Physiology Team 439

MED439
KING SAUD UNIVERSITY

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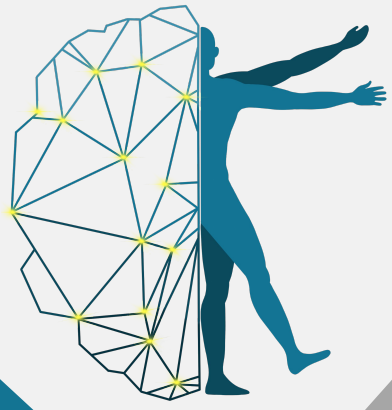


Phototransduction of Light

Objectives:

- List and compare functional properties of rods and cones in scotopic and photopic vision
- Know the convergence and its value
- 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
- To recognize types of ganglion cells

Color index:

- Important.
- Girls slide only.
- Boys slide only.
- Dr's note.
- Extra information.

Editing File

Physiology of vision

Stimulus: Boys slides only*

Light: Defined as, Electromagnetic radiation that is capable of exciting the human eye. and It is extremely fast.

Receptor Boys slides only*

Retina (Photoreceptors)

Visible light spectrum

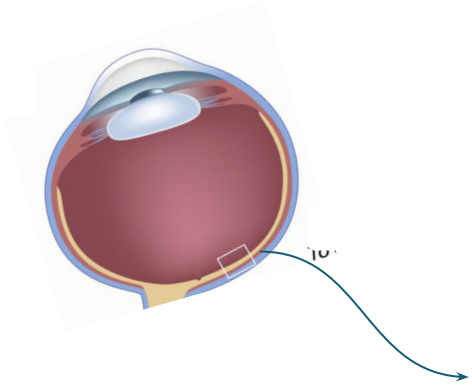
- **Definition :** is the portion of the electromagnetic spectrum that is visible to the human eye.
- Extend from 397 to 723nm.
- Eye functions under two 2 conditions of illumination:

Duplicity theory vision

- Bright light (Photopic vision)...Cones
- Dim light (Scotopic vision) ..Rods

Retina Boys slides only*

the light is coming through the inner limiting towards the rods and cones, so the electrical events direction is the opposite



Choroid: Layer of the eye behind the retina, pigment epithelium.

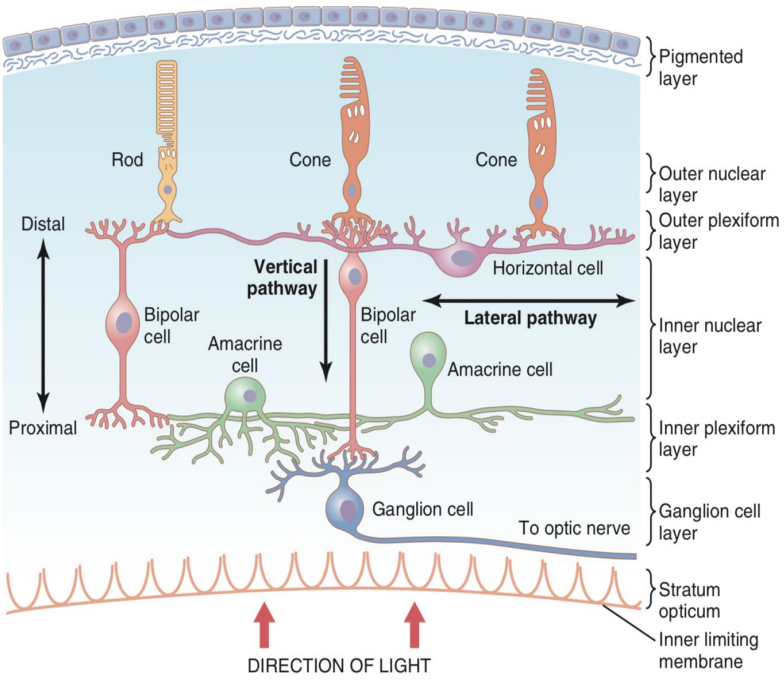


Figure 51-1. Layers of the retina.

