light

# Rod Receptor Potential (Cont'd)

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- ✍ When rhodopsin decomposes it causes a *hyperpolarization* of the rod by decreasing  $\text{Na}^+$  permeability of the outer segment.
- ✍ The  $\text{Na}^+$  pump in the inner segment keeps pumping  $\text{Na}^+$  out of the cell causing the membrane potential to become more negative (hyperpolarization).
- ✍ The greater the amount of light the greater the electronegativity.

# The Rod Receptor Potential

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- ✍ Normally about -40 mV
- ✍ Normally the outer segment of the rod is very permeable to Na<sup>+</sup> ions.
- ✍ In the dark an inward current (*the dark current*) carried by the Na<sup>+</sup> ions flows into the outer segment of the rod.
- ✍ The current flows out of the cell, through the efflux of K<sup>+</sup>, ions in the inner segment of the rod.

# Duration and Sensitivity of the Receptor Potential

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- ✍ A single pulse of light causes activation of the rod receptor potential for more than a second.
- ✍ In the cones these changes occur 4 times faster.
- ✍ Receptor potential is proportional to the logarithm of the light intensity.
  - ✍ very important for discrimination of the light intensity

# Role of Vitamin A

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- ✍ Vitamin A is the precursor of *all-trans-retinal*, the pigment portion of rhodopsin.
- ✍ Lack of vitamin A causes a decrease in retinal.
- ✍ This results in a decreased production of rhodopsin and a lower sensitivity of the retina to light or *night blindness*.

# Dark and Light Adaptation

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- ✍ In light conditions most of the rhodopsin has been reduced to retinal so the level of photosensitive chemicals is low.
- ✍ In dark conditions retinal is converted back to rhodopsin.
- ✍ Therefore, the sensitivity of the retinal automatically adjusts to the light level.
- ✍ Opening and closing of the pupil also contributes to adaptation because it can adjust the amount entering the eye.

