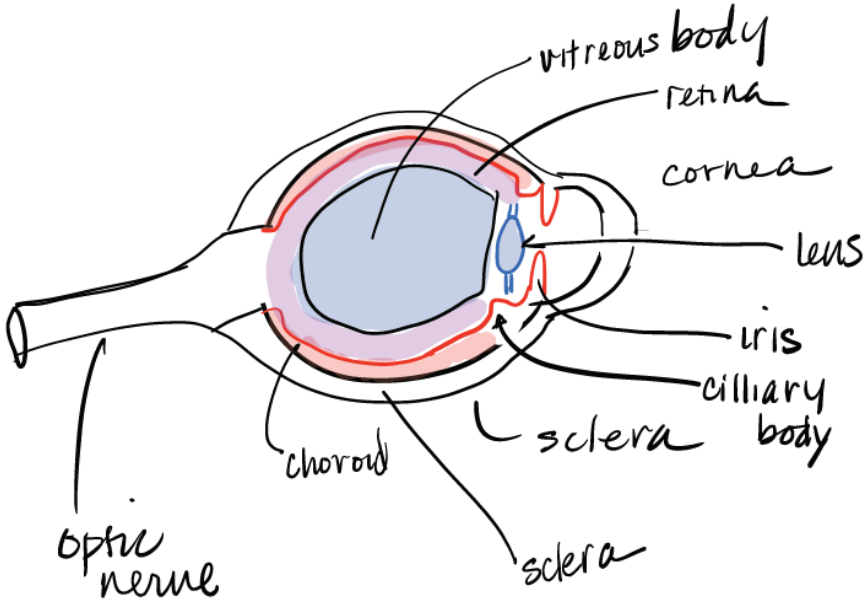
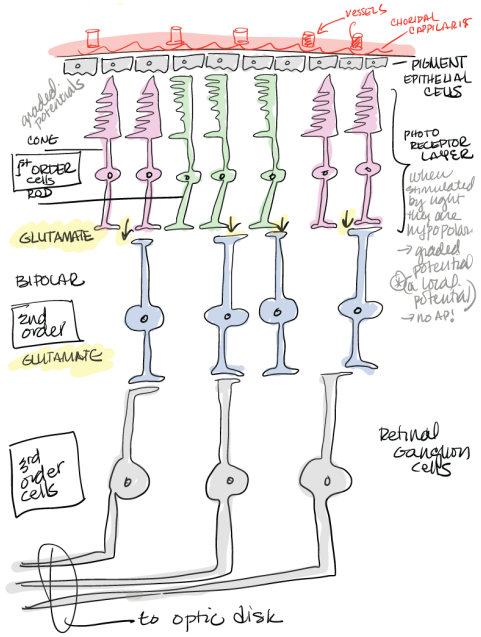
The Visual System





Note: The majority of the Lecture material based on CH9 and Dr. Johnson's slides.

Visual system – Part 1

* significant importance clinically
  - within the brain it has long distance projections from the retina to the occipital cortex
  - vulnerable to:
    - tumors – pressure
    - white matter diseases (eg MS)
    - hemorrage
    - head trauma

Basics:

1. Optic nerve ← it is a special somatic afferent
   → a central track.

this is NOT a peripheral nerve

what is the evidence for this?

① myelinated by oligodendrocytes (not Schwann cells)

② MS is a white matter (oligo) disease & OPTIC nerve is affected

③ does not regenerate - peripheral nerves will regenerate bc of Schwann cells.

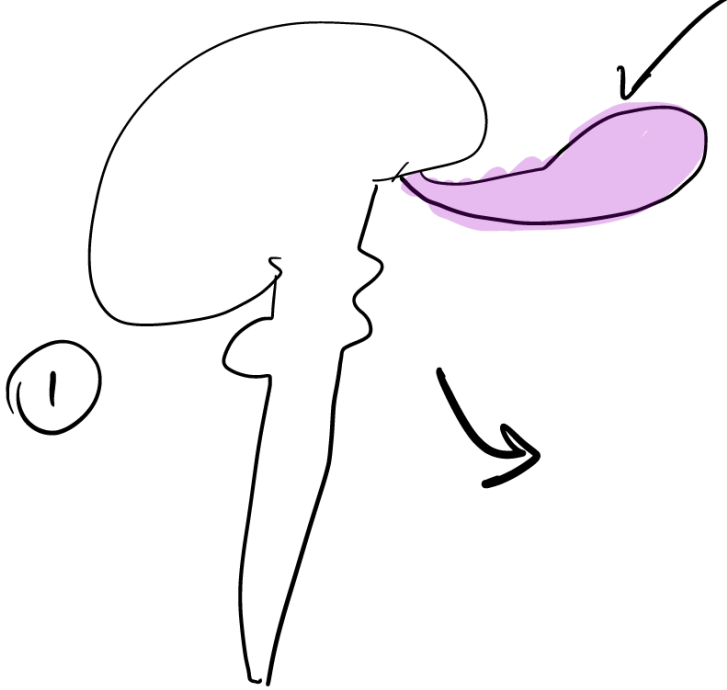
④ optic nerve - embryonically it is an "outpouching" of the diencephalon

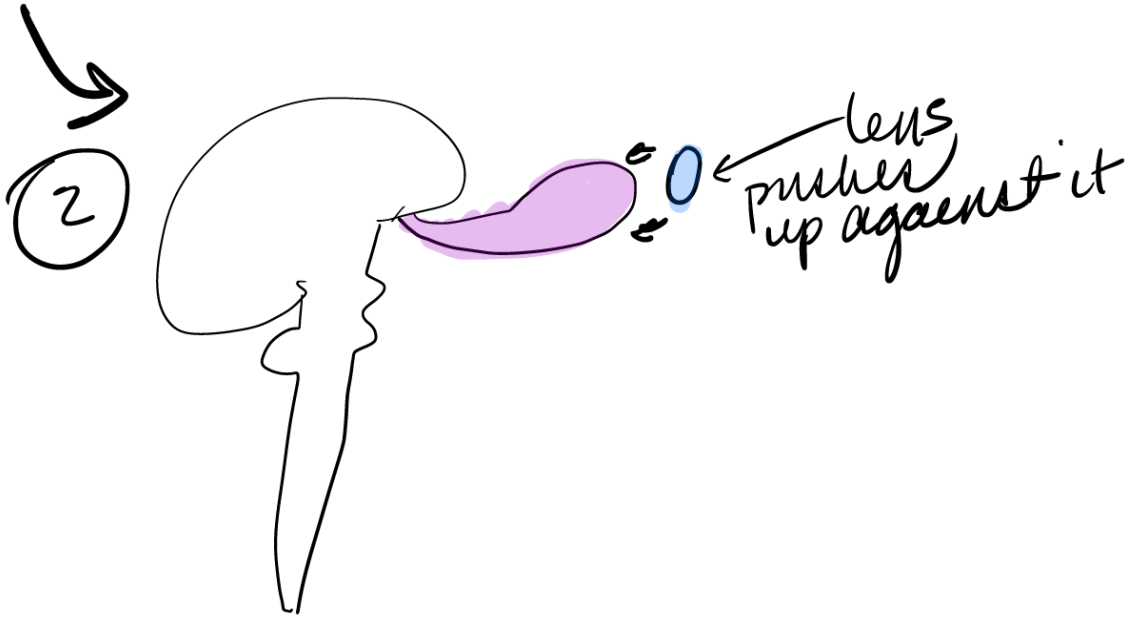
⑤ peripheral nerves are covered with a collagenous covering called epineurium —
note optic nerve has dura mater + arachnoid mater & subarachnoid space w/ CSF around it w/ PIA covering.

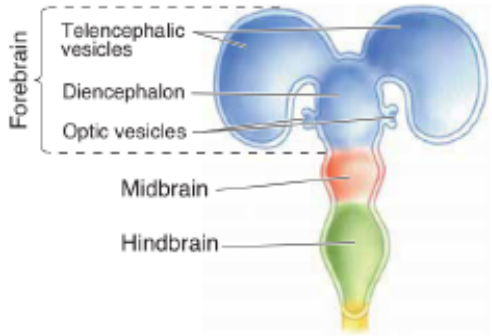
Retina details

development

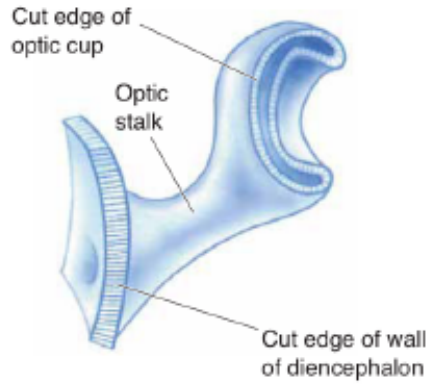
optic vesicle out pouch from the diencephalon







▲ FIGURE 7.12
The secondary brain vesicles of the forebrain. The forebrain differentiates into the paired telencephalic and optic vesicles, and the diencephalon. The optic vesicles develop into the eyes.



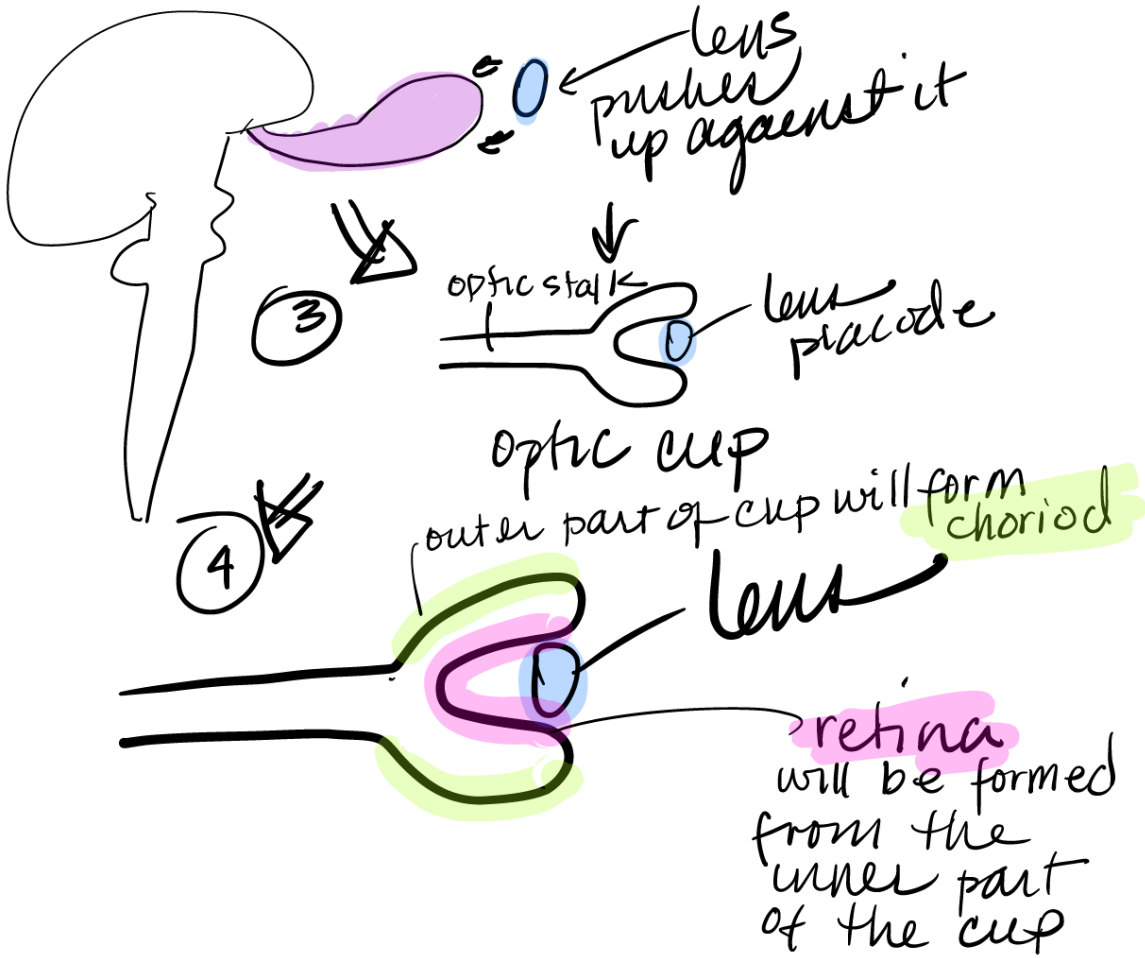
▲ FIGURE 7.13
Early development of the eye. The optic vesicle differentiates into the optic stalk and the optic cup. The optic stalk will become the optic nerve, and the optic cup will become the retina.

Differentiation of the Forebrain

The next important developments occur in the forebrain, where secondary vesicles sprout off on both sides of the prosencephalon. The secondary vesicles are the *optic vesicles* and the *telencephalic vesicles*. The central structure that remains after the secondary vesicles have sprouted off is called the **diencephalon**, or "between brain" (Figure 7.12). Thus, the forebrain at this stage consists of the two optic vesicles, the two telencephalic vesicles, and the diencephalon.

The optic vesicles grow and invaginate (fold in) to form the optic stalks and the optic cups, which will ultimately become the *optic nerves* and the two *retinas* in the adult (Figure 7.13). The important point is that the retina at the back of the eye, and the optic nerve containing the axons that connect the eye to the diencephalon and midbrain, are part of the brain, not the PNS.

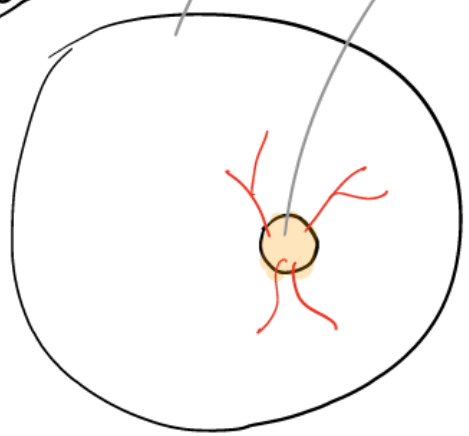
Bear, Mark F., Barry W. Connors, and Michael A. Paradiso. *Neuroscience : Exploring the Brain*. China: Wolters Kluwer, 2016. p196


lens
pushed up against it
3
optic stalk
lens placode
optic cup
4
outer part of cup will form choriod
lens
retina
will be formed from the inner part of the cup

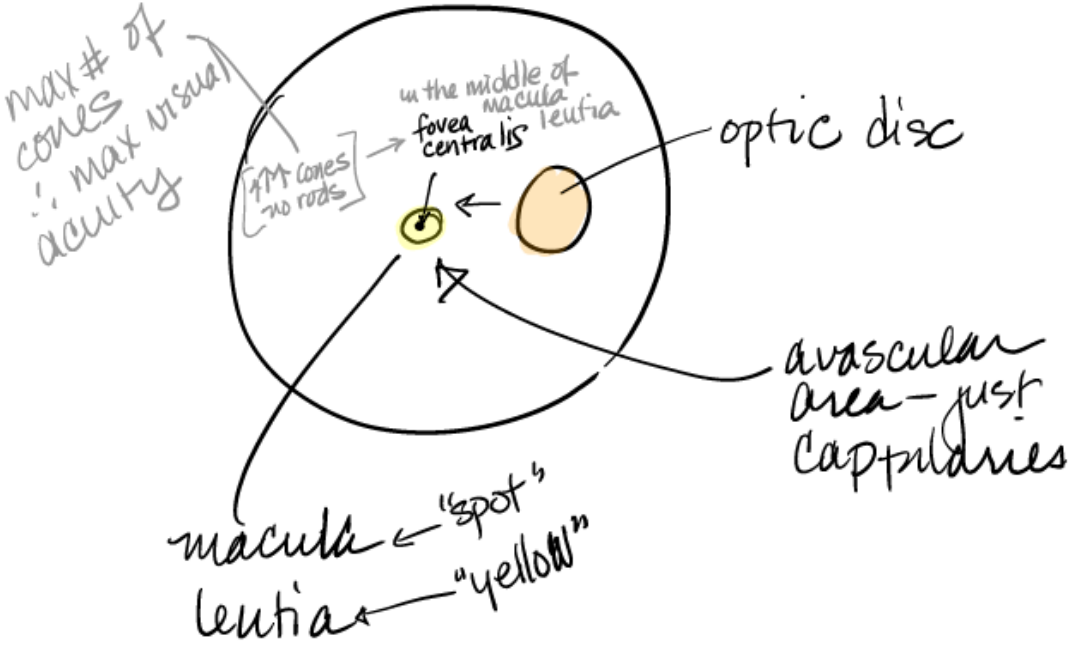
Fundal Detail

[RIGHT EYE]

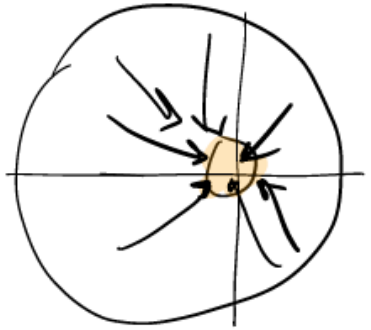
Fundoscope



in disease –
- the disc margins are not crisply delineated
- the blood vessels are not clear
- physiological cup that is not too deep.



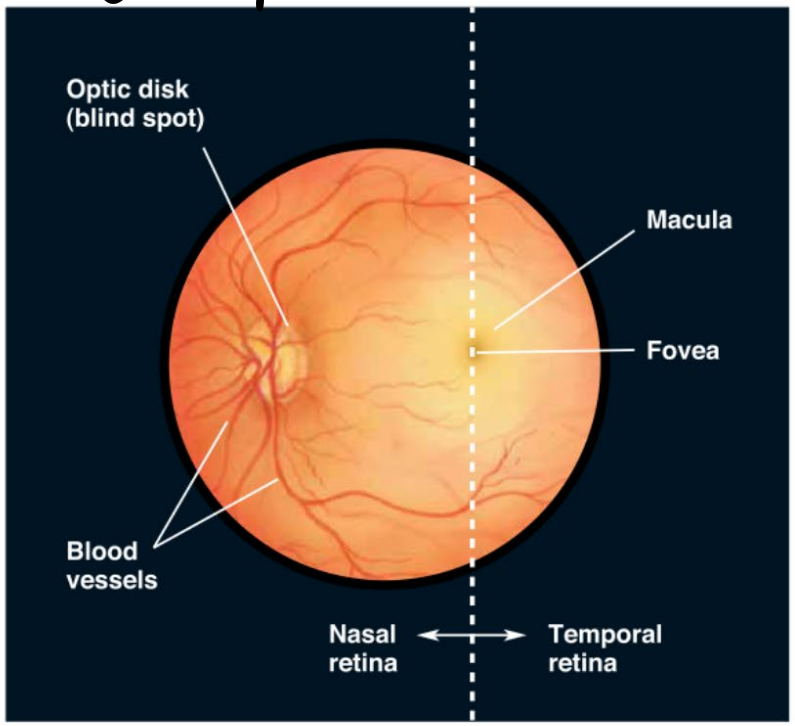
- recognize that the optic disc is the **head of the optic nerve**
  - ↳ all of the fibers (axons) from the retinal ganglion cells are converging onto the optic disk



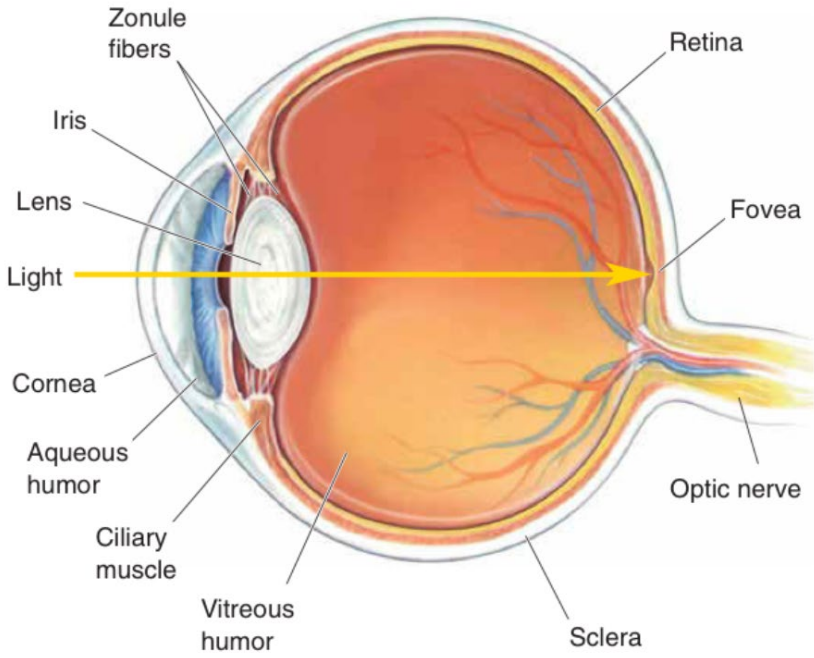
Ⓐ note optic disc does not have any rods & cones

implication
- ↳ ∴ no light receptors
  - ↳ in the visual field at that spot there is a **blind spot**

left eye



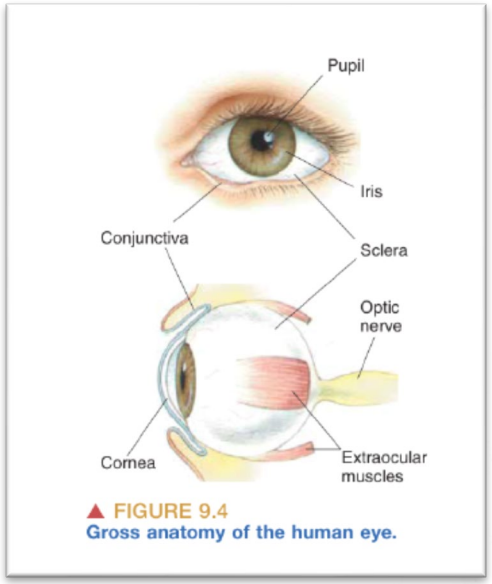
◀ FIGURE 9.5
The retina, viewed through an ophthalmoscope. The dotted line through the fovea represents the demarcation between the side of the eye nearer the nose (nasal retina) and the side of the eye nearer the ear (temporal retina). The imaginary line crosses through the macula, which is in the center of the retina (it appears slightly to one side here because the photograph was taken to include the optic disk off to the nasal side of the retina).



▲ FIGURE 9.6
The eye in cross section. Structures at the front of the eye regulate the amount of light allowed in and refract light onto the retina, which wraps around the inside of the eye.

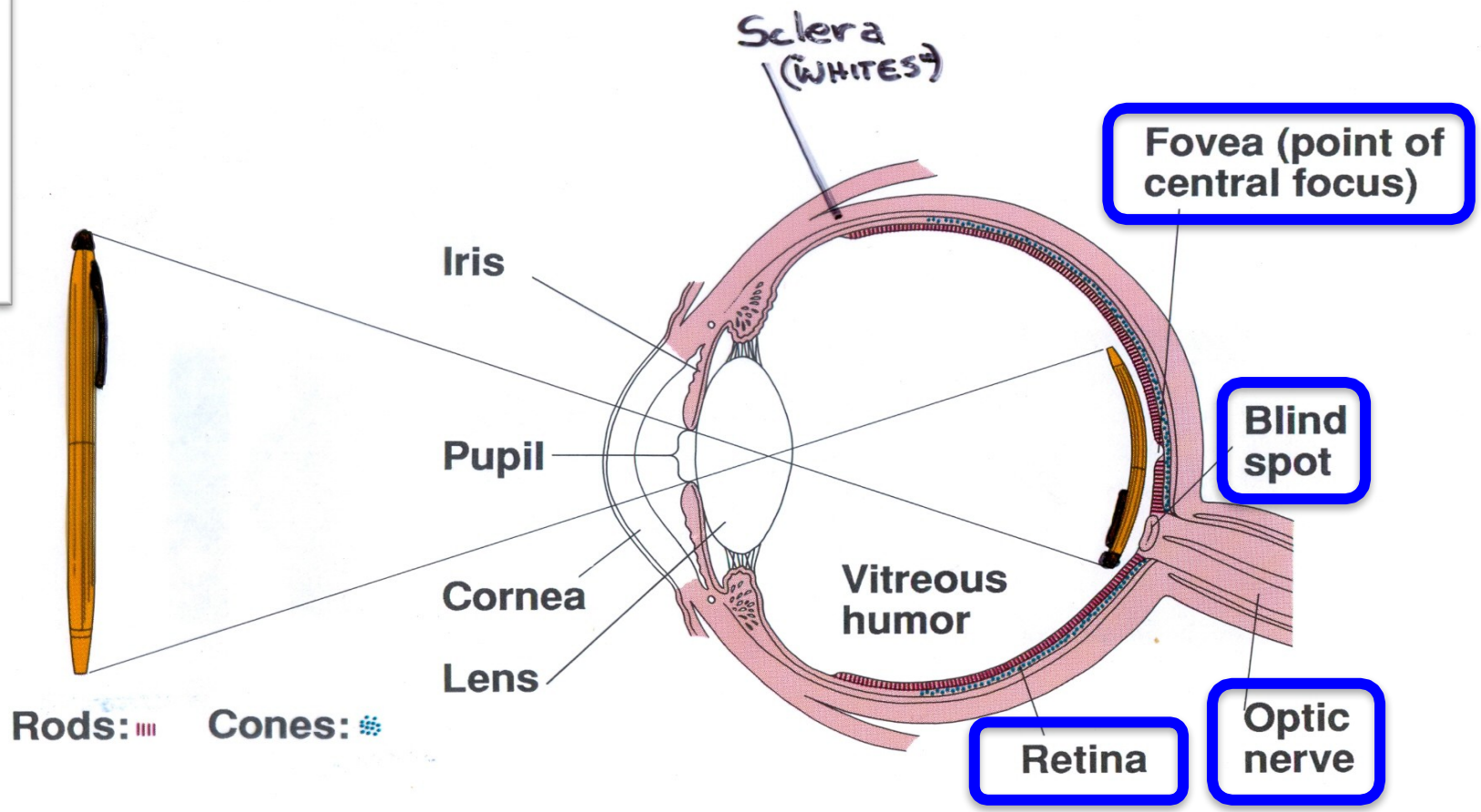
Bear, Mark F., Barry W. Connors, and Michael A. Paradiso. *Neuroscience : Exploring the Brain*. China: Wolters Kluwer, 2016. p297,299.

The Eye



▲ FIGURE 9.4
Gross anatomy of the human eye.

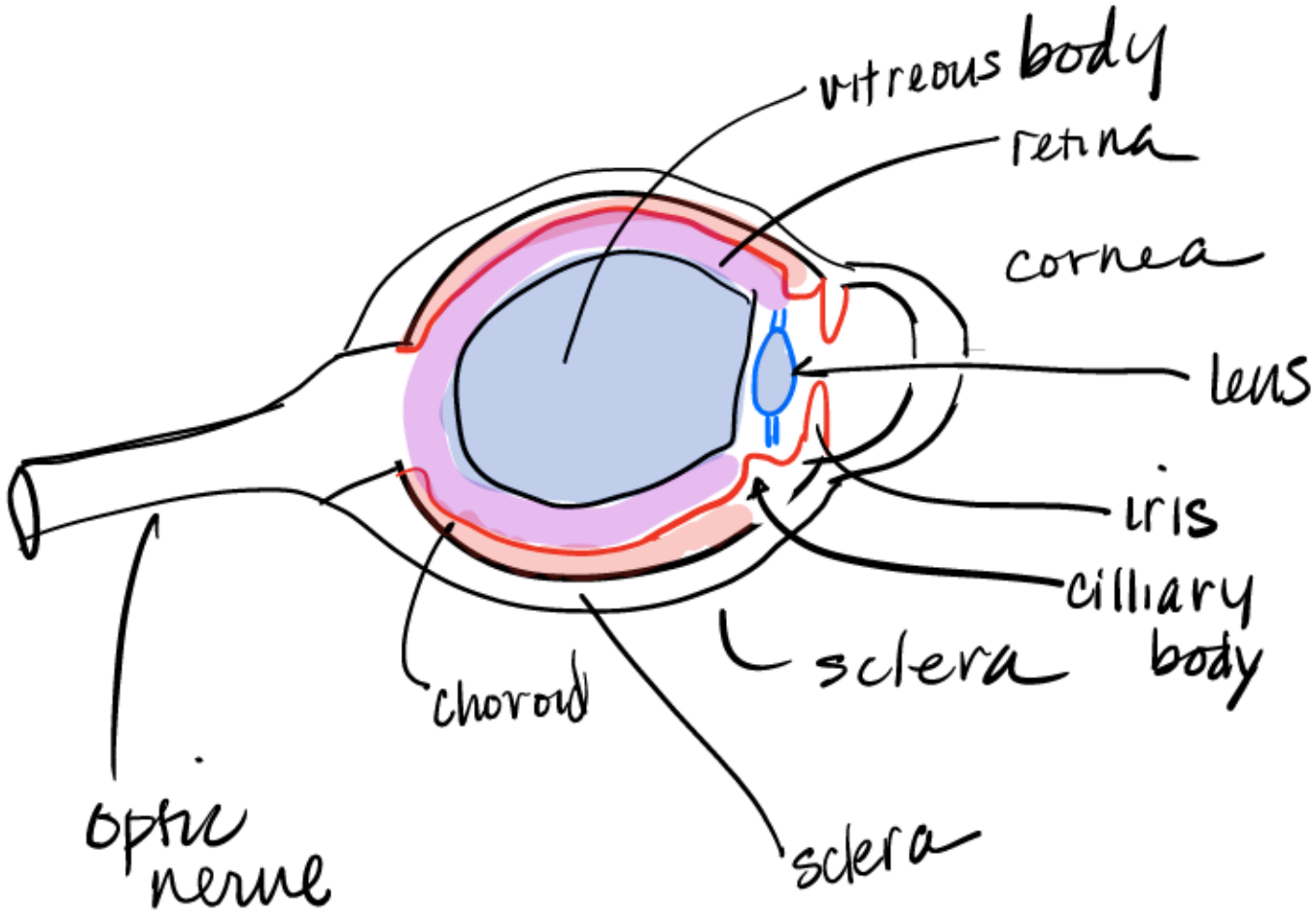
Bear, M. et al p 296



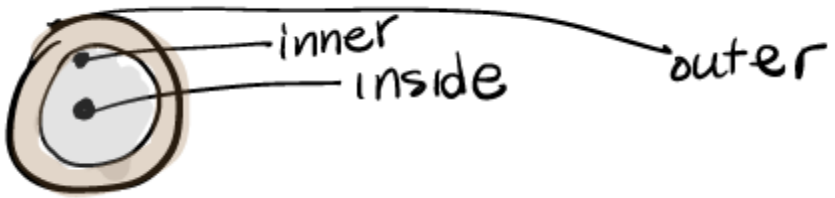
Structure of the eye

Slide from Dr. Christine Johnson

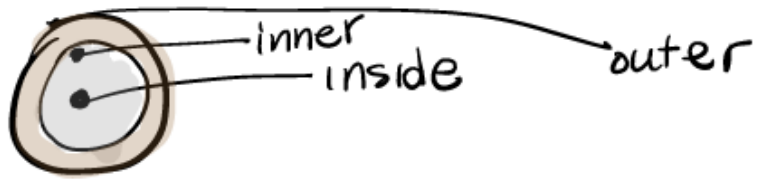
Layers of the retina

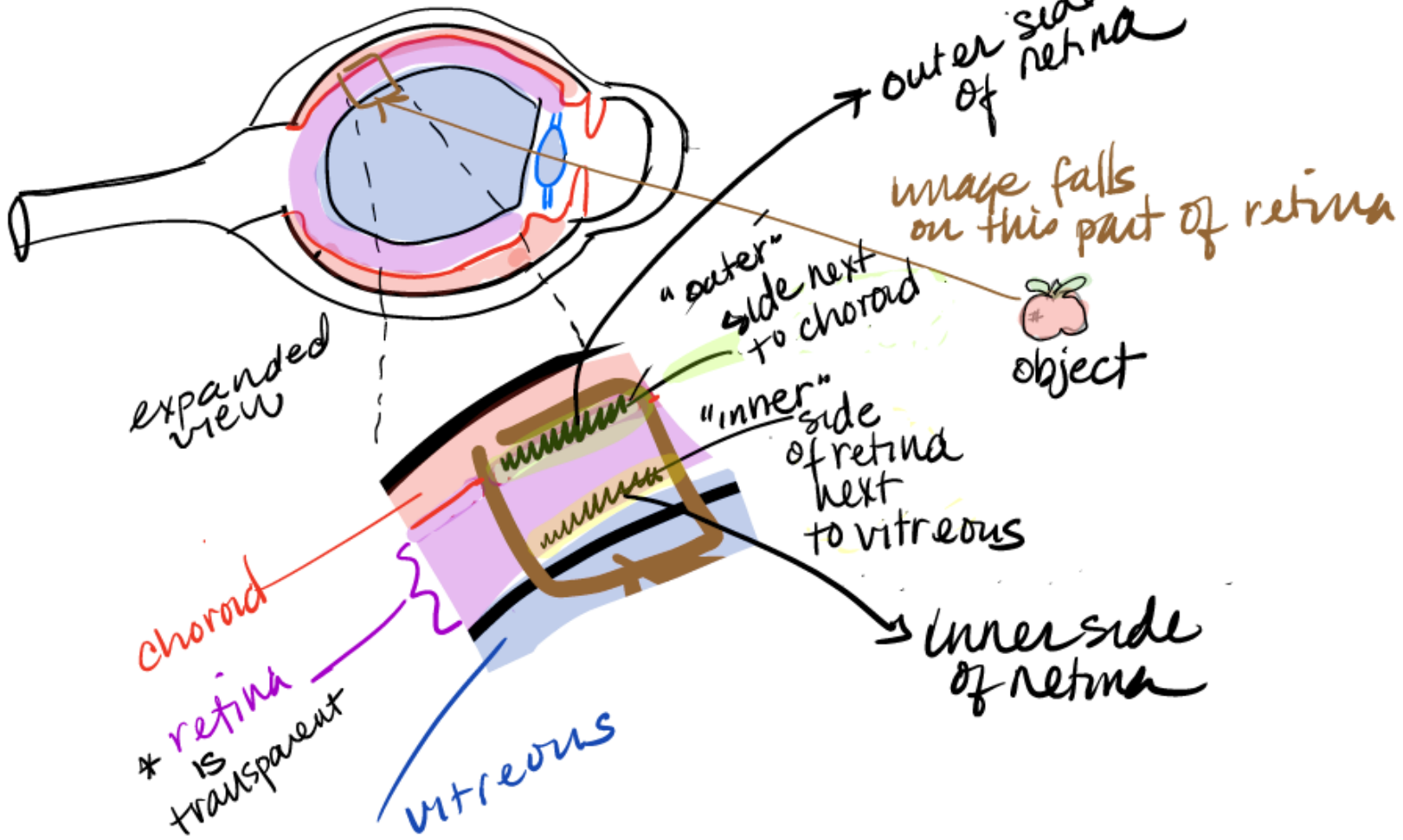


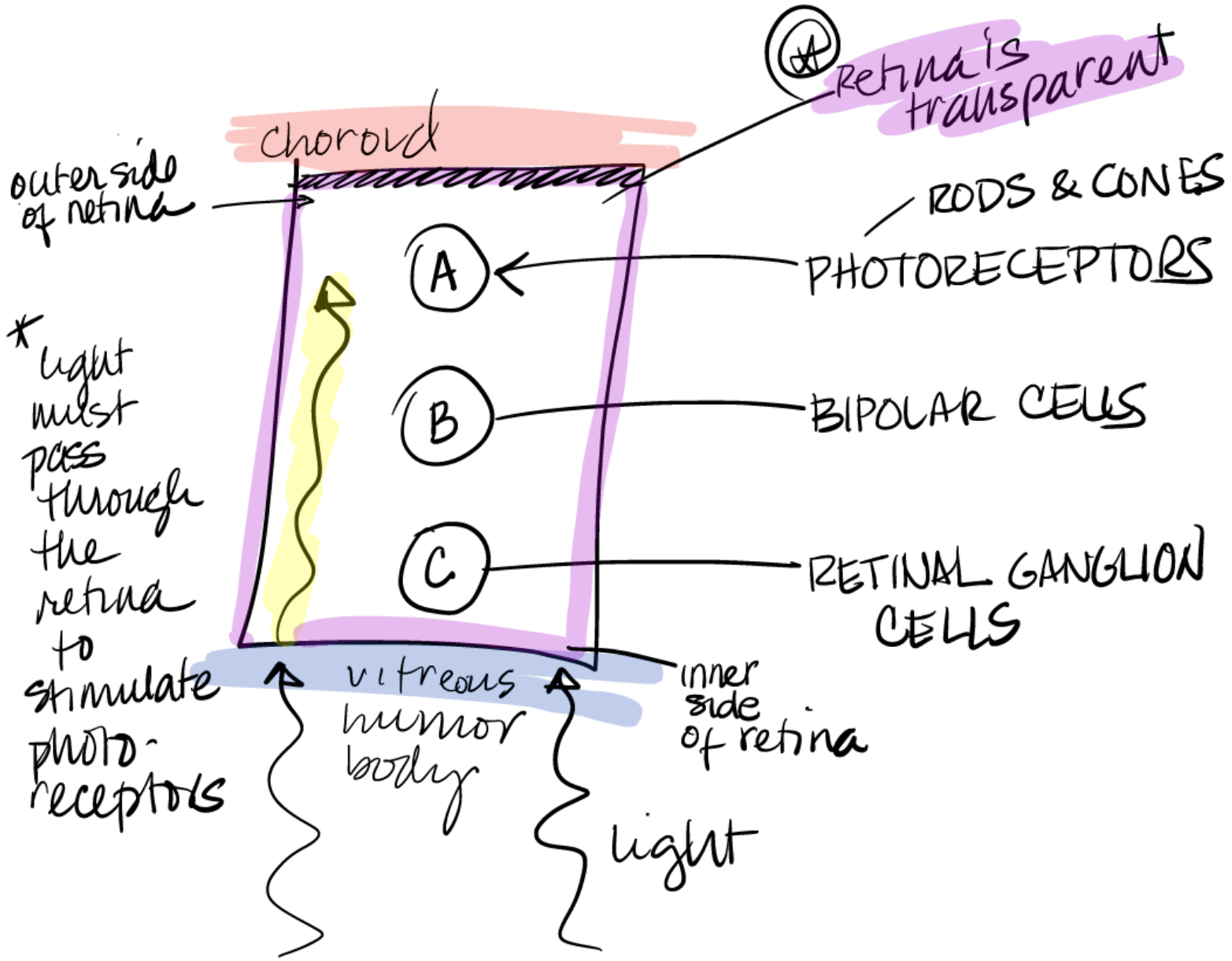
note the outer & inner references are from the middle of the eye ball.

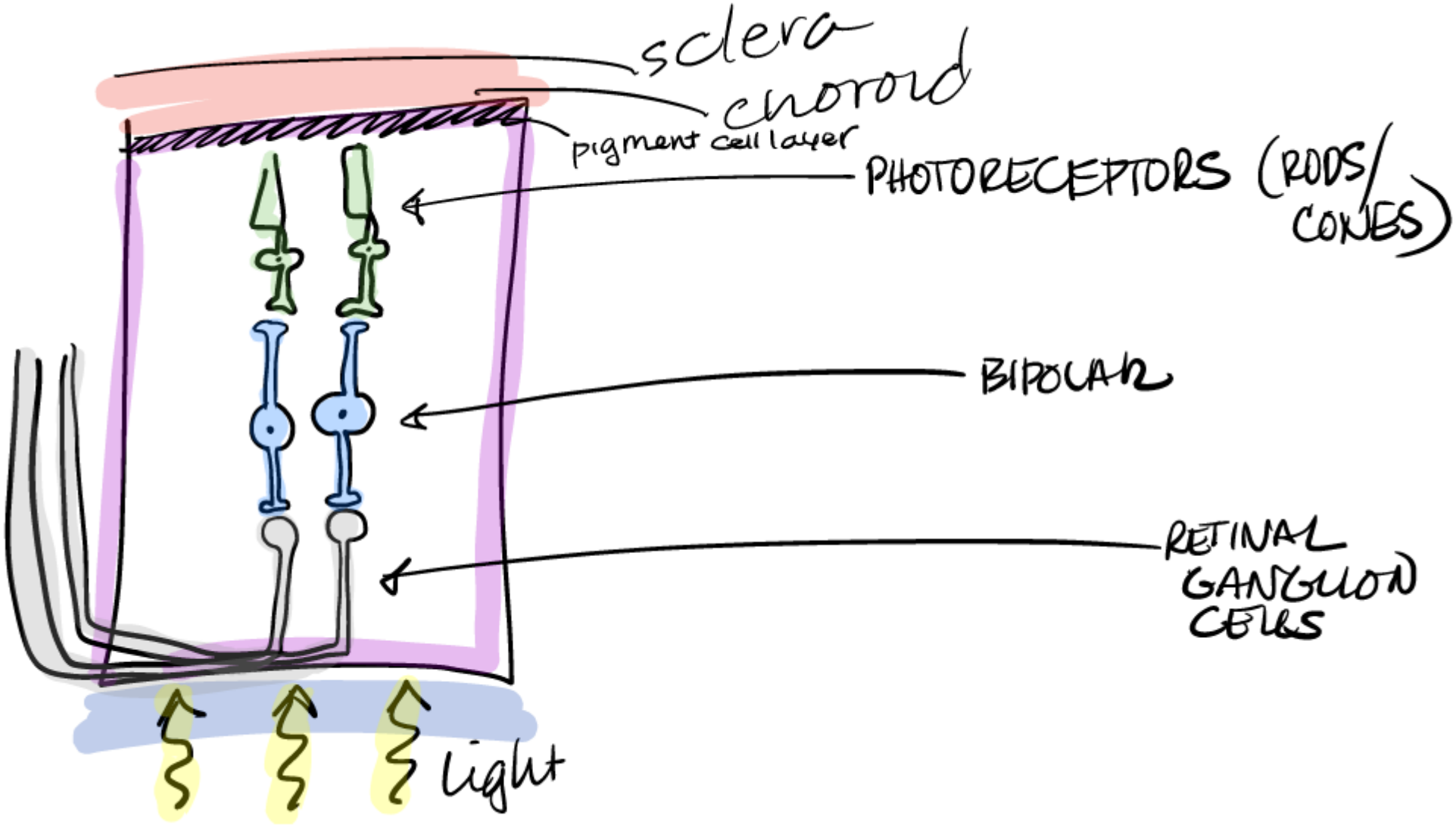


* note the outer & inner references are from the middle of the eye ball. →

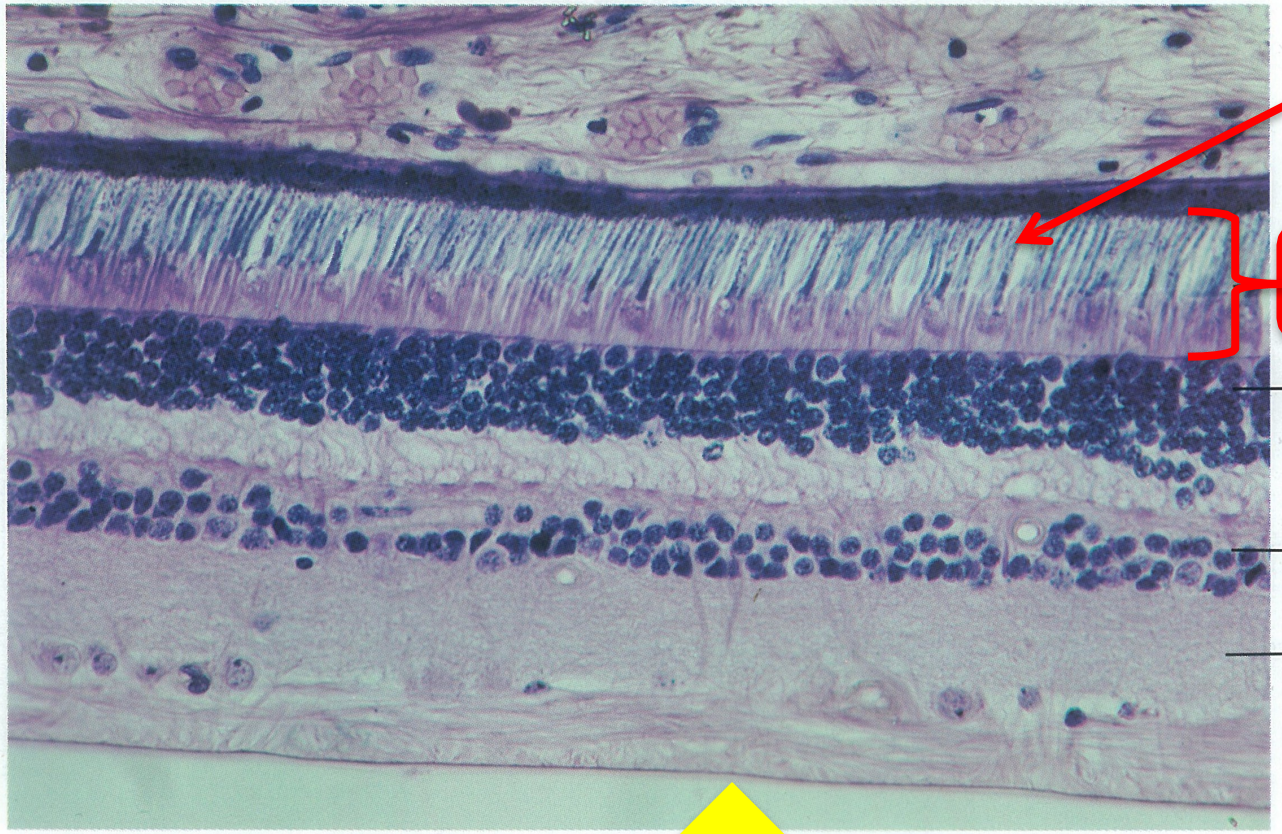





Retina is transparent
choroid
outer side of retina
RODS & CONES
PHOTORECEPTORS
A
* light must pass through the retina to stimulate photo-receptors
B
BIPOLAR CELLS
C
RETINAL GANGLION CELLS
vitreous humor body
inner side of retina
light


sclera
choroid
pigment cell layer
PHOTORECEPTORS (RODS/CONES)
BIPOLAR
RETINAL GANGLION CELLS
light

The Retina



Outer Segments of Receptors, respond to light

Receptors

Mostly bipolar cells

Ganglion cells

Axons from ganglion cells

Light

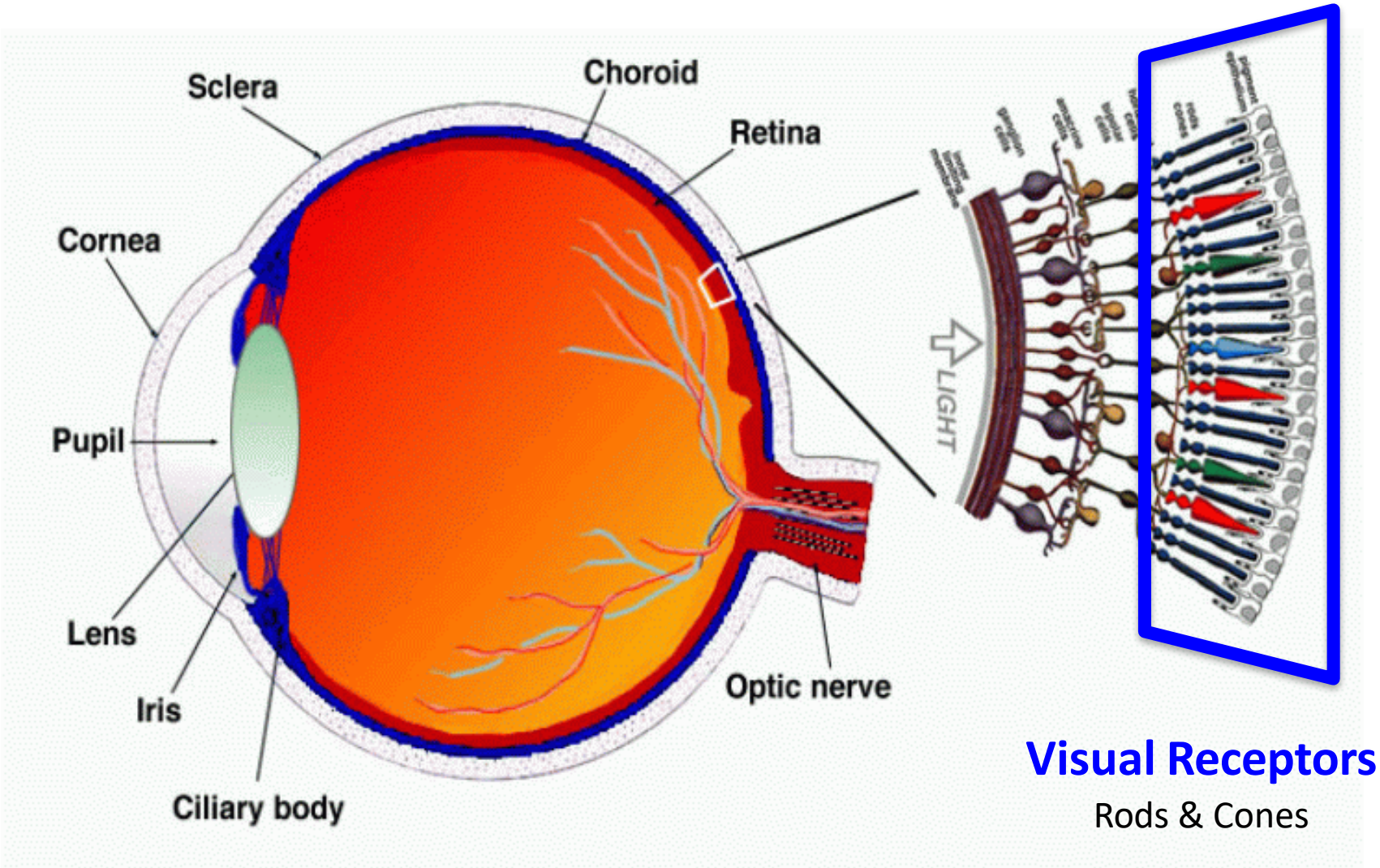
Cross section of the retina

Photo by Ed Reschke

NOTE:
Not a particularly "intelligent design" !

