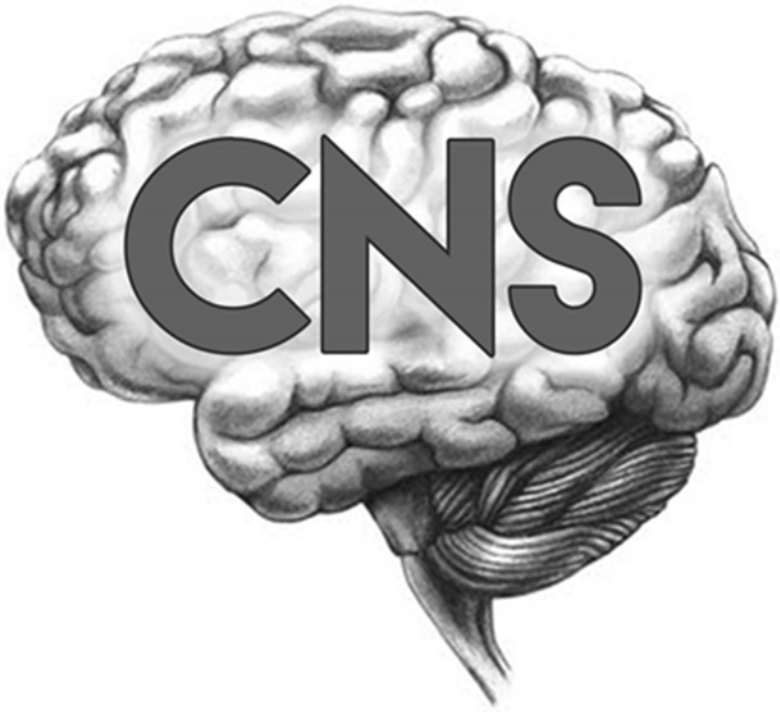

PHYSIOLOGY

○ Sheet ☑ Slide ○ Handout

Number

10

Subject

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

Doctor

Faisal Mohammed

Date: **00/00/2016**

Price:

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

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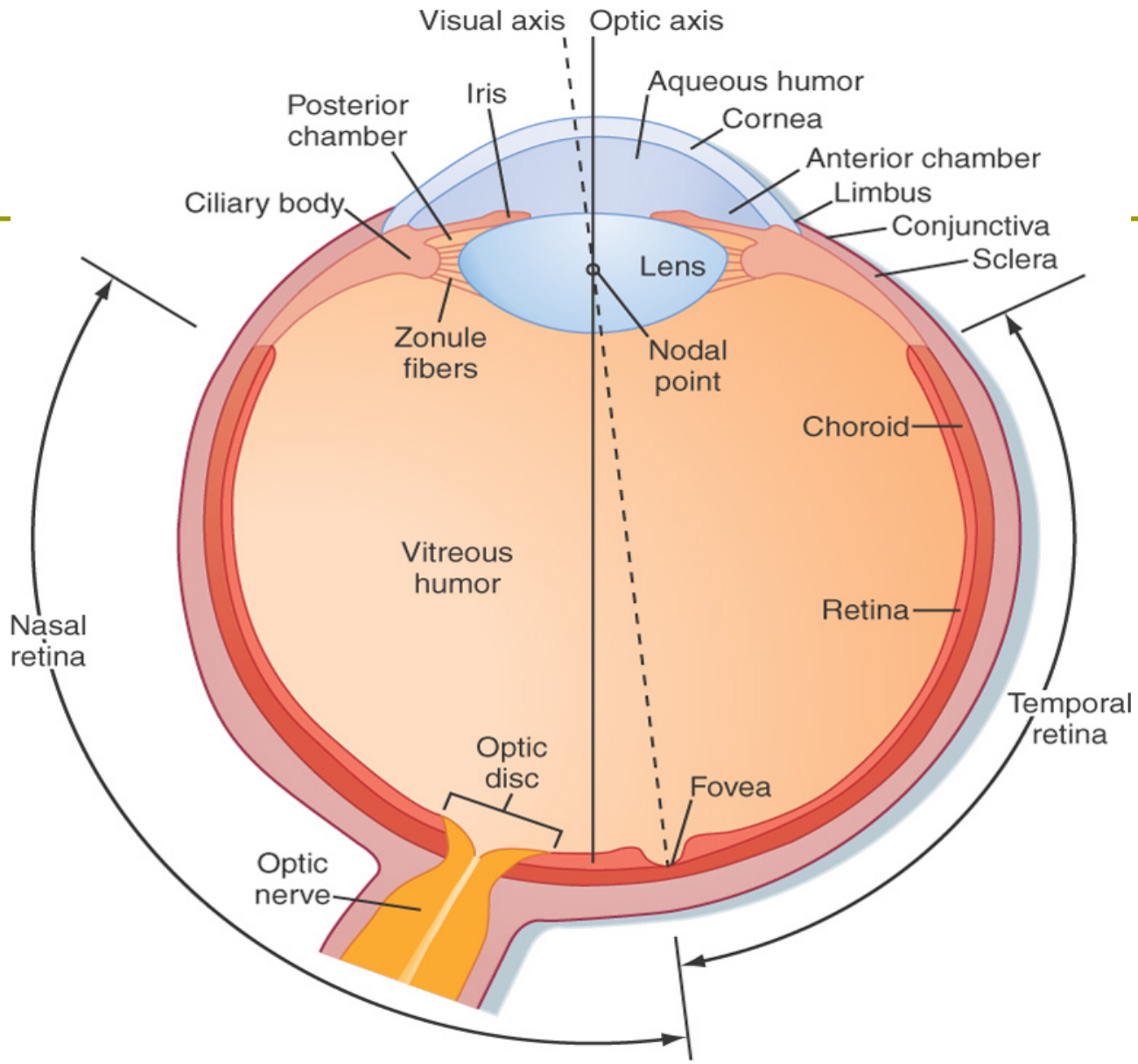
Objectives

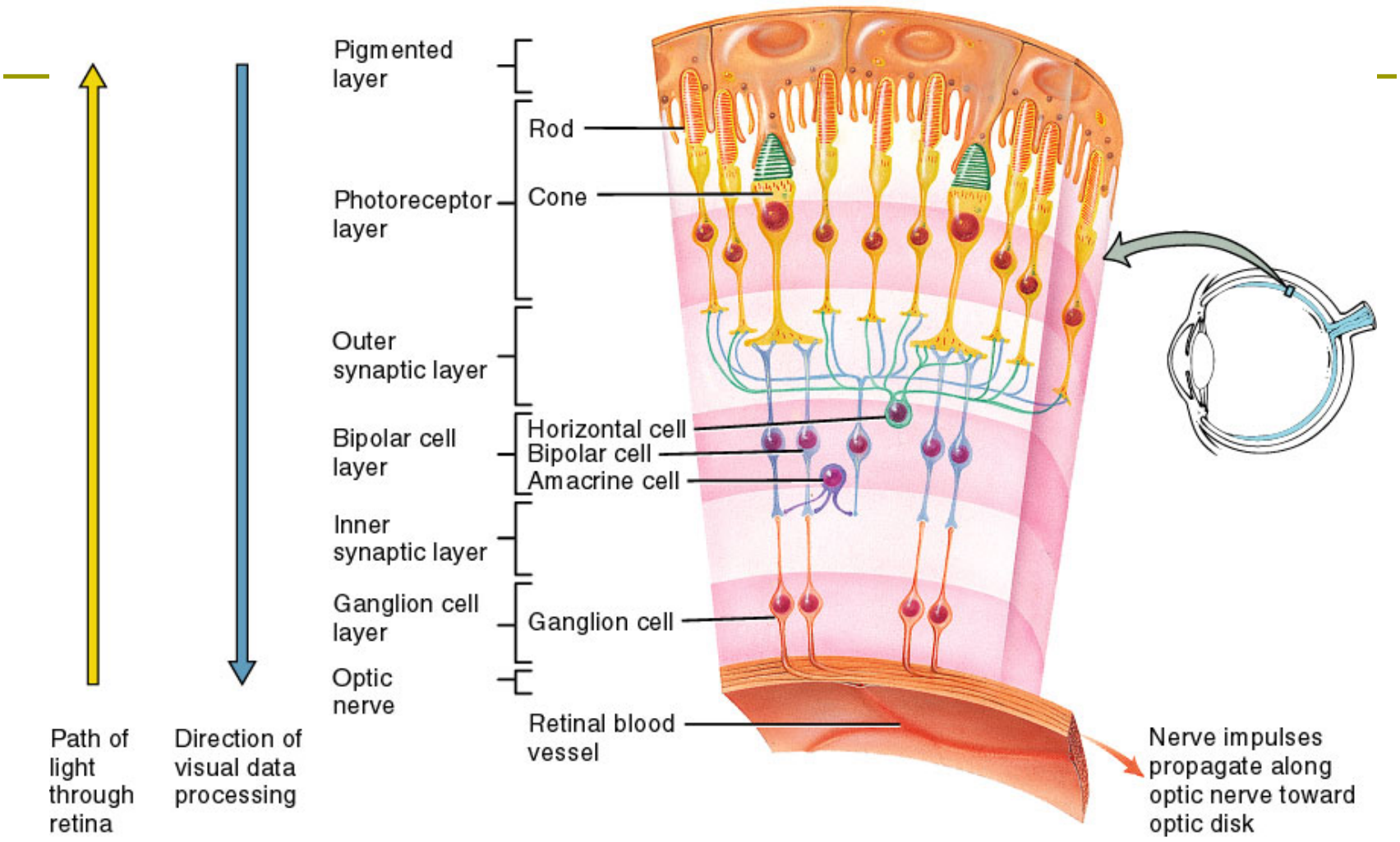
- Describe visual receptors and characterize them
- List the layers of the retina and its cellular makeup
- Explain visual transduction mechanism
- Outline light and dark adaptation
- Describe vitamin A importance for vision
- Explain color blindness