# Dark Adaptation and Rods and Cones

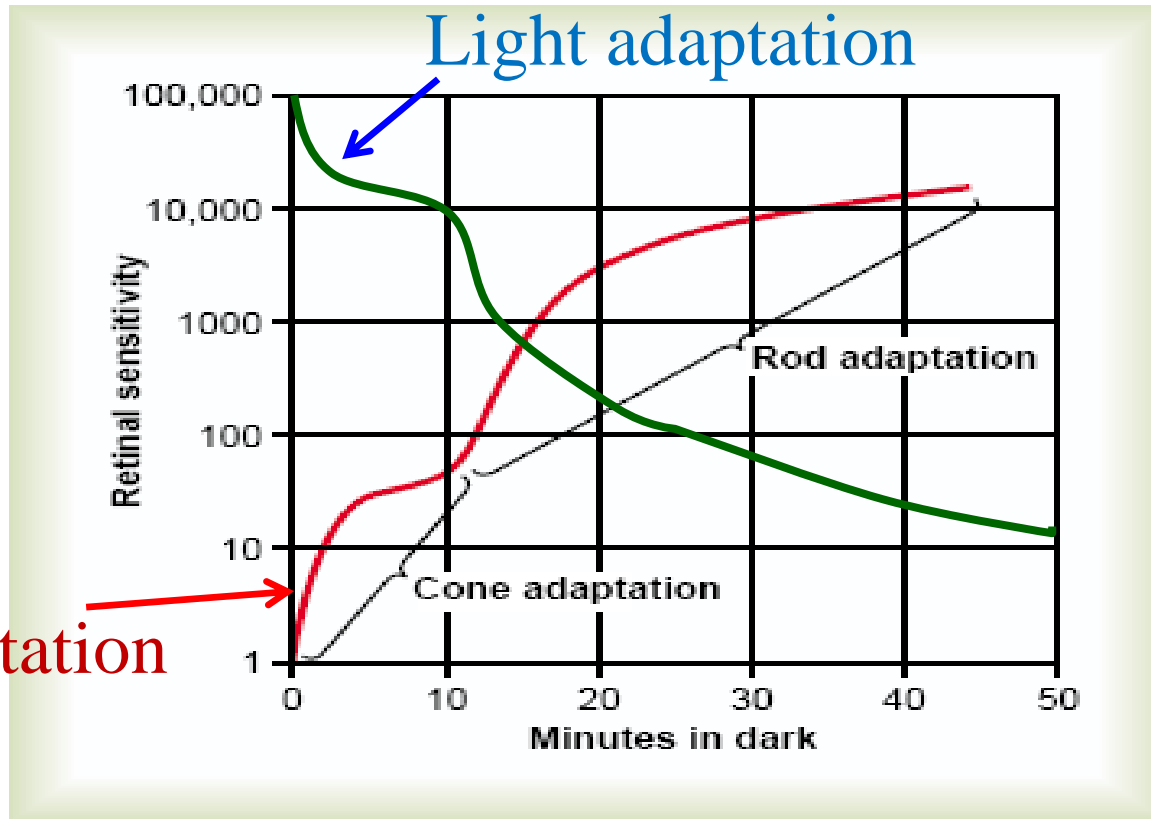


Figure 50-8

Dark adaptation, demonstrating the relation of cone adaptation to rod adaptation.

# Importance of Dark and Light Adaptation

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- ✍ The detection of images on the retina is a function of discriminating between dark and light spots.
- ✍ It is important that the sensitivity of the retina be adjusted to detect the dark and light spots on the image.
- ✍ Enter the sun from a movie theater, even the dark spots appear bright leaving little contrast.
