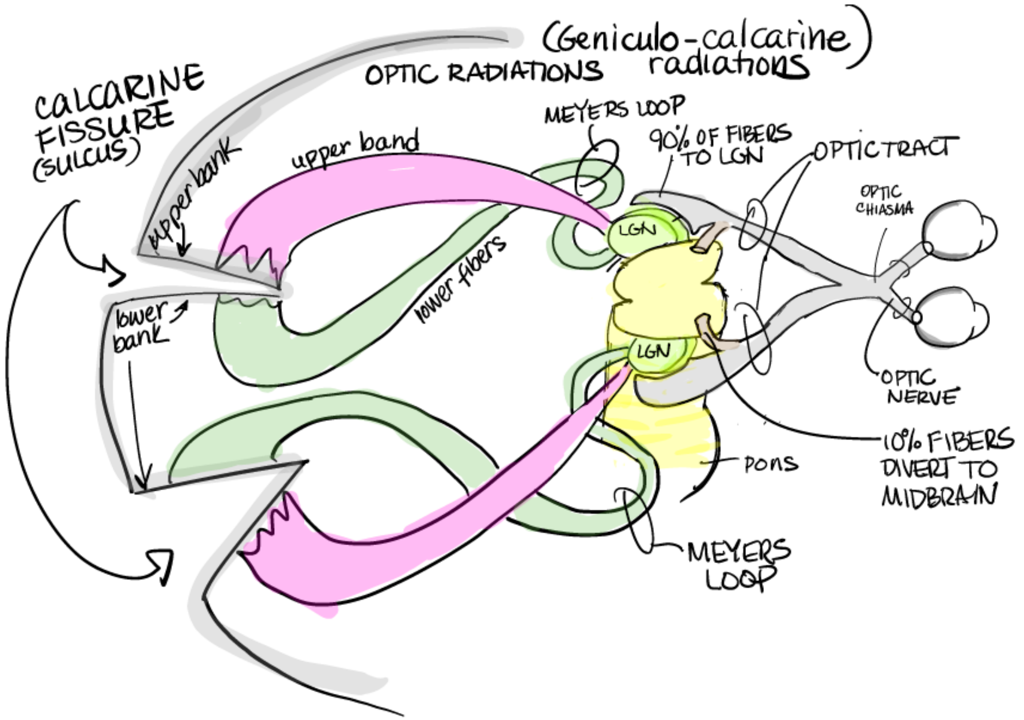
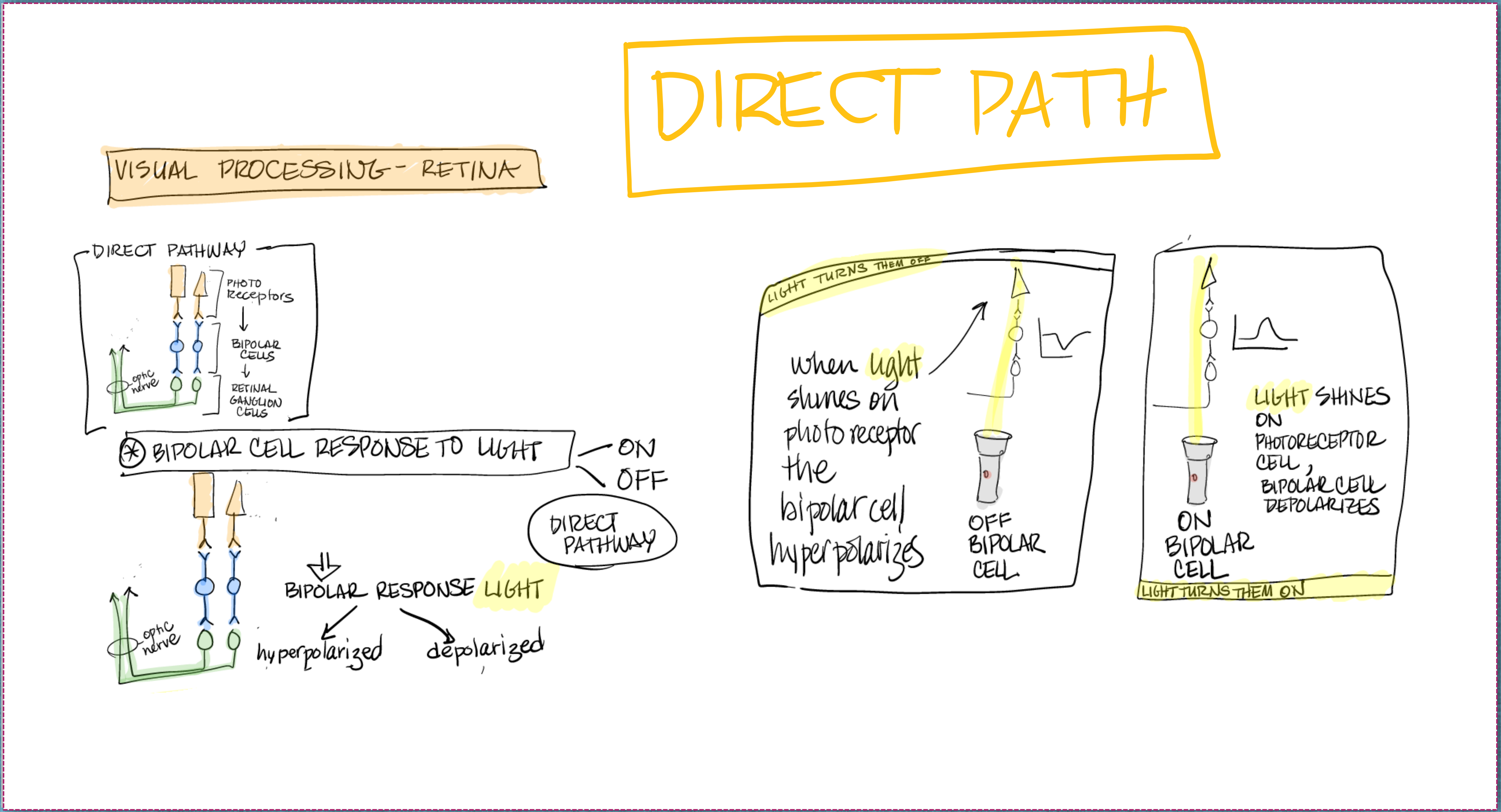
Visual Signaling

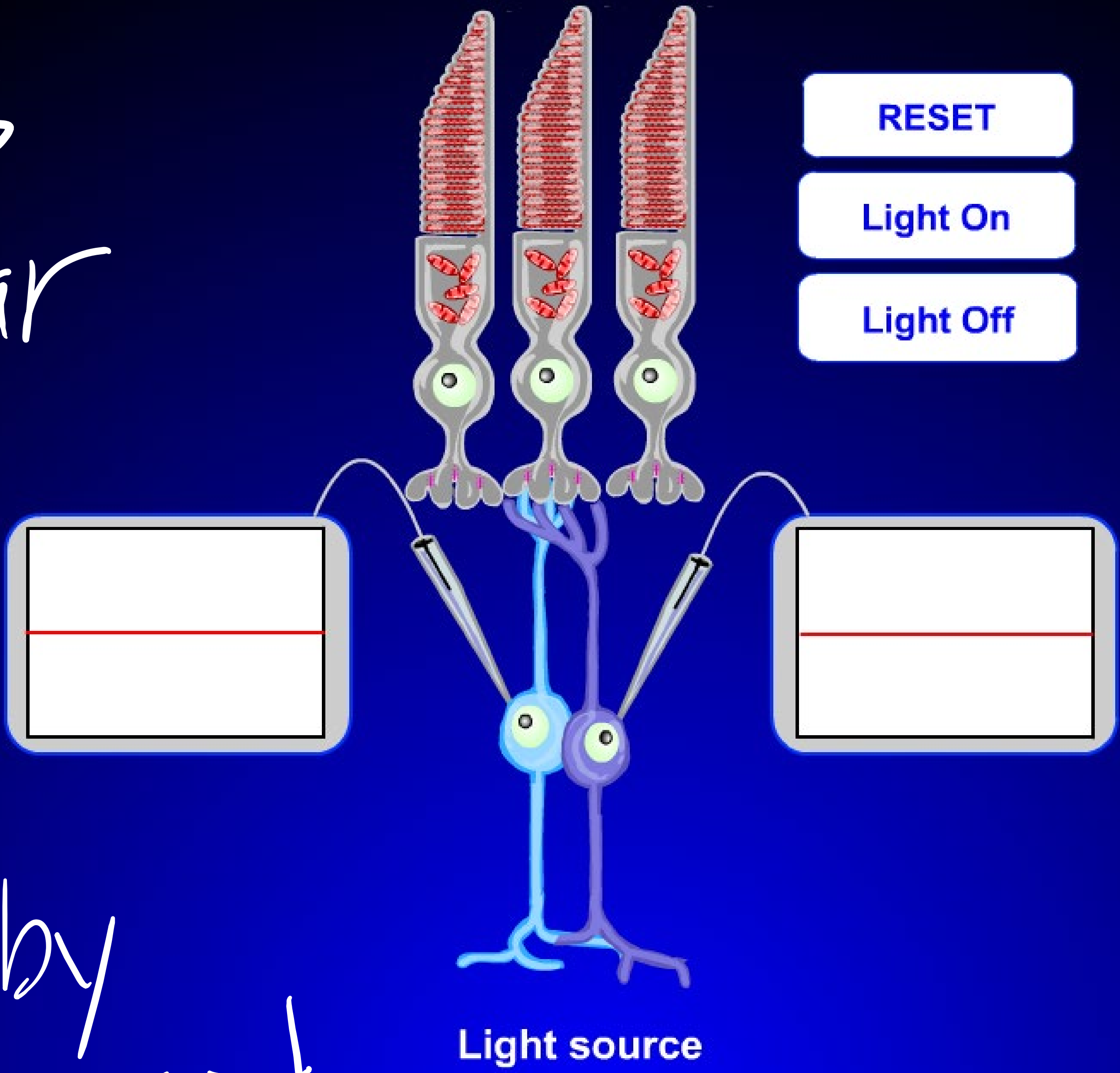
Part 2



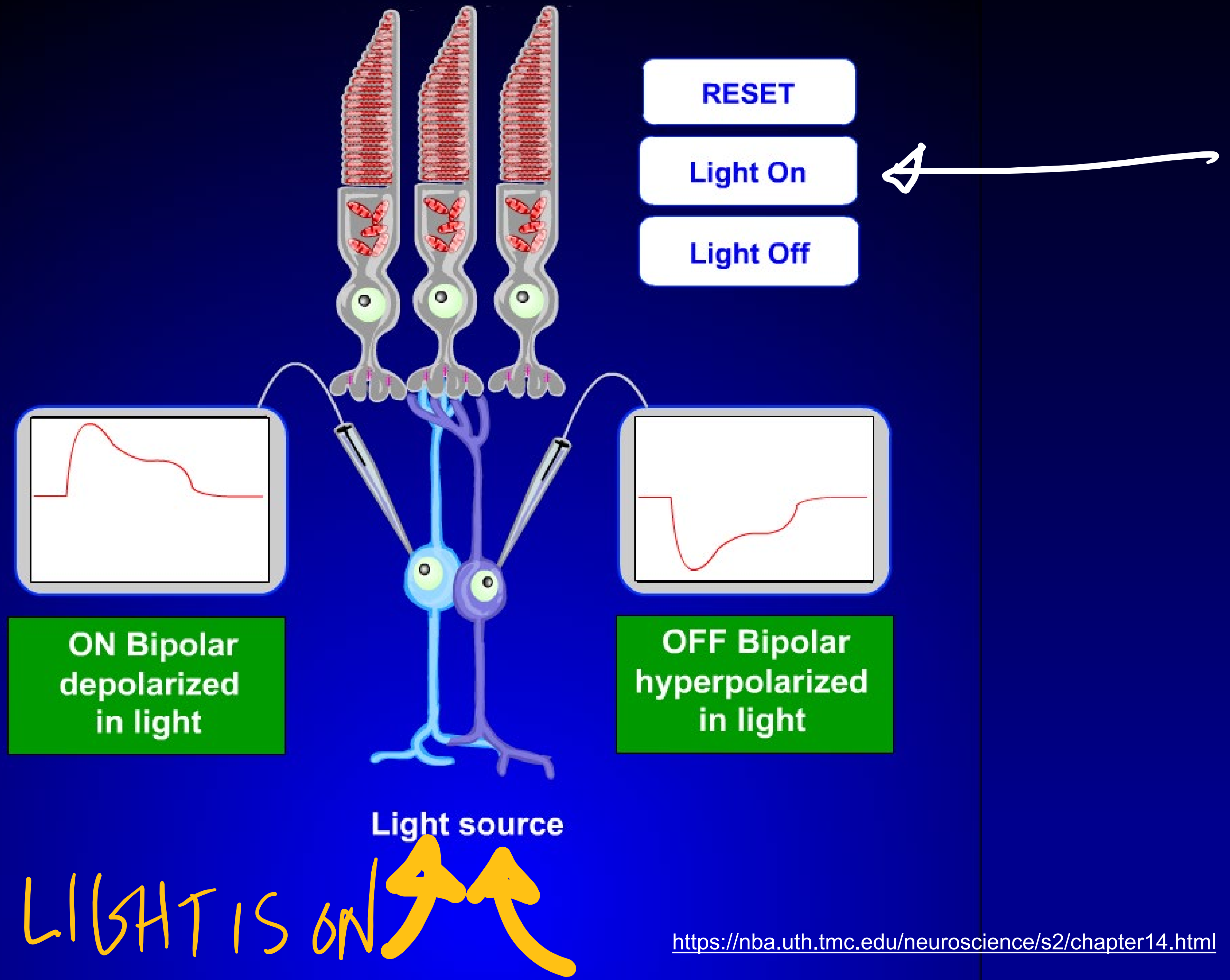

DIRECT PATH
VISUAL PROCESSING - RETINA
DIRECT PATHWAY
PHOTO Receptors
BIPOLAR CELLS
RETINAL GANGLION CELLS
optic nerve
BIPOLAR CELL RESPONSE TO LIGHT
ON
OFF
DIRECT PATHWAY
BIPOLAR RESPONSE LIGHT
hyperpolarized
depolarized
optic nerve
LIGHT TURNS THEM OFF
when light shines on photo receptor the bipolar cell hyperpolarizes
OFF BIPOLAR CELL
LIGHT SHINES ON PHOTORECEPTOR CELL, BIPOLAR CELL DEPOLARIZES
ON BIPOLAR CELL
LIGHT TURNS THEM ON

Two types of bipolar cells

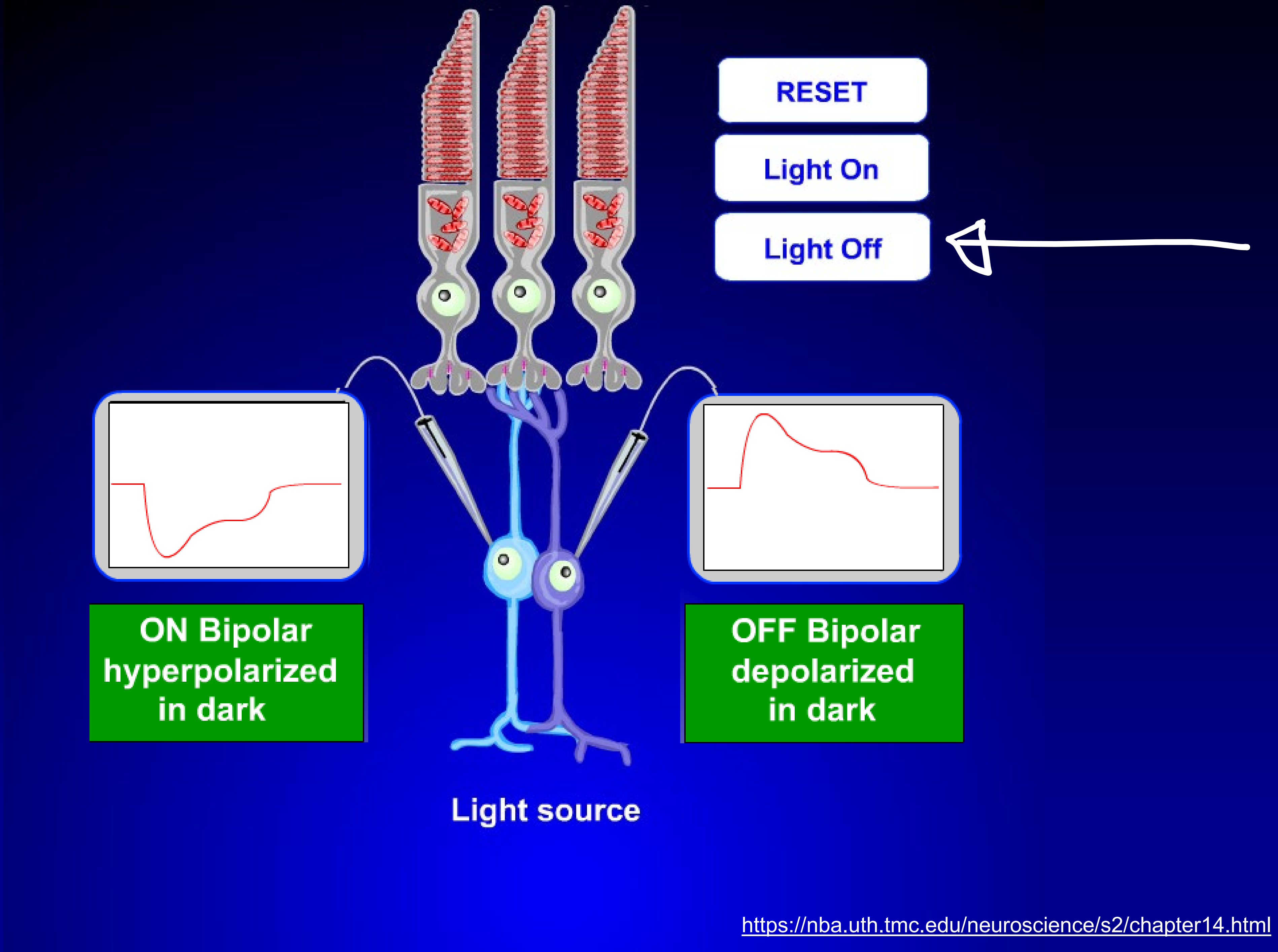
they are classified by how they respond to light



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



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


RESET
Light On
Light Off
ON Bipolar
hyperpolarized
in dark
OFF Bipolar
depolarized
in dark
Light source
https://nba.uth.tmc.edu/neuroscience/s2/chapter14.html

THE MECHANISM UNDERLYING ON & OFF BIPOLAR CELLS

1. ALL PHOTORECEPTORS RELEASE GLU IN THE DARK

2. BIPOLAR CELLS HAVE TWO RESPONSES

* BIPOLAR CELL RESPONSE TO GLUTAMATE!

* BIPOLAR CELL RESPONSE TO GLUTAMATE!

→ DEPOLARIZE

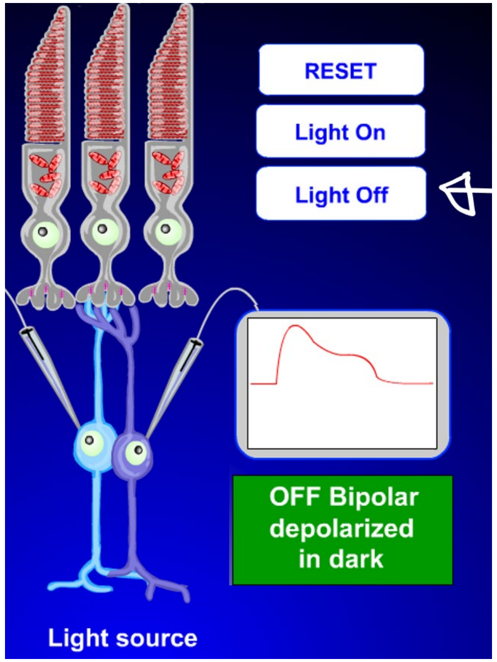
→ HYPERPOLARIZE

* BIPOLAR CELL RESPONSE TO GLUTAMATE!

DEPOLARIZE

OFF CELL

HYPERPOLARIZE

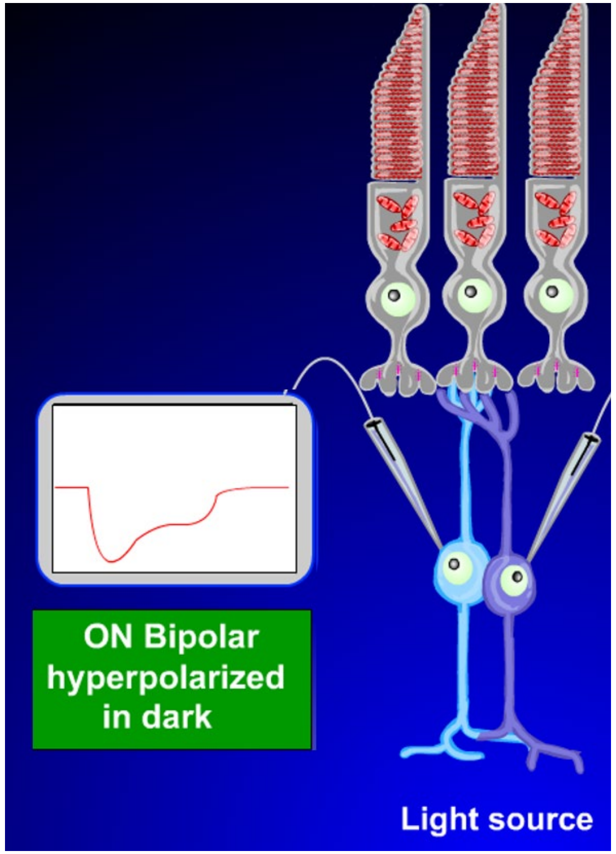


* BIPOLAR CELL RESPONSE TO GLUTAMATE!

→ DEPOLARIZE

→ HYPERPOLARIZE

ON-CELL



* BIPOLAR CELL RESPONSE TO GLUTAMATE!

DEPOLARIZE

(ionotropic) AMPA

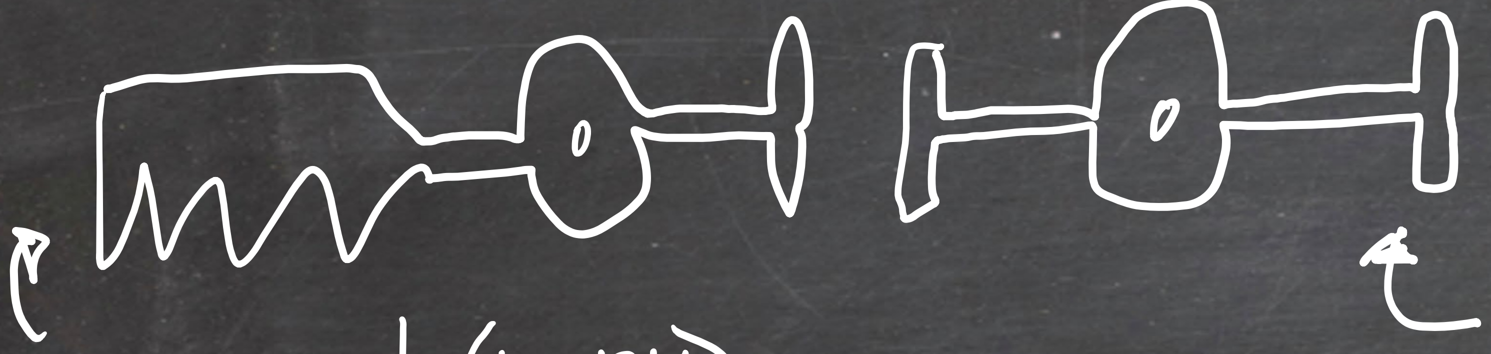
HYPERPOLARIZE

(metabotropic)

mGLUR6

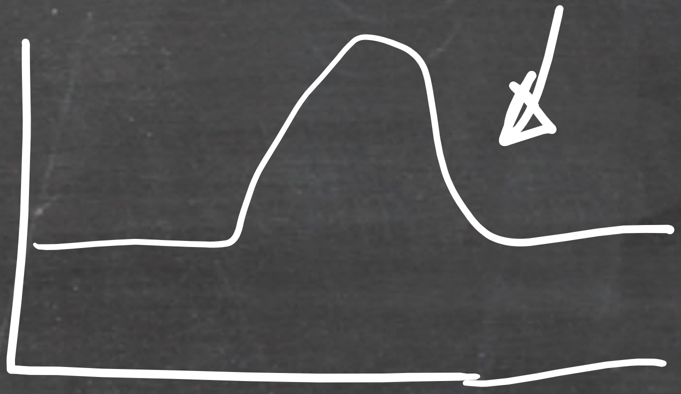
Depends on receptor type

OFF- BIPOLAR CELLS

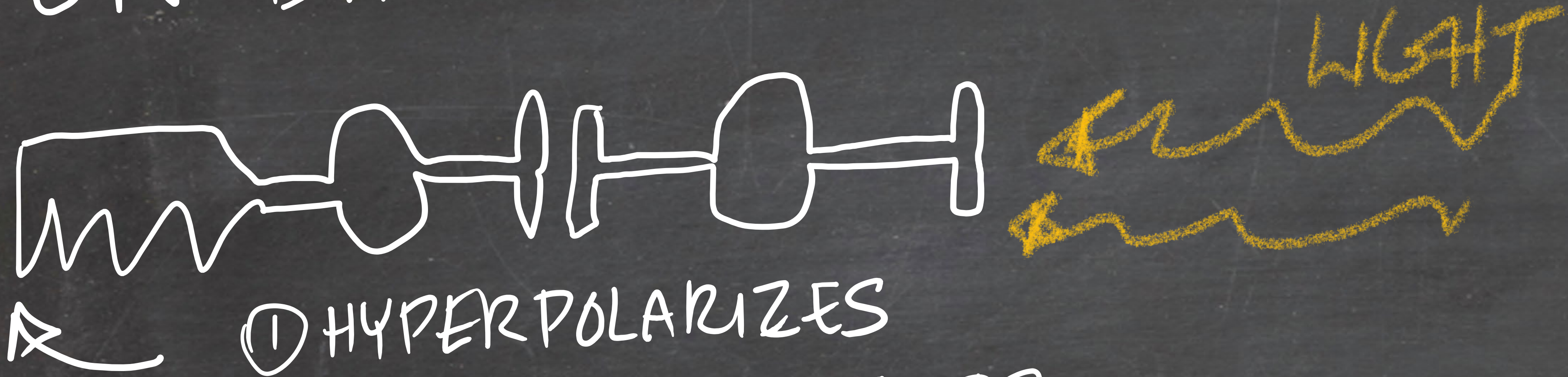


1. Depol (DARK)
2. GLUTAMATE RELEASED (DARK)

GLUTAMATE DEPOLARIZES



ON- BIPOLAR CELLS

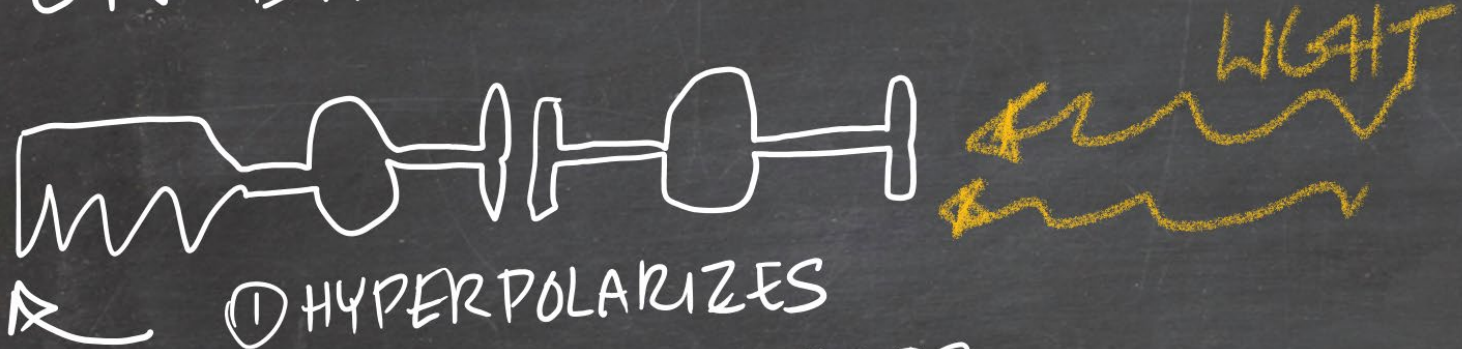


① HYPERPOLARIZES

② GLUTAMATE STOPS

⊗ ON-BIPOLAR CELLS ARE INHIBITED BY GLUTAMATE

ON-BIPOLAR CELLS



1. HYPERPOLARIZES
2. GLUTAMATE STOPS

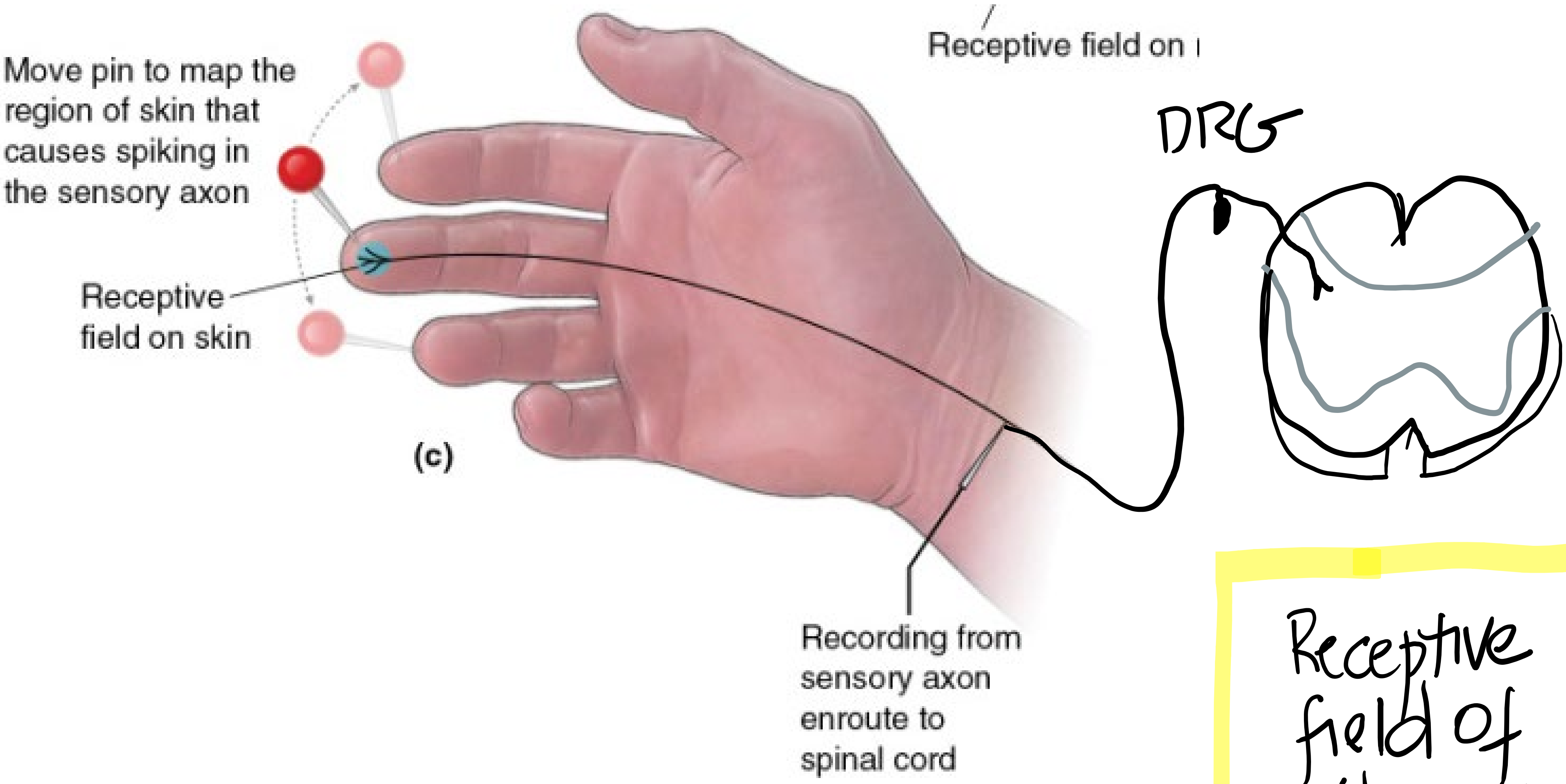
WOW

* ON-BIPOLAR CELLS ARE INHIBITED BY GLUTAMATE

WITHOUT INHIBITION

ON-BIPOLAR CELLS DEPOL.