Slide from Dr. Christine Johnson

The Retina



Visual Receptors

Rods & Cones

Slide from Dr. Christine Johnson

See SUPPLEMENTARY handout!

Comparing Rods and Cones:

	RODS	CONES
Shape?	Outer Segment rod-like	Outer Segment cone-like
Outer Segment Contents?	Discs with embedded visual pigment molecules	Folded Sheet w/embedded visual pigment molecules
Size?	Larger (more vis pigment)	Smaller (less vis. pigment)
# ?	~ 120 million/eye	~ 6.5 million/eye
Distribution?	None in fovea High conc in periphery	High conc. in fovea Dispersed in periphery
Code Color?	No (Grays only)	Yes (Per proportions of Red, Green, Blue)
Detect Motion?	Excellent	Poor
Acuity?	Low	High (esp. in fovea)
Light Sensitivity?	High (can operate in dim light)	Not as good (require brighter light)
Connectivity?	High Convergence (many rods:1ganglion)	Low Convergence (1 or few cones:1 ganglion)

Slide from Dr. Christine Johnson

Visual Receptors: Rods & Cones

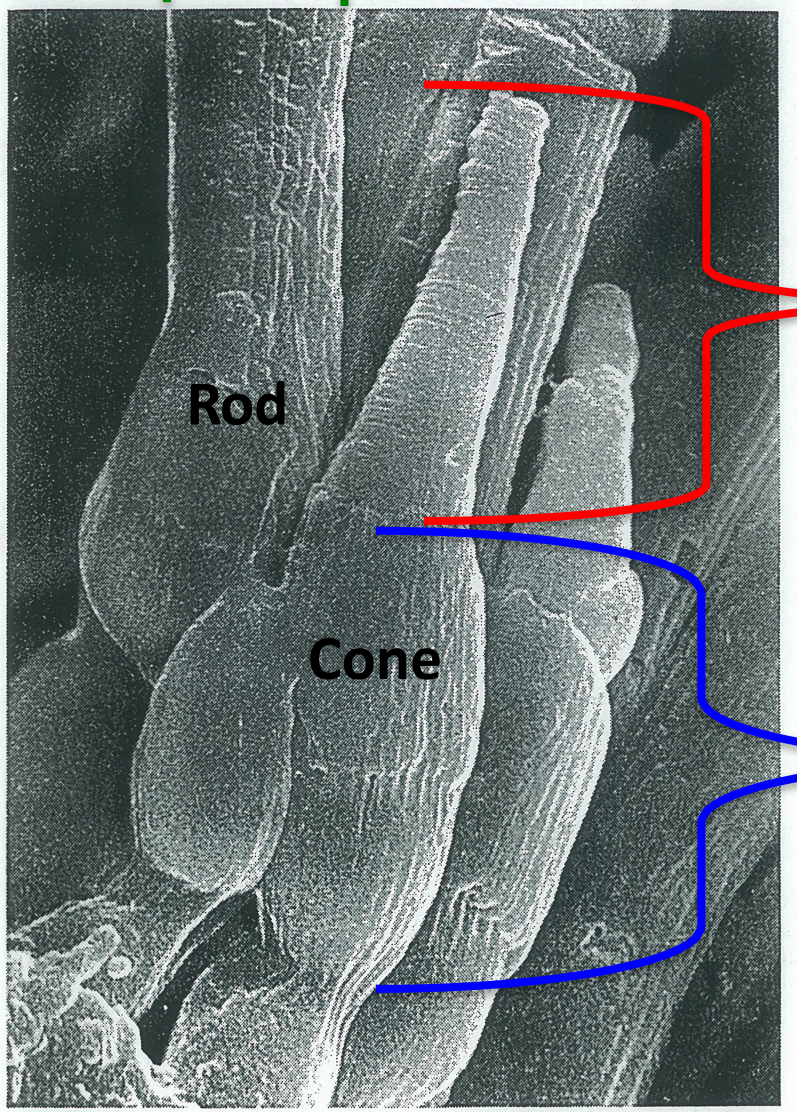
Rod's Outer Segment much larger than Cone's

Rods, being larger, have MORE Photo-pigment

Also differ in #:

Rods ~120 million/eye

Cones ~6 million/eye

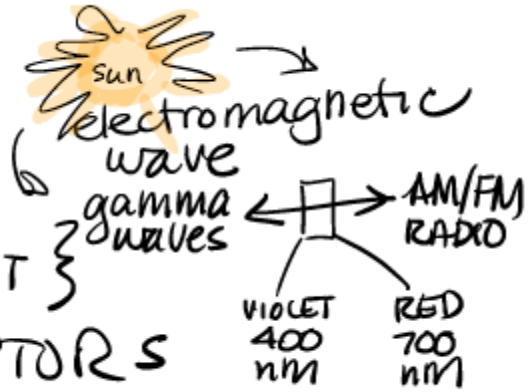


Cone-shaped **Outer Segment**, layered with Photo-Pigment

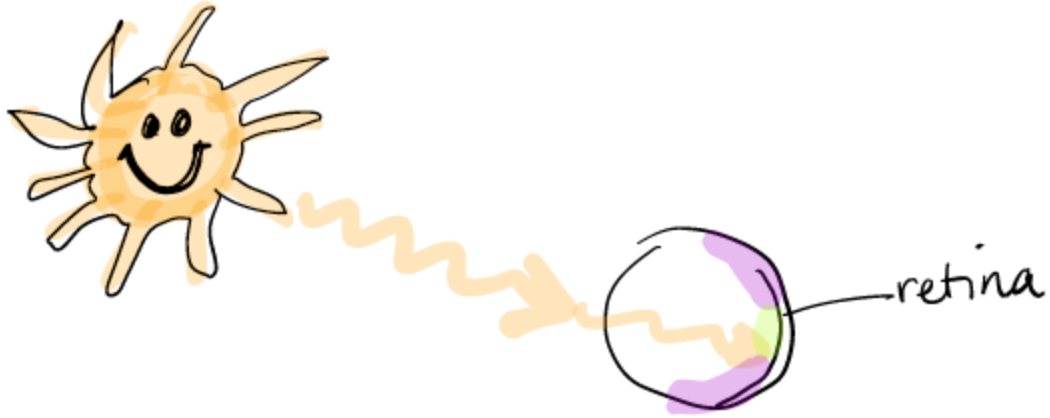
Cell body

Slide from Dr. Christine Johnson

Sensation - Vision



1. PHYSICAL STIMULUS ← LIGHT
2. RECEPTOR ← PHOTORECEPTORS



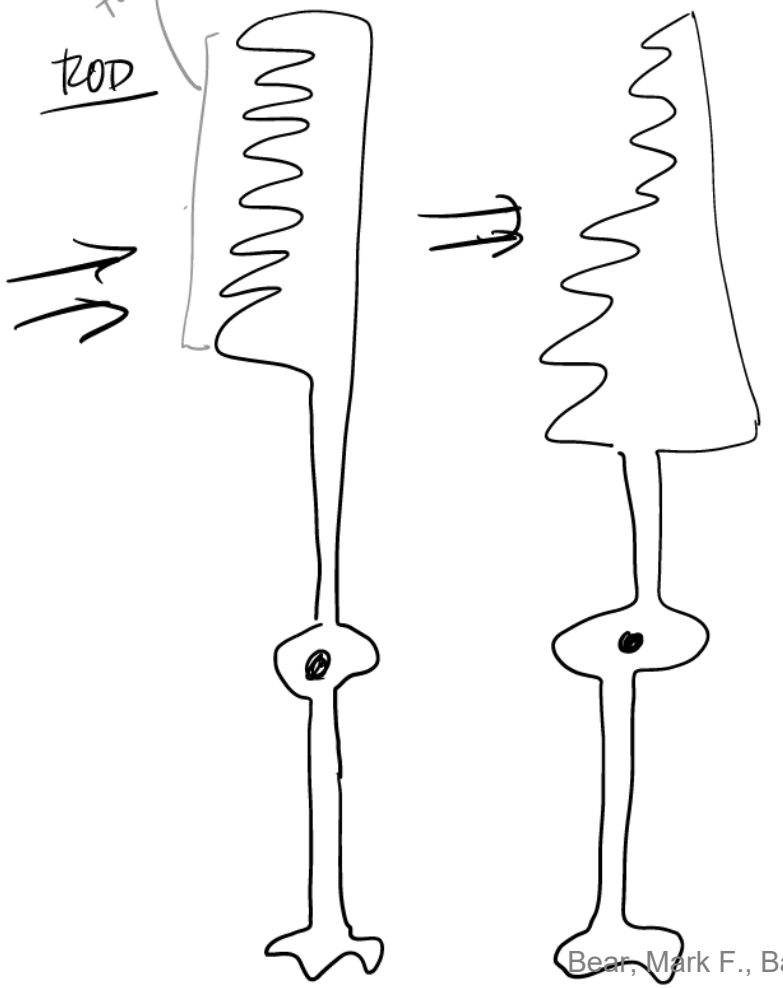
photoreceptors → rods, cones

sense electromagnetic wave

membrane foldings

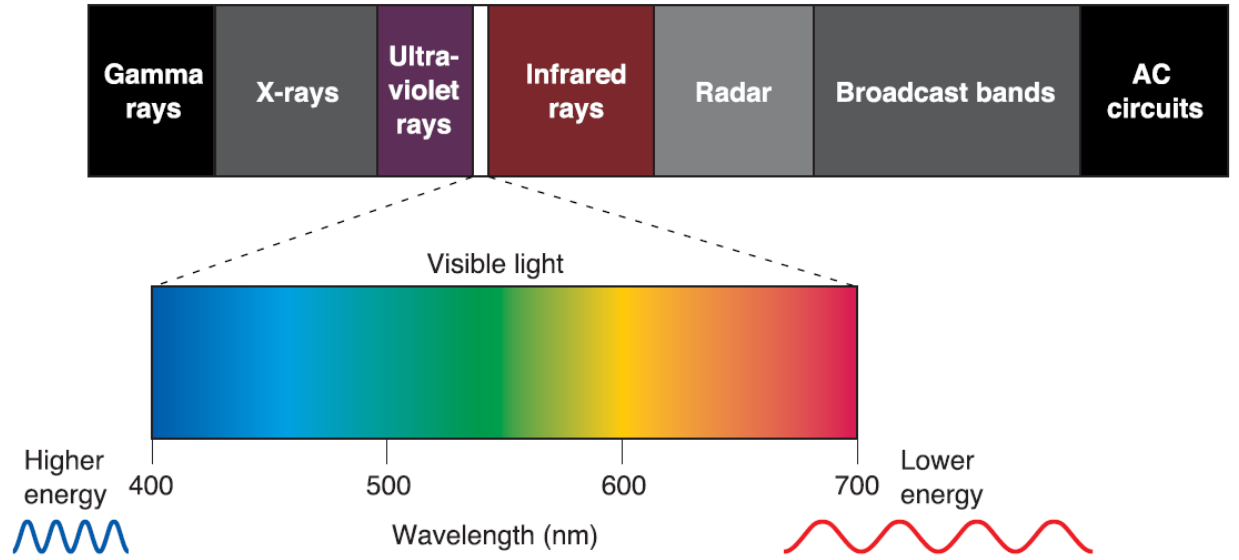
ROD

⇓ generate electrical signal

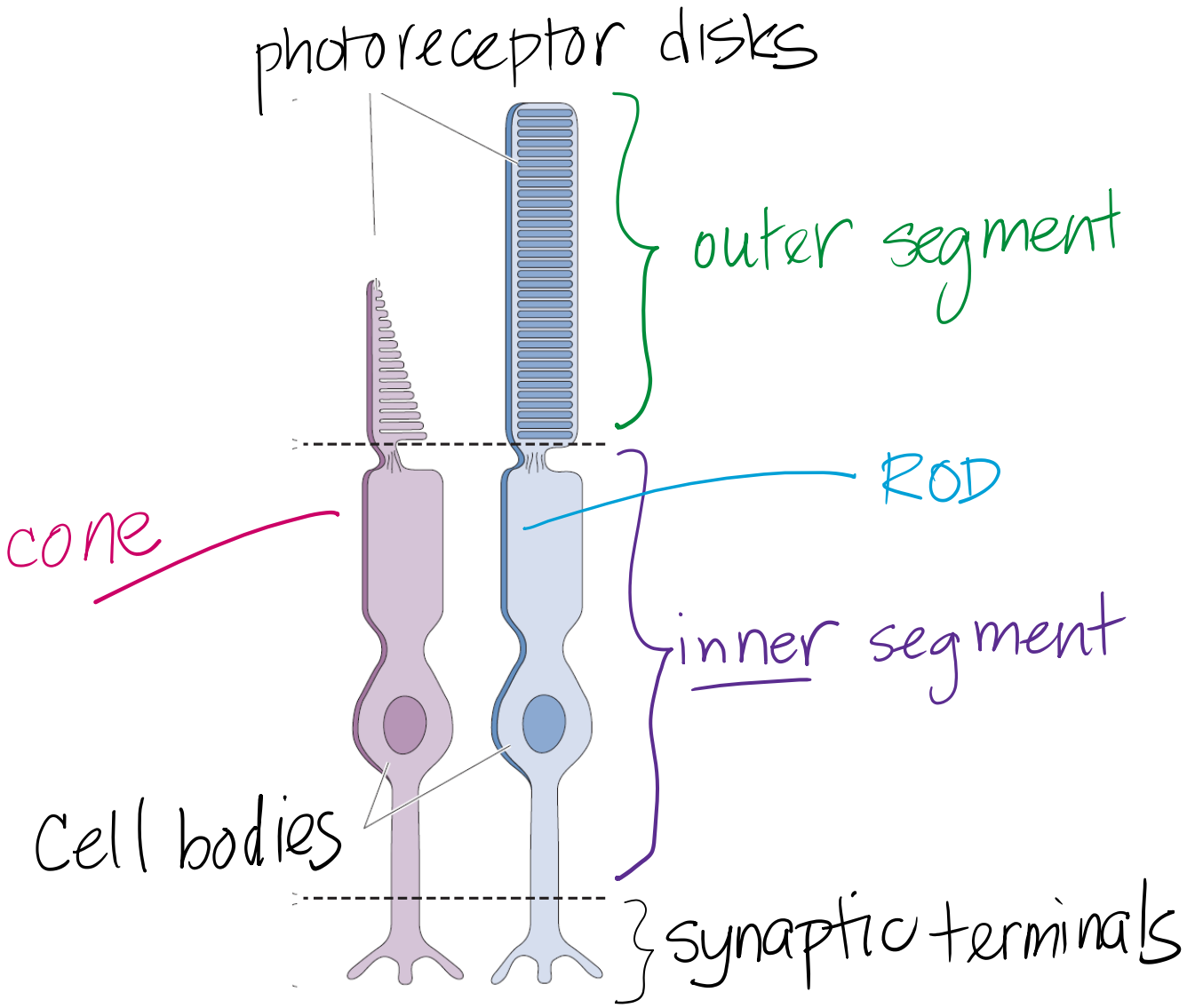


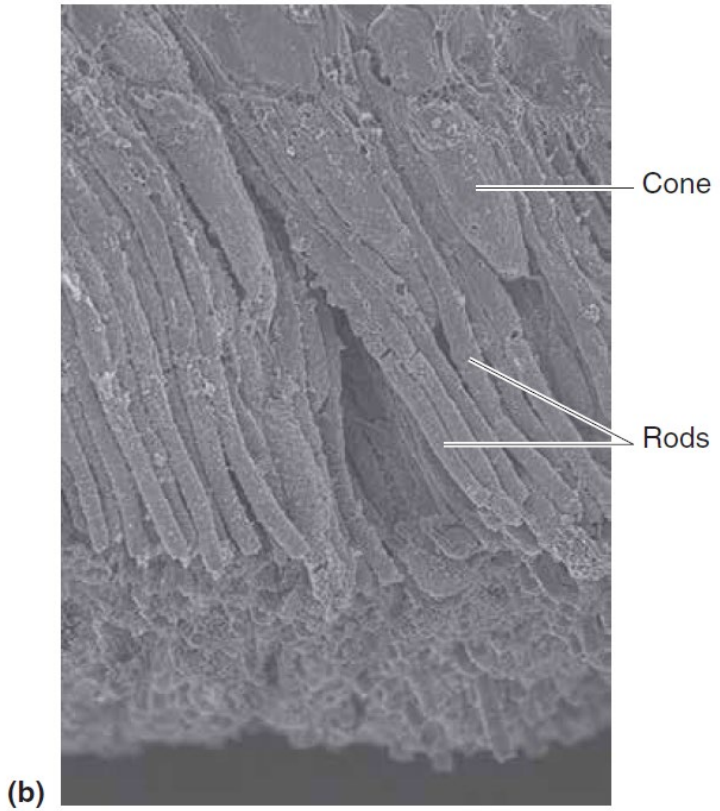
◀ FIGURE 9.2

The electromagnetic spectrum. Only electromagnetic radiation with wavelengths of 400–700 nm is visible to the human eye. Within this visible spectrum, different wavelengths appear as different colors.



Bear, Mark F., Barry W. Connors, and Michael A. Paradiso. *Neuroscience : Exploring the Brain*. China: Wolters Kluwer, 2016. p 295





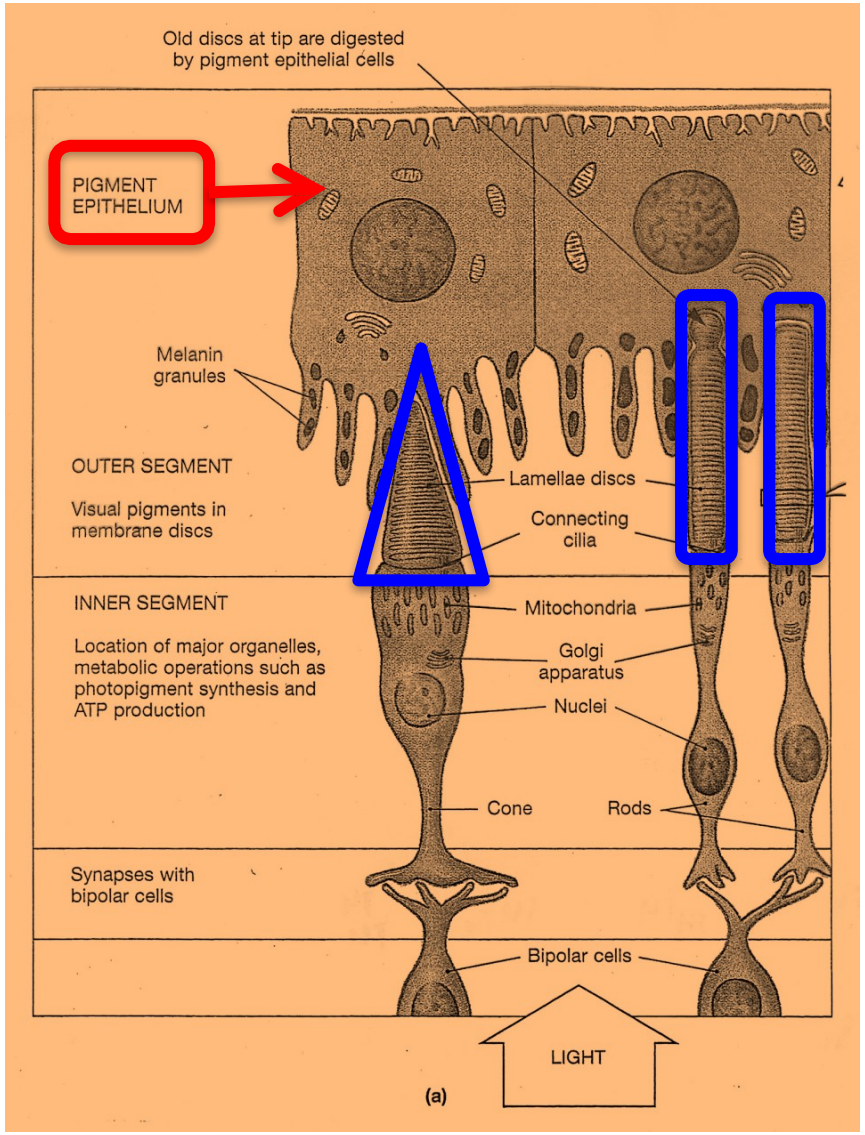
◀ FIGURE 9.14
Rods and cones. **(a)** Rods contain more disks and make vision possible in low light; cones enable us to see in daylight. **(b)** Scanning electron micrograph of rods and cones. (Source: Courtesy of J. Franks and W. Halfter.)

Bear, Mark F., Barry W. Connors, and Michael A. Paradiso. *Neuroscience : Exploring the Brain*. China: Wolters Kluwer, 2016. p 307

Visual Receptors: Rods & Cones

SIMILARITIES

- Molecules of photo-pigment embedded in outer segments
- Outer segments embedded in "Pigment epithelium"
- Graded Potentials
- Release Inhibitory NT

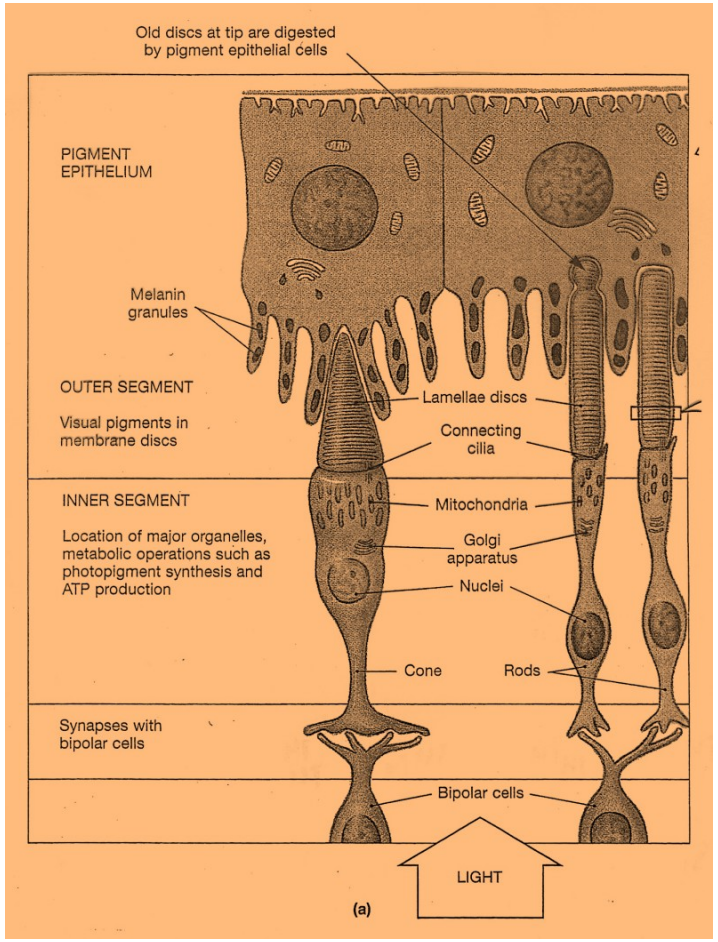


Slide from Dr. Christine Johnson

Visual Receptors: Rods & Cones

CONES

- 3 kinds of photo-pigment (1 type per cone)
- Do code **color**
- Poor for motion detection
- Excellent **acuity** (detail discrimination)
- Low sensitivity (require bright light)
- Mainly **Ventral** Path

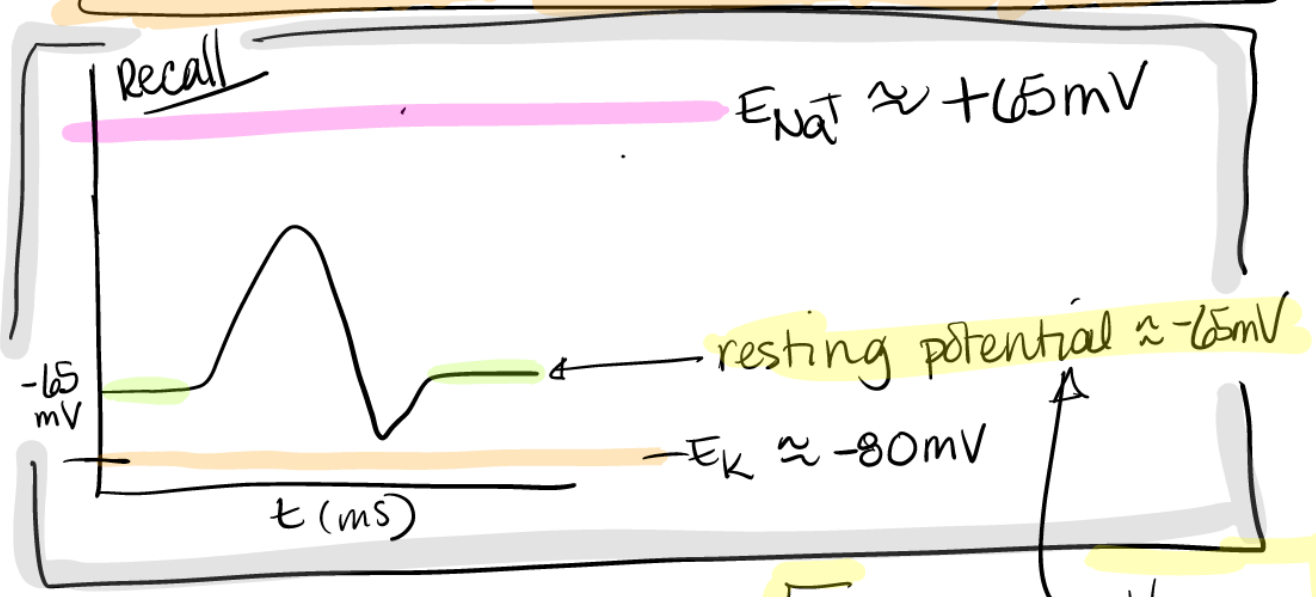


RODS

- 1 kind of photopigment
- Do not code color
- Excellent for **motion** detection
- Poor acuity
- High **sensitivity** (operate in dim light)
- Mainly **Dorsal** Path

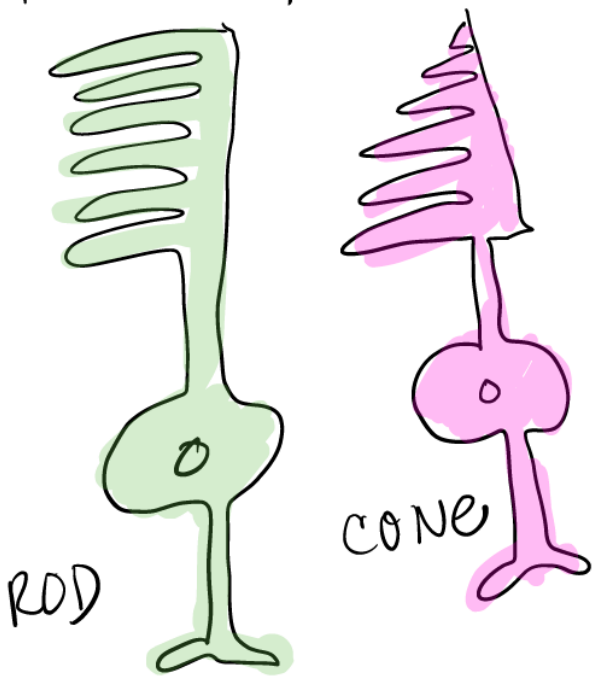
Slide from Dr. Christine Johnson

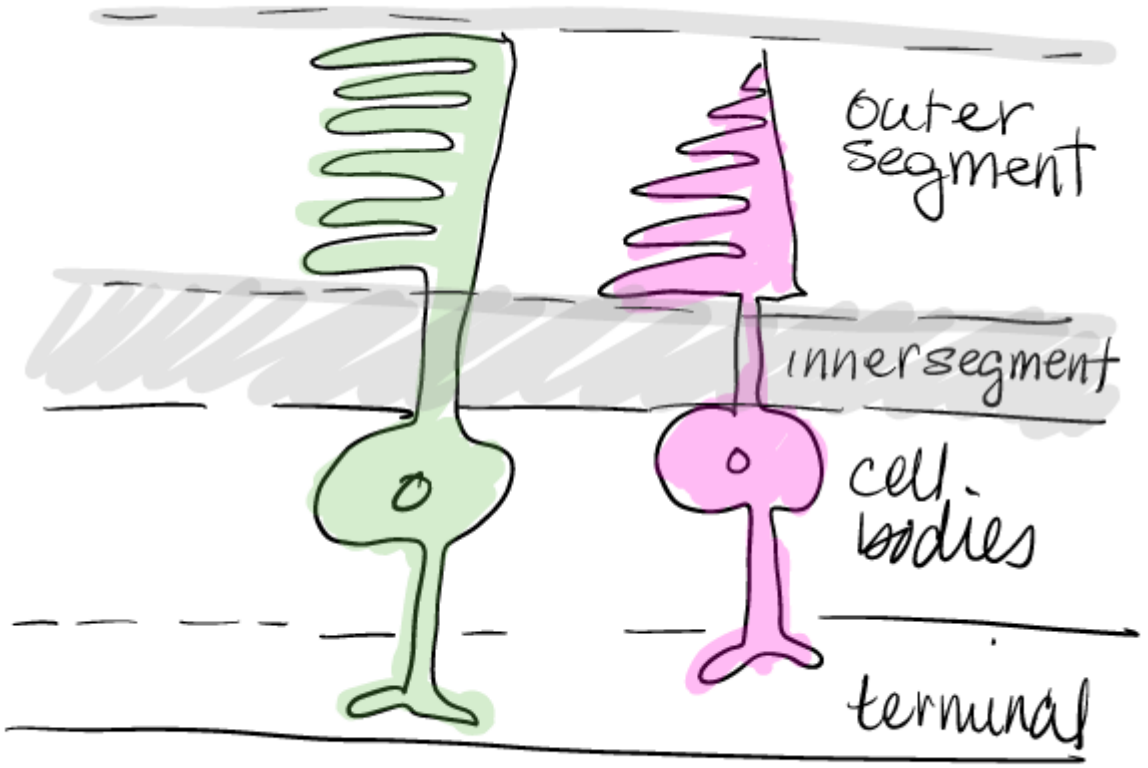
TRANSDUCTION → FROM LIGHT TO ELECTRICAL POTENTIALS

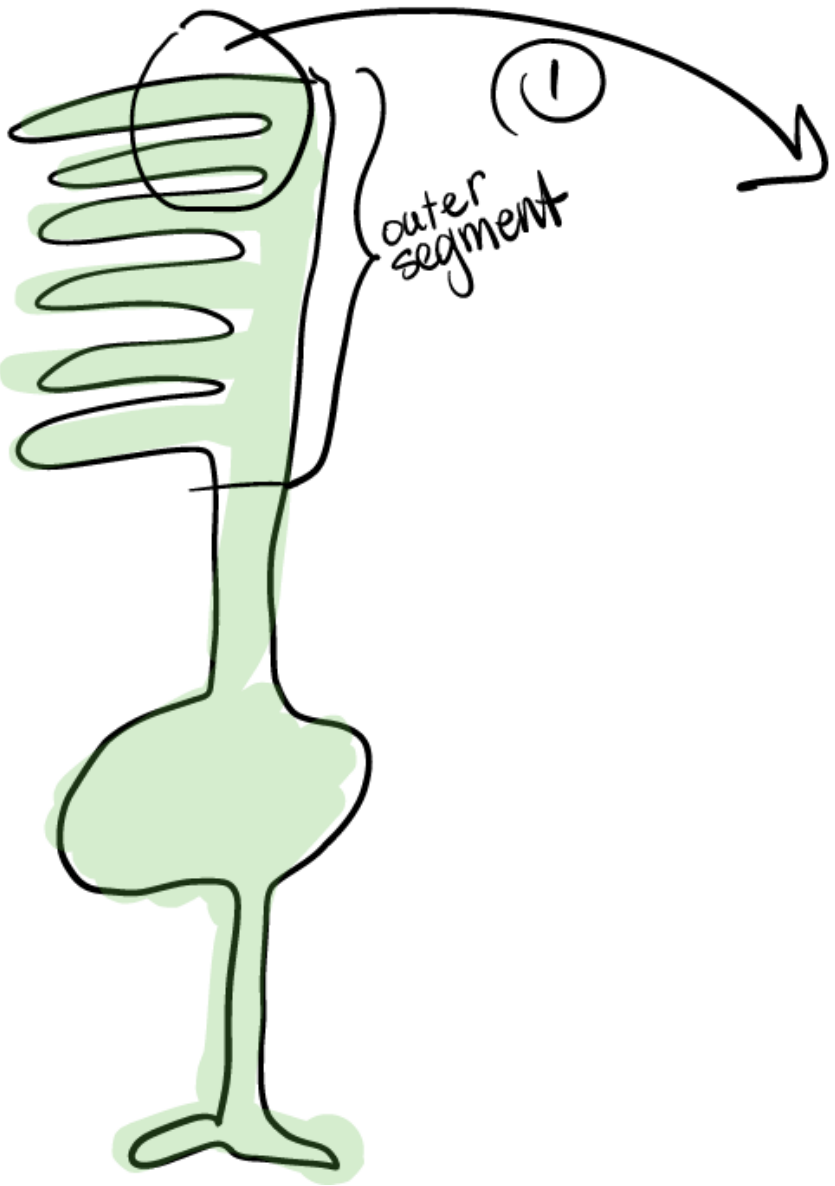


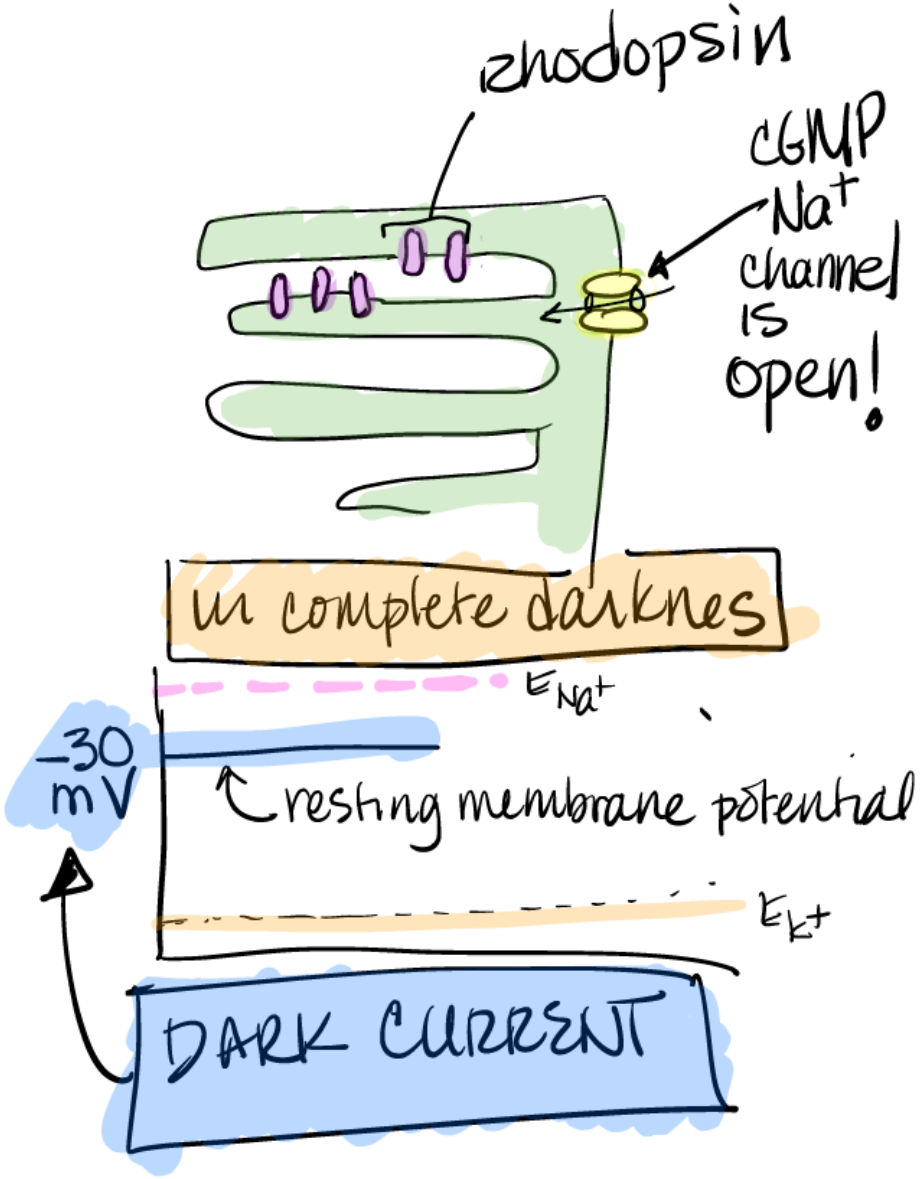
the reason the resting memb. potential is so close to E_{K^+} is b/c of the K^+ leak channels.

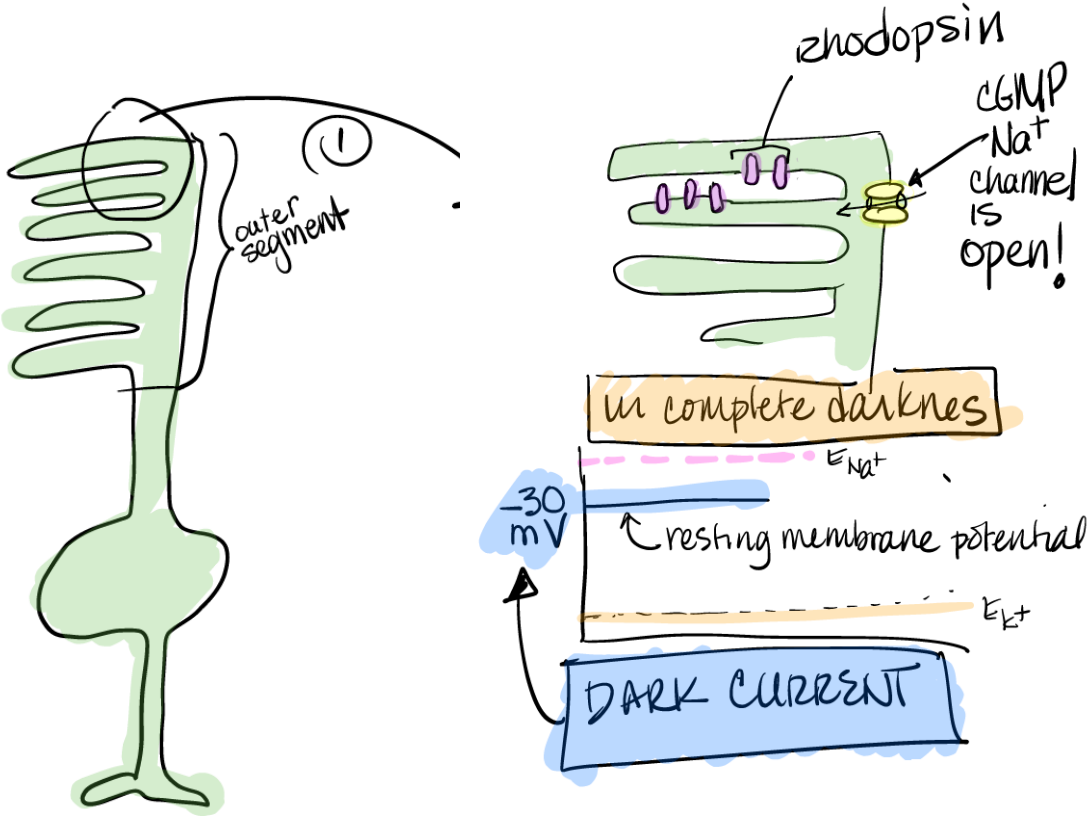
Consider the photoreceptors:






outer segment

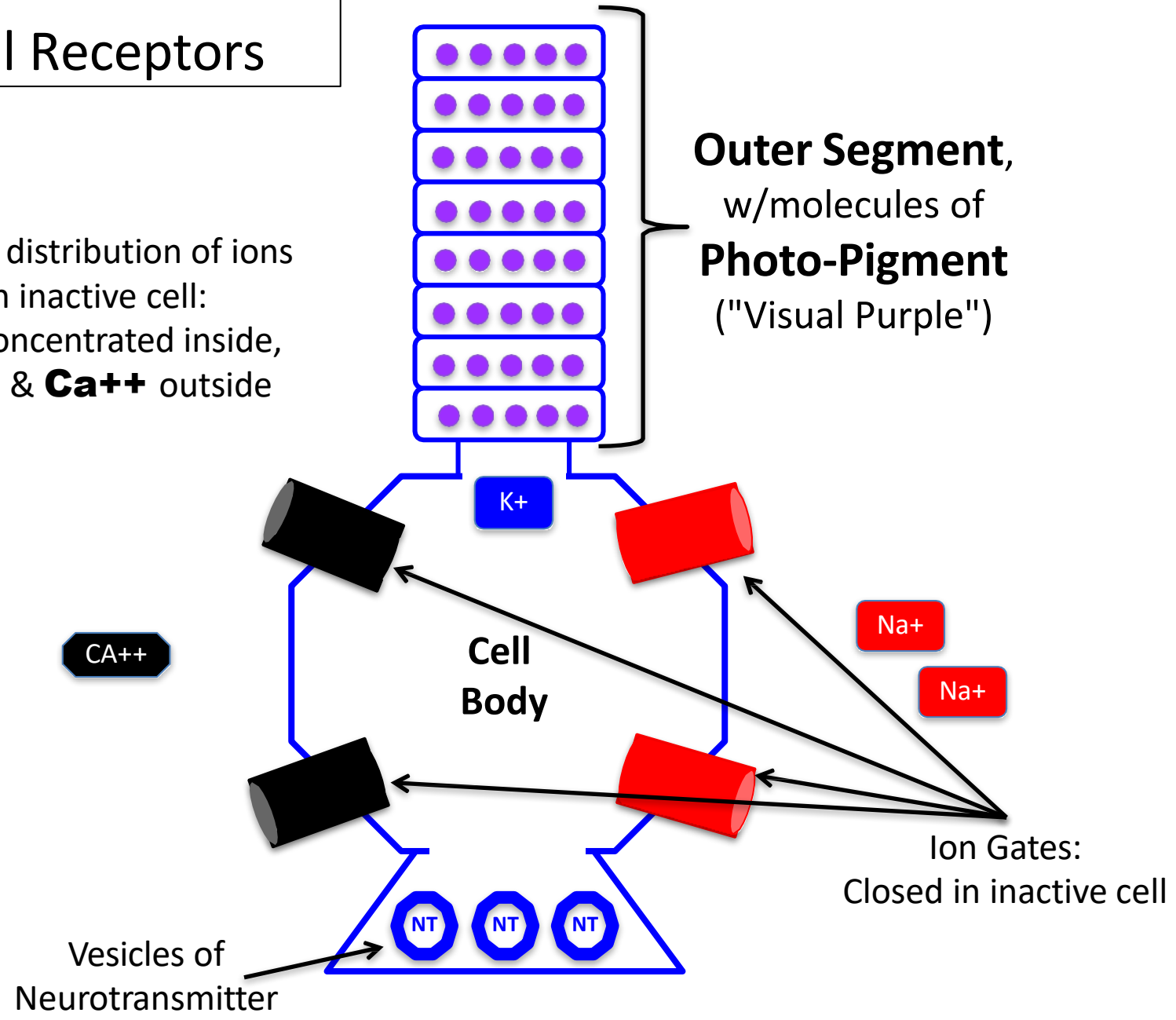

rhodopsin
cGMP
Na+ channel is open!
in complete darknes
E_{Na^+}
-30 mV
resting membrane potential
E_{K^+}
DARK CURRENT



In the dark, the cGMP Na^+ channel is activated.