- ✍ Enter darkness from light, the light spots are not light enough to register.

# Dark Adaptation

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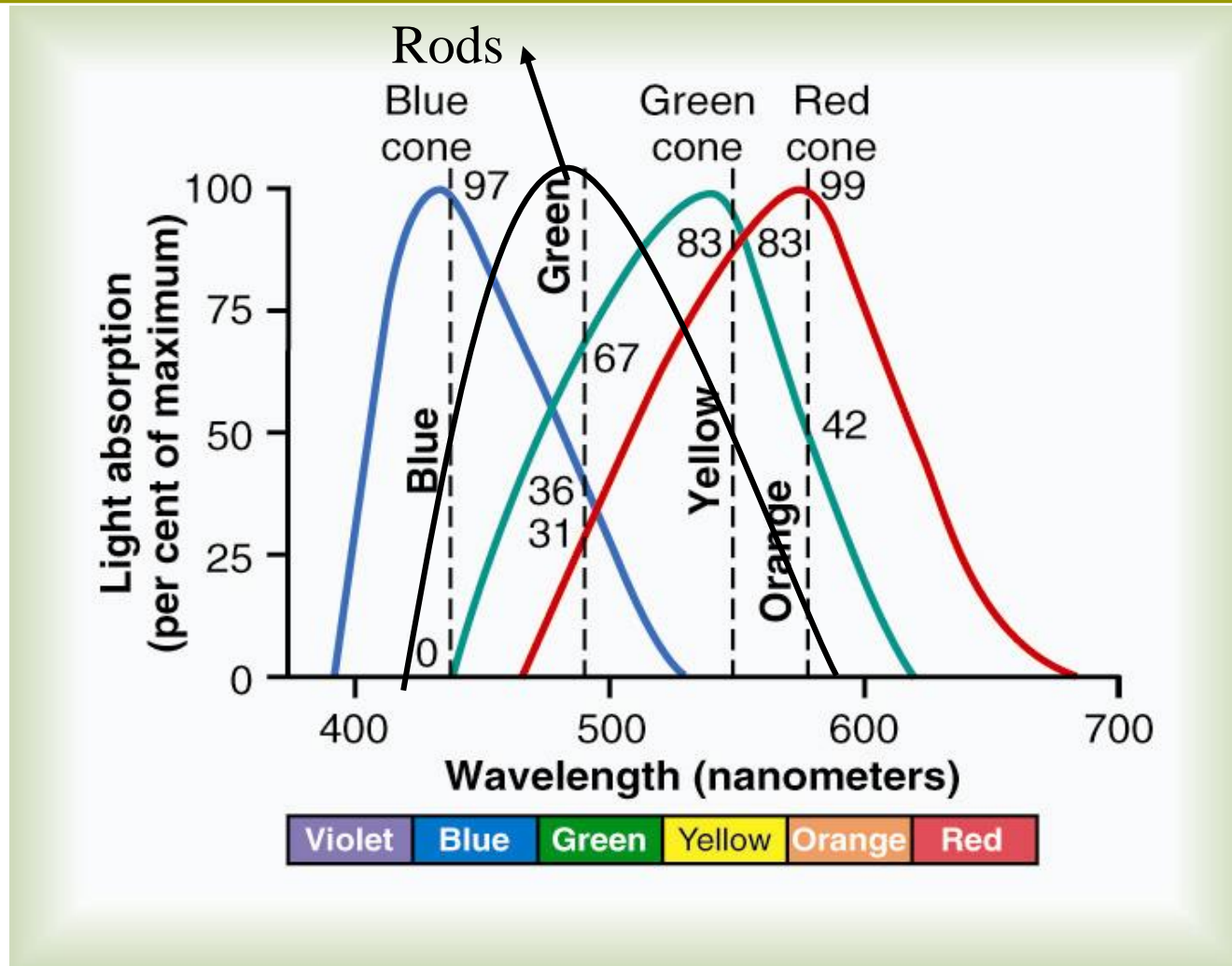
- ❑ Gradual increase in photoreceptor sensitivity when entering a dark room.
  - Maximal sensitivity reached in 20 min.
- ❑ Increased amounts of visual pigments produced in the dark.
  - Increased pigment in cones produces slight dark adaptation in 1<sup>st</sup> 5 min.
  - Increased rhodopsin in rods produces greater increase in sensitivity.
    - ❑ 100,000-fold increase in light sensitivity in rods.