The Receptive Field

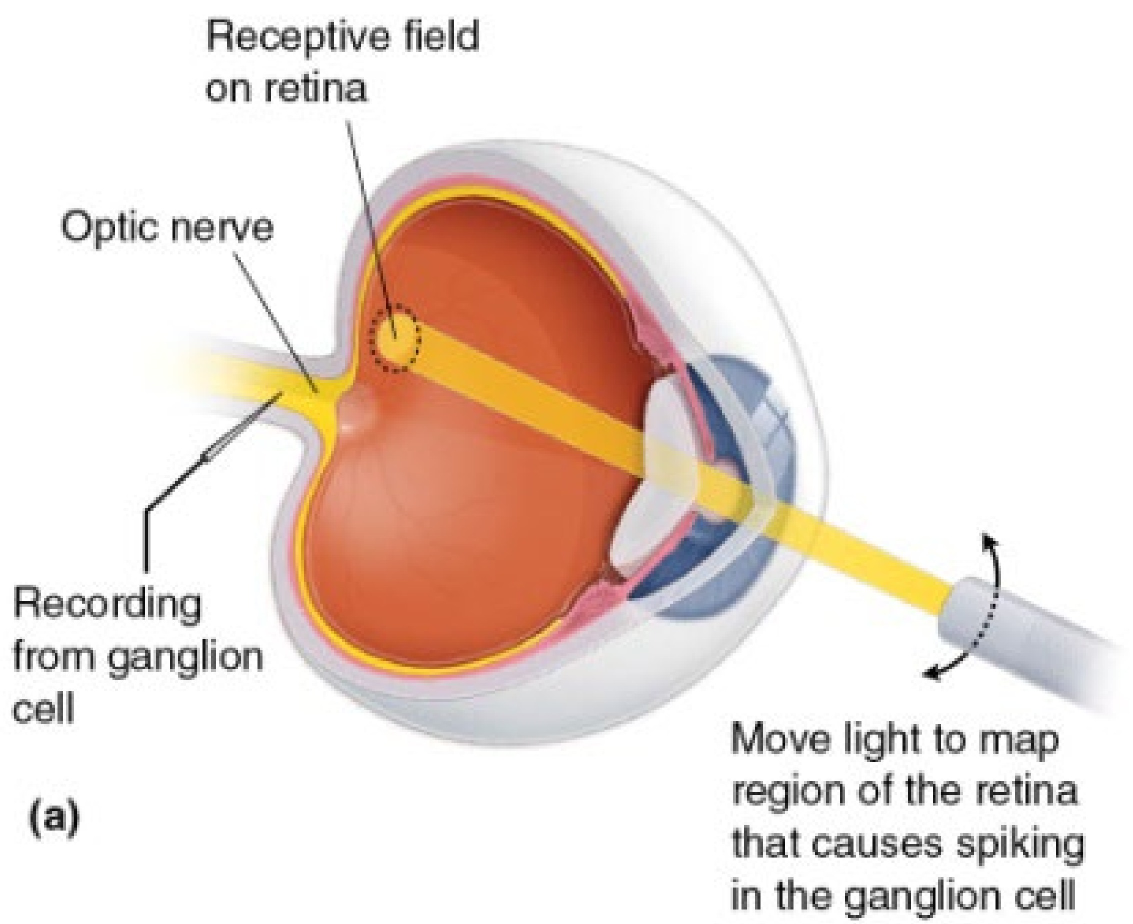


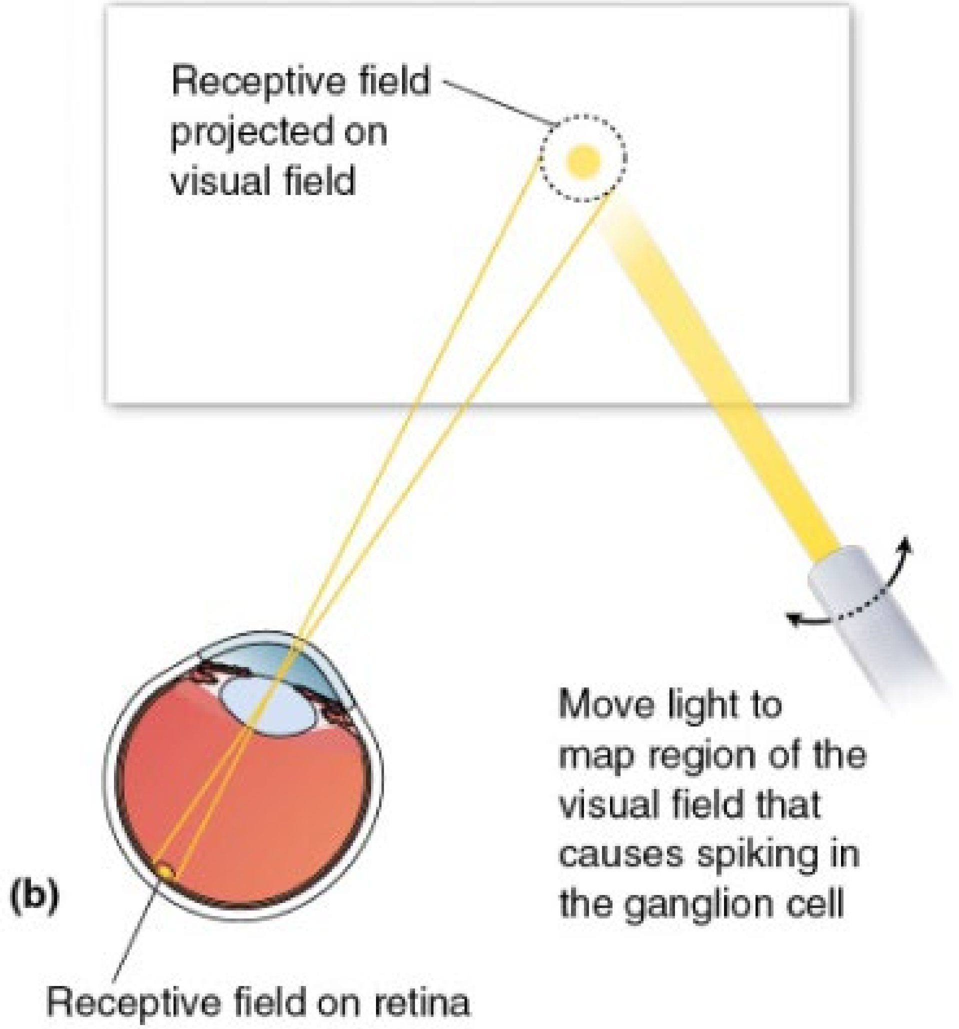
Receptive field of the sens. neuron.

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.

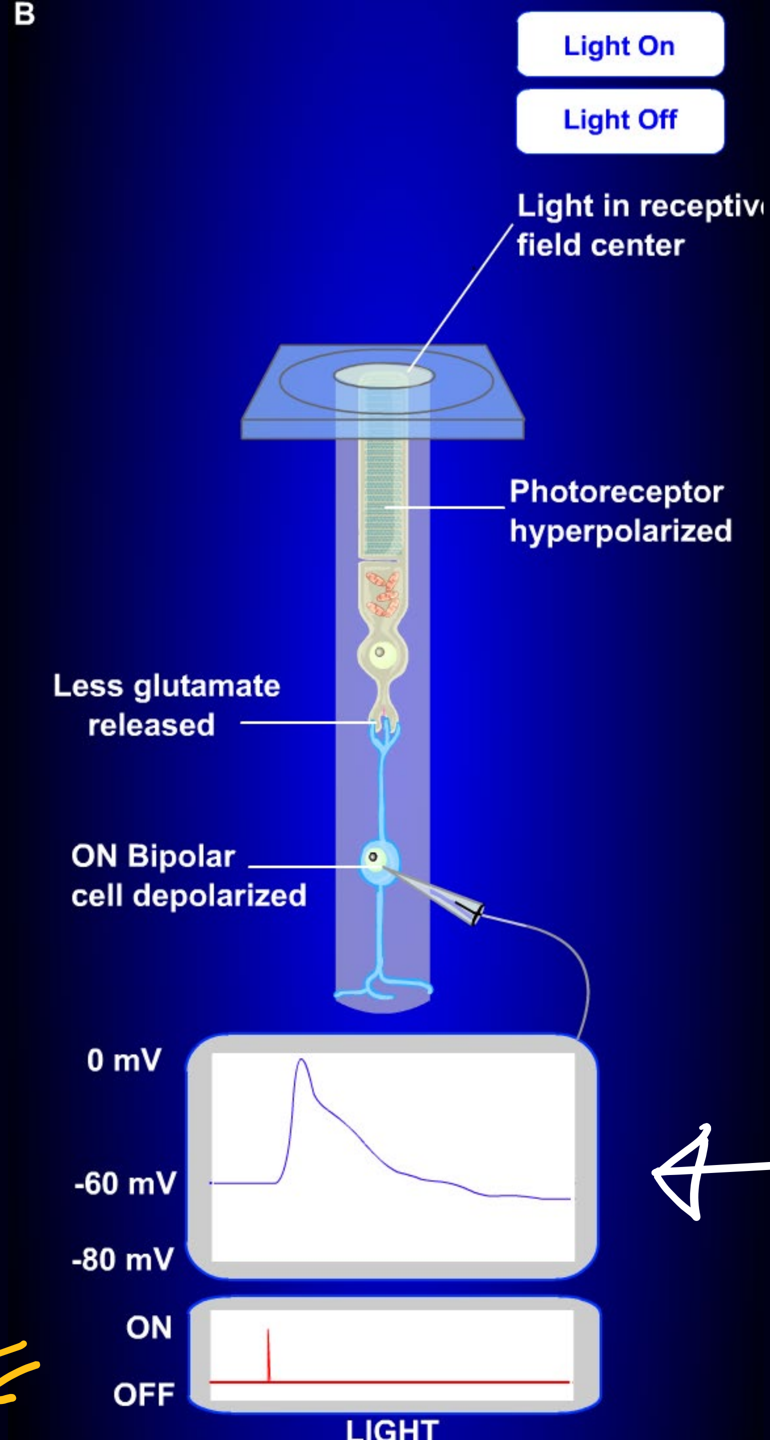




Slide from Bear, M. et al 5th edition publisher: Wolters-Kluwer 2016

ON BIPOLAR CELL RESP.

LIGHT PULSE

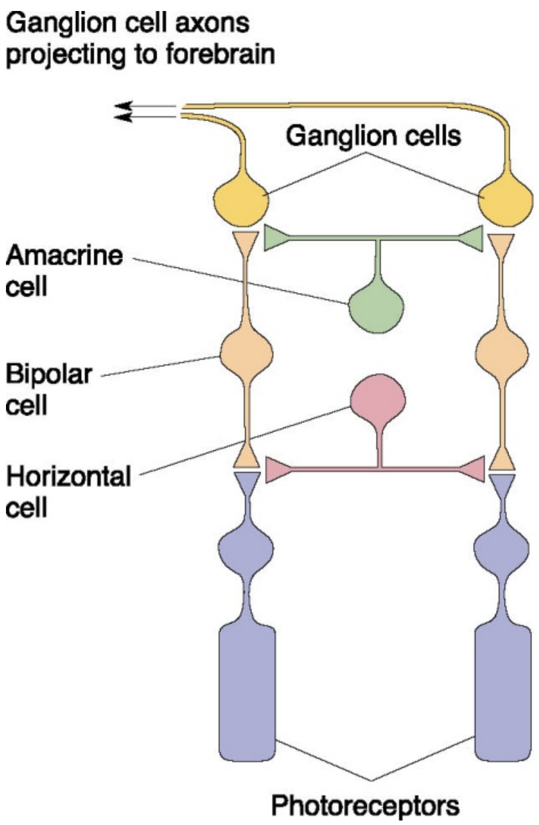


← depolarized

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

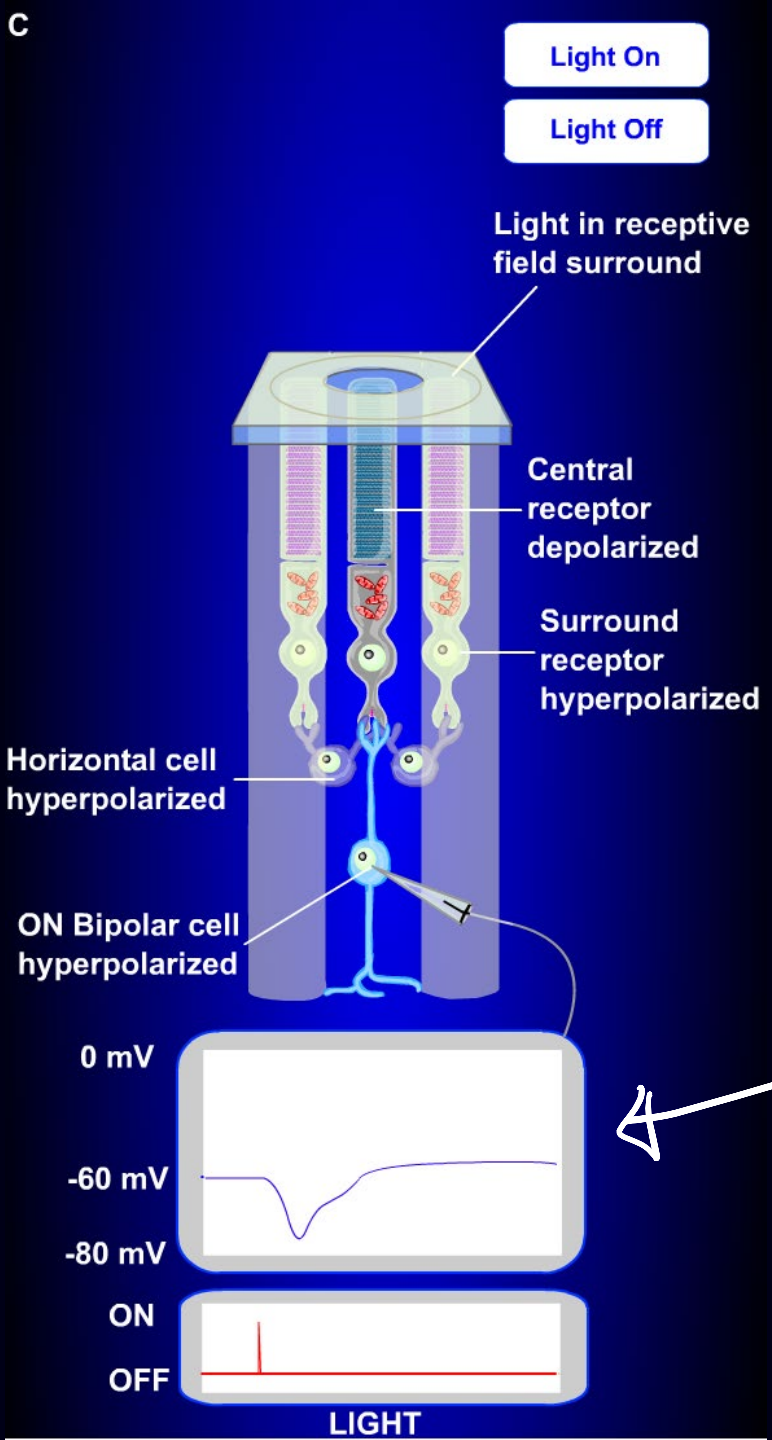
Microscopic Anatomy of the Retina—(cont.)

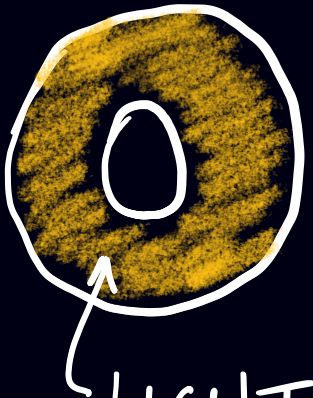
- Retinal processing also influenced by lateral connections
  - Horizontal cells
    - Receive input from photoreceptors and project to other photoreceptors and bipolar cells
  - Amacrine cells
    - Receive input from bipolar cells and project to ganglion cells, bipolar cells, and other amacrine cells



"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

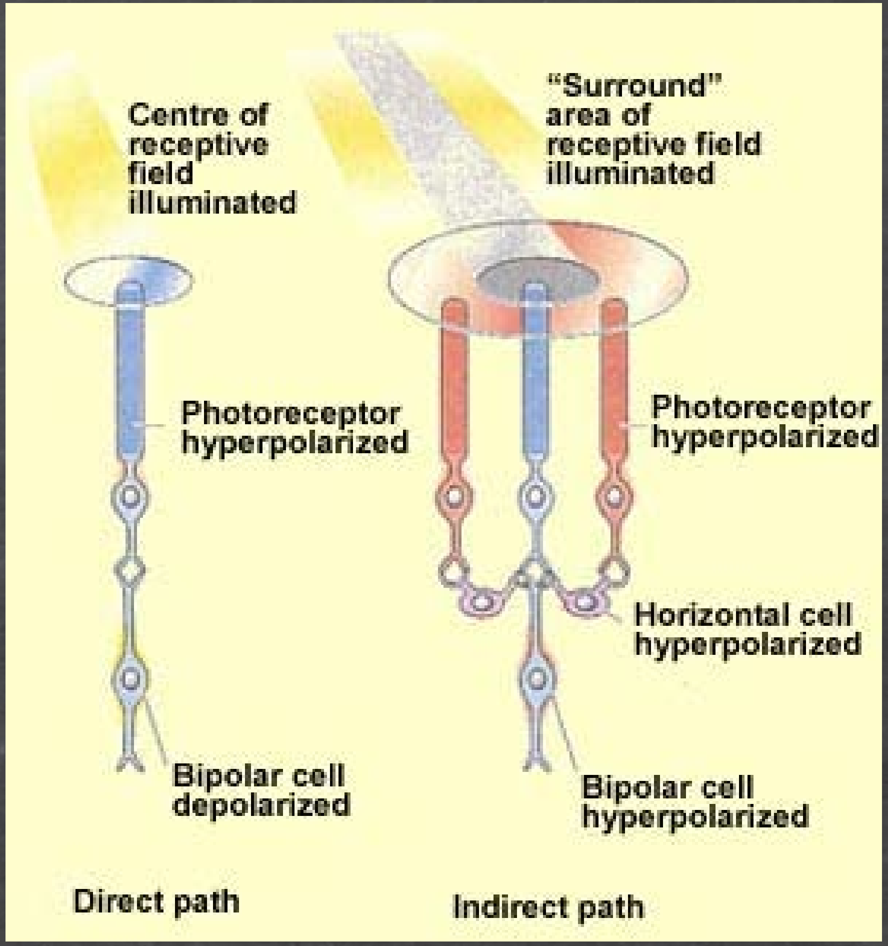
https://nba.uth.tmc.edu/neuroscience/s2/chapter14.html

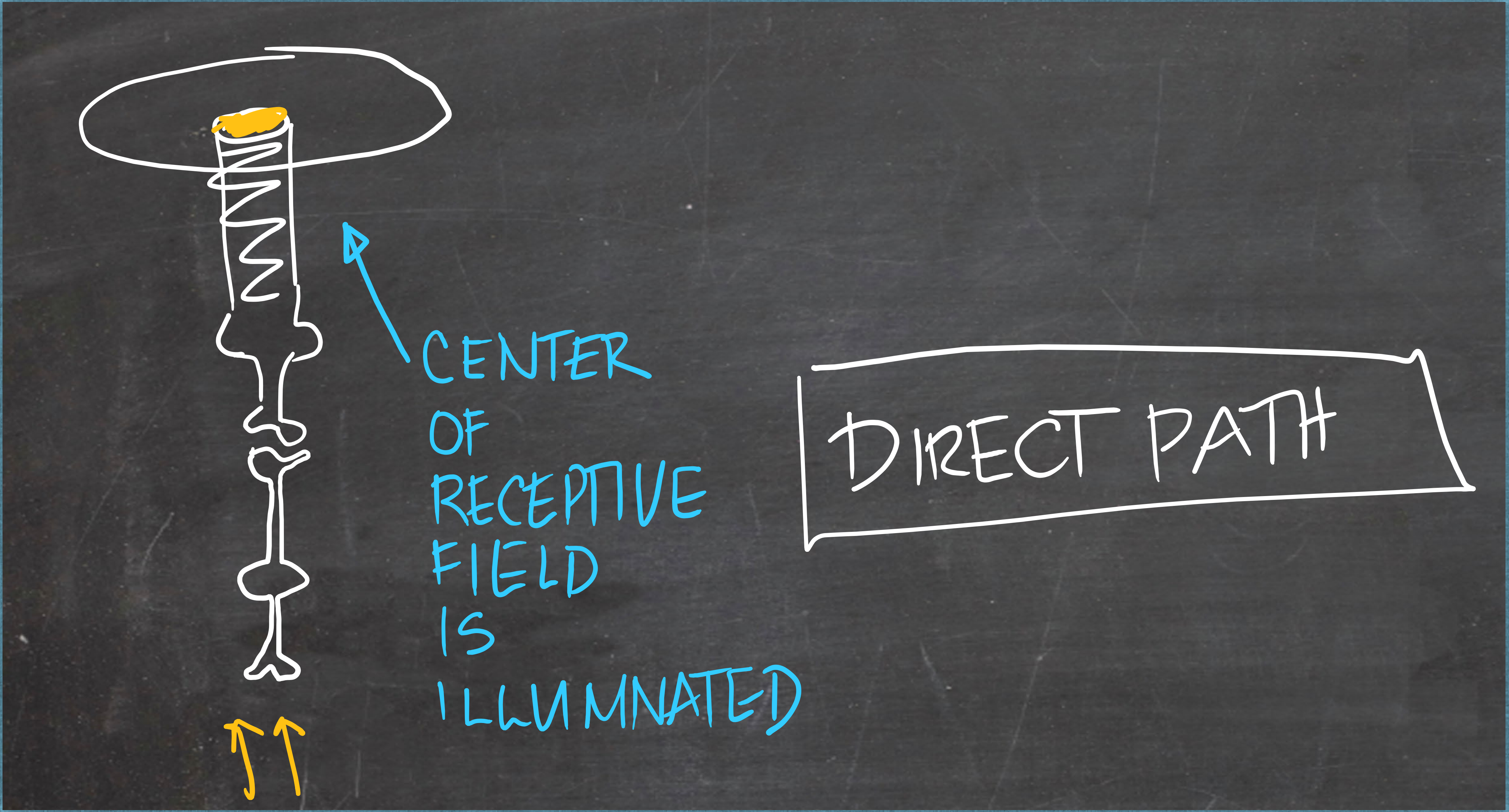
COMARE RECEPTIVE FIELD:

- ⊛ DIRECT PATH

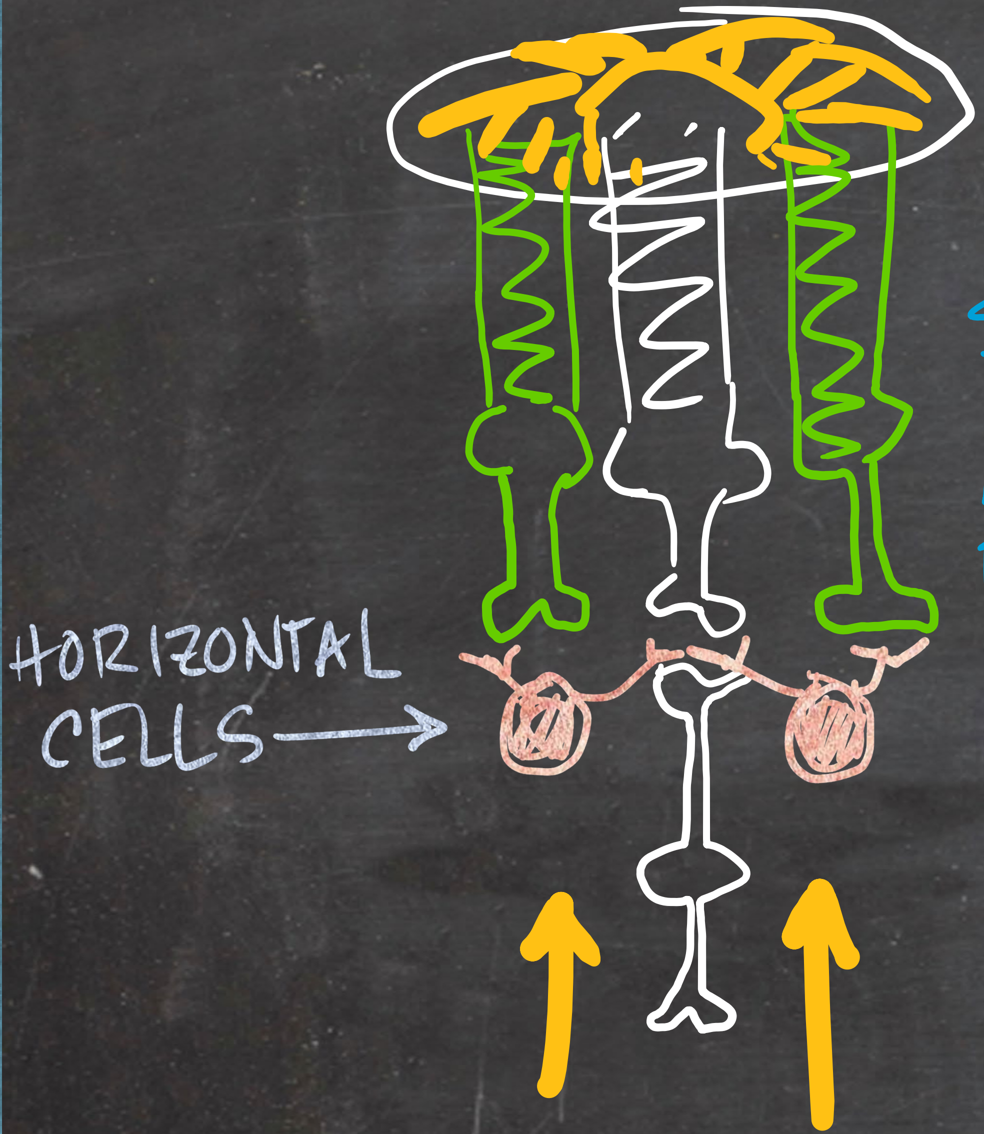
VS

- ⊛ INDIRECT PATH



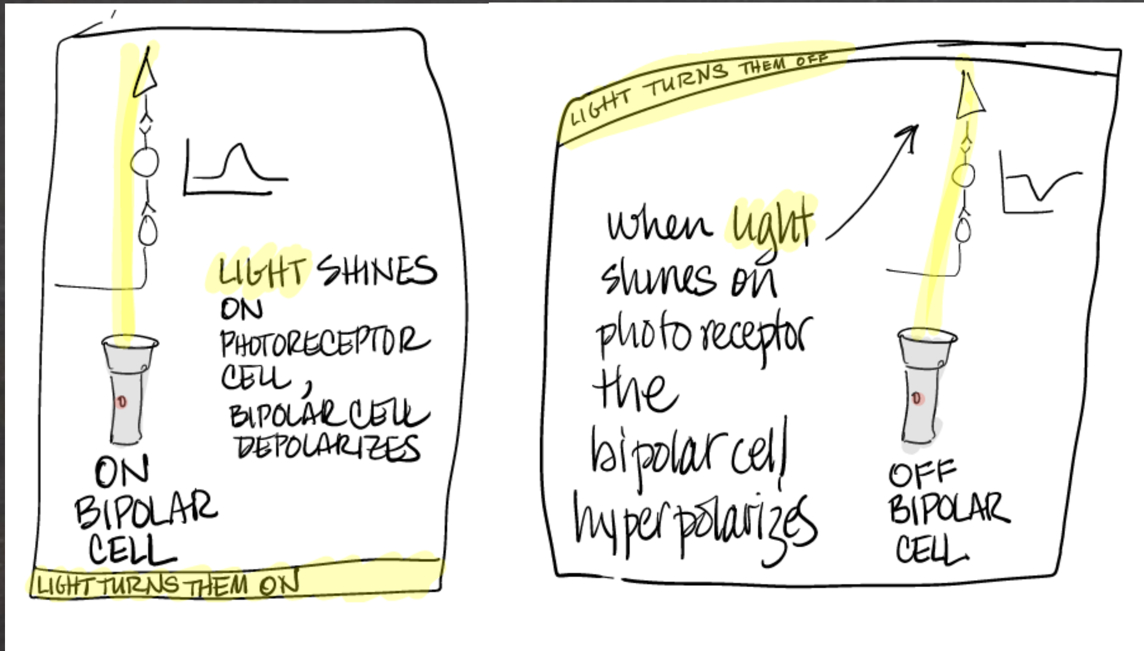

CENTER OF RECEPTIVE FIELD IS ILLUMNATED
DIRECT PATH

INDIRECT PATH



SURROUND AREA OF RECEPTIVE FIELD ILLUMINATED

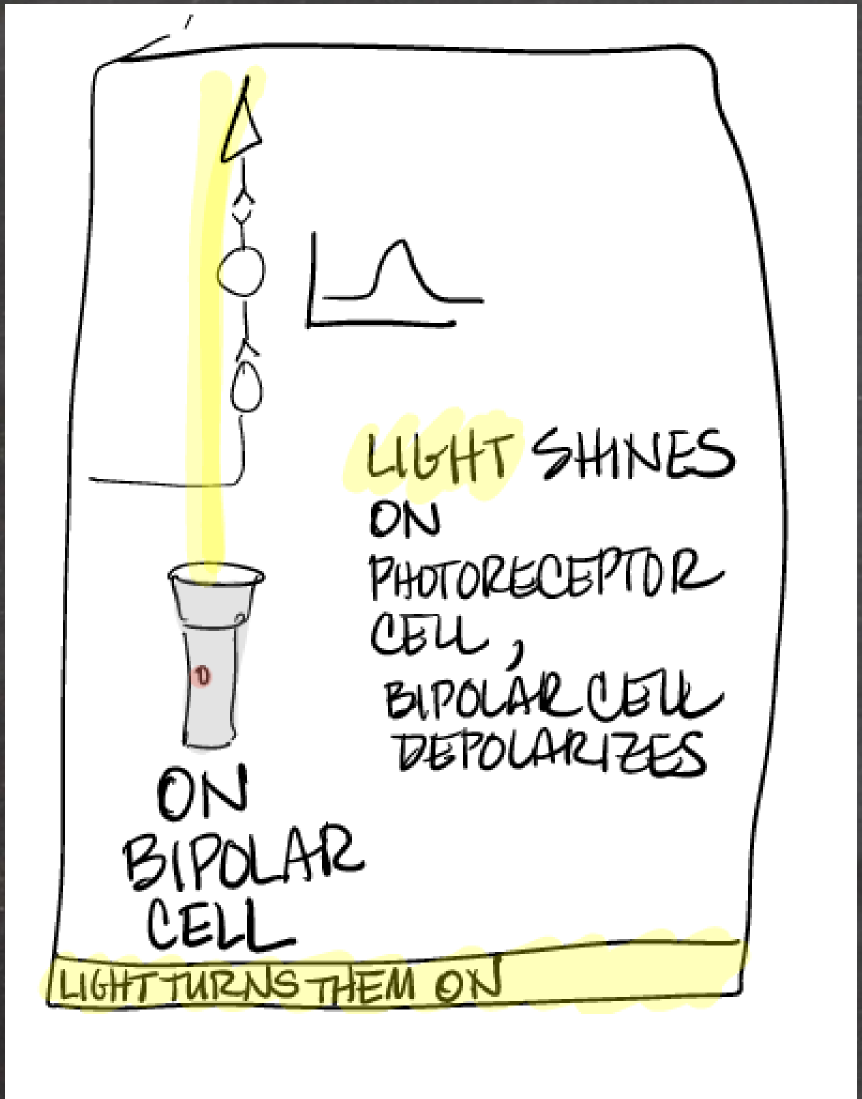
RECALL:



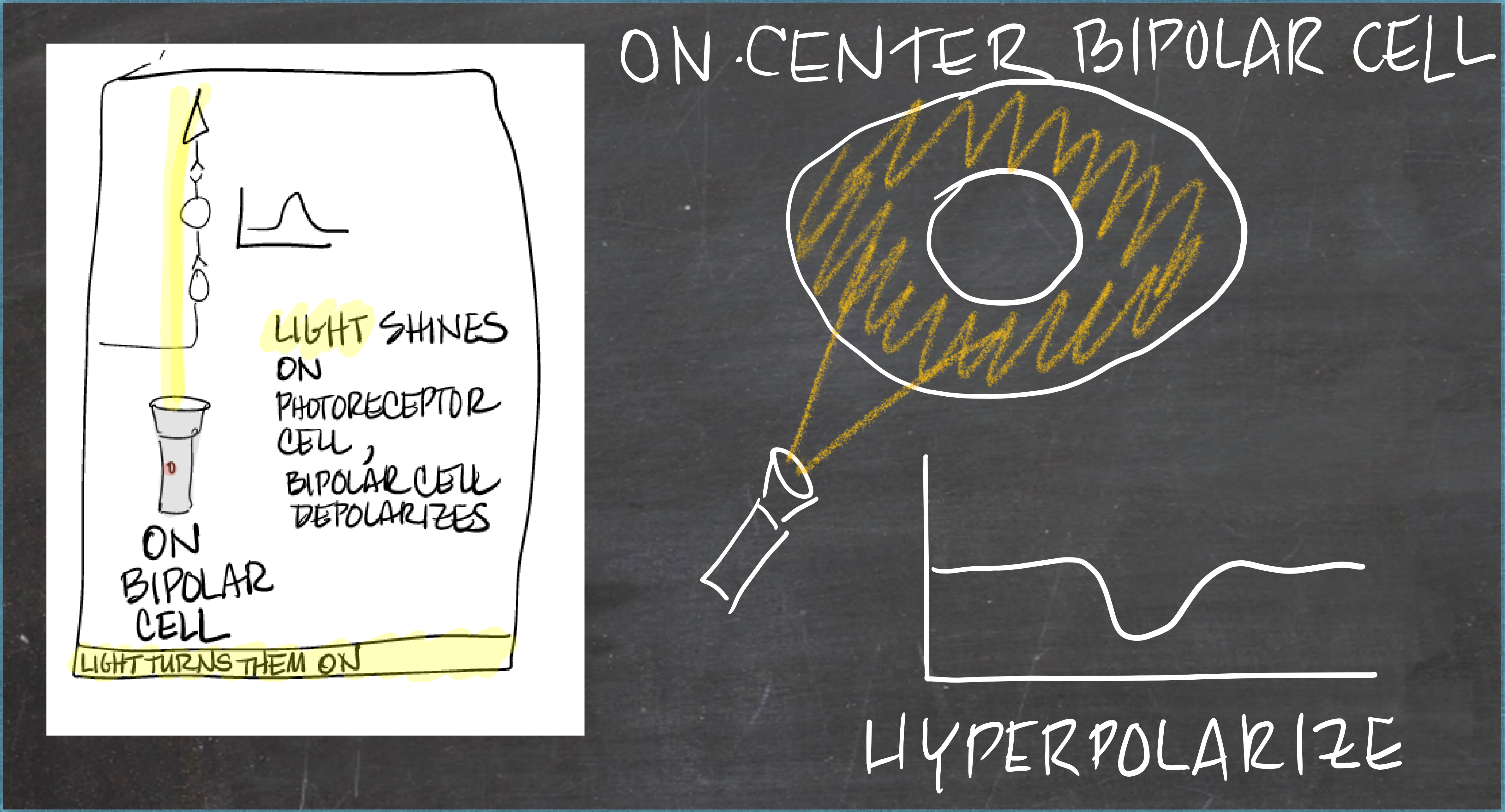
① INDIRECT PATH

② RECEPTIVE FIELDS HAVE 2 PARTS:

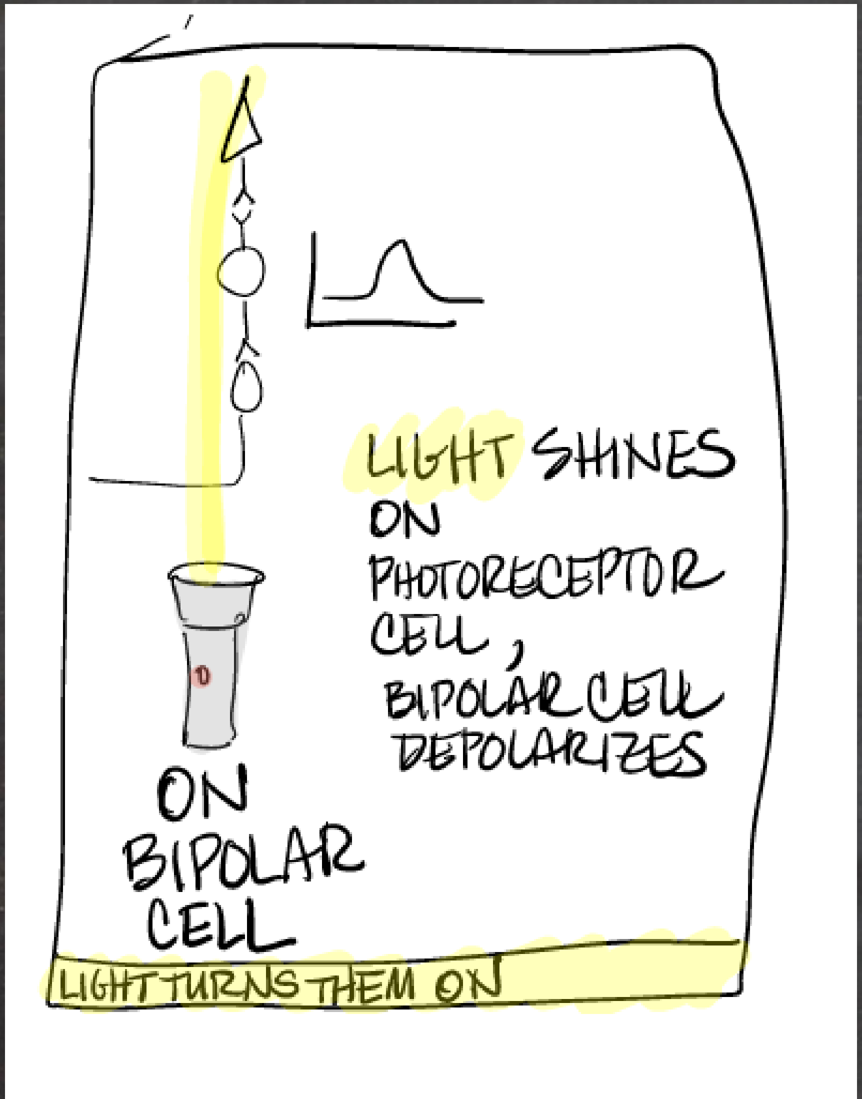
ON-CENTER BIPOLAR CELL

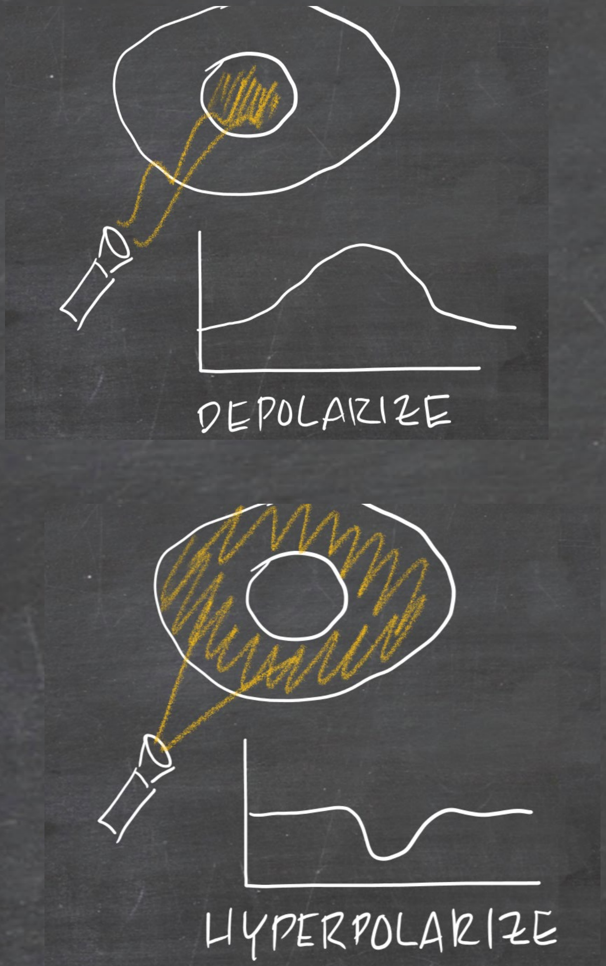


DEPOLARIZE

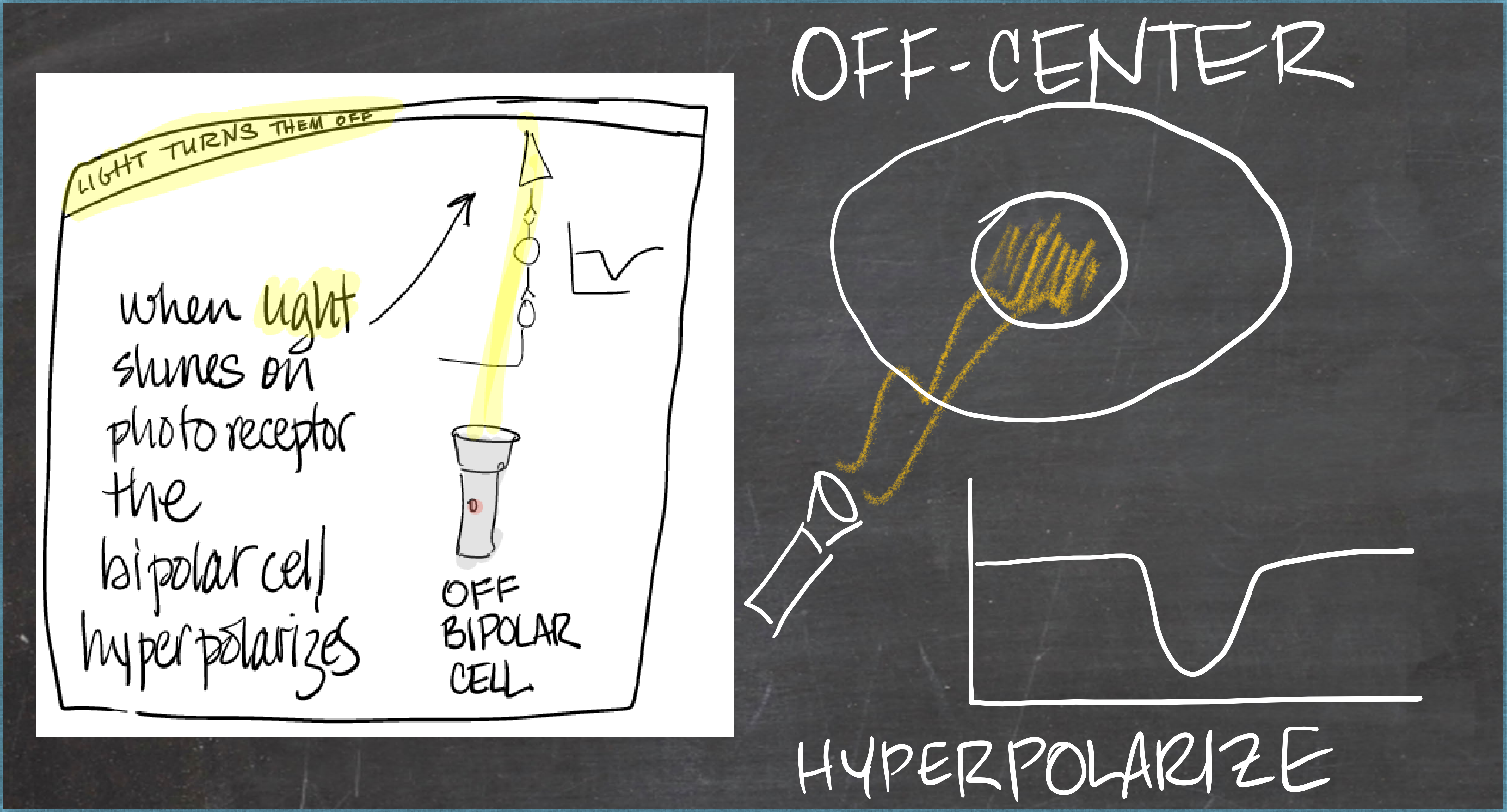

ON CENTER BIPOLAR CELL
LIGHT SHINES ON PHOTORECEPTOR CELL, BIPOLAR CELL DEPOLARIZES
ON BIPOLAR CELL
LIGHT TURNS THEM ON
HYPERPOLARIZE

ON CENTER BIPOLAR CELL

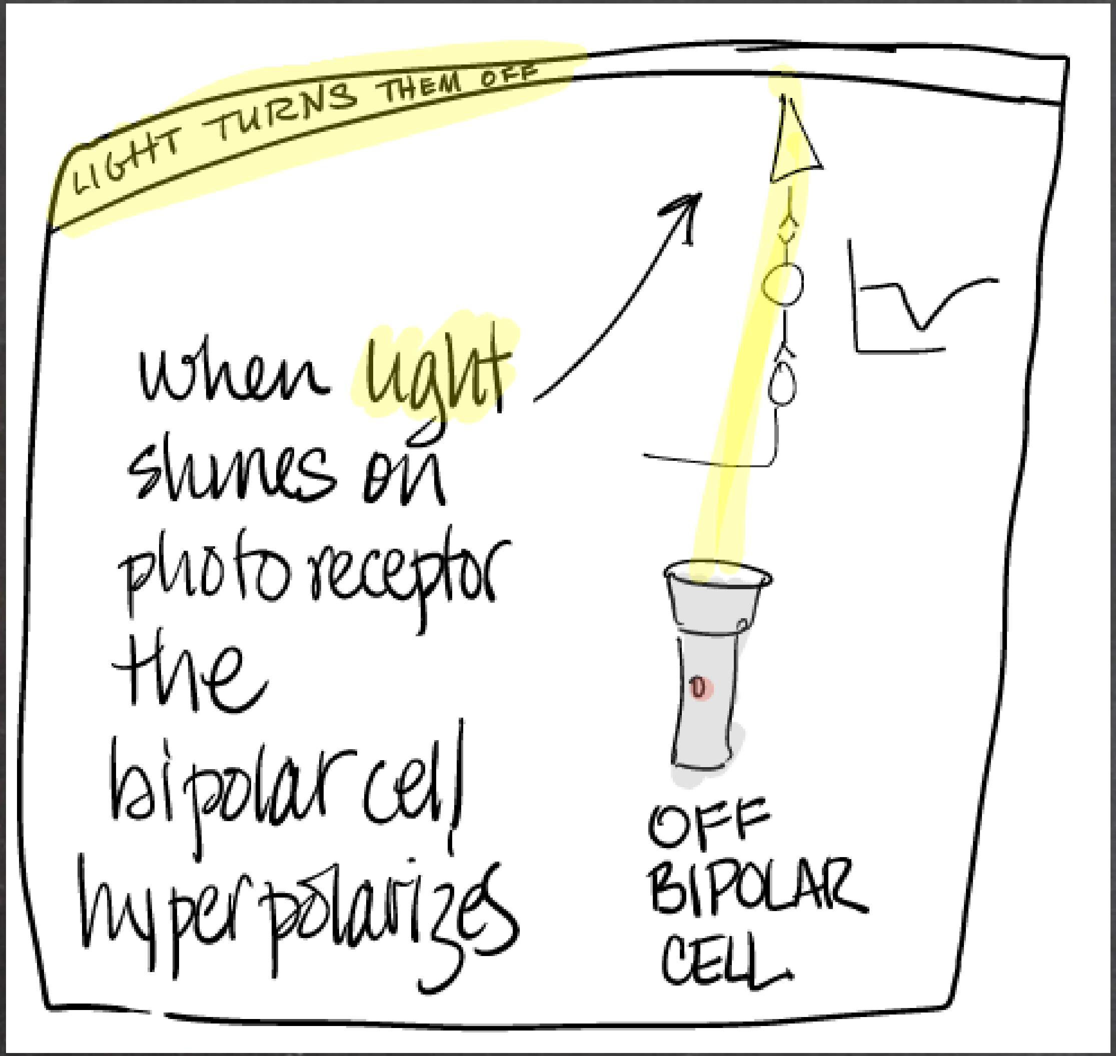




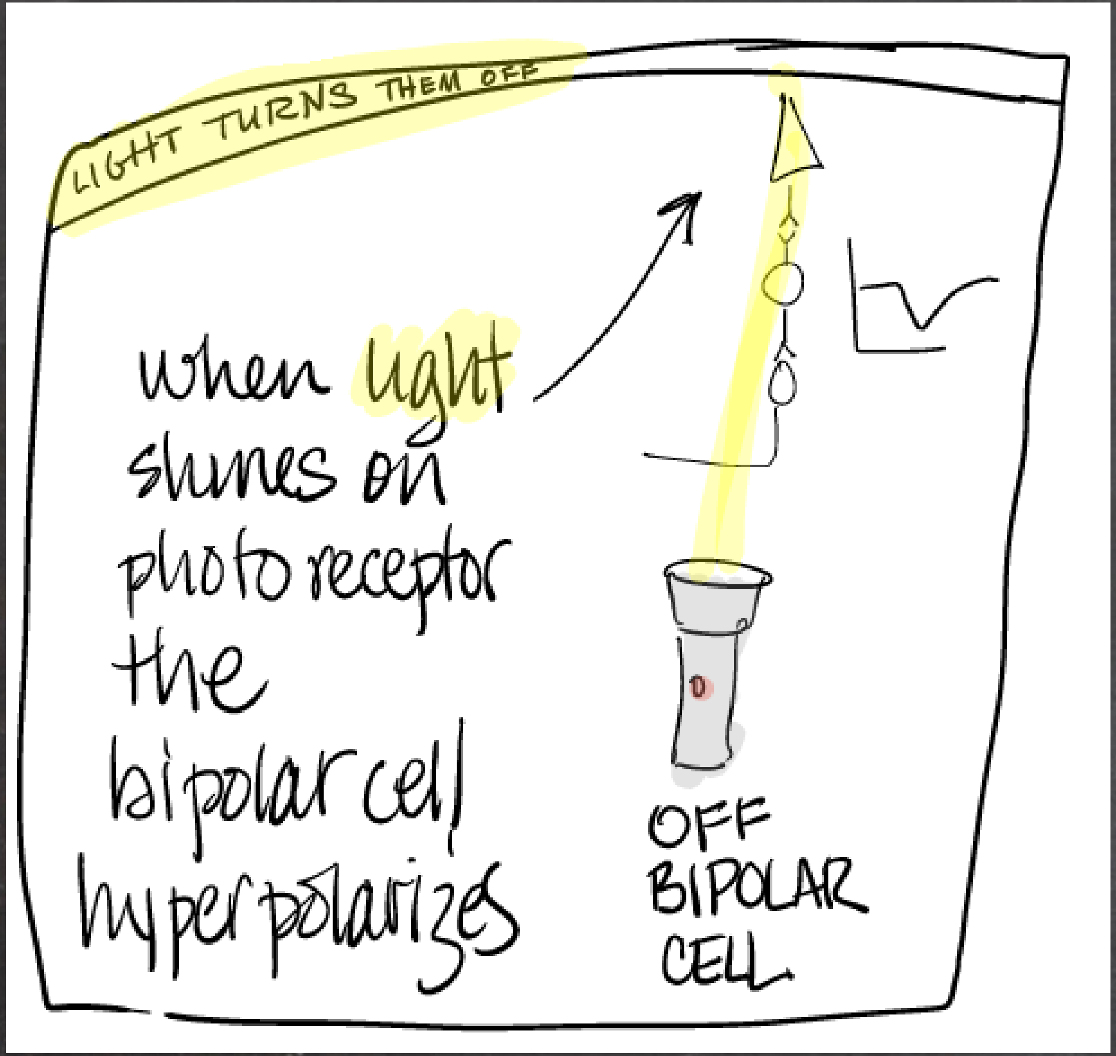
*note: center & surround have an opposite effect.