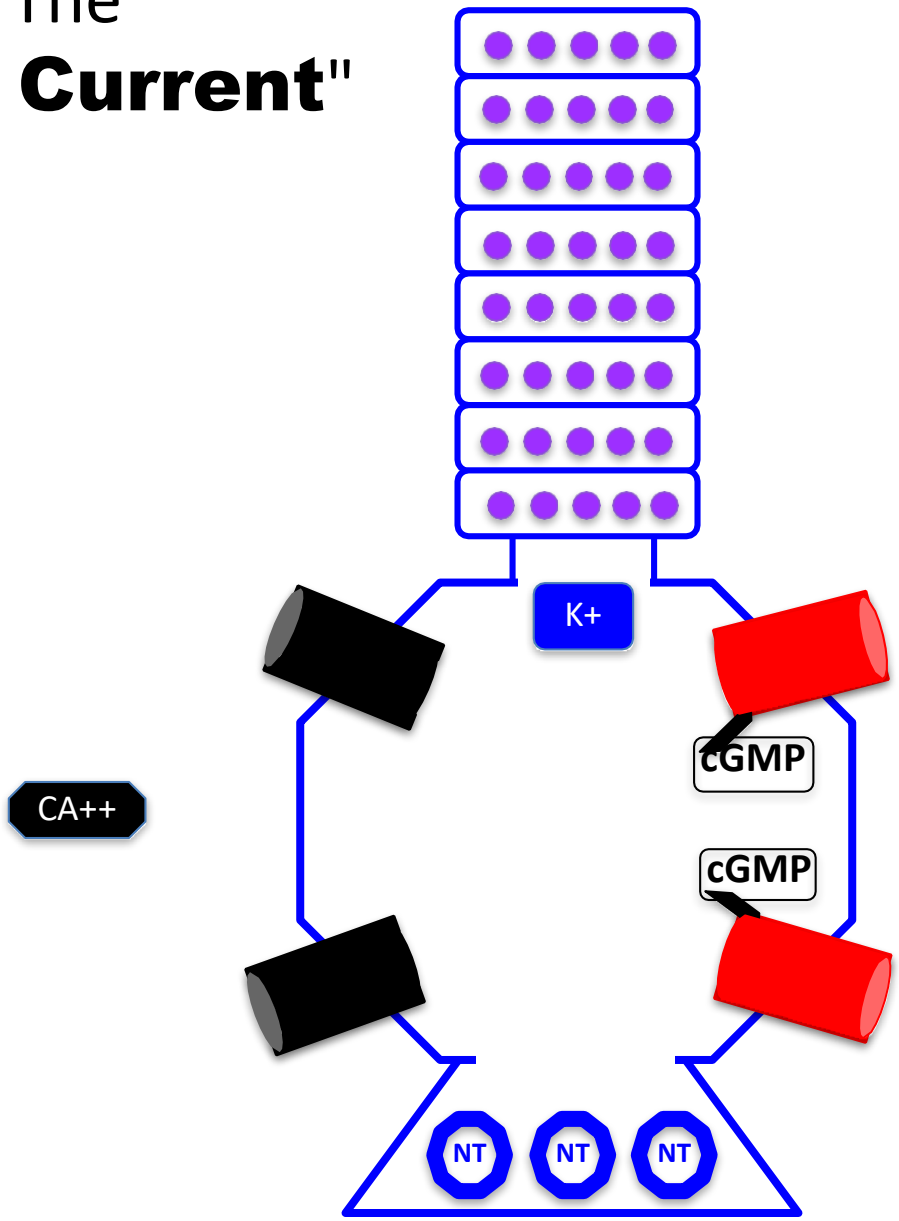
Visual Receptors

Typical distribution of ions
in inactive cell:
K+ concentrated inside,
Na+ & **Ca++** outside



Slide from Dr. Christine Johnson

The "**Dark Current**"



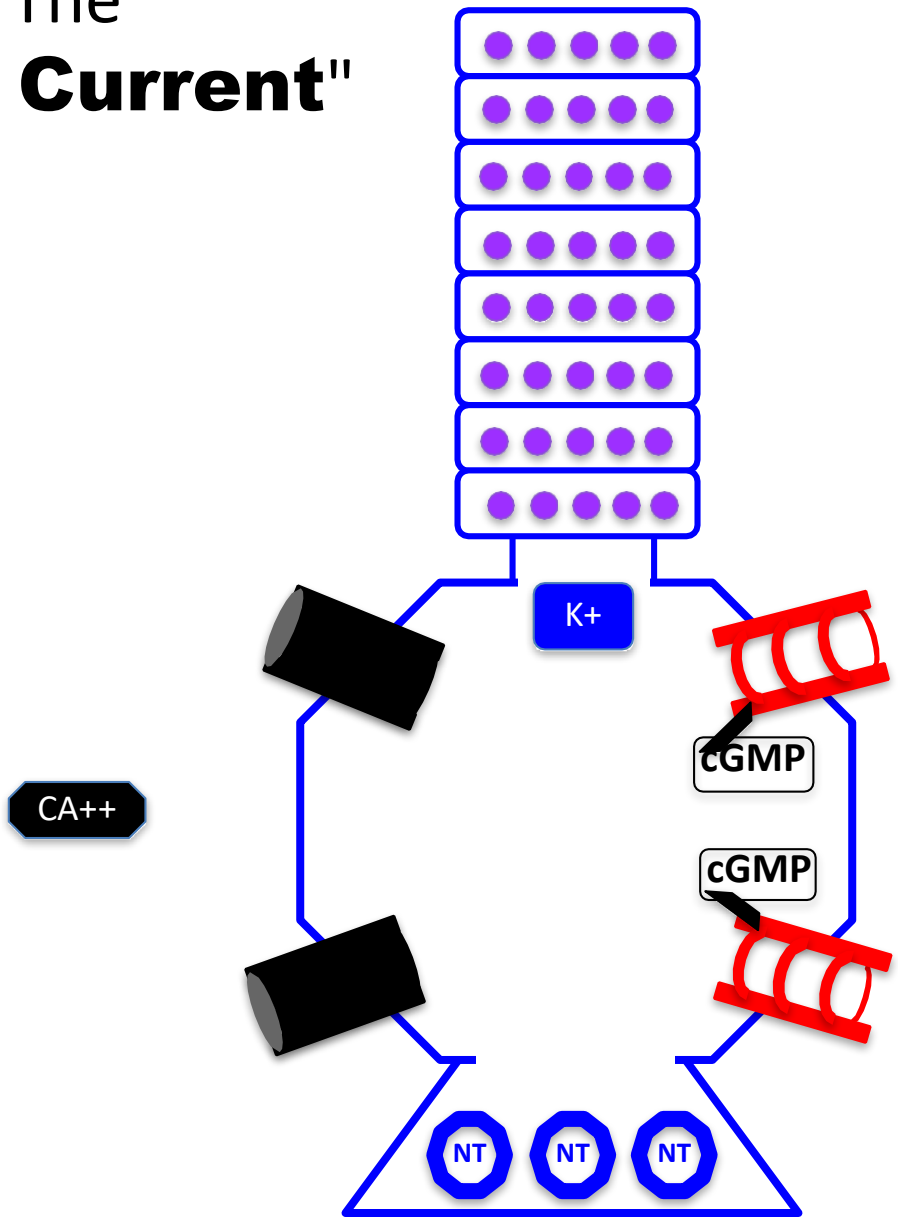
In the **Dark**, cGMP holds **Na+** gates open...

Na+

Na+

Slide from Dr. Christine Johnson

The "**Dark Current**"



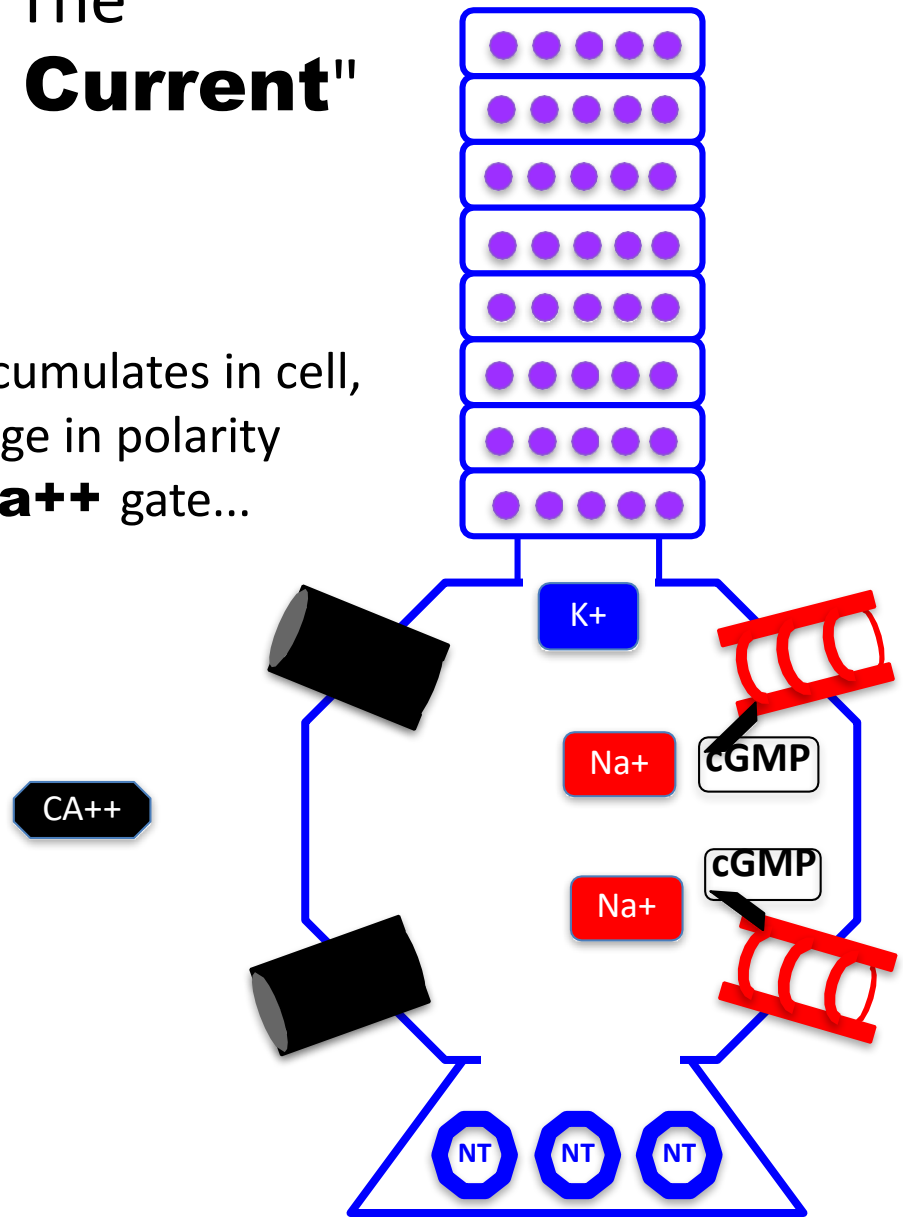
In the **Dark**, cGMP holds **Na+** gates open...

Na+

Na+

The "**Dark Current**"

As **Na+** accumulates in cell, the change in polarity opens **Ca++** gate...



In the **Dark**, cGMP holds **Na+** gates open...

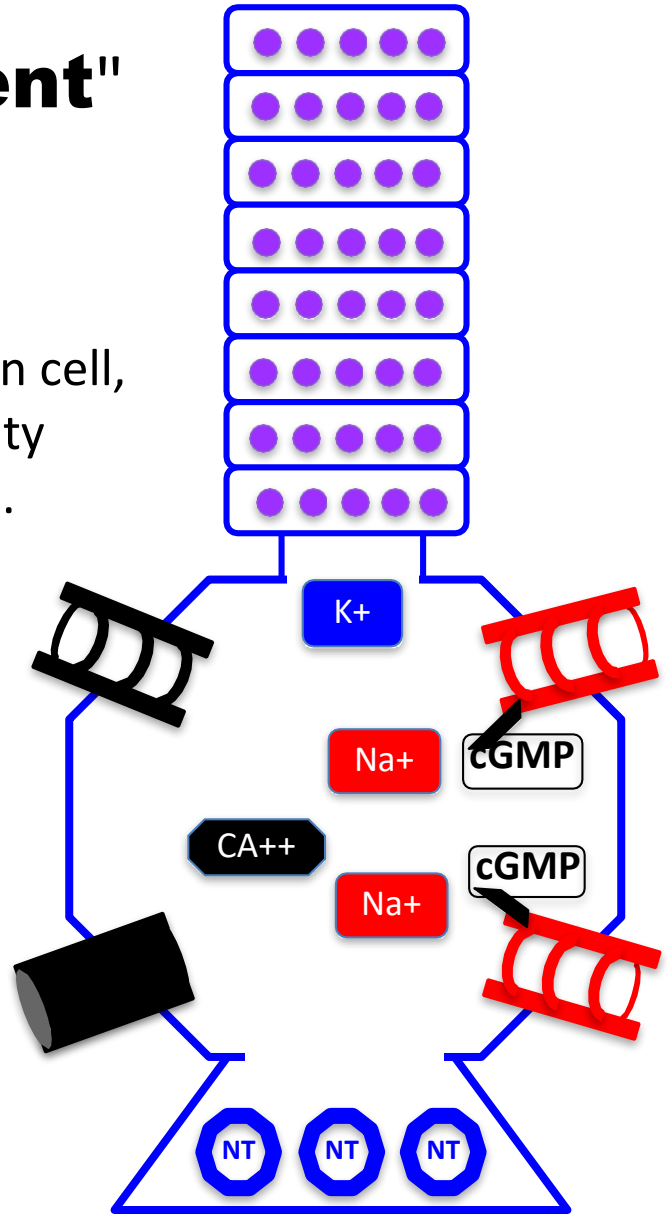
...**Na+** enters

Slide from Dr. Christine Johnson

The "**Dark Current**"

As **Na+** accumulates in cell, the change in polarity opens **Ca++** gate...

... **Ca++** enters



In the **Dark**, cGMP holds **Na+** gates open...

...**Na+** enters

Slide from Dr. Christine Johnson

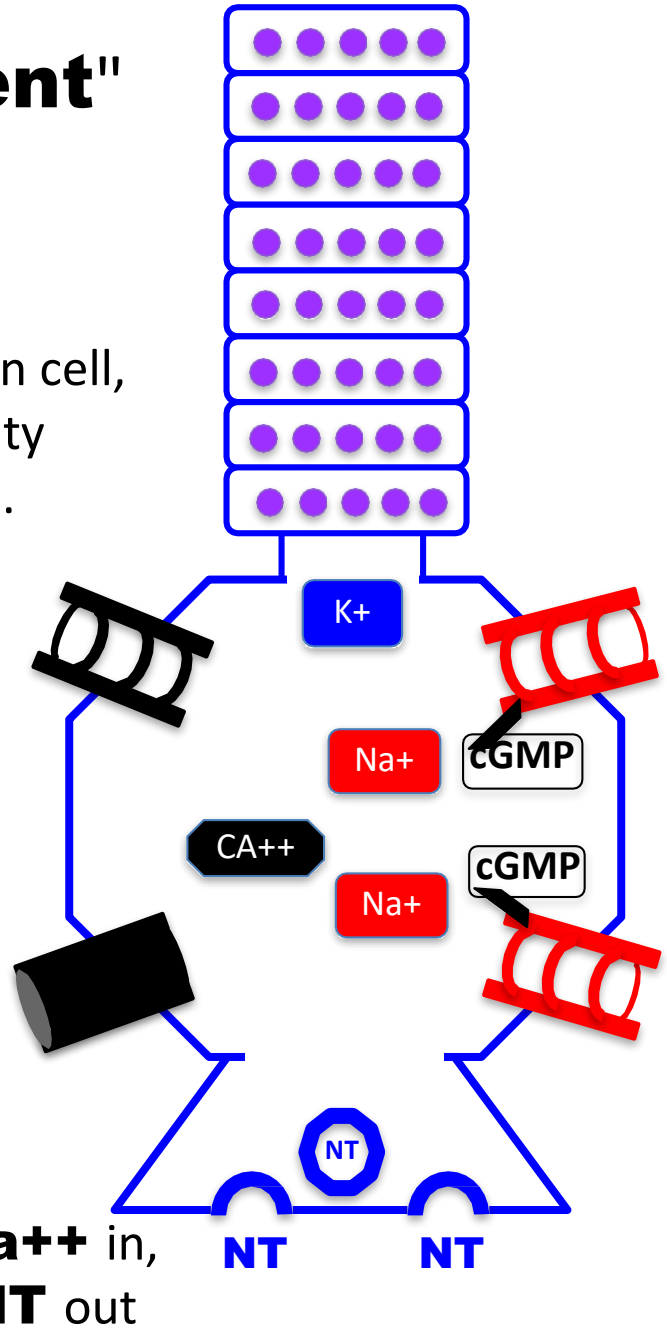
The "**Dark Current**"

As **Na+** accumulates in cell, the change in polarity opens **Ca++** gate...

... **Ca++** enters

In the **Dark**, cGMP holds **Na+** gates open...

...**Na+** enters

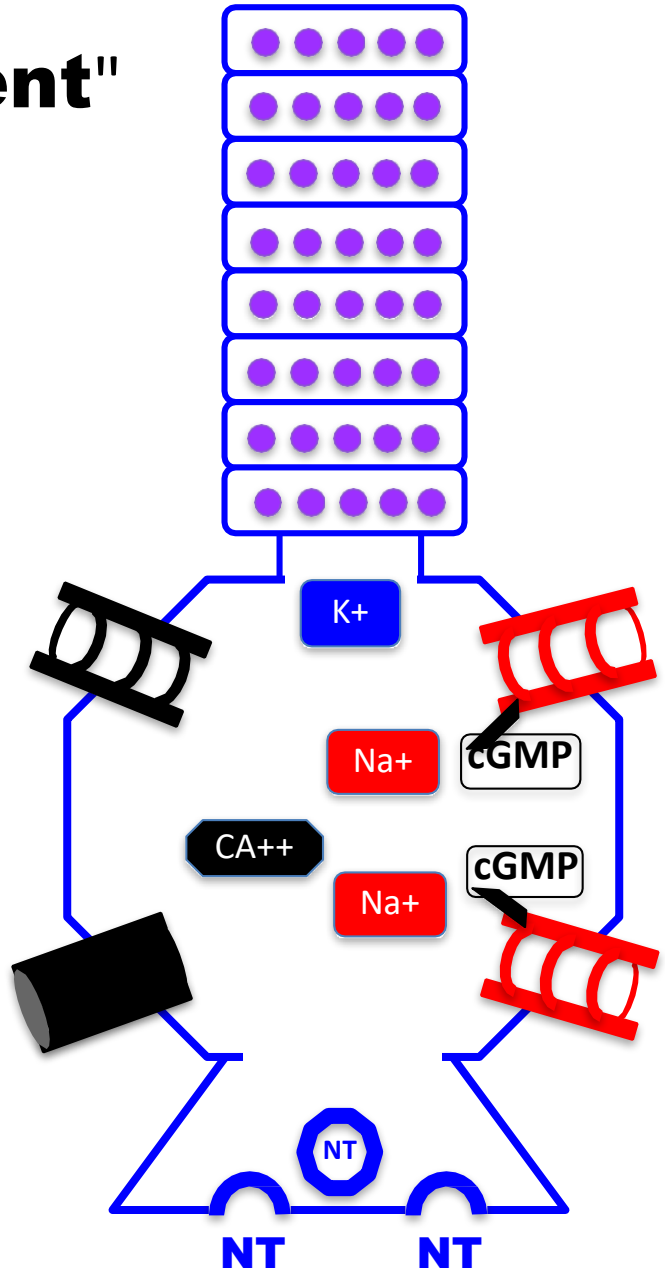


Ca++ in, **NT** out

Visual Receptors fire in the dark!

Slide from Dr. Christine Johnson

The "**Dark Current**"

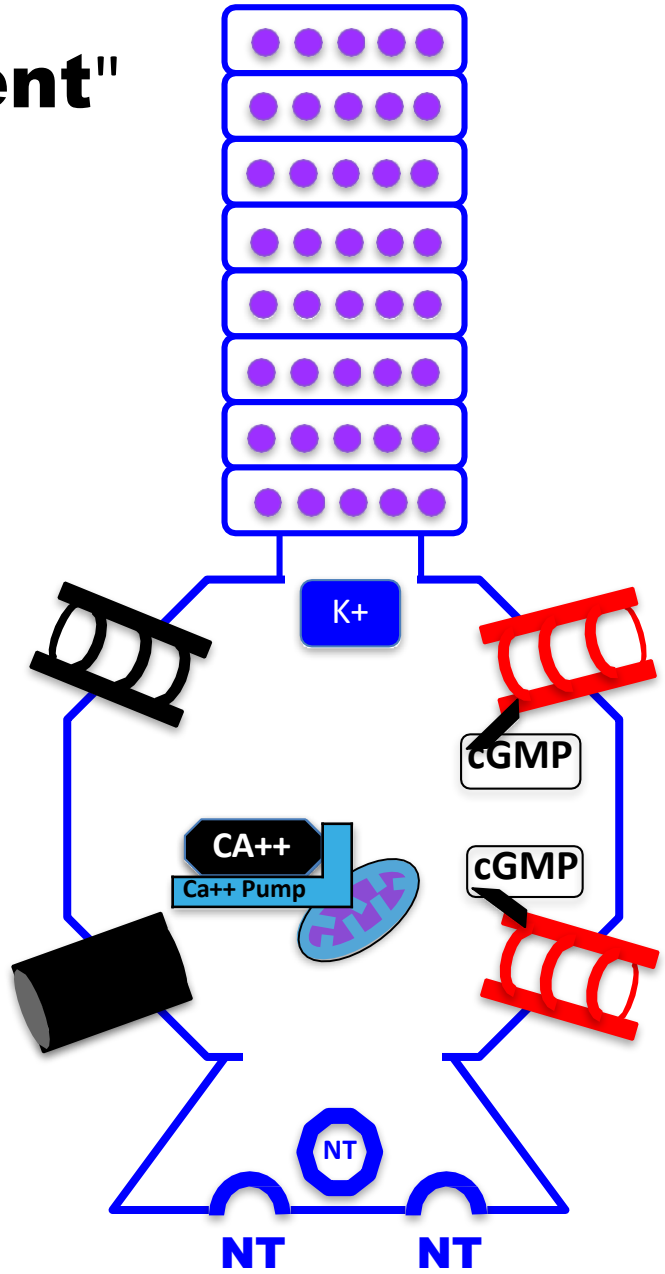


As positive charges accumulate in cell, **Na+** exits, via Electrostatic Pressure

.

Slide from Dr. Christine Johnson

The "**Dark Current**"



Ca++ Pump
ejects Ca++
(requires energy)

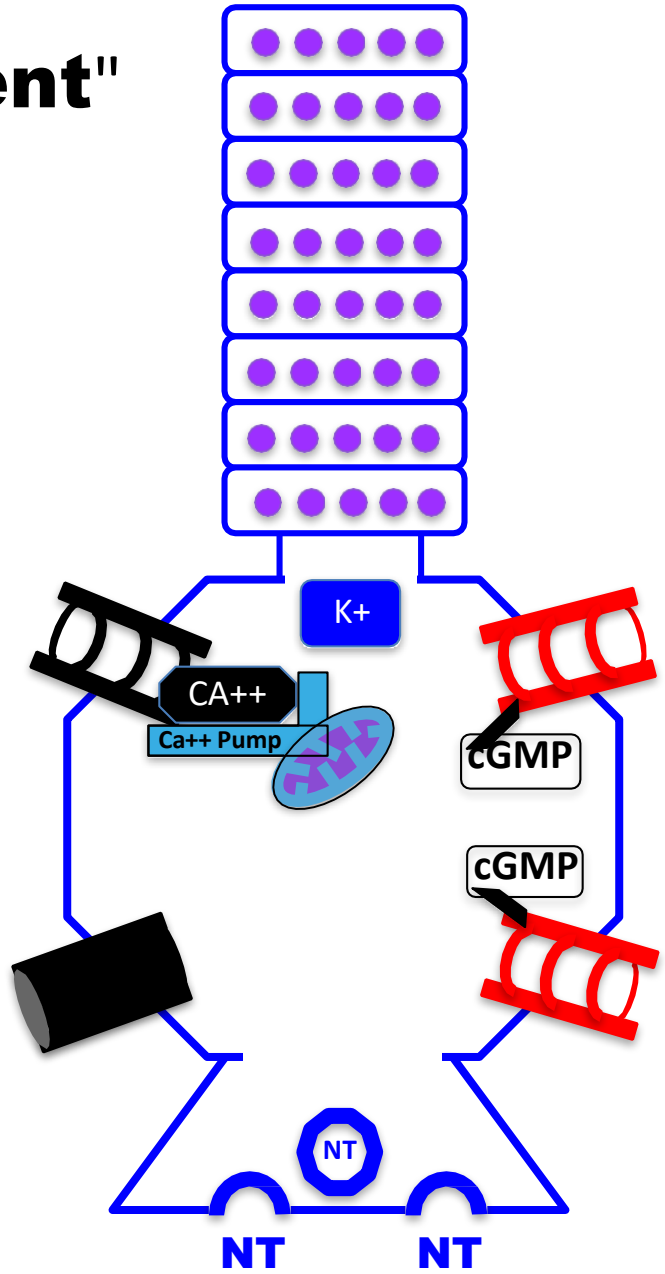
As positive charges
accumulate in cell,
Na+ exits,
via Electrostatic Pressure
.

Na+

Na+

Slide from Dr. Christine Johnson

The "**Dark Current**"



Ca++ Pump
ejects Ca++
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As positive charges
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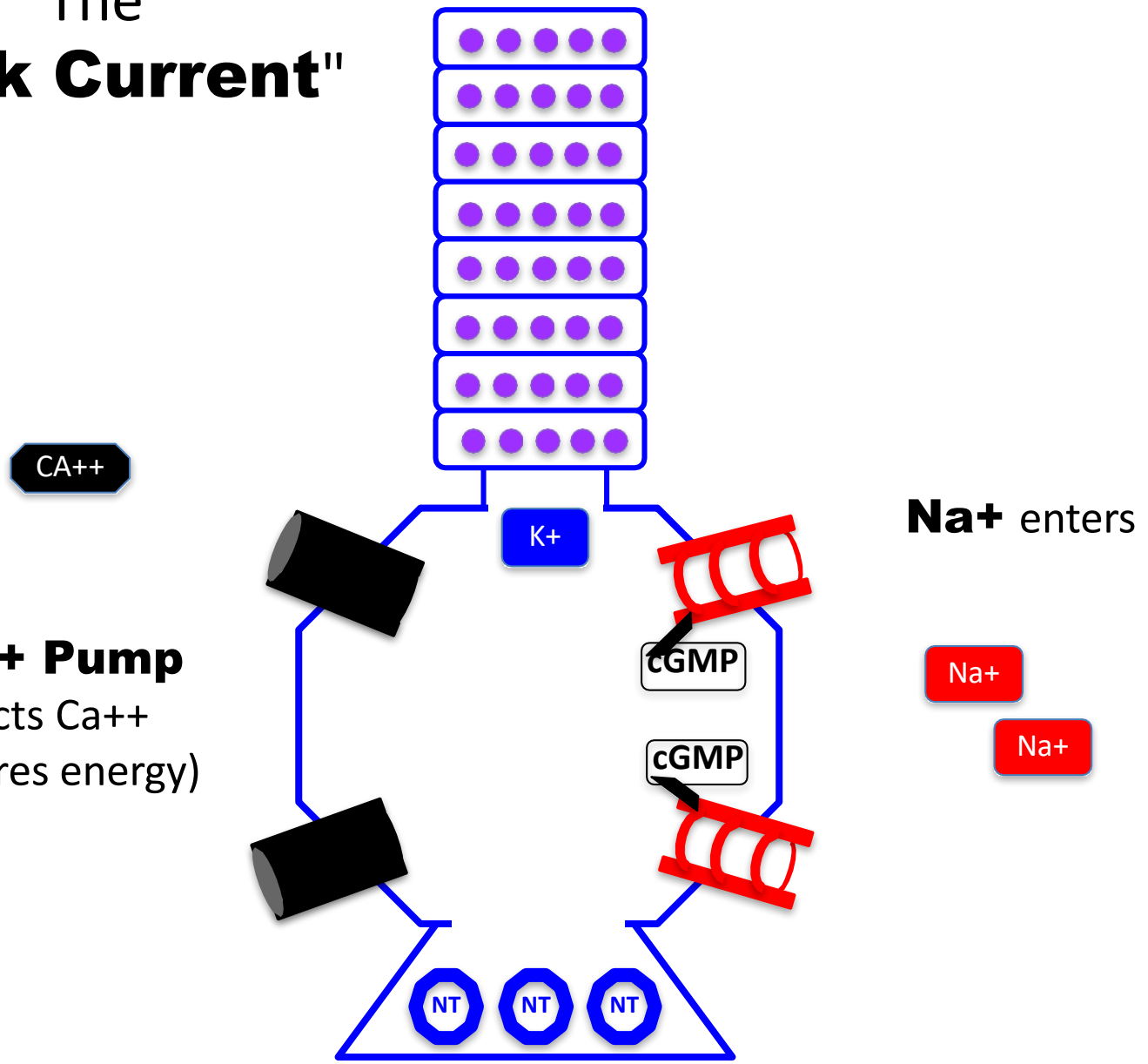
Na+

Na+

Slide from Dr. Christine Johnson

The "**Dark Current**"



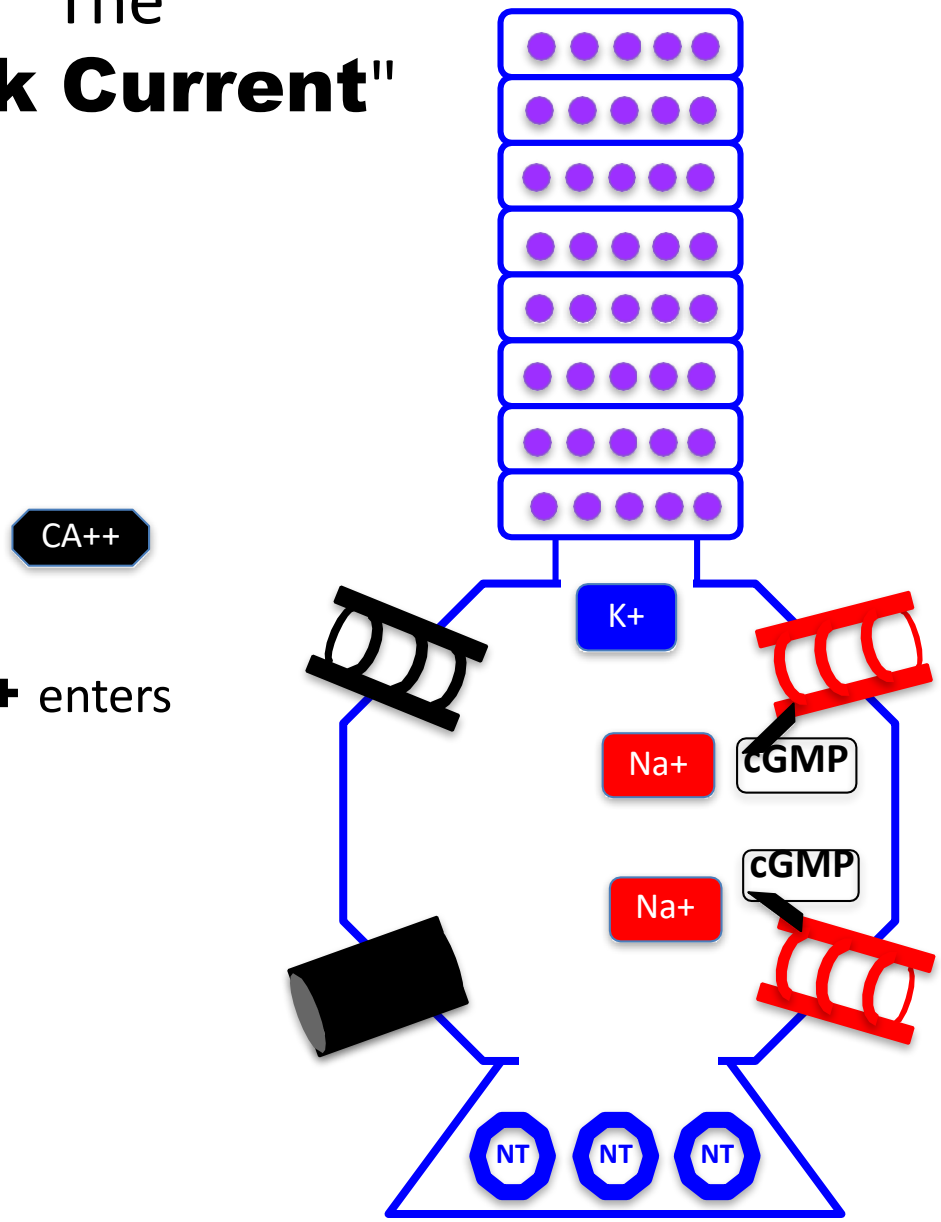
Ca++ Pump
ejects Ca++
(requires energy)

Na+ enters

Ejection of **Ca++** should end **NT** release, <u>but</u> whole cycle begins again . . .

Slide from Dr. Christine Johnson

The "**Dark Current**"



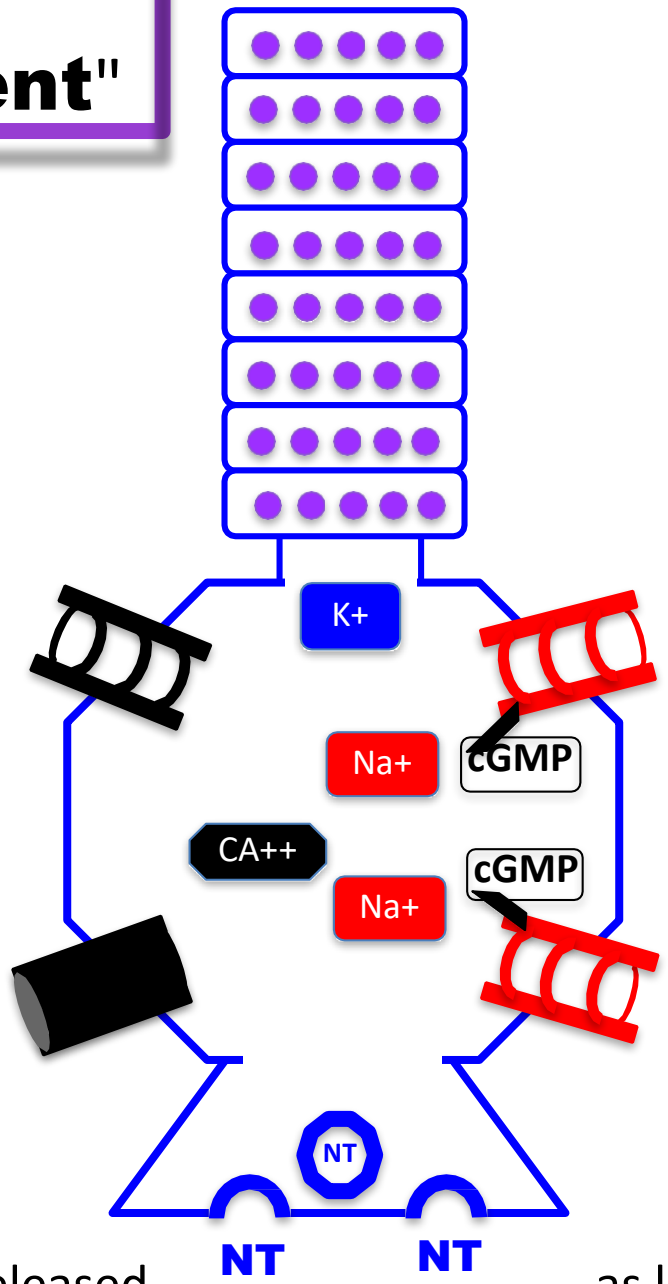
Ca++ enters

Na+ enters

Ejection of **Ca++** should end **NT** release, <u>but</u> whole cycle begins again . . .

Slide from Dr. Christine Johnson

The "**Dark Current**"



Ca++ enters

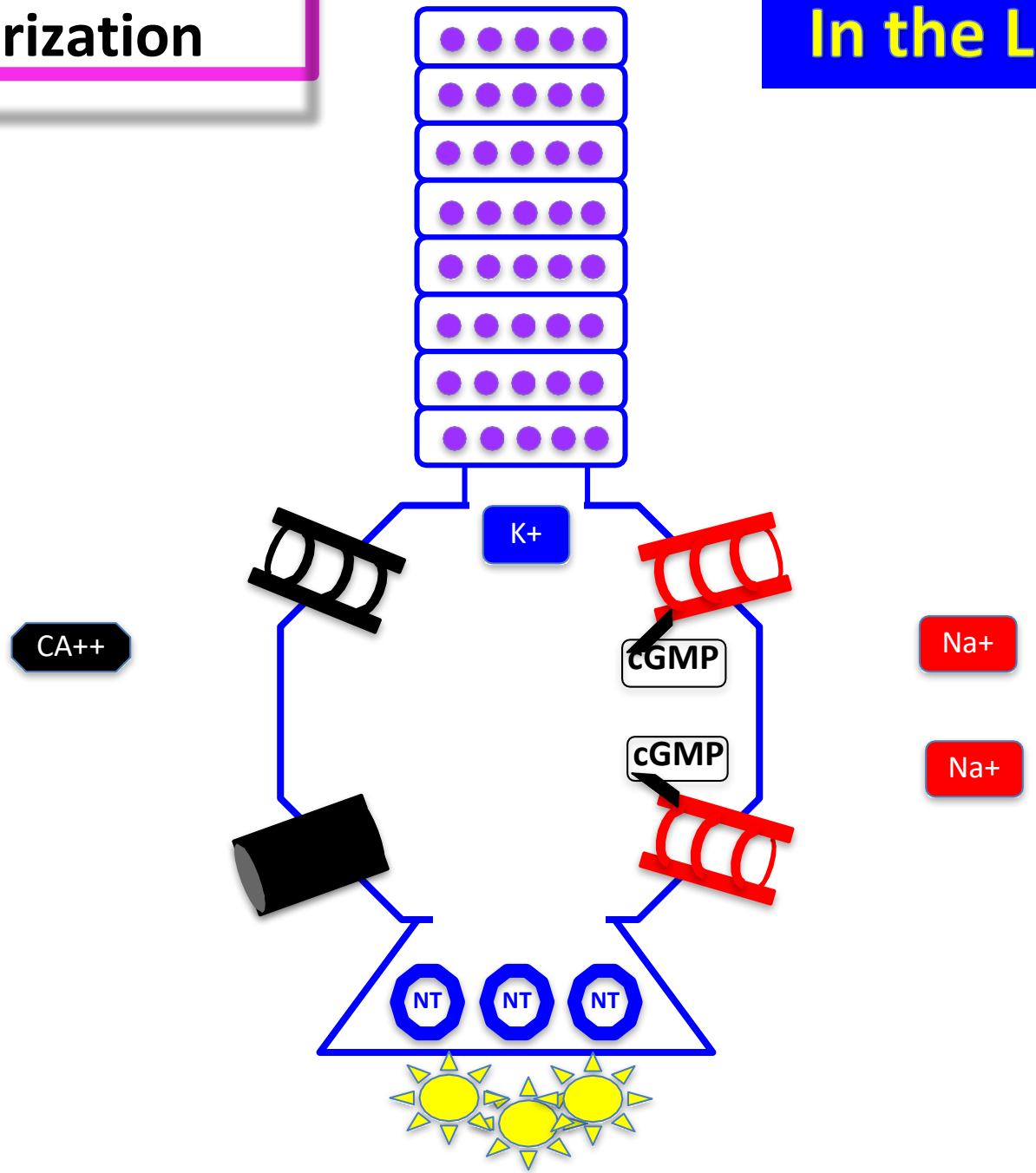
Na+ enters

NT is repeatedly released...

... as long as there is no light.

Isomerization

In the Light

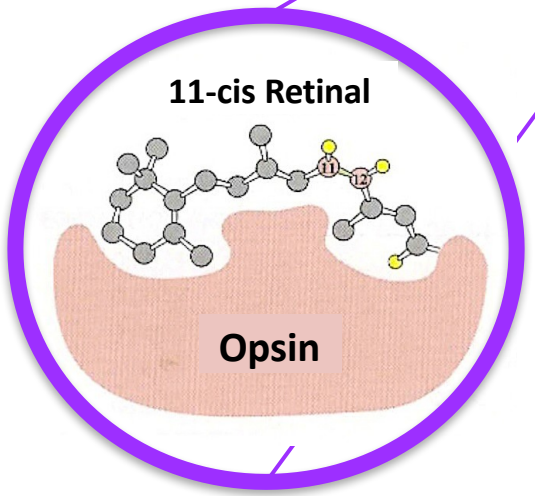


Slide from Dr. Christine Johnson

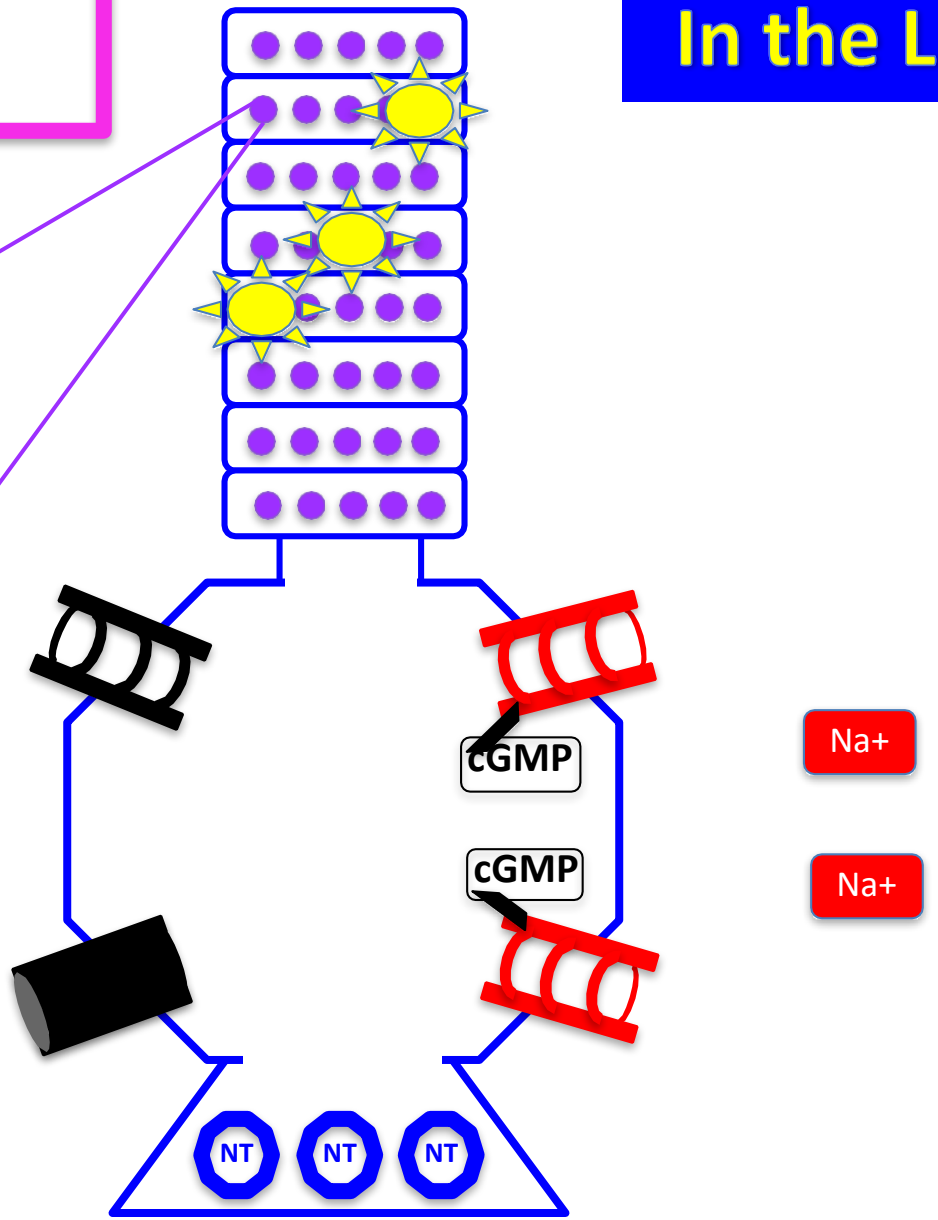
Isomerization

In the Light

A molecule of photo-pigment



"Visual Purple" . . .



Na+

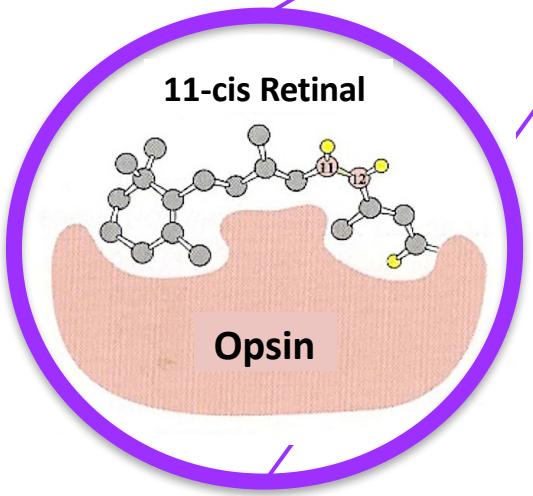
Na+

Slide from Dr. Christine Johnson

Isomerization

In the Light

A molecule of photo-pigment



"Visual Purple" . . .

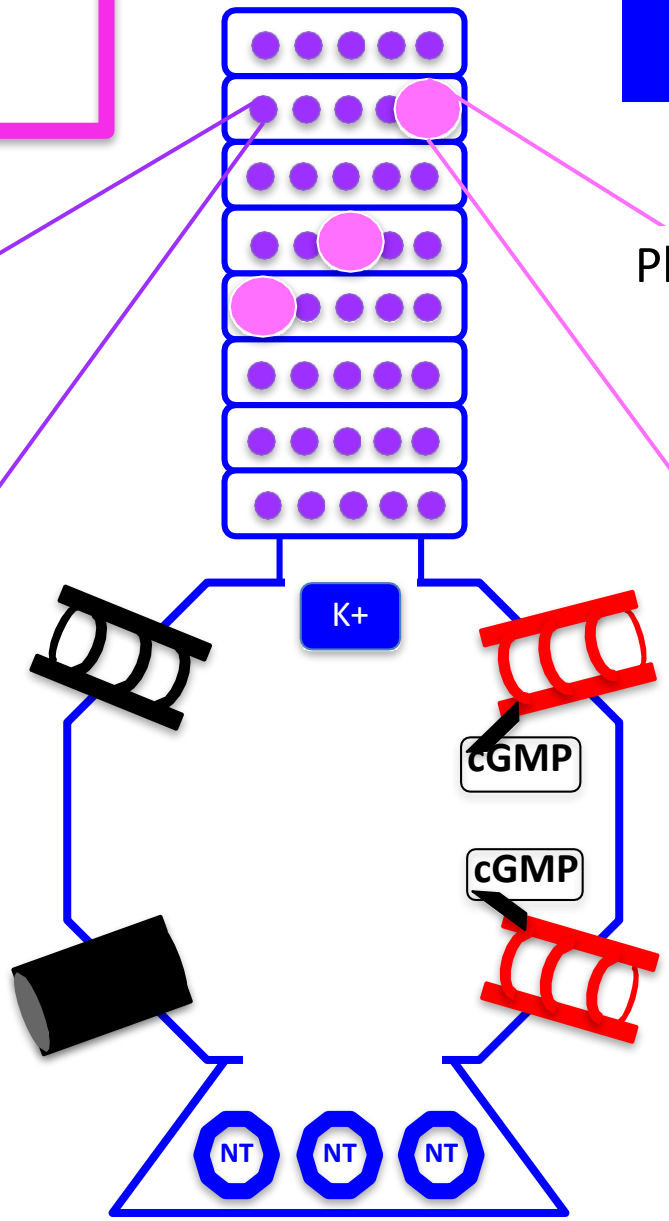
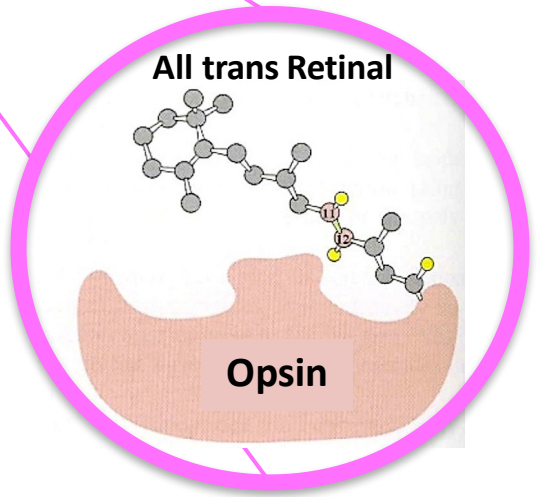


Photo-pigment absorbs light, gets "Bleached"

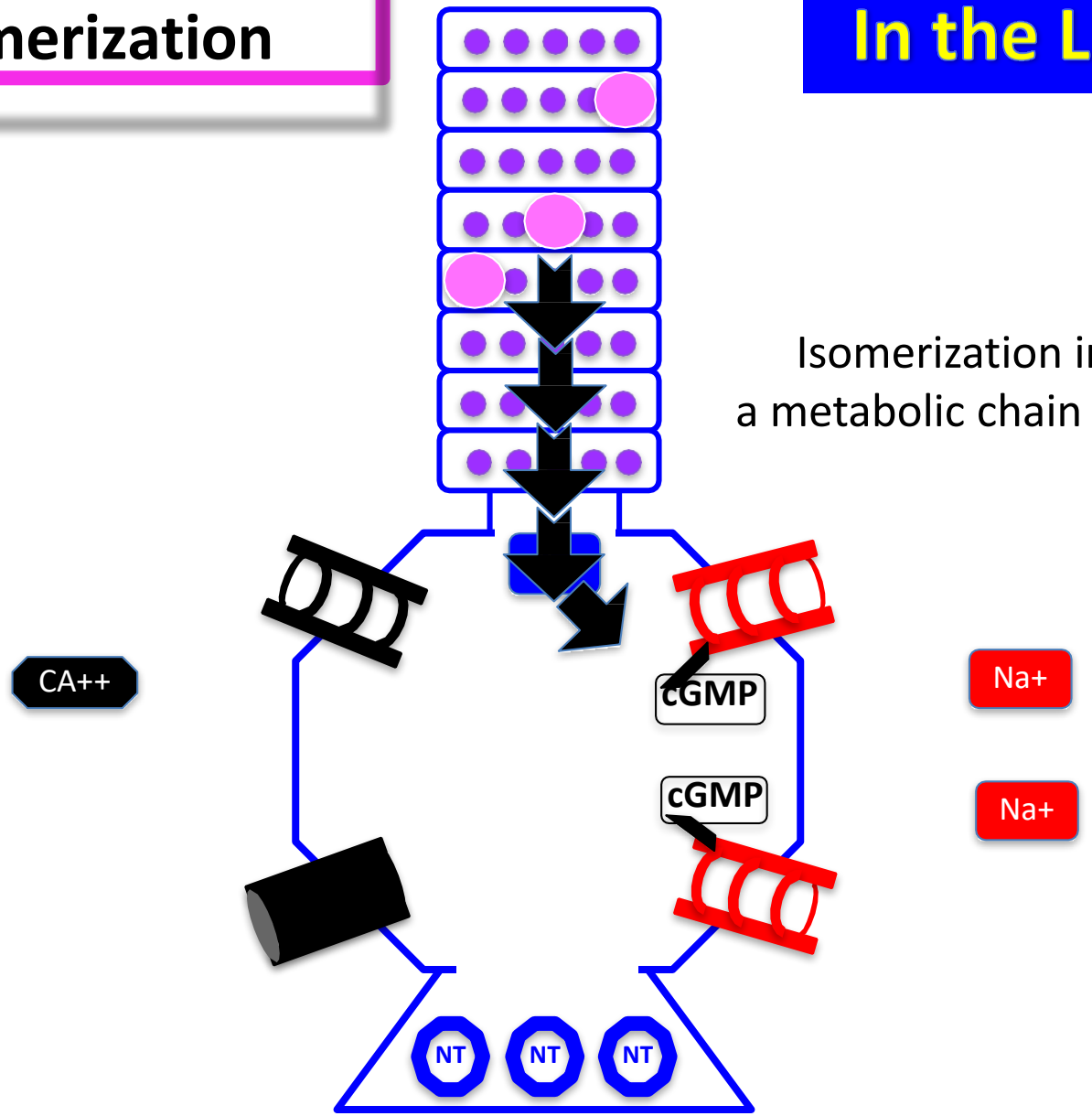


. . . turns pink

Slide from Dr. Christine Johnson

Isomerization

In the Light

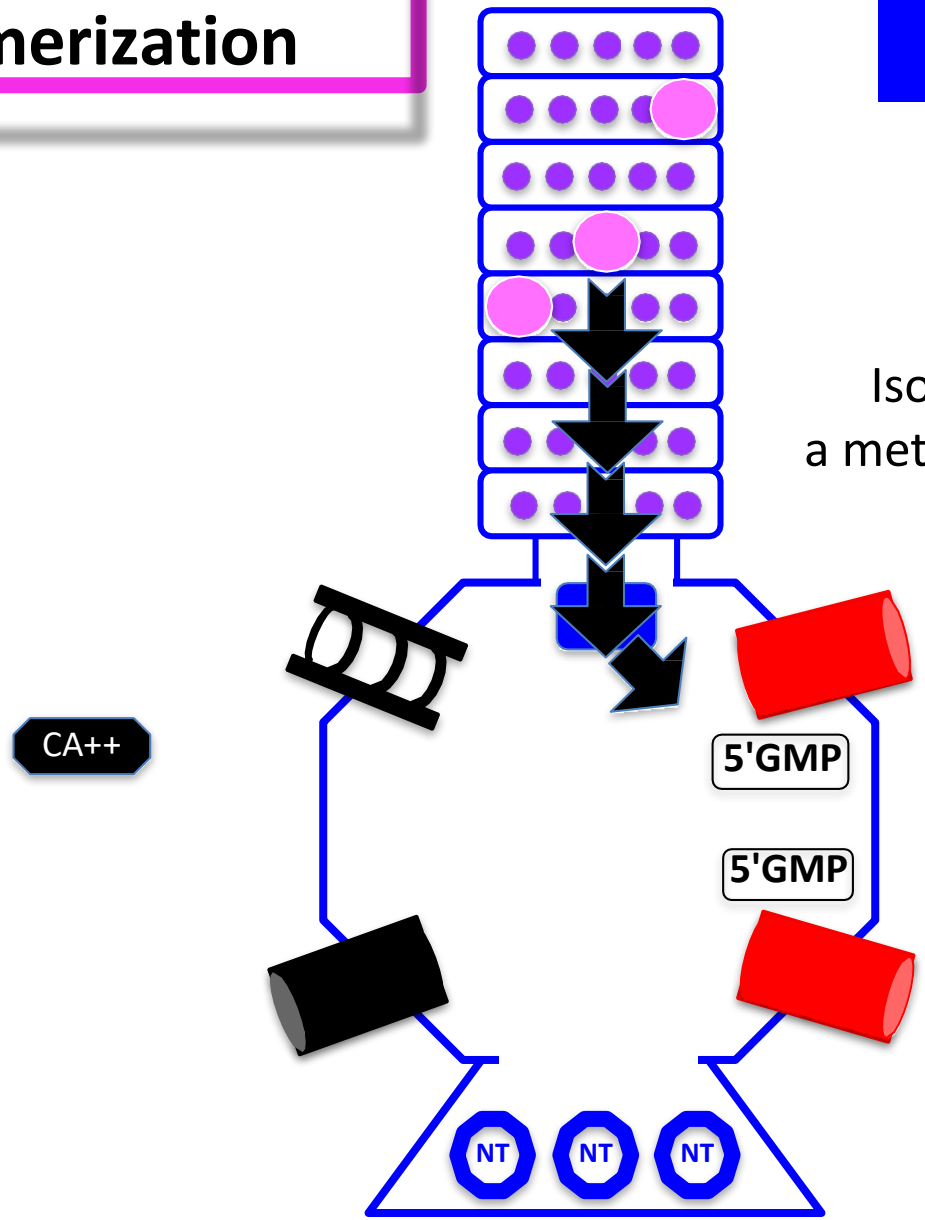


Isomerization initiates
a metabolic chain reaction...