# Color Vision

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- ✍ Color vision is the result of activation of cones.
- ✍ 3 types of cones:
  - ✍ **blue cone**
  - ✍ **green cone**
  - ✍ **red cone**
- ✍ The pigment portion of the photosensitive molecule is the same as in the rods, the protein portion is different for the pigment molecule in each of the cones.
- ✍ Makes each cone receptive to a particular wavelength of light

# Each Cone is Receptive to a Particular Wavelength of Light



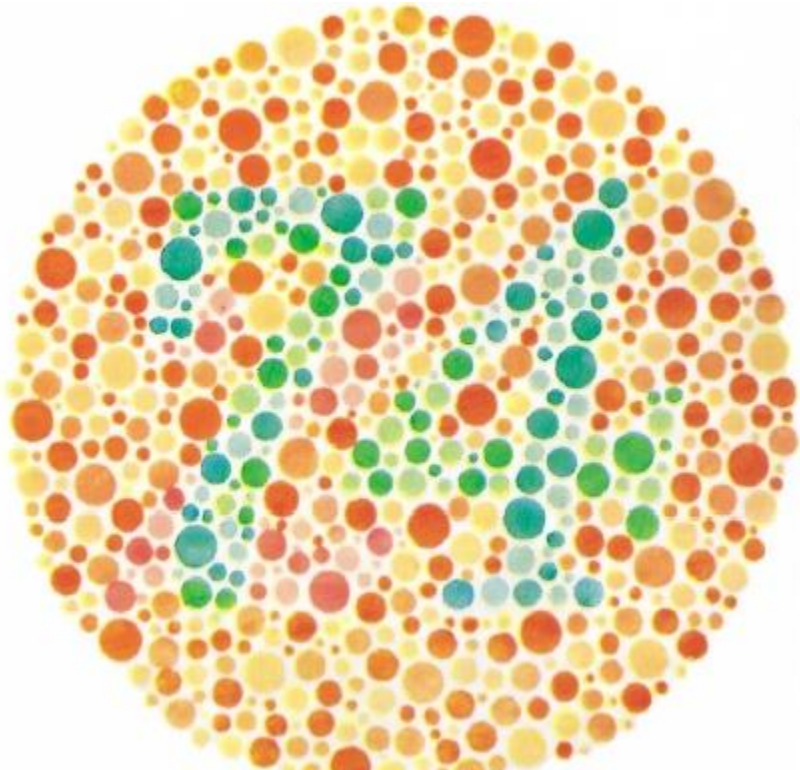
# Color Blindness

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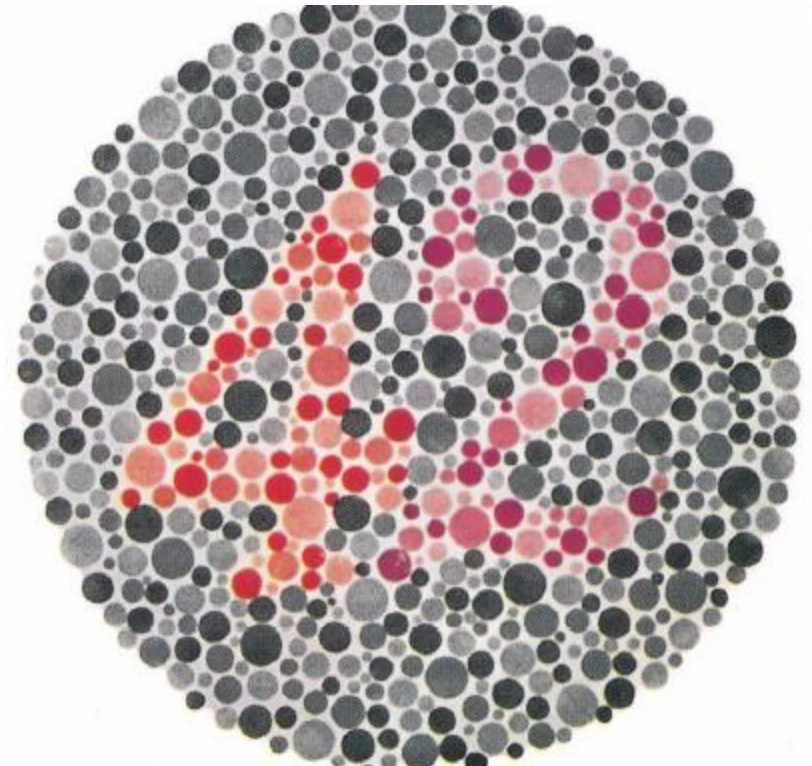
- ✍ lack of a particular type of cone
- ✍ genetic disorder passed along on the X chromosome
- ✍ occurs almost exclusively in males (blue color blindness is usually autosomal recessive gene but it is rare)
- ✍ about 8% of women are color blindness carriers
- ✍ most color blindness results from lack of the red or green cones
  - ✍ lack of a red cone, *protanope*.
  - ✍ lack of a green cone, *deuteranope*.