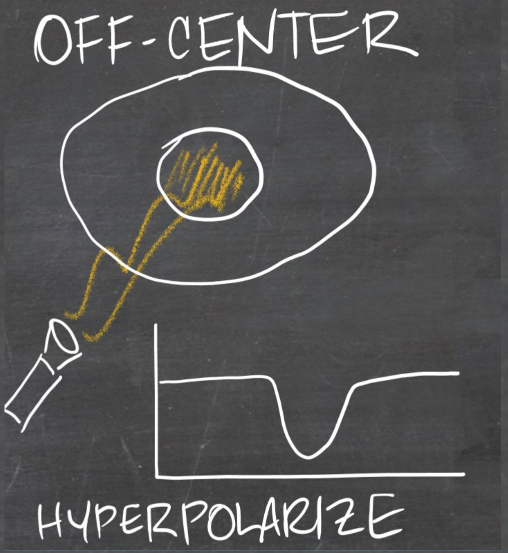

OFF-CENTER
LIGHT TURNS THEM OFF
when light shines on photoreceptor the bipolar cell hyperpolarizes
OFF BIPOLAR CELL
HYPERPOLARIZE

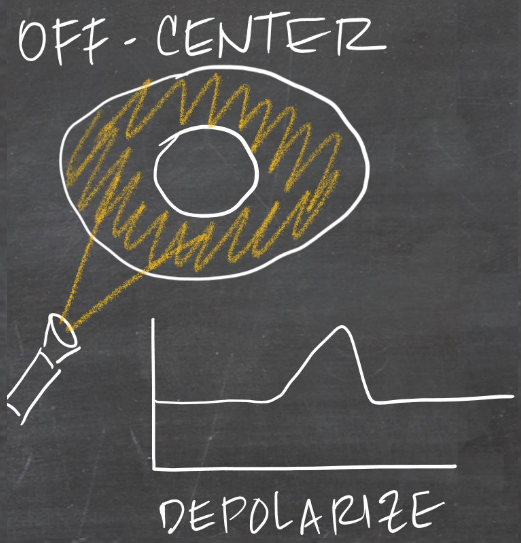
OFF-CENTER



DEPOLARIZE







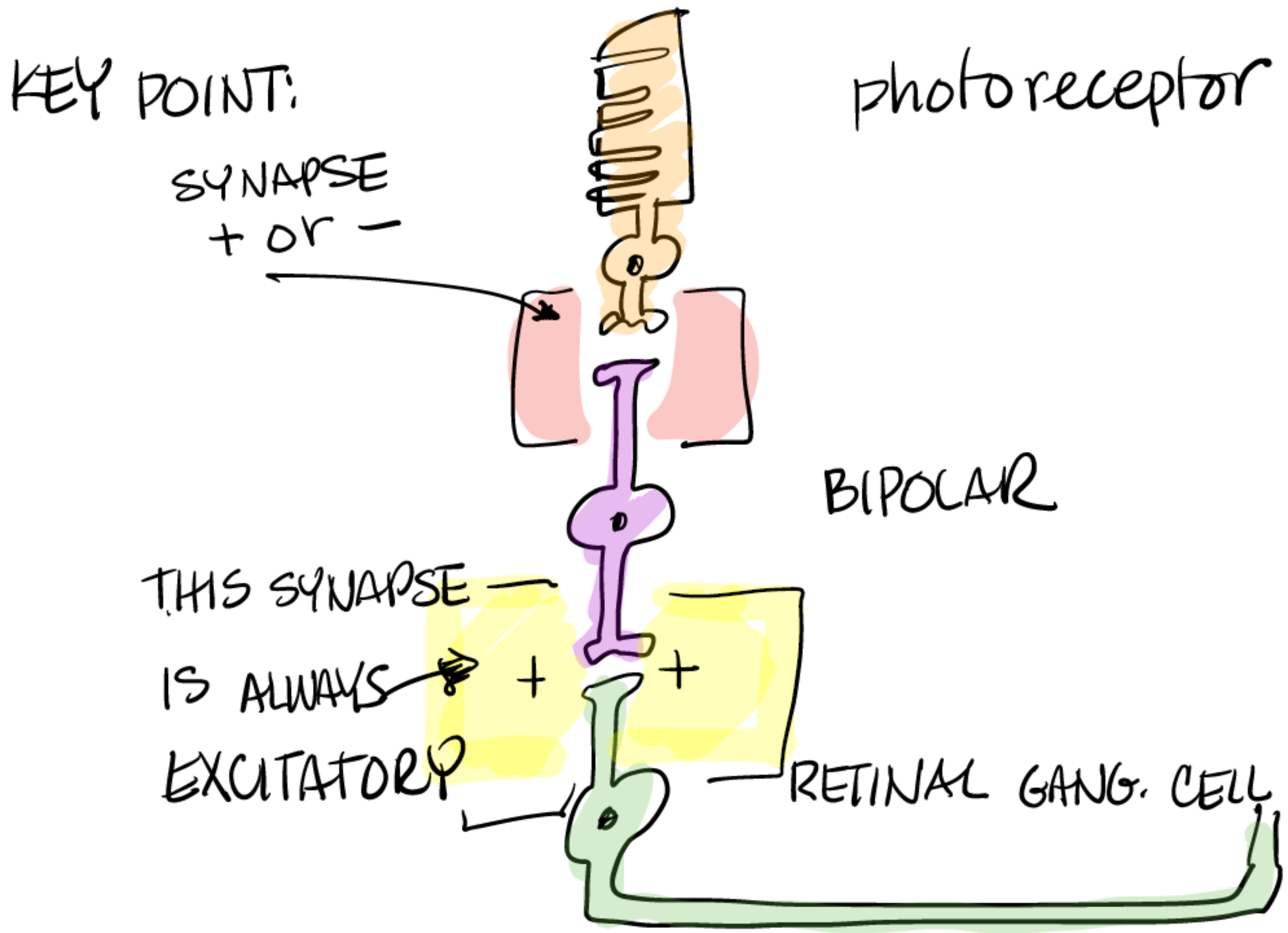
b

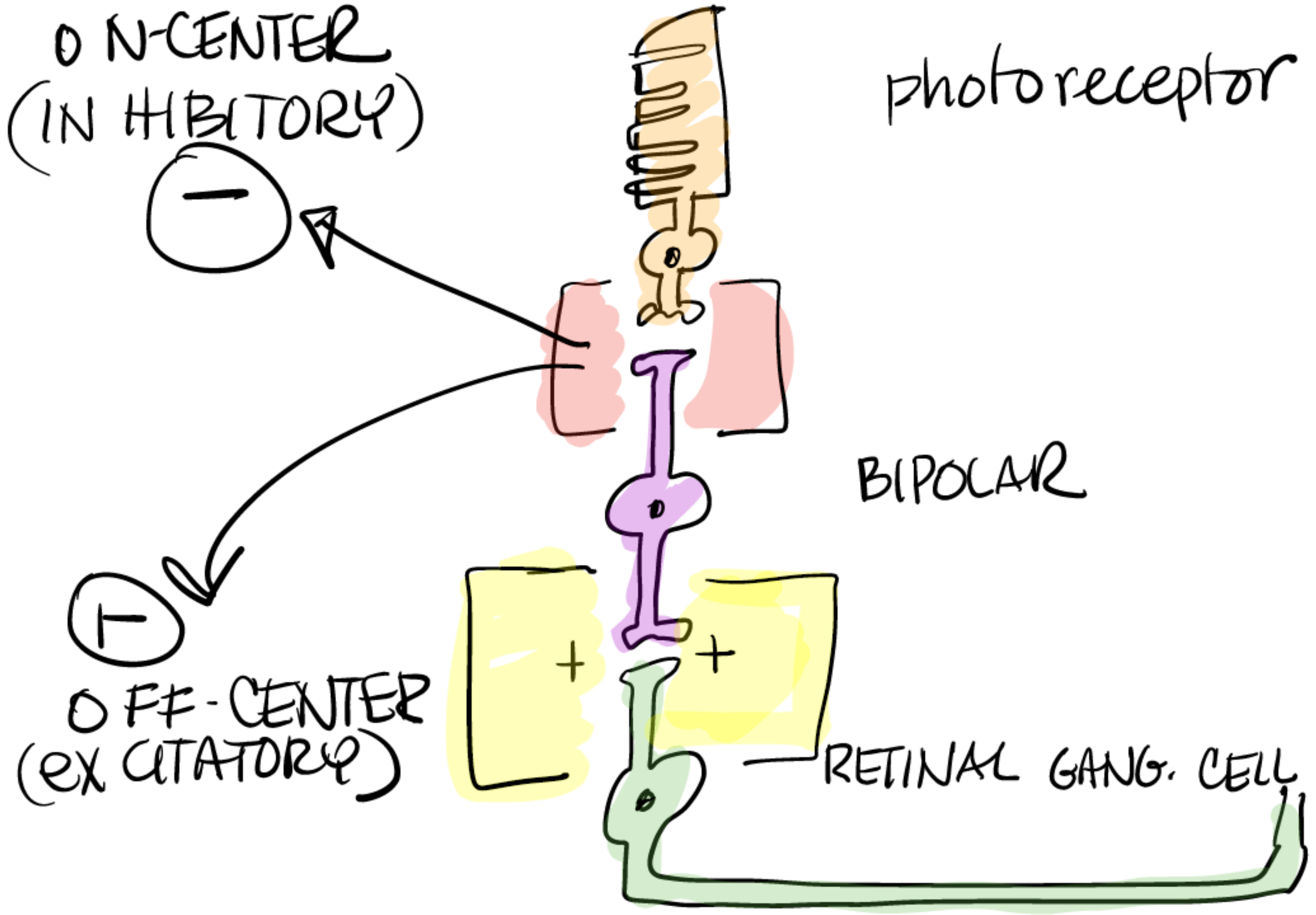
OFF-CENTER BIPOLAR CELLS BEHAVE IN A SIMILAR MANNER.

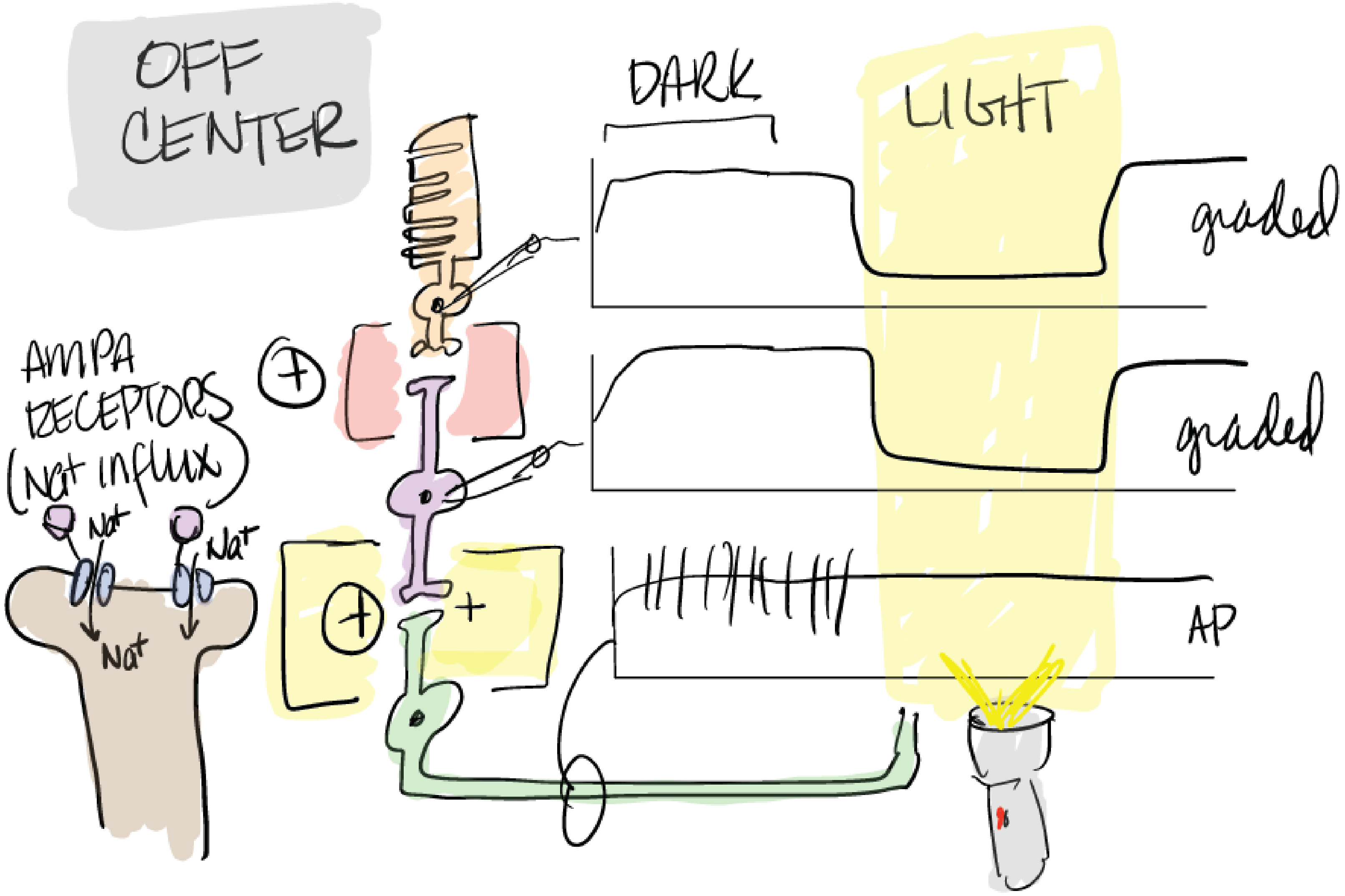
Q: HOW DOES THIS INFORMATION TRANSFER TO THE RETINAL GANGLION CELL?

ON-CENTER

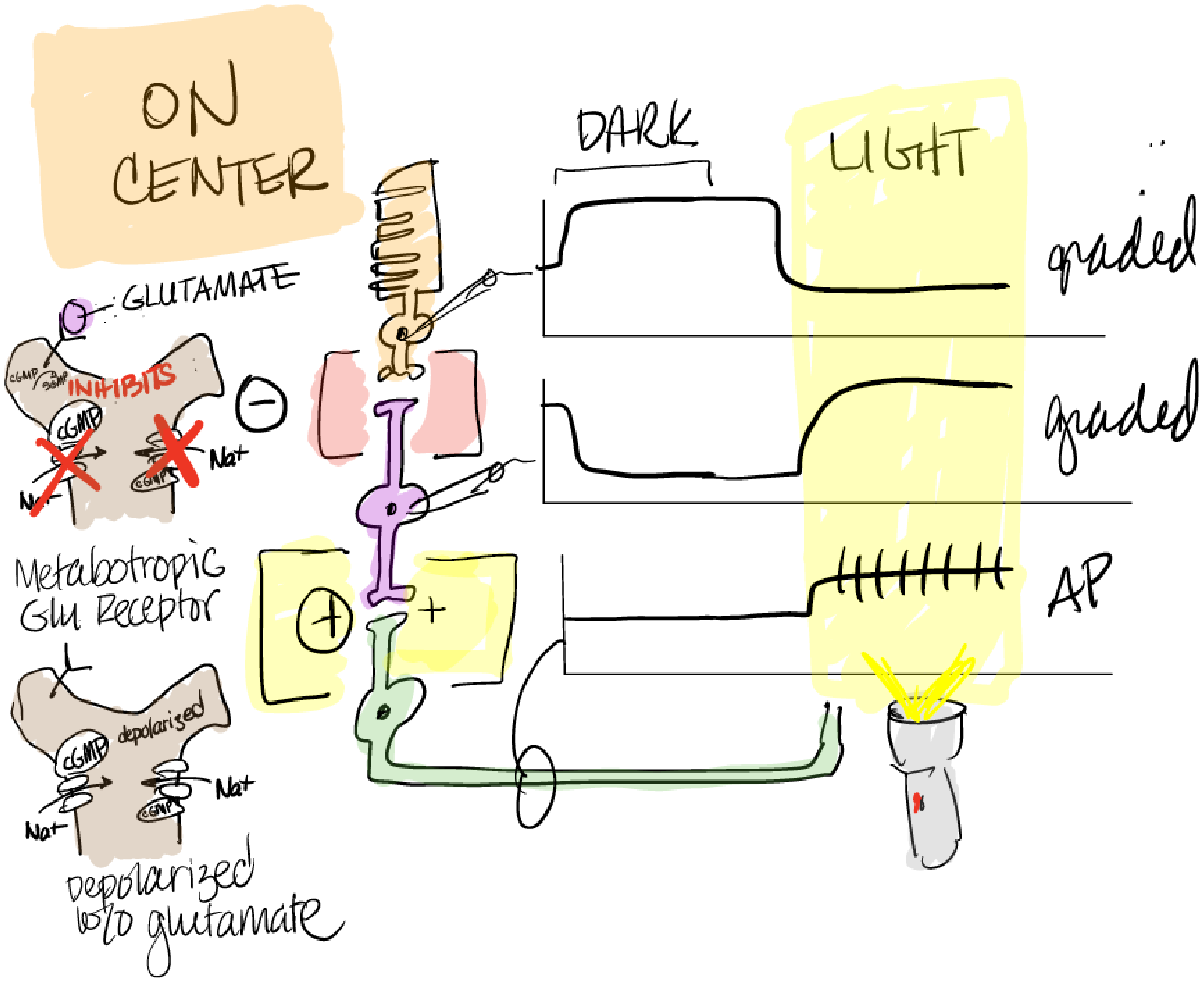
OFF-CENTER


KEY POINT:
SYNAPSE
+ or −
photoreceptor
BIPOLAR
THIS SYNAPSE
IS ALWAYS
EXCITATORY
+
+
RETINAL GANG. CELL


ON-CENTER
(INHIBITORY)
photoreceptor
BIPOLAR
+
+
OFF-CENTER
(EXCITATORY)
RETINAL GANG. CELL

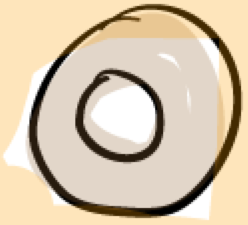


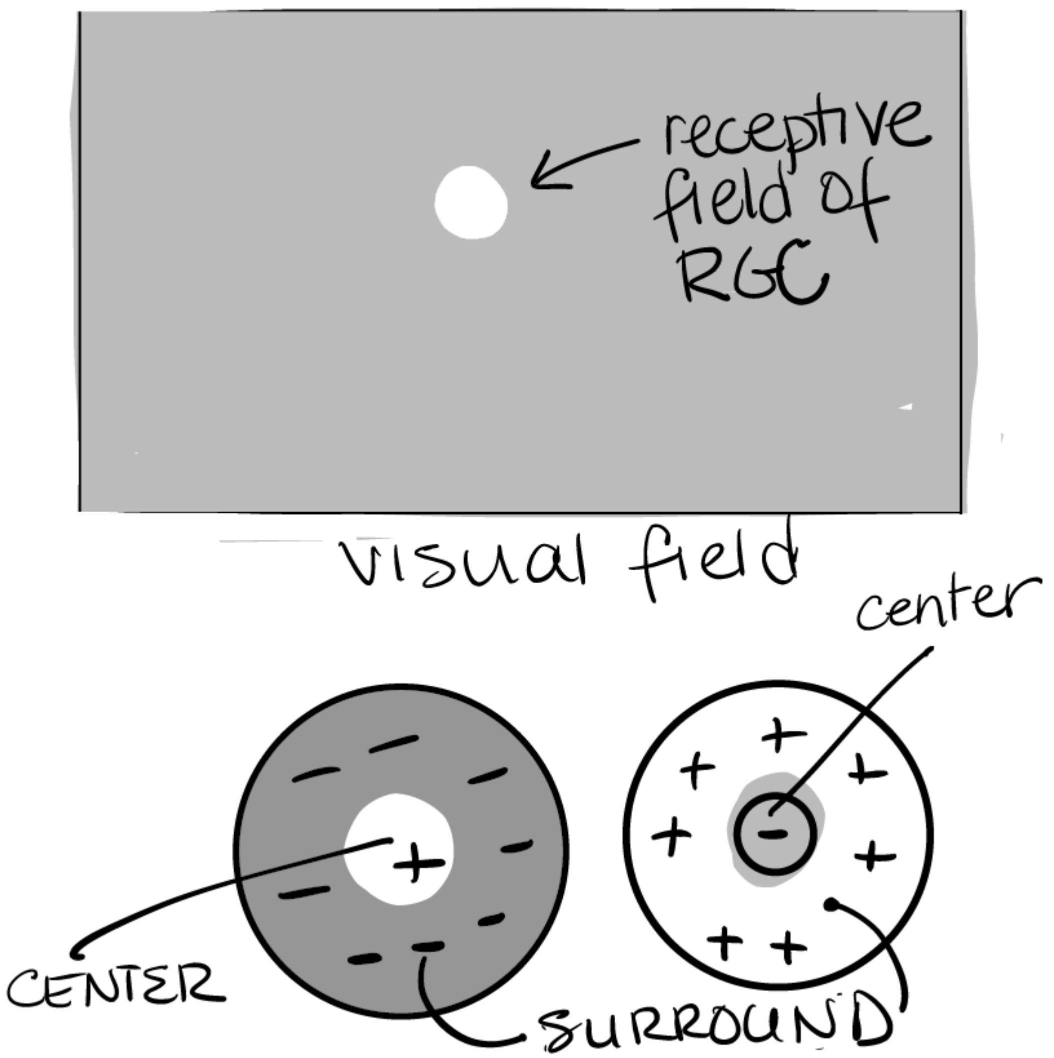
OFF CENTER
DARK
LIGHT
graded
graded
AP
AMPA RECEPTORS (Na+ influx)
Na+
Na+
Na+
+
+
+


ON CENTER
GLUTAMATE
INHIBITS
cGMP
Na+
Metabotropic Glu Receptor
depolarized
depolarized w/o glutamate
DARK
LIGHT
graded
graded
AP

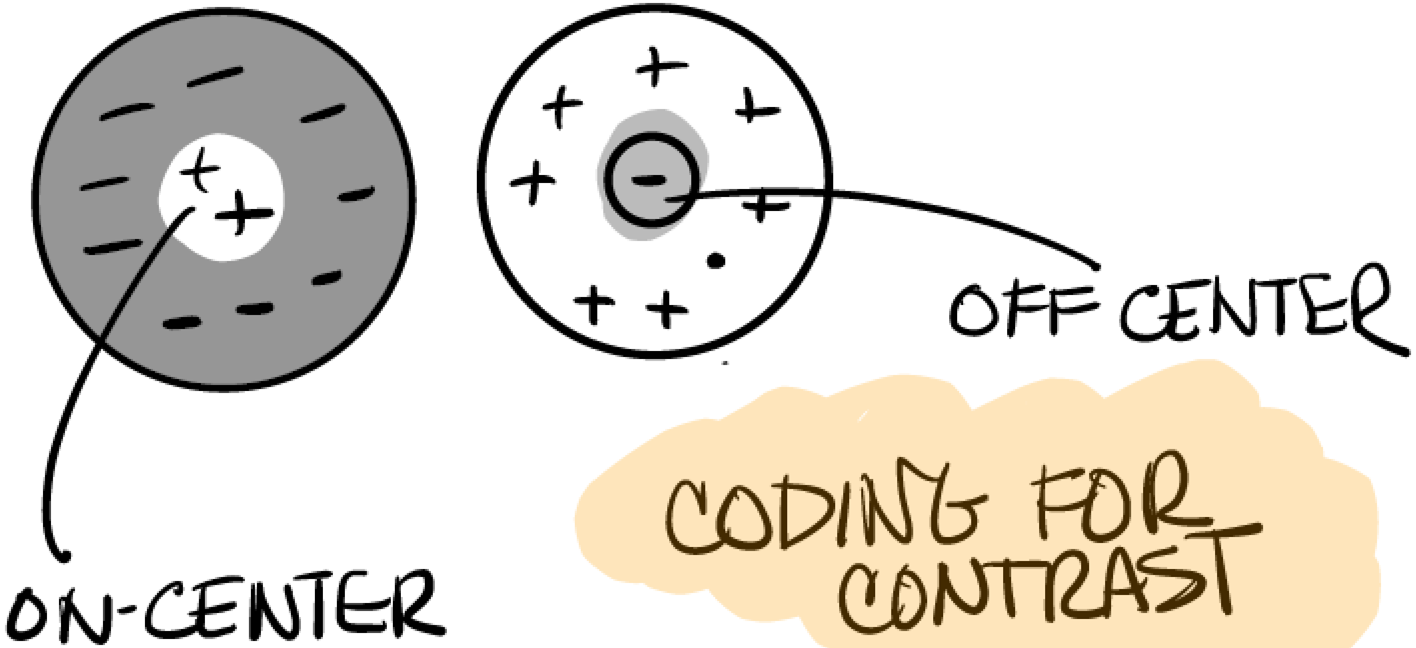
Retinal Ganglion Cells

center surround Receptive Fields

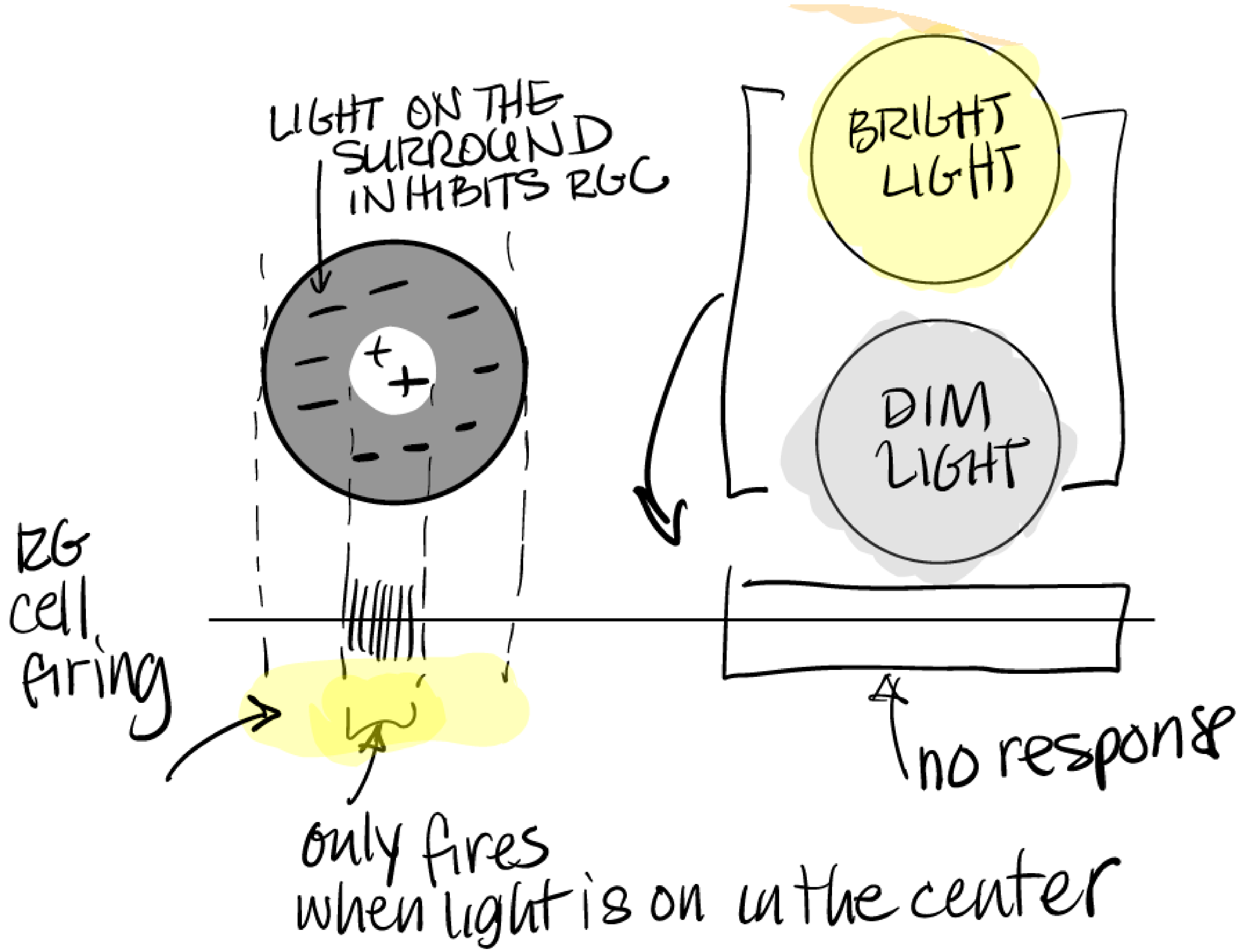



receptive field of RGC
visual field
center
CENTER
SURROUND

TWO TYPES OF RGC

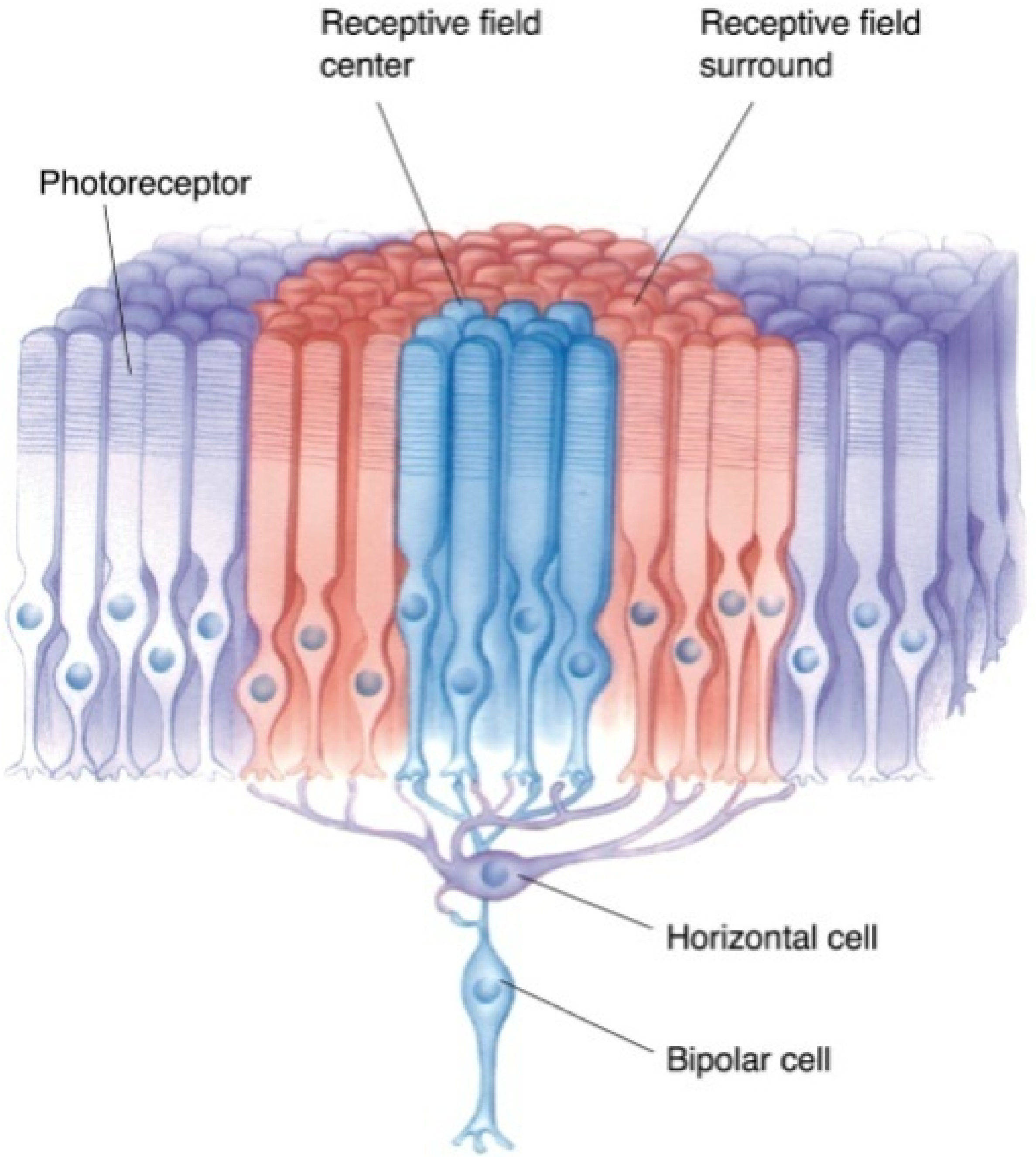


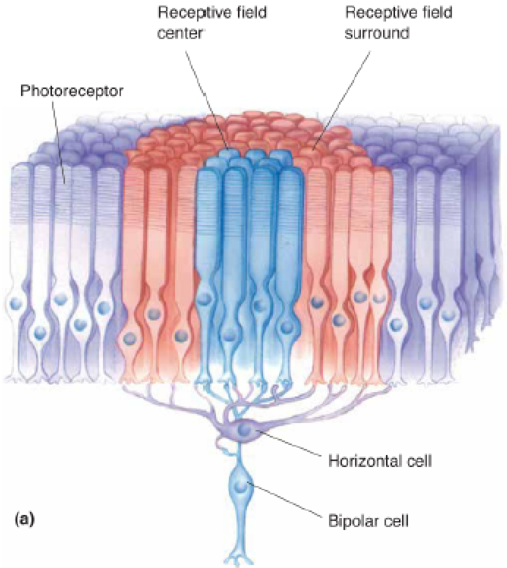
CODING FOR CONTRAST


LIGHT ON THE SURROUND INHIBITS RGC
BRIGHT LIGHT
DIM LIGHT
RG cell firing
no response
only fires when light is on in the center