Retina

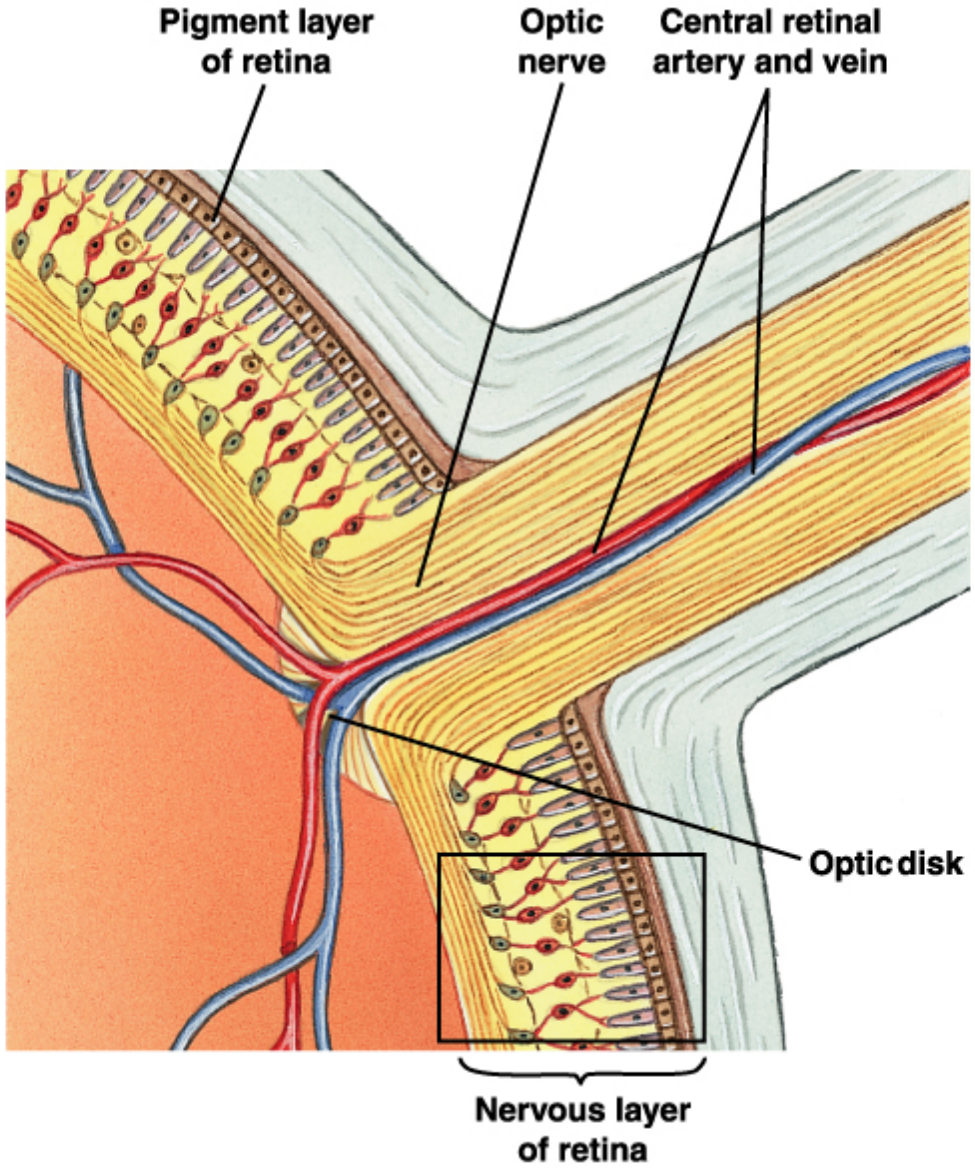
- light sensitive portion of the eye
- contains *cones* for day and color vision
- contains *rods* for night vision
- contains neural architecture
- light must pass through the neural elements to strike the light sensitive rods and cones



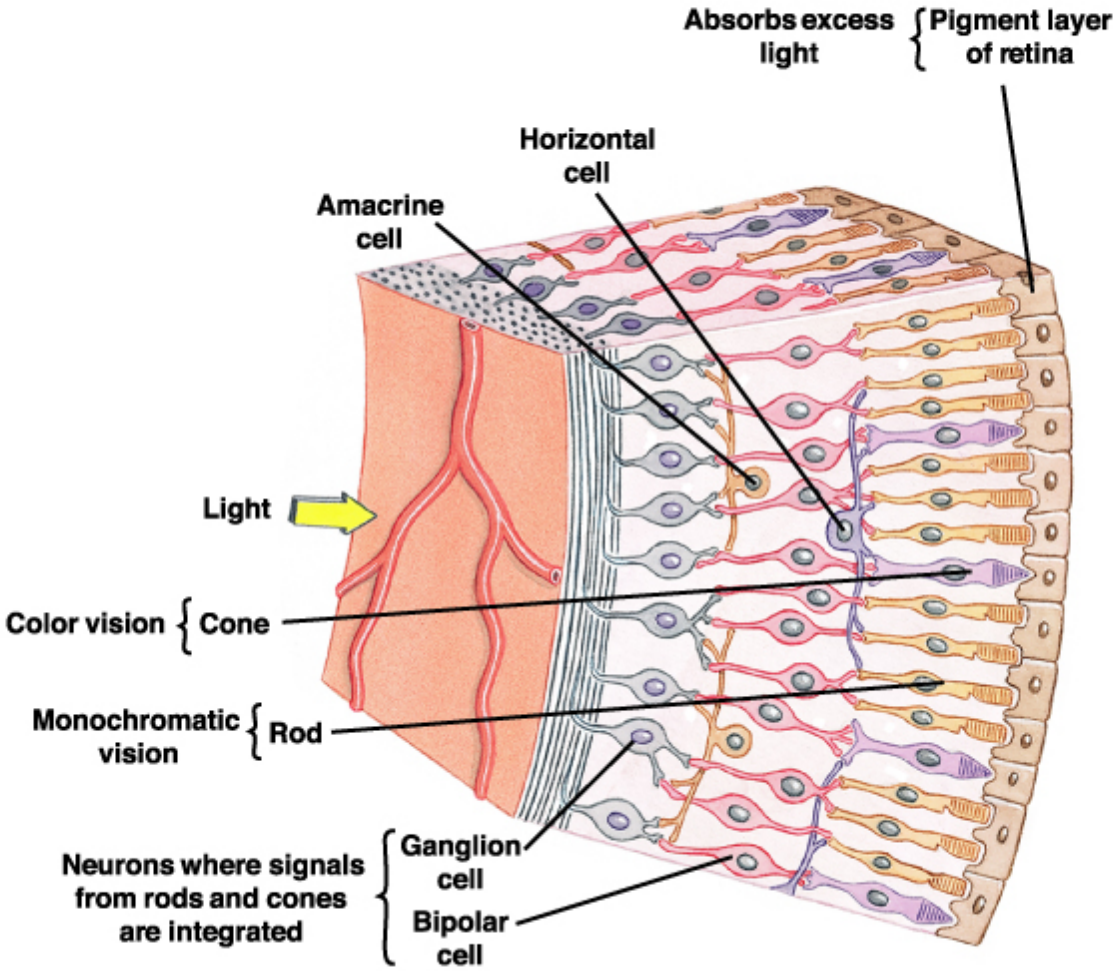
(Redrawn from Wall GL: The Vertebrate Eye and Its Adaptive Radiation. Bloomfield Hills, MI, Cranbrook Institute of Science, 1942.)


Pigmented layer
Photoreceptor layer
Outer synaptic layer
Bipolar cell layer
Inner synaptic layer
Ganglion cell layer
Optic nerve
Rod
Cone
Horizontal cell
Bipolar cell
Amacrine cell
Ganglion cell
Retinal blood vessel
Path of light through retina
Direction of visual data processing
Nerve impulses propagate along optic nerve toward optic disk

16.09


Pigment layer of retina
Optic nerve
Central retinal artery and vein
Optic disk
Nervous layer of retina