Photoreceptors

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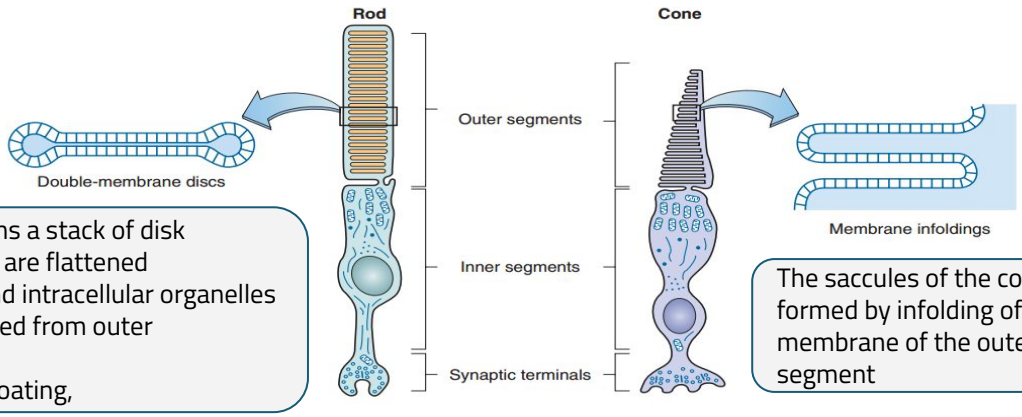
Types of Visual Receptors (Photoreceptors)	
Rods	**Cones**
Abundant in the periphery of the retina	Abundant in & around fovea (More central)
Best for low light (dim light) conditions	best for bright light conditions.
see black/white and shades of gray (Monochromatic)	see all colors
100,000,000-120,000,000 rods	5,000,000-6,000,000 cones
Sensitivity to light: • Low Threshold • Sensitive to low intensity light • Night vision	**Sensitivity to light:** • High Threshold • Sensitive to High intensity light • Day vision **Photochemistry of color vision by the cones:**The cones are about 30 to 300 times less sensitive than rods to light
Low acuit	**High acuity**
Color vision: No	**Color vision:** Yes
Dark adaptation: Adapt late	**Dark adaptation:** Adapt early

Shape of Visual Receptors (Photoreceptors) Rods & Cones	
Outer segments	**Inner segments**
Outer segment (modified cilia) has disks full of photosensitive pigment (rhodopsin) react with light to initiate action potential	There is Na-K pump In inner segment
In cones is conical , small and contain 3 types of photosensitive pigments/rhodopsin	Full of mitochondria (source of energy for Na-K pump), it is thick in cones synthesis of the pigment
In rods it is big, rode like and contain one type of rhodopsin	-
There are Na channels in the outer segment (Open and close in response to cGMP)	-
The inner and outer segment are connected by a ciliary stalk through which the photosensitive compound travel from the inner segment (where they are manufactured) to the outer segment of the rods and cones (where they are used)	

Photoreceptors cont...

Structure of Photoreceptors Girls slides only*



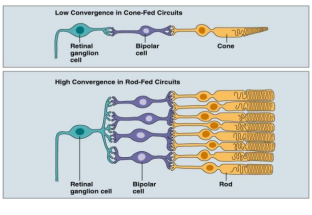
-Each rod contains a stack of disk membranes that are flattened membrane-bound intracellular organelles that have detached from outer membrane
-Disks are free floating,

The saccules of the cones are formed by infolding of the membrane of the outer segment

The saccules and disks contain the photosensitive compounds that react to light initiating action potentials in the postsynaptic cells

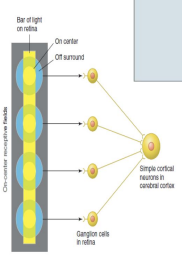
Convergence

Low convergence	High convergence
In cones	**In rods**
Each foveal cone synapse with → one bipolar cell → one ganglion cell → single optic nerve fiber 1 to 1 representation, it will increase speed of transmission	Several rods about 300 synapse with one bipolar cell & one ganglion cell يسمح بال summation
Advantage: increases visual acuity → integrated information from small area of retina	**Advantage:** increases sensitivity to light i.e so low light threshold stimulates the rods
Disadvantage: decreases sensitivity to light i.e need high threshold of illumination to stimulate cones)	**Disadvantage:** decreases visual acuity = integrated information from large area of retina
120 million rode and 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 of ganglion cells: Girls slides only*

