10

Photo transduction in light and dark

Color Index:

- Main text
- Important
- Girls Slides
- Boys Slides
- Notes
- Extra

Editing File

objectives

1. List and compare functional properties of rods and cones in scotopic and photopic vision
2. Know the convergence and its value
3. Describe the photosensitive compounds
4. Contrast the phototransduction process for rods and cones in light and dark and the ionic basis of these responses
5. Know the meaning of nyctalopia
6. Contrast the dark and light adaptation
7. To know the process of rhodopsin regeneration
8. To know the visual cycle and rhodopsin regeneration

helpful video

Physiology of vision

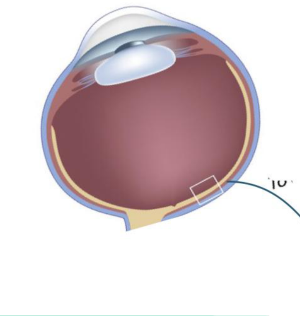
Stimulus:

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

Receptor:

Retina (Photoreceptors)

Retina



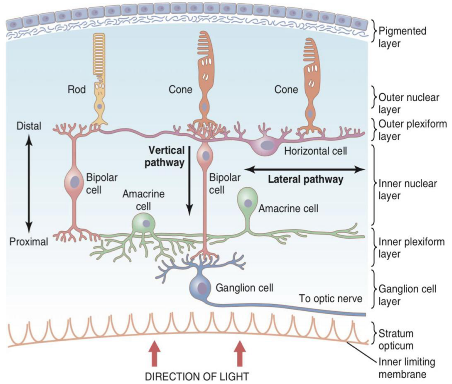
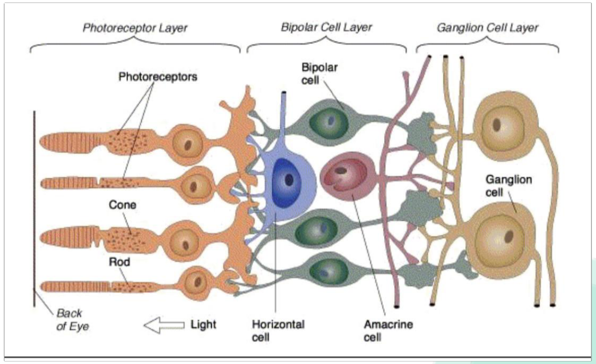


Figure 51-1. Layers of the retina.

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 back of the retina, pigment epithelium.



Electrical impulse direction

ال Light يعبر كل الطبقات حتى يوصل ل photoreceptors ويصير لها stimulation, بعدها ال receptors ترسل ال impulse للاتجاه المعاكس لل bibolar cells ومن ثم لل gangilion cells ثم تروح لل optic nerve

Visible light & Duplicity Theory of vision

Visible light spectrum:

Extend from 397 to 723nm

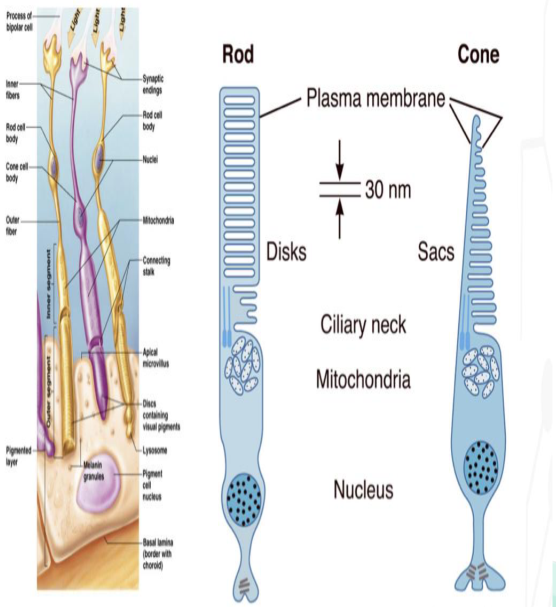
❖ Definition : is the portion of the electromagnetic spectrum that is visible to the human eye.