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



The Fovea

- 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

- 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

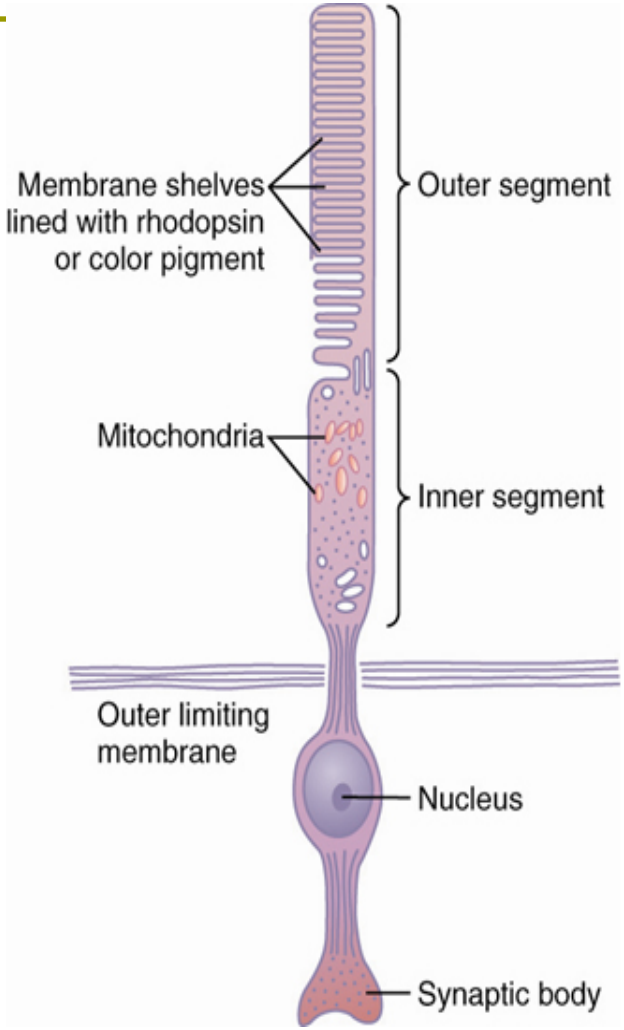
Rods

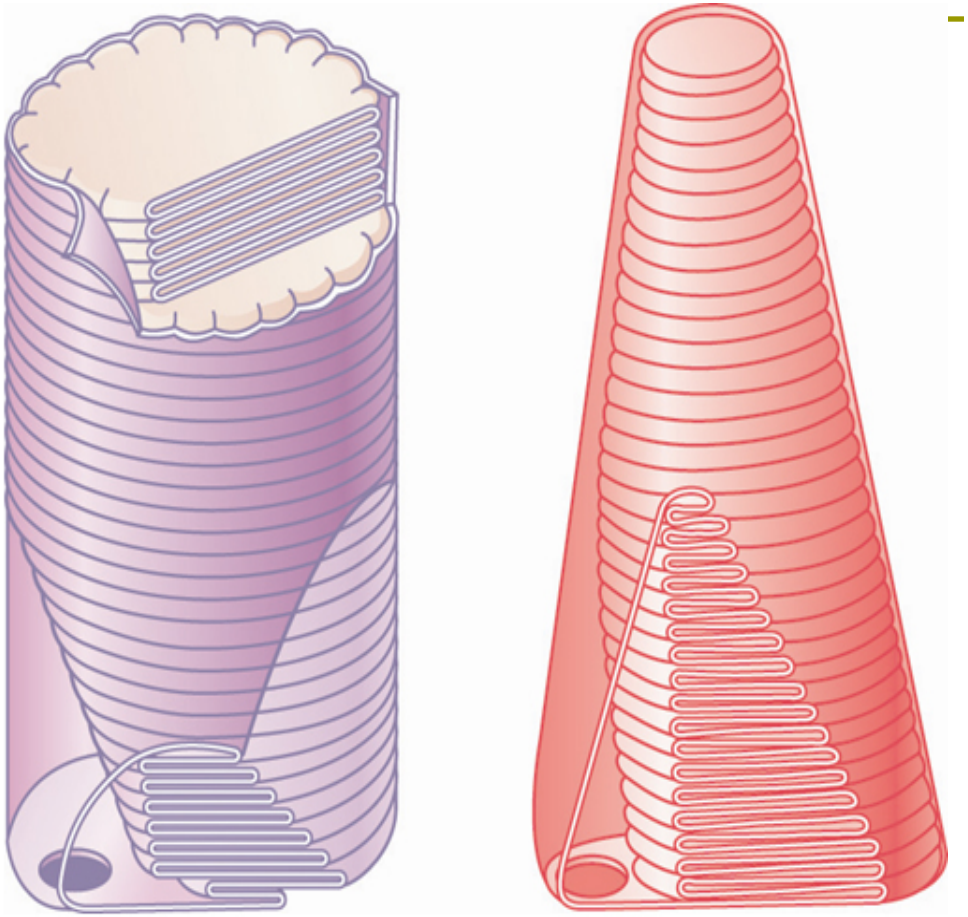
- low acuity; highly convergent retinal pathways, not present in central fovea
- achromatic; one type of rod pigment

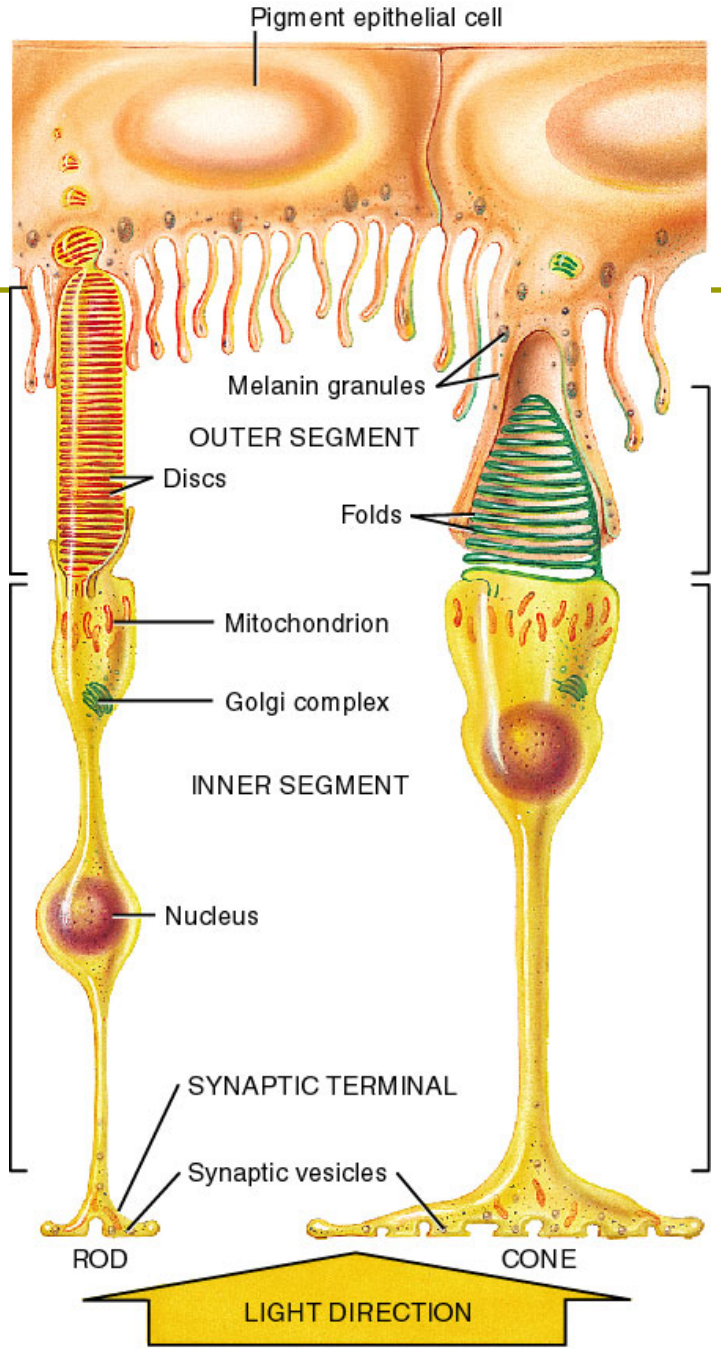
Cones

- 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 epithelial cell
Melanin granules
OUTER SEGMENT
Discs
Folds
Mitochondrion
Golgi complex
INNER SEGMENT
Nucleus
SYNAPTIC TERMINAL
Synaptic vesicles
ROD
CONE
LIGHT DIRECTION