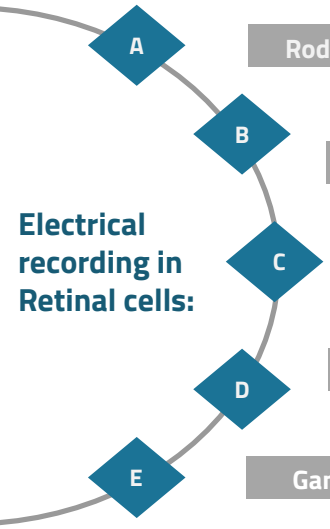
- The receptive field of a ganglion cell in the retina of the eye is composed of input from all of the photoreceptors which synapse with it
- A group of ganglion cells in turn forms the receptive field for a cell in the brain. This process is called convergence



Genesis of photoreceptor potential

- Rods & cones potentials are graded, local potential (generator potential) propagated (and summated) as A.P in ganglion cells, due to short distance its a generator potential (also called receptor potential)
- Ganglion cell action potential (all or none A.P) transmitted to optic nerve.
- Cones respond to high levels of light intensity (illumination)
- Rods respond to low levels of light intensity (illumination) below threshold levels for cones, so rods are more sensitive.

Electrical recording in Retinal cells:



Rods and cones	are stimulated by hyperpolarization/generator potential
Bipolar cells	Hyper- & Depolarization
Horizontal cells	Hyperpolarization
Amacrine cells	Depolarizing potential
Ganglion cells	Depolarizing potential (High enough to be transmitted in the optic nerve)

Photosensitive Compound (Rhodopsin)

Cones

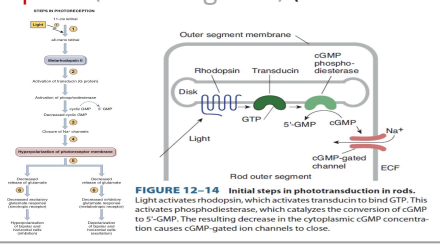
- In cones rhodopsin (iodopsine) **formed of:**
- Opsin protein (photopsin) + Retinal (also known as retinene1) = aldehyde form of Vit A)
- There are 3 types of rhodopsin/iodopsin in cones (photopsine I,II,III) each respond to a certain wavelength of light for color vision.

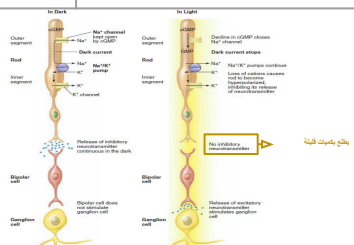
Rods

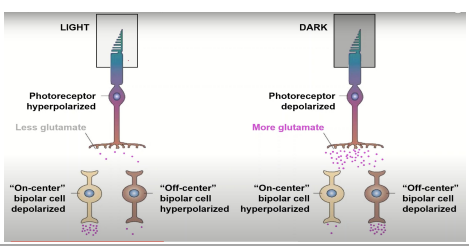
- In rods its rhodopsin **formed of:**
- Scotopsin protein (opsin) + Retinal (also known as retinene1) = aldehyde form of Vit A) = **Visual purple**
- Rhodopsin of the rods most strongly absorbs green-blue light and, therefore, appears reddish-purple
- Rhodopsin forms 90% of rods protein ,stored in disks of rods at outer segment
- **At dark** At dark rhodopsin is in **11 cisretinal form (inactive)** *Activated and degraded in response to light* but light sensitive form which increase sensitivity of rods to light.

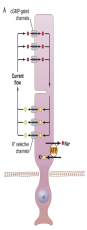
Retinal (Retinene) is produced in the retina from Vitamin A, from dietary beta-carotene.

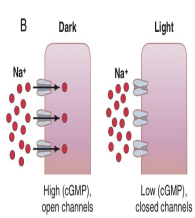
Electrophysiology of vision (phototransduction) Girls slides only*

	At dark (scotopic vision, dim light vision)	Incident light (photopic vision)
Rhodopsin	Rhodopsin in 11-cisretinal (inactive form-light sensitive form which increase sensitivity of rods to light) -At dark rhodopsin is inactive (11 cis-retinal needs light for its activation) / inactive rhodopsin is essential for depolarization - its inactivation keeps Na channels open & Na current occurs	Light → Conformational change of photopigment retinine-1 in rhodopsin (11-cisretinal form changed to → all-trans isomer called metarhodopsin II which is an active form of rhodopsin) →
cyclic GMP	(5 –GMP) of the outer segment, Na channels is in the c-GMP form (-c-GMP at c-GMP gated Na channels of the outer segment , it bound to proteins at Na channel membrane & keep them <u>open</u>) → opening of Na channels at outer segment → allow Na influx after its is pumped out from Na –K pump of the inner segment→ depolarization. (-40mvolt , instead of -80 mvolt in most receptors) Dark current (Na current):-. at the inner segment Na is pumped by Na/K Pump out and it Re-enter through Na Channels (at outer segment)	Activation of G protein (transducin) → activation of phosphodiesterase enzyme → conversion of c-GMP to 5- GMP. Decrease intracellular c-GMP → Closure of Na Channels in outer segment . But still Na/K pump of the inner segment would still occur → Hyperpolarization of Photoreceptors (more negative) (-70 ~ - 80 millivolt)  **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.
The potential recording:	Depolarization→ Steady and continuous increased release of Glutamate at synapses with bipolar cells → Response in bipolar cells (**OFF –center bipolar cells** in the periphery) (depolarization) → ganglion cells- → AP in optic nerve- → vision at dark.	Hyperpolarization → Decreased release of synaptic transmitter (Glutamate) → Response in bipolar cells <u>off-center</u> bipolar cells get hyperpolarized→ gradually **depolarize** <u>on center</u> bipolar cells leads to Generator potential in amacrine cells & ganglion cells (depolarize) → AP → optic nerve → optic pathway
	1-hyperpolarize ON- center bipolar cells 2-depolarize OFF-center bipolar cells	1-depolarize ON- center bipolar cells 2-hyperpolarize OFF-center bipolar cells (inactive)
NB/	OFF- center bipolar (synaptic connection with peripheral photoreceptors= rods , so dark depolarize them to see in dark)	ON centre bipolar (synaptic connection with center photoreceptors= cones , so light depolarize them to see in bright light)
	We have 10 types of cones bipolar cells & one type of rod bipolar cell All these help to sharpen signal from rods in dark and from cones in light	









Retinal photoreceptor mechanism Boys slides only*

L12

LIGHT → Absorption by photosensitive substances → Structural change in photosensitive substances → Phototransduction → Action potential in the optic nerve

Synaptic mediators in retina: Girls slides only*

Ach, glutamate, dopamine, serotonin,GABA, substance P,somatomedin, VIP, enkephalins, glucagons,neurotensin.

In Dark Girls slides only*

Depolarization of receptors → Constant release of glutamate by depolarization of rods, depolarize bipolar cell (**OFF-center**)→ generator potential → AP in ganglion cells

In Light Girls slides only*

Hyperpolarization of the receptors → decrease glutamate release → hyperpolarize bipolar cells (OFF-center) gradual depolarize (**on –center cells**) .
depolarize amacrine cell → generator potential → AP in ganglion cells, more light less pigment, less light more pigment

Photoreceptor pigment:

Composition:

- Retinine1 (Aldehyde of vitamin A) , Same in all pigments
- Opsin (protein), Different amino acid sequence in different pigments
- Rhodopsin (Rod pigment): Retinine + scotopsin

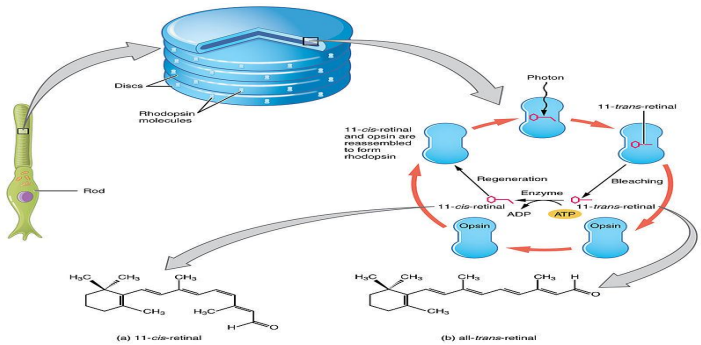
Rhodopsin (visual purple, scotopsin):

Activation of Rhodopsin In the dark:

Retinine in the 11-cis configuration → All- transisomer → Metarhodopsin II → closure of Na channels

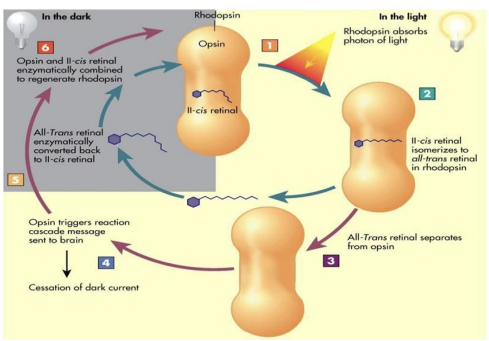
Light

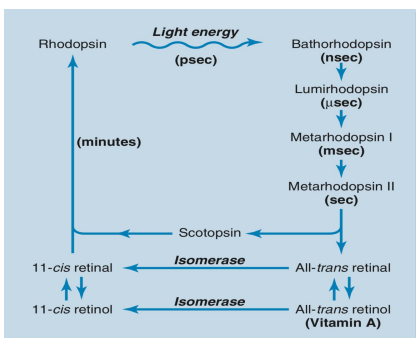
RHODOPSIN CYCLING:

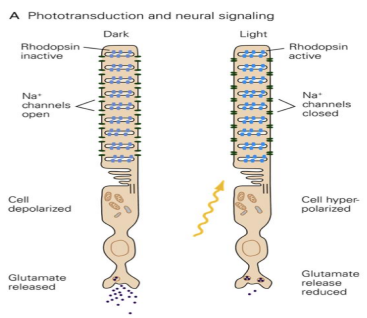


Visual cycle (Bleaching & regulation):

	Light	Dark
In :	**Light** induce Isomerization of 11-cis-retinal into metarhodopsin I then into metarhodopsin II, then into all-trans-retinal (more broken form of metarhodopsin) by a conformational change (bleaching) and all trans-retinal separate from opsin by light and opsin remains alone. Light breaks down rhodopsin.	**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. Dark regenerate rhodopsin. **At dark:** 11cis-Retinal in rods + scotopcin → rhodopsin regeneration
cyclic GMP Boys slides only*	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.	In the dark, there is an **increase** in cyclic in cyclic GMP levels, which produces an NA+ inward current (or "dark current")
The potential recording: Boys slides only*	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)	depolarization of the photoreceptor membrane (the cell remains at about -40mv), which leads to steady release of glutamate at dark
Retinal Visual cycle:	When there is excess retinal in the retina, it is converted in light back into vitamin A, thus reducing the amount of light-sensitive pigment in the retina	The amount of rhodopsin in the receptors varies inversely with the incident light level. (decreases with light) More exposure to light → more Rhodopsin breakdown.







Dark Adaptation:

- **It means:** increase sensitivity of the photoreceptors when
- vision shifts from bright to dim light
- When a person moves from lighted environment → a dimly lighted environment,
- the retina becomes more sensitive to light & the person will see at dark (accustomed to dark) in about 20 min.(only gross features but no details or colors).
- Rhodopsin in darkness is essential for depolarization of rodes to see in dark & for dark adaptation)
- Reaches max in 20 minutes
- First 5 minutes threshold of cones decrease
- 5 to 20 Sensitivity of rods increase
- **Mechanism of dark adaptation:** increase regeneration of rhodopsin.

Dark adaptation has 2 component: Girls slides only*

1- Rapid

- (It's about 5min) drop in visual threshold.
- Fast dark adaptation of cones , only in fovea.
- Half of the cone rhodopsin regenerate in only 90 seconds.

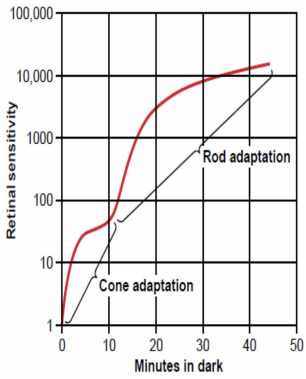
2- less rapid

- (till 20min) drop in visual threshold stimulates dark adaptation of rodes in the peripheral retina
- Sesitivity of rodes to light increases in each 1 min increase 10 folds
- Rods increase their sensitivity to light by convergence 300:1 ganglion cell, so summation at ganglion cells potential will increase sensitivity to light)

N.B. : 20 min for dark adaptation are for regeneration of rhodopsin → increase sensitivity of rodes to light due to a drop in visual threshold

Adaptation Curve: The text is found in males but the diagram is found in both

- 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.



Light Adaptation:

When light switch on again, the rodes 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, it takes less time because here we are breaking the pigments (bleaching) and it takes less time, in dark we are regenerating the pigment which takes more time عملية الهدم تاخذ وقت اقل من عملية البناء

Other mechanisms of light and dark adaptation:

Boys slides only*

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 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

Q/ Why radiologists & aircraft pilots wear red google 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.

Nyctalopia: (Night Blindess):

This condition is called night blindness because the amount of light available at night it too little to permit adequate vision in vitamin A-deficient persons.

Vitamine A (main source of retinal of rhodopsin)

Vitamin A deficiency cause rods , cones & retinal degeneration & loss of rods

R/ its not enough to just take dietary Vitamin A so we give Intravenous vit A if receptors are well So it can make rhodopsin before it degenerates completely

MCQ & SAQ:

Q1: in the light, the release of glutamate from the synaptic terminals :
A. Increase
B.decrease
C. doesn't change
D. B+C

Q2: the amount of rhodopsin in the receptors :
A.increase in light
B. Increase in the dark
C. Decrease in the light
D. B+C

Q3: a decrease in cyclic GMP levels will cause :
A.closure of NA channel and depolarization of the photoreceptor membrane
B. Closure of Na channel and hyperpolarization of the photoreceptor membrane
C. Opening of Na channel and depolarization of the photoreceptor membrane
D. Opening of Na channel and hyperpolarization of the photoreceptor membrane

Q4: What is the range of visible light spectrum ?
A. 297 - 723 nm
B. 370-723nm
C. 470-830nm
D. 397- 723nm

Q5: Which of the following statements is true ?
A.Cone are more sensitive than rods
B.rods becomes depolarized in the dark
C. 1 Rods synapses with one bipolar cell
D.300 Cones synapses one bipolar cell

Q6: Which of the following is wrong about Cones ?
A. Abundant more centrally than peripherally
B. Best used for dim light
C. See all colors
D. Less sensitive than Rods

answer key:
1: B
2: D
3: B
4: D
5: B
6: B

1- how does all trans-retinal converted to 11-cis- retinal?

2- what are the mechanism of light and dark adaptation?

3-What are the composition of rhodopsin in Cones ?

4- What are the advantage and disadvantage of High Convergence ?

A1: by a retinal isomerase enzyme.

A2: 1-change in the rhodopsin concentration 2-neural adaptation 3-change in the pupillary size

A3: Opsin protein (photopsin) + Retinal (also known as retinene1) = aldehyde form of Vit A

A4: Advantage : Increased light sensitivity
Disadvantage : Decreased visual acuity

A special thanks to Rania Almutiri

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