Slide from Dr. Christine Johnson

Isomerization

In the Light



Isomerization initiates
a metabolic chain reaction...

Na+

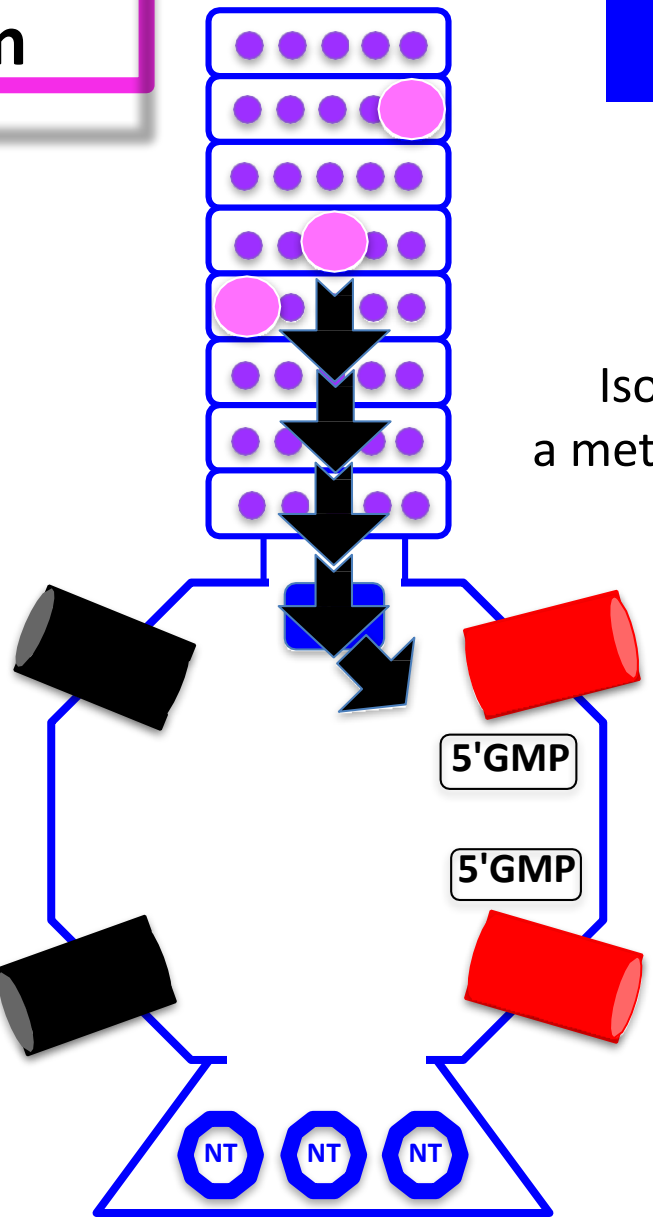
Na+

...that changes cGMP
into 5'GMP,
which will not hold
Na+ gates open.

Slide from Dr. Christine Johnson

Isomerization

In the Light



Isomerization initiates
a metabolic chain reaction...

With no influx of Na+,
Ca++ gates remain shut.

CA++

Na+

Na+

...that changes cGMP
into 5'GMP,
which will not hold
Na+ gates open.

So, in the Light,
the "Dark Current"
is shut down

No NT is released

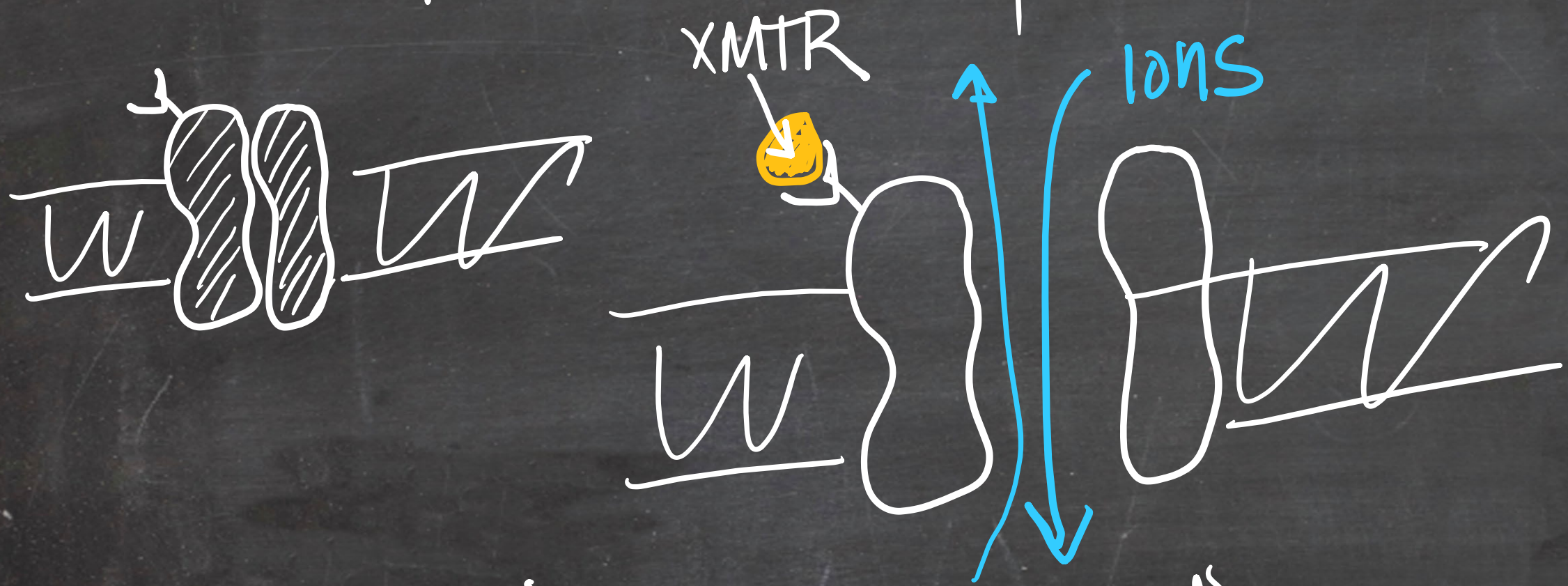
Slide from Dr. Christine Johnson

Recall — Receptors mediate signaling

Categories of cellular receptors

1

channel-linked receptor



(ionotrophic - ligand gated)

② G-PROTEIN-COUPLED RECEPTORS

- regulate intracellular reactions using G-proteins

(metabotropic receptors)

many G-protein-linked receptors

eg β-adrenergic receptor

muscarinic (ACh) receptor

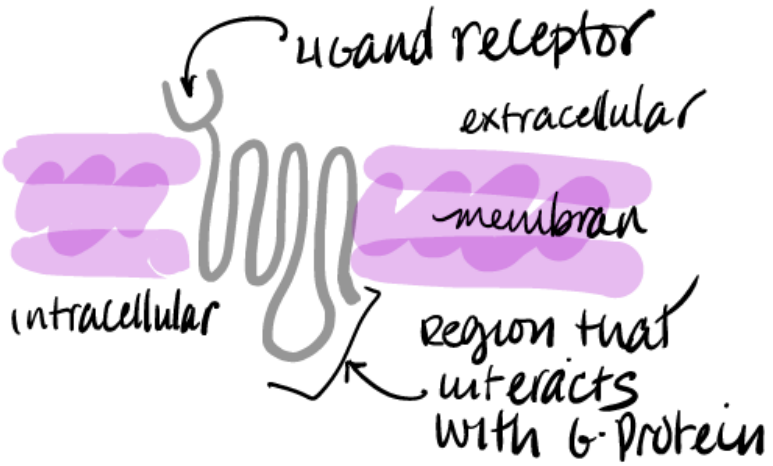
metabotropic glutamate receptor

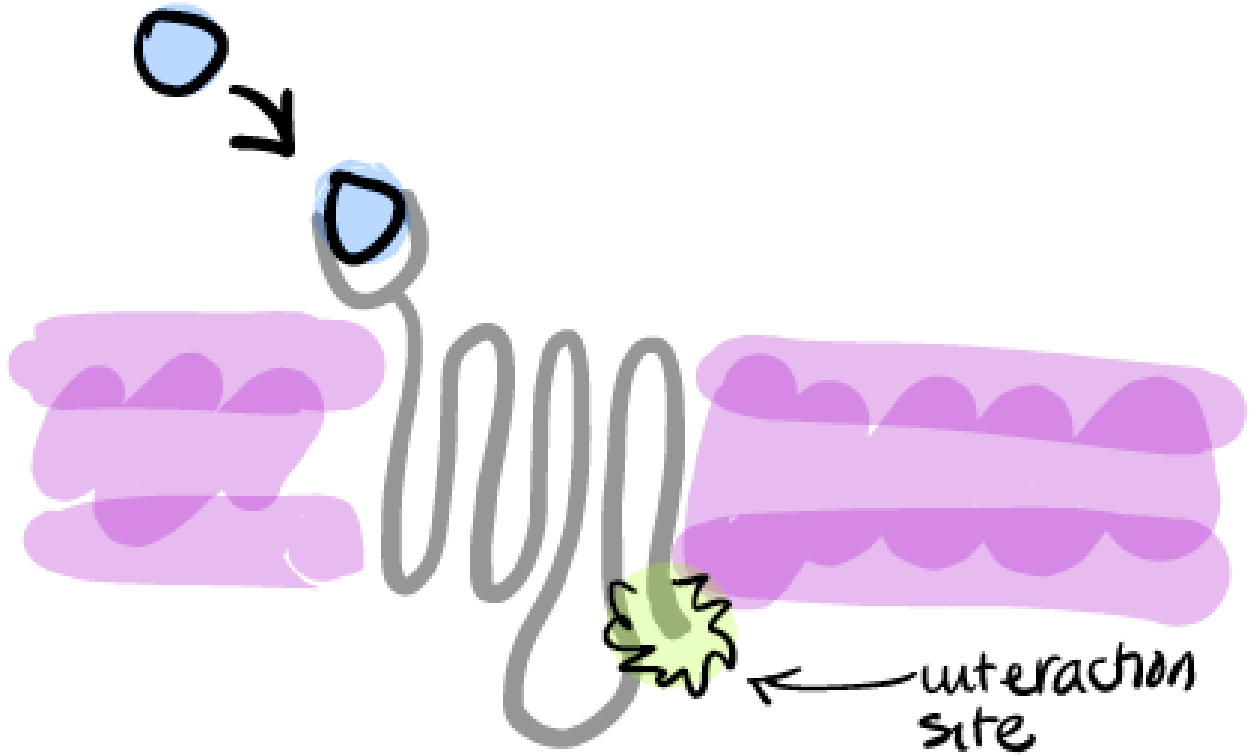
...

Rhodopsin is another G-protein coupled/linked receptor

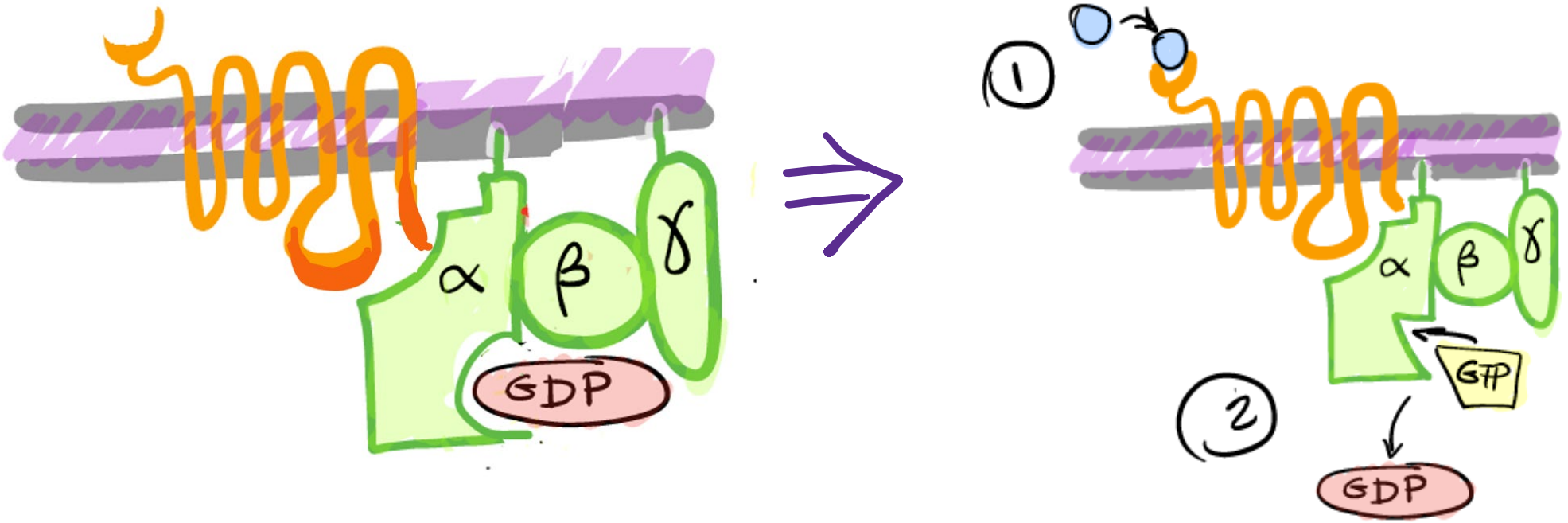
G-Protein coupled receptors

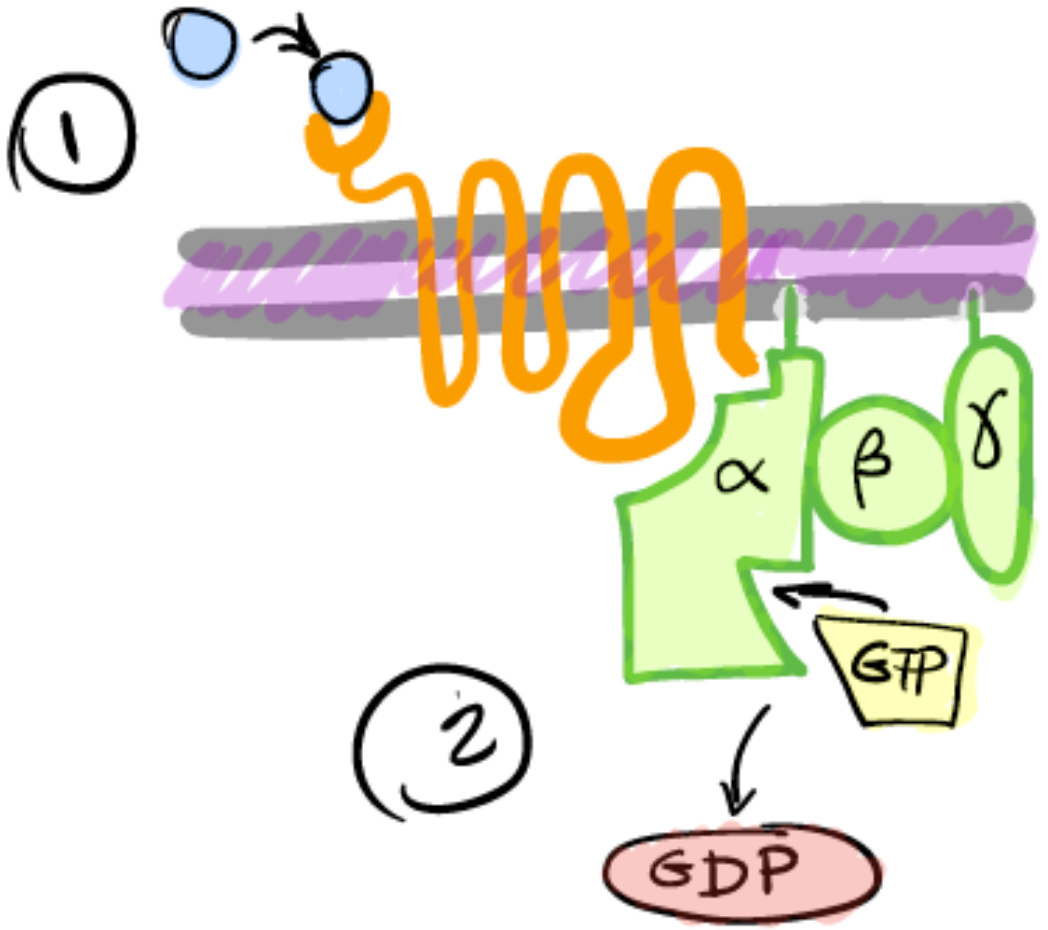
G-Protein coupled receptors





inactive state

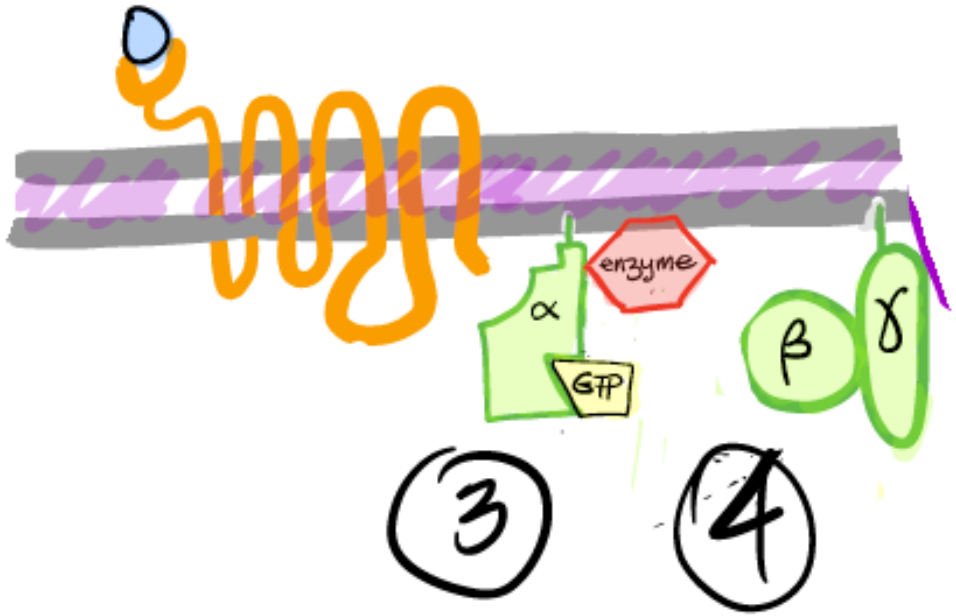




① when ligand is bound to the receptor the

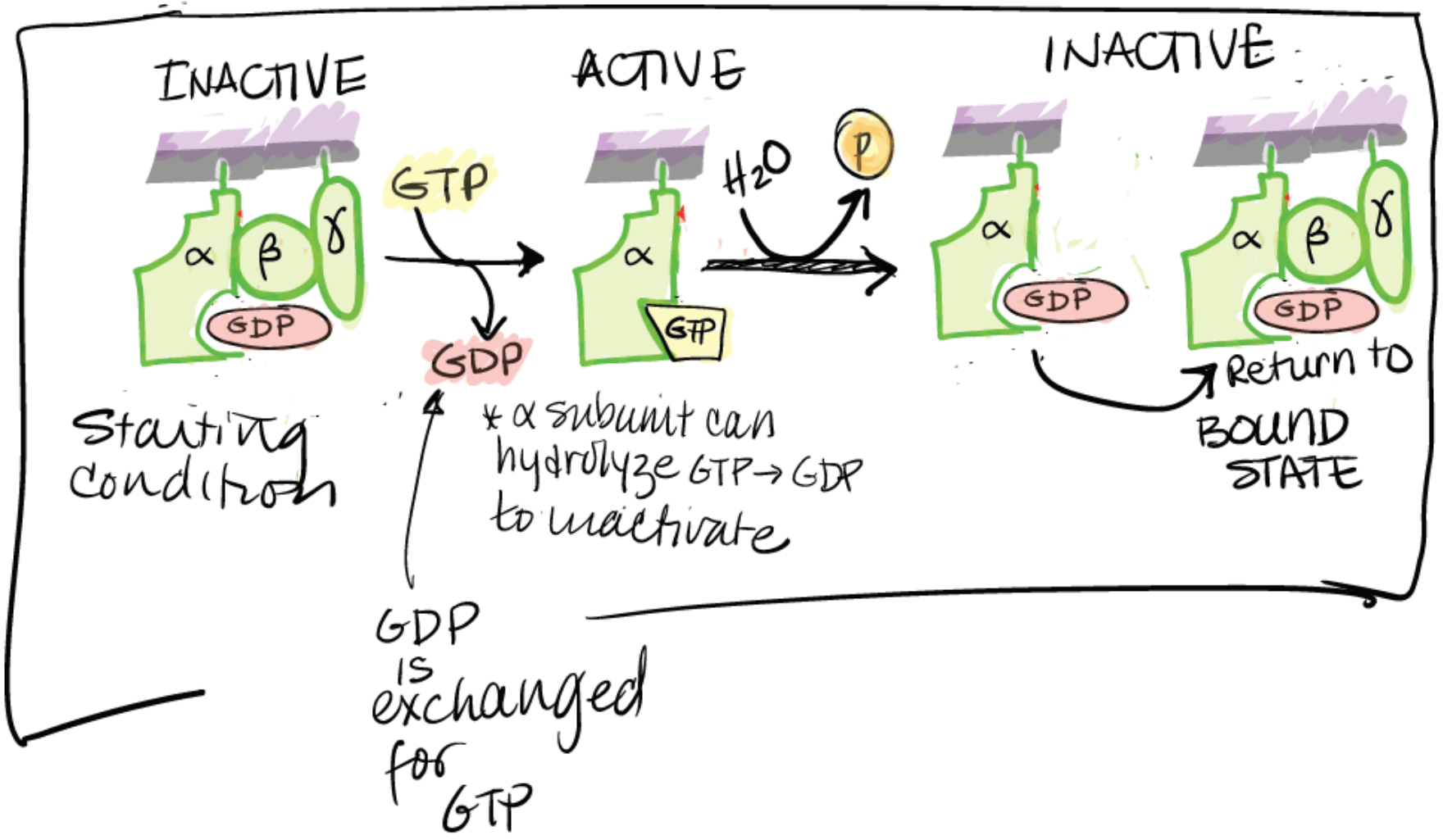
② cytosolic tail interacts & changes the conformation of a G-protein

↳ The α-subunit loses the GDP & binds GTP instead



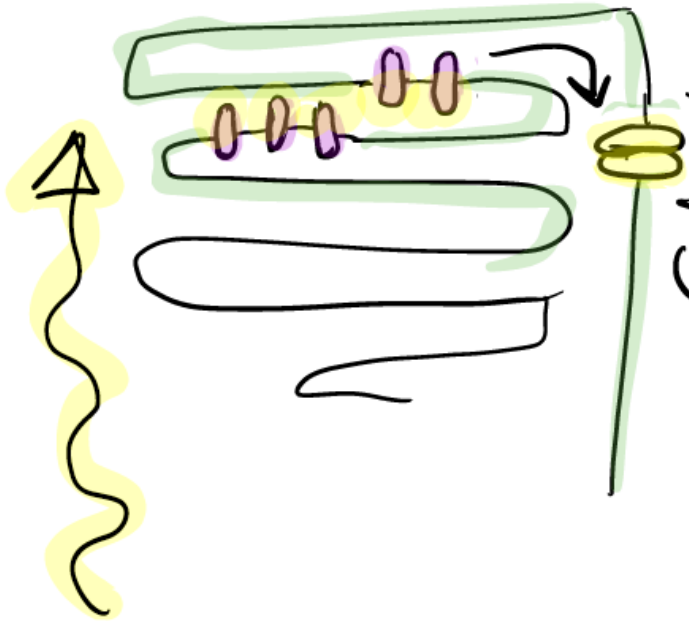
④ The two components can then act on other targets. → open ion chan. & /or regulate enz. acty.

③ G-protein breaks up into α-GTP & β γ parts


INACTIVE
ACTIVE
INACTIVE
GTP
GDP
H_2O
P
α
β
γ
GDP
GTP
GDP
GDP
Starting condition
* α subunit can hydrolyze GTP → GDP to inactivate
Return to BOUND STATE
GDP is exchanged for GTP

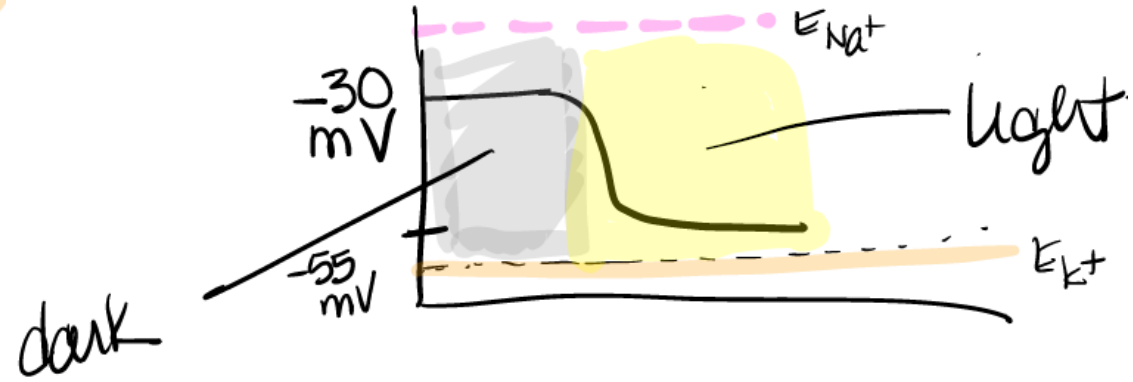
When there is light

(2)



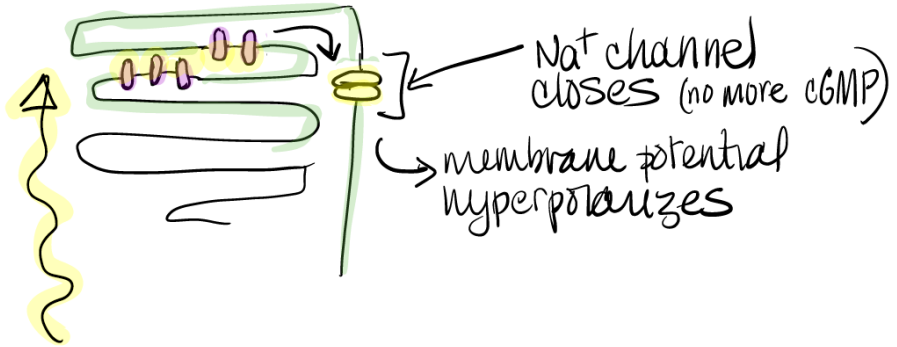
Na^+ channel closes (no more cGMP)

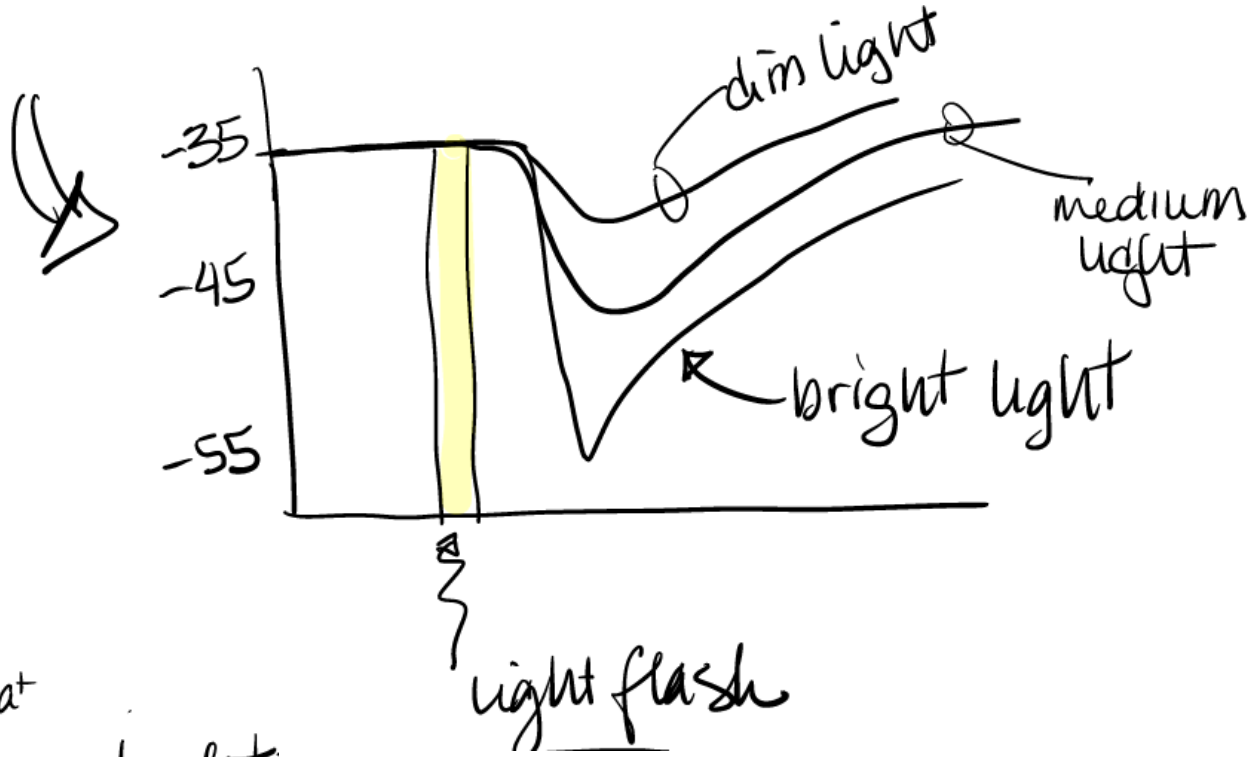
→ membrane potential hyperpolarizes

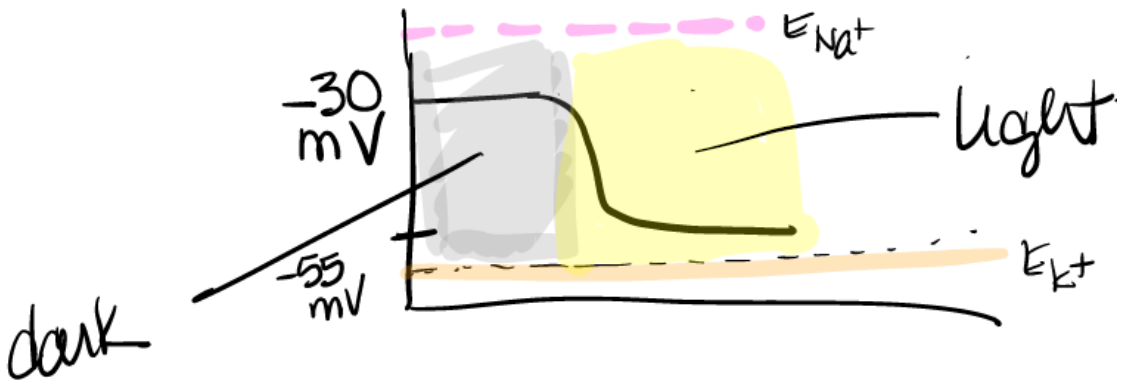


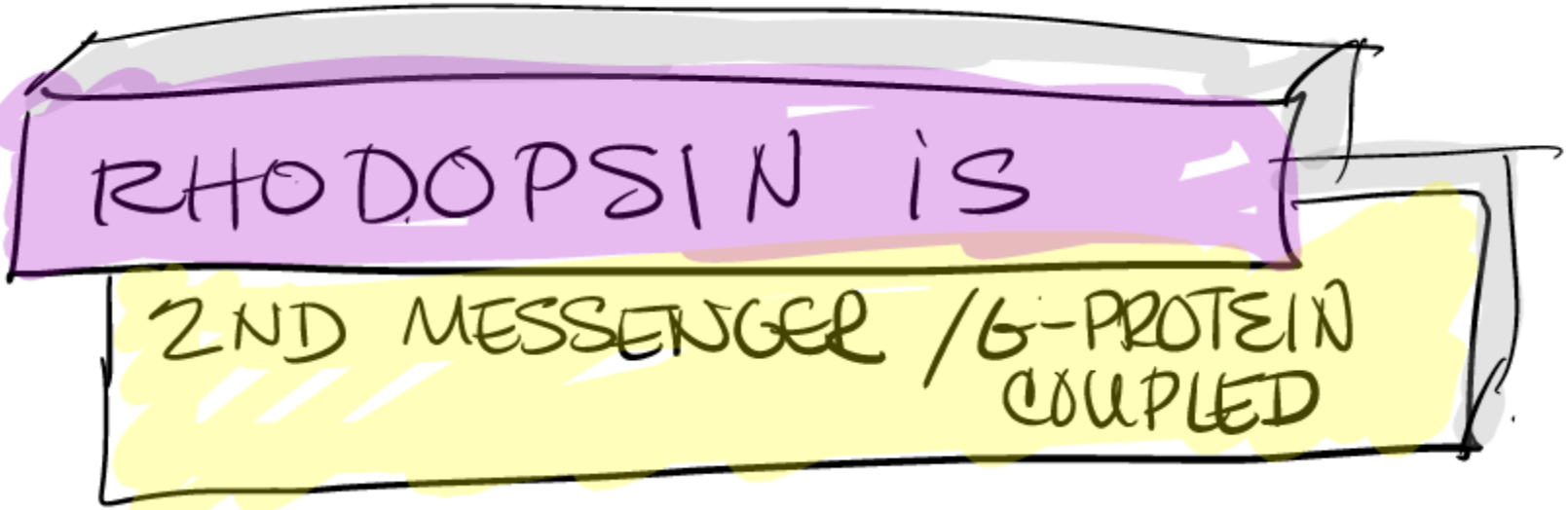
When there is light

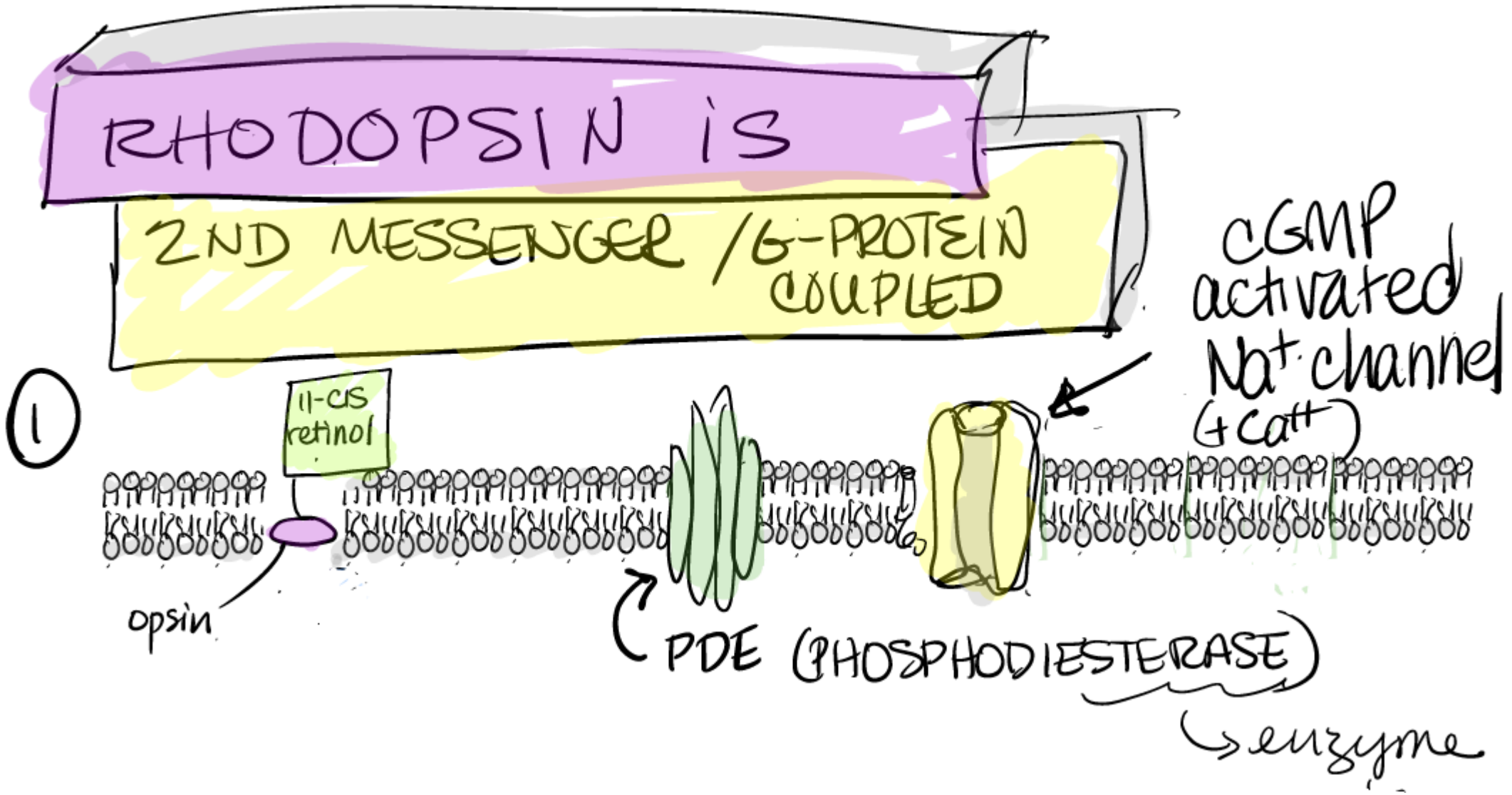
(2)

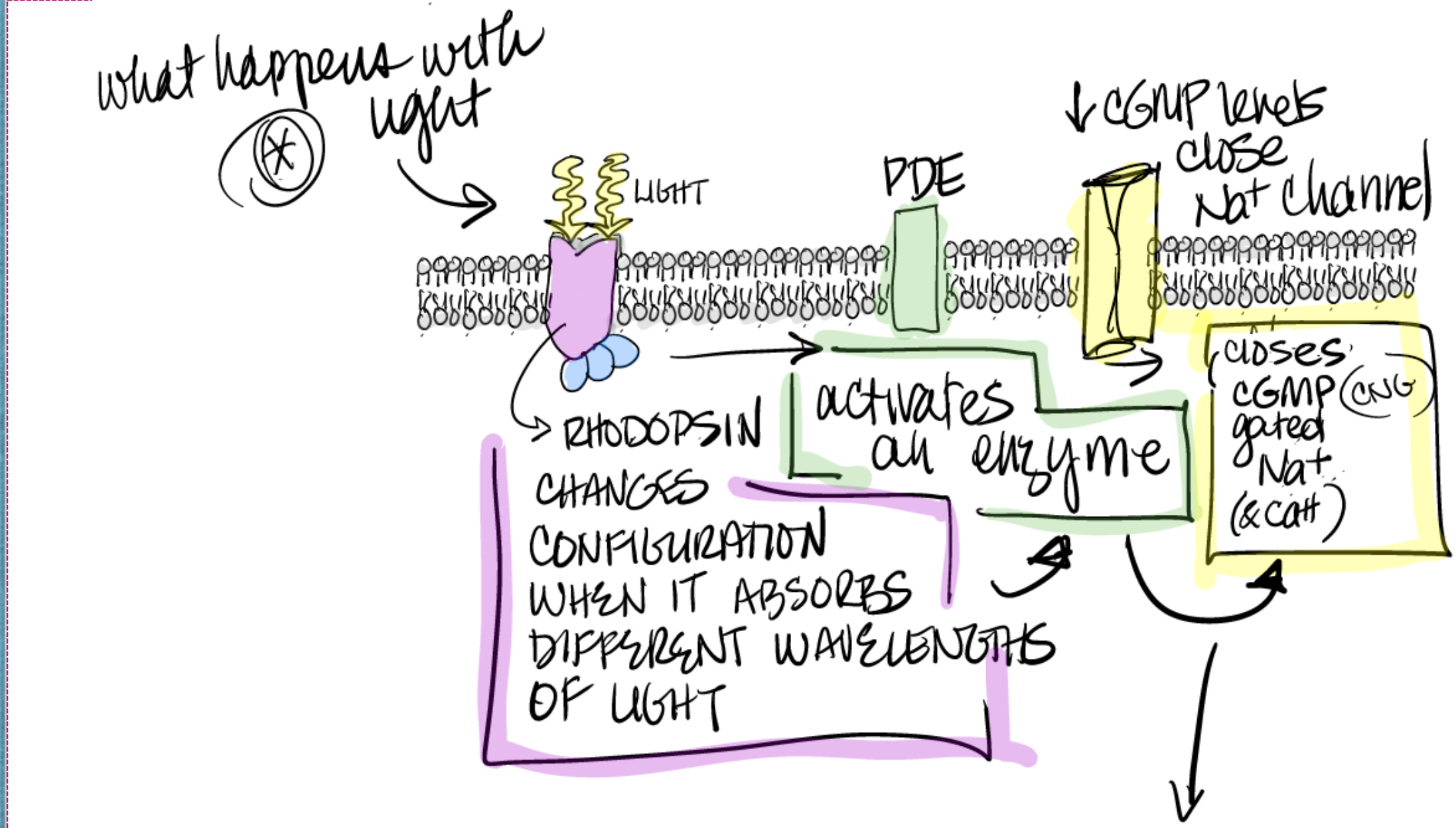


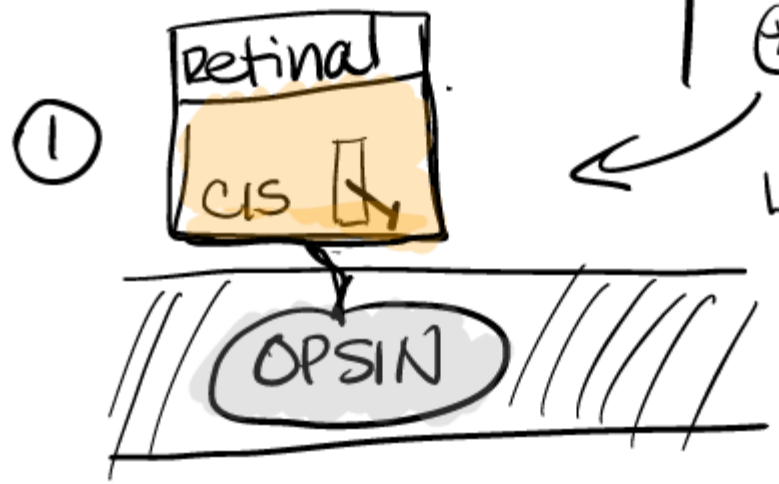





RHODOPSIN IS
2ND MESSENGER /G-PROTEIN
COUPLED

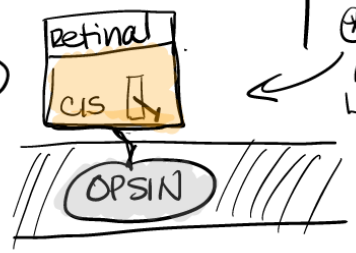

RHODOPSIN IS
2ND MESSENGER /G-PROTEIN COUPLED
cGMP activated Na+ channel
(+ Ca++)
1
11-cis retinol
opsin
PDE (PHOSPHODIESTERASE)
↳ enzyme


what happens with light
LIGHT
PDE
↓ cGMP levels close Na+ channel
RHODOPSIN CHANGES CONFIGURATION WHEN IT ABSORBS DIFFERENT WAVELENGTHS OF LIGHT
activates an enzyme
closes cGMP (CNG) gated Na+ (& Ca++)



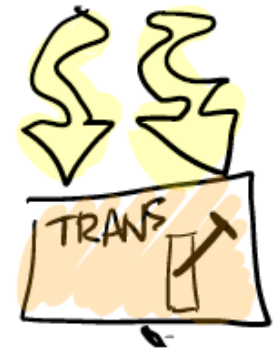
①

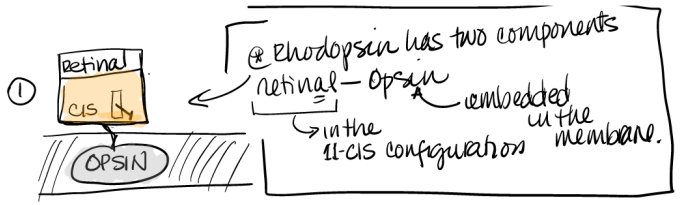
* Rhodopsin has two components
retinal – Opsin
retinal
↳ in the 11-cis configuration
embedded in the membrane.