16.13

Pigment Layer of Retina

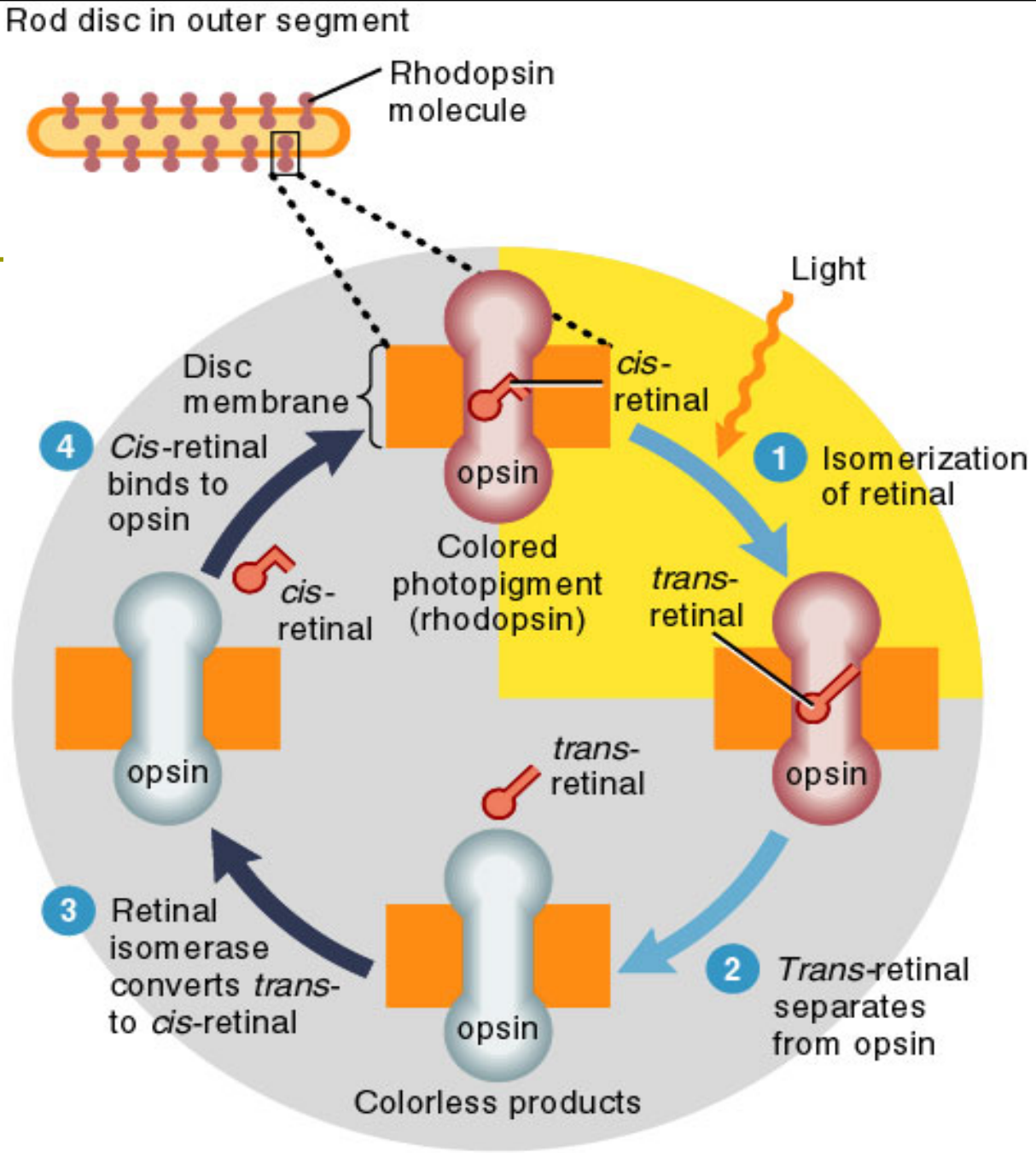
- Pigment layer of the retina is very important
- Contains the black pigment *melanin*
- Prevents light reflection in the globe of the eye
- Without the pigment there would be diffuse scattering of light rather than the normal contrast between dark and light.
- This is what happens in *albinos (**genetic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

Photochemistry of Vision

- 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.

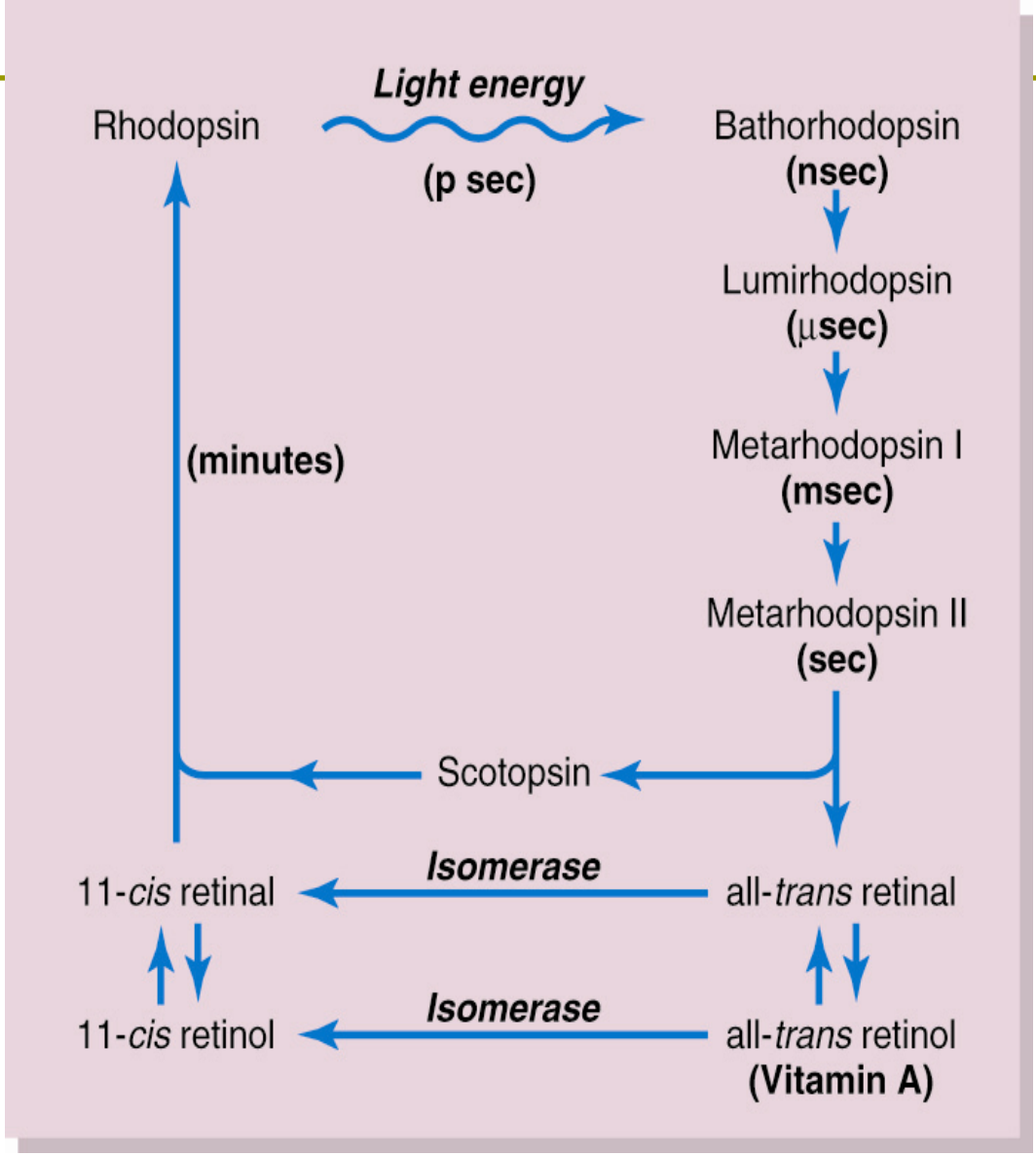
Light and Rhodopsin

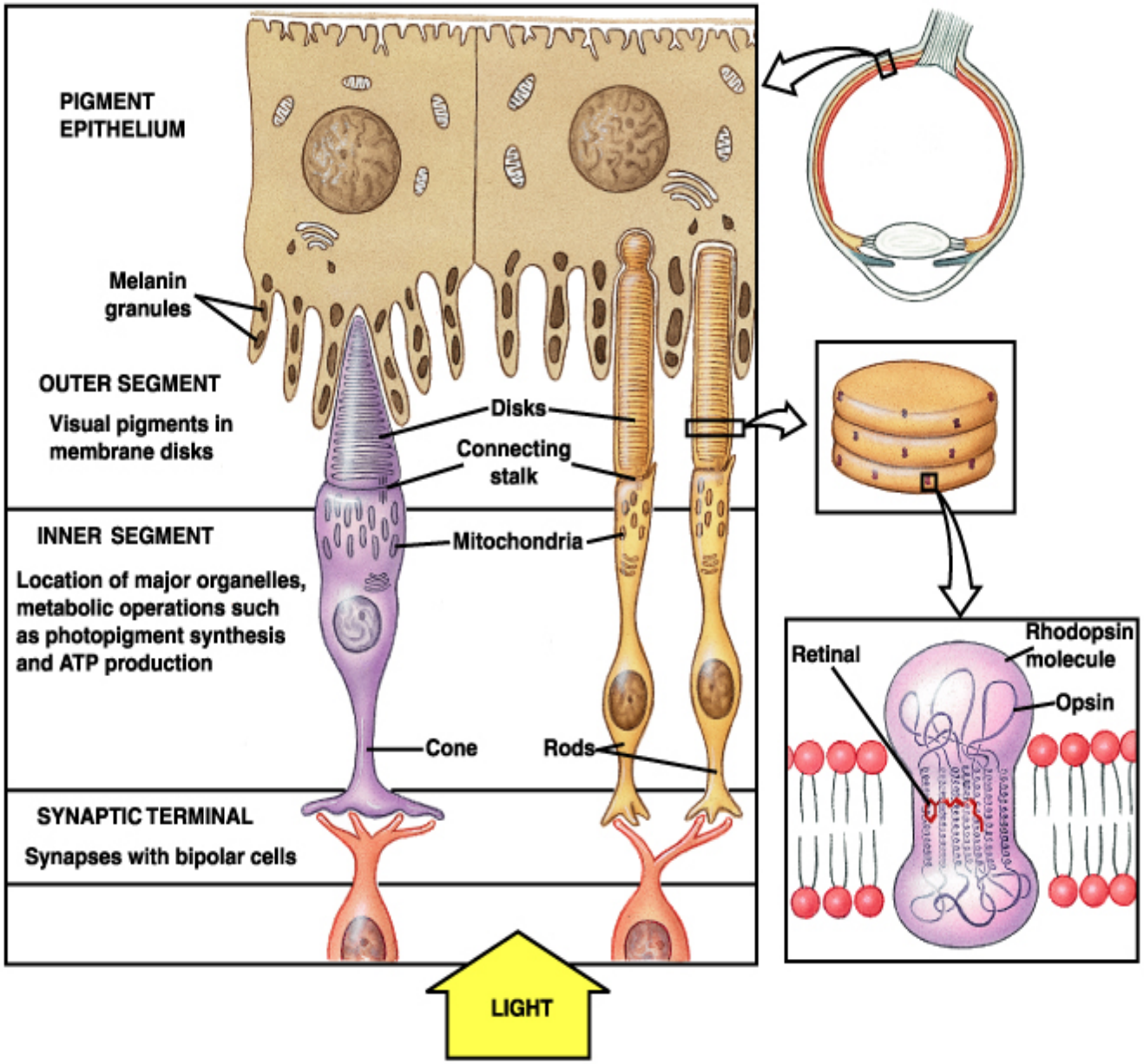
- When light is absorbed by rhodopsin it immediately begins to decompose.
- Decomposition is the result of photoactivation of electrons in the *retinal portion* of rhodopsin which leads to a change from the *cis form* of the retinal to the *trans form* of the molecule.
  - *Trans* retinal has the same 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 molecule
Light
Disc membrane
cis-retinal
opsin
1 Isomerization of retinal
trans-retinal
opsin
2 Trans-retinal separates from opsin
opsin
Colorless products
3 Retinal isomerase converts trans- to cis-retinal
trans-retinal
opsin
4 Cis-retinal binds to opsin
cis-retinal
Colored photopigment (rhodopsin)