# Color Blindness Charts

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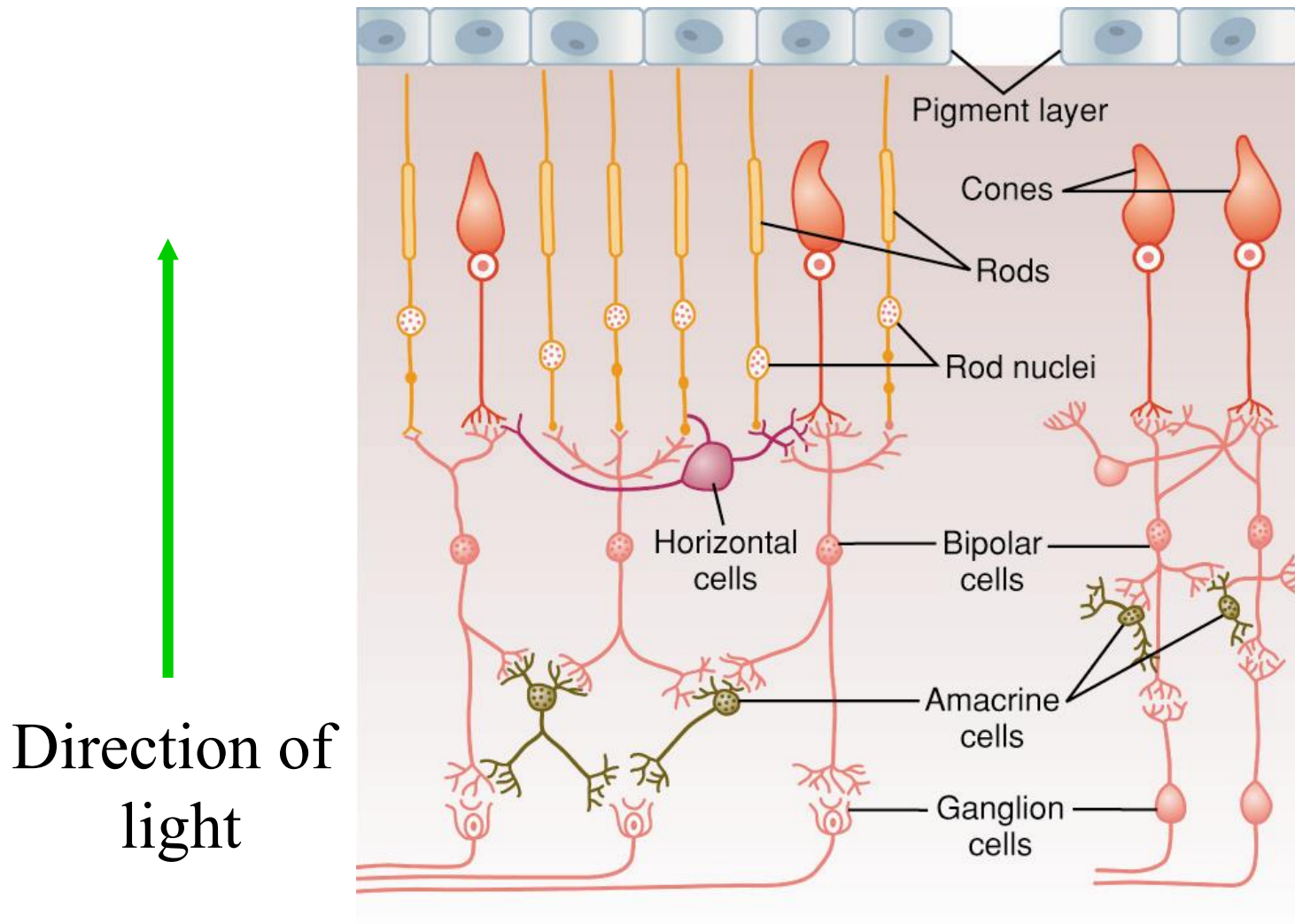