① 

* Rhodopsin has two components
retinal – Opsin
retinal → in the 11-cis configuration
Opsin → embedded in the membrane.

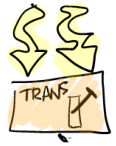
② When a photon of light hits the retinal, its conformation changes from CIS to TRANS

② 

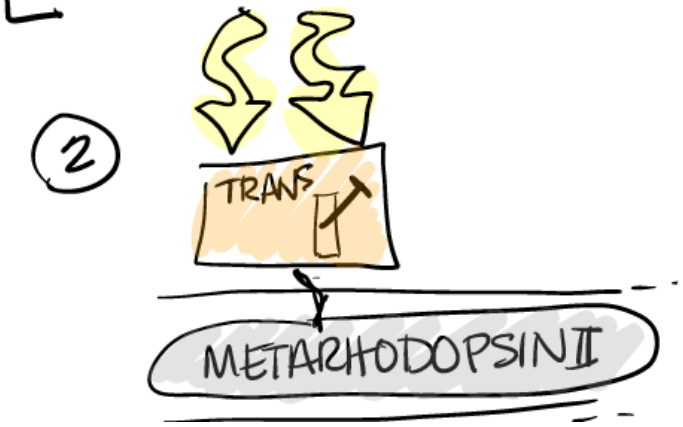


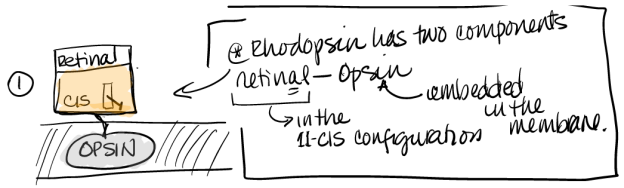
① * Rhodopsin has two components
retinal — Opsin (embedded in the membrane)
retinal = in the 11-cis configuration

② when a photon of light hits the retinal, its conformation changes from CIS to TRANS



② when a photon of light hits the retinal, its conformation changes from CIS to TRANS ⇒ when retinal is in the trans-state it activates opsin into metarhodopsin II

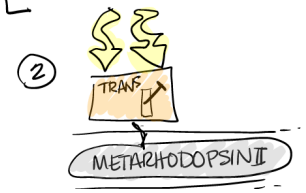




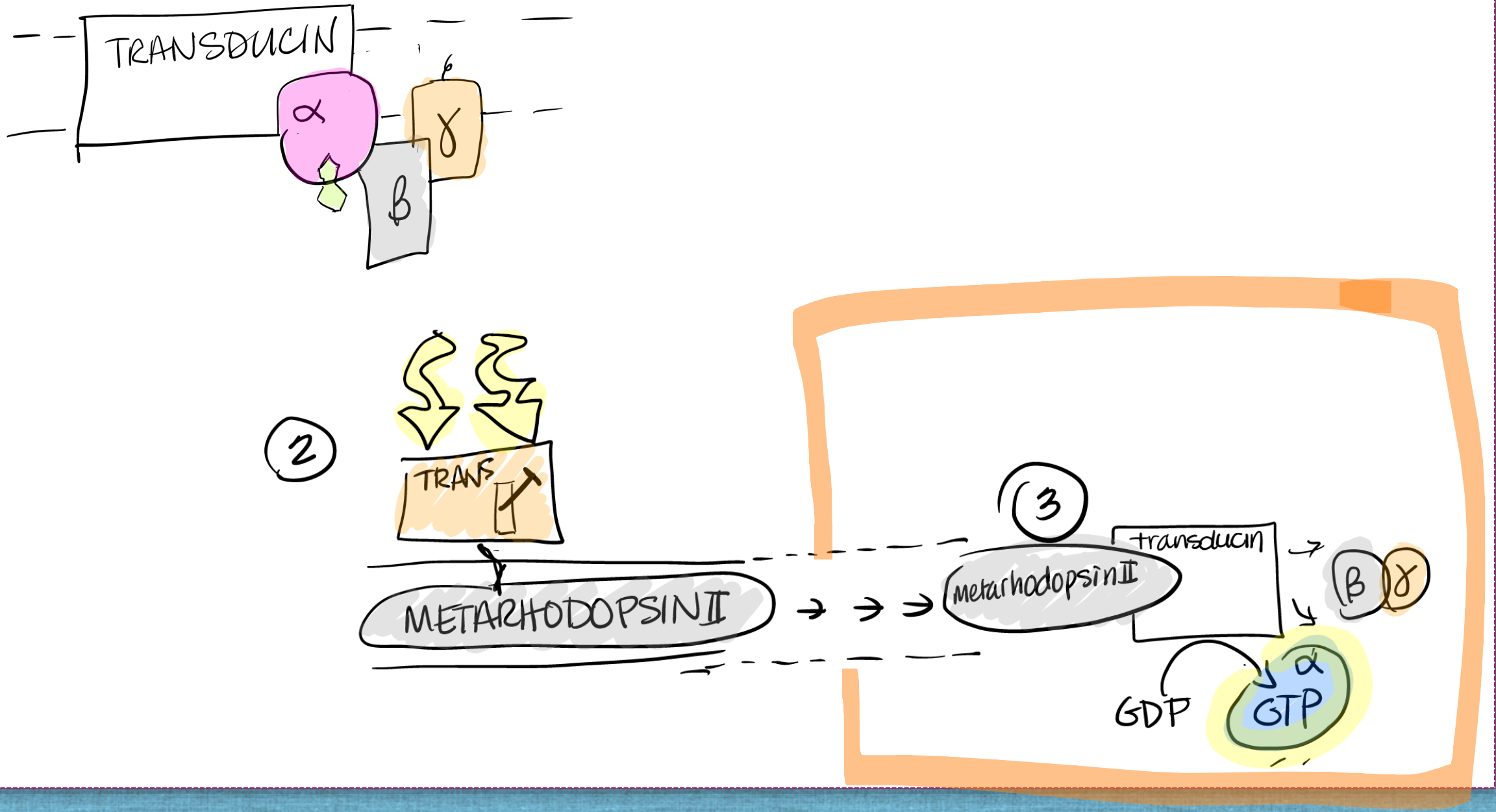
2

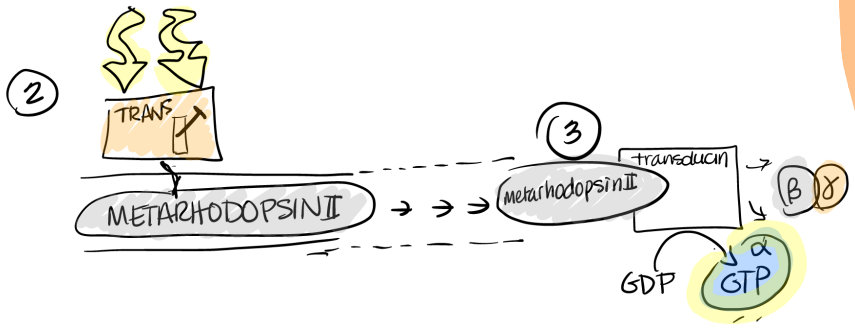
when a photon of light hits the retinal, its conformation changes from CIS to TRANS

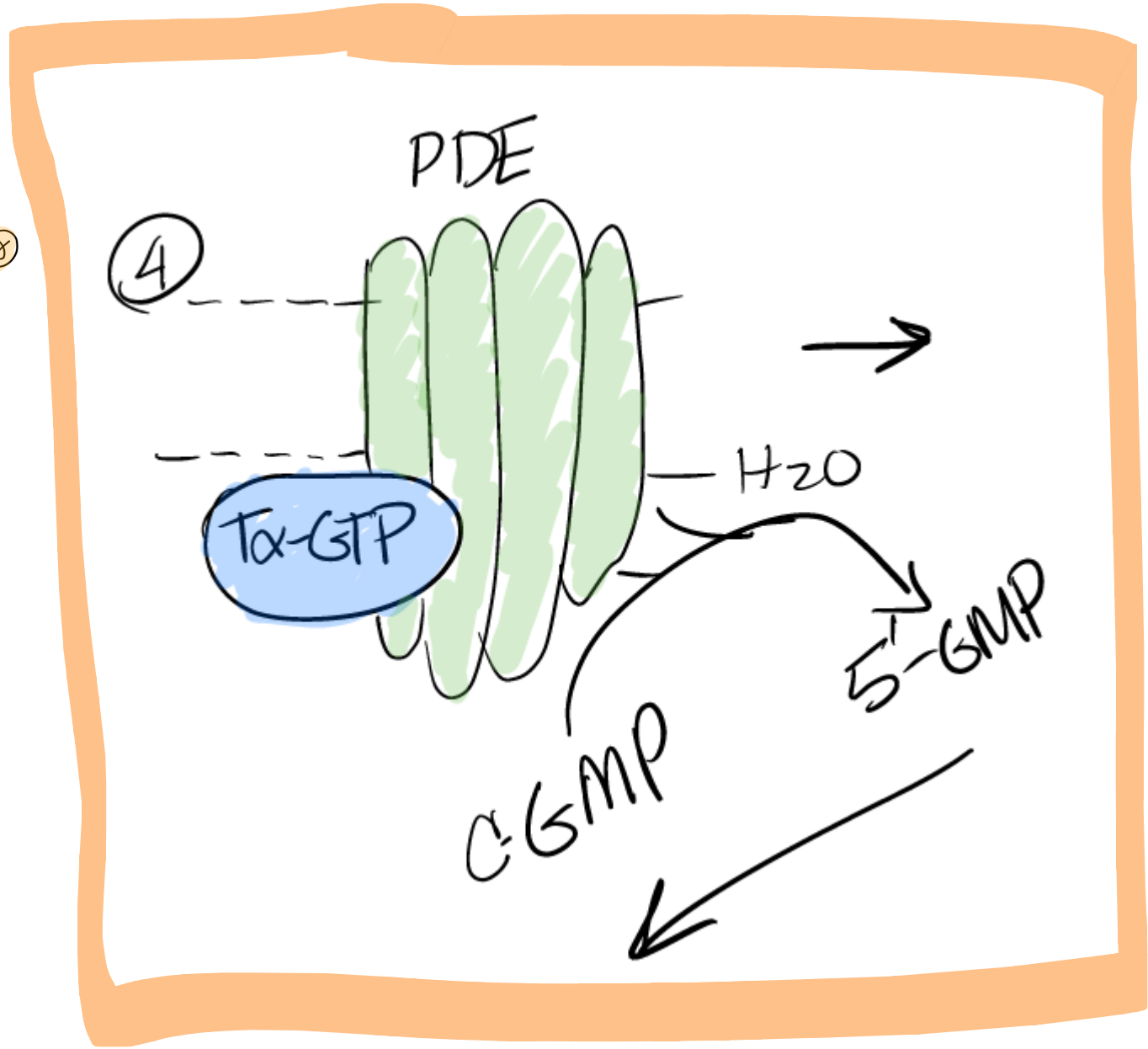
when retinal is in the trans-state it activates opsin into metarhodopsin II



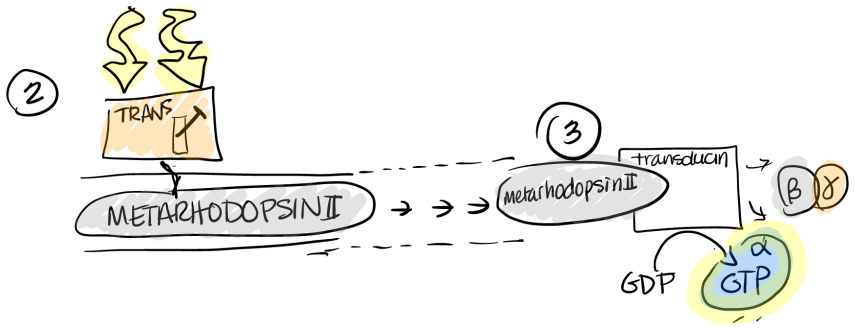
Metarhodopsin II diffuses in the membrane & associates with transducin

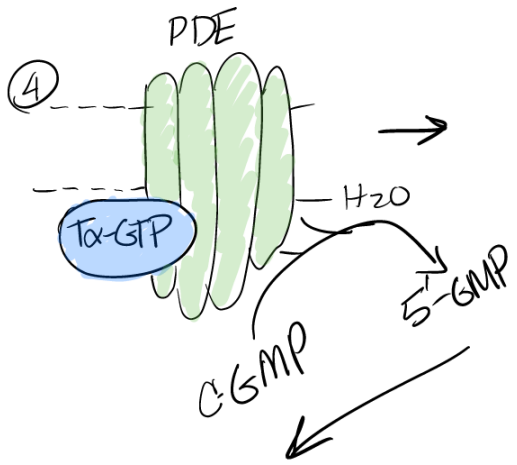

TRANSDUCIN
α
γ
β
2
TRANS
METARHODOPSIN II
3
metarhodopsin II
transducin
β
γ
α
GDP
GTP



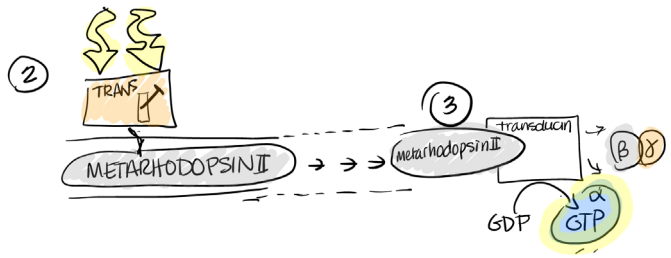


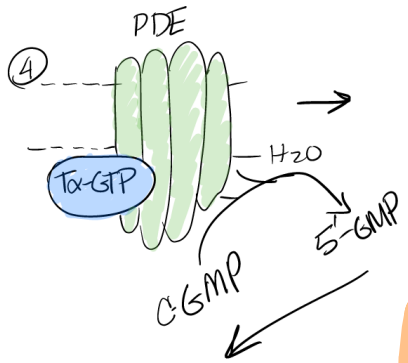
PDE (PHOSPHODIESTERASE)

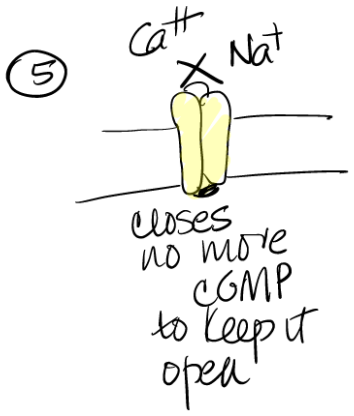




closes no more cGMP to keep it open





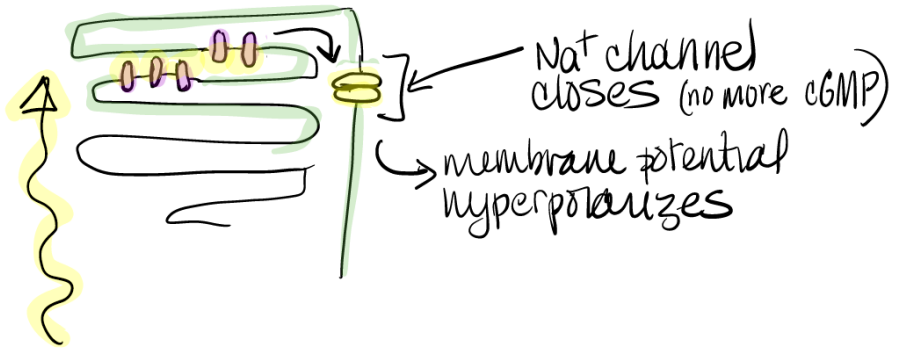


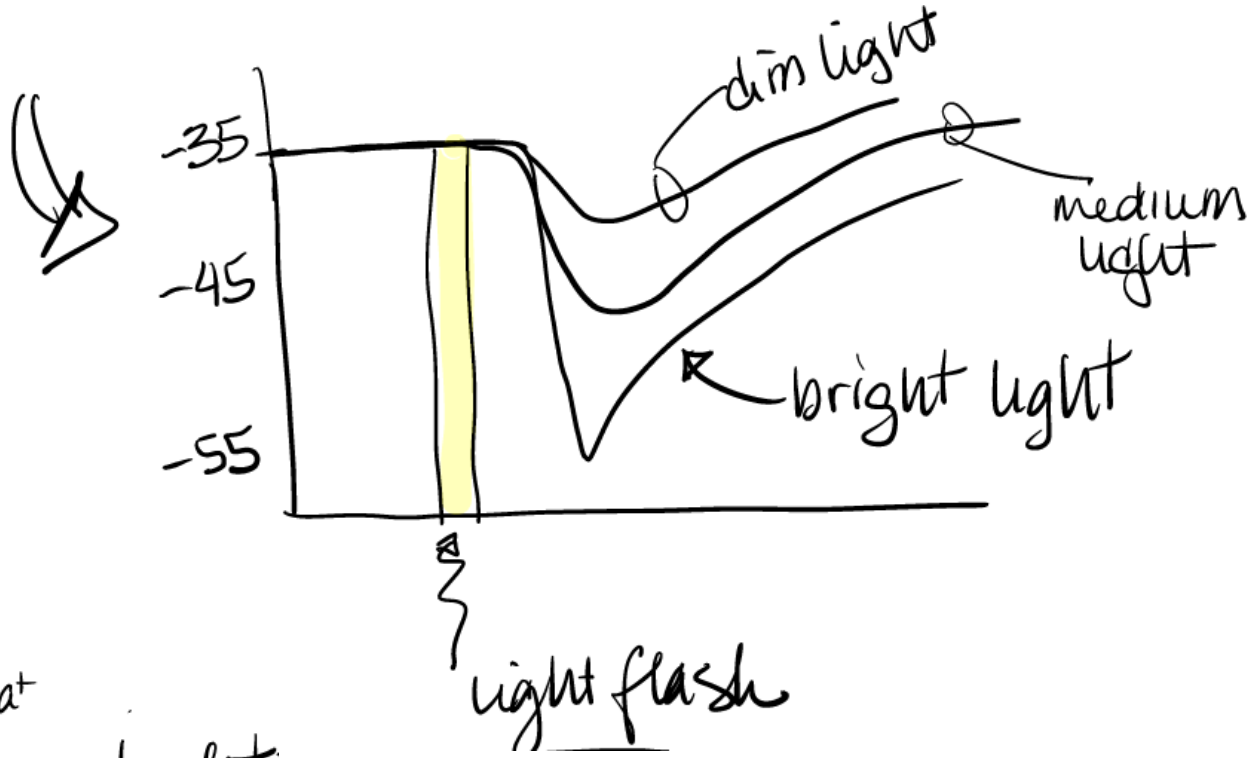
membrane potential hyperpol

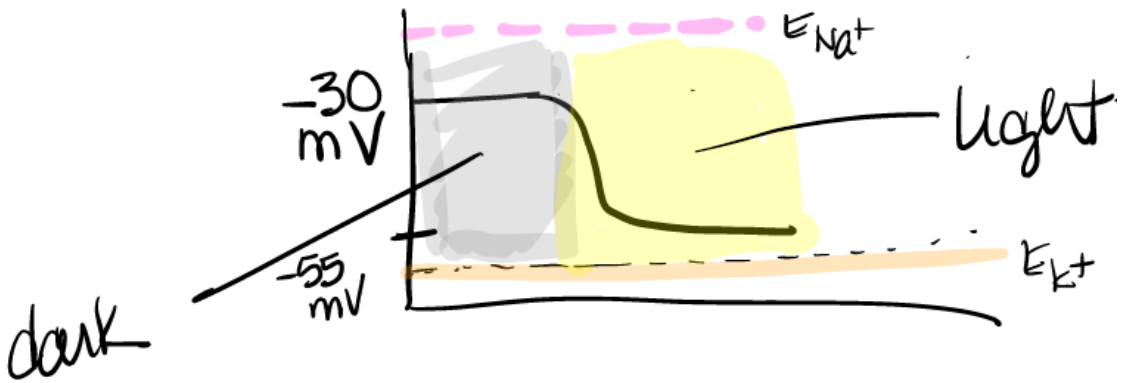
GRADED POTENTIAL:

When there is light

(2)

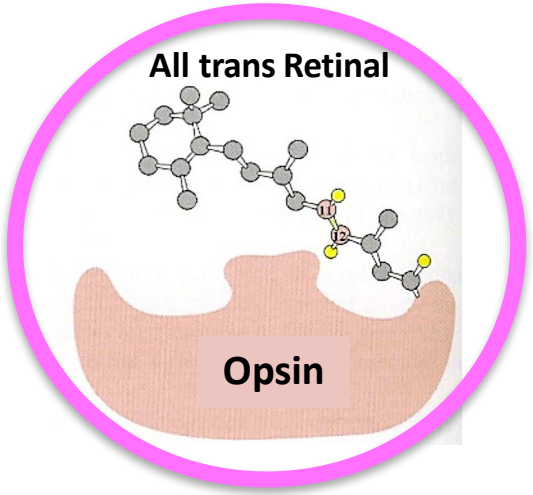




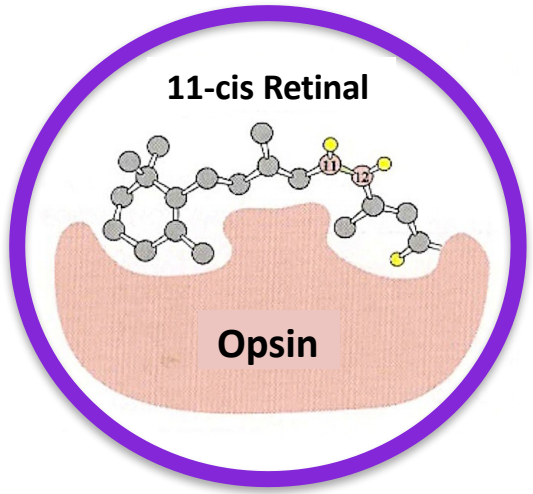


Isomerization & Re-Generation of Photo-Pigment

After a photon of light has Isomerized a molecule of photo-pigment...



...it will soon regenerate into its original form, so it is ready to respond to the next photon.

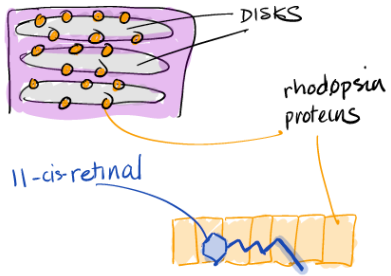


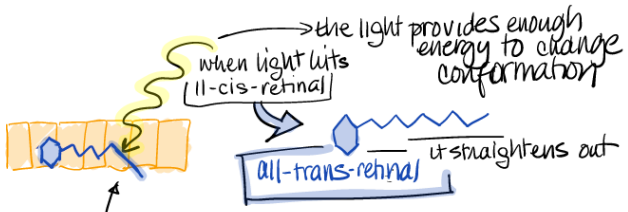
- We are "**Light Adapted**" when much of our photo-pigment has been isomerized
  - Come inside on a sunny day, at first the indoor light seems very dim
  - In the snowy arctic, so much bright light at once can temporarily BLIND you, if ALL your photopigment is isomerized at once
  - Eventually, you can see well again, because, in time, your photopigment will regenerate
- We are "**Dark Adapted**" after spending time in the dark
  - At first, when you turn out the light, you cannot see anything
  - But in time, as your photo-pigment regenerates, you can see faint shapes etc in the dark

Slide from Dr. Christine Johnson

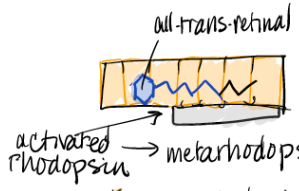
Phototransduction cascade

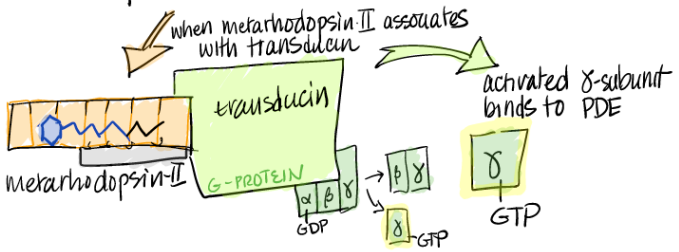
- molecular level

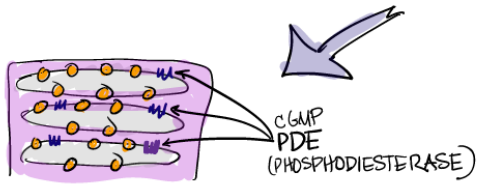




this also causes rhodopsin molecule to change shap

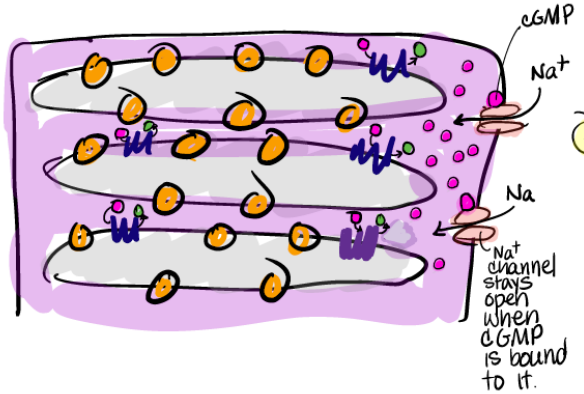




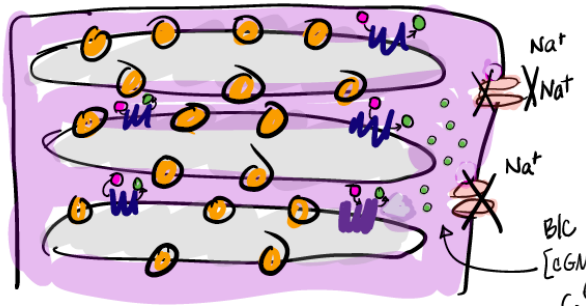


When PDE is activated

1. takes cGMP (which is floating all around inside the cell)
2. and converts it to GMP
3. this reduces the concentration of cGMP & increases the concentration of GMP.

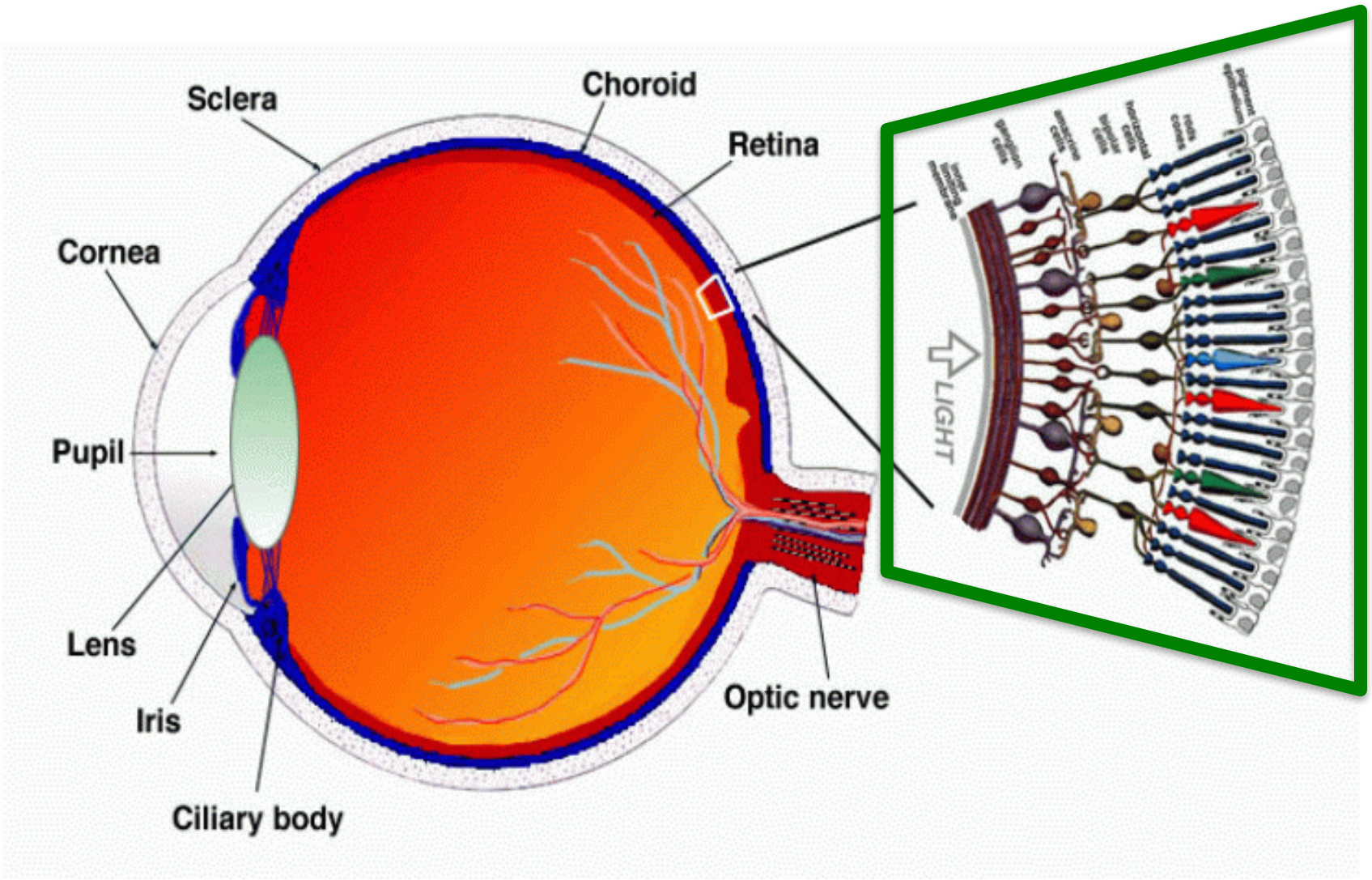


cause → RODS HYPERPOLARIZE B/C Na+ channels close



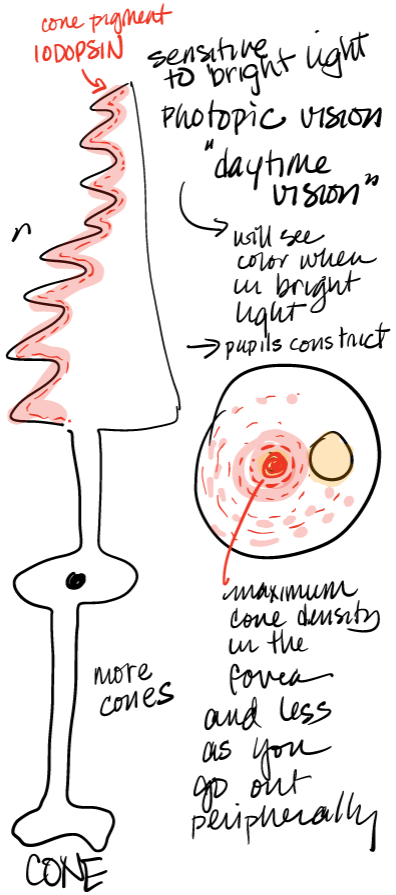
B/C PDE is activated [cGMP]↓↓ ∴ Na+ channel closes → graded hyperpolarization

The Retina



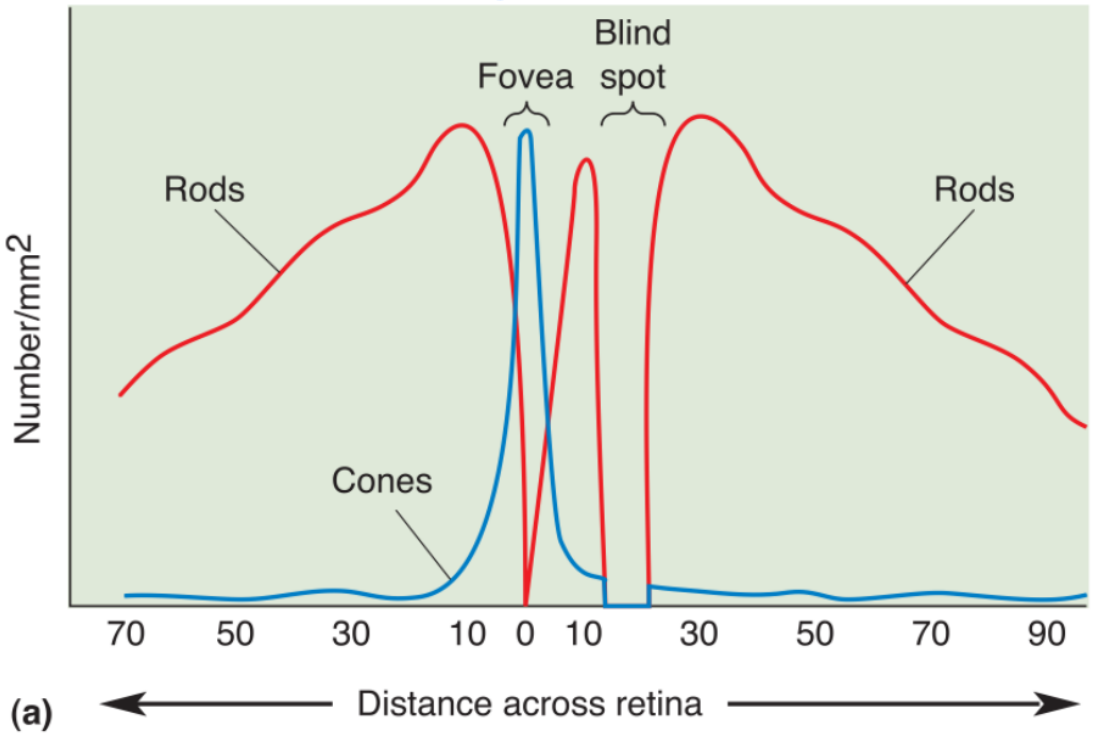
Slide from Dr. Christine Johnson


scotopic vision
"night vision"
sensitive to dim light
rhodopsin pigment
peripheral retina
have more disks
& more photo pigment
∴ more sensitive
shades no color information different shades of gray
pupil will dilate
→ ↑ light input
↑↑ rod
as you go centrally rod concentration goes down
no rods in fovea
ROD

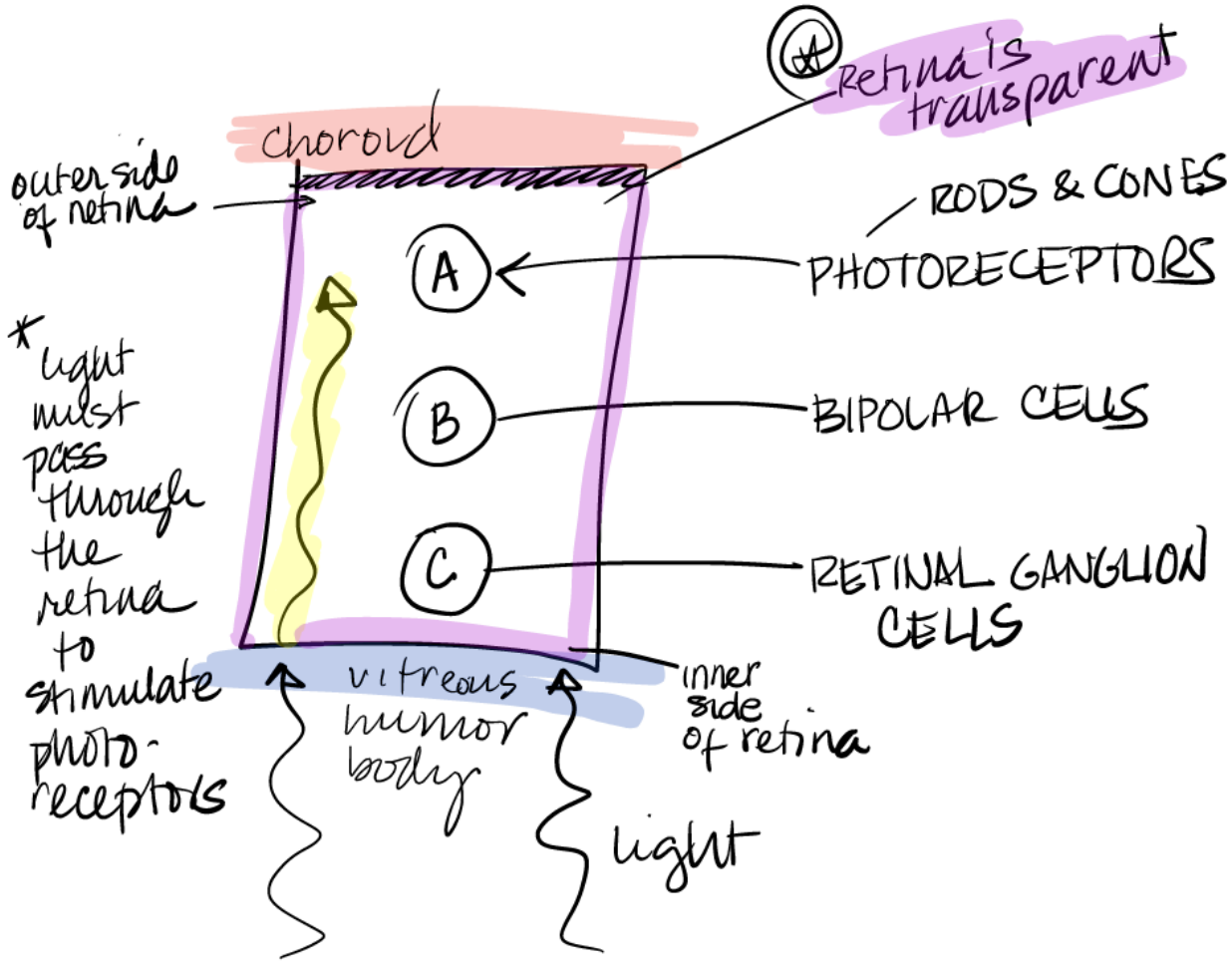

cone pigment
IODOPSIN
sensitive to bright light
photopic vision
"daytime vision"
will see color when in bright light
→ pupils constrict
maximum cone density in the fovea and less as you go out peripherally
more cones
CONE

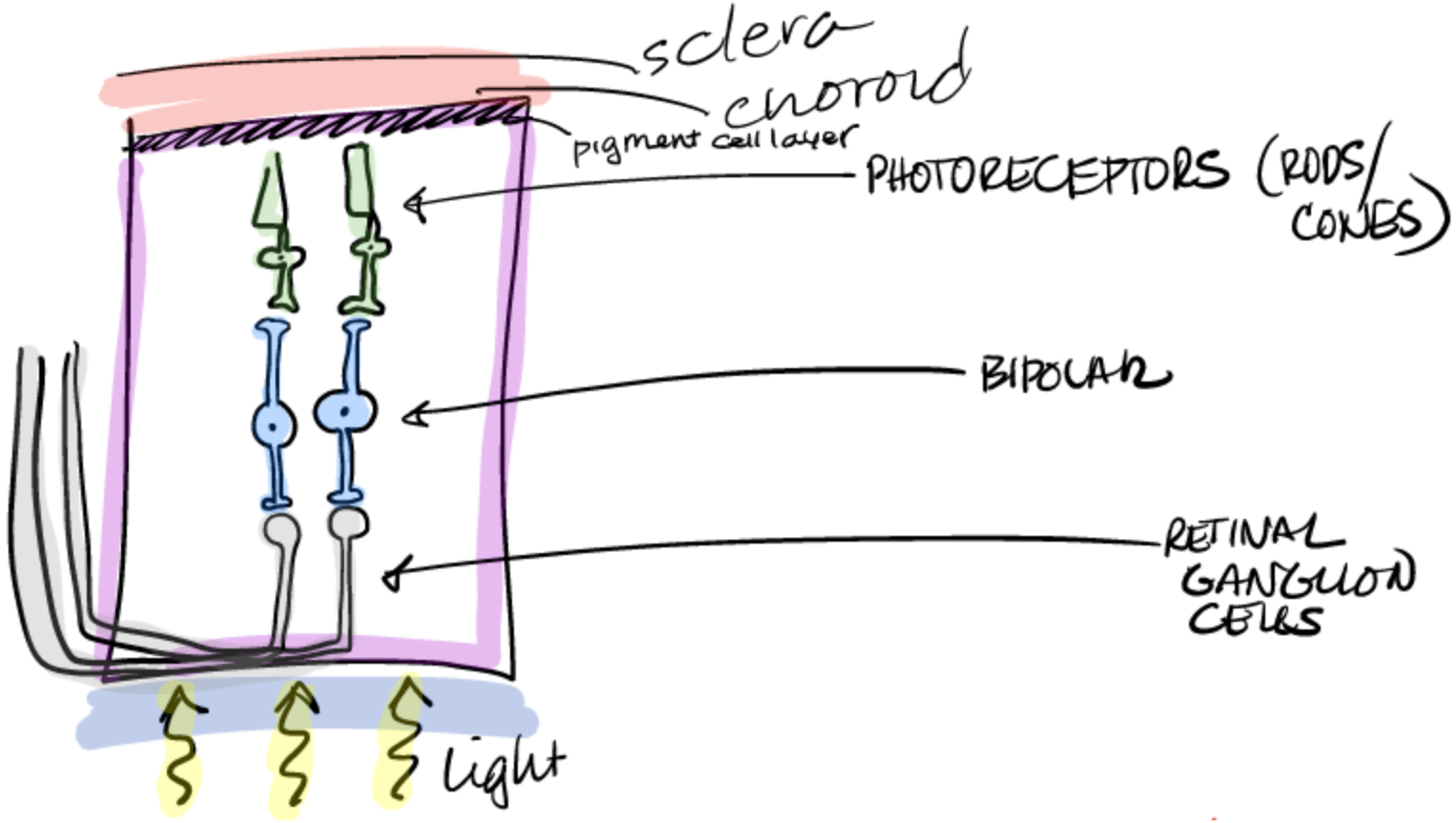
Distribution of cone/rod in the retina.