Duplicity theory vision:
Eye functions under two 2 conditions of illumination:

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

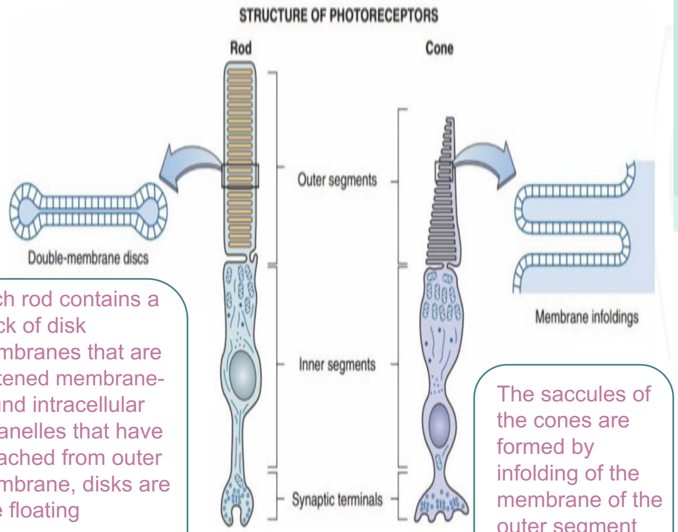
Photoreceptors

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/levels	best for High bright light conditions/levels.
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 time less sensitive than rods to light
Poor acuity	Good acuity
Color vision: No	Color vision: Yes
Dark adaptation: Adapt late	Dark adaptation: Adapt early
Low light levels (dim light)	High light levels



Photoreceptors

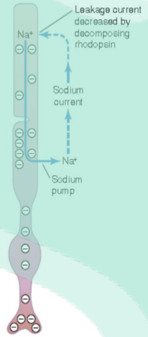
Shape of Visual Receptors (Photoreceptors) Rods & Cones	
Outer segments	Inner segments
Outer segment (modified cilia) has disks full of photosensitive pigment (rhodopsin) react with light to initiate action potential	There is Na-K pump In inner segment بيطلع ال Na من ال inner segment ويروح لل Na channels في ال outer segments
In cones is conical , small and contain 3 types of photosensitivity pigment /rhodopsin	Full of mitochondria (source of energy for Na-K pump), it is thick in cones .
In rods it is big, rode like and contain one type of rhodopsin	Rhodopsin synthesis in inner segment
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 compounds travel from the inner segment (where they are manufactured) to the outer segment of the rods and cones (where they are used)	



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

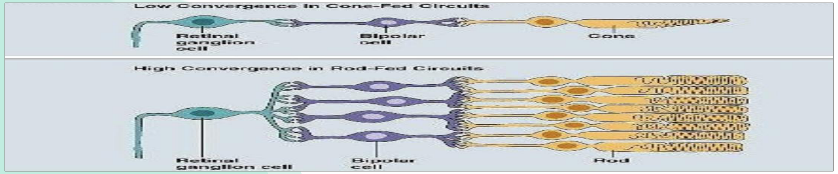
The saccules of the cones are formed by infolding of the membrane of the outer segment

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 .	Several rods about 300 synapse with one bipolar cell & one ganglion cells
Value of low convergence /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
3-120 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	



Female slides

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, and a group of ganglion cells in turn forms the receptive field for a cell in the brain.
This process is called convergence

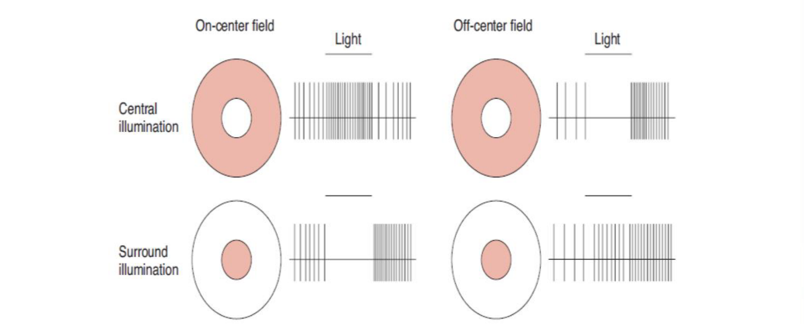


FIGURE 12–16 Responses of retinal ganglion cells to light on the portions of their receptive fields indicated in white. Beside each receptive field diagram is a diagram of the ganglion cell response, indicated by extracellularly recorded action potentials. Note that in three of the four situations, there is increased discharge when the light is turned off. (Modified from Kandel E, Schwartz JH, Jessell TM [editors]: *Principles of Neural Science*, 4th ed. McGraw-Hill, 2000.)

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**.