16.14

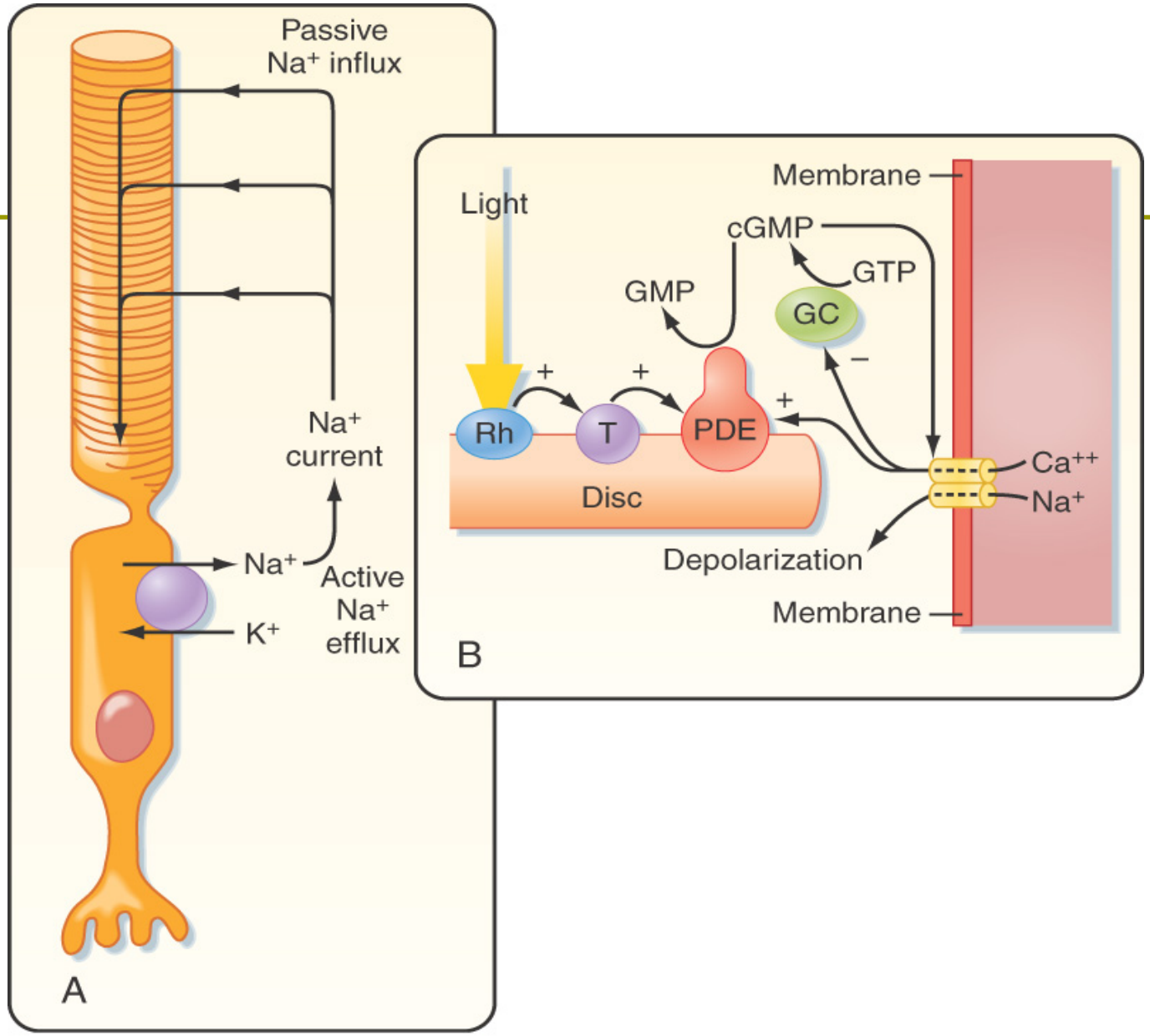
Rhodopsin Cycle



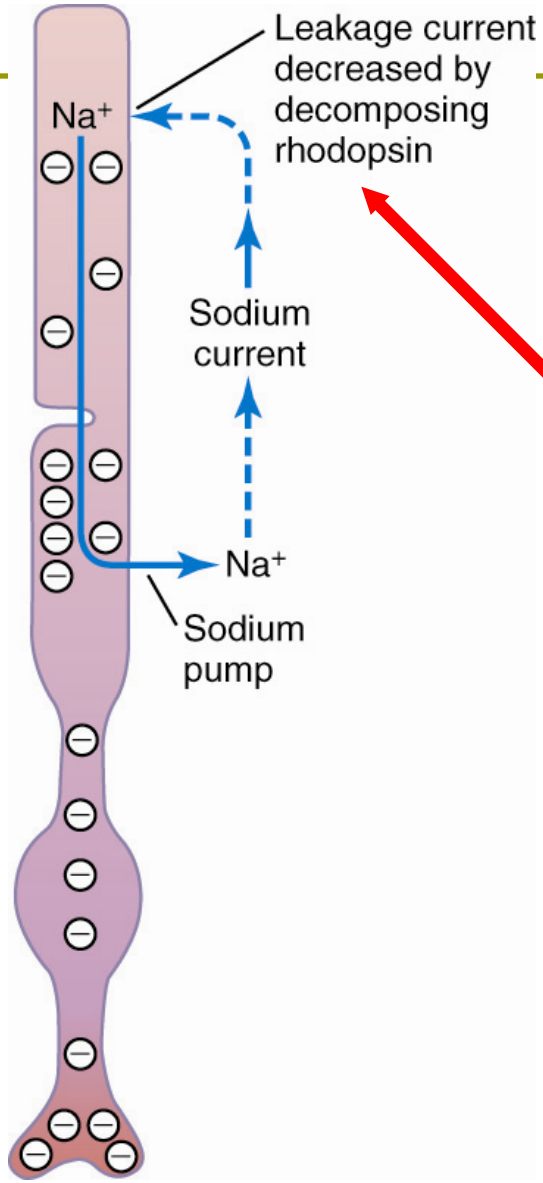

PIGMENT EPITHELIUM
Melanin granules
OUTER SEGMENT
Visual pigments in membrane disks
Disks
Connecting stalk
INNER SEGMENT
Location of major organelles, metabolic operations such as photopigment synthesis and ATP production
Mitochondria
Cone
Rods
SYNAPTIC TERMINAL
Synapses with bipolar cells
LIGHT
Retinal
Rhodopsin molecule
Opsin

Mechanism for Light to Decrease Sodium Conductance

- cGMP is responsible for keeping Na^+ 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^+ channels.