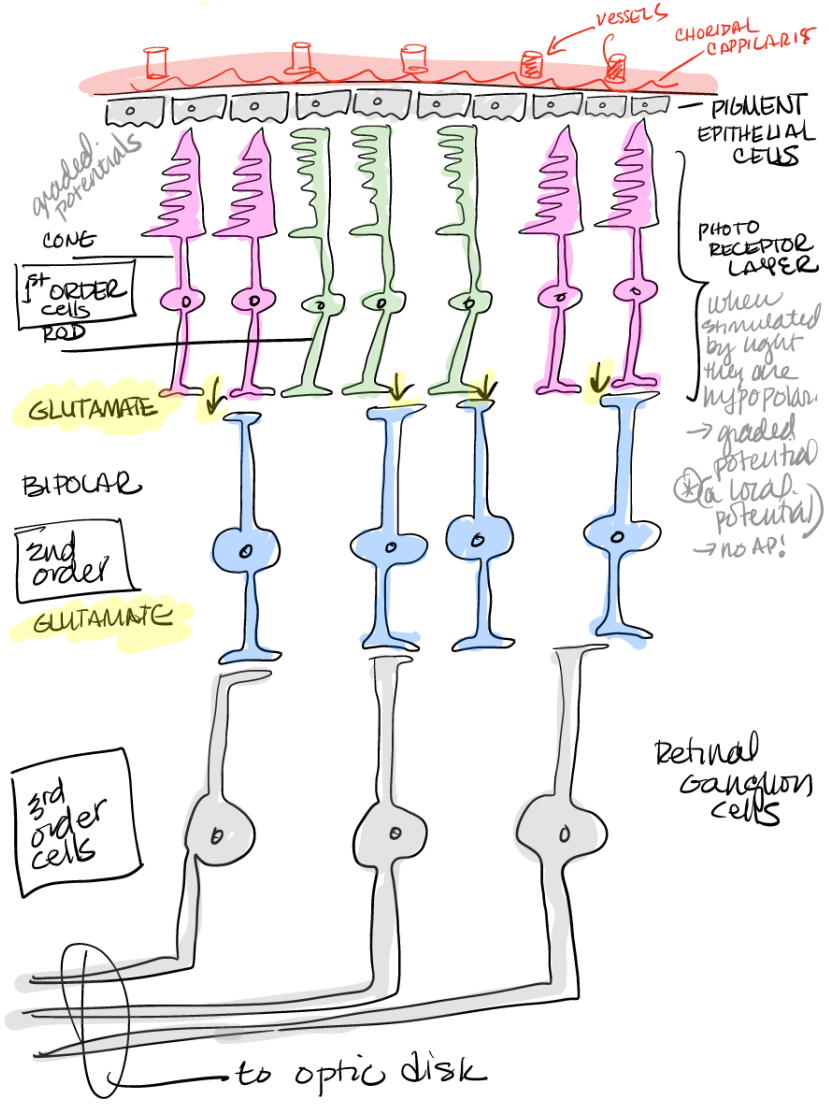
- Most of the 5 million cones are in the fovea

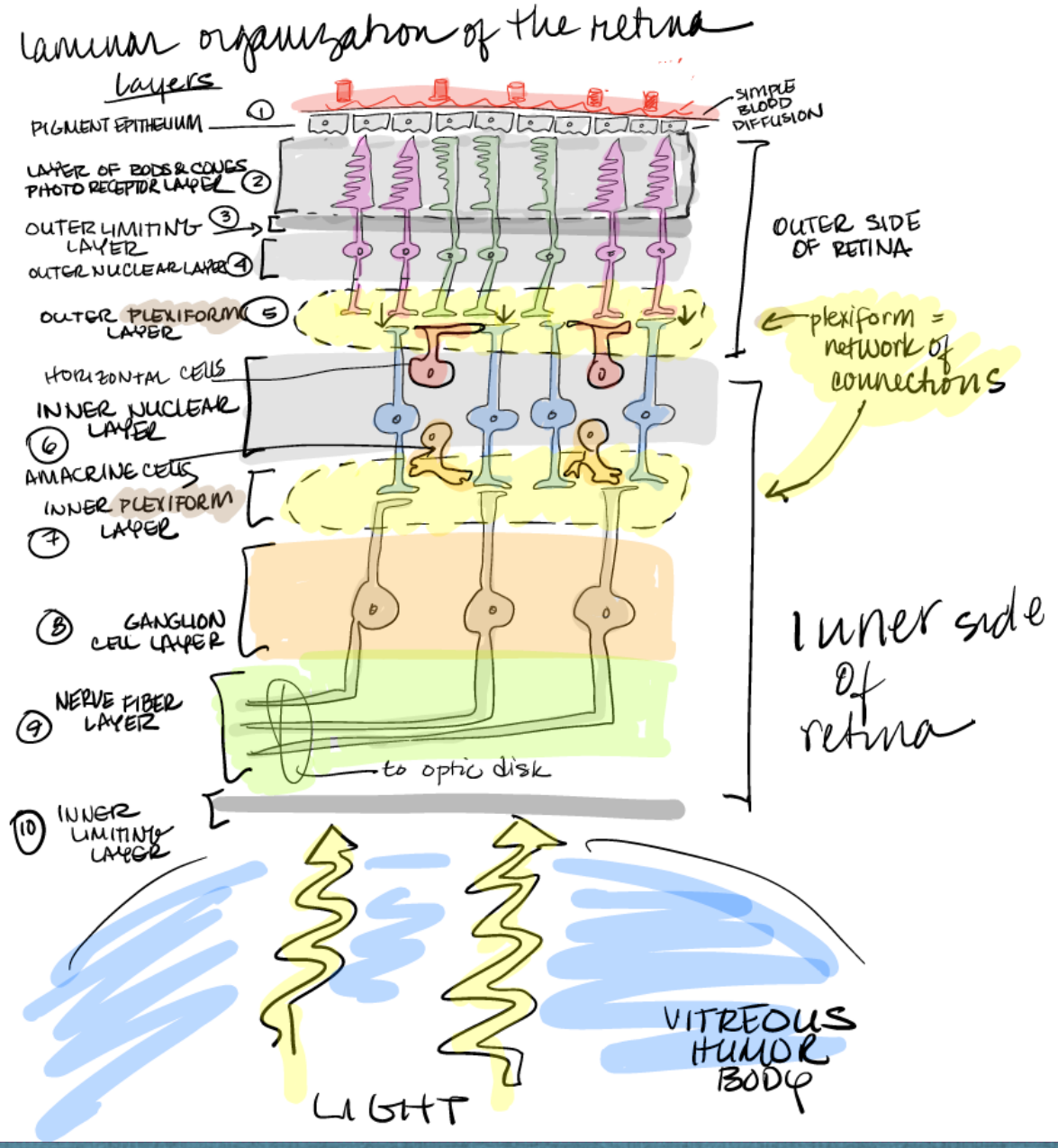


Bear, Mark F., Barry W. Connors, and Michael A. Paradiso. *Neuroscience : Exploring the Brain*. China: Wolters Kluwer, 2016. p 310

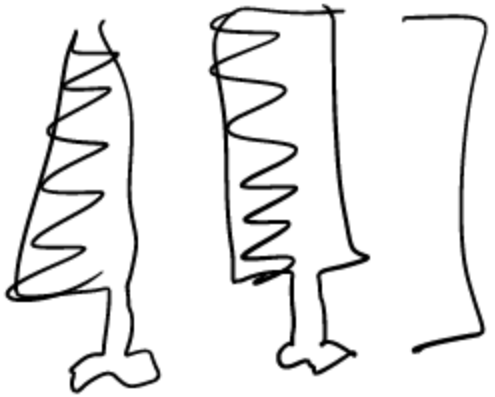

Retina is transparent
choroid
outer side of retina
RODS & CONES
PHOTORECEPTORS
A
B
BIPOLAR CELLS
C
RETINAL GANGLION CELLS
* light must pass through the retina to stimulate photo-receptors
vitreous humor body
inner side of retina
light


sclera
choroid
pigment cell layer
PHOTORECEPTORS (RODS/CONES)
BIPOLAR
RETINAL GANGLION CELLS
light


VESSELS
CHORIDAL CAPPILARIS
PIGMENT EPITHELIAL CELLS
graded potentials
CONE
1st ORDER cells
ROD
PHOTO RECEPTOR LAYER
when stimulated by light they are hypopolar
→ graded potential (a local potential)
→ no AP!
GLUTAMATE
BIPOLAR
2nd order
GLUTAMATE
3rd order cells
Retinal Ganglion cells
to optic disk


Lamellar organization of the retina
Layers
PIGMENT EPITHELIUM ①
SIMPLE BLOOD DIFFUSION
LAYER OF RODS & CONES PHOTO RECEPTOR LAYER ②
OUTER LIMITING LAYER ③
OUTER NUCLEAR LAYER ④
OUTER PLEXIFORM LAYER ⑤
OUTER SIDE OF RETINA
plexiform = network of connections
HORIZONTAL CELLS
INNER NUCLEAR LAYER ⑥
AMACRINE CELLS
INNER PLEXIFORM LAYER ⑦
⑧ GANGLION CELL LAYER
⑨ NERVE FIBER LAYER
to optic disk
⑩ INNER LIMITING LAYER
Inner side of retina
LIGHT
VITREOUS HUMOR BODY

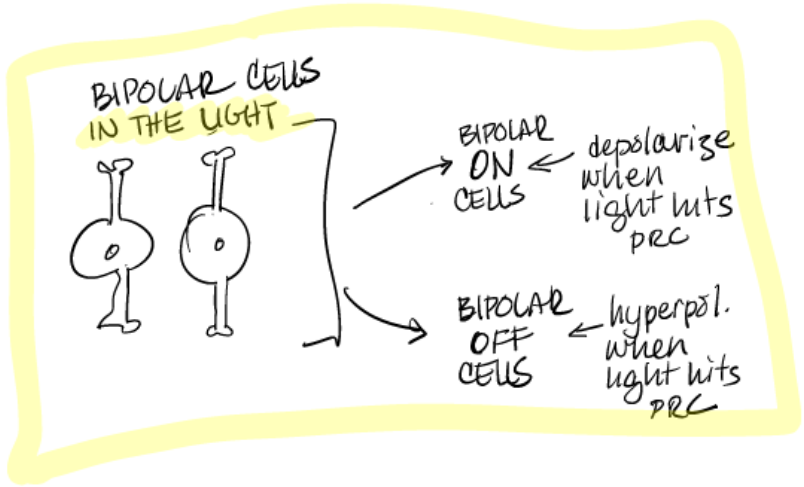
COMPLEXITY IN RETINAL SIGNALING

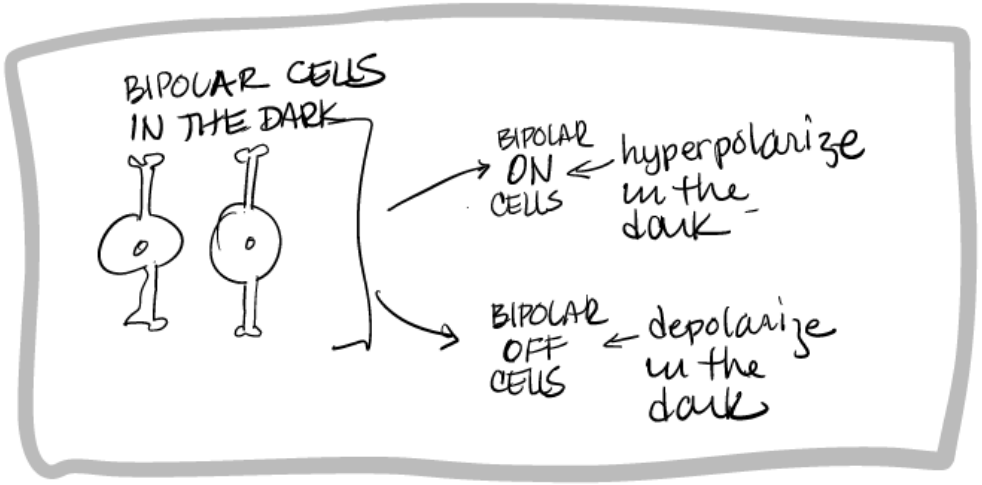


photoreceptors have simple graded responses

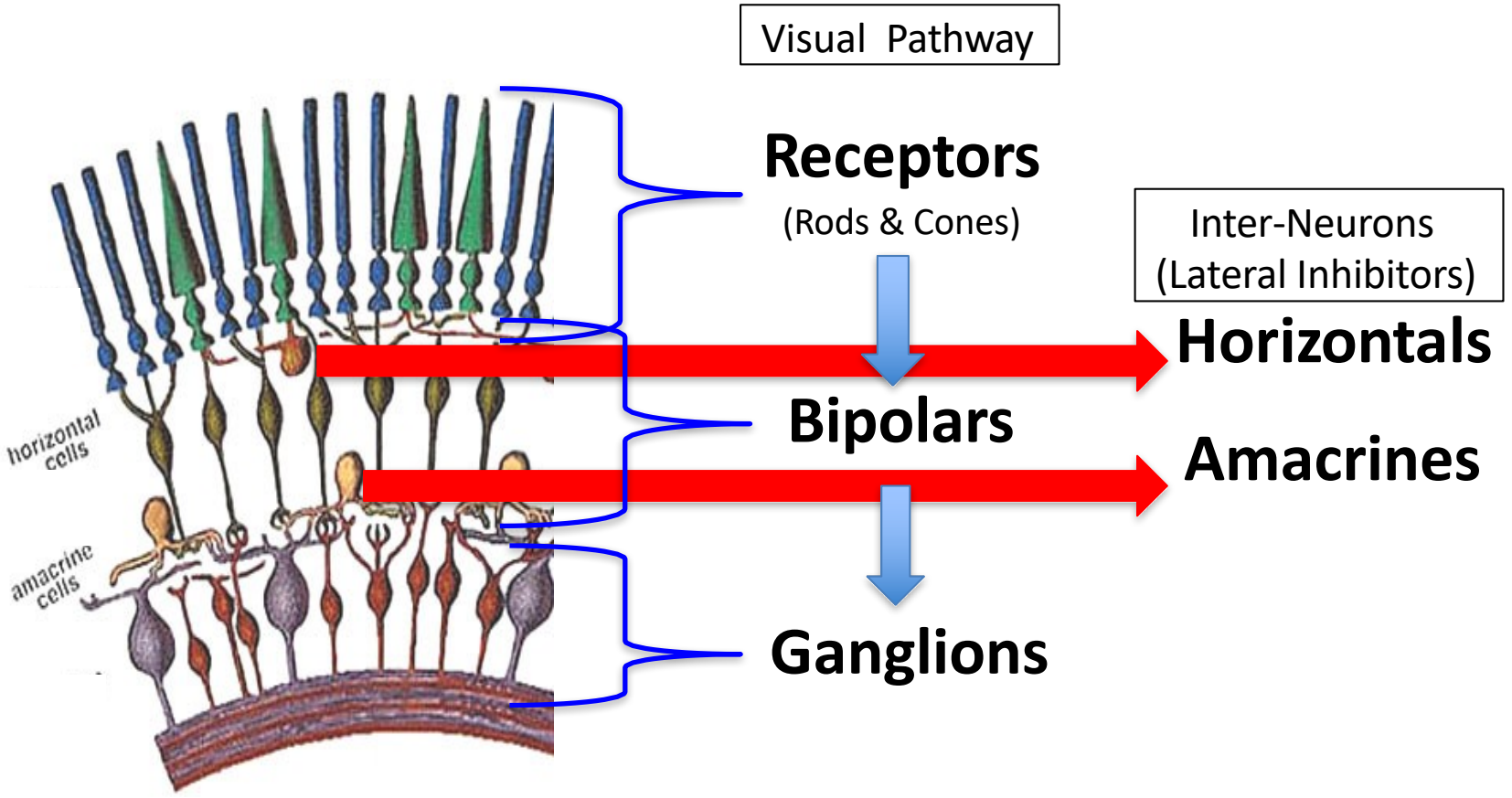
hyperpolarize

depolarize


BIPOLAR CELLS
IN THE LIGHT
BIPOLAR ON CELLS
depolarize when light hits PRC
BIPOLAR OFF CELLS
hyperpol. when light hits PRC


BIPOLAR CELLS
IN THE DARK
BIPOLAR ON CELLS
hyperpolarize in the dark
BIPOLAR OFF CELLS
depolarize in the dark

The Retina - Five Layers of Neurons



Slide from Dr. Christine Johnson

The Retina

RECALL:
Whether a neurotransmitter
(like Glutamate)
is "Excitatory" or "Inhibitory"
depends on what effect it has
on Post-Synaptic Cell

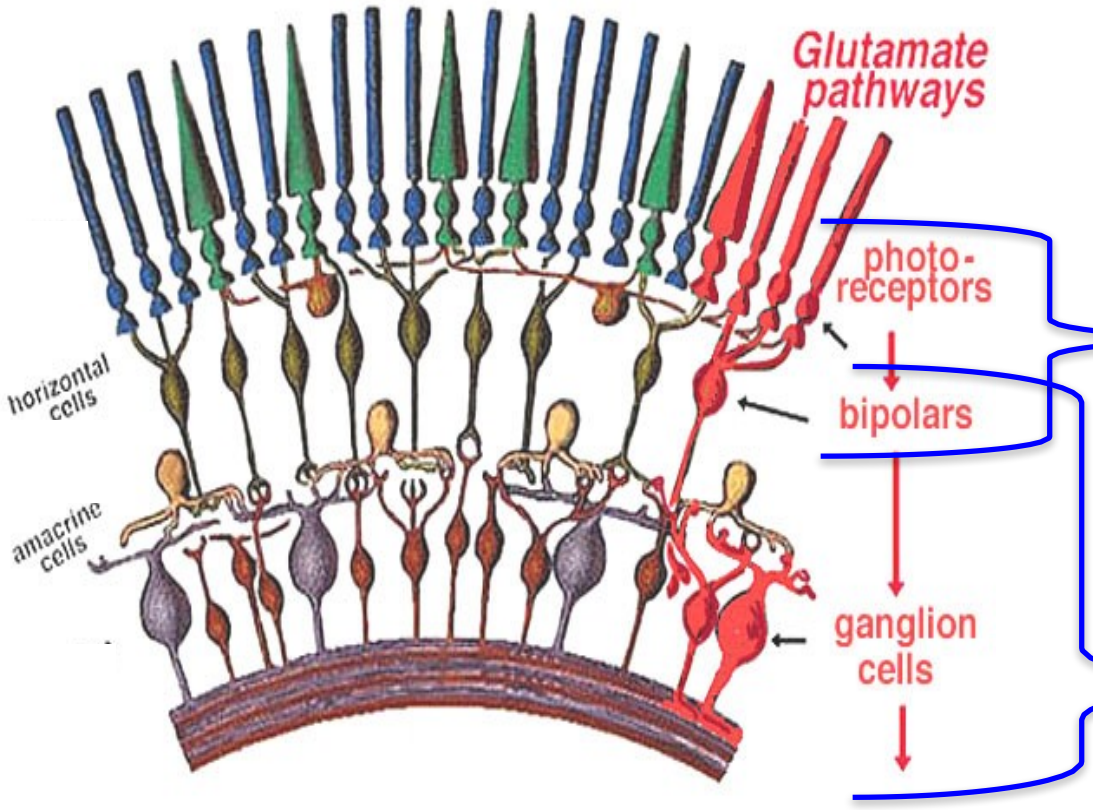


Fig. 13. The types of neurons in the vertebrate retina that use glutamate as a neurotransmitter (red).

At junction of
Receptors & Bipolars,
Glutamate has an
Inhibitory Effect
(letting Cl- into next cell)

At junction of
Bipolars & Ganglions,
Glutamate has an
Excitatory Effect
(letting Na+ into next cell)

Slide from Dr. Christine Johnson

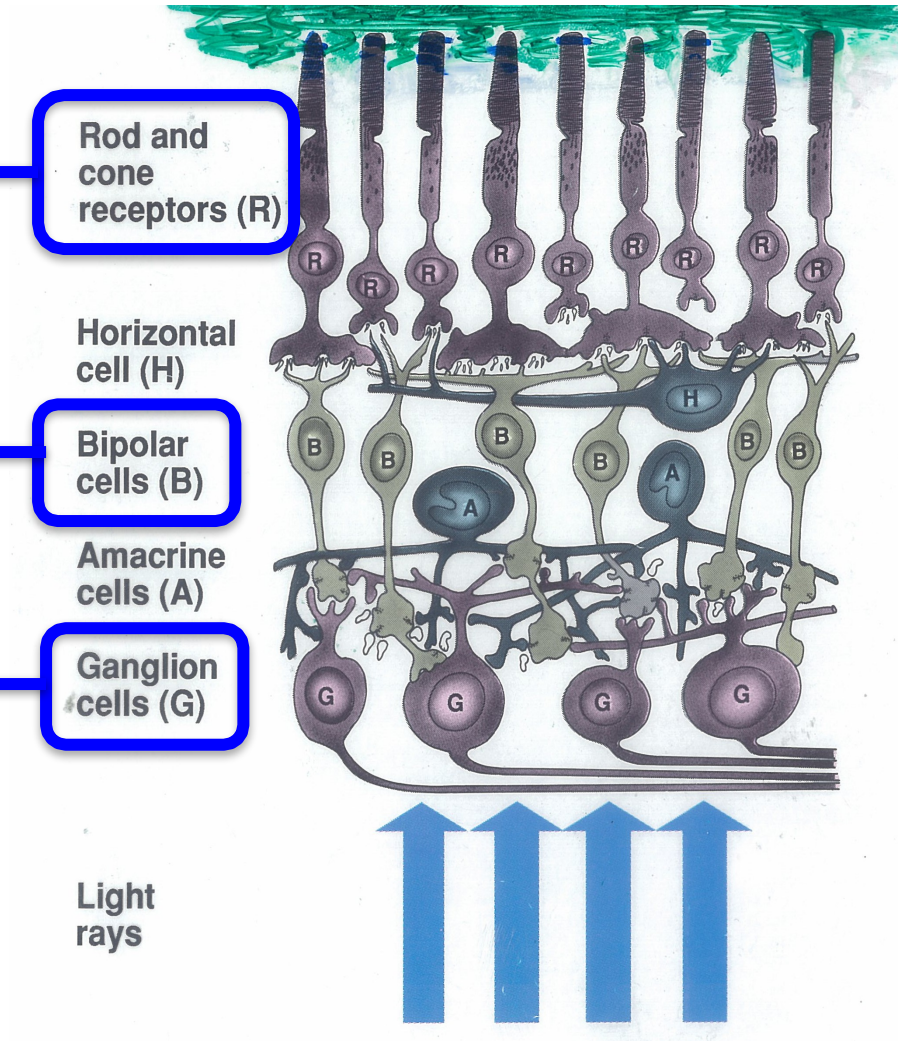
The Retina

Visual Pathway

Spontaneous, Graded, & **Inhibitory** → Rod and cone receptors (R)

Spontaneous, Graded, & **Excitatory** → Bipolar cells (B)

Action Potentials & **Excitatory** → Ganglion cells (G)



Slide from Dr. Christine Johnson

The Retina

Visual Pathway

Inter-Neurons

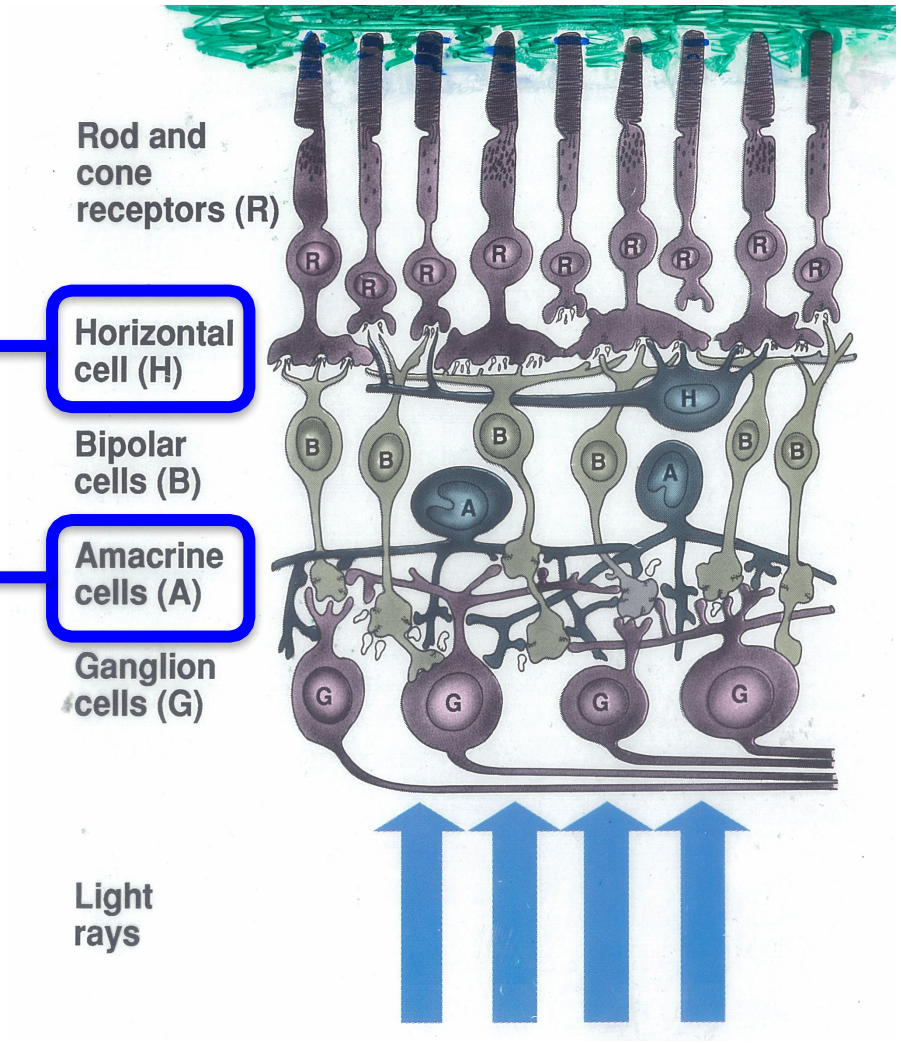
Spontaneous, Graded, & **Inhibitory**

Spontaneous, Graded, & **Inhibitory**

Spontaneous, Graded, & **Excitatory**

Graded & **Inhibitory**

Action Potentials & **Excitatory**



MNEMONIC
Once you get to the Ganglion
Firing is All-or-None

Slide from Dr. Christine Johnson

Strange But True – Receptors are turned OFF by light

If Receptor cells are turned OFF by light

(really, turned down – reducing their release of NT)

(i.e. If Dark Current is reduced by incoming light)

how do they signal that light is present..???

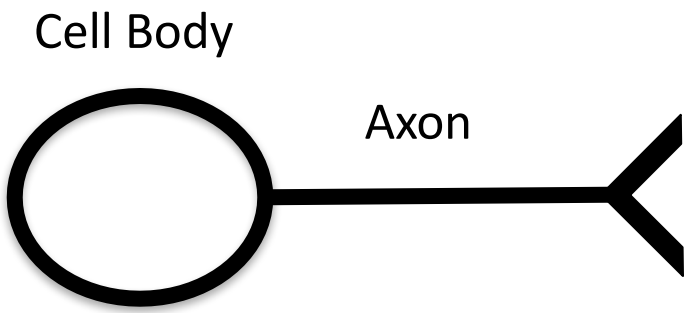
ANSWER:

What matters is NOT what one cell does,

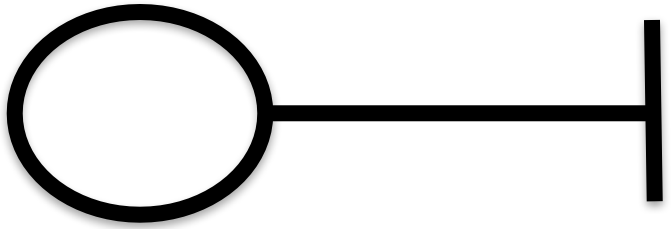
but how they are CONNECTED!

Slide from Dr. Christine Johnson

By convention, when we draw neural circuits . . .



Excitatory



Inhibitory

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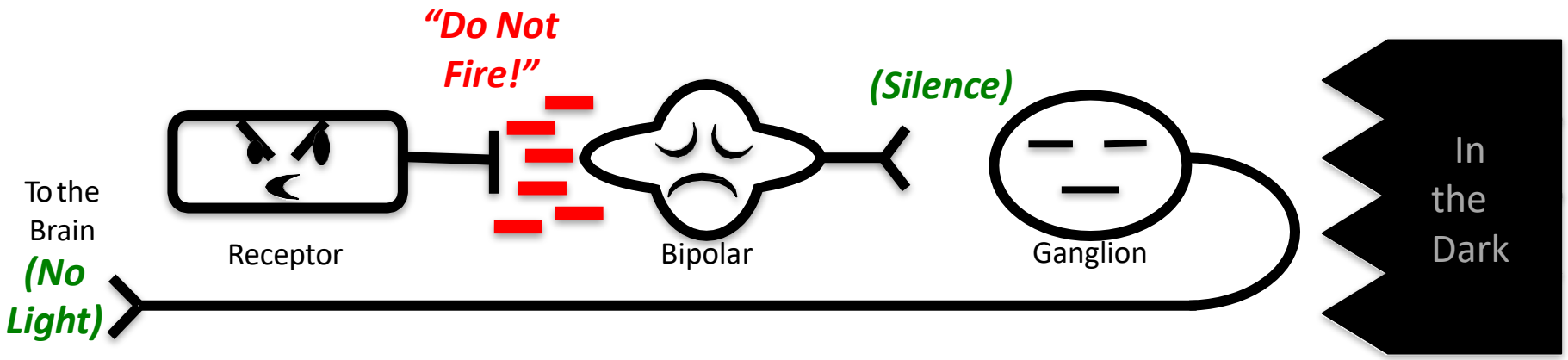
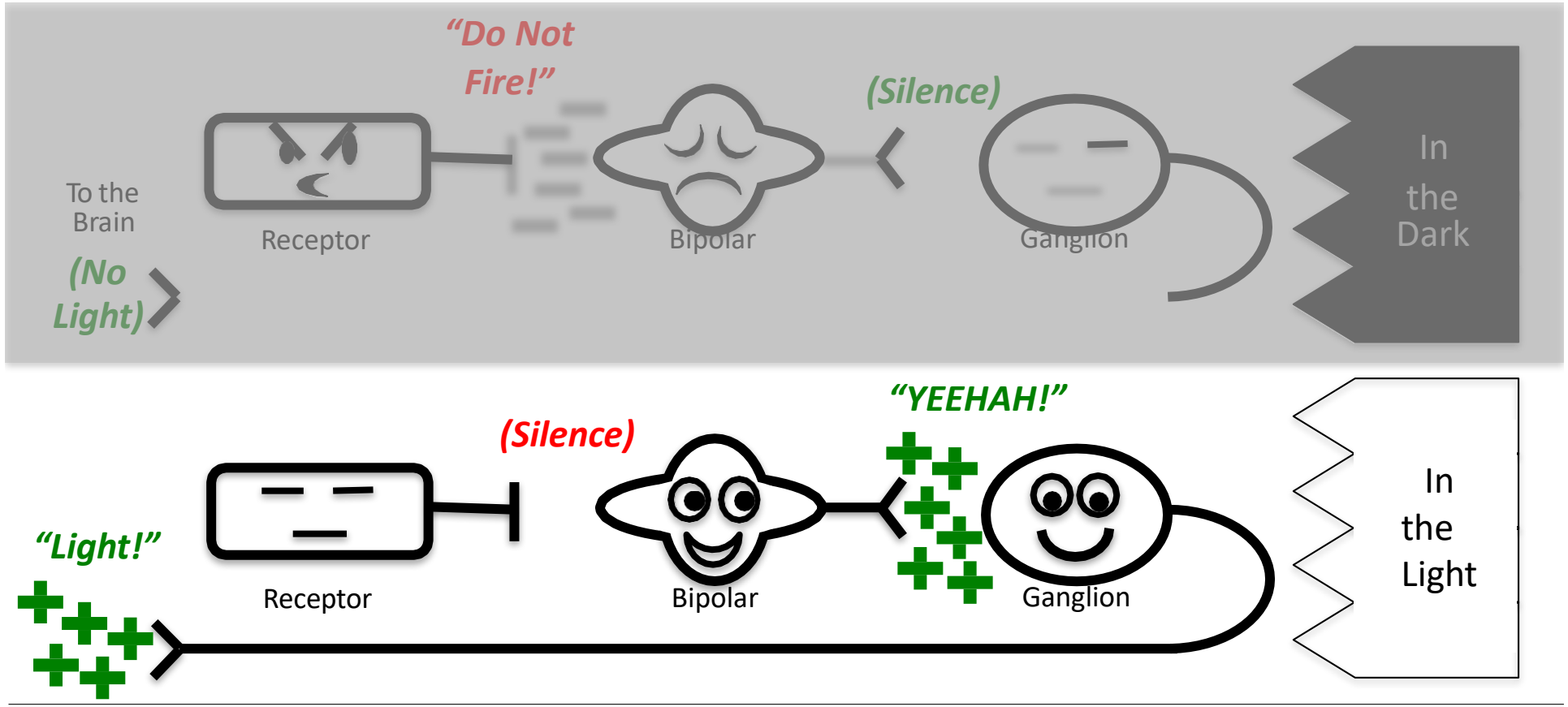
Strange But True – Receptors are turned OFF by light



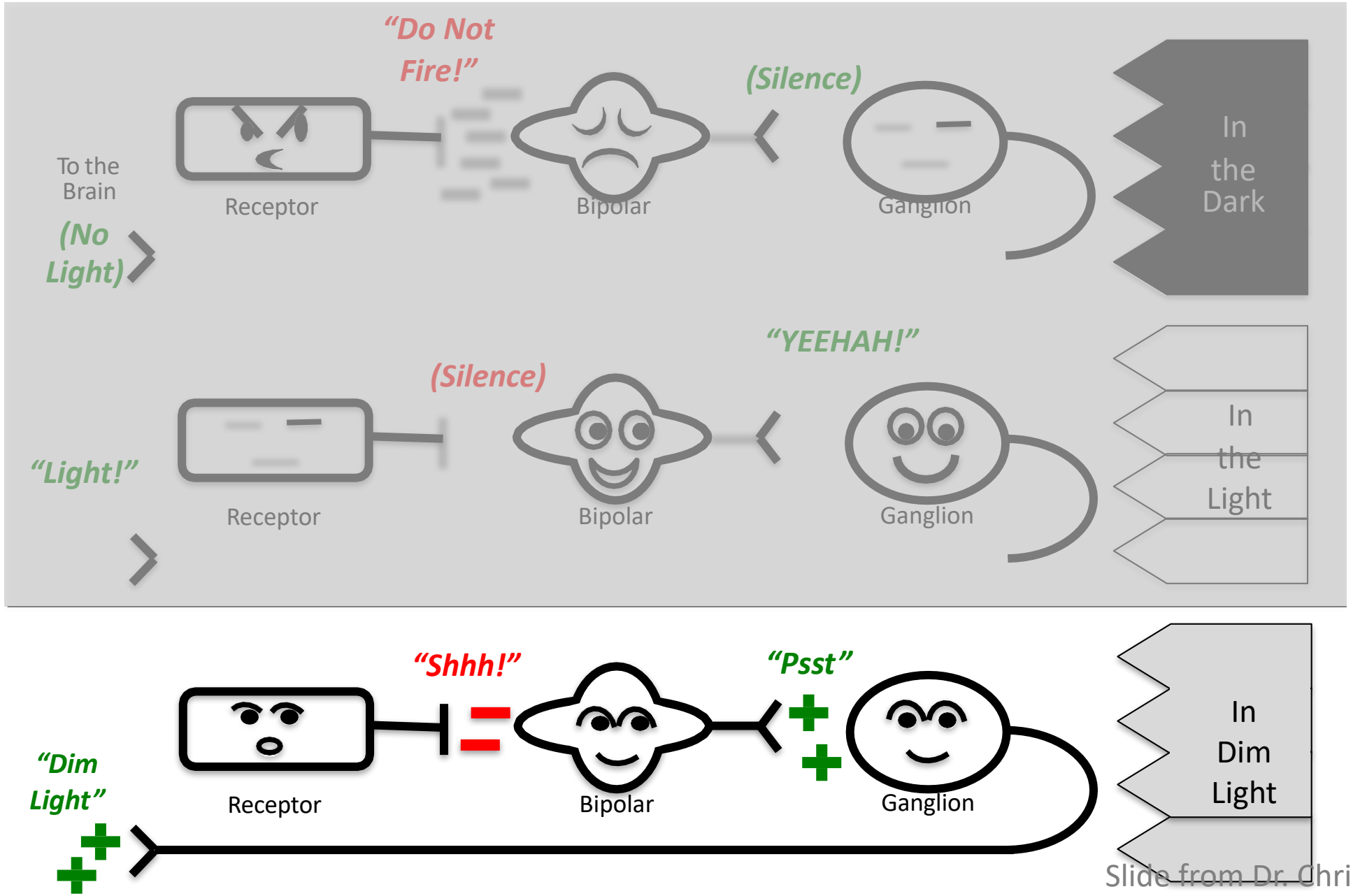
Slide from Dr. Christine Johnson

Strange But True – Receptors are turned OFF by light



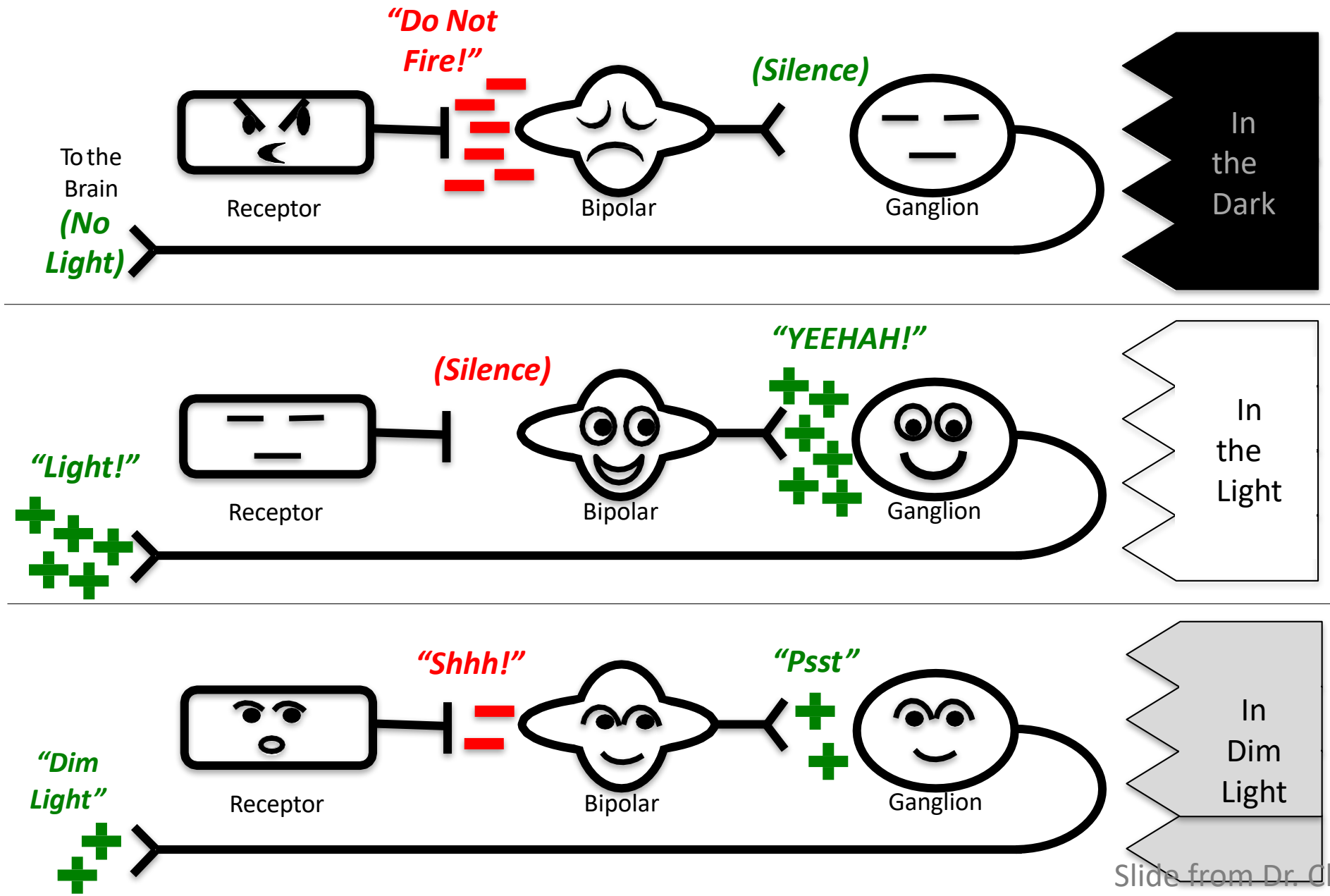
Slide from Dr. Christine Johnson

Strange But True – Receptors are turned OFF by light



Slide from Dr. Christine Johnson

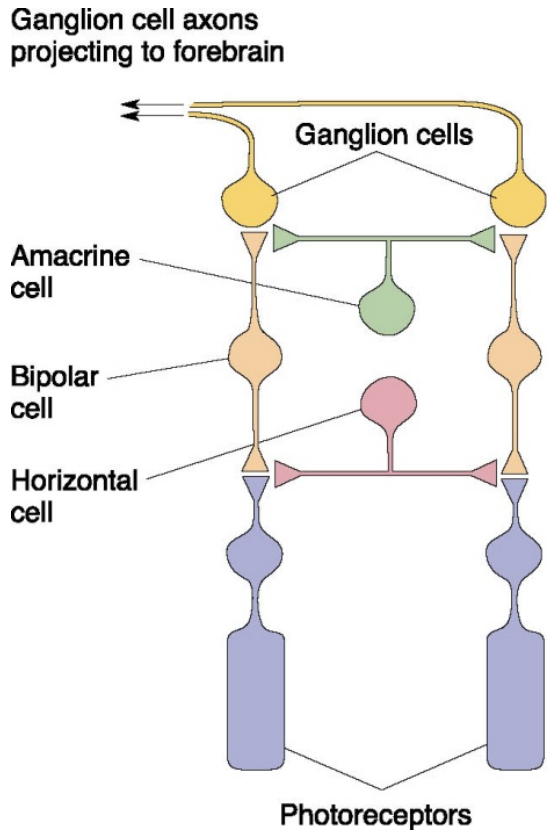
Strange But True – Receptors are turned OFF by light



Slide from Dr. Christine Johnson

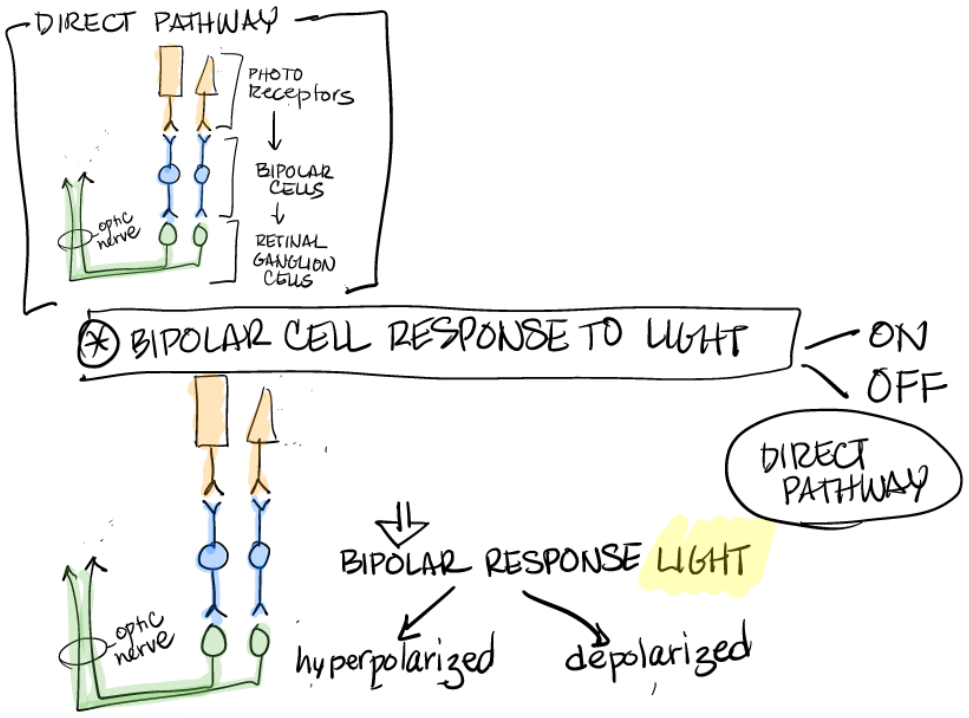
Microscopic Anatomy of the Retina

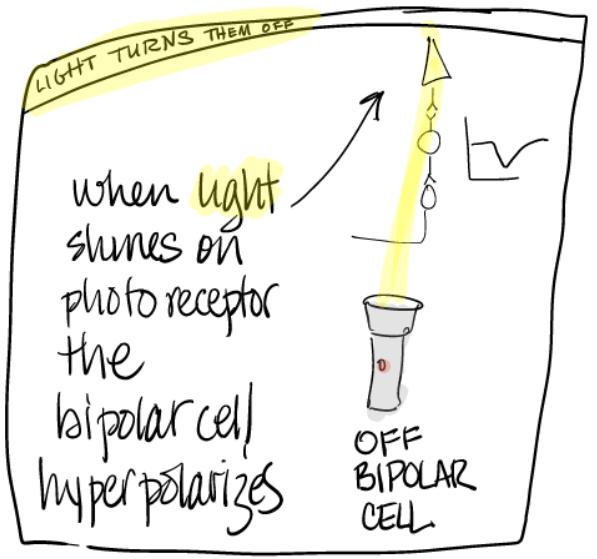
- Direct (vertical) pathway
  - Ganglion cells
  - ↑
  - Bipolar cells
  - ↑
  - Photoreceptors

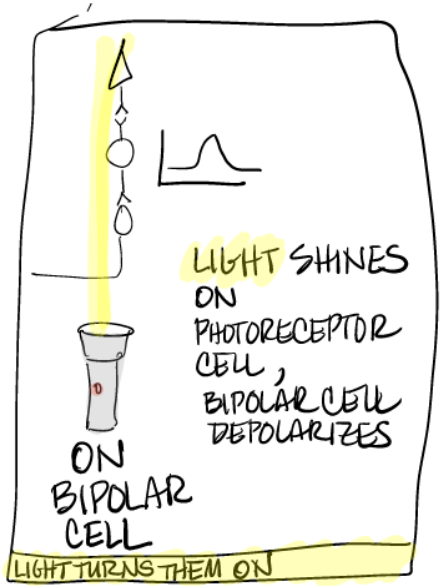


Slide from Bear, M. et al 5th edition publisher: Wolters-Kluwer 2016

VISUAL PROCESSING - RETINA

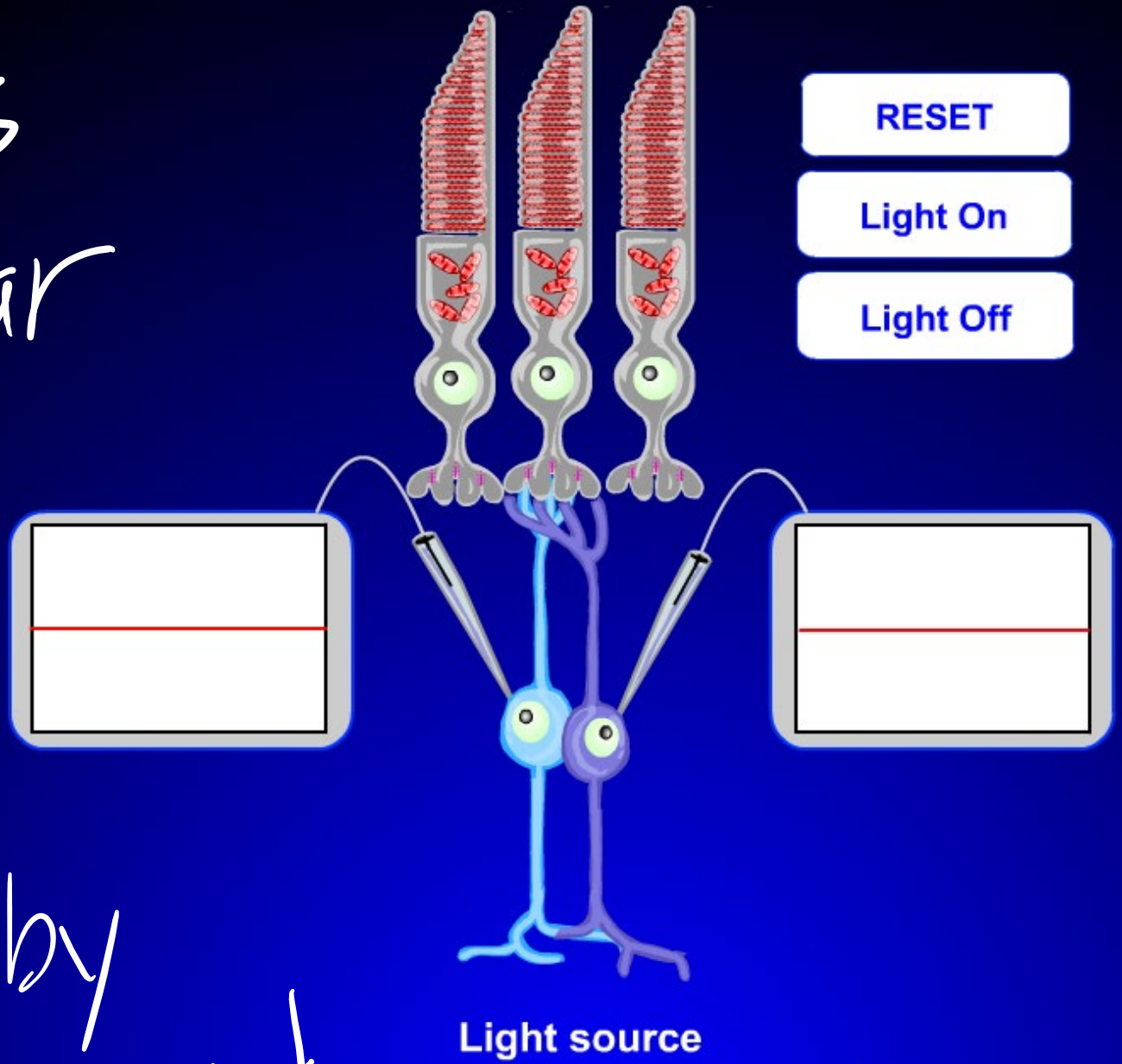




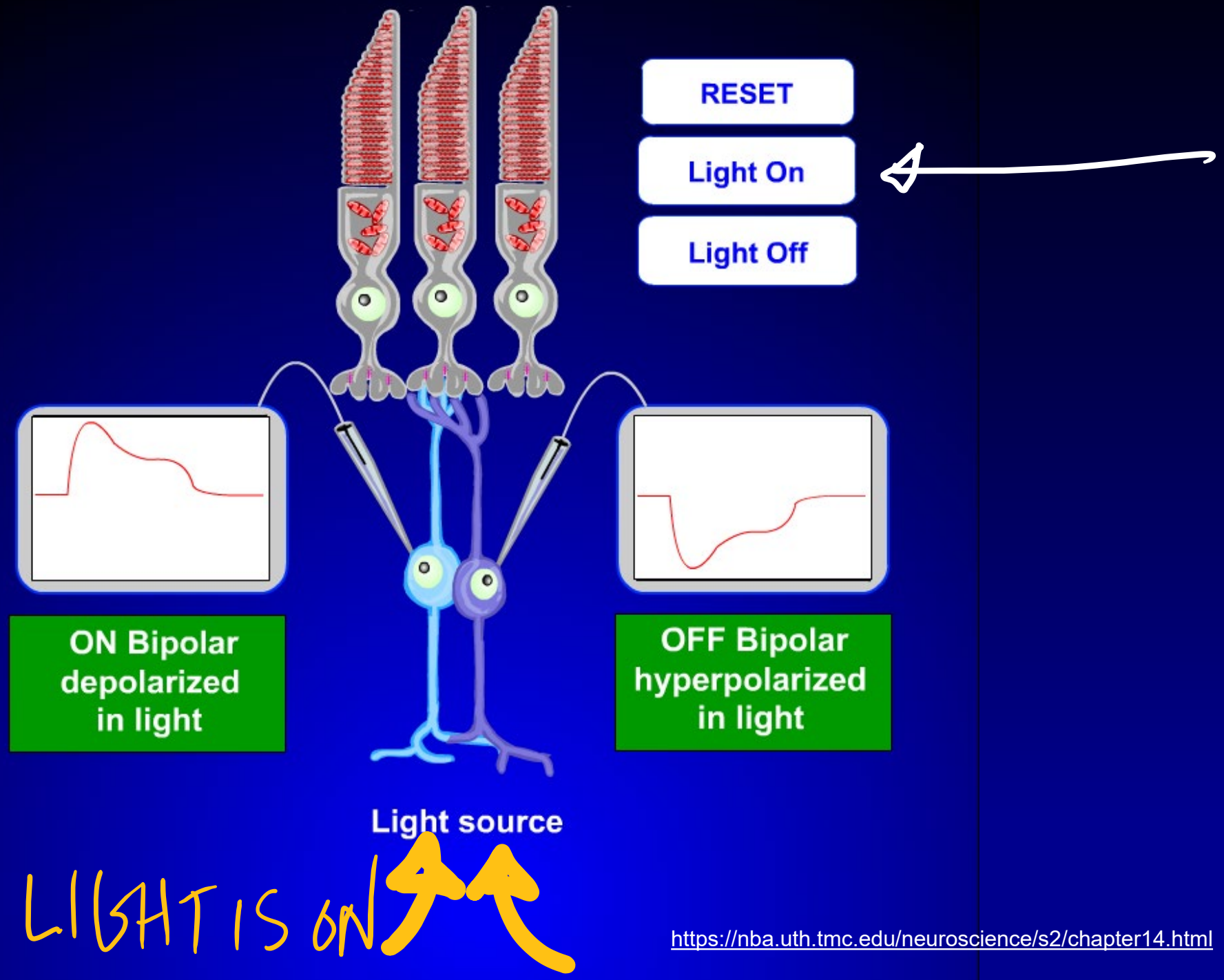


Two types of bipolar cells

they are classified by how they respond to light



https://nba.uth.tmc.edu/neuroscience/s2/chapter14.html



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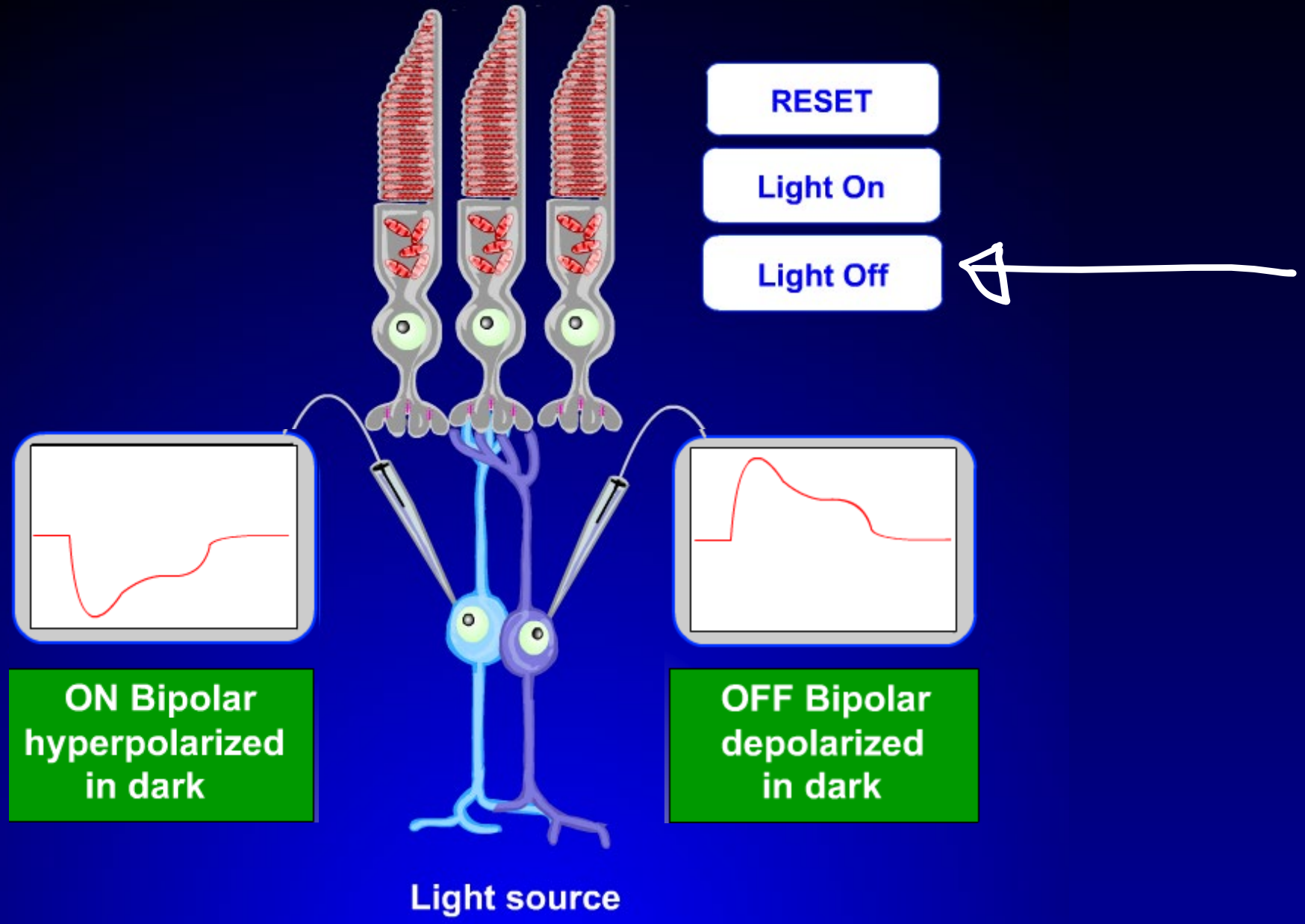
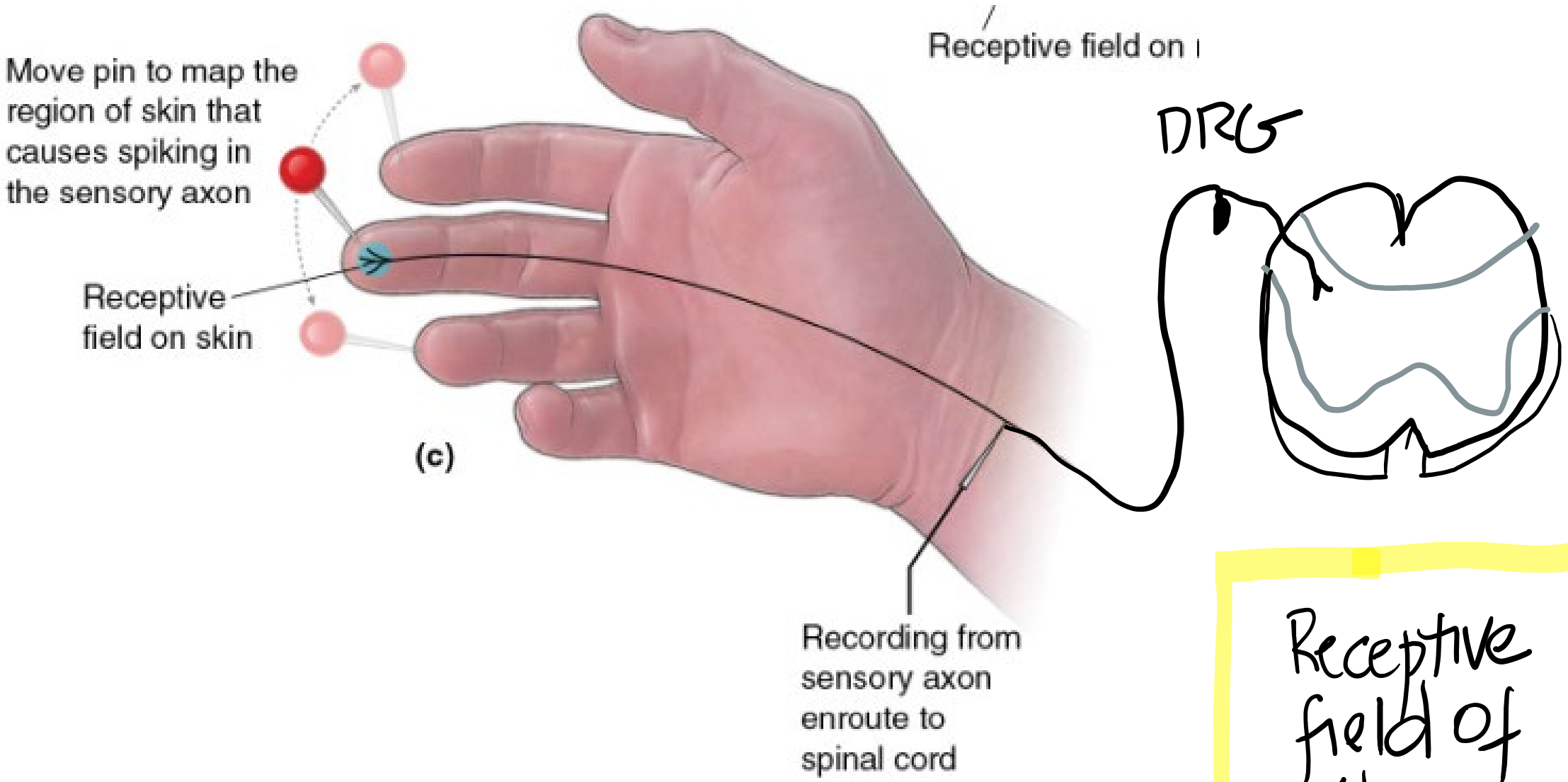