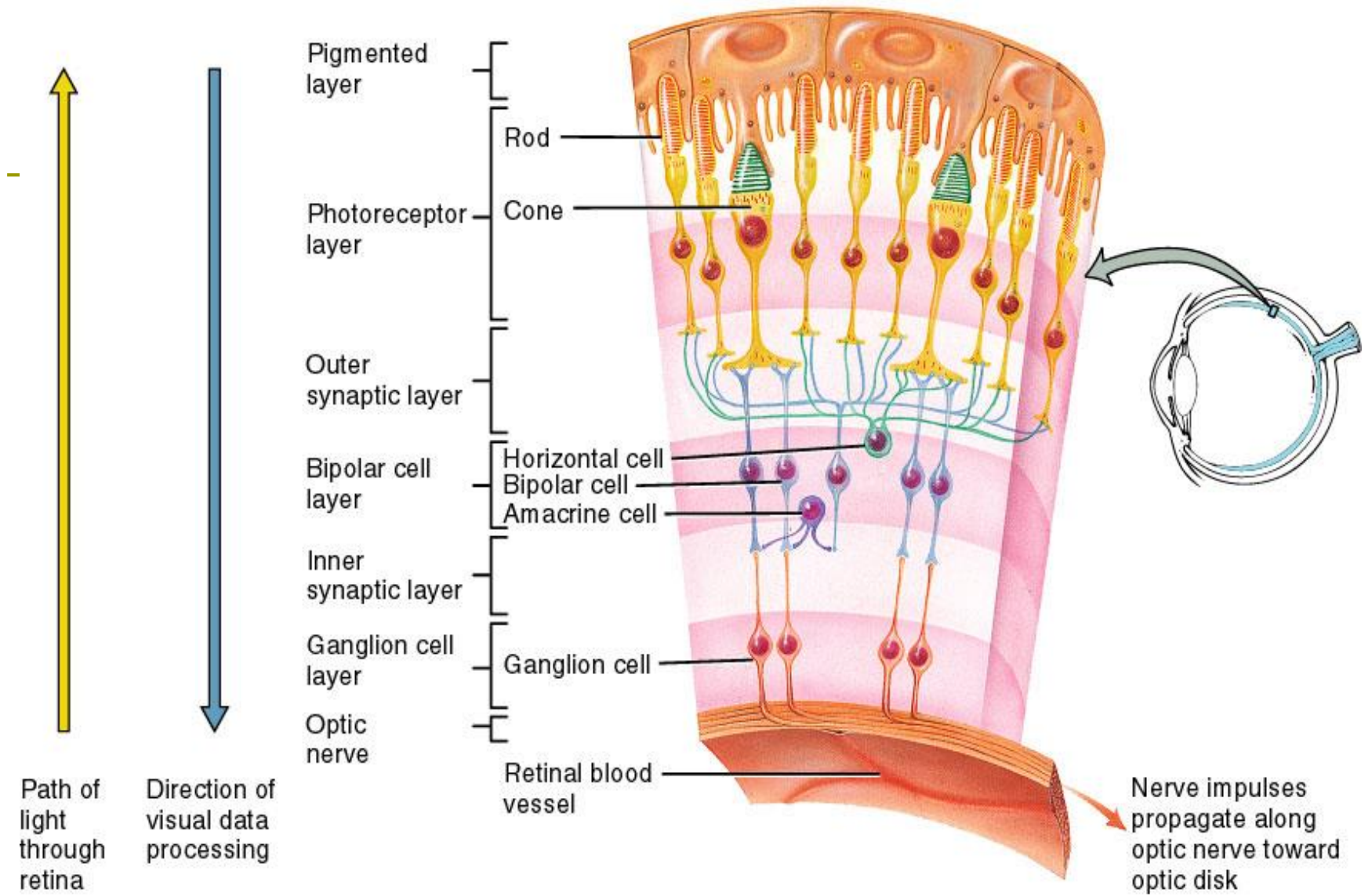
Normal read 74, Red-Green read  
it 21



Normal read it 42, Red blind  
read 2, Green blind read it 4

# Neural Organization of the Retina





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# Signal Transmission in the Retina