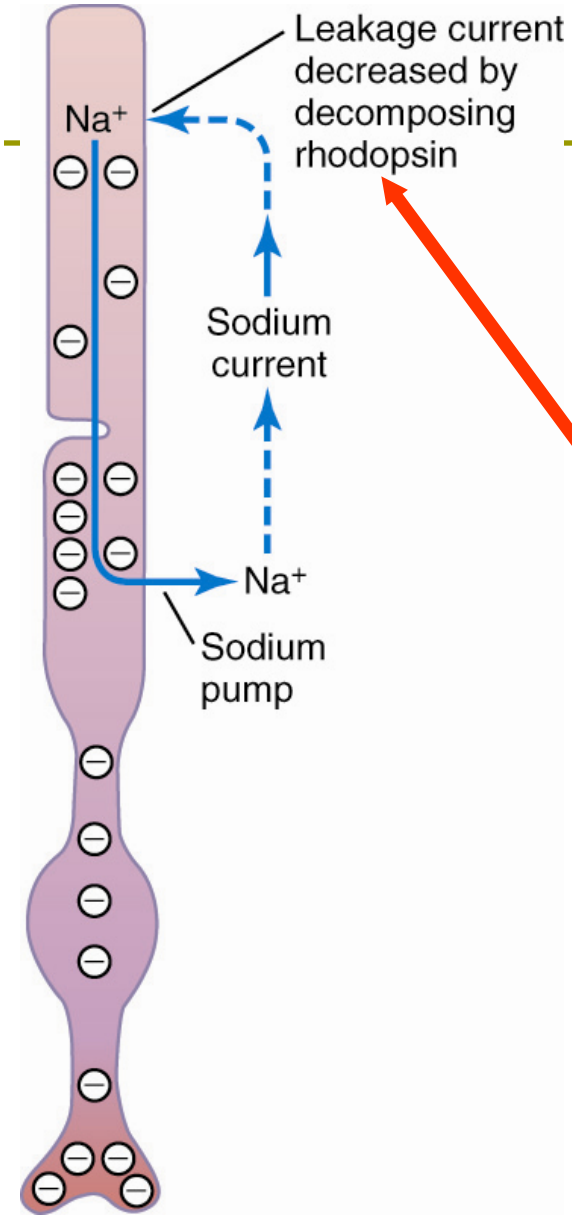


The Dark Current

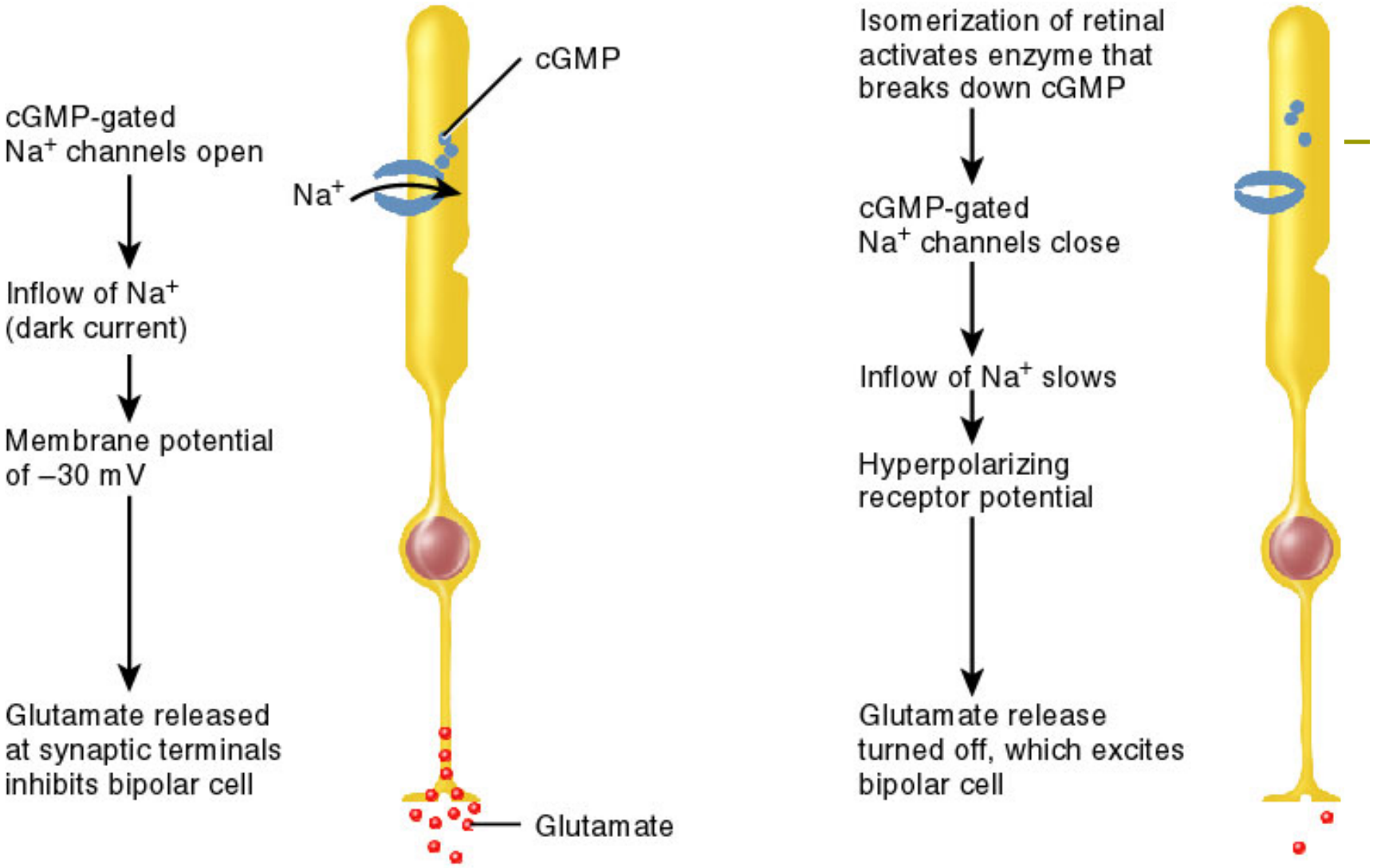


In the dark an inward current (*the dark current*) carried by the Na+ ions flows into the outer segment of the rod.

The Dark Current



When rhodopsin decomposes in response to light it causes a ***hyperpolarization*** of the rod by decreasing Na+ permeability of the outer segment.


cGMP-gated
Na+ channels open
Inflow of Na+
(dark current)
Membrane potential
of –30 mV
Glutamate released
at synaptic terminals
inhibits bipolar cell
cGMP
Na+
Glutamate
(a) In darkness
Isomerization of retinal
activates enzyme that
breaks down cGMP
cGMP-gated
Na+ channels close
Inflow of Na+ slows
Hyperpolarizing
receptor potential
Glutamate release
turned off, which excites
bipolar cell
(b) In light

16.15

Rod Receptor Potential (Cont'd)

- When rhodopsin decomposes it causes a ***hyperpolarization*** of the rod by decreasing Na^+ permeability of the outer segment.
- The Na^+ pump in the inner segment keeps pumping 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

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

Duration and Sensitivity of the Receptor Potential

- 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

- 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

- 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

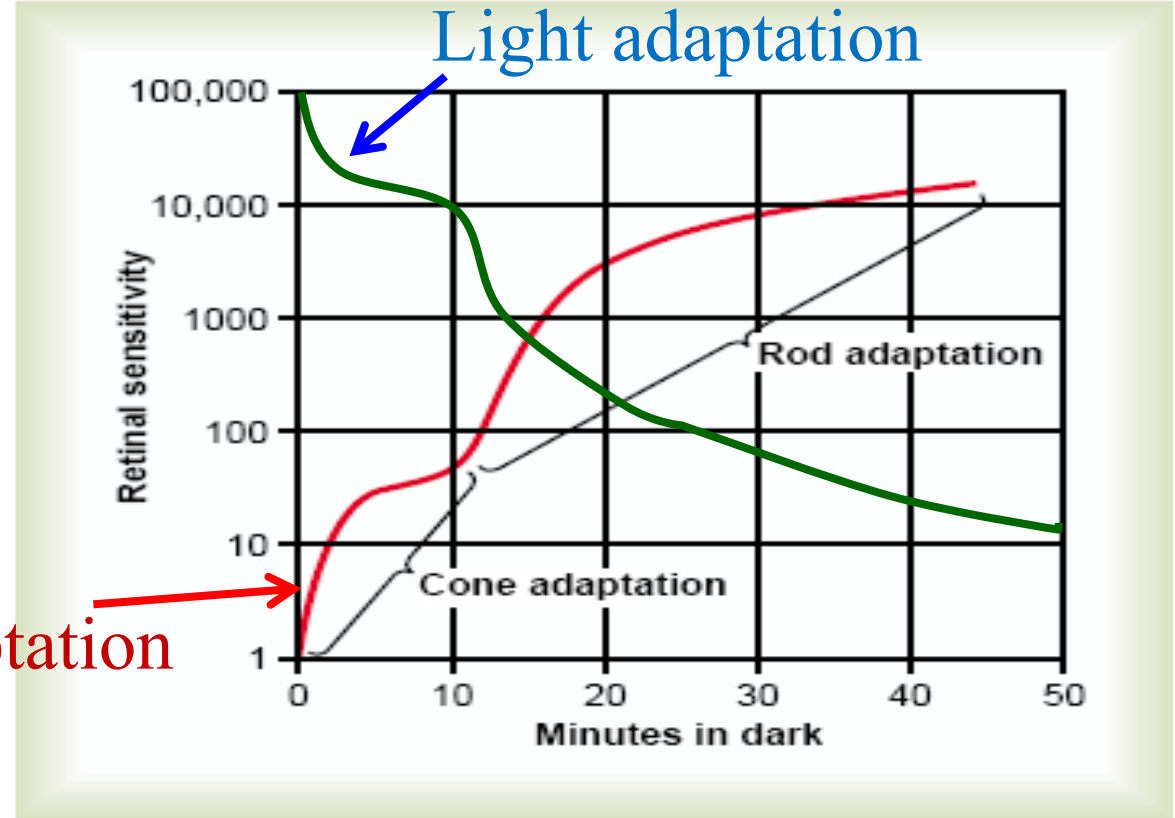


Figure 50–8

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

Importance of Dark and Light Adaptation

- 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.