Bipolar Cell Receptive Fields

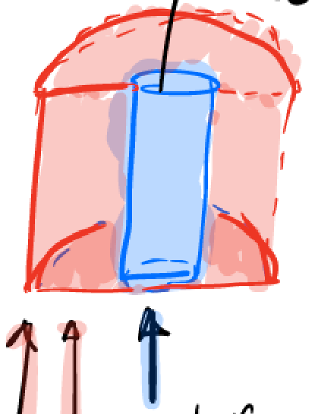
- Receptive field: ON and OFF bipolar cells
  - Receptive field: Stimulation in a small part of the visual field changes a cell's membrane potential.
  - Antagonistic center-surround receptive fields





Bear, M. et al p 322

center of RGC receptive field

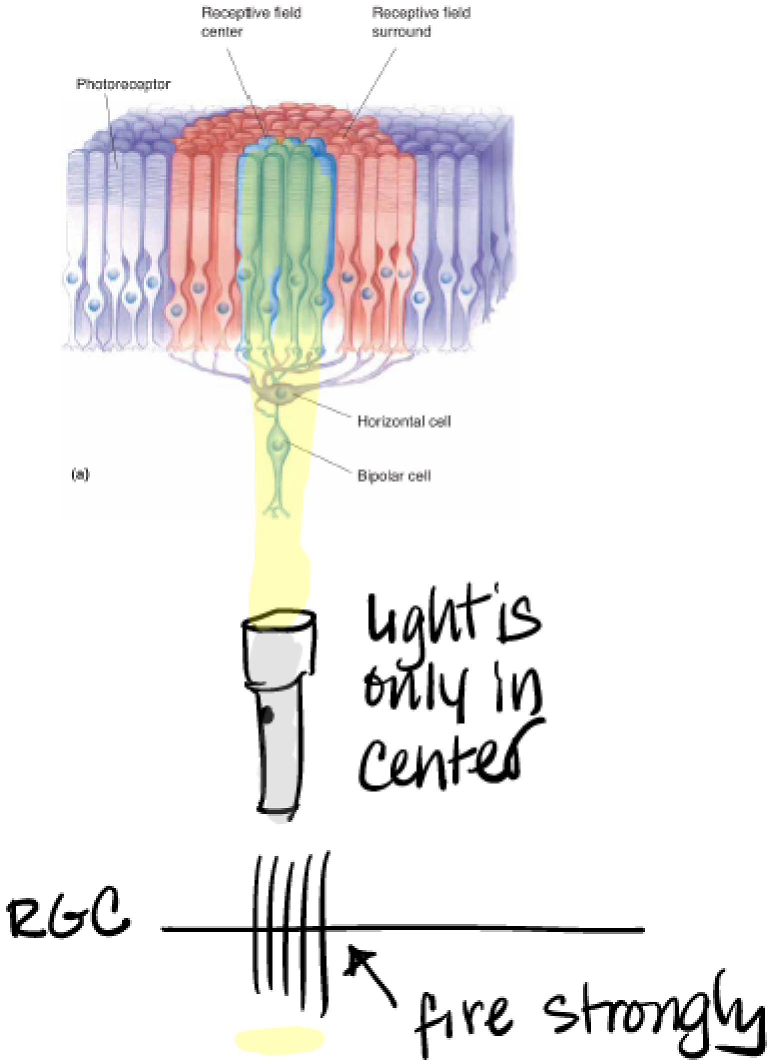


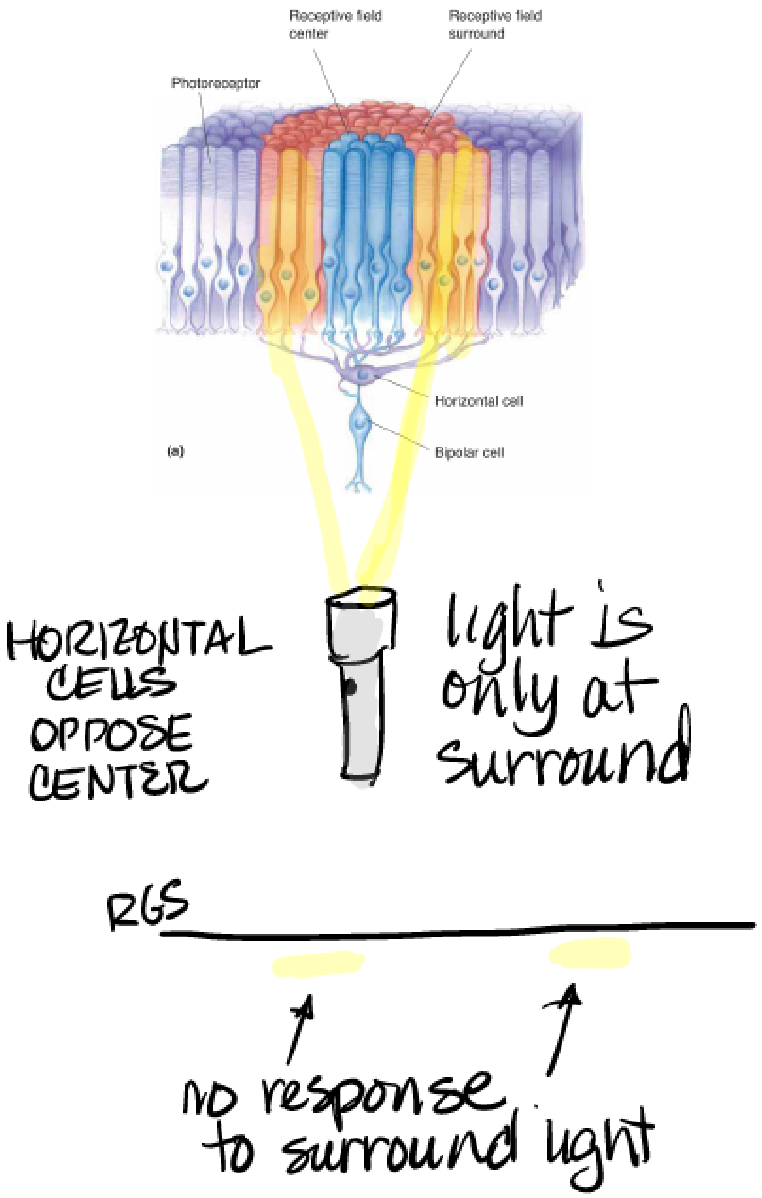
center cells have direct path

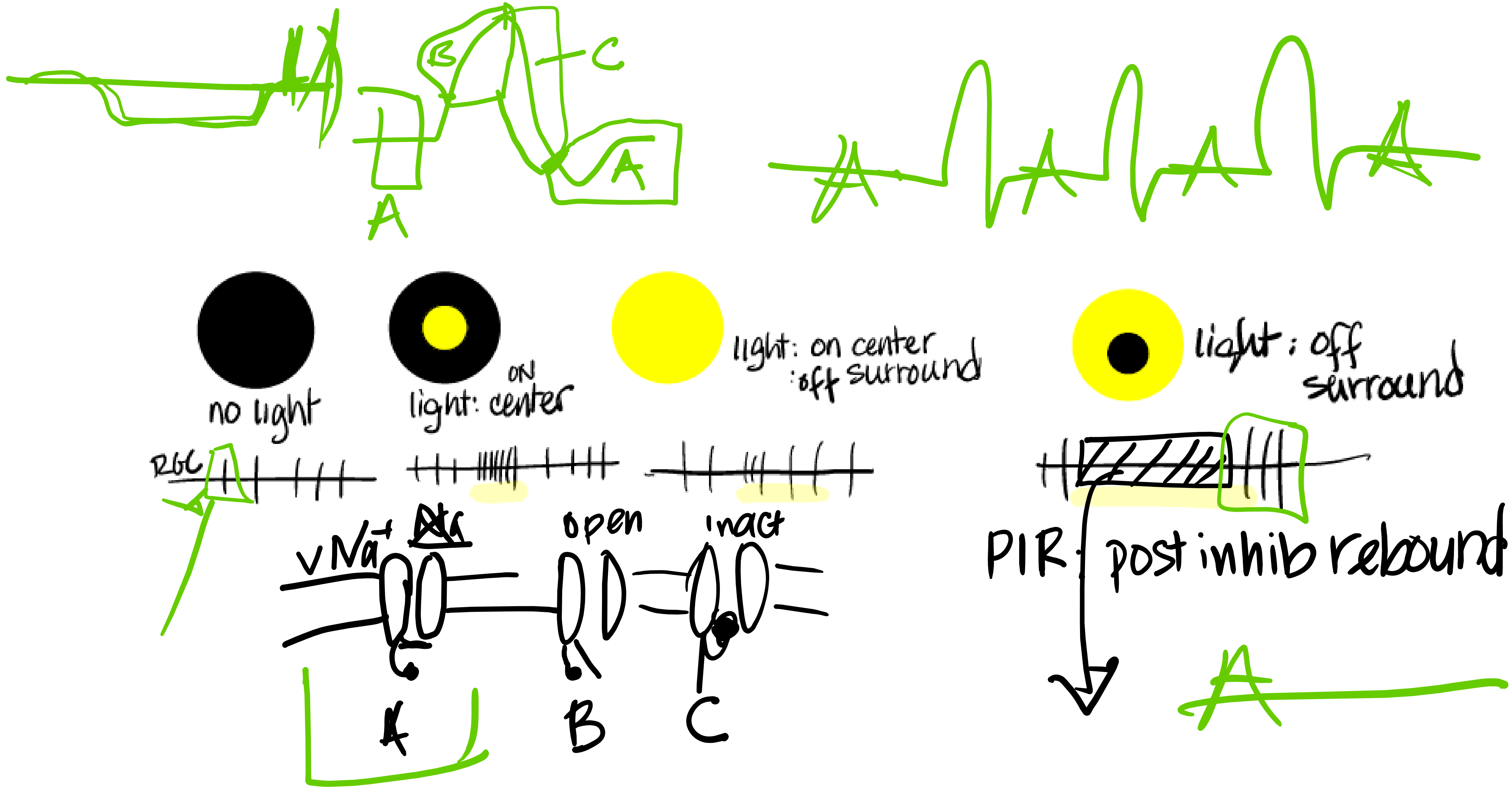
surround has horizontal cell connections

* BIPOLAR CELL IS INFLUENCED BY BLUE (center) & RED (surround) CONNECTIONS

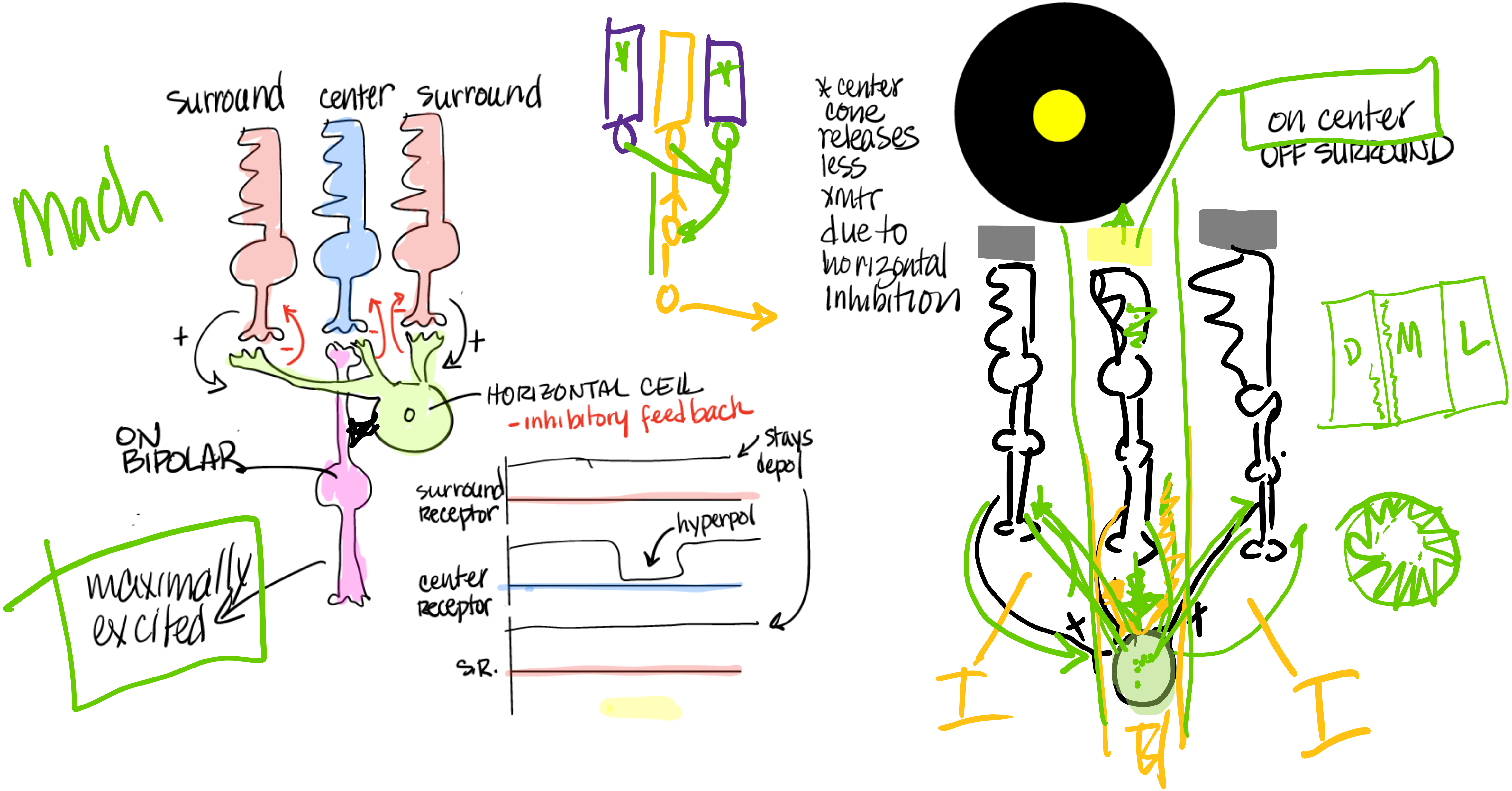
Example of: ON-center/off surround


Receptive field center
Receptive field surround
Photoreceptor
Horizontal cell
Bipolar cell
(a)
light is only in center
RGC
fire strongly

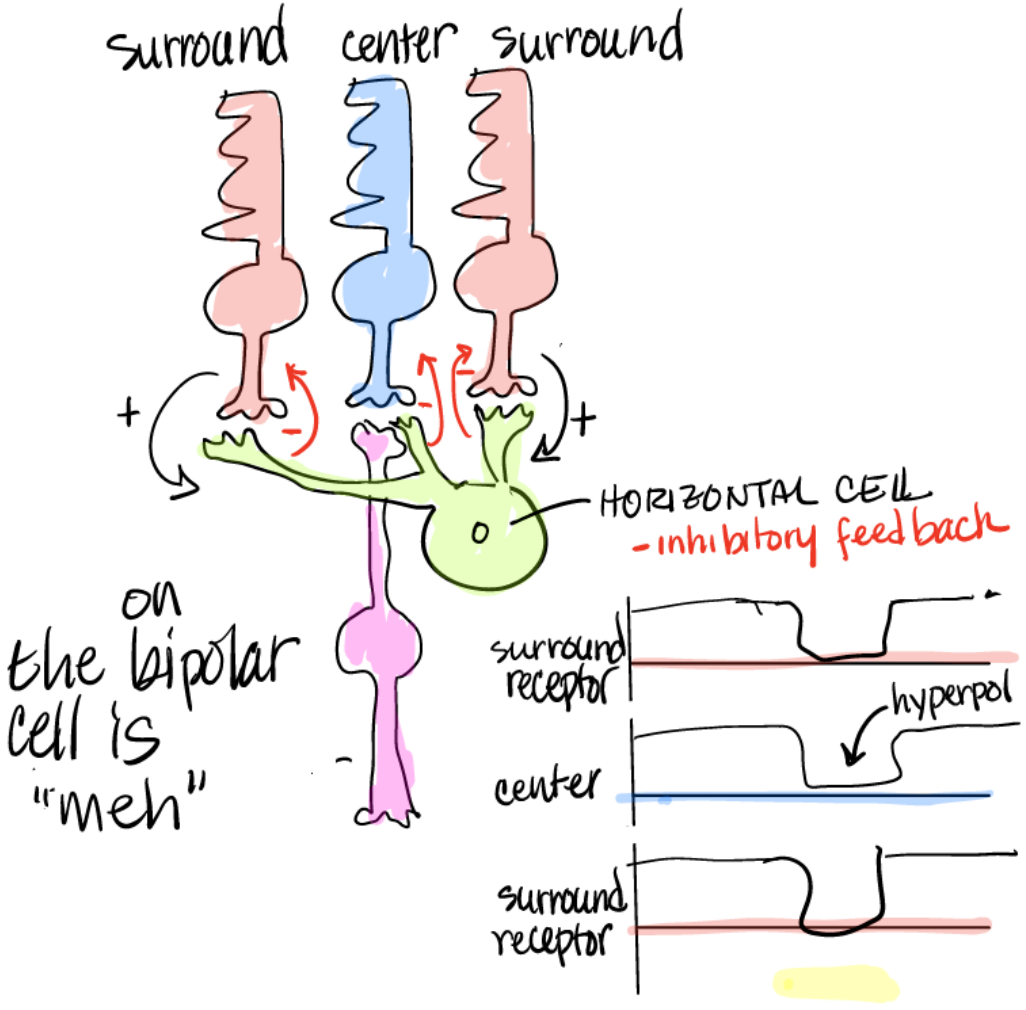

Receptive field center
Receptive field surround
Photoreceptor
Horizontal cell
Bipolar cell
(a)
HORIZONTAL CELLS OPPOSE CENTER
light is only at surround
RGS
no response to surround light



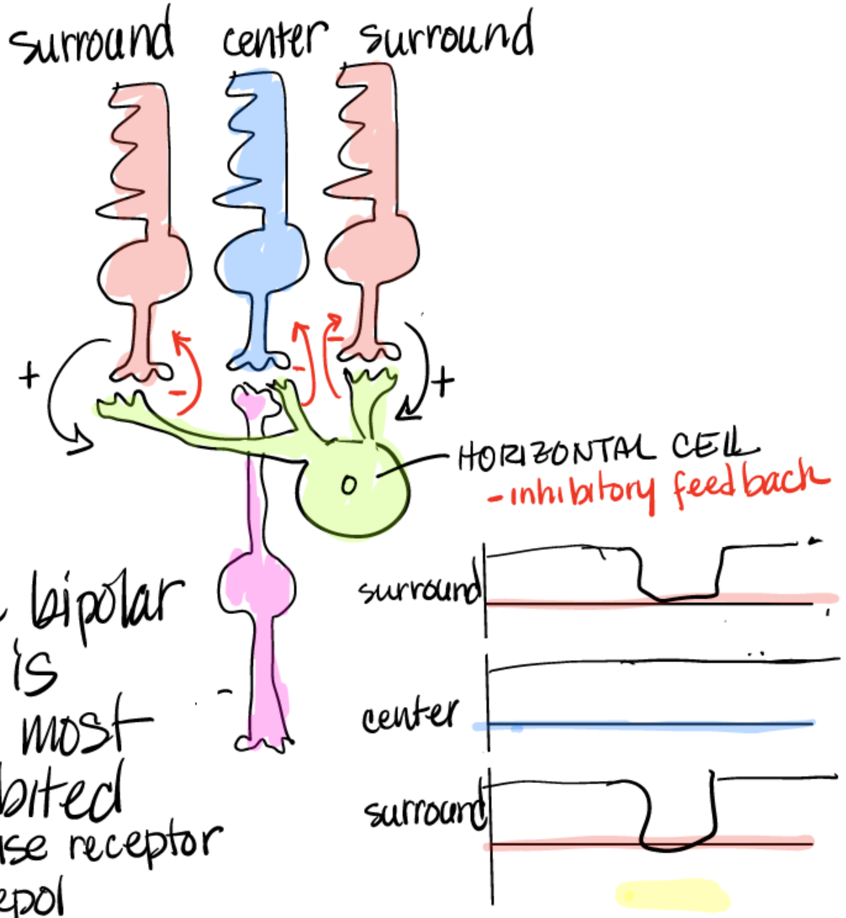
B
C
A
no light
light: ON center
light: on center
:off surround
light: off
surround
RGC
vNa+
open
inact
A
B
C
PIR: post inhib rebound



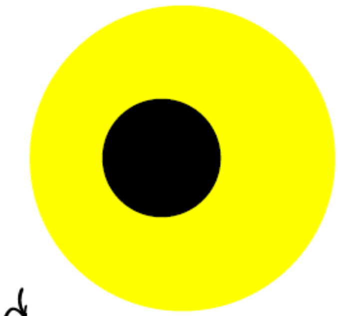
Mach
surround
center
surround
+
+
-
HORIZONTAL CELL
- inhibitory feedback
ON BIPOLAR
maximally excited
surround receptor
center receptor
S.R.
stays depol
hyperpol
* center cone releases less xmtr due to horizontal inhibition
on center
OFF SURROUND
D
M
L
I
I
B



*horizontal cell is less excited
-inhibition to center receptor is reduced

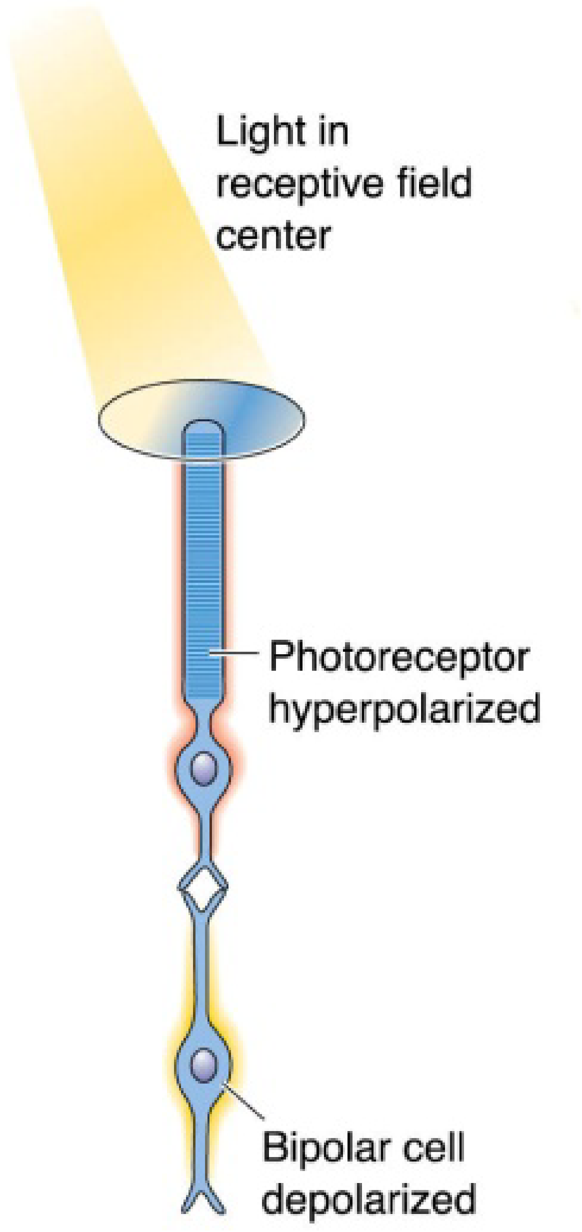


the bipolar cell is the most inhibited because receptor is depol & hc is not inhibiting



* surround receptors → hyperpol → horizontal cell minimally excited

∴ inhibitory signals are low

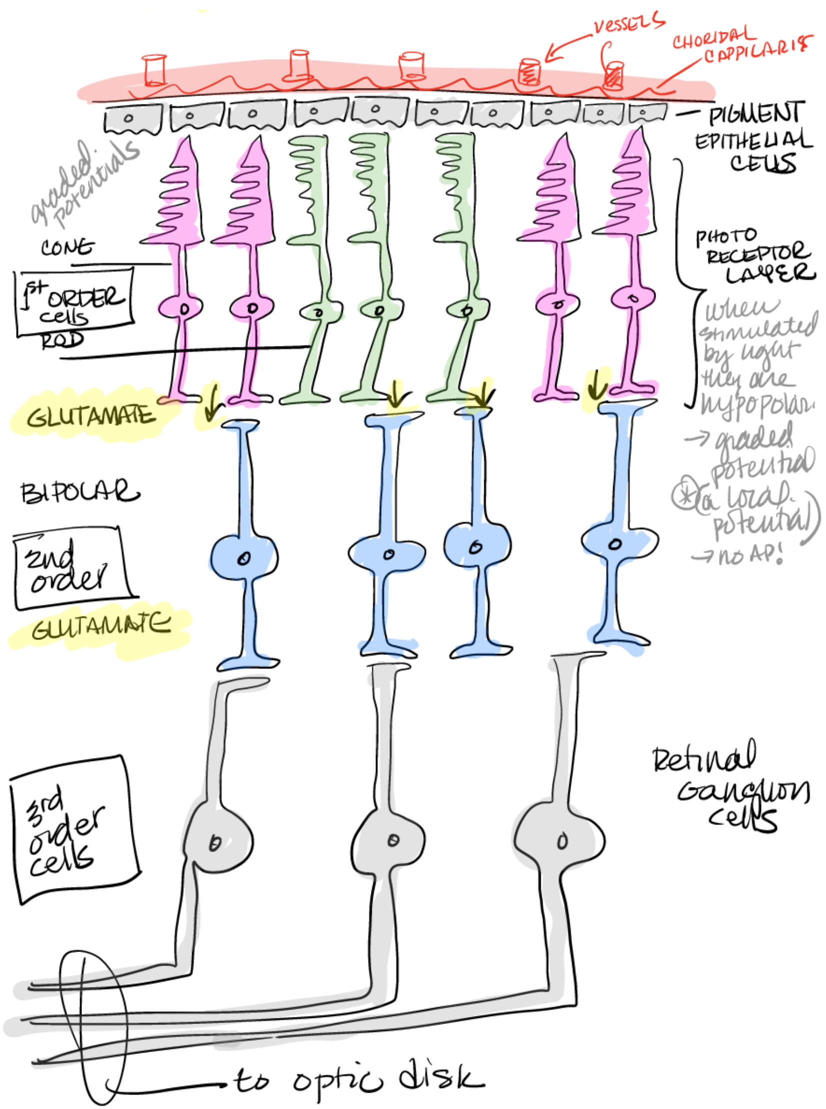


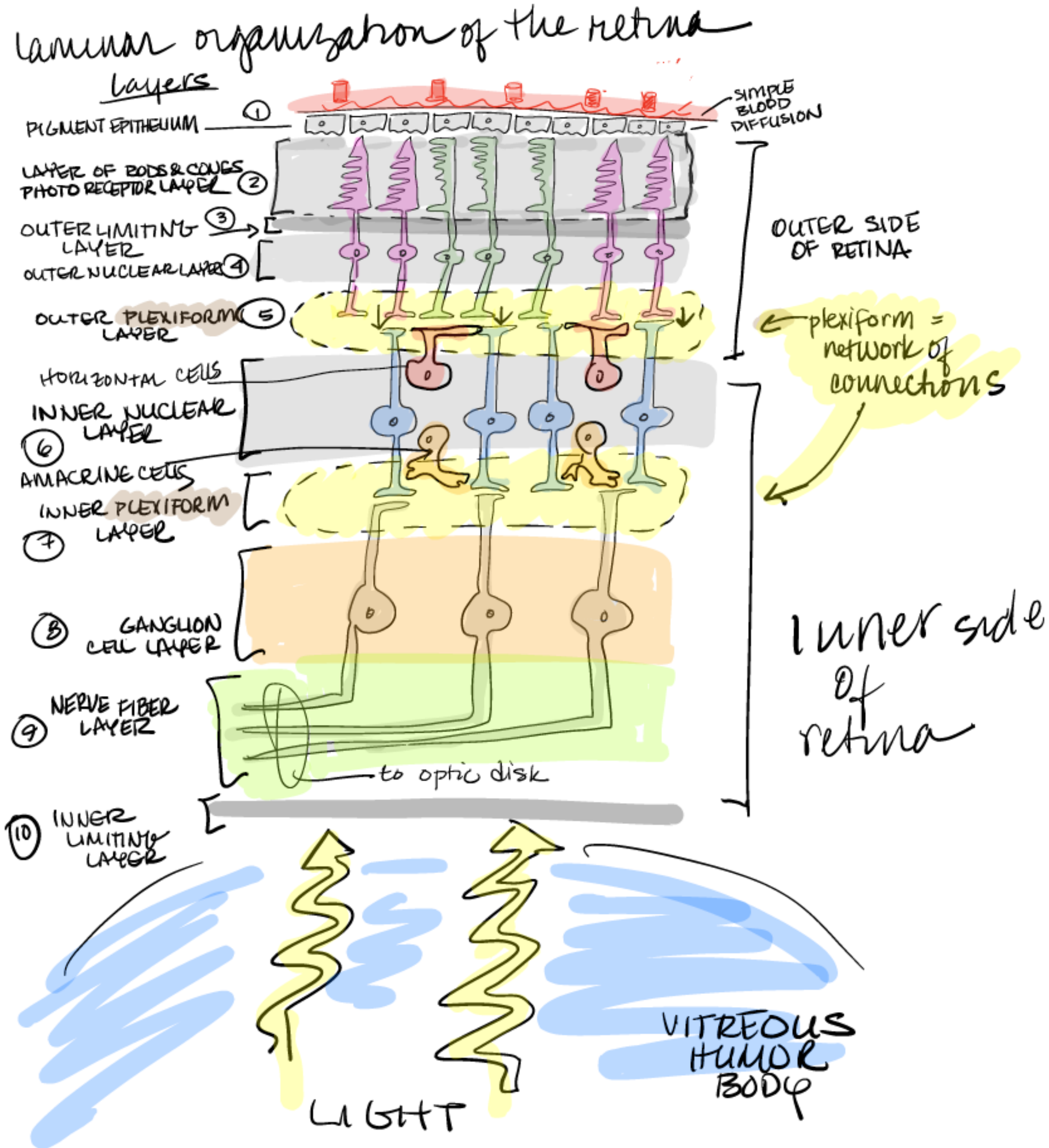
Direct pathway

Bipolar Cell Receptive Fields—(cont.)

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

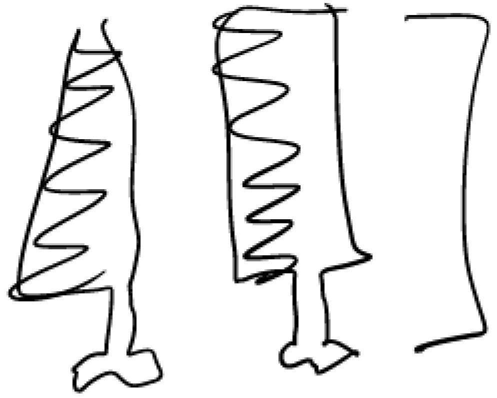
Slide from Bear, M. et al 5th edition publisher: Wolters-Kluwer 2016


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



laminar 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 SIDE OF RETINA
OUTER PLEXIFORM LAYER ⑤
plexiform = network of connections
HORIZONTAL CELLS
INNER NUCLEAR LAYER ⑥
AMACRINE CELLS
INNER PLEXIFORM LAYER ⑦
⑧ GANGLION CELL LAYER
Inner side of retina
⑨ NERVE FIBER LAYER
to optic disk
⑩ INNER LIMITING LAYER
VITREOUS HUMOR BODY
LIGHT

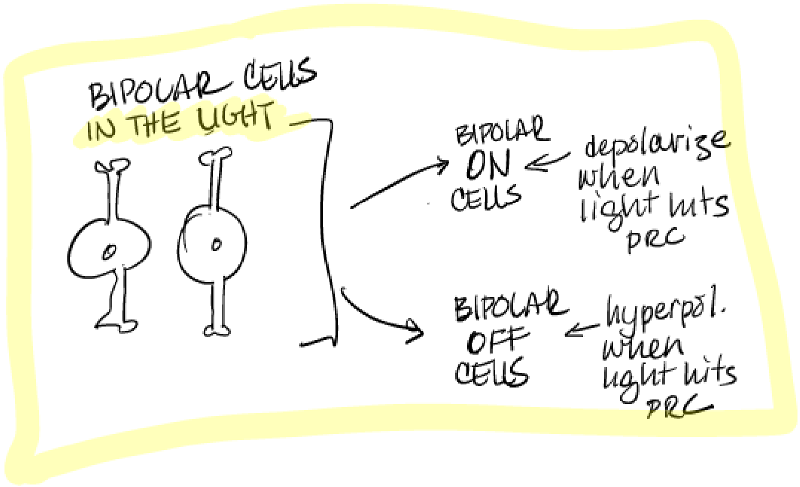
COMPLEXITY IN RETINAL SIGNALING

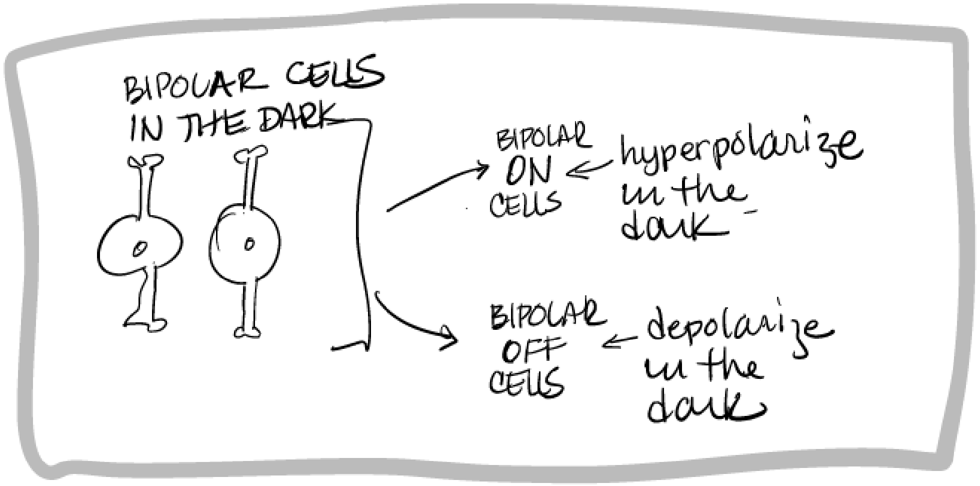


photoreceptors
have simple
graded responses

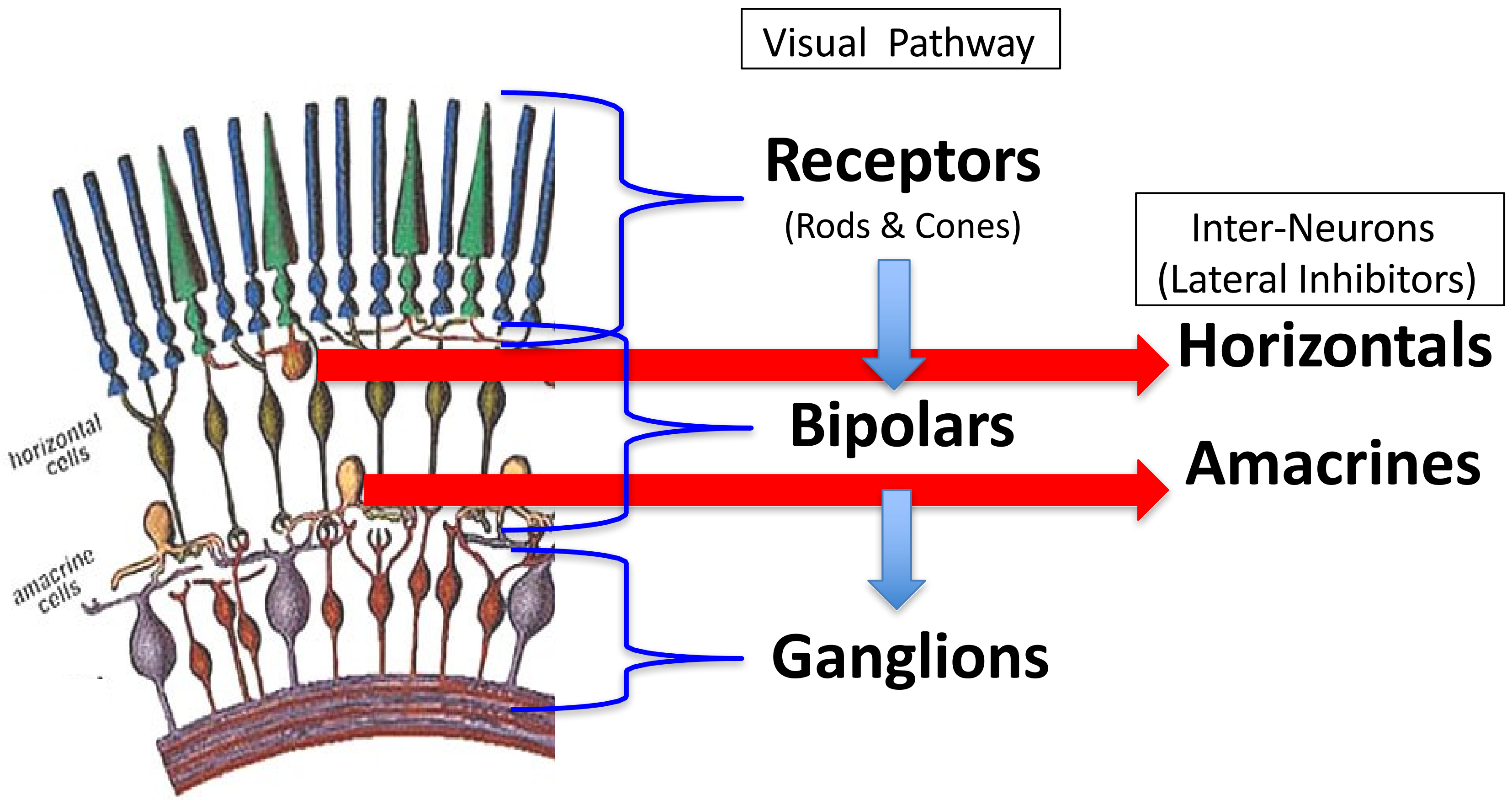
→ hyperpolarise

→ 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

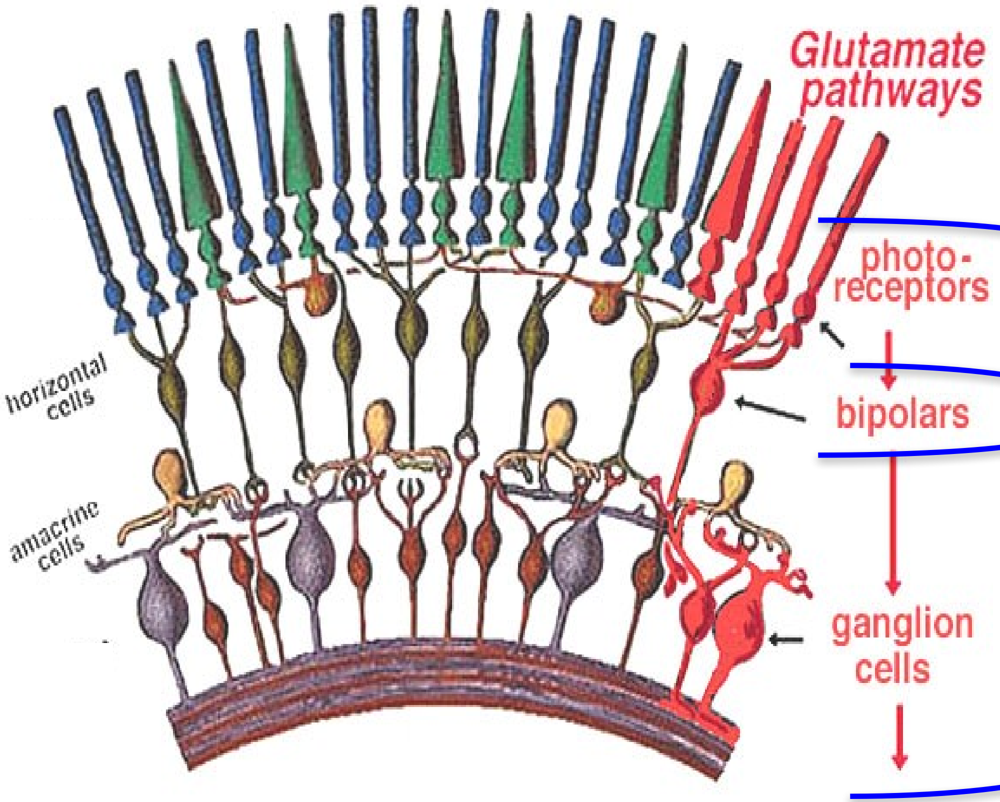


Fig. 13. The types of neurons in the vertebrate retina that use glutamate as a neurotransmitter (red).

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)

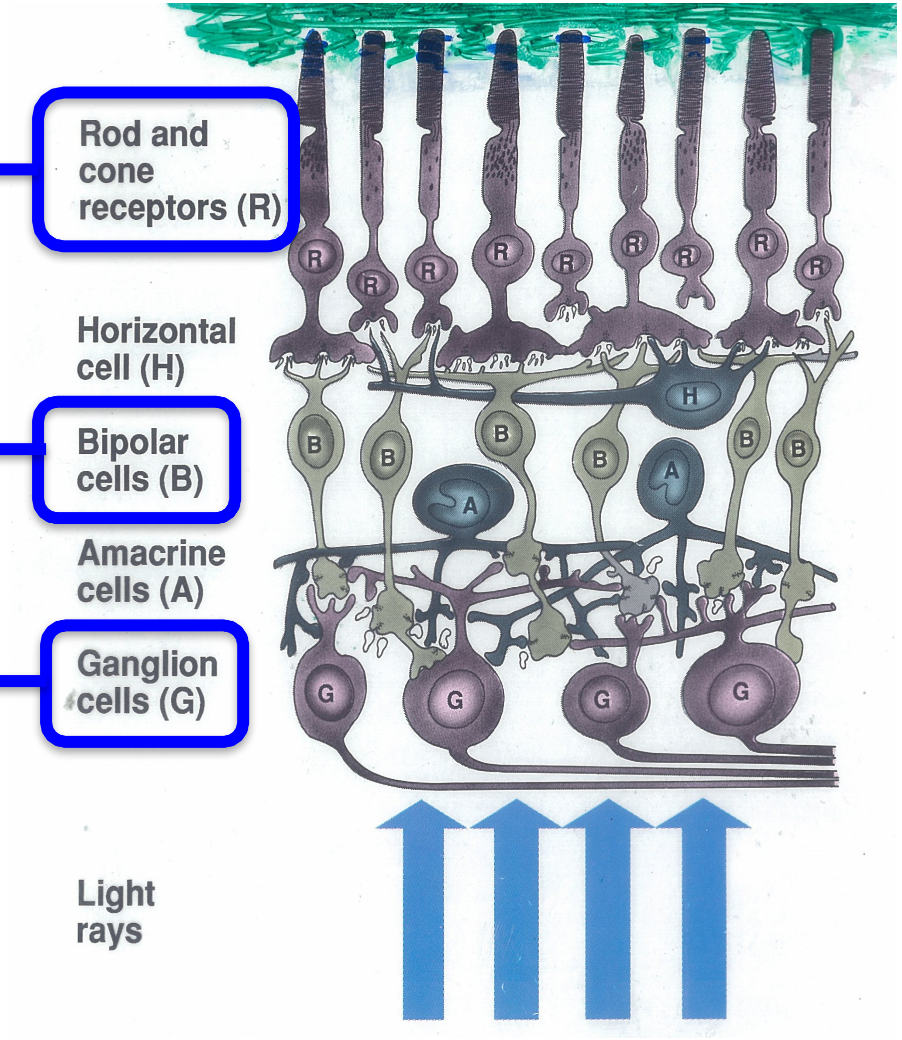
The Retina

Visual Pathway

Spontaneous,
Graded,
& Inhibitory

Spontaneous,
Graded,
& Excitatory

Action Potentials
& Excitatory



The Retina

Visual Pathway

Inter-Neurons

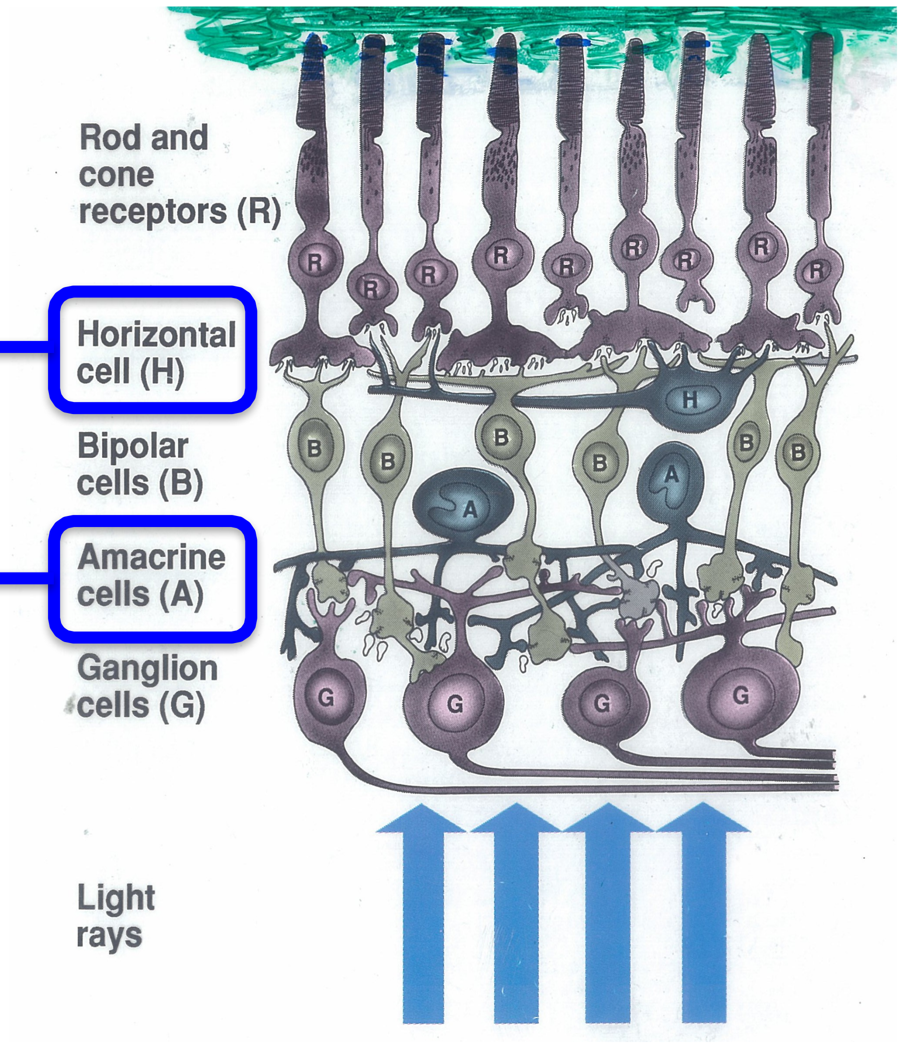
Spontaneous,
Graded,
& **Inhibitory**

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)

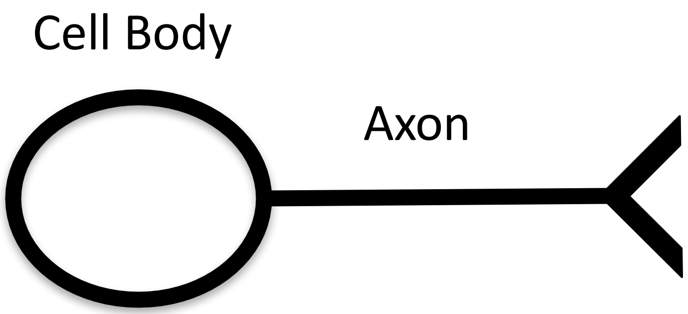
how do they signal that light is present..???

ANSWER:

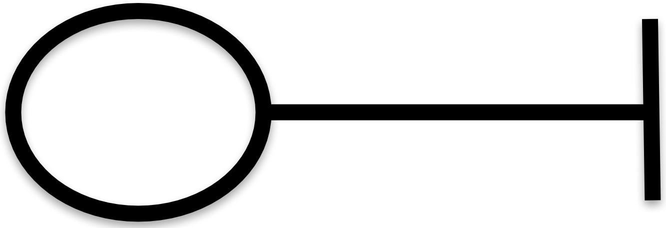
What matters is NOT what one cell does,

but how they are CONNECTED!

By convention, when we draw neural circuits . . .



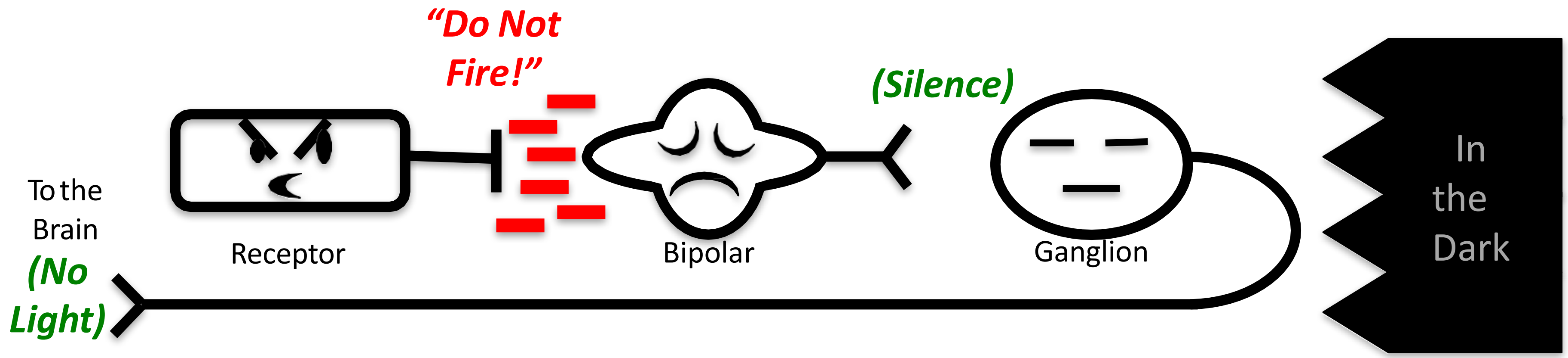
Excitatory



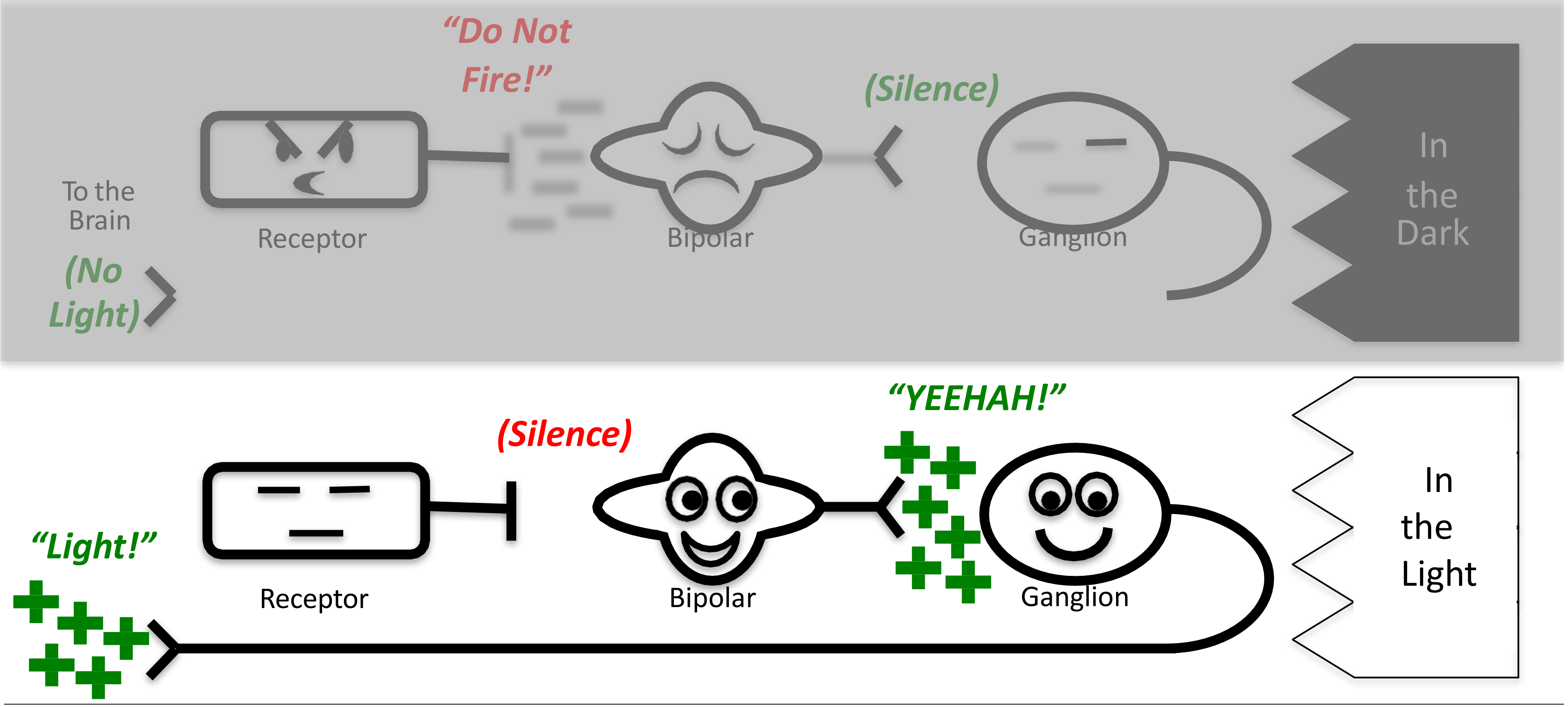
Inhibitory

Slide from Dr. Christine Johnson

Strange But True – Receptors are turned OFF by light

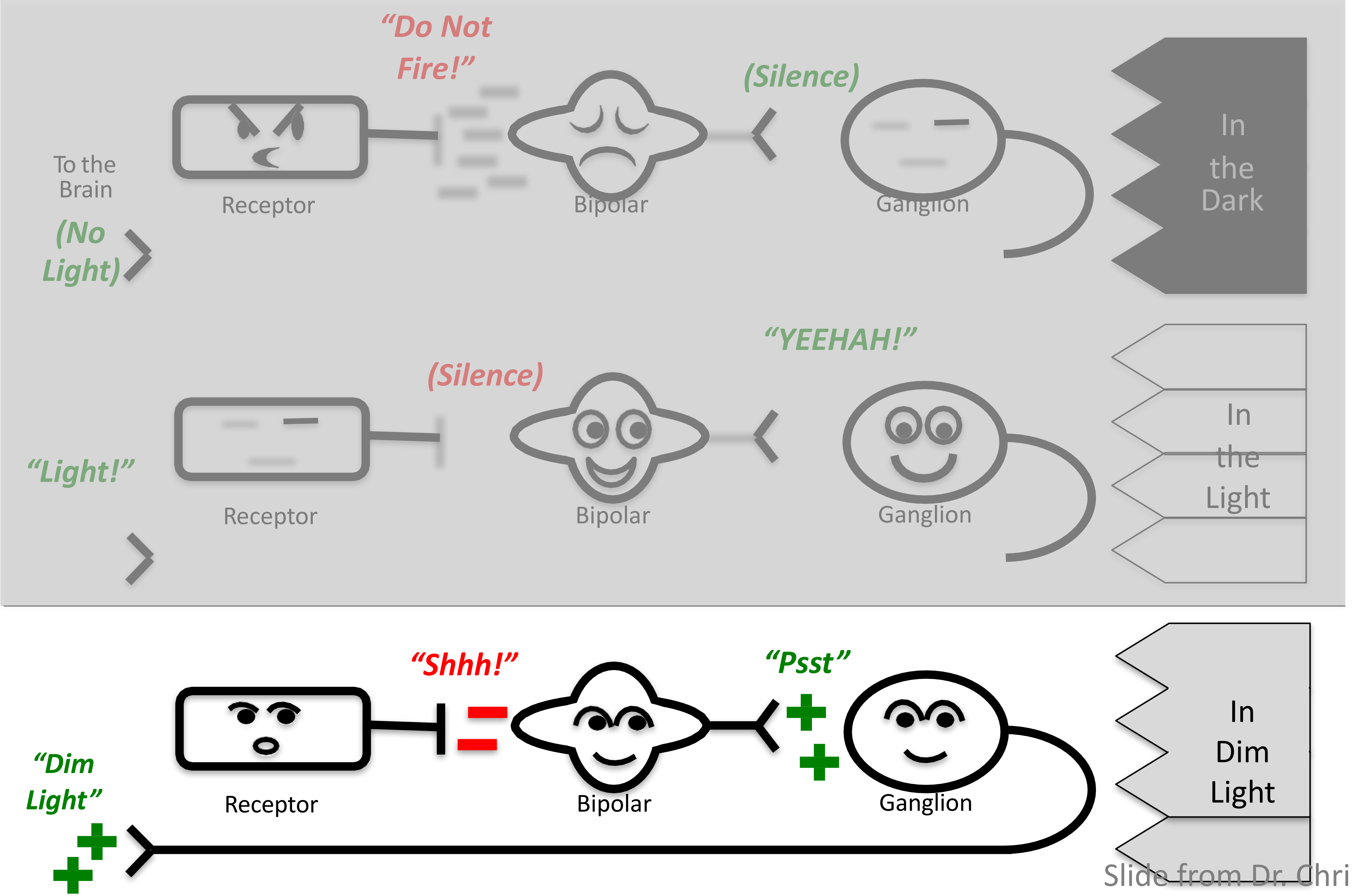


Strange But True – Receptors are turned OFF by light



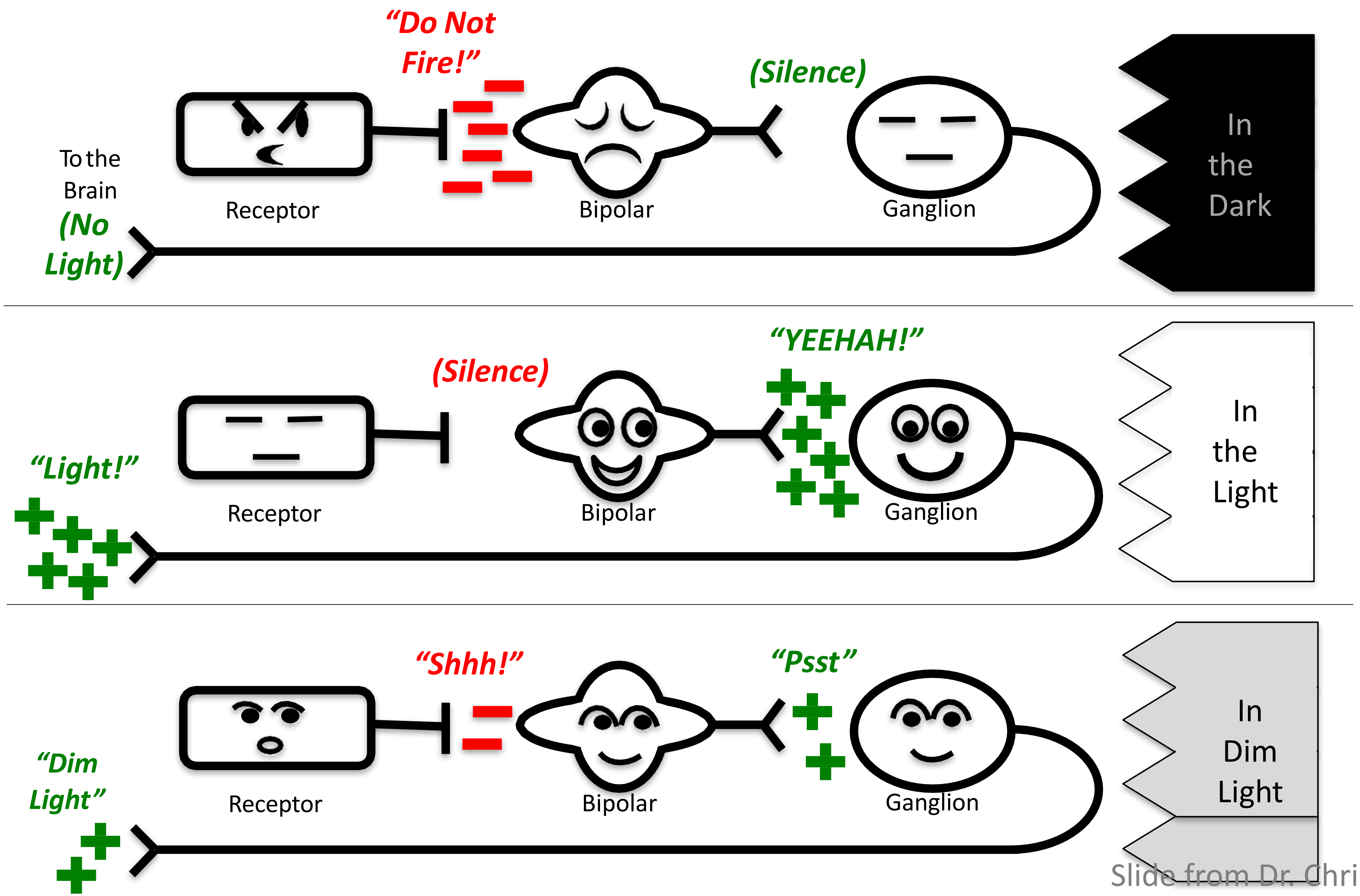
Slide from Dr. Christine Johnson

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

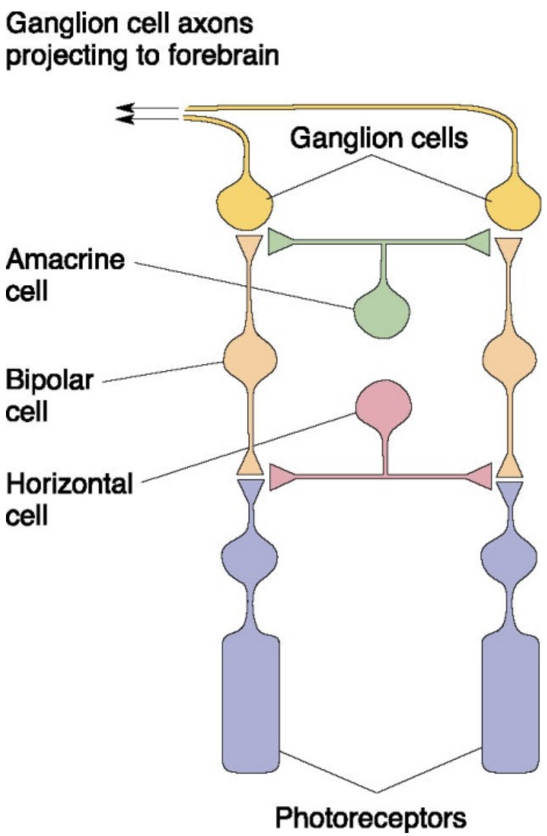
- Direct (vertical) pathway
  - Ganglion cells

    ↑

  - Bipolar cells

    ↑

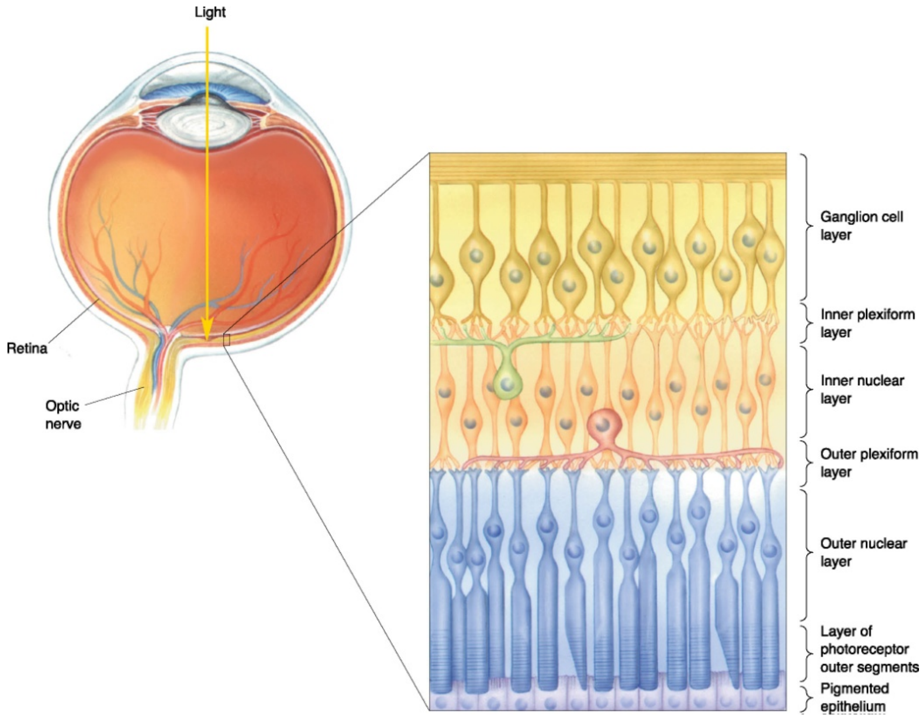
  - Photoreceptors



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

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

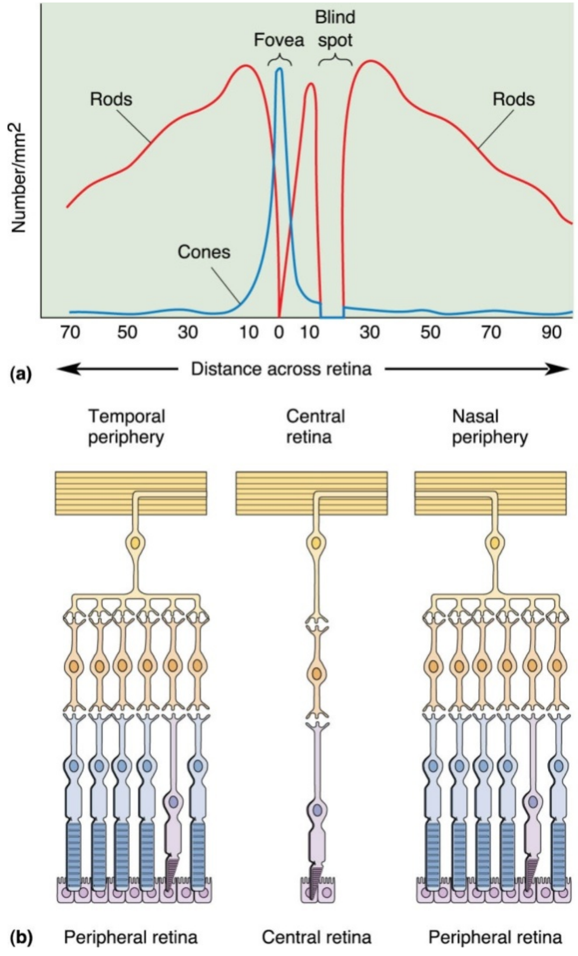
e.g. Sensitivity in Rods

e.g. Receptive Fields

e.g. Simultaneous Contrast

Regional Differences in Retinal Structure

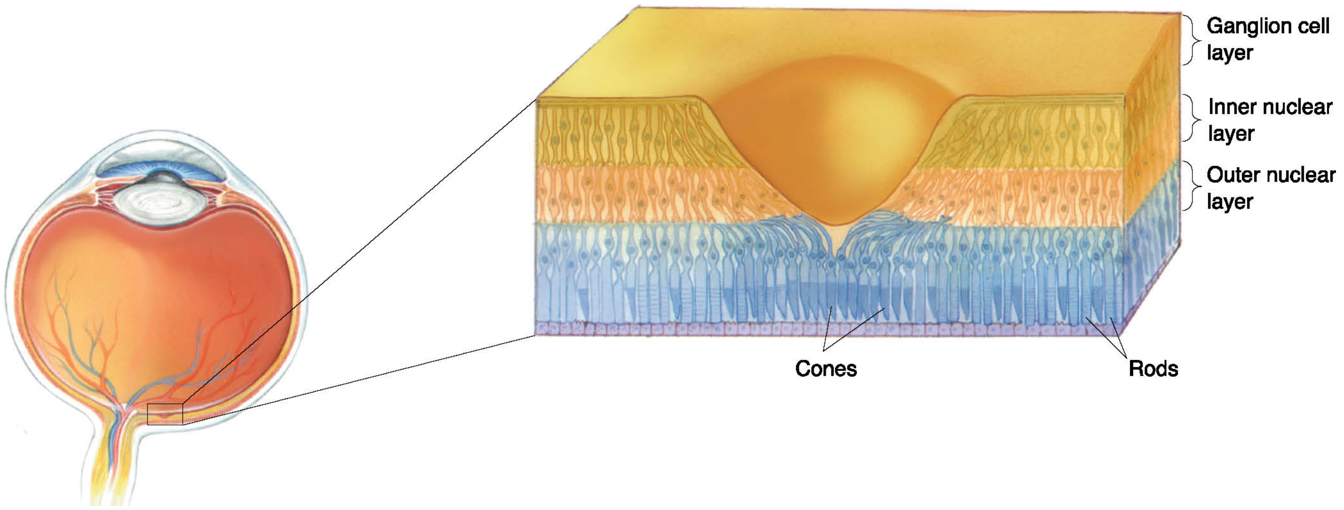
- Structure varies from fovea to retinal periphery.
- Peripheral retina
  - Higher ratio of rods to cones
  - Higher ratio of photoreceptors to ganglion cells
  - More sensitive to low light



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

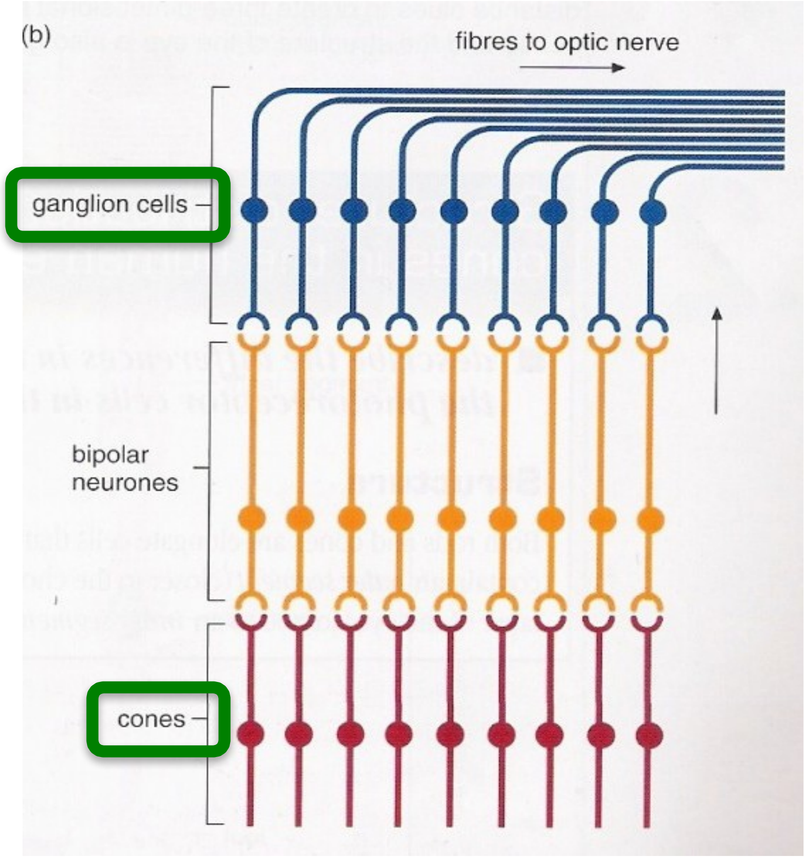
Regional Differences in Retinal Structure—(cont.)

- 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

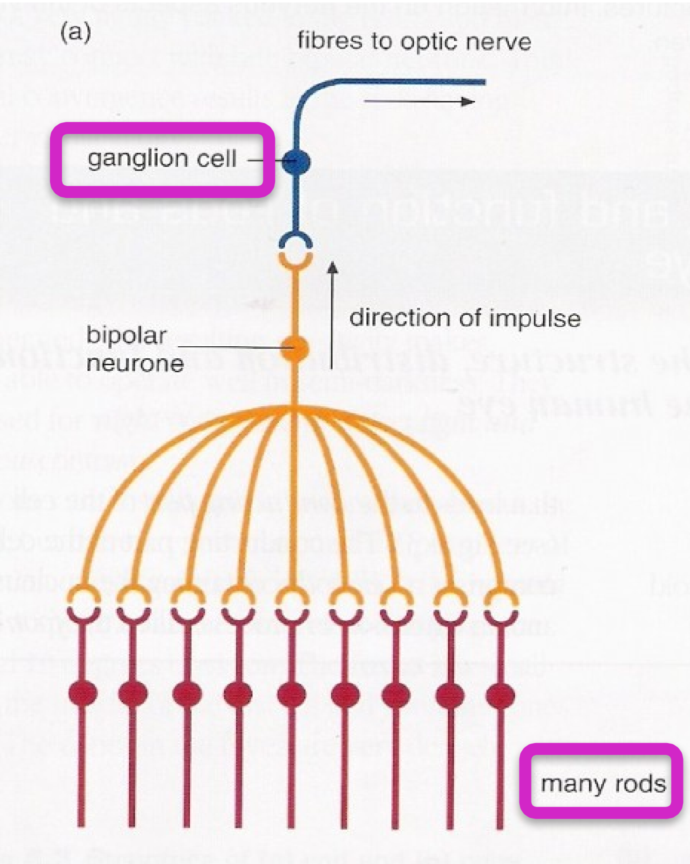
Cones show LOW convergence



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**)

Slide from Dr. Christine Johnson

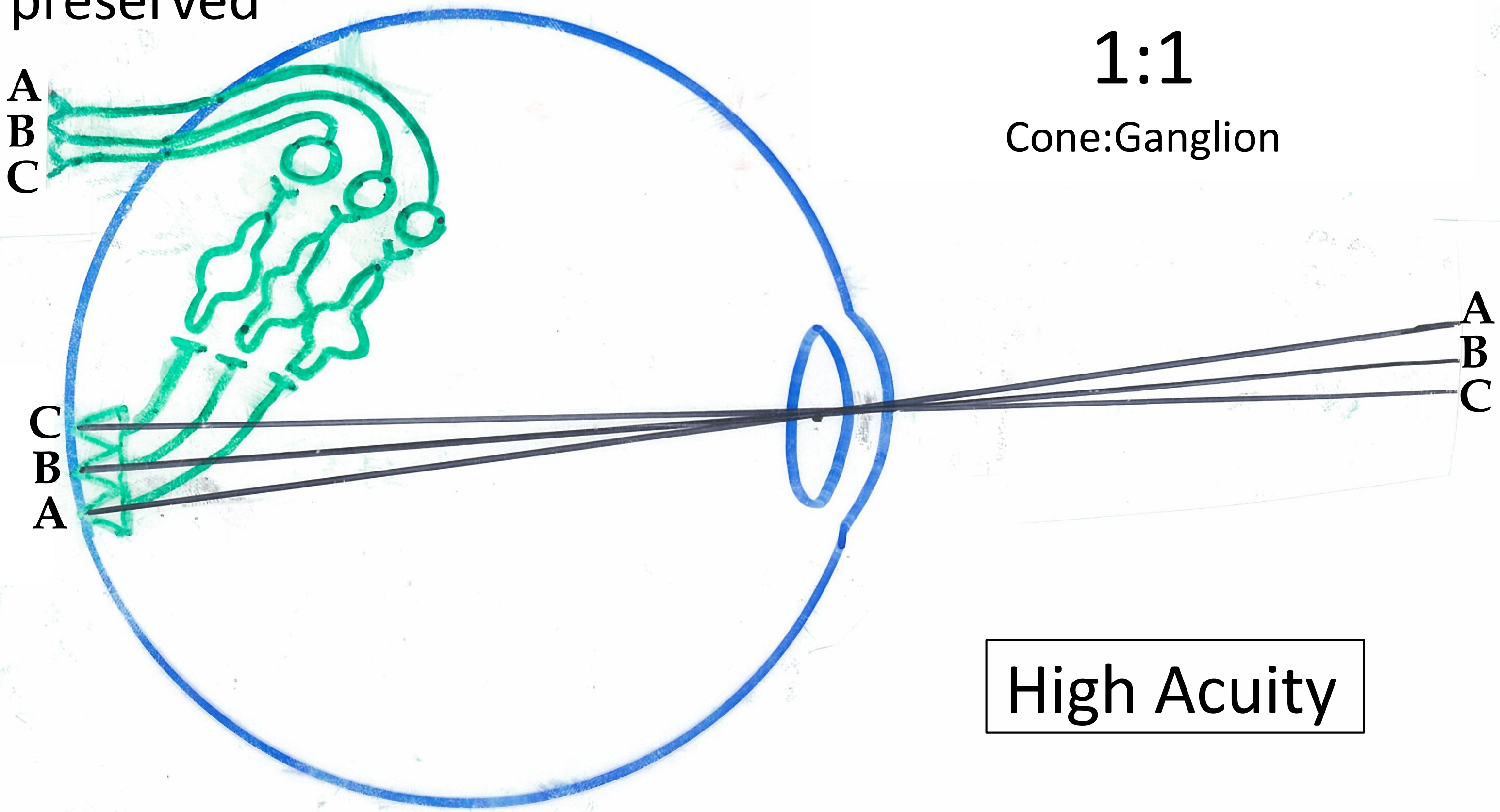
Connectivity Matters

Due to connectivity pattern, details are preserved

CONES

1:1

Cone:Ganglion



High Acuity

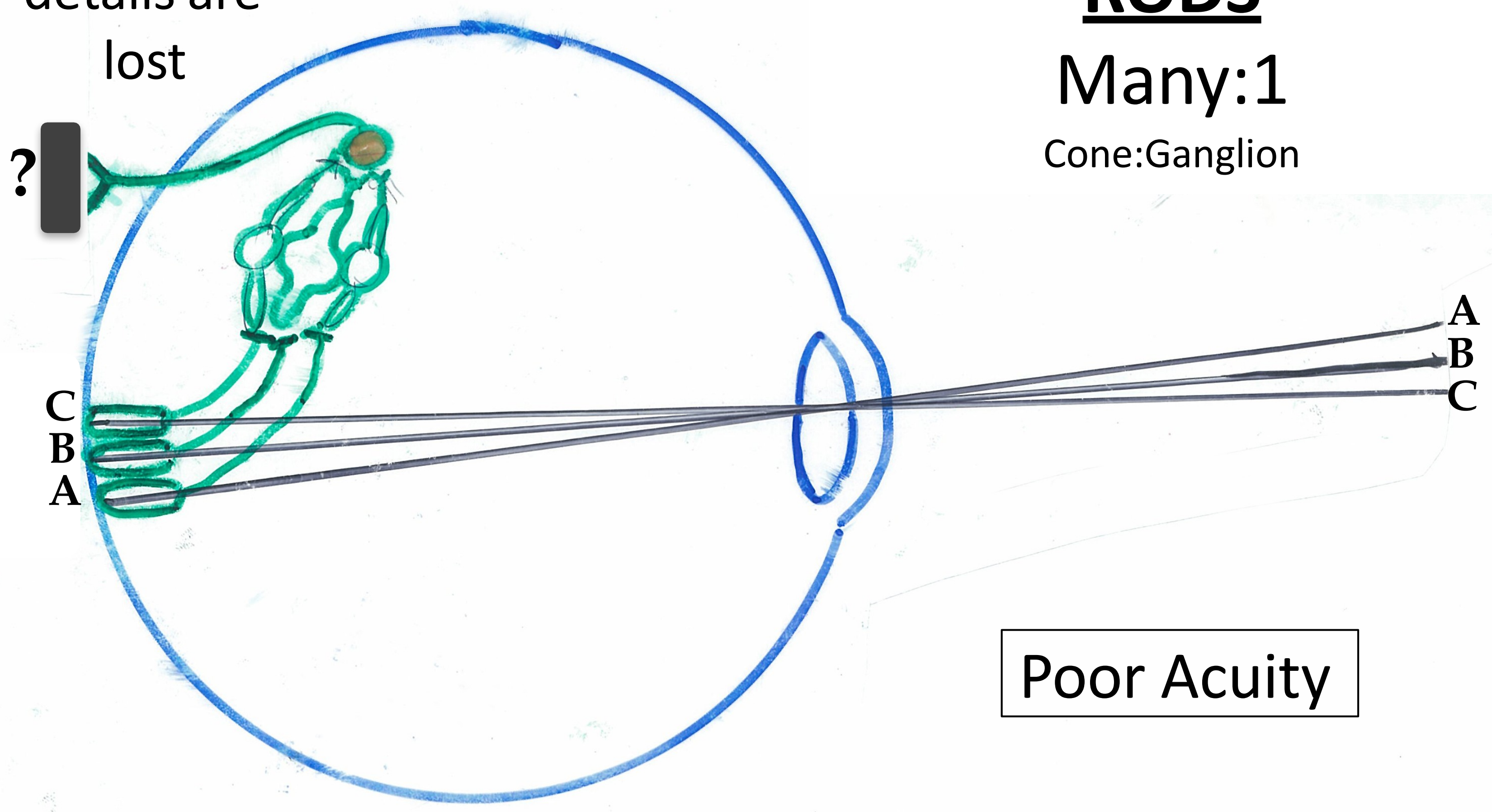
Connectivity Matters

Due to
Connectivity pattern,
details are
lost

RODS

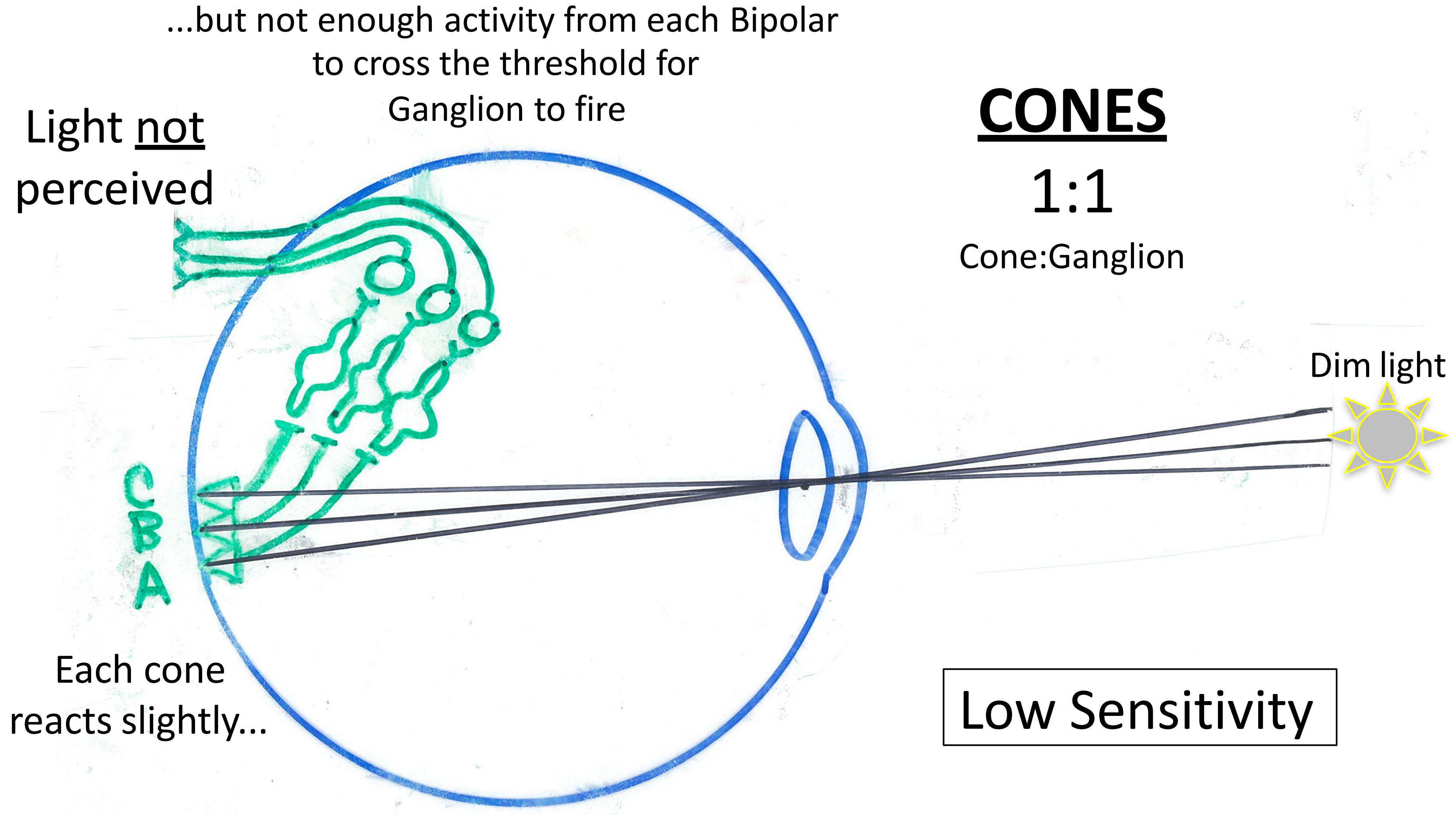
Many:1

Cone:Ganglion



Poor Acuity

Connectivity Matters



CONES

1:1

Cone:Ganglion

Low Sensitivity

Connectivity Matters

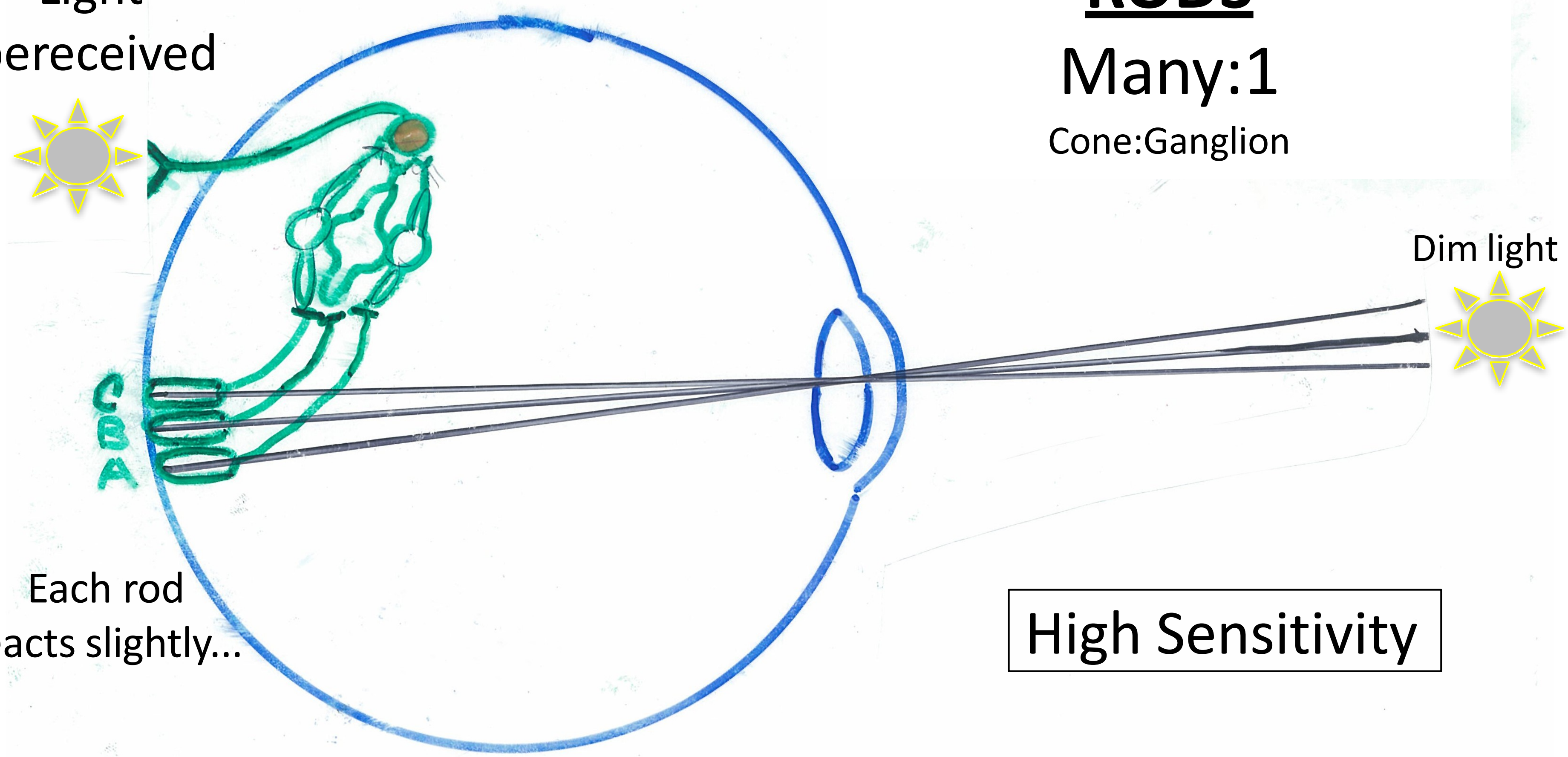
...and activity of Bipolars summates, sufficient to cross the threshold for Ganglion to fire

Light pereceived

RODS

Many:1

Cone:Ganglion



Dim light

Each rod reacts slightly...

High Sensitivity

Although note...

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

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

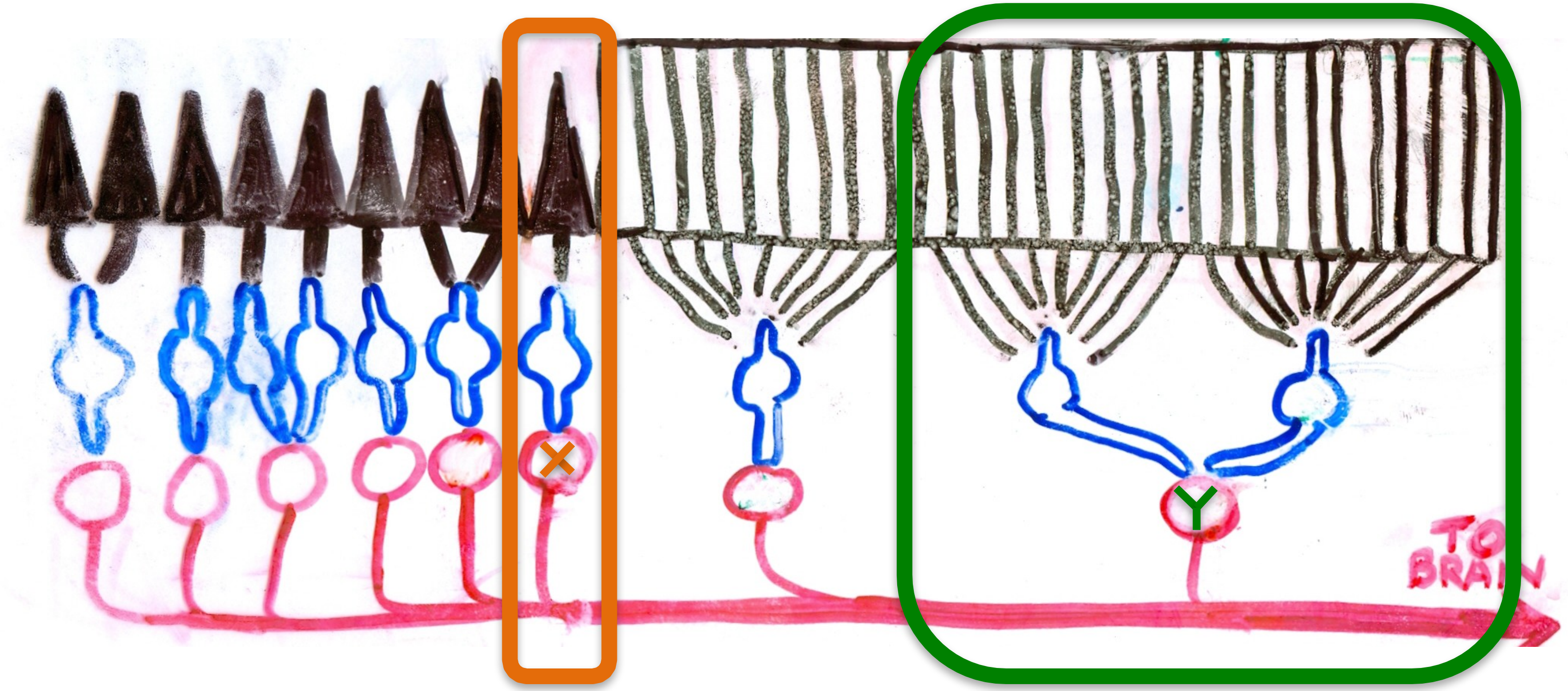
- That is, there is a better chance that a given photon of light will hit a Rod than a Cone, so in low light,
  Rods are more likely to be the receptors to respond

MNEMONIC
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

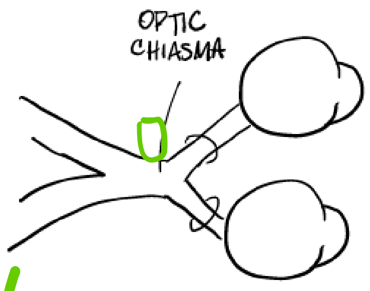


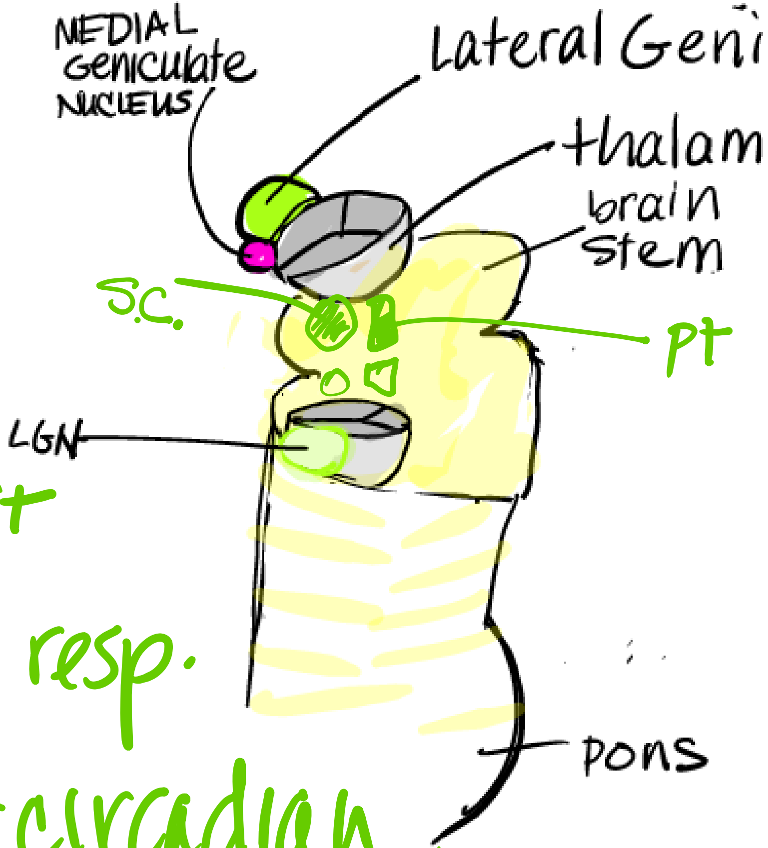
Ganglion X has a Small Receptive field

Ganglion Y has a Large Receptive field

Slide from Dr. Christine Johnson

VISUAL PATHWAYS



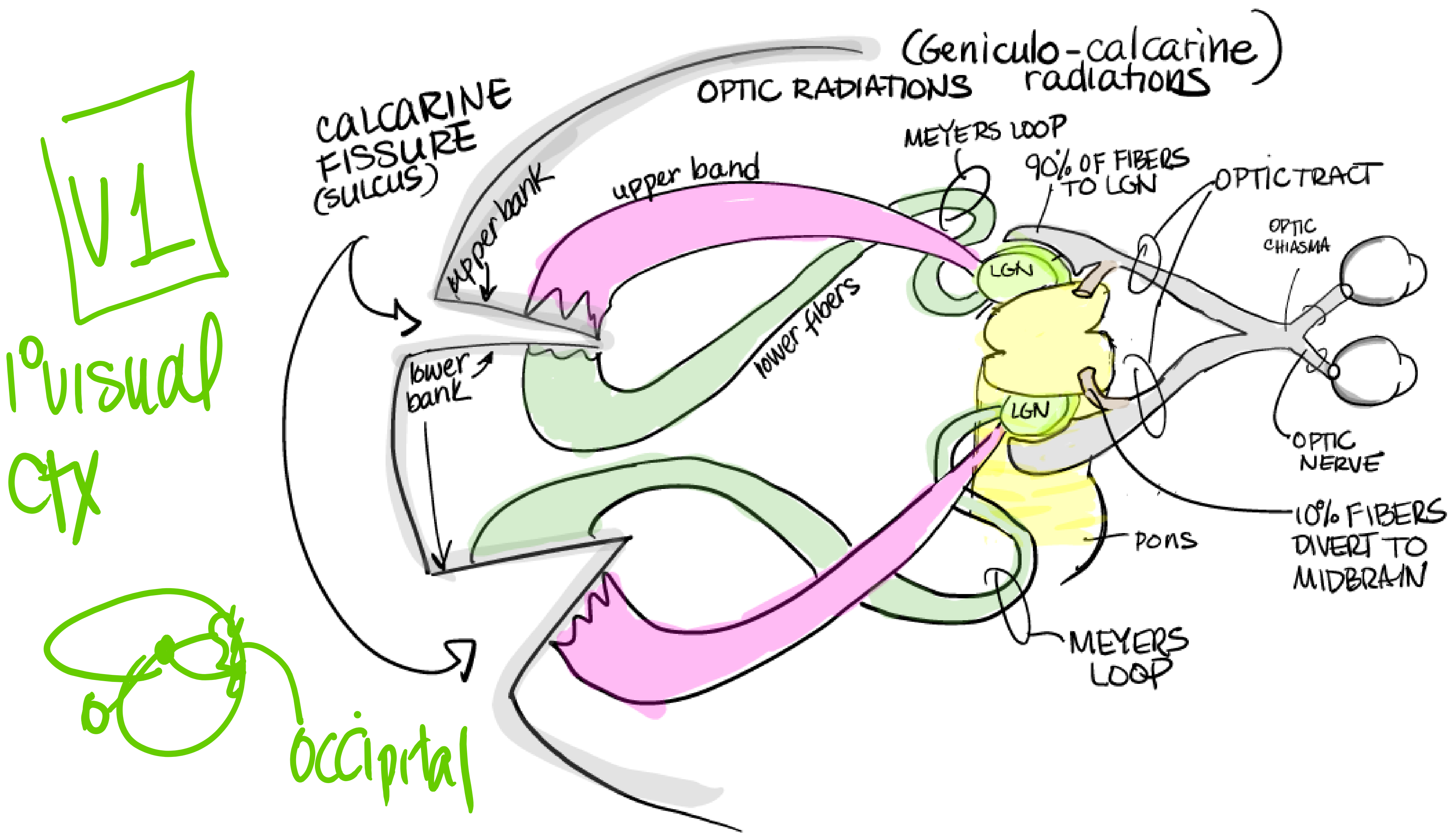


Major - LGN

Superior colliculus - mvt

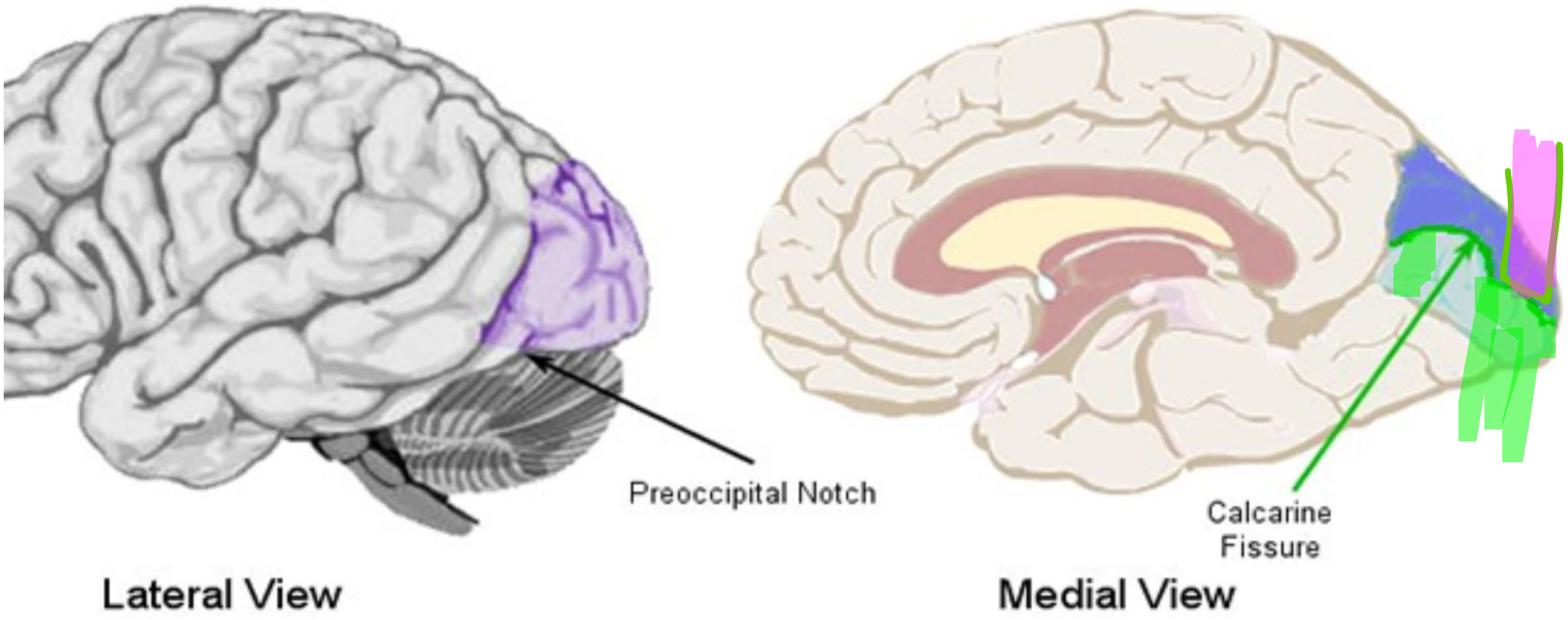
Pretectal Nuc. ← Pupil resp.

suprachiasmatic N. ← circadian rhythms ← cone (B)



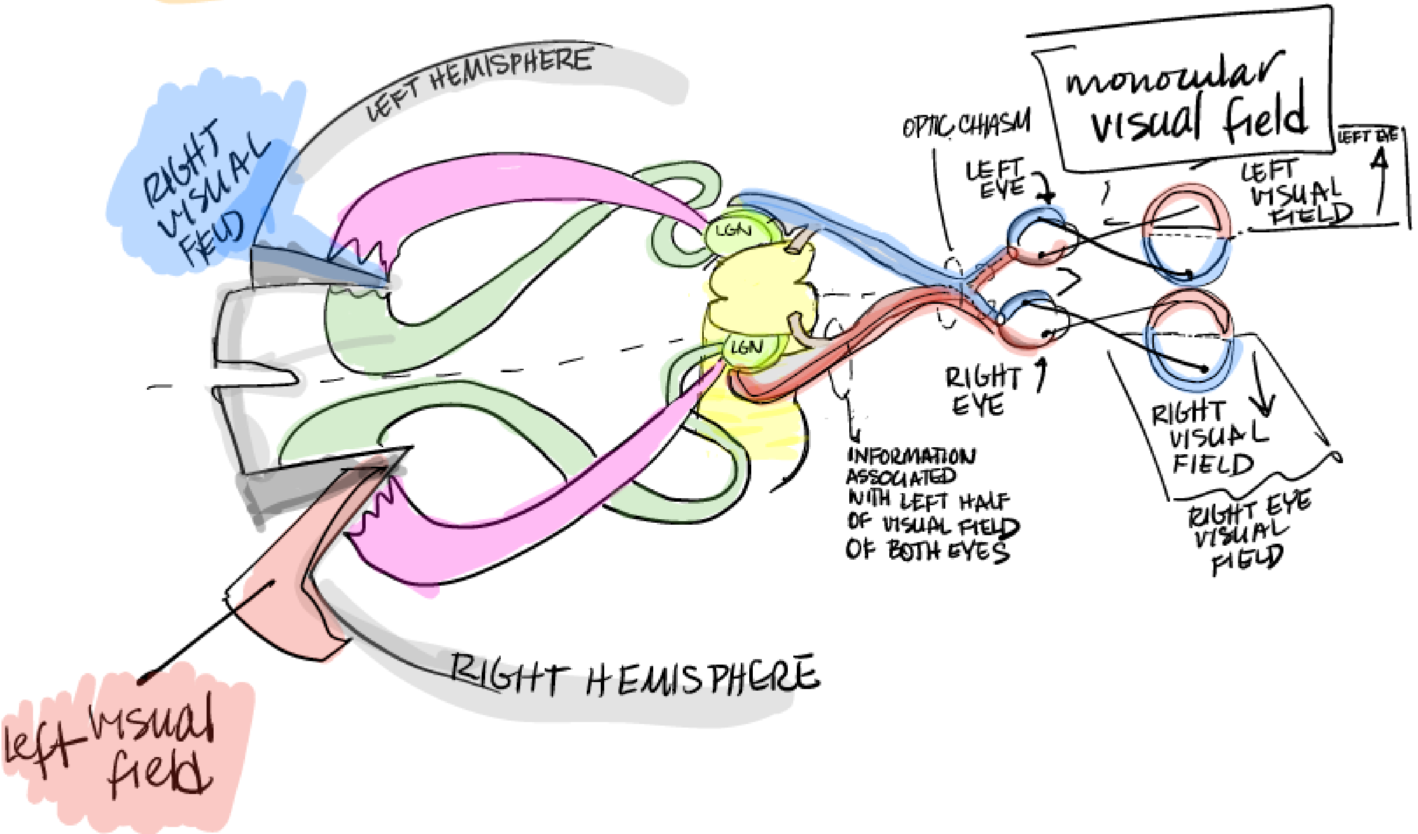
V1
1° visual ctx
occipital
CALCARINE FISSURE (SULCUS)
upper bank
lower bank
upper band
lower fibers
OPTIC RADIATIONS
(Geniculo-calcarine radiations)
MEYERS LOOP
90% OF FIBERS TO LGN
OPTIC TRACT
OPTIC CHIASMA
LGN
LGN
OPTIC NERVE
10% FIBERS DIVERT TO MIDBRAIN
PONS
MEYERS LOOP

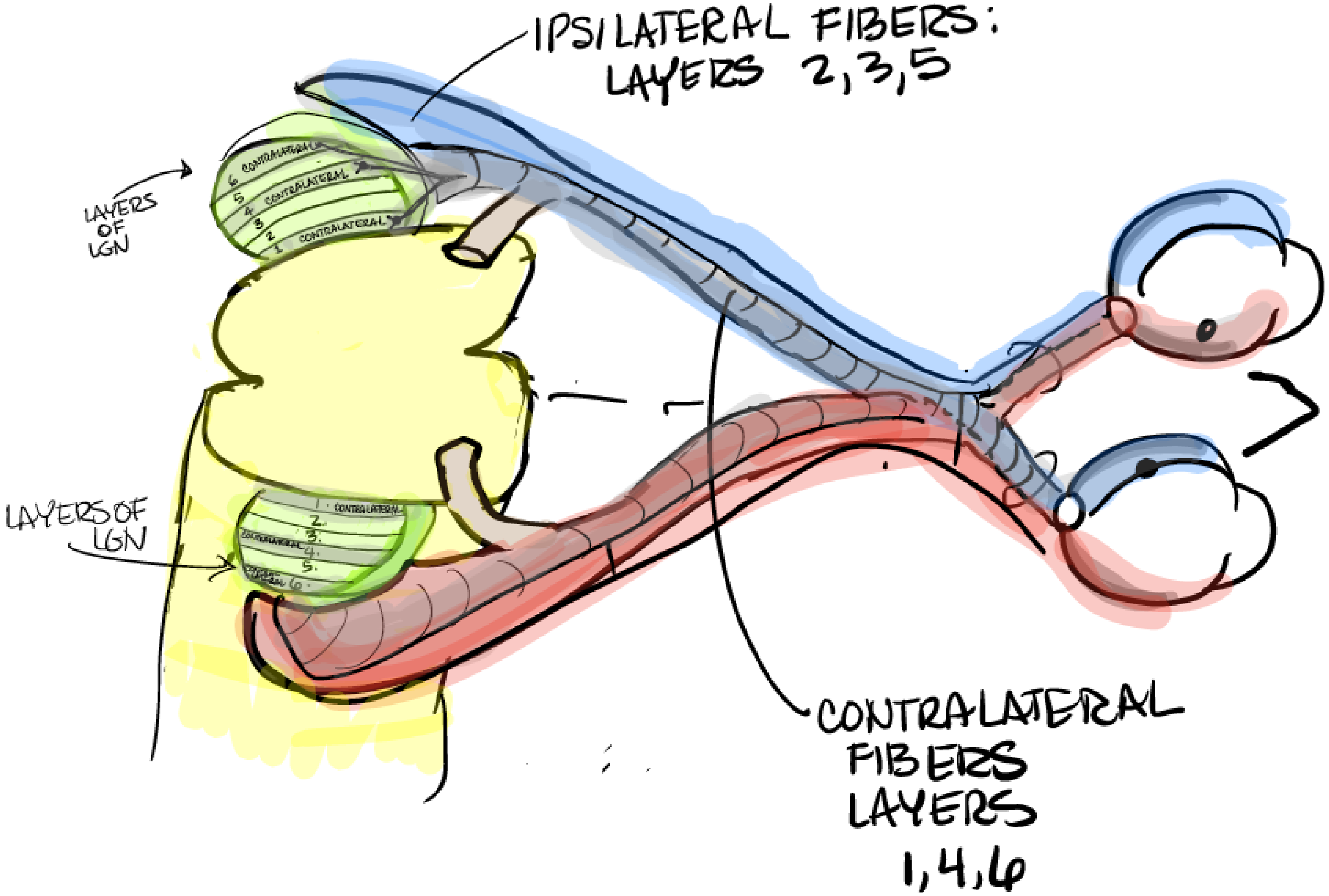
The Occipital Lobe

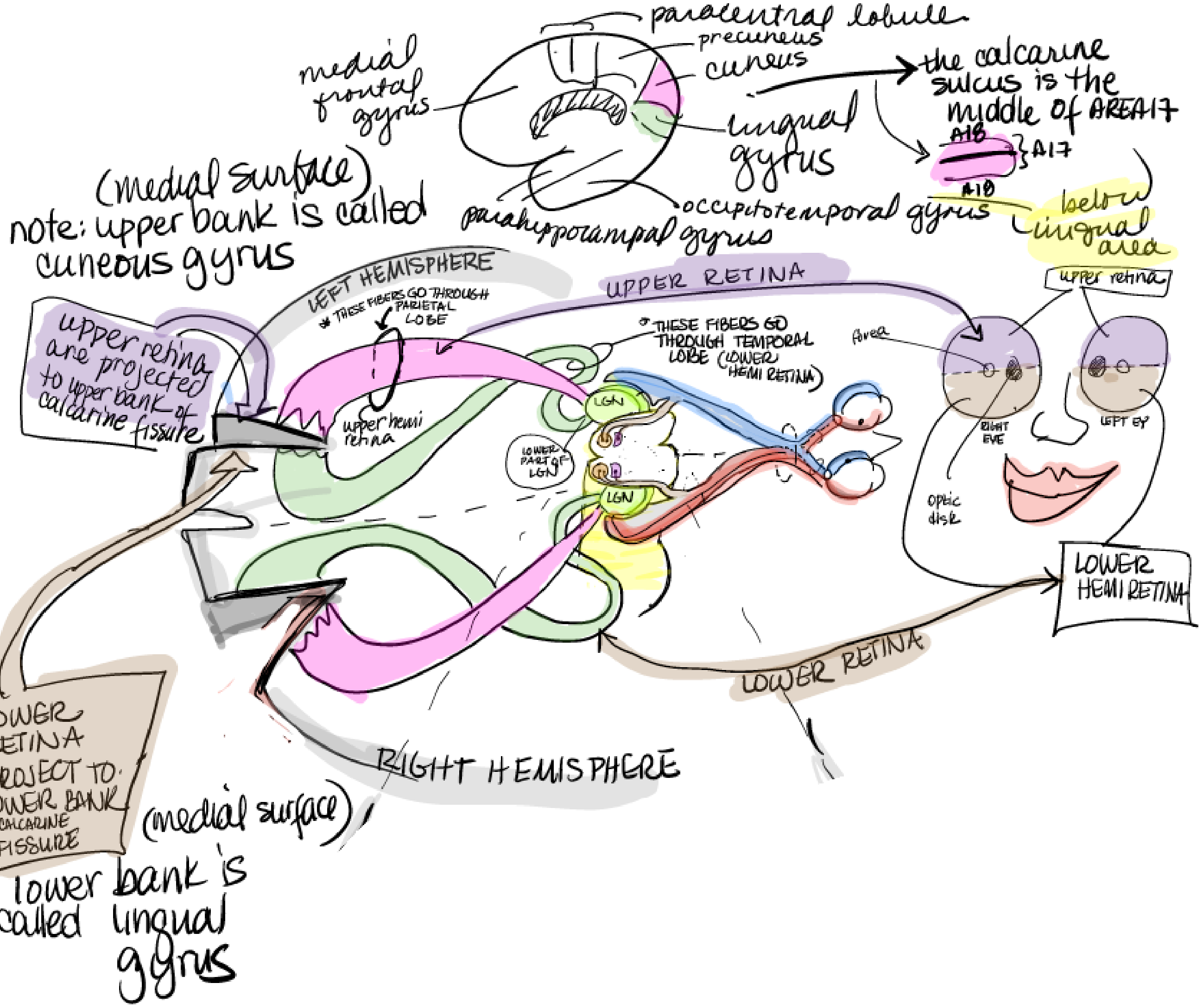


VISION IS A CROSSED SENSATION

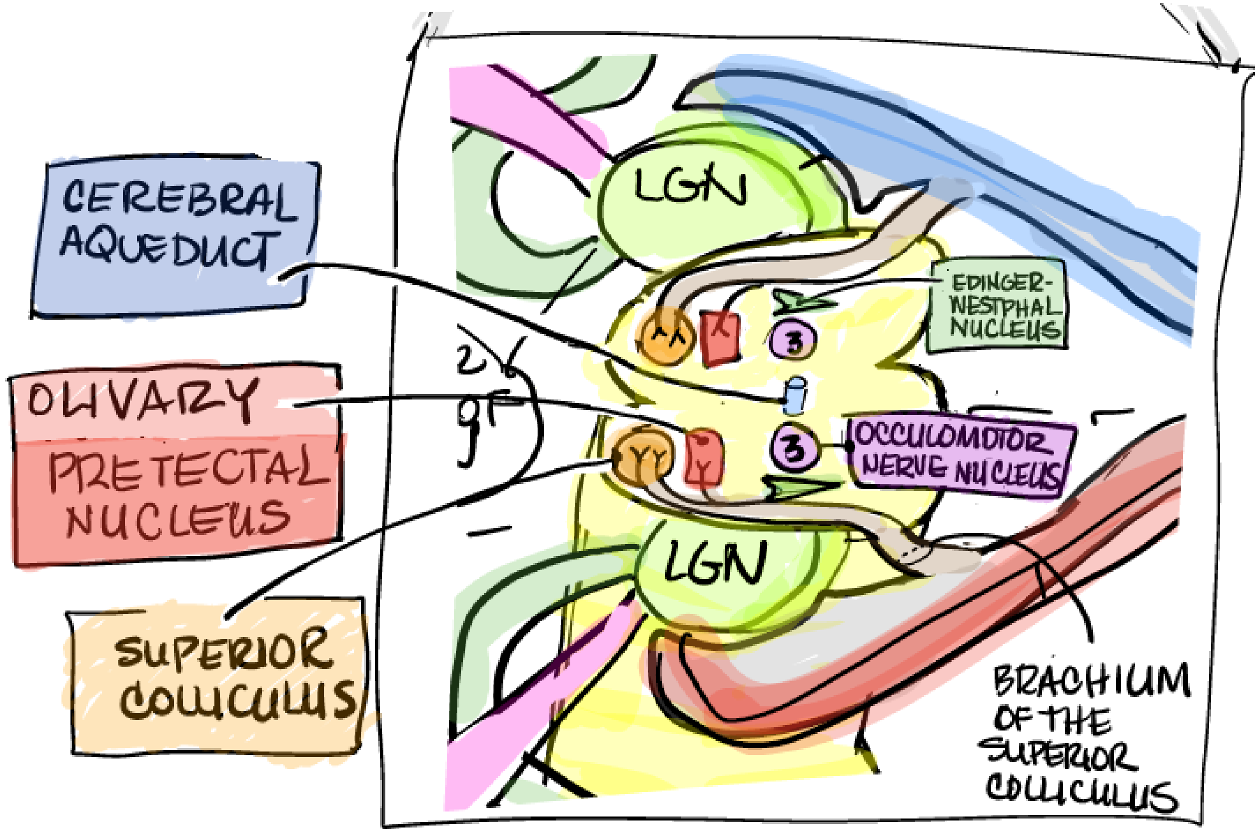
* LEFT VISUAL FIELD → RIGHT V1.