https://nba.uth.tmc.edu/neuroscience/s2/chapter14.html

The Receptive Field

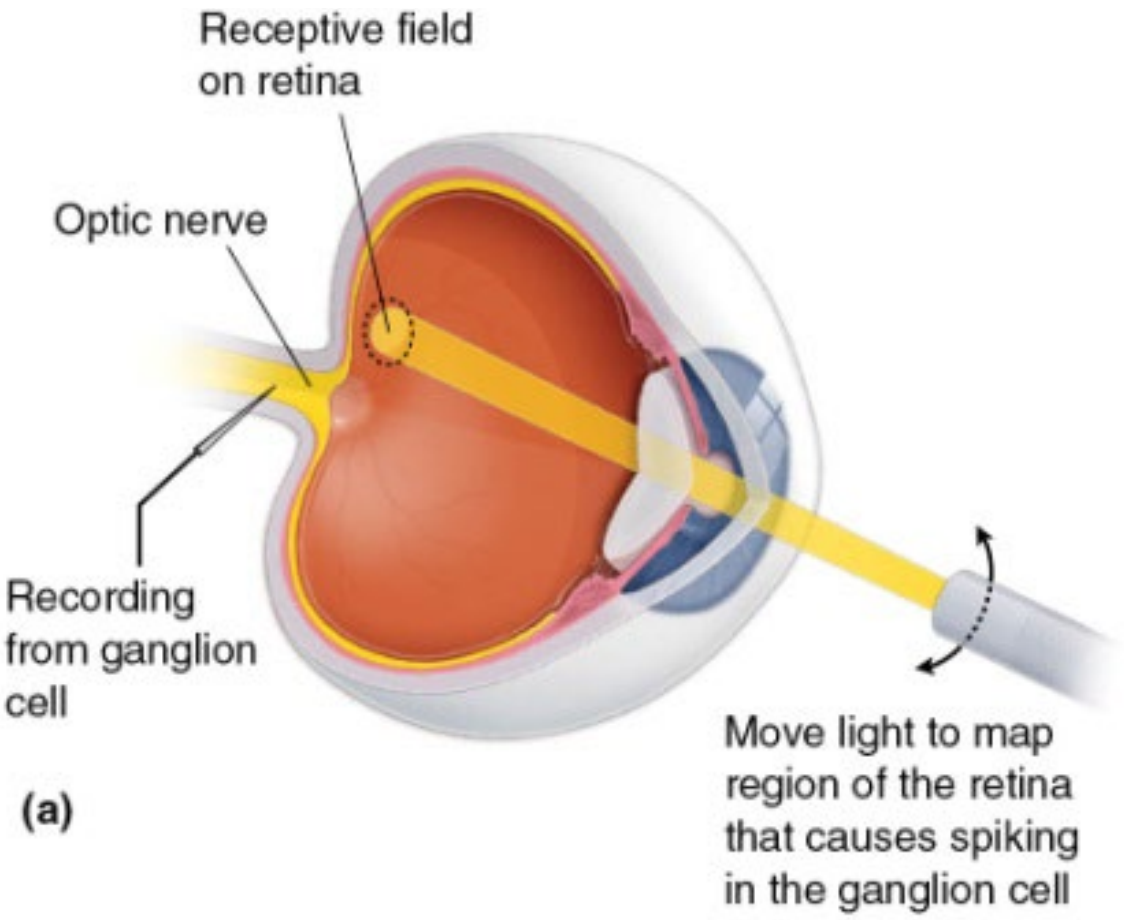


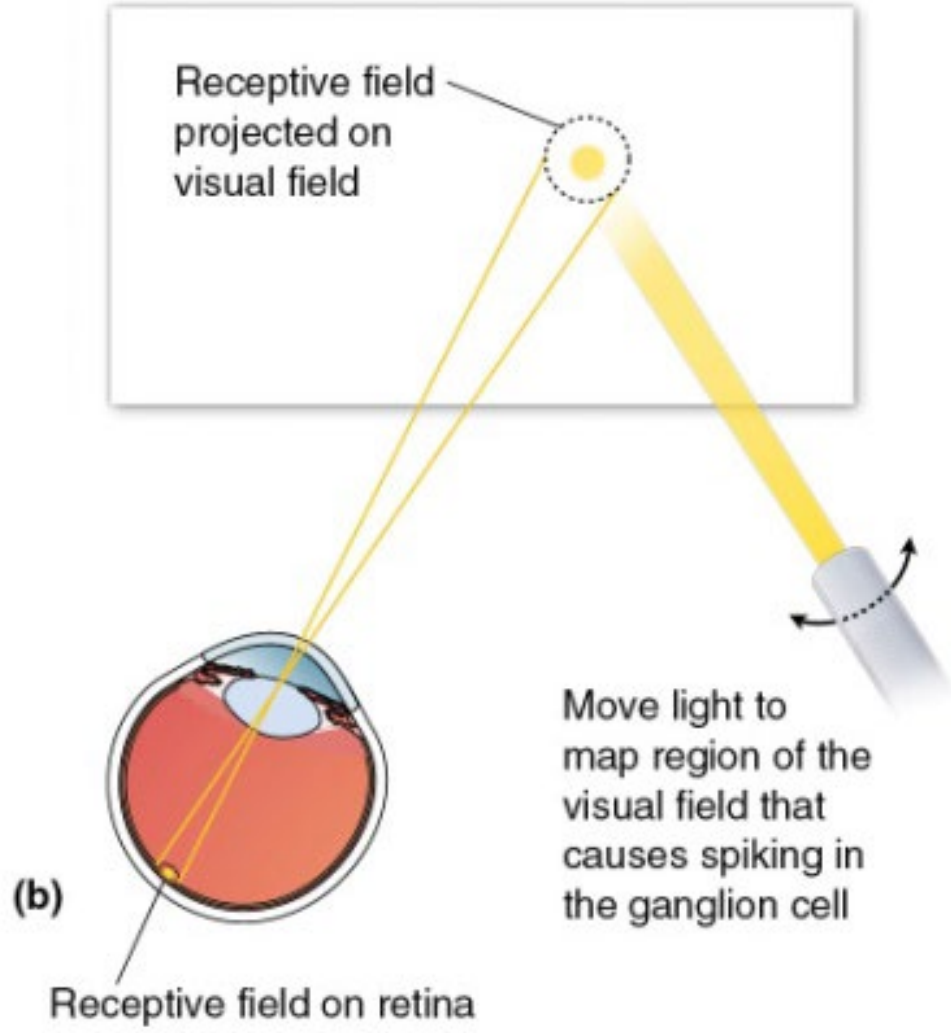
Receptive field of the sens. neuron.

Slide from Bear, M. et al 5th edition publisher: Wolters-Kluwer 2016

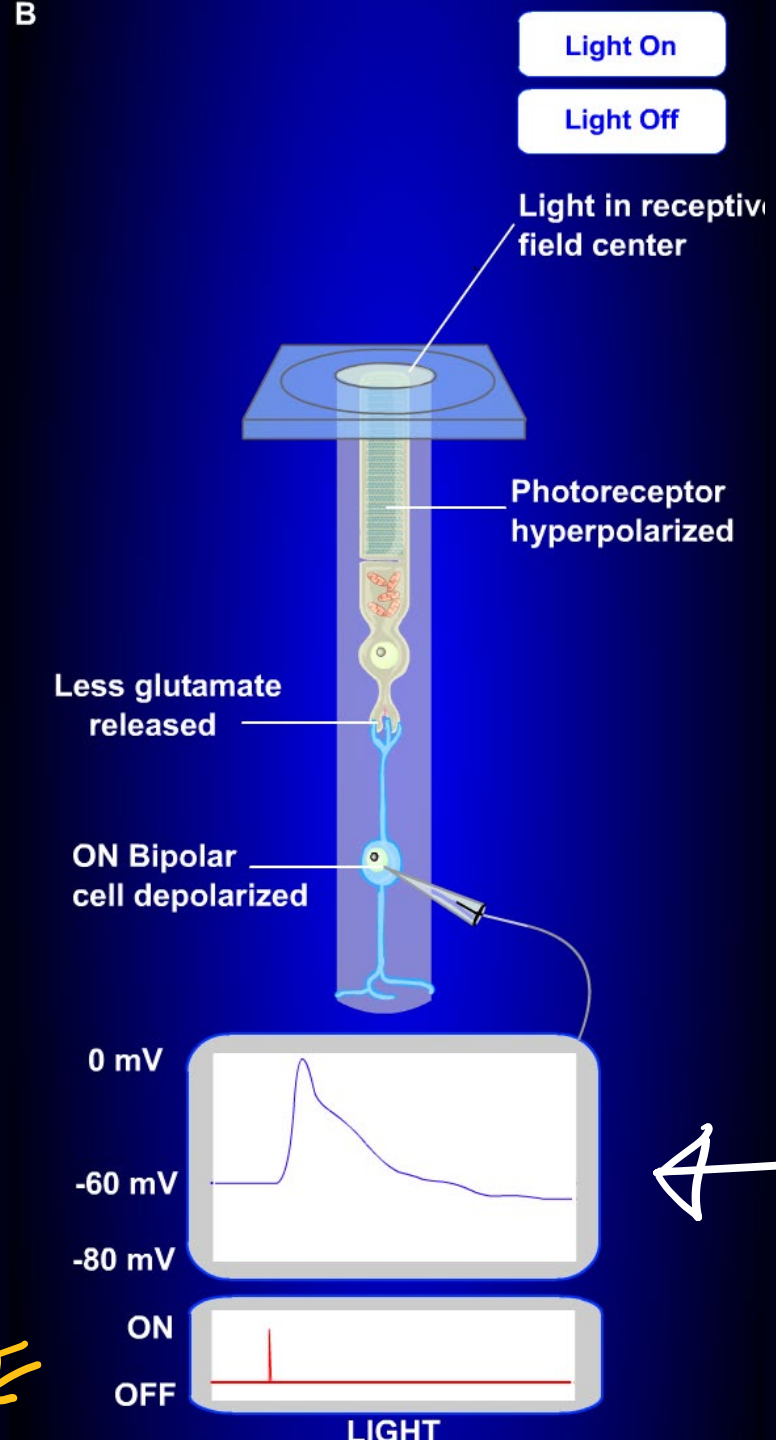
The Receptive Field

- Area of retina where light changes neuron's firing rate
- Fields change in shape and stimulus specificity.





Slide from Bear, M. et al 5th edition publisher: Wolters-Kluwer 2016



ON BIPOLAR CELL RESP.

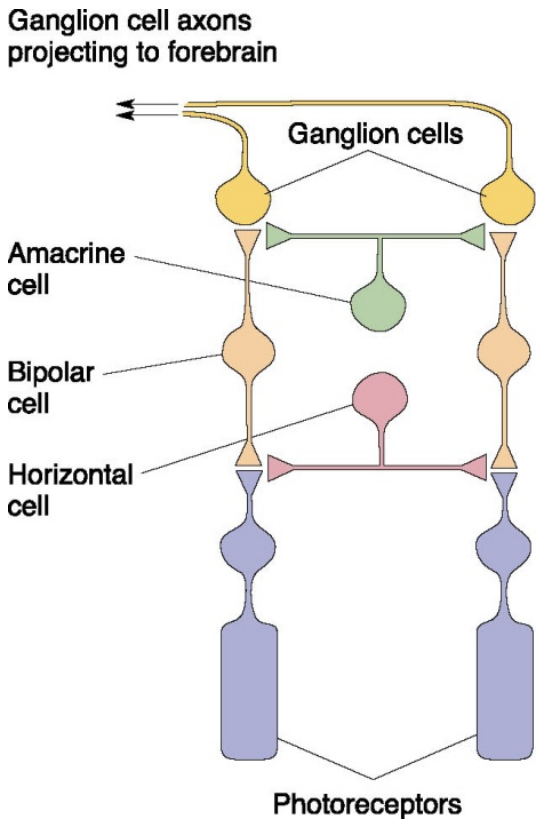
LIGHT PULSE

← depolarized

https://nba.uth.tmc.edu/neuroscience/s2/chapter14.html

Microscopic Anatomy of the Retina—(cont.)

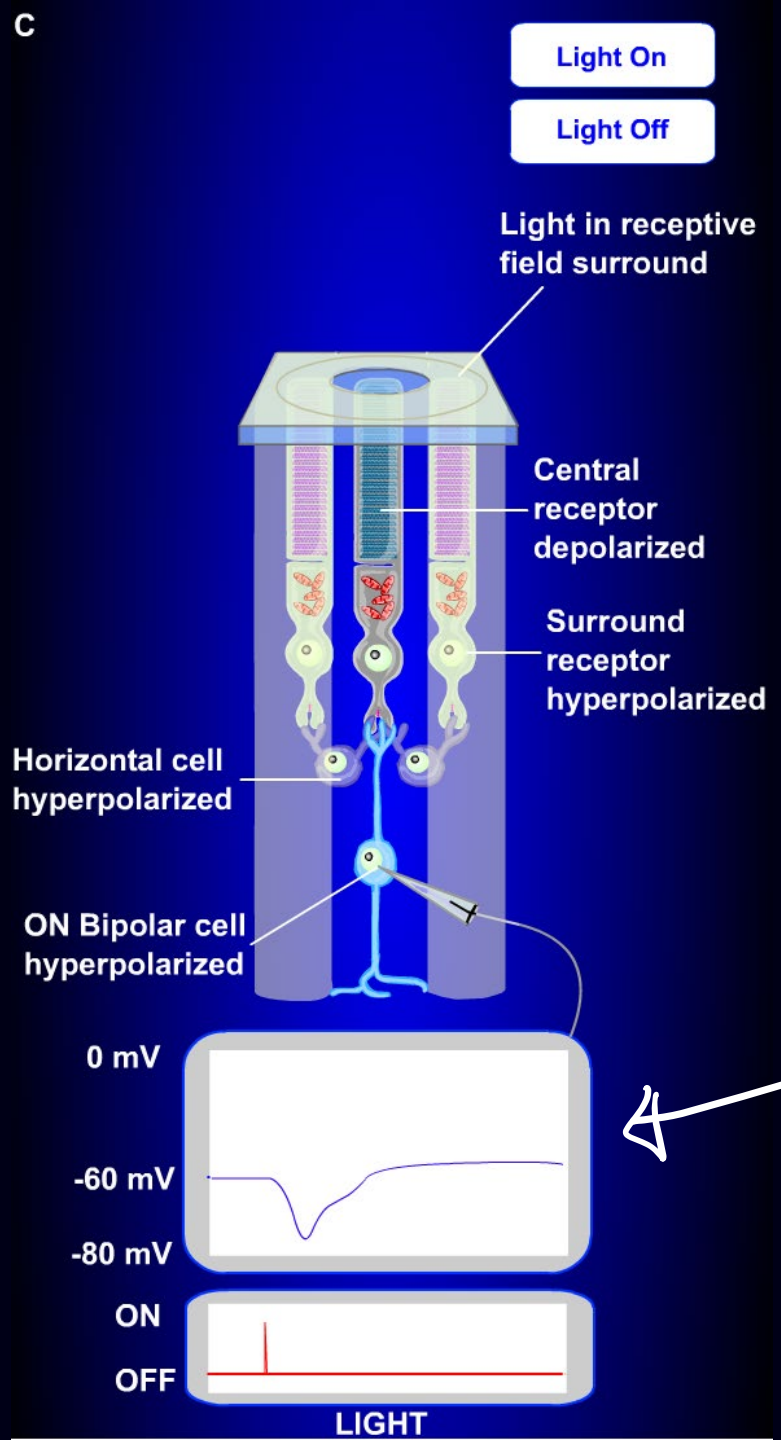
- Retinal processing also influenced by lateral connections
  - Horizontal cells
    - Receive input from photoreceptors and project to other photoreceptors and bipolar cells
  - Amacrine cells
    - Receive input from bipolar cells and project to ganglion cells, bipolar cells, and other amacrine cells

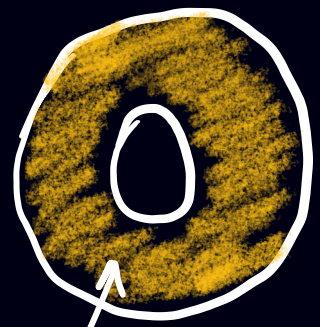


Slide from Bear, M. et al 5th edition publisher: Wolters-Kluwer 2016

"Bipolar cells have concentric receptive fields.

When the receptors surrounding the center receptors of the on bipolar receptive field are illuminated ("Light On") and the center receptors kept in the dark, the On-Bipolar cell is hyperpolarized."





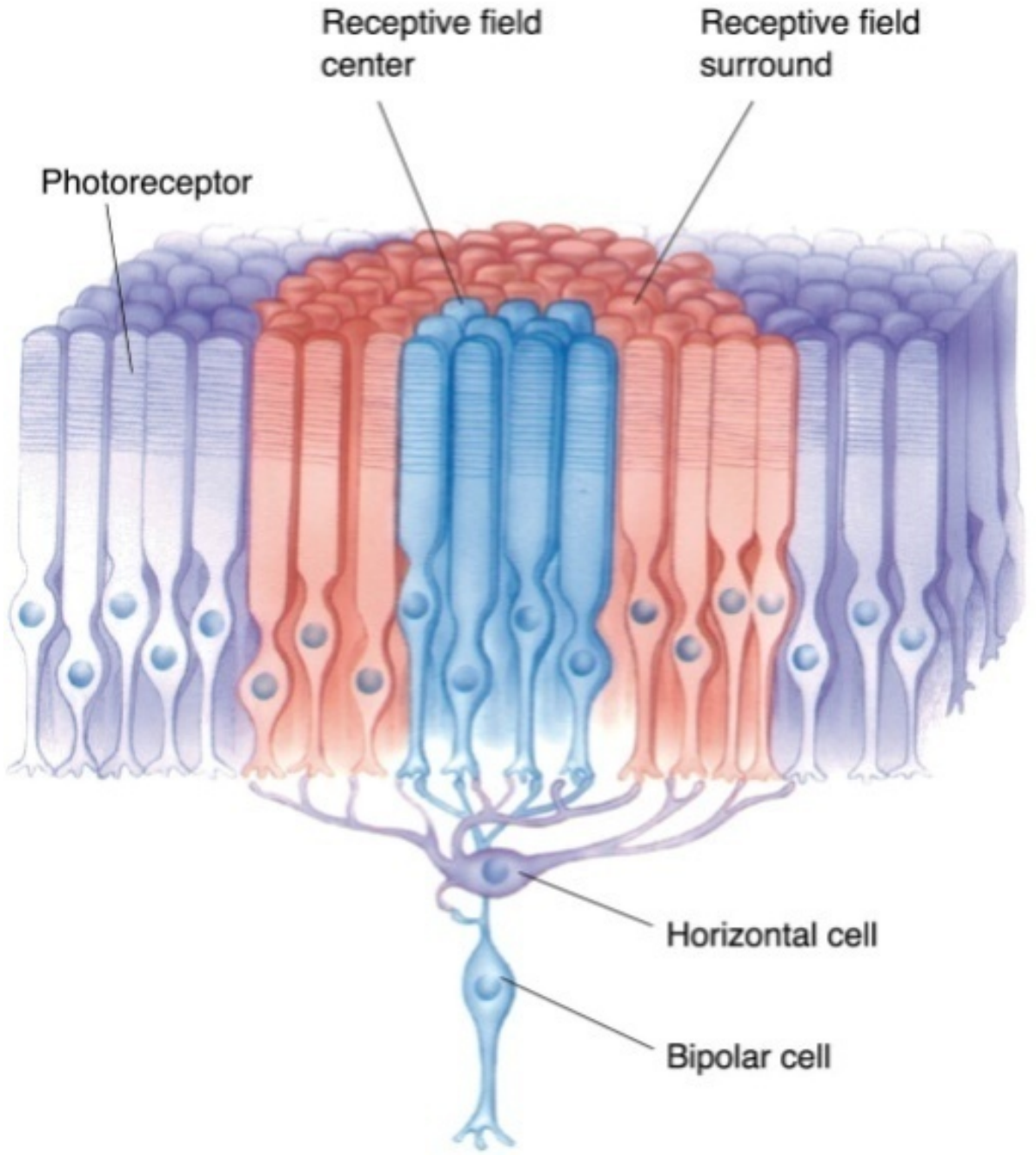
LIGHT ON SURROUND

ON BIPOLAR HYPERPOLARIZED

https://nba.uth.tmc.edu/neuroscience/s2/chapter14.html

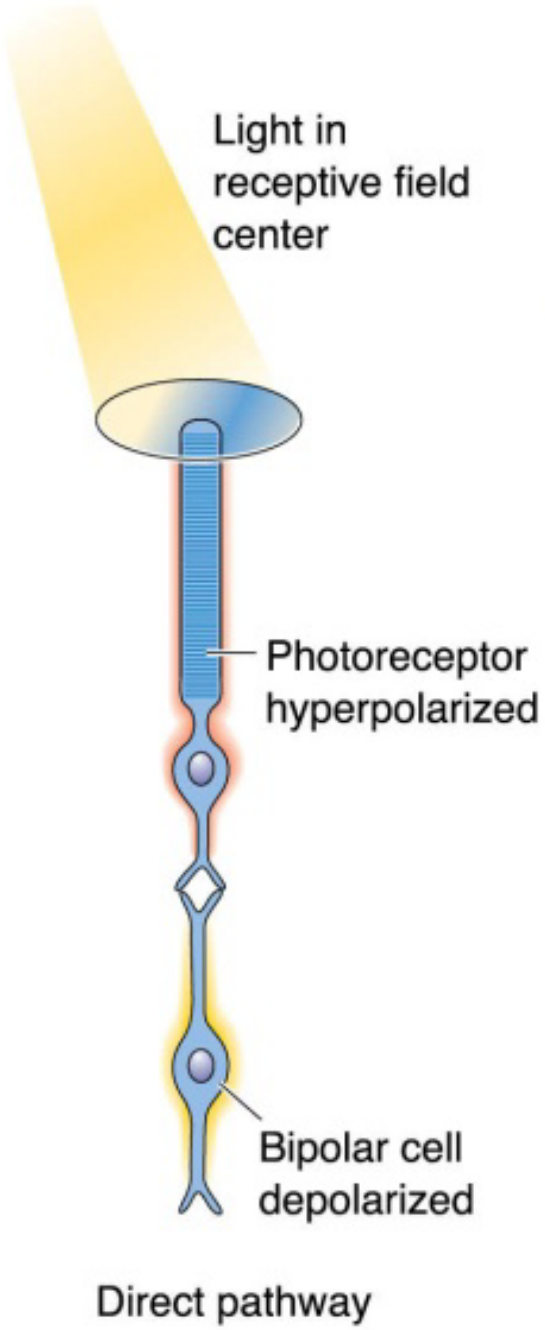
Bipolar Cell Receptive Fields

- Receptive field: ON and OFF bipolar cells
  - Receptive field: Stimulation in a small part of the visual field changes a cell's membrane potential.
  - Antagonistic center-surround receptive fields



Slide from Bear, M. et al 5th edition publisher: Wolters-Kluwer 2016

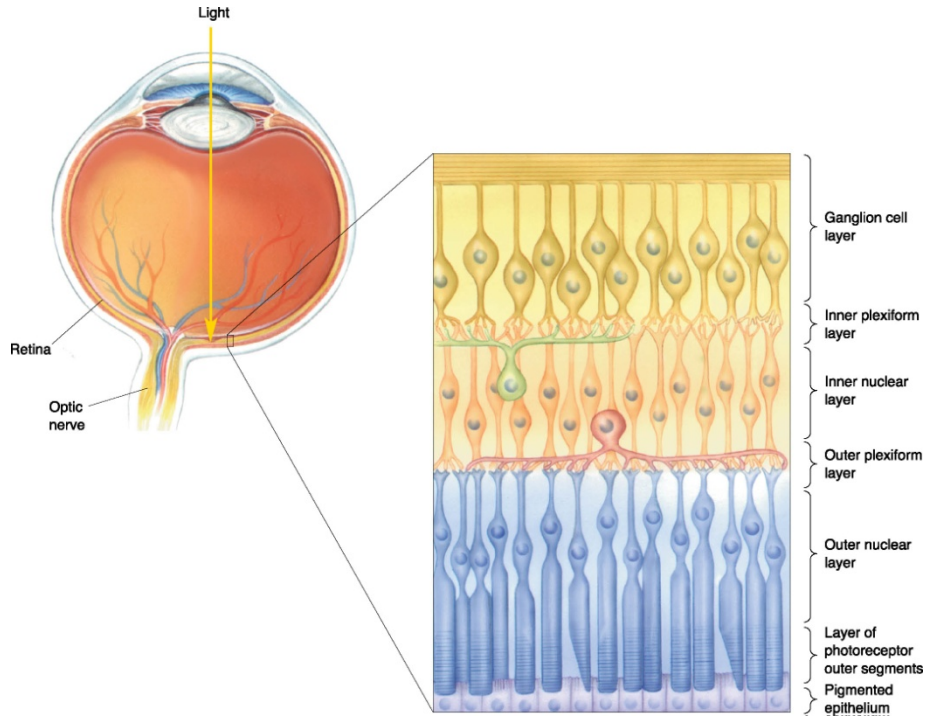
Bipolar Cell Receptive Fields—(cont.)



- ON-center bipolar cell
  - Depolarized by light in receptive field center
  - Hyperpolarized by light in receptive field surround

Laminar Organization of the Retina

- Seemingly inside-out layers
- Light passes through ganglion cells and bipolar cells before reaching photoreceptors.



Slide from Bear, M. et al 5th edition publisher: Wolters-Kluwer 2016

Connectivity Patterns

play a critical role in information-transmission functions

e.g. Acuity in Cones

e.g. Sensitivity in Rods

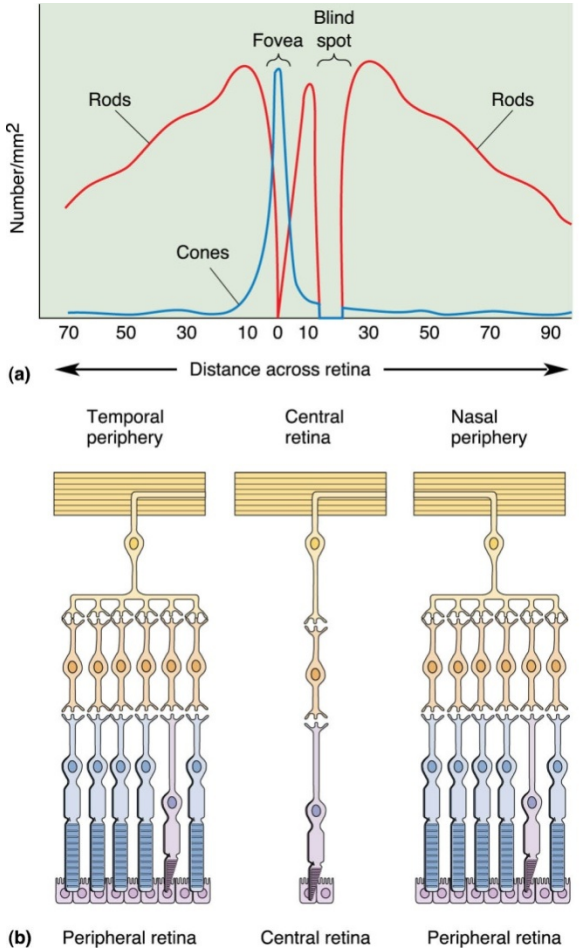
e.g. Receptive Fields

e.g. Simultaneous Contrast

Slide from Dr. Christine Johnson

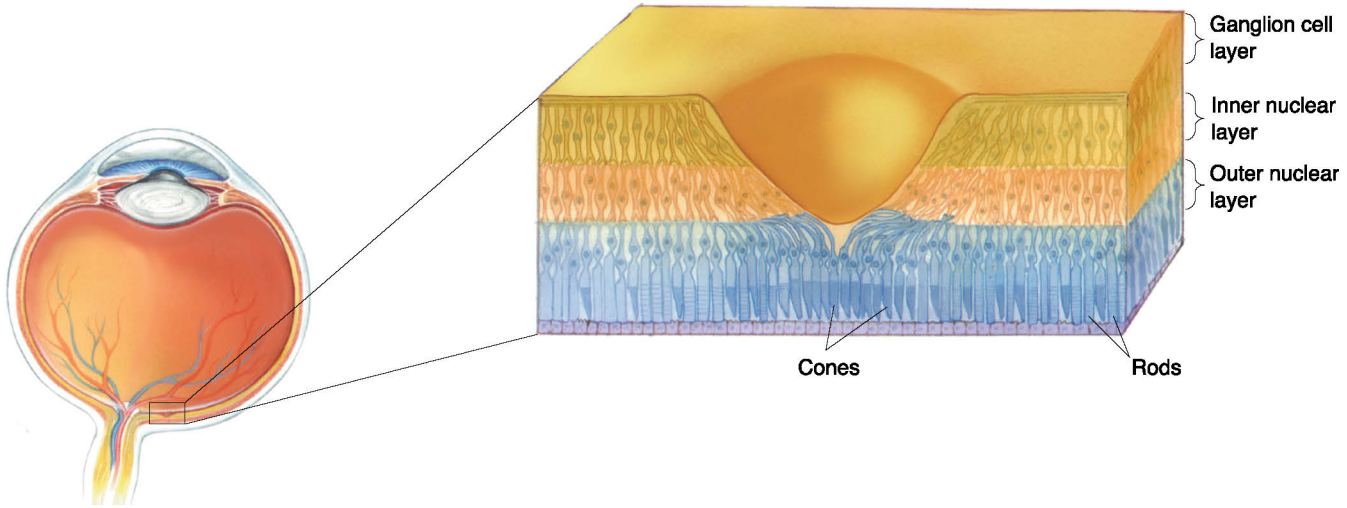
Regional Differences in Retinal Structure

- Structure varies from fovea to retinal periphery.
- Peripheral retina
  - Higher ratio of rods to cones
  - Higher ratio of photoreceptors to ganglion cells
  - More sensitive to low light



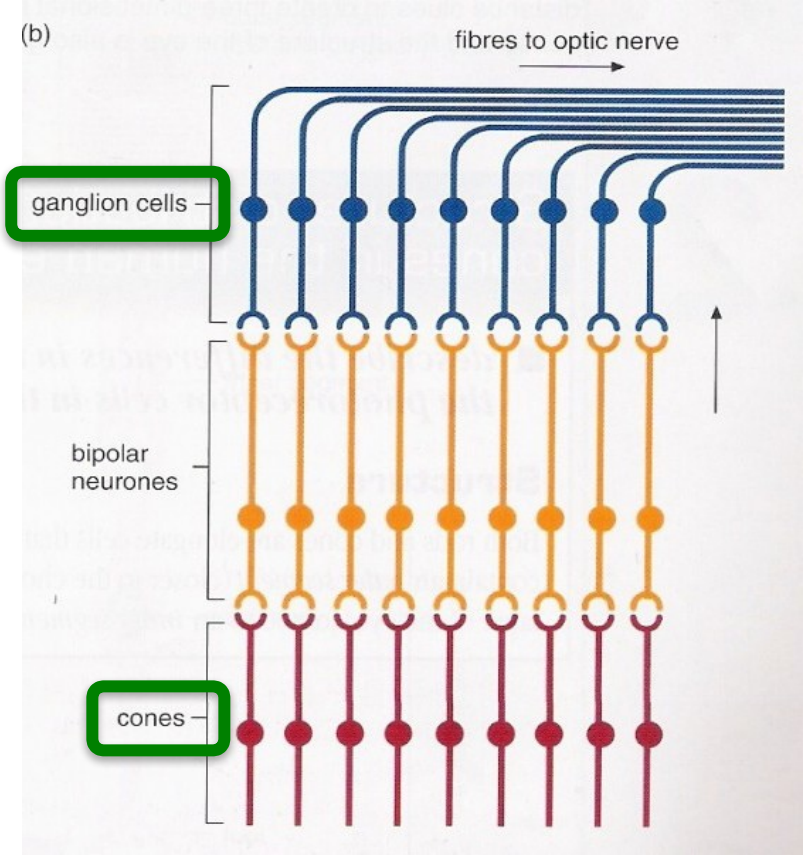
Regional Differences in Retinal Structure—(cont.)

- Cross section of fovea: pit in retina where outer layers are pushed aside
  - Maximizes visual acuity
- Central fovea: all cones (no rods)
  - Area of highest visual acuity



Convergence

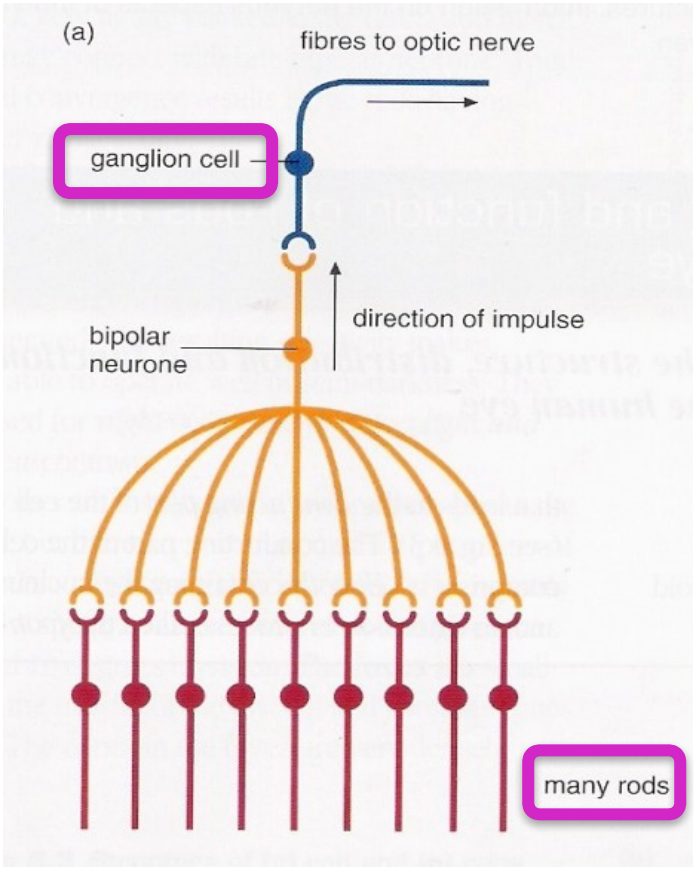
Cones show LOW convergence



Cones 1:1 or Few:1

(Cones per Ganglion,
on average across retina, **6:1**)

Rods show HIGH convergence



Rods Many:1

(Rods per Ganglion,
on average across retina, **120:1**)

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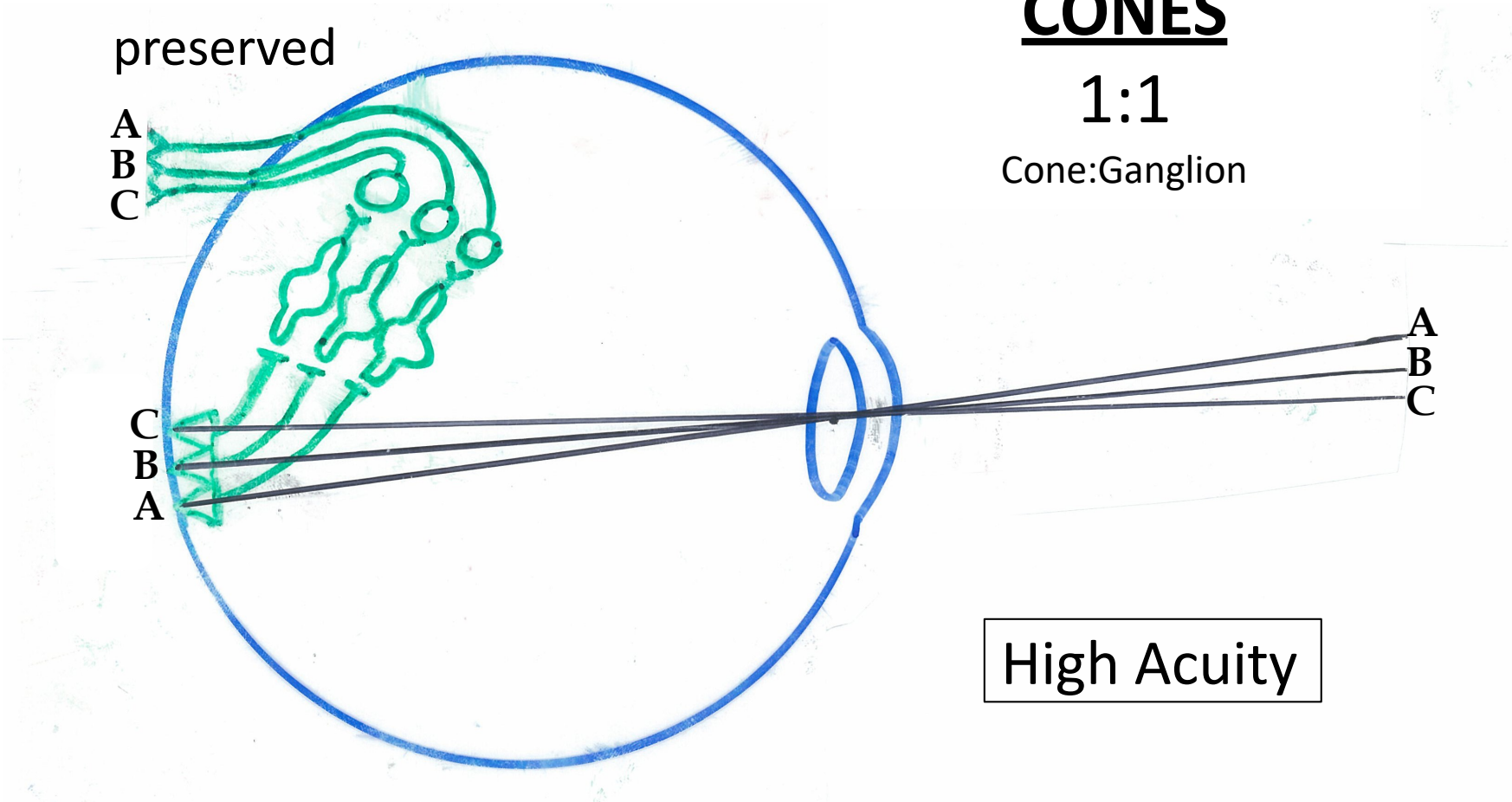
Connectivity Matters

Due to connectivity pattern, details are preserved



CONES

1:1

Cone:Ganglion

High Acuity

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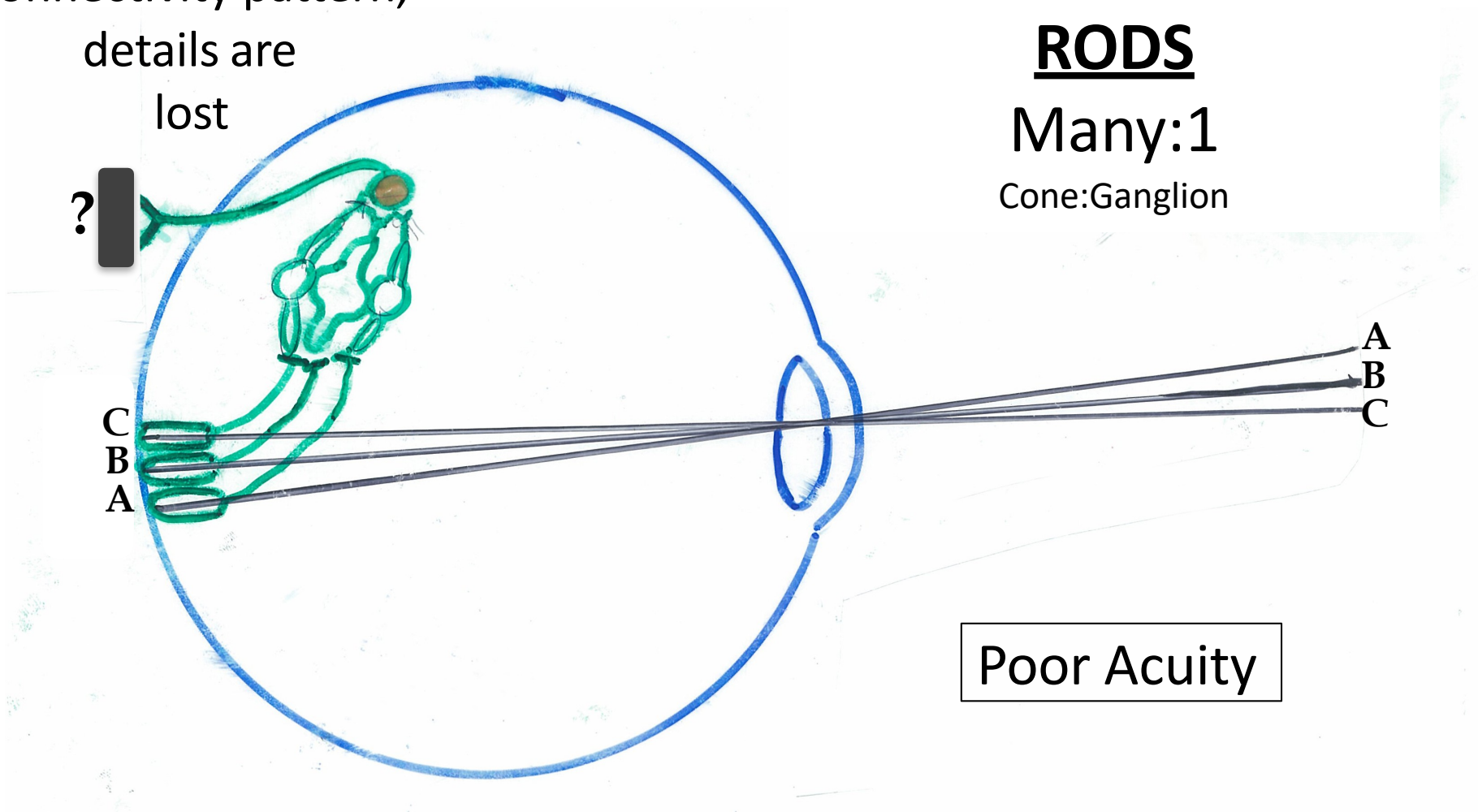
Connectivity Matters

Due to Connectivity pattern, details are lost



RODS

Many:1

Cone:Ganglion

Poor Acuity

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Connectivity Matters

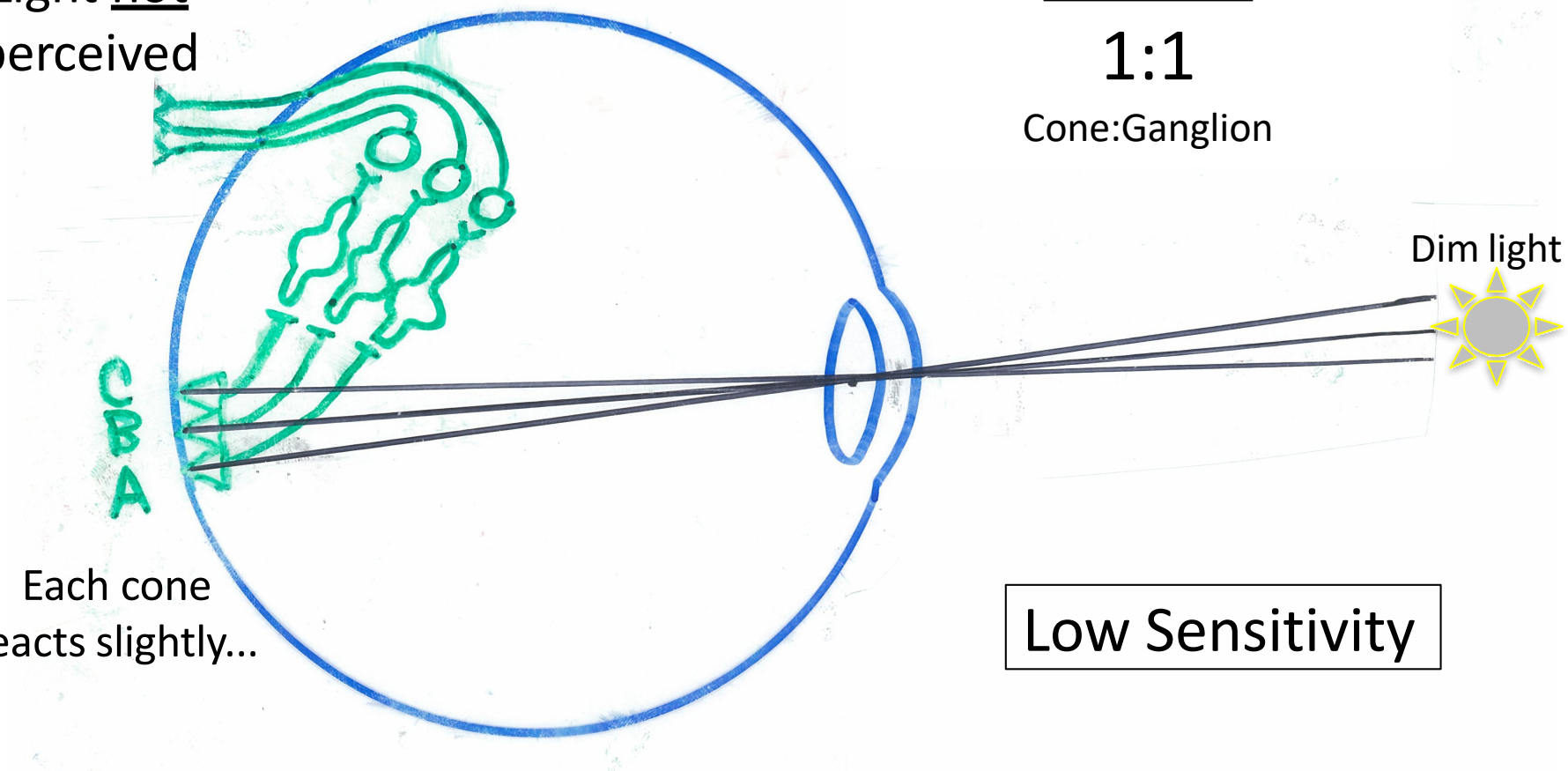
...but not enough activity from each Bipolar to cross the threshold for Ganglion to fire

Light <u>not</u> perceived

<u>CONES</u>

1:1

Cone:Ganglion



Each cone reacts slightly...