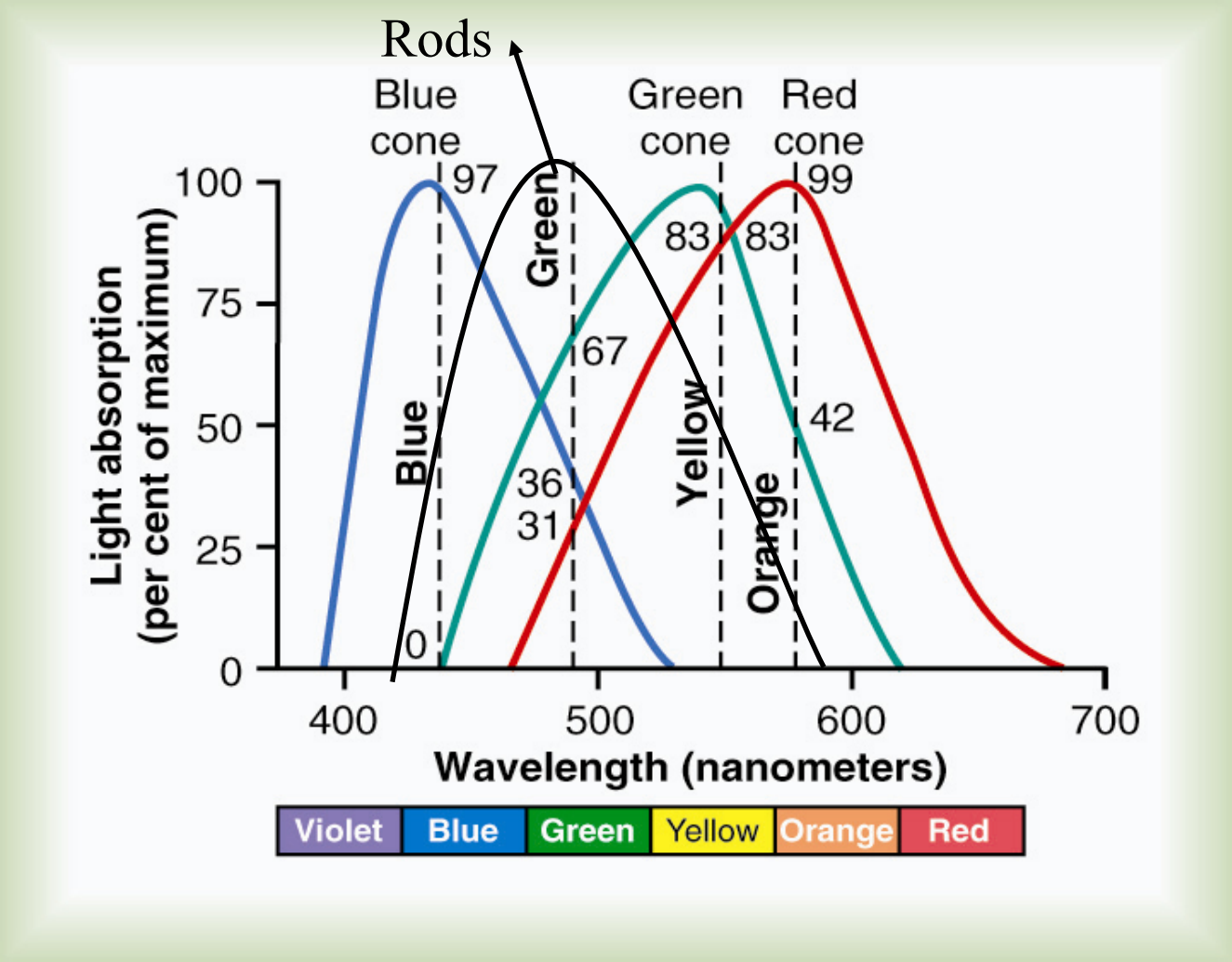
Dark Adaptation

- 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 1st 5 min.
  - Increased rhodopsin in rods produces greater increase in sensitivity.
    - 100,000-fold increase in light sensitivity in rods.

Color Vision

- 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

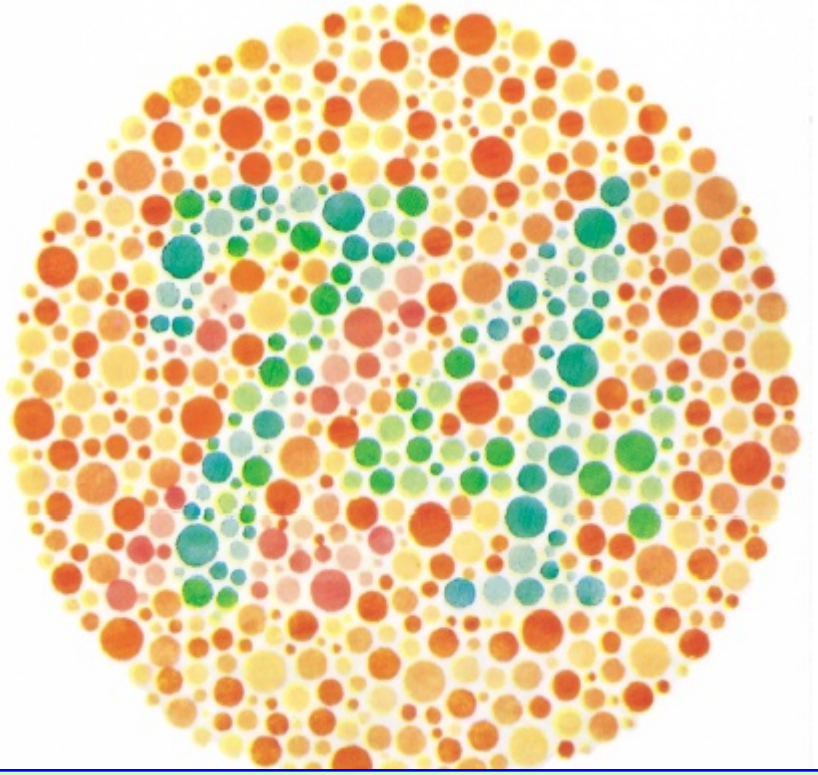
Each Cone is Receptive to a Particular Wavelength of Light