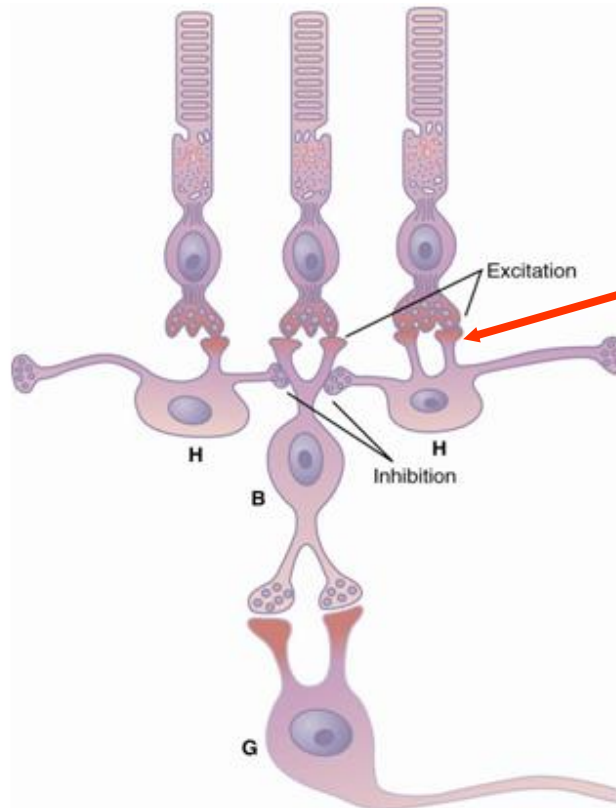
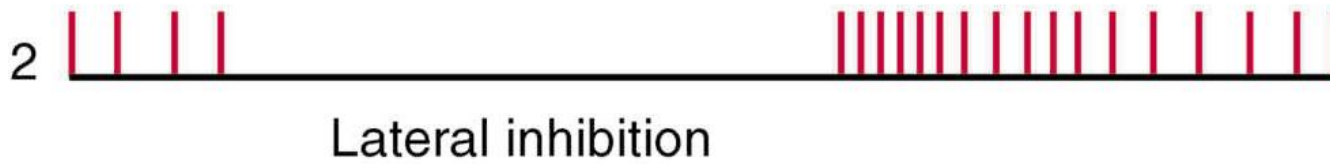
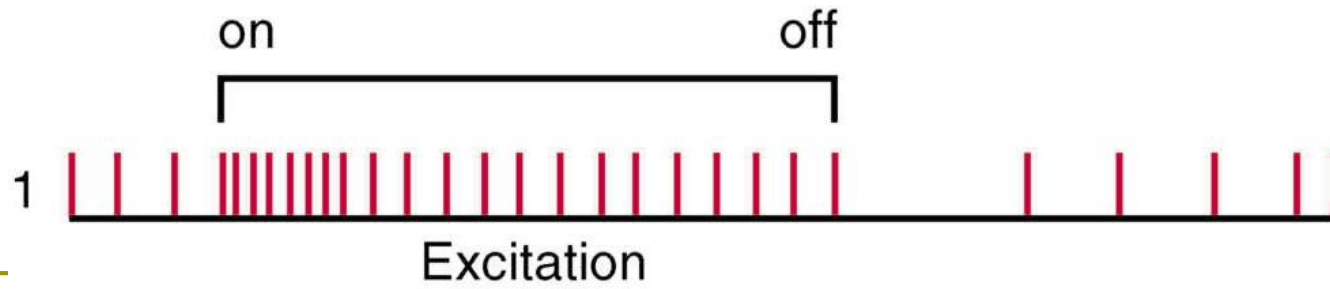
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- ✍ Transmission of signals in the retina is by electrotonic conduction.
- ✍ Allows graded response proportional to light intensity.
- ✍ The only cells that have action potentials are ganglion cells and amacrine cells.
  - ✍ send signals all the way to the brain

# Lateral Inhibition to Enhance Visual Contrast

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- ✍ horizontal cells connect laterally between the rods and cones and the bipolar cells
- ✍ output of horizontal cells is always inhibitory
- ✍ prevents the lateral spread of light excitation on the retina
- ✍ have an *excitatory center* and an *inhibitory surround*
- ✍ essential for transmitting contrast borders in the visual image



Lateral inhibition, the function of horizontal cells

# Function of Amacrine Cells

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- ✍ About 30 different types
- ✍ Some involved in the direct pathway from rods to bipolar to amacrine to ganglion cells
- ✍ Some amacrine cells respond strongly to the onset of the visual signal, some to the extinguishment of the signal
- ✍ Some respond to movement of the light signal across the retina
- ✍ Amacrine cells are a type of interneuron that aid in the beginning of visual signal analysis.

# Three Types of Ganglion Cells

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- ✍ **W cells** (40%) receive most of their excitation from rod cells.
  - ✍ sensitive to **directional movement** in the visual field
- ✍ **X cells** (55%) small receptive field, discrete retinal locations, may be responsible for **the transmission of the visual image** itself, always receives input from at least one cone, may be responsible for **color transmission**.
- ✍ **Y cells** (5%) large receptive field respond to **instantaneous changes in the visual field**.

# Excitation of Ganglion Cells

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- ✍ spontaneously active with continuous action potentials
- ✍ visual signals are superimposed on this background
- ✍ many excited by changes in light intensity
- ✍ respond to contrast borders, this is the way the pattern of the scene is transmitted to the brain



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Relay Runners  
We're on Track  
For a Cure