Genesis of photoreceptor potential

Male slides:

Amacrine cells : **Depolarizing** potential

Horizontal cells: **Hyperpolarization**

Bipolar cells: **Hyper-** & **Depolarization**

Rods and cones : are stimulated by hyperpolarization

Ganglion cells: **Depolarizing** potential (High enough to be transmitted in the optic nerve)

Photosensitive Compound (Rhodopsin):

Cones

- photosensitive pigment In cones rhodopsin (iodopsin) formed of:

-Opsin protein + Retinal (also known as retinene 1 = 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 (it will be discussed in color version lecture)

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

Rods

In rods its rhodopsin formed of:

-Scotopsin protein (opsin) + Retinal(also known as retinene 1) = aldehyde form of Vit A) =Visual purple

- Rhodopsin of the rods most strongly absorbs green-blue light and, therefore ,appears **reddish-purple,** which is why it's called "Visual 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 photoreceptor mechanism

1. LIGHT
2. Absorption by photosensitive substances
3. Structural change in photosensitive substances (will be discussed in details)
4. Phototransduction (it will be discussed next slide)
5. Action potential in the optic nerve (will be discussed in details)

Transduct light to electrical energy

Male slides

Please understand this before going any further

Phototransduction in rods

Incident Light

↓

Change in photopigment (will be discussed in the next slides)

↓

Metarhodopsin II (it will activate transducin)

↓

Activation of transducin

↓

Activation of phophodiesterase

↓

Decrease IC cyclic GMP

↓

Closure of Na channels

↓

Hyperpolarization of receptor

↓

Decrease release of synaptic transmitter (glutamate)

>

Action potential in optic nerve fibres

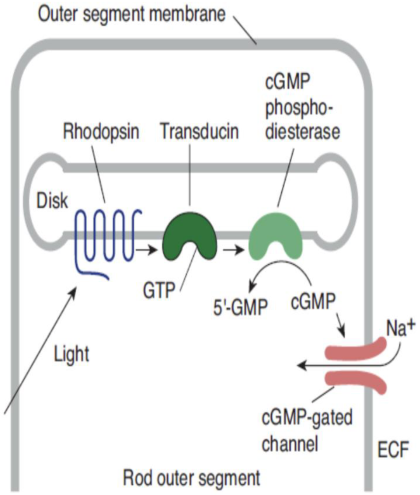
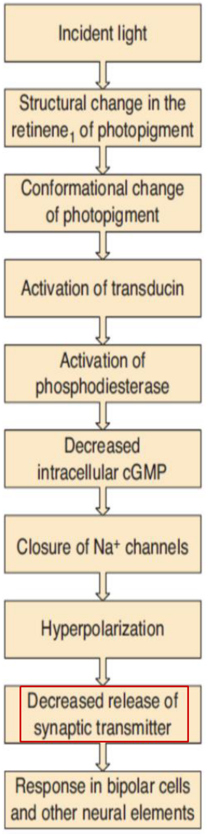


FIGURE 12–14 Initial steps in phototransduction in rods. Light activates rhodopsin, which activates transducin to bind GTP. This activates phosphodiesterase, which catalyzes the conversion of cGMP to 5'-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels to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

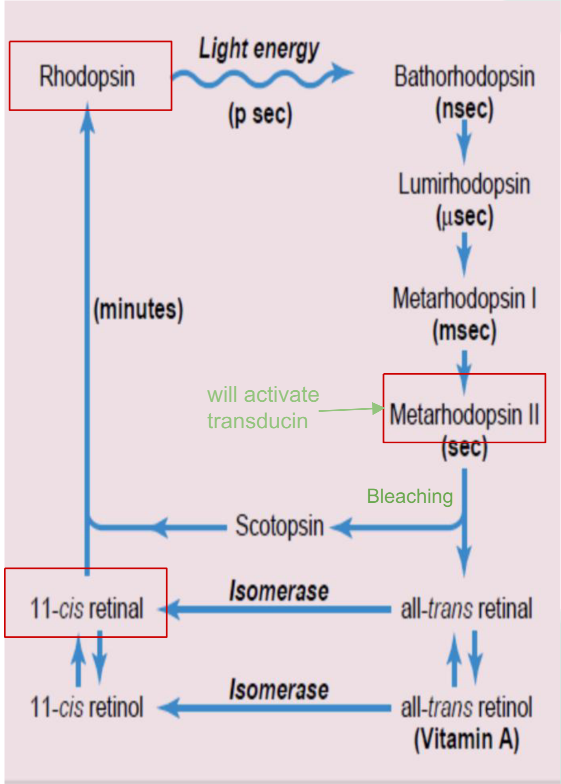
Guyton: Phototransduction in the outer segment of the p receptor (rod or cone) membrane. When light hits the photoreceptor (e.g., a rod cell), the light- absorbing retinal portion of rhodopsin is activated. This activation stimulates transducin, a G protein, which then activates cyclic guanosine monophosphate (cGMP) phosphodiesterase. This enzyme catalyzes the degradation of cGMP into 5′-GMP. The reduction in cGMP then causes closure of the sodium channels, which, in turn, causes hyperpolarization of the photoreceptor.



*Pictures were in both male and female slides in rodes opsin=scotopsin

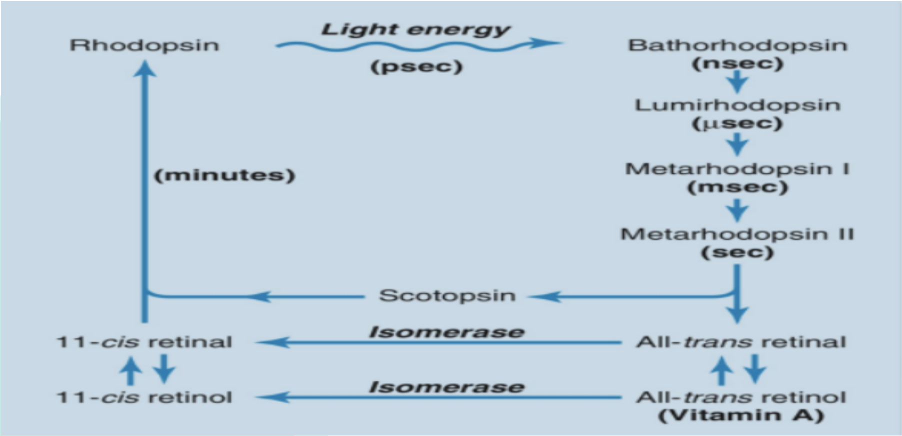
Visual cycle (Bleaching & regulation)

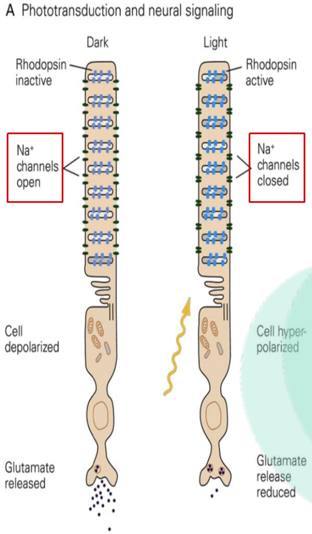
Visual cycle (Bleaching & regulation):		
	Light	Dark
In:	Light induces Isomerization of 11-cis-retinal into metarhodopsin I then into metarhodopsin II, then into all-trans-retinal (more broken form of metarhodopsin) by a conformational change (bleaching) and all trans-retinal separate from opsin by light 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	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")



Visual cycle (Bleaching & regulation) Cont.

The potential recording:	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.





Female slides

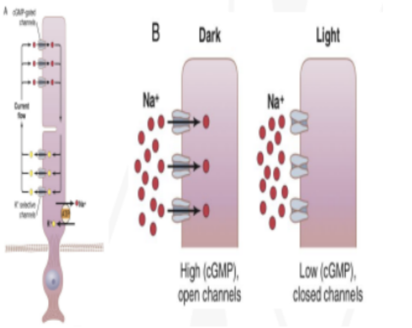
basically the same we said but with more details, do not skip it though

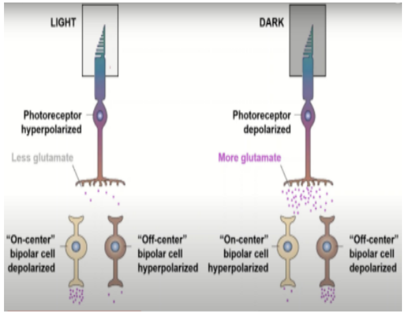
Electrophysiology of vision (phototransduction)

Electrophysiology of vision (phototransduction)		
	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
Cycle 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 open) → 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 outside 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)

Electrophysiology of vision (phototransduction) Cont.

The potential recording:	Depolarization flow to synaptic endings→ 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. electronegativity inside the membrane of the rod, measuring about −40 millivolts rather than the usual −70 to −80 millivolts found in most sensory receptors.	Hyperpolarization → Decreased release of synaptic transmitter (Glutamate) → Response in bipolar cells (off- center bipolar cells get hyperpolarized)→ gradually depolarize on center 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	





NB/ these reactions occur in both rods & cones but in rods occur at low illumination as in dimlight & in cones at high illumination.
- in cones 4 times faster

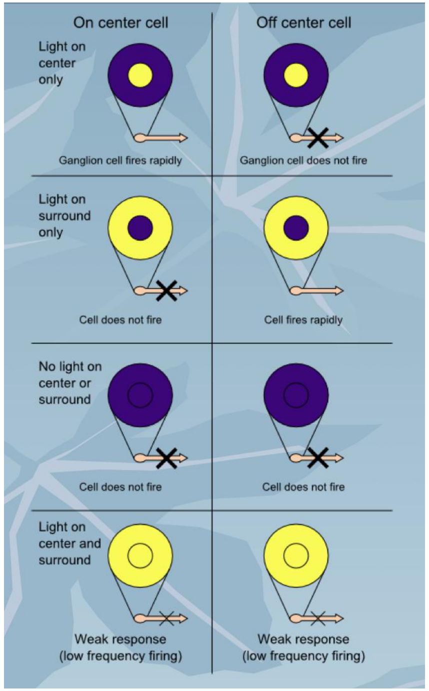
Electrophysiology of vision (phototransduction) Cont.

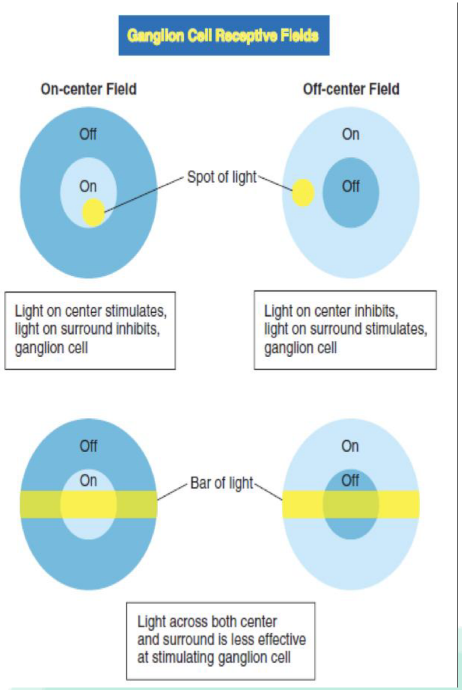
There are two types of retinal ganglion cells:
1- on- center
2- off- center

- An on- center cell : is stimulated when the center of its receptive field is exposed to light, and is inhibited when the surround is exposed to light

- Off- center cells : have just the opposite reaction. Stimulation of the center of an on- center cell's receptive field produces depolarization and an increase in the firing of the ganglion cell, stimulation of the surround produces a Hyperpolarization and a decrease in the firing of the cell, and stimulation of both the center and surround produces only a mild response (due to mutual inhibition of center and surround)

- An off- center cell is stimulated by activation of the surround and inhibited by stimulation of the center





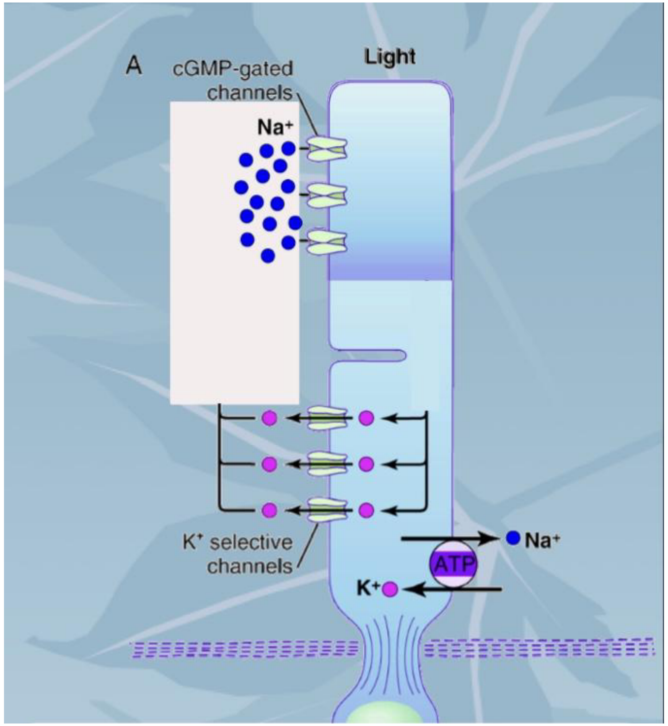
Electrophysiology of vision (phototransduction) Cont.

1 Light exposure will lead to closure of the CGMP NA+ channels

2 However, the inner segment still is continually pumping sodium from inside the rod th outside

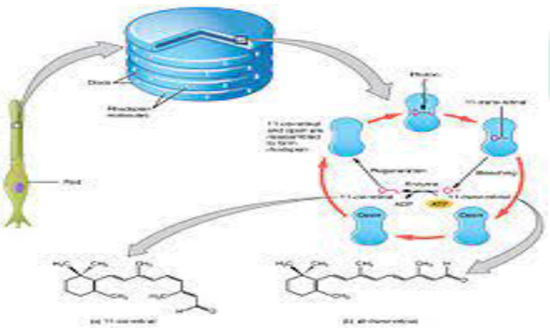
3 Despite potassium ions being pumped to the inside cell , potassium ions still leak out of the cell through non- gated potassium channels in the inner segment of the rod

4 Therefore with loss of positivity charged NA+ this creates a negative potential on the inside of the entire cell of about -70 to -80



With the cell hyperpolarised at about -70 to -80 glutamate release is greatly inhibited

Retinal photoreceptor mechanism

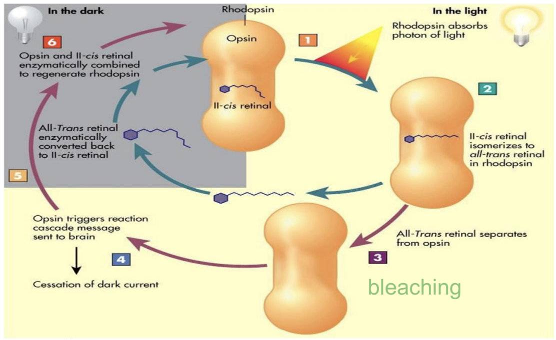


Photoreceptor pigment:

- Composition:

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

RHODOPSIN CYCLING



Rhodopsin (visual purple, scotopsin):

Extra

- Activation of Rhodopsin In the dark:

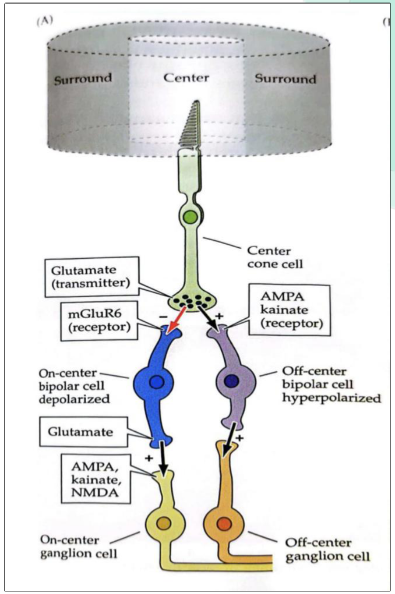
Retinine in the 11-cis configuration → (Light) → All-Transisomer → Metarhodopsin II → Closure of Na channels

Action potential (last step)

Synaptic mediators in retina

Female slides

- Ach, glutamate(excitatory,acts depending on the receptor), dopamine, serotonine, GABA, substance P, somatomedin, VIP, enkephalins, glucagons,neurotensin.



In dark	In light
depolarization of receptors →glutamate is continuously (steadily) released by depolarization of rods depolarize bipolar cell (OFF-center)→generator potential → AP in ganglion cells	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.

Explanation:After the phototransduction step there will be hyperpolarization of the receptor(slide 11)→decrease the glutamate secretion to the bipolar cells

When there is light, the on center receptor will be stimulated, and the off center receptor will be inhibited

1- usually when glutamate bind to the on center receptor, it will hyperpolarize.
But because there is a decrease in the secretion of glutamate, the opposite will happen (it will depolarize and the ganglion cell will send the AP to the optic nerve)

2- usually when glutamate bind to the of center receptor, it will depolarize.
But because there is a decrease in the secretion of glutamate, the opposite will happen (it will hyperpolarize and the ganglion cell **will not** send the AP to the optic nerve)

Dark adaptation

1. It means: increase sensitivity of the photoreceptors when vision shifts from bright to dim light

2. When a person moves from lighted environment → a dimly lighted environment,

3. 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).

4. Rhodopsin in darkness is essential for depolarization of rodes to see in dark & for dark adaptation)

5. Reaches max in 20 minutes

6. First 5 minutes →threshold of cones decrease

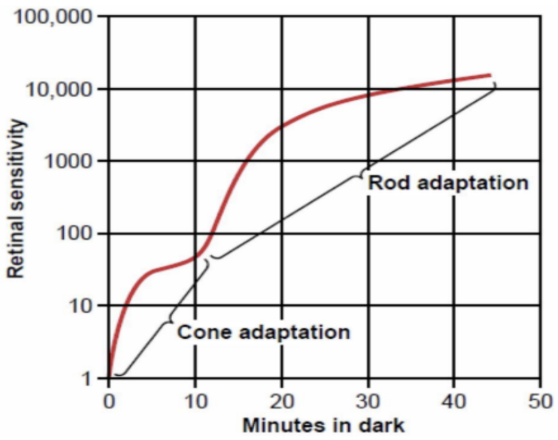
7. 5 to 20→ Sensitivity of rods increase

8. Mechanism of dark adaptation: increase regeneration of rhodopsin.

Dark adaptation

Rapid	Less rapid
- (It's about 5 min) drop in visual threshold. - Fast dark adaptation of **cones**, only in fovea. - Half of the cone rhodopsin regenerate in only 90 seconds.	- (till 20min) drop in visual threshold stimulates dark adaptation of rods in the peripheral retina - Sensitivity of rods 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 rods to light due to a drop in visual threshold



Light adaptation

When light switch 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.

it takes less time because here we are breaking the pigments (bleaching) and it takes less time, in the dark we are regenerating the pigment which takes more time

عملية الهدم تاخذ وقت اقل من عملية البناء

Q/ 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 dim light, 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:

1. 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.
2. Vitamine A (main source of retinal of rhodopsin)
3. Vitamin A deficiency cause rods , cones & retinal degeneration & loss of rods
4. R(treatment)/ Intravenous vit A if receptors are well → it is 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

Light adaptation

Three Types of Retinal Ganglion Cells and Their Respective Fields:

1. **W cells:** sensitive for detecting directional movement in the field of vision, and they are probably important for much of our rod vision under dark conditions

2. **X Cells:** Transmission of the Visual Image and Color vision

3. **Y Cells :** to Transmit Instantaneous & rapid Changes in the Visual Image , either rapid movement or rapid change in light intensity

TEST YOURSELF !

1) which one of the following is responsible for scotopic vision?

A) rods

B) cones

C) retina

D) photoreceptors

2) what is the photosensitive pigment found in rods called?

A)iodopsin

B)rhodopsin

C)scotopsin

D)opsin2

3) where are the Na channels found in photoreceptors?

A)inner segment

B)outer segment

C)mitochondria

D)cones

8) which of the following structures connects the inner and outer segments?

A) ciliary stalk

B)ciliary body

C)suspensory ligaments

D)iris

SAQ

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

A1: by a retinal isomerase enzyme.

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

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

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

A3: Advantage : Increased light sensitivity
Disadvantage : Decreased visual acuity

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Jana Alshiban
Razan Alsoteehi
Lena Alrasheed
Layan Aldosary
Shahad Alzaid
Norah Almania
Lama Almutairi
Raghad Alhamid

Layla Alfrhan
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Salma Alkhlassi
Shoug Alkhalifa
Sarah Alajajii
Sarah Alshahrani
Wafa Alakeel
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Sarah Alshahrani

Hamad Alyahya
Mishal aldakhail
Ziyad Alsalamah
Omar Alamri
sultan almishrafi
Mohammad Alzahrani
Khalid Alanezi
sami Mandoorah
Abdullah alzamil
Mohammed Alqutub

Salmam Althunayan
faisal alzuhairy
Mohammed Alarfaj
Ryan alghizzi
Mohammed Maashi
Zeyad Alotaibi
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Faisal Alshowier
Ziad Alhabardi
Osamah almubbadel

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