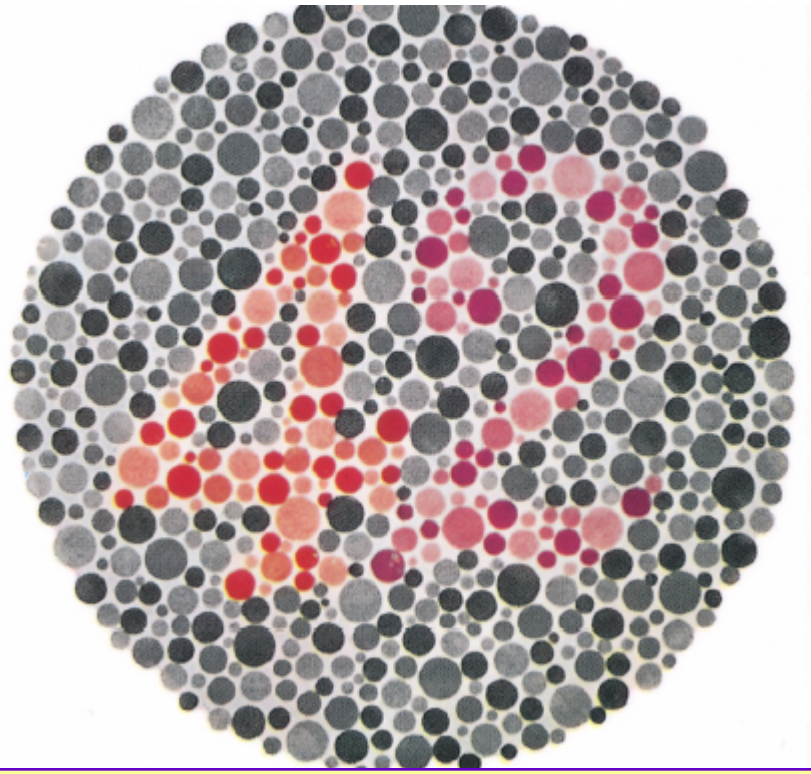
Color Blindness

- 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

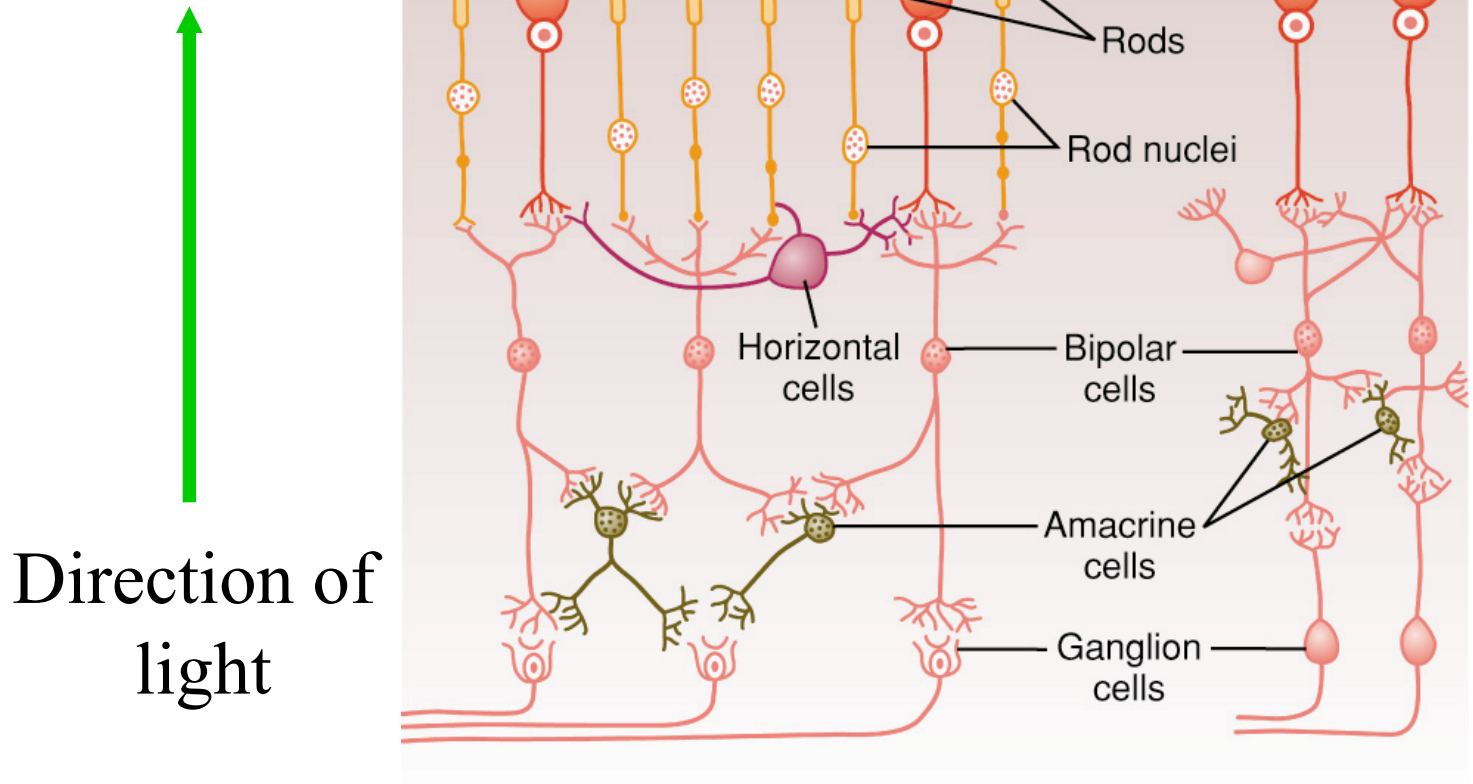


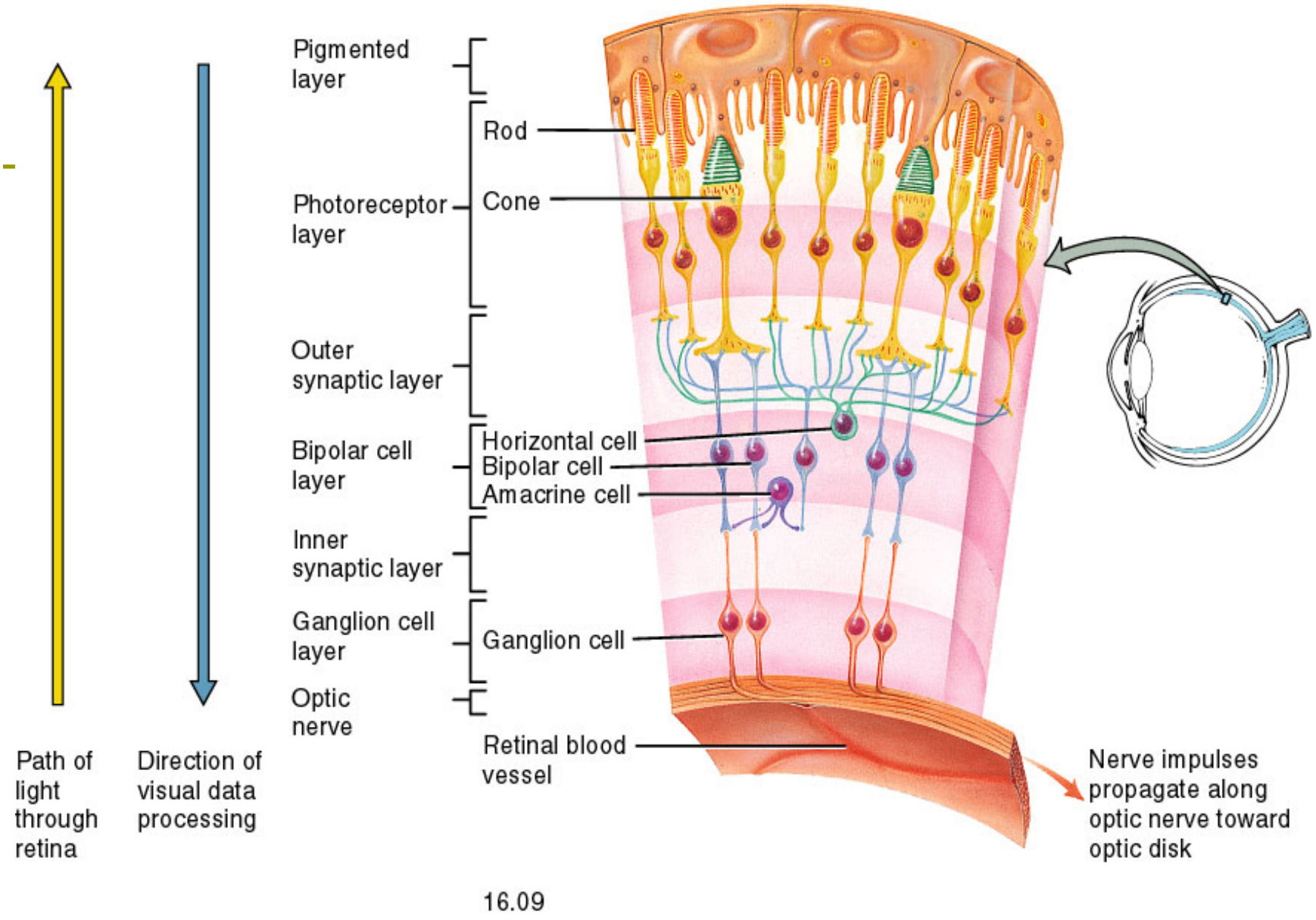
Normal read 74, Red-Green read it 21



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

Neural Organization of the Retina




Pigmented layer
Photoreceptor layer
Rod
Cone
Outer synaptic layer
Bipolar cell layer
Horizontal cell
Bipolar cell
Amacrine cell
Inner synaptic layer
Ganglion cell layer
Ganglion cell
Optic nerve
Retinal blood vessel
Path of light through retina
Direction of visual data processing
Nerve impulses propagate along optic nerve toward optic disk

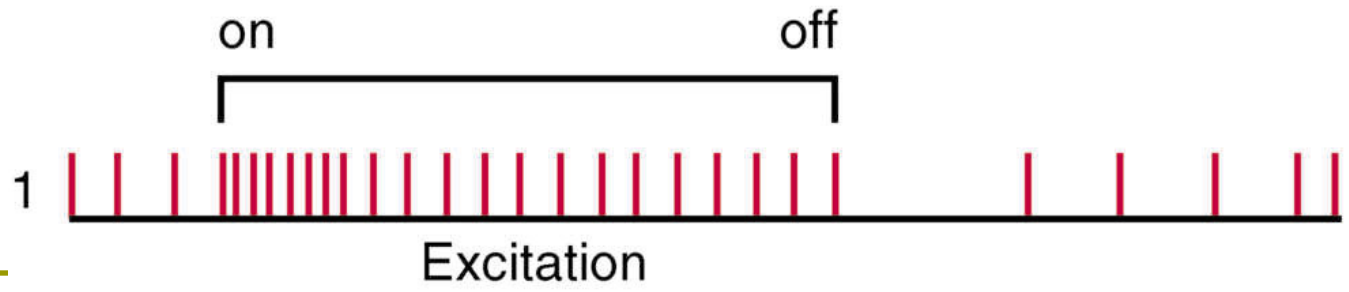
16.09

Signal Transmission in the Retina

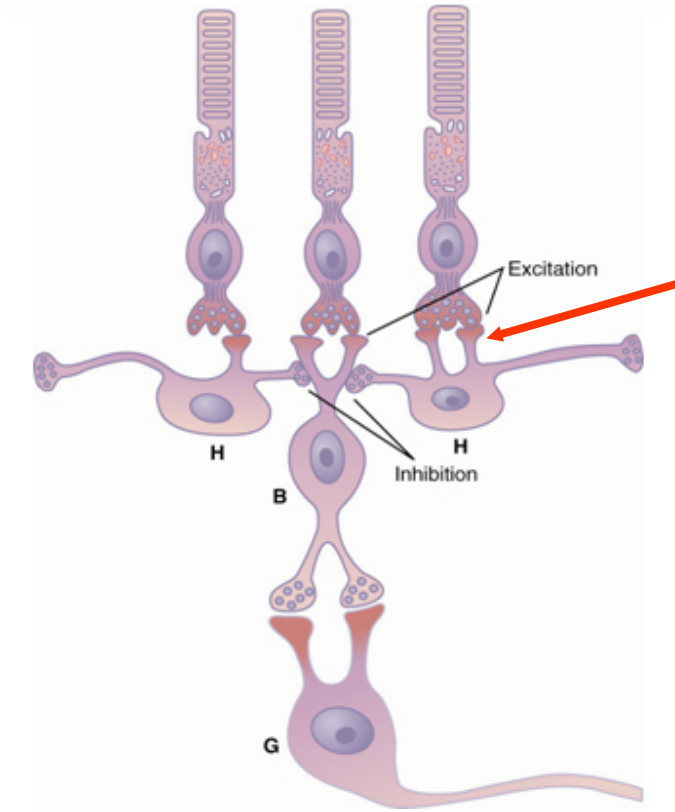
- Transmission of signals in the retina is by electrotonic conduction.
- Allows graded response proportional to light intensity.
- The only cells that have action potentials are ganglion cells and amacrine cells.
  - send signals all the way to the brain

Lateral Inhibition to Enhance Visual Contrast

- 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



Lateral inhibition, the function of horizontal cells

Function of Amacrine Cells

- 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

- **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

- 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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