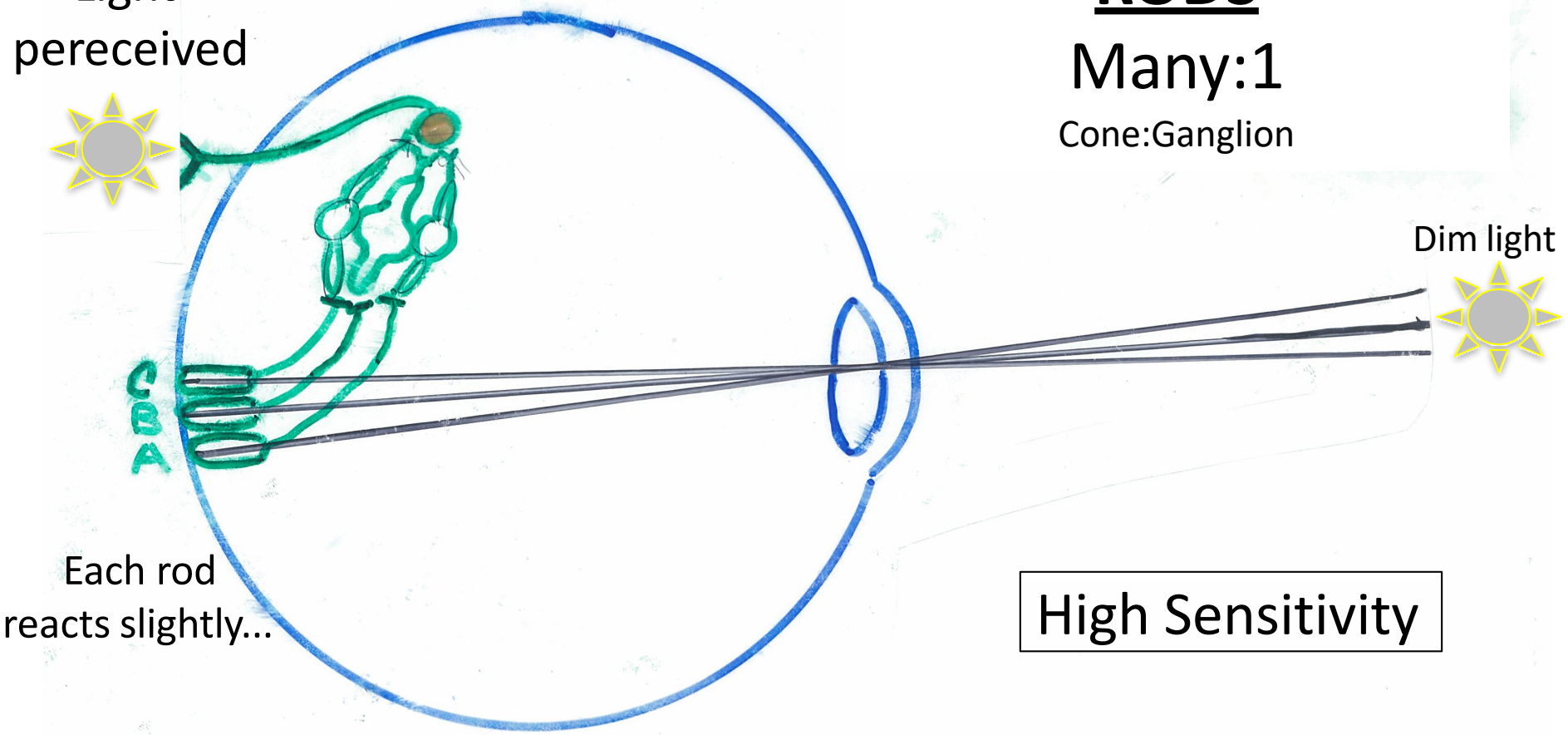
Low Sensitivity

Slide from Dr. Christine Johnson

Connectivity Matters

...and activity of Bipolars summates, sufficient to cross the threshold for Ganglion to fire

Light pereceived



RODS

Many:1

Cone:Ganglion

Dim light

Each rod reacts slightly...

High Sensitivity

Slide from Dr. Christine Johnson

Although note...

- Yes, Rod connectivity accounts, to a large extent, for the SENSITIVITY of the Rod system . . .

- But, <u>also</u>, Rods are LARGER and have MORE PHOTO-PIGMENT than Cones do, & this also contributes to sensitivity

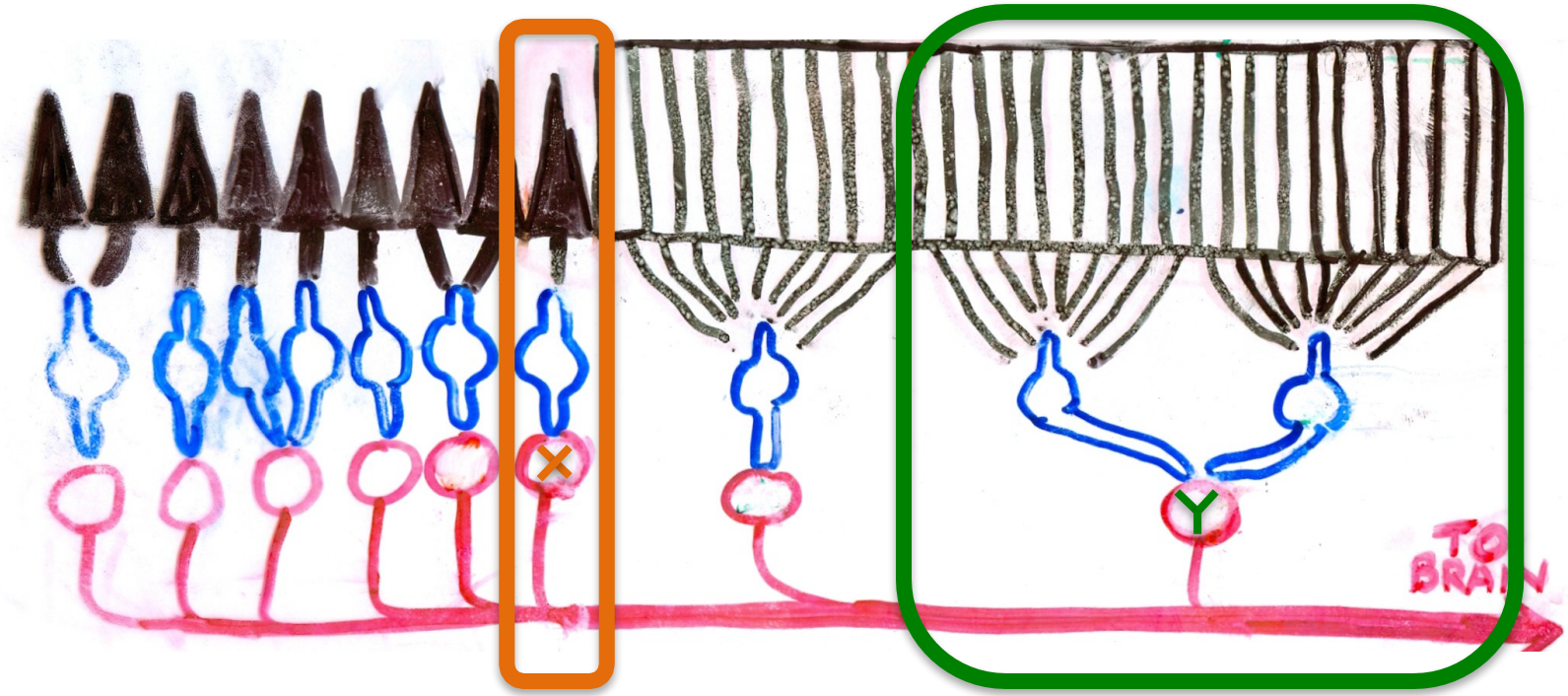
- That is, there is a better chance that a given photon of light will hit a Rod than a Cone, so in low light,
  Rods are more likely to be the receptors to respond

<u>MNEMONIC</u>
More and bigger rods,
Better the odds!

Slide from Dr. Christine Johnson

Receptive Field

= Set of Receptors whose activity influences
the activity of a "Target" cell

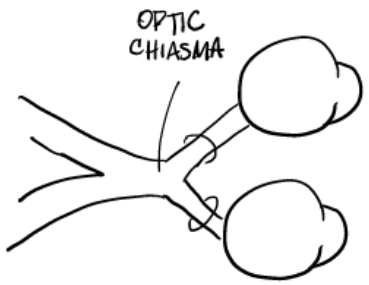


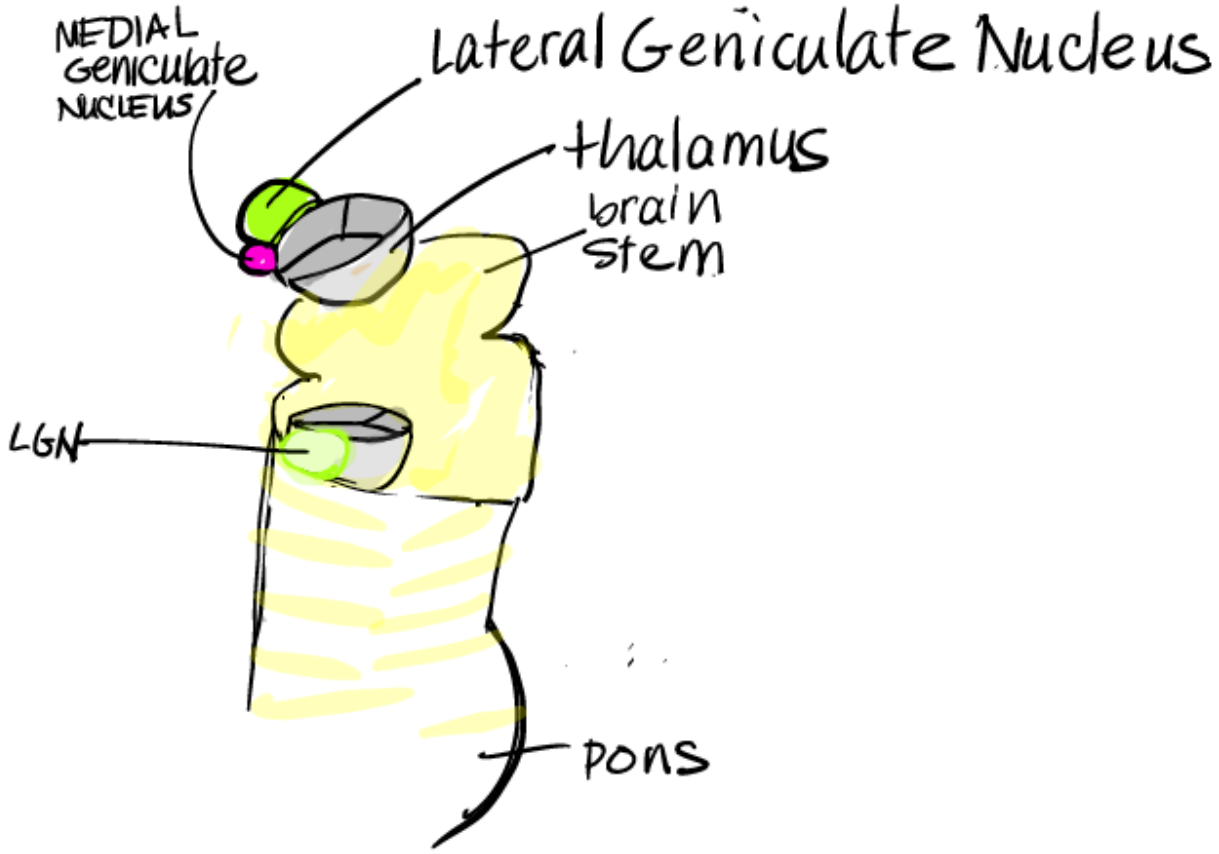
Ganglion X has a Small Receptive field

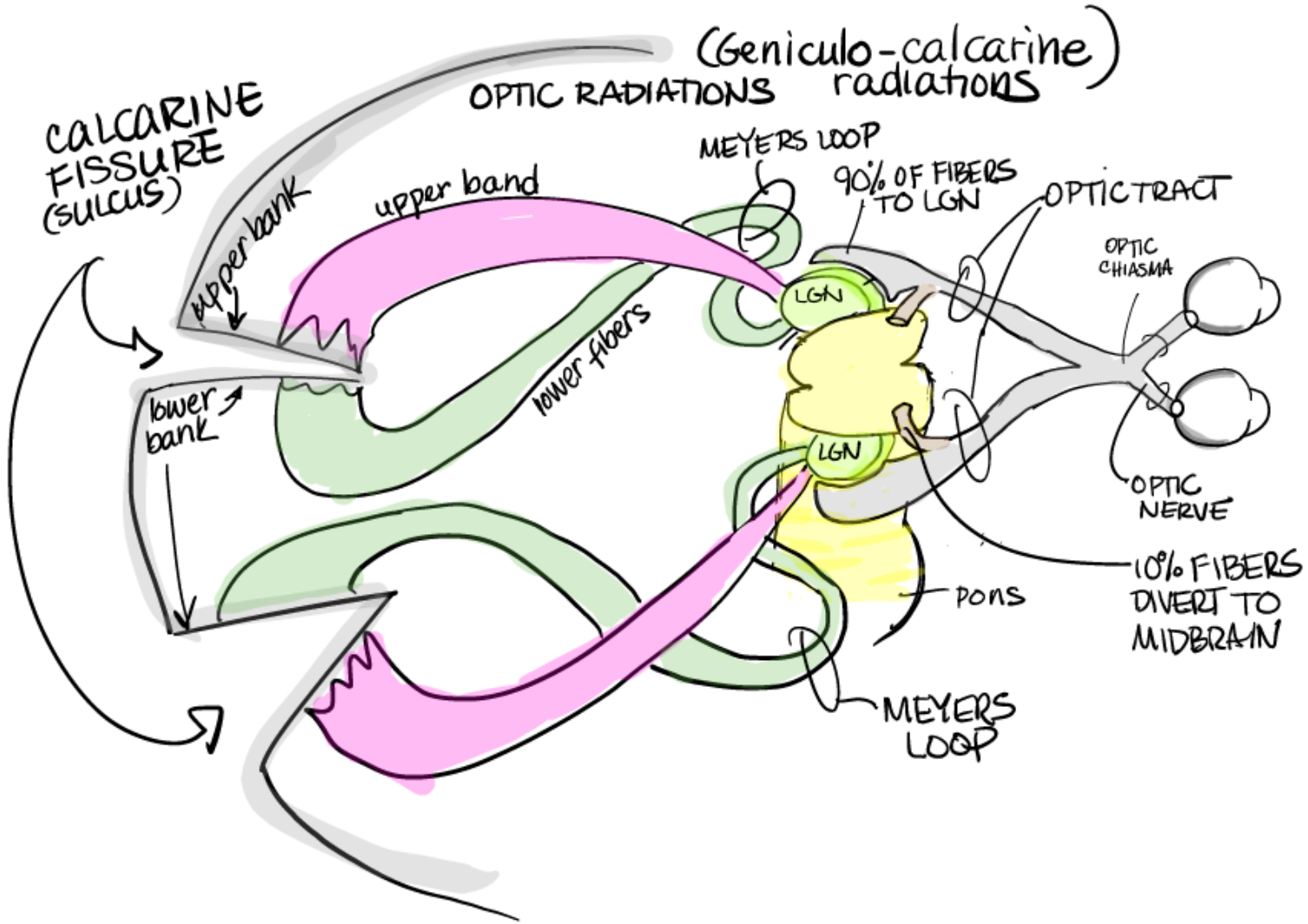
Ganglion Y has a Large Receptive field

Slide from Dr. Christine Johnson

VISUAL PATHWAYS

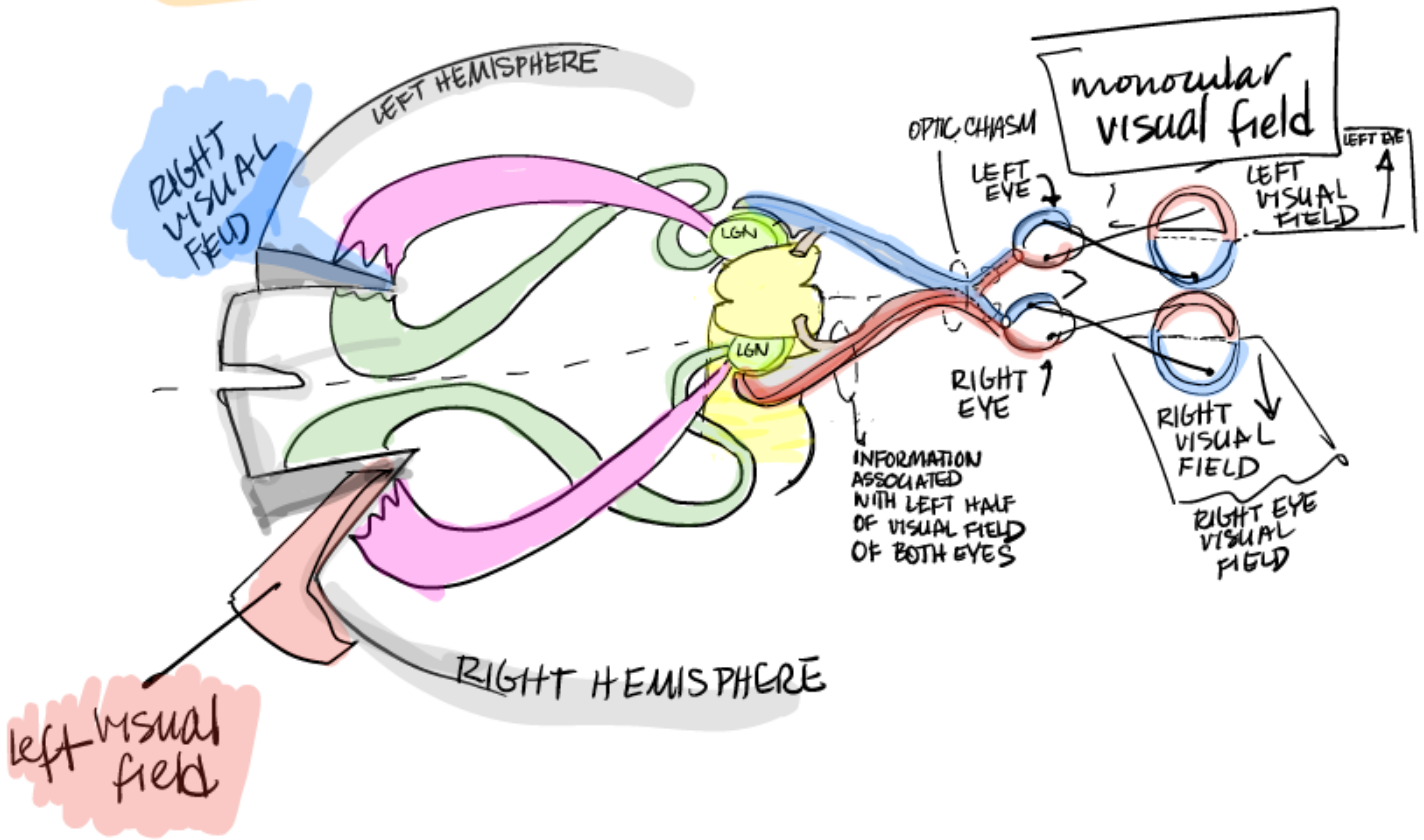


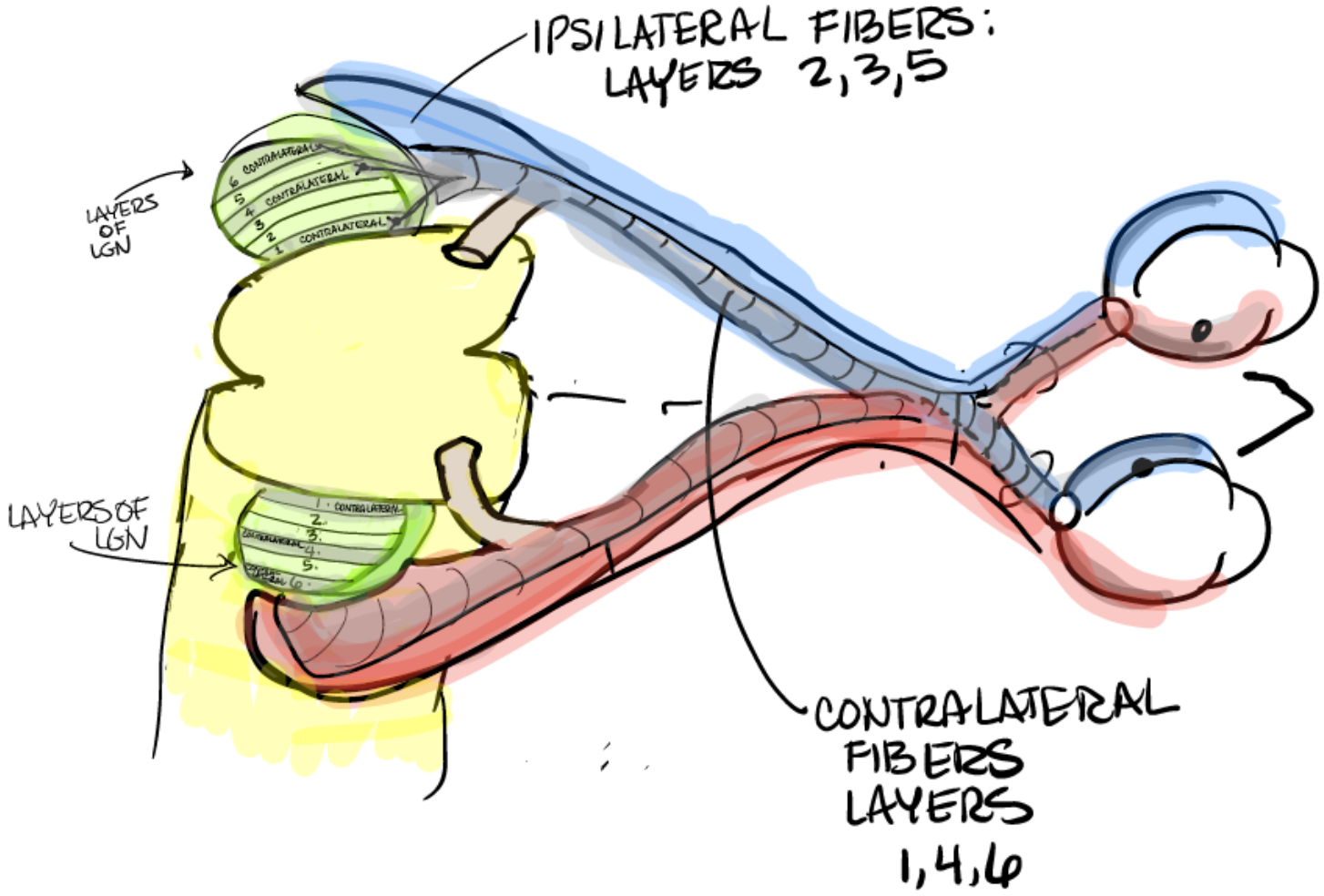


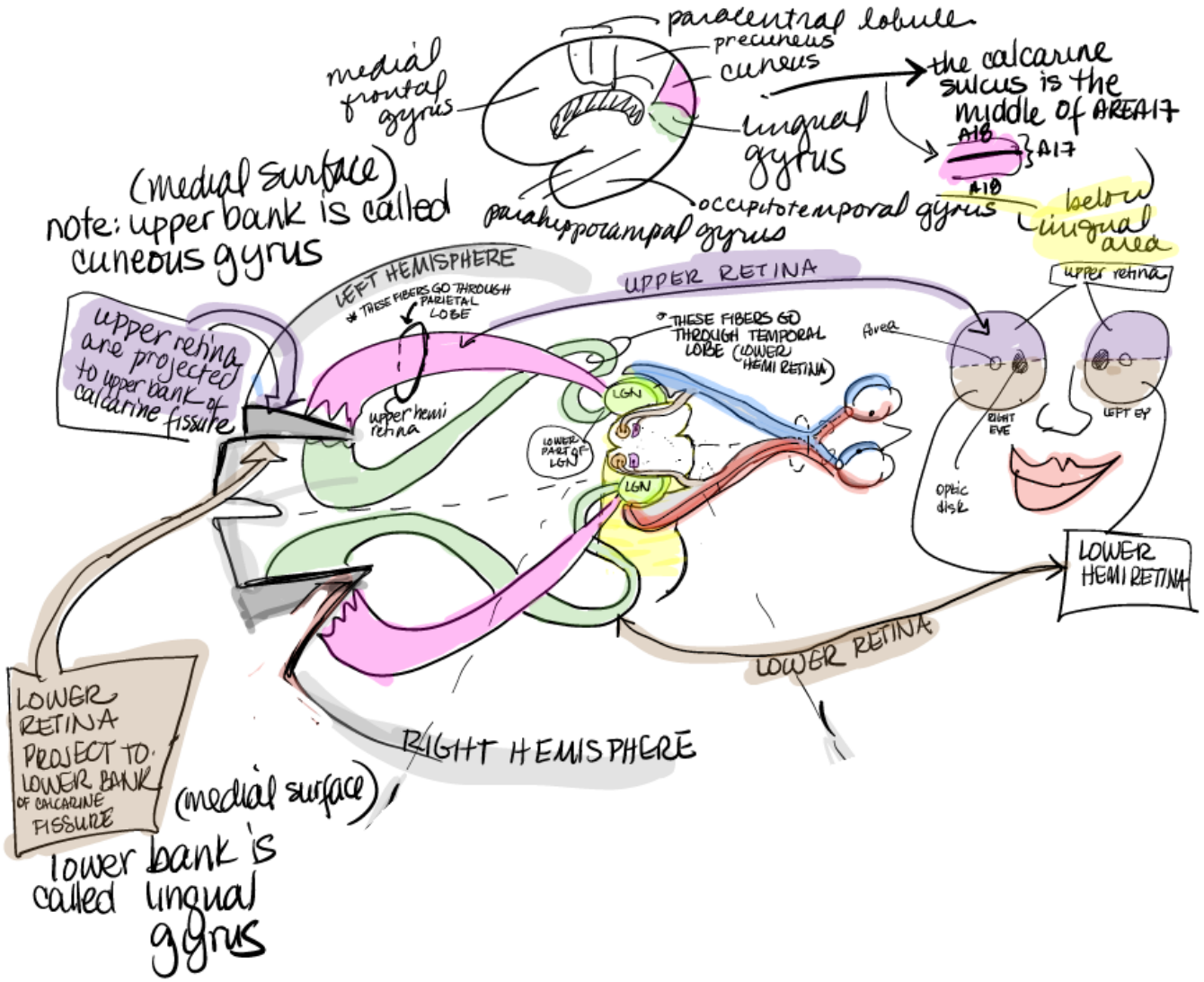

OPTIC RADIATIONS (Geniculo-calcarine radiations)
CALCARINE FISSURE (SULCUS)
upper bank
upper band
lower bank
lower fibers
MEYERS LOOP
90% OF FIBERS TO LGN
OPTIC TRACT
OPTIC CHIASMA
LGN
LGN
OPTIC NERVE
10% FIBERS DIVERT TO MIDBRAIN
PONS
MEYERS LOOP

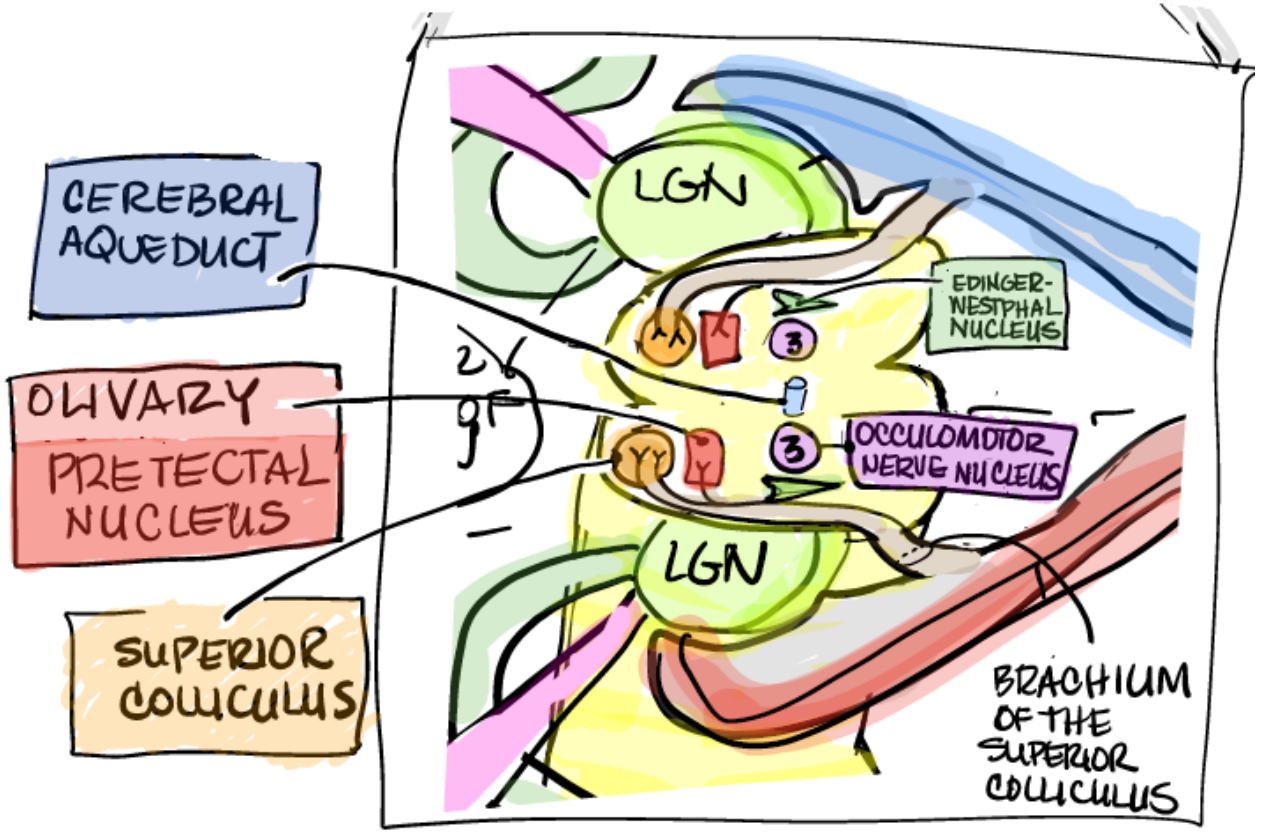
VISION IS A CROSSED SENSATION

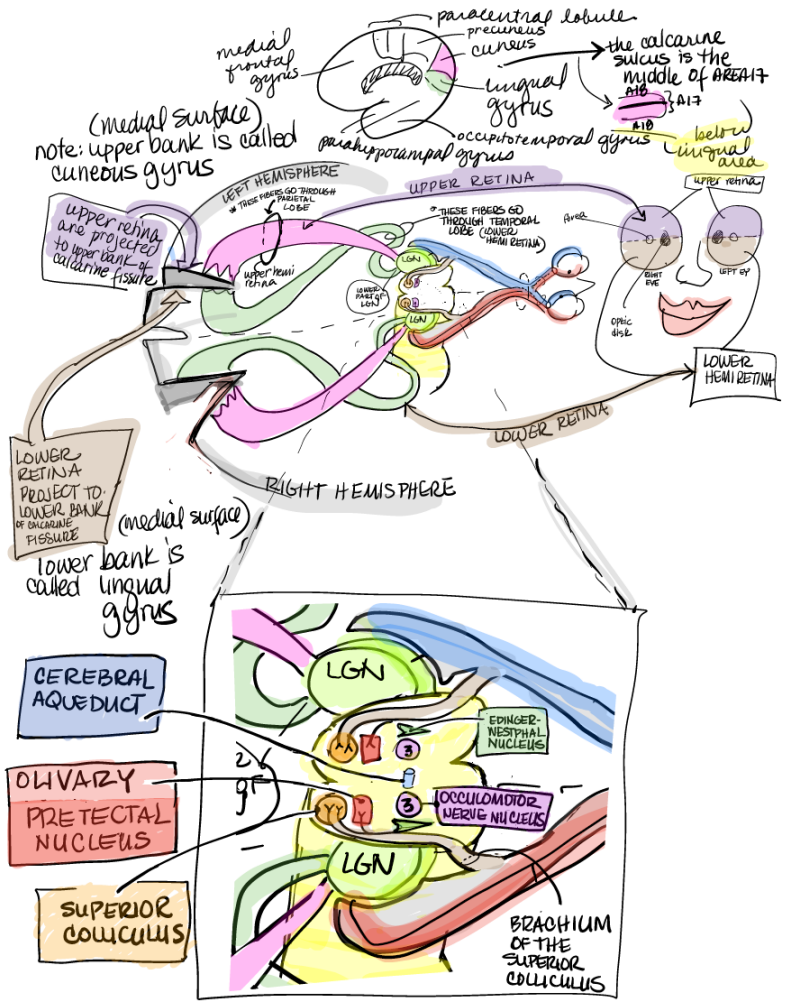
* LEFT VISUAL FIELD → RIGHT V1.




IPSILATERAL FIBERS:
LAYERS 2,3,5
LAYERS OF LGN
6 CONTRALATERAL
5
4 CONTRALATERAL
3
2
1 CONTRALATERAL
LAYERS OF LGN
1 CONTRALATERAL
2
3
4
5
6
CONTRALATERAL FIBERS LAYERS 1,4,6


paracentral lobule
precuneus
cuneus
lingual gyrus
medial frontal gyrus
occipitotemporal gyrus
parahippocampal gyrus
the calcarine sulcus is the middle of AREA17
A18
A17
A18
below lingual area
(medial surface)
note: upper bank is called cuneous gyrus
LEFT HEMISPHERE
UPPER RETINA
upper retina
upper retina are projected to upper bank of calcarine fissure
THESE FIBERS GO THROUGH PARIETAL LOBE
THESE FIBERS GO THROUGH TEMPORAL LOBE (LOWER HEMI RETINA)
fovea
upper hemi retina
LGN
LOWER PART OF LGN
LGN
RIGHT EYE
LEFT EYE
OPTIC disk
LOWER HEMI RETINA
LOWER RETINA
LOWER RETINA PROJECT TO LOWER BANK OF CALCARINE FISSURE
RIGHT HEMISPHERE
(medial surface)
lower bank is called lingual gyrus


CEREBRAL AQUEDUCT
OLIVARY PRETECTAL NUCLEUS
SUPERIOR COLLICULUS
LGN
EDINGER-WESTPHAL NUCLEUS
OCCULOMOTOR NERVE NUCLEUS
LGN
BRACHIUM OF THE SUPERIOR COLLICULUS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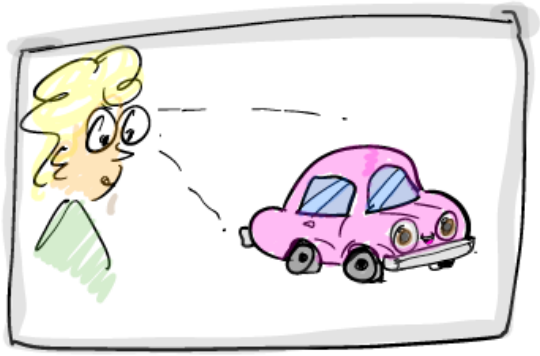
upper retina are projected to upper bank of calcarine fissure
upper hemi retina
LOWER RETINA PROJECT TO LOWER BANK OF CALCARINE FISSURE
(medial surface)
lower bank is called lingual gyrus
LOWER RETINA
LOWER HEMI RETINA
RIGHT HEMISPHERE
CEREBRAL AQUEDUCT
OLIVARY PRETECTAL NUCLEUS
SUPERIOR COLLICULUS
LGN
EDINGER-WESTPHAL NUCLEUS
OCCULOMOTOR NERVE NUCLEUS
LGN
BRACHIUM OF THE SUPERIOR COLLICULUS

Feature Detection

"EXTRACTING INFORMATION" when we look at an object:



PARALLEL PROCESSING

1. COLOR INFO.
   - ↳ CONES
     - RED 60%
     - GREEN 30%
     - BLUE 10%
2. FORM INFO
   - ↳ WHAT ARE THE BOUNDARIES OF OBJECT?

* PARVO PATHWAY (PARVOCELLULAR PATHWAY) P-PATHWAY

P-CELL

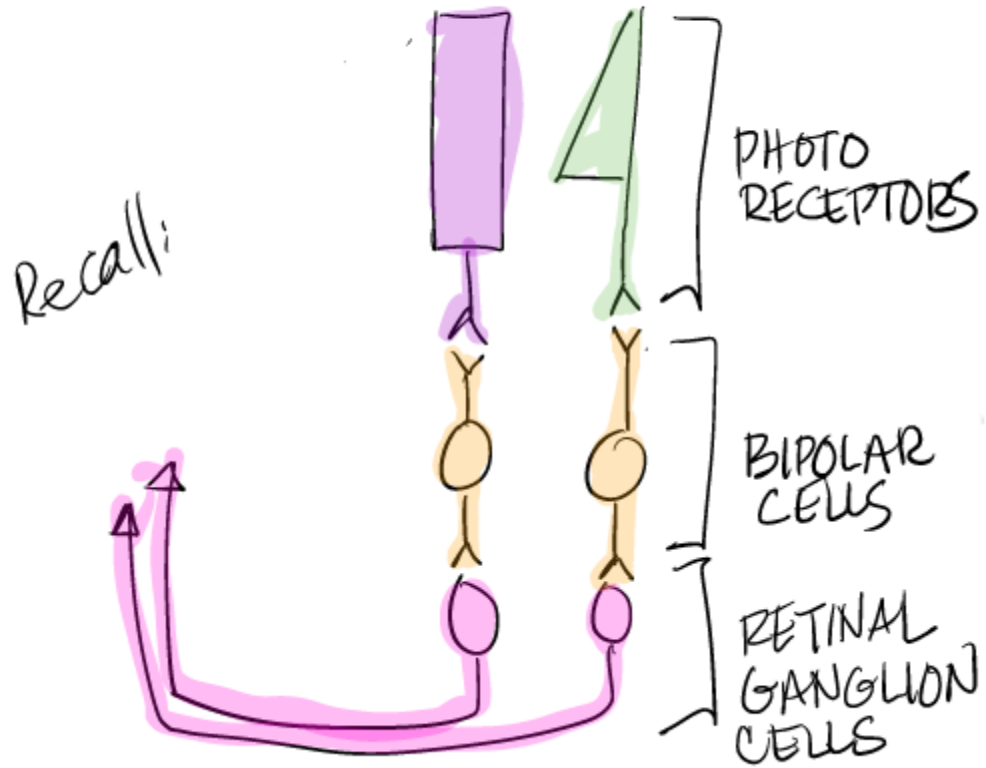
* very good spatial resolution → high level of detailed information
* poor temporal resolution (motion)
* USED FOR STATIONARY OBECTS
* COLOR INFORMATION) - CONES

③ MOTION

* Magno (M-PATHWAY (MAGNOCELLULAR PATHWAY))

M-CELL

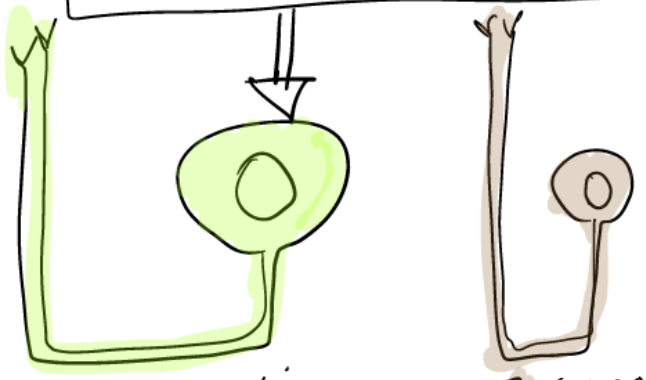
* motion tracking
* high temporal resolution
* "blurry image"
* no color information
* has high contrast sensitivity



NOTE
the M- & P- pathways respond to different stimuli

THE DIFFERENCE BETWEEN:

- MAGNO (M) PATHWAY
- PARVO (P) PATHWAY



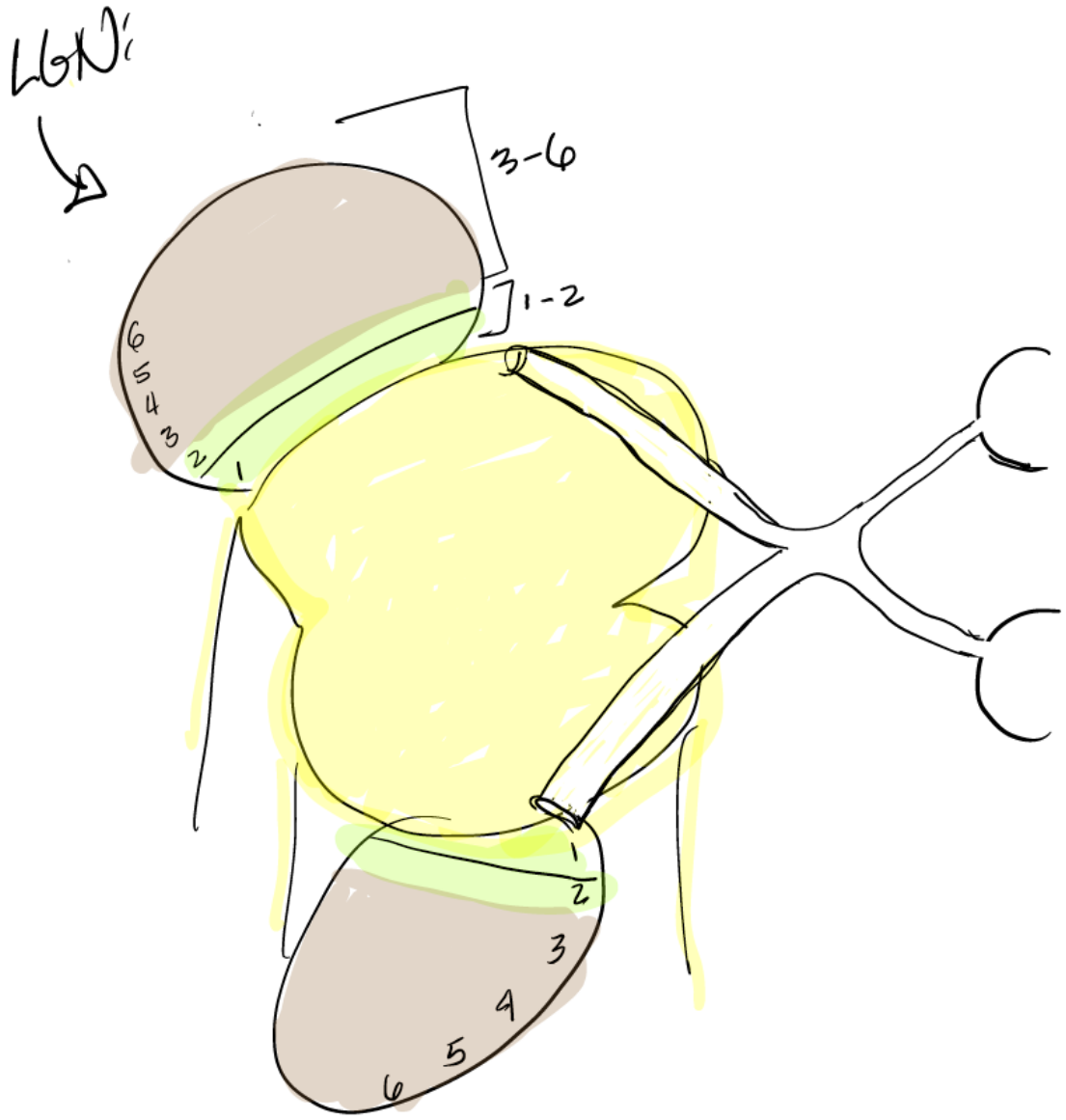
M-Ganglion cells

* transient response
* larger cell body ("parasol")
* project to layers 1 & 2 in LGN (CO-RICH LAYERS)
* PROJECT (4cα) V1 (CO: cytochrome oxydase darkly reacting)
* V2 → THICK STRIPES

P-Ganglion cells

* small cell body (midget)
* sustained response
* project to layers 3-6 in LGN
* P OJET TO V1: [4A & 4Cβ]
* BOTH CO-RICH & NON CO-RICH] LGN layers
* CO-RICH LAYER IN V1
* P-pathway is further divided into: streams

- P-B
  - CO-Blobs in V1
  - thin stripes V2
- P-I
  - non-CO inter BLOBS V1
  - inter stripes of V2


LGN
3-6
1-2
6
5
4
3
2
1
1
2
3
4
5
6

Slide from Dr. Christine Johnson