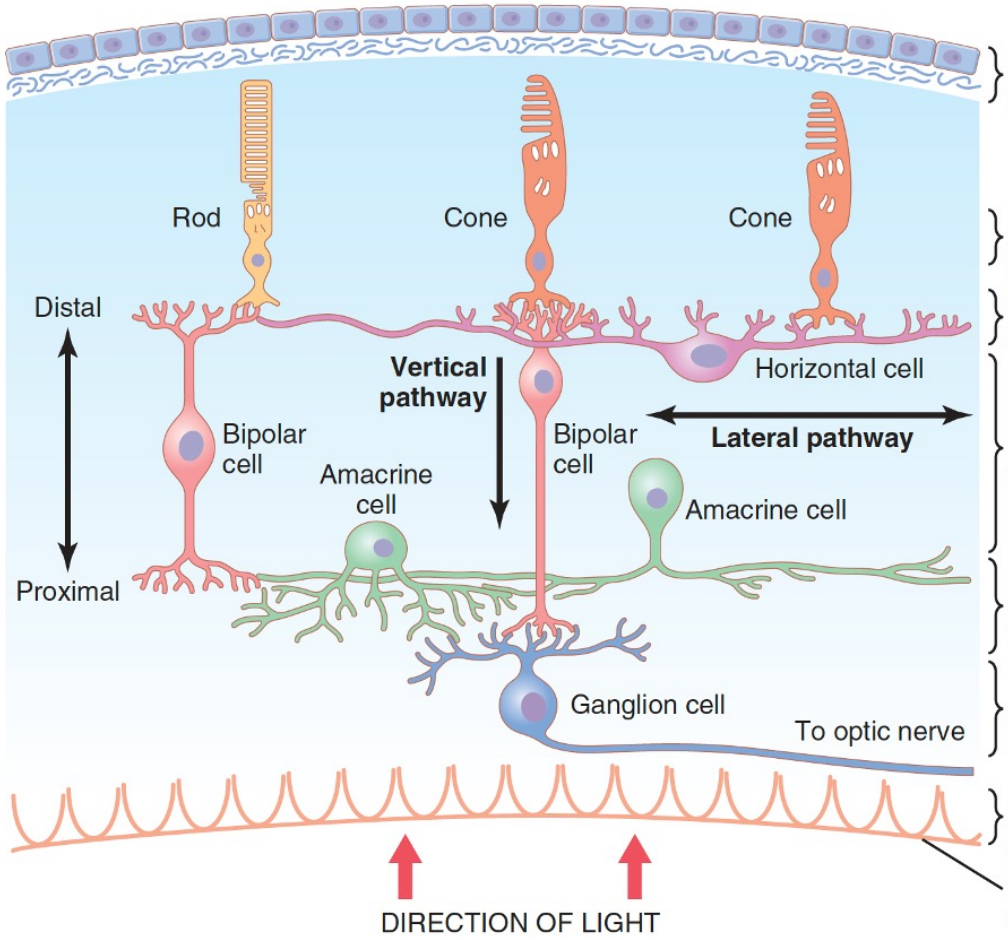
Lecture 3
The Eye: II. Receptor and Neural Function of the Retina
Chapter 51

Layers of retina

outer layers of the retina → nutrition from choroid→ retinal detachment→ damage



Pigmented layer — melanin called fuscin→ absorbs light & prevents reflection of light rays back from retina
Albinos-poor visual acuity because of the scattering of light.
stores vitamin A (precursor of the photosensitive chemicals)

Outer nuclear layer — cell bodies of rods and cones

Outer plexiform layer — synapses between dendrites of horizontal cells, bipolar cells & and photoreceptor cell

Inner nuclear layer — bipolar cells, horizontal cells & amacrine cells.

Inner plexiform layer — synapses between dendrites of ganglionic cells & axons of bipolar cells+ processes from amacrine cells.

Ganglion cell layer — giant & midget ganglion cells → axons form the optic nerve
Retinal blood vessels

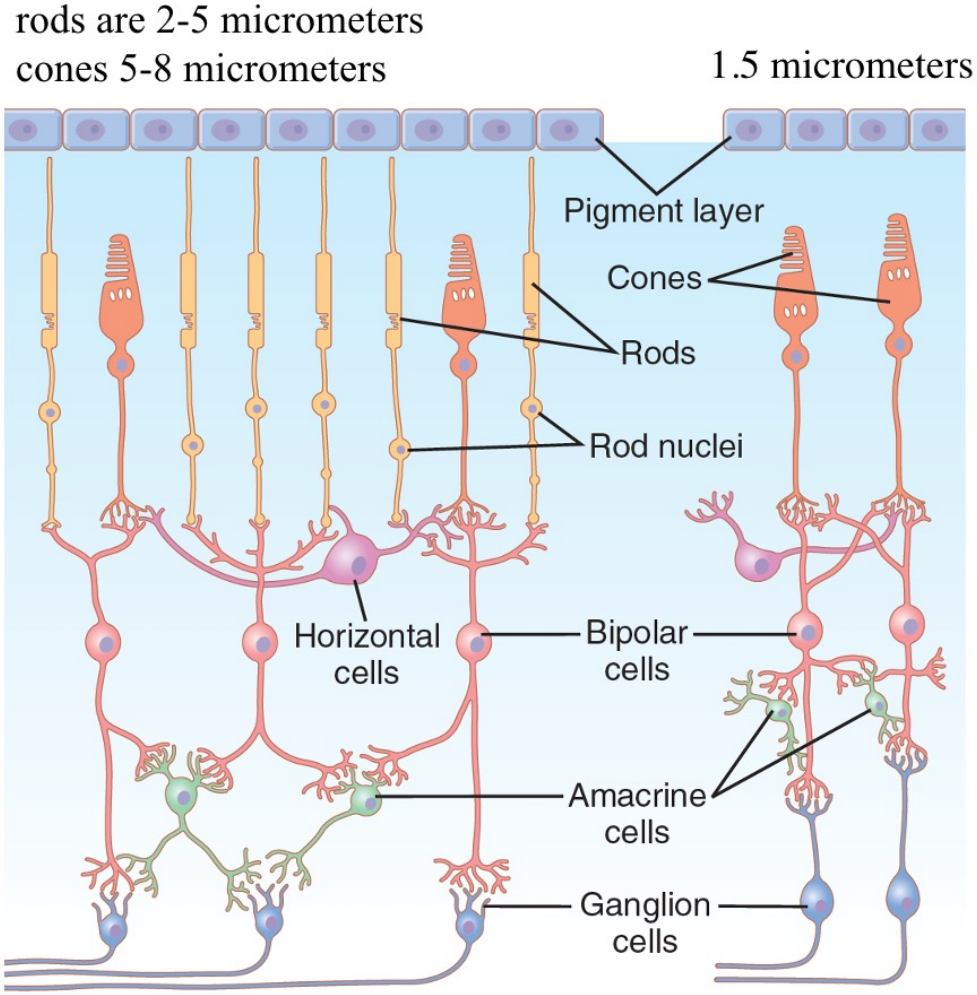
Stratum opticum — horizontal non-myelinated axons of ganglionic cells converge → optic disk

Inner limiting membrane — separates retina from the vitreous body formed by Müller fibers

Inner layers of the retina → nutrition from central retinal artery

Foveal region of the retina

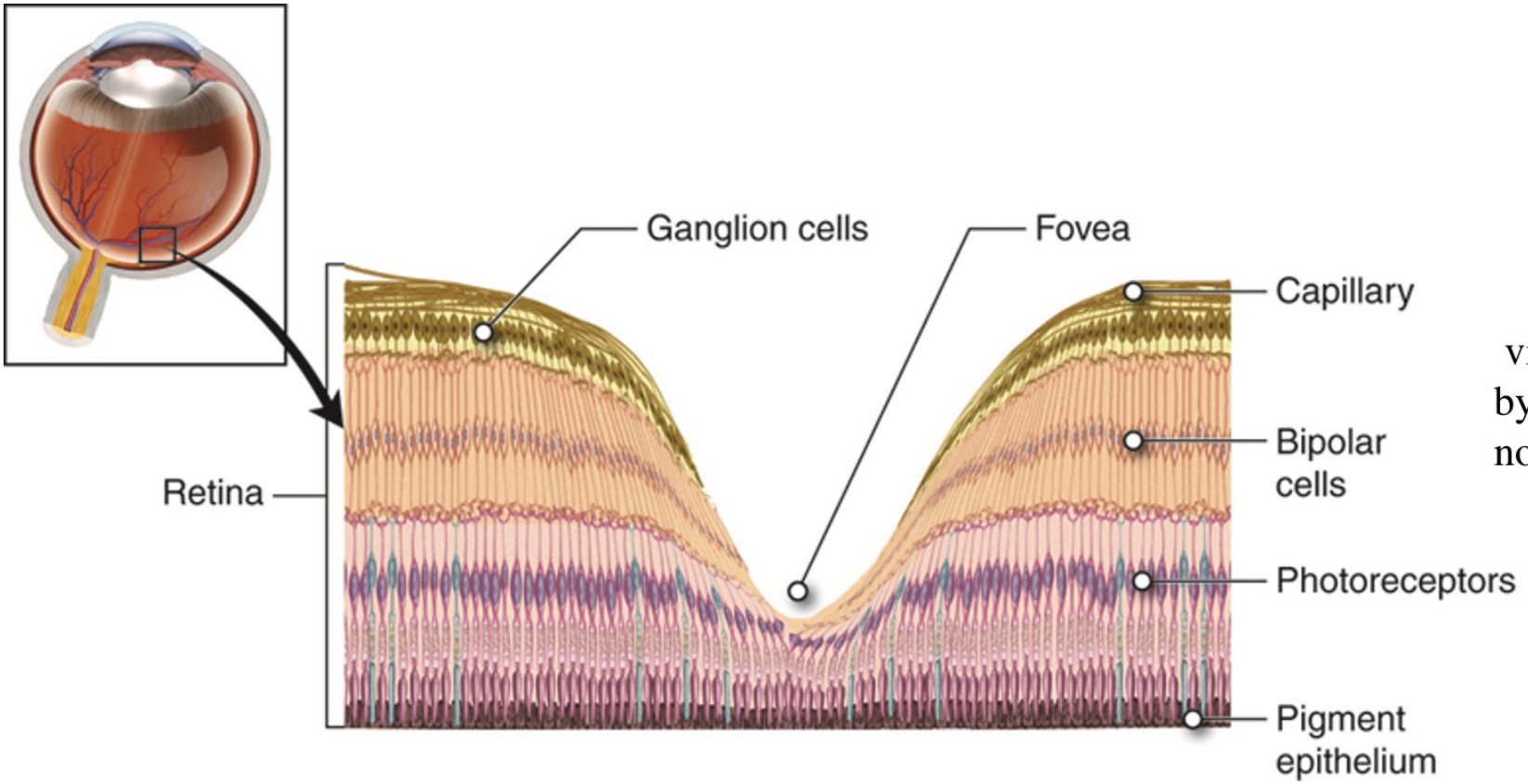
- composed of cones only (long and slender) →acute and detailed vision
- 1: 1 connection→ no convergence



Foveal region of the retina

FOVEA

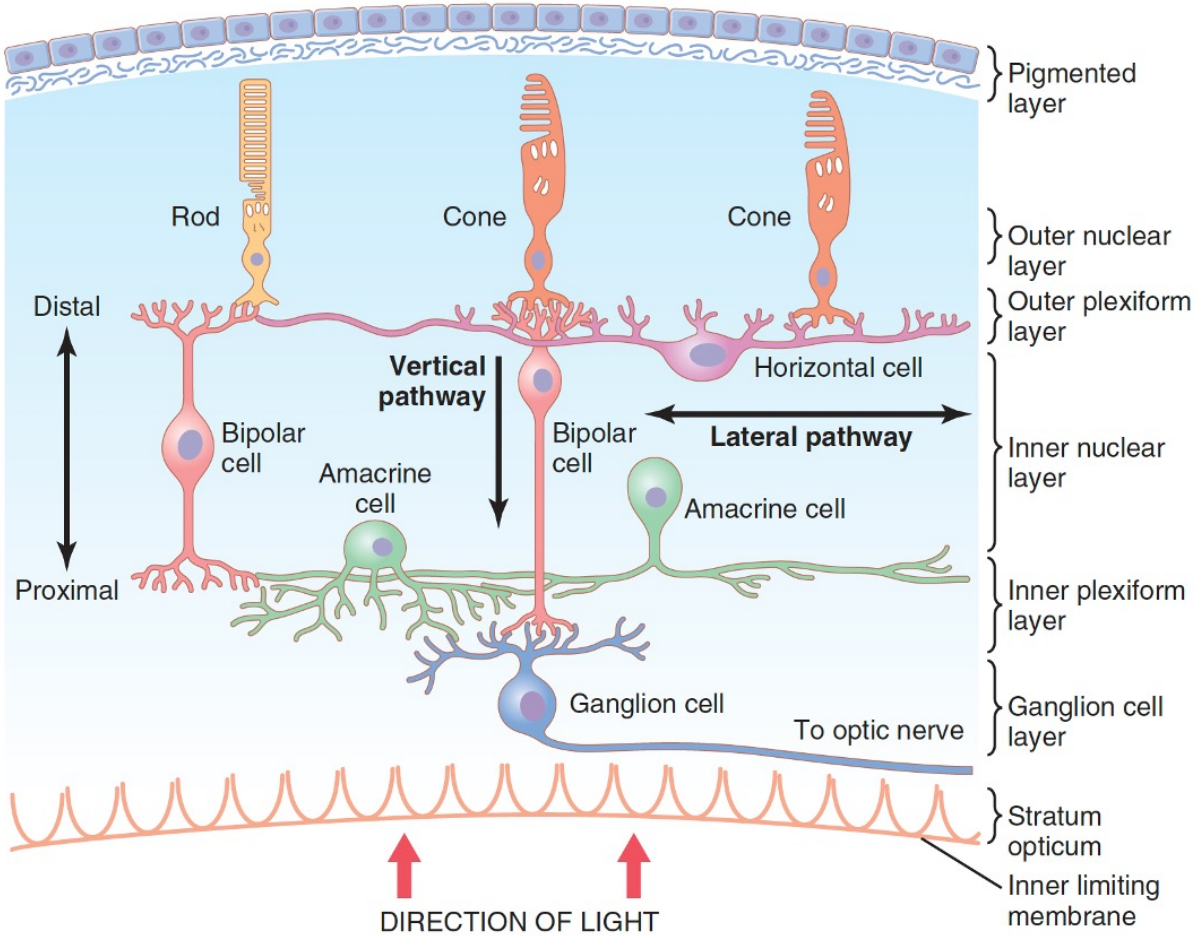
FOr **VE**ry **A**cute vision



visual acuity is decreased by light passage through nonhomogeneous tissue

blood vessels, ganglion cells, inner nuclear layer of cells, and plexiform layers are all displaced to one side → light pass unimpeded to cones→ highest visual acuity

Rods and Cones



When rods or cones are excited

↓

signals are transmitted through neurons in retina

↓

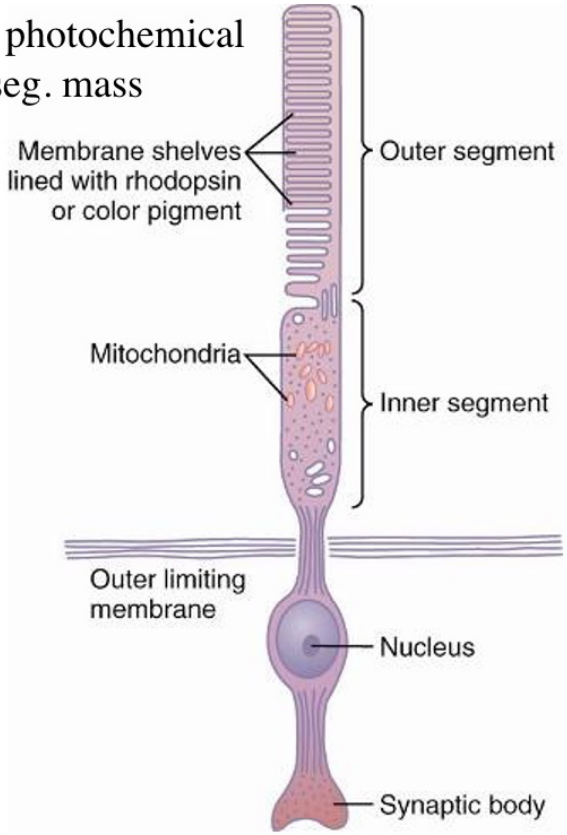
optic nerve fibers

↓

cerebral cortex

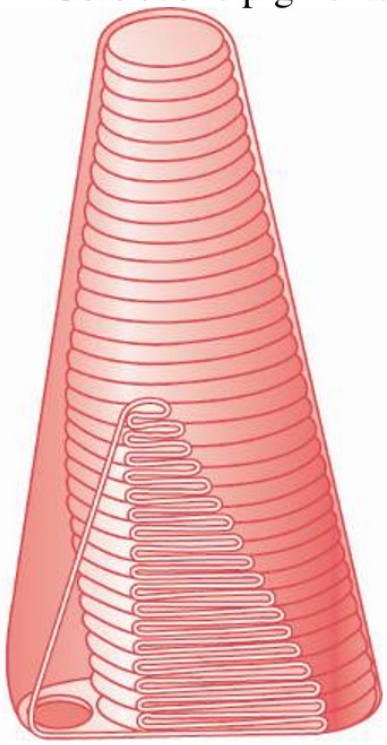
Structure of the Rods and Cones

light-sensitive photochemical
40% of outer seg. mass



rhodopsin

photopsin
Color/cone pigments



connects with horizontal and bipolar cells

Rods

- 100 million
- Mainly at periphery
- Low threshold
- high sensitivity; specialized for night vision(black & white)
- high amplification; single photon detection
- slow response
- sensitive to scattered light

Cones

- 3 million
- Mainly at center
- High threshold
- lower sensitivity; specialized for day vision/color vision
- less amplification
- fast response
- more sensitive to direct axial rays

Rods vs. cone function RoD: Dim light.
Cones: Color.

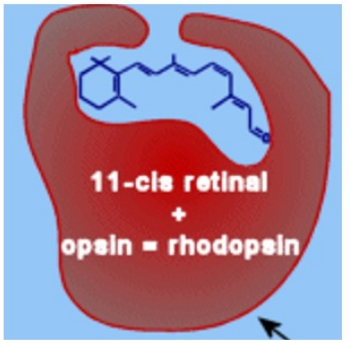
Rods

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

Cones

- high acuity; less convergent retinal pathways, concentrated in central fovea
- chromatic; three types of cones (red, green & blue/Porphyropsin or iodopsin or cyanopsin), each with a different pigment that is sensitive to a different part of the visible spectrum

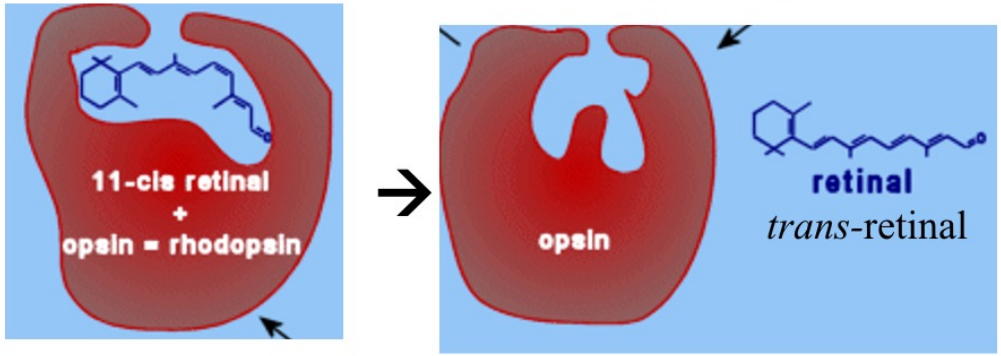
Photochemistry of Vision

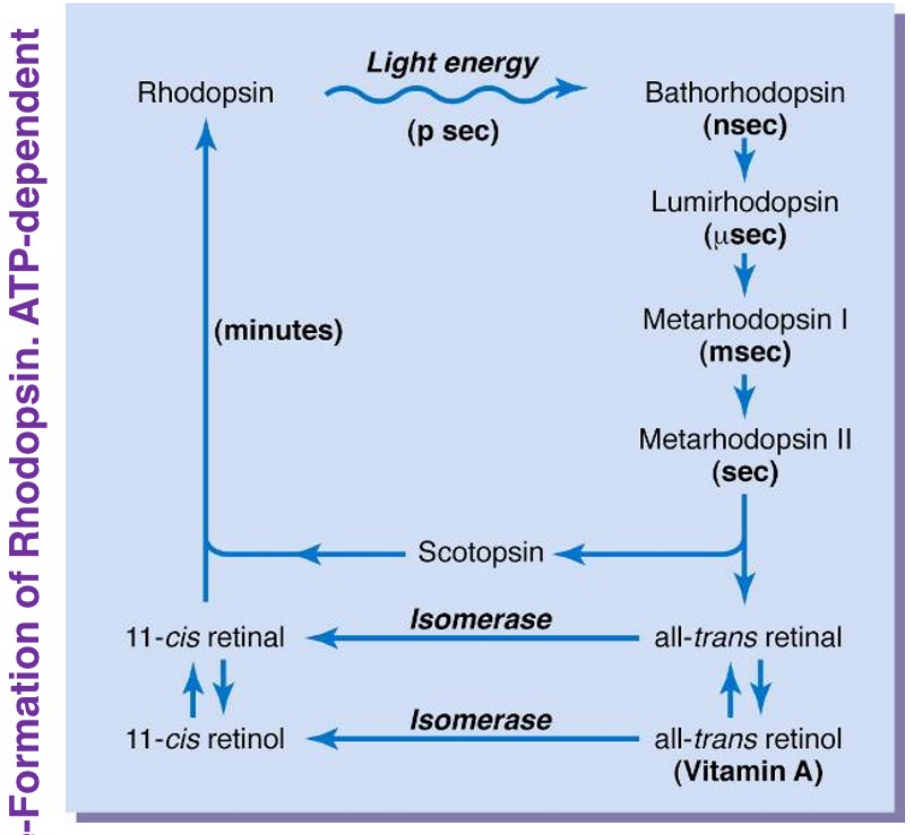


- **rhodopsin** is a combination of a protein called ***scotopsin*** and a pigment, ***retinal***.
- the retinal is in the ***cis*** configuration (11-cis retinal).
- only the *cis* configuration can bind with scotopsin to form rhodopsin.

Light and Rhodopsin

- **photochemicals decompose** on exposure to light→ excitation of nerve fibers leading from eye.
- decomposition is the result of **photoactivation** of electrons in the *retinal portion* of rhodopsin→ change from *cis*-retinal to *trans*-retinal.
  - *trans* retinal 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.





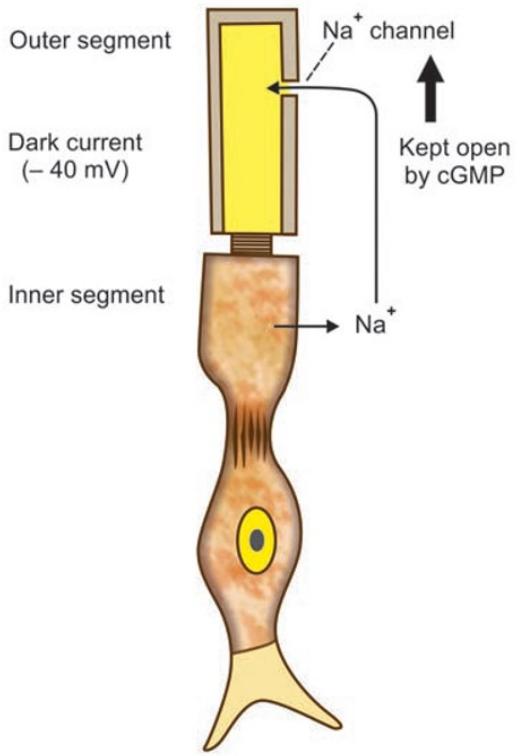
Role of Vitamin A

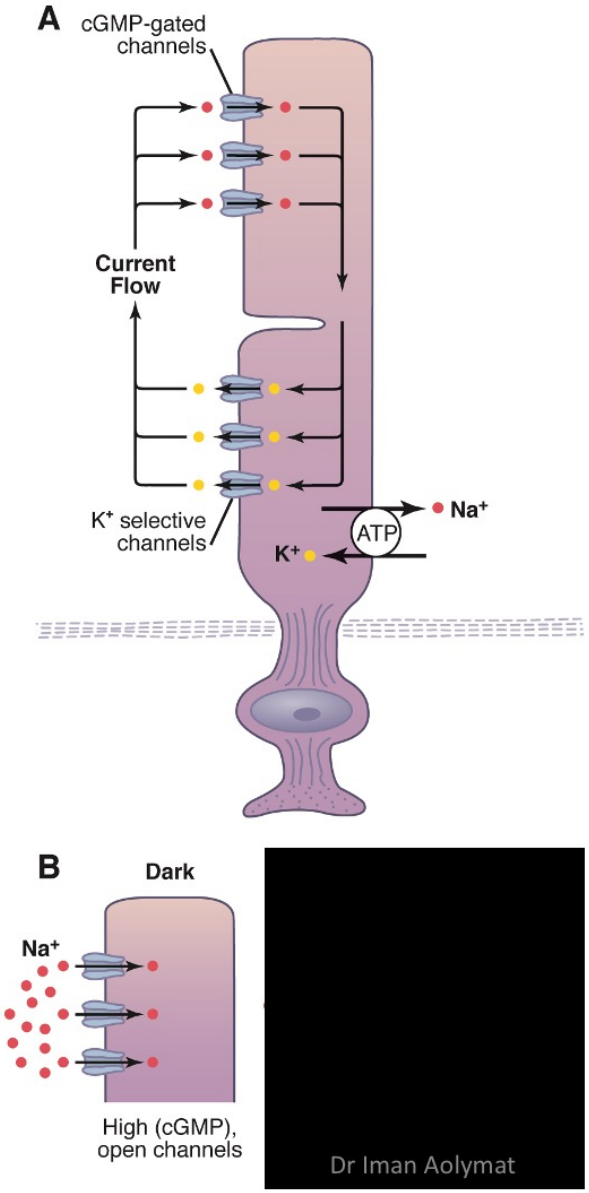
- vitamin A is the precursor of *all-trans-retinal*
- present in cytoplasm of photoreceptors and in pigment layer of the retina
- lack of vitamin A causes a decrease in retinal →*night blindness*.

The Rod Receptor Potential

- **Phototransduction**: conversion of **light energy** into **receptor potential** in *visual receptors*
- normally the outer segment of the rod is very permeable to Na^+ (cGMP dependent)
- Na^+ pump in inner segment → pumping Na^+ out

- **in the dark**→↑ cGMP →an inward Na current (*the dark current*) into the outer segment of the rod→ depolarization (RMP = about –40 mV)→ increase neurotransmitter release (glutamate)




A
cGMP-gated channels
Current Flow
K+ selective channels
Na+
ATP
K+
B
Dark
Na+
High (cGMP), open channels

Rod Receptor Potential (Cont'd)

- **In light vision**

rhodopsin decomposes

↓

↓ cGMP

↓

↓ Na^+ permeability (outer segment)+ continuous Na pumping (inner segment)

↓

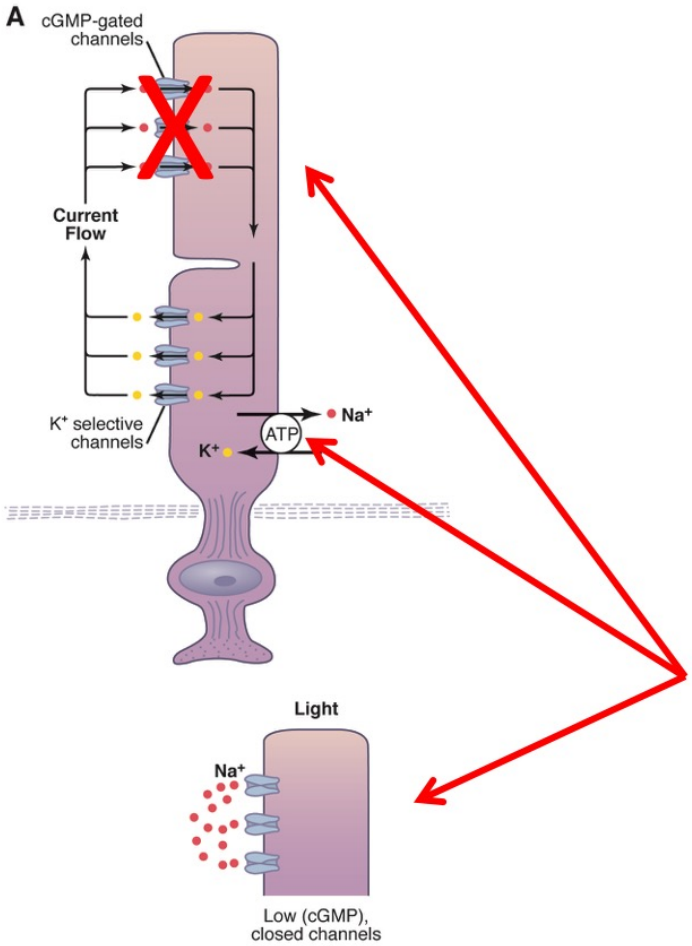
hyperpolarization ((RMP = about –80 mV)

↓

decrease neurotransmitter release (glutamate)

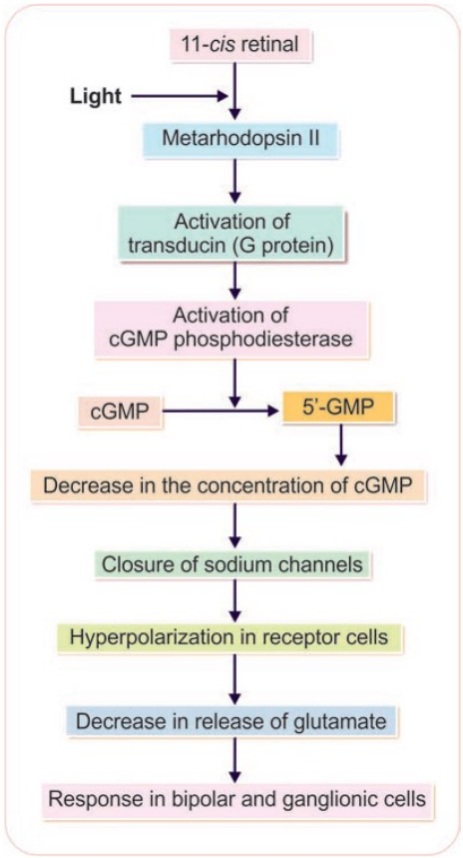
- the greater the amount of light the greater the electronegativity.

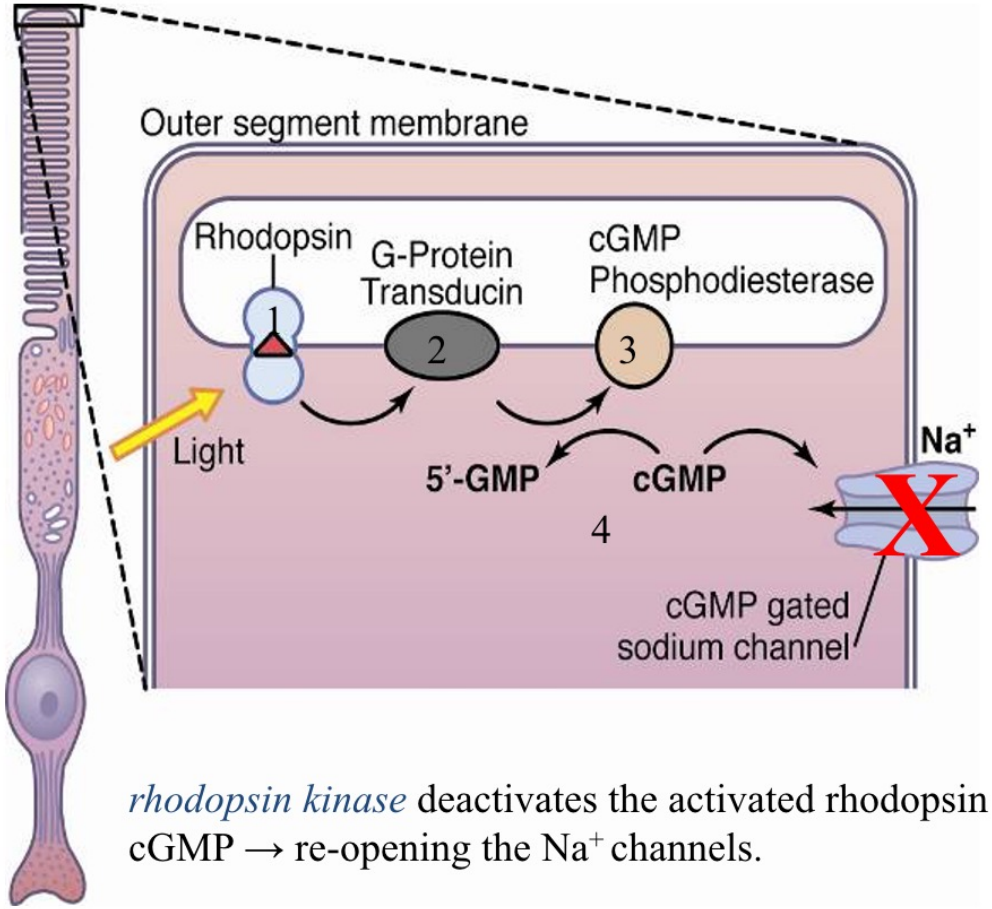
The Light Current



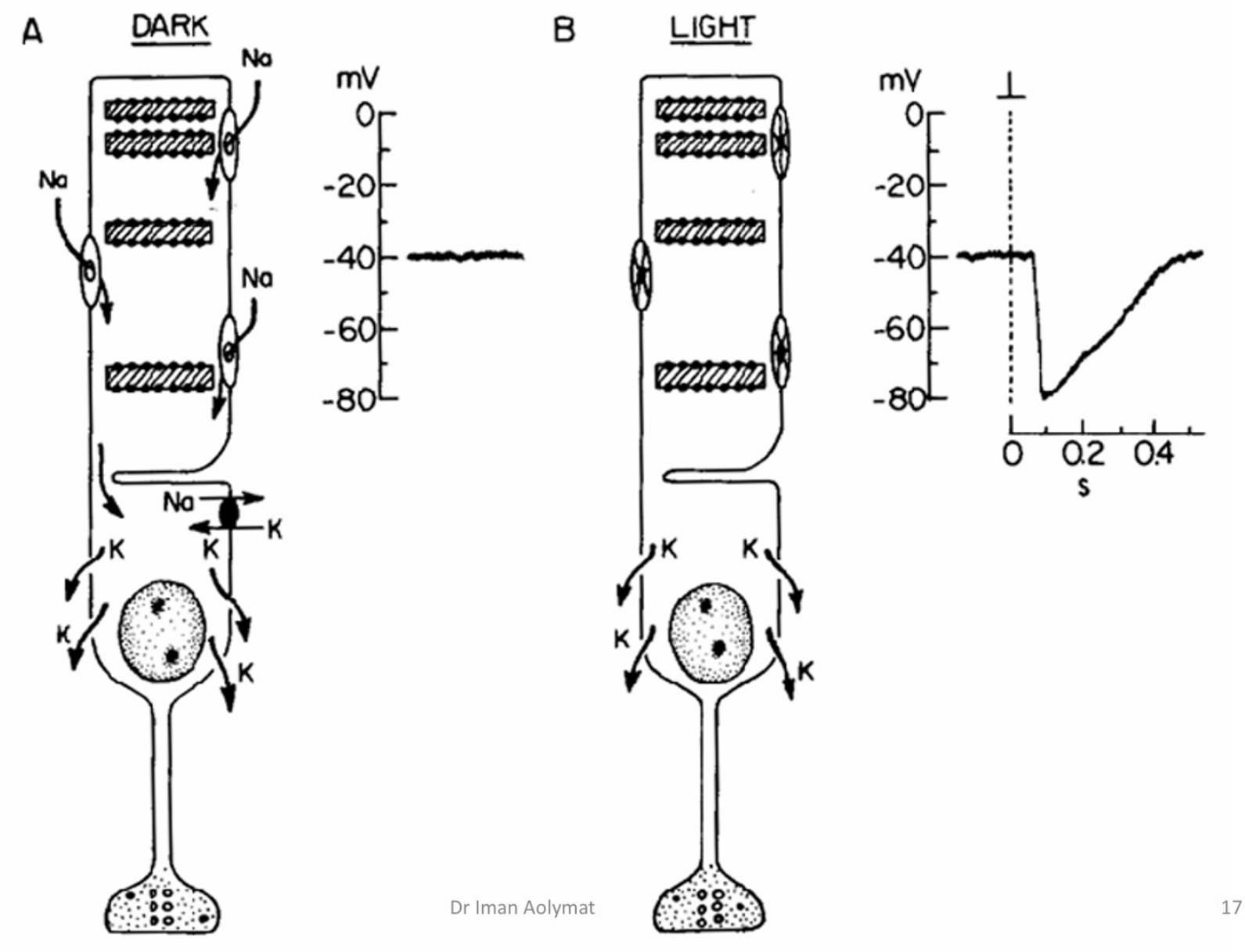
When rhodopsin decomposes in response to light it causes a ***hyperpolarization*** of the rod by decreasing Na+ permeability of the outer segment + continuous pumping of Na outside in the inner seg.

Mechanism for Light to Decrease Sodium Conductance





rhodopsin kinase deactivates the activated rhodopsin and →↑ cGMP → re-opening the Na^+ channels.


A
DARK
Na
Na
Na
Na
K
K
K
K
K
K
mV
0
-20
-40
-60
-80
B
LIGHT
K
K
K
K
mV
0
-20
-40
-60
-80
0
0.2
0.4
s

Receptor Potential

- receptor potential is **a graded response** to a stimulus that may be DEPOLARIZING or HYPERPOLARIZING.
- graded means the amplitude of the receptor potential is proportional to the size of the stimulus/ log of light intensity →allows eye to discriminate light intensities

- receptor potential faster in **cones** (4X)

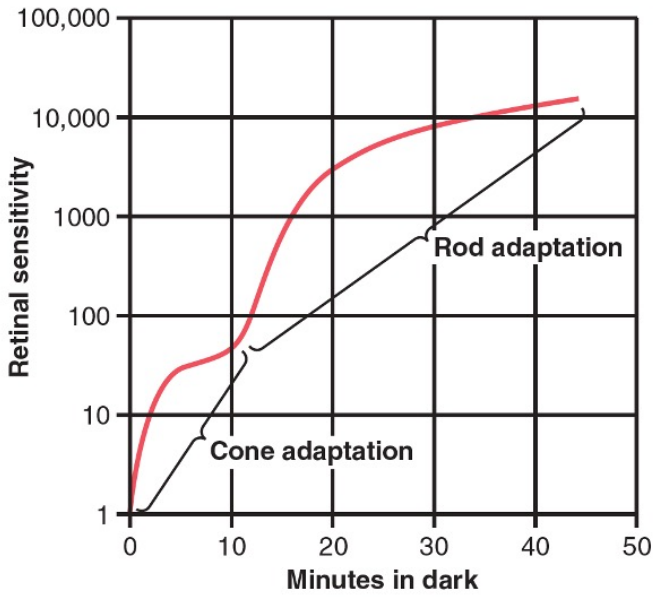
- extreme sensitivity of **rods** under dark conditions? because rods amplify the effect of a single photon of light → cause movement of millions of sodium ions.

Dark Adaptation

- Dark adaptation: is the process by which the person is able to see the objects in dim light
- If a person enters darkroom from a bright area, he cannot see any object, but after sometime his eyes get adapted and he starts seeing the objects slowly (max 20 min)

Causes of dark adaptation

- resynthesis of rhodopsin
- Dilatation of pupil



rod sensitivity begins to exceed cone sensitivity

neuronal signal convergence of 100 or more rods onto a single ganglion cell in the retina=summation

Light Adaptation

- Light adaptation: is the process in which eyes get adapted to increased illumination

Causes of Light Adaptation

- Reduced sensitivity of rods→ due to the breakdown of rhodopsin.
- Constriction of pupil→ reduces quantity of light entering eye.

The End

Lecture 4
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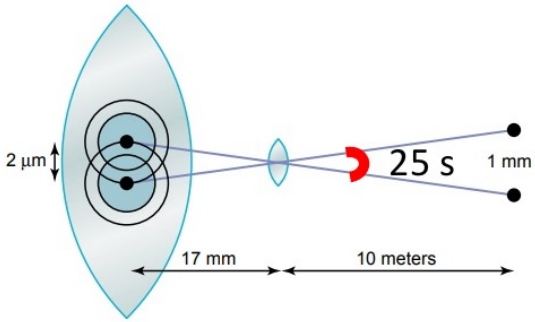
Chapter 51

Visual Acuity

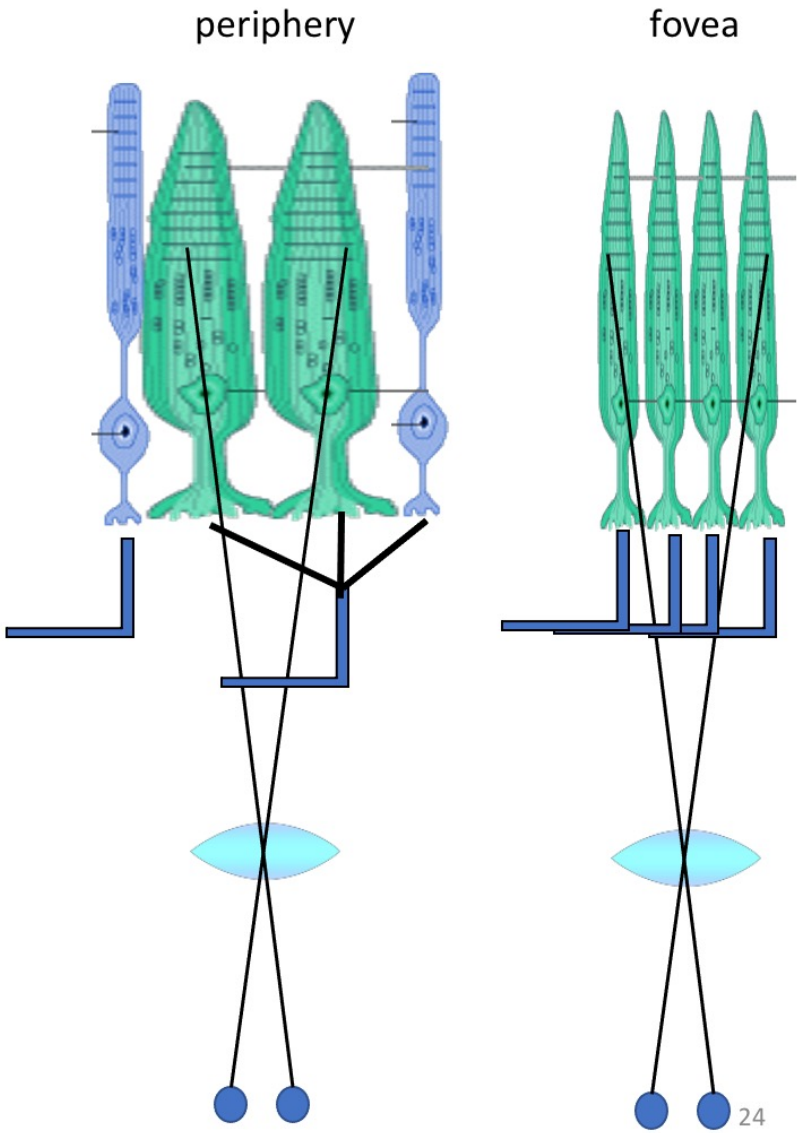
- The ability of eye to detect *finest details* of an object
- person can distinguish *two separate points* if their centers are 2 micrometers apart on the retina/ at least 1 receptor in between unstimulated
- light rays from two separate points strike the eye with an angle of at least 25 seconds between them, they can usually be recognized as two points



Maximum visual acuity for two point sources of light.

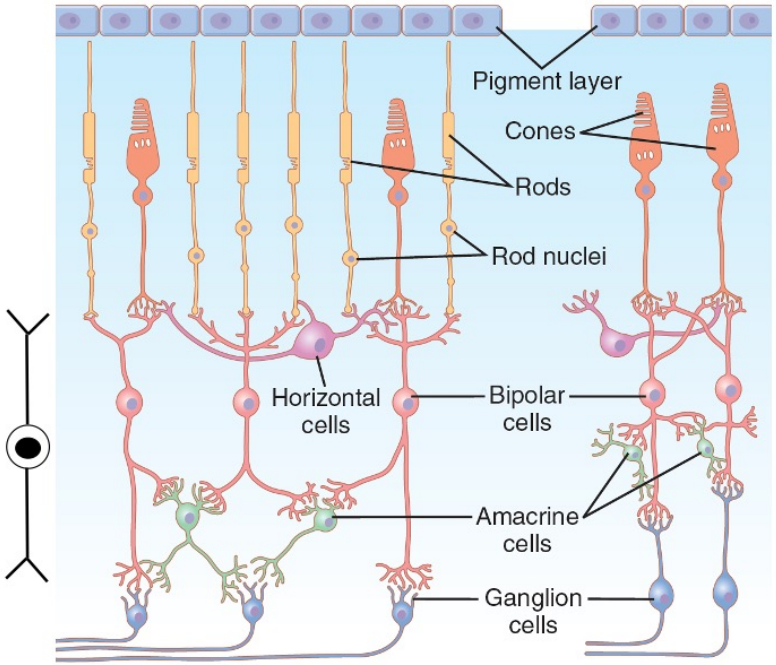
Visual Acuity

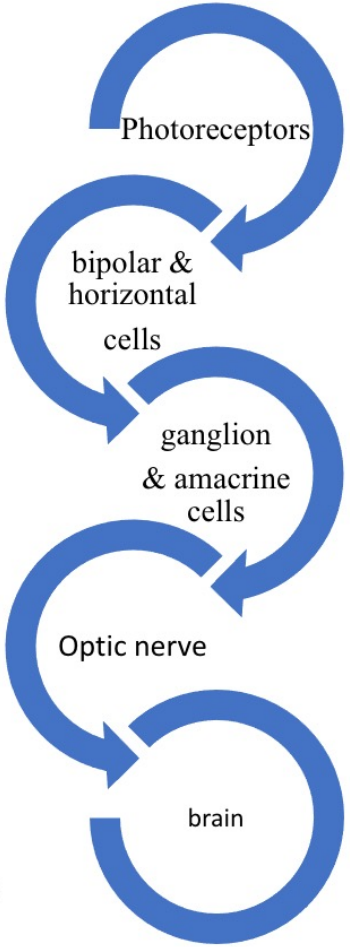
- Highest visual acuity→ fovea
- average diameter of cones in **fovea** is about 1.5 micrometers
- Peripherally becomes progressively poorer- caused by connection of more and more rods and cones to each optic nerve fiber



Signal Transmission in the Retina

Interplexiform cell
inhibitory signals
control lateral spread of visual signals by H.cells
control the degree of contrast in the visual image.





Fatter cones
slower
Indirect to g. cells
Smaller nerve fibers
Greater sensitivity to weak light

Slender cones
Faster
Direct to g. cells
Larger nerve fibers

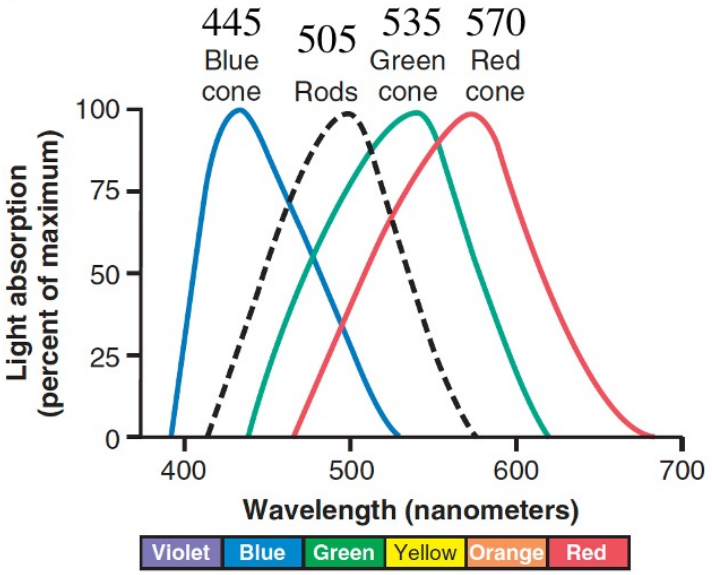
Color Vision

- Primary colors are red, green and blue.
- These three colors in equal proportion give **white**
- visible spectrum→ ROYGBIV
- Peripheral retina → no cones → insensitive to color → white, black & grey vision
- Central retina (fovea centralis)→ cones only → color vision
- Other regions → cones & rods

Color Vision

- 3 types of cones (blue, green & red).
- the protein portion "the opsins" is different for the pigment molecule in each of the cones.
- makes each cone receptive to a particular wavelength of light.
- maximal stimulation of cones by yellow.
- maximal stimulation of rods by green.
- Retinal area sensitive to blue is **largest** and to green is **smallest**.
- Blue>Red>yellow>green

wavelengths for peak light sensitivity for each type of cone



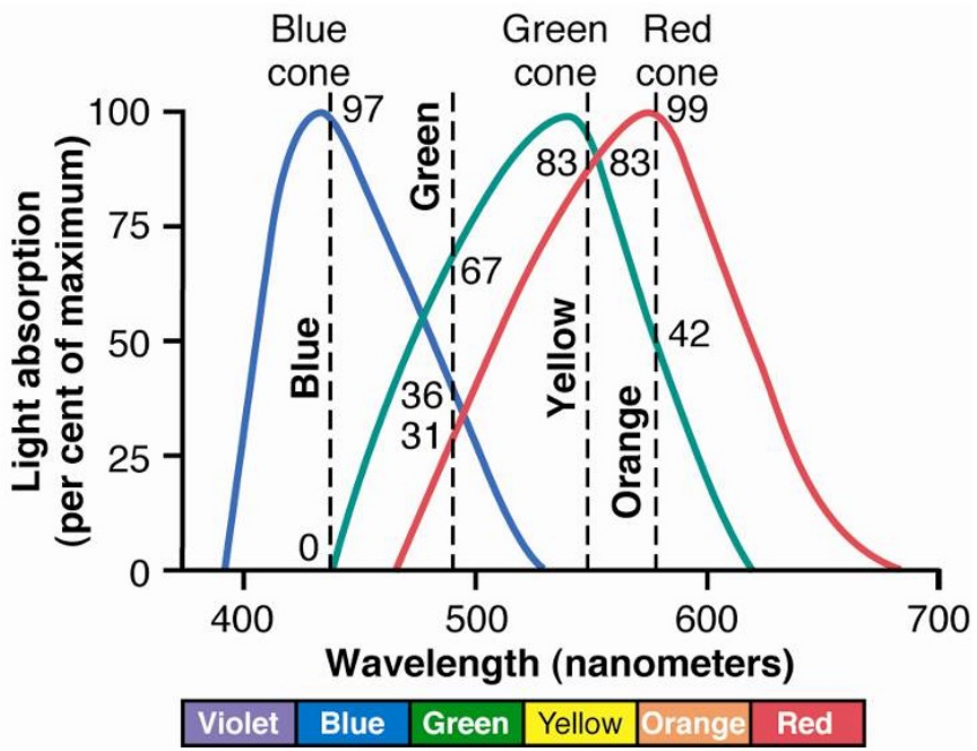
absorption curve

Each cone is receptive to a particular wavelength of light

- Each cone gives response to one of the primary colors – red, green and blue.
- Different colour sensations are produced by the stimulation of various combinations of these three types of cones.

Red	Green	Blue	perception
99	42	0	orange
0	0	97	blue
83	83	0	yellow

equal stimulation of all red, green& blue cones → stimulate same ganglion cell → white



Color Blindness

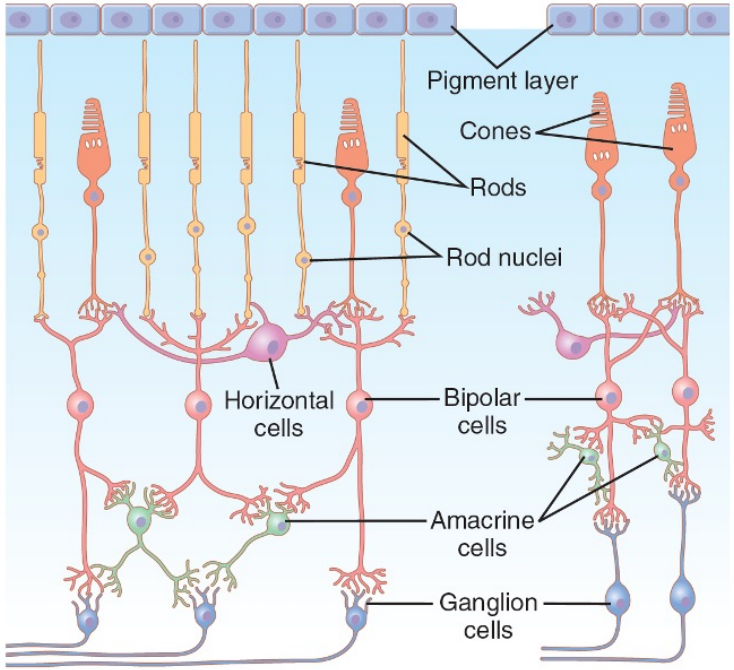
- lack of a particular type of cone.
- Inherited sex-linked recessive character (8% ♂, 0.4% ♀)
- about 8% of ♀ are color blindness carriers.
- most color blindness results from lack of the *red or green* cones.
  - lack of a red cone, *protanope (long wavelength spectrum defect).*
  - lack of a green cone, *deuteranope (use blue and red colors and they cannot appreciate green color → inability to distinguish red and green).*
  - *Blue weakness: rare, missing blue cone*

Neurotransmitters Released by Retinal Neurons

- rods and cones → glutamate at their synapses with bipolar cells.
- amacrine cells inhibitory transmitter e.g GABA, glycine, dopamine, acetylcholine, and indolamine
- horizontal cells release inhibitory transmitters.

Horizontal cells

- horizontal cells connect laterally between the rods and cones and bipolar cells.
- output of horizontal cells is always **inhibitory**.
- prevents the lateral spread of light excitation on the retina =Lateral Inhibition
- enhancement of visual contrast.



Bipolar Cells

Two types of bipolar cells
1- depolarizing (excitatory)
2- hyperpolarizing (inhibitory)

some depolarize when photoreceptors are excited, and others hyperpolarize.

Function:
- Visual contrast
- provides lateral inhibition (a much greater distance than H. cells).

Amacrine Cells

- about 30 different types.
- major carriers of rod signals to the ganglion cells.
- some amacrine cells respond strongly to **onset** of the visual signal, some to **offset** of visual signal.
- Some respond to **change in illumination**
- some respond to direction of motion of light signal across the retina (directionally sensitive).

i.e amacrine cells help analyze visual signals before they leave the retina.

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.

Ganglion Cells

- 3 ypes

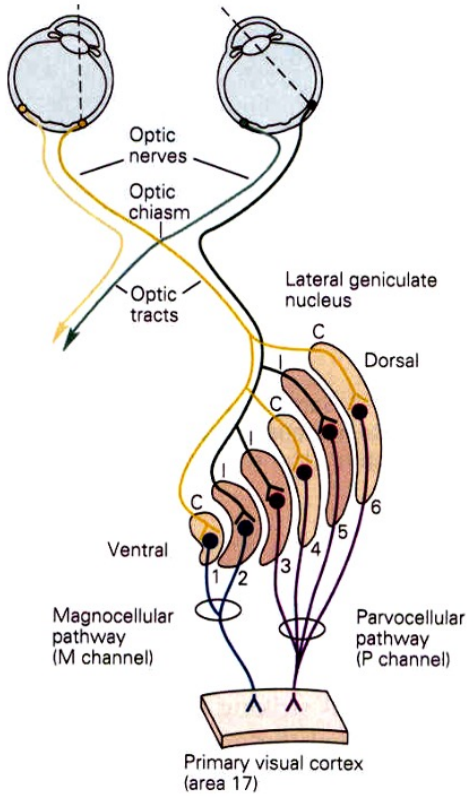
1- parvocellular (P) cells-beta/midget ganglion cells (in central retina)

✓project to the parvocellular (small cells) layer of lateral geniculate nucleus (LGN) of thalamus.

2- magnocellular (M) cells-alpha/parasol cells

✓project to magnocellular (large cells) layer of LGN

3- Melanopsin containing cells: control circadian rhythms



P and M Cells

	P cells	M cells
Receptive fields	smaller	larger
Conduction	slower	faster
Response to stimuli	sustained	transient
Sensitivity to color	sensitive	Not sensitive
Sensitivity to black & white	Less sensitive	More sensitive
Function	Fine details (color and texture)	Detection of movement and change in light intensity

Signal Transmission in the Retina

- transmission of signals in retina is by **electrotonic conduction/graded potential** not AP.
- electrotonic conduction=flow of electric current in cytoplasm & axon
- allows **graded** response proportional to light intensity-No on off response.
- the only cells that have repetitive AP are ganglion cells.
  - send signals all the way to the brain.

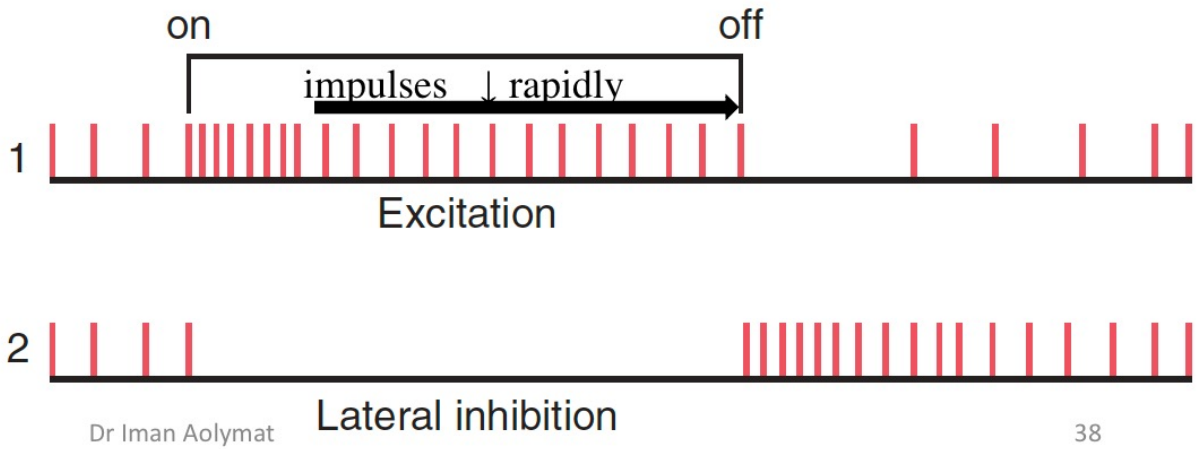
Transmission of Changes in Light Intensity—The On-Off Response.

- Ganglion cells transmit signals by AP.
- even when unstimulated, they still transmit continuous impulses.
- many ganglion cells excited by changes in light **intensity**.

- **Lateral inhibition**
- Causes of On-Off response

1- presence of depolarizing (excitatory) & hyperpolarizing (inhibitory) bipolar cells

2- amacrine cells (transient responses)



Color-contrast mechanisms

One **colour type** of cone →excites ganglion cell by a **depolarizing** bipolar cell, whereas the other colour type → inhibits ganglion cell by **hyperpolarizing** bipolar cell → retina begins to differentiate colours.

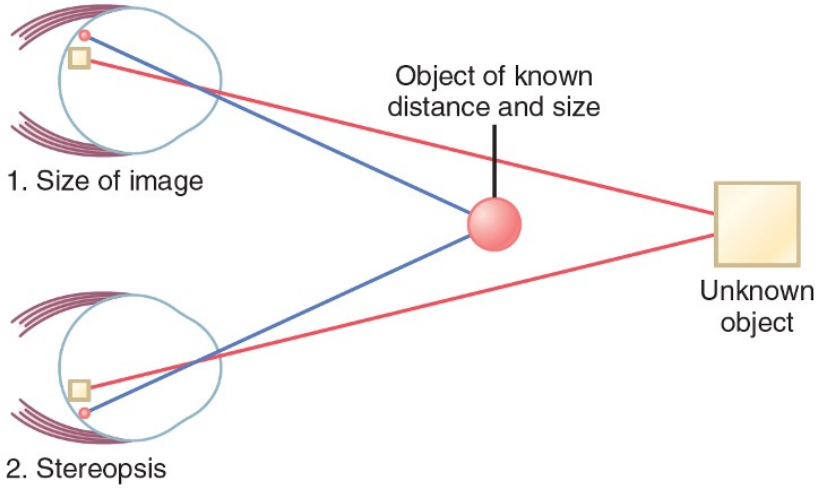
Depth perception

Determination of distance of an object from the eye:
(1) sizes of images of objects on retina

(2) phenomenon of **moving parallax**
when person moves head, images of close-by objects move rapidly across retinas, while images of distant objects remain almost completely stationary (relative distances)

(3) phenomenon of stereopsis (Binocular Vision) seeing "in 3D".
2 different eyes →2 different images on retina
Close object → different position on each retina
Far Object →same position on each retina

Stereopsis is useless for depth perception at distances beyond 50 to 200 feet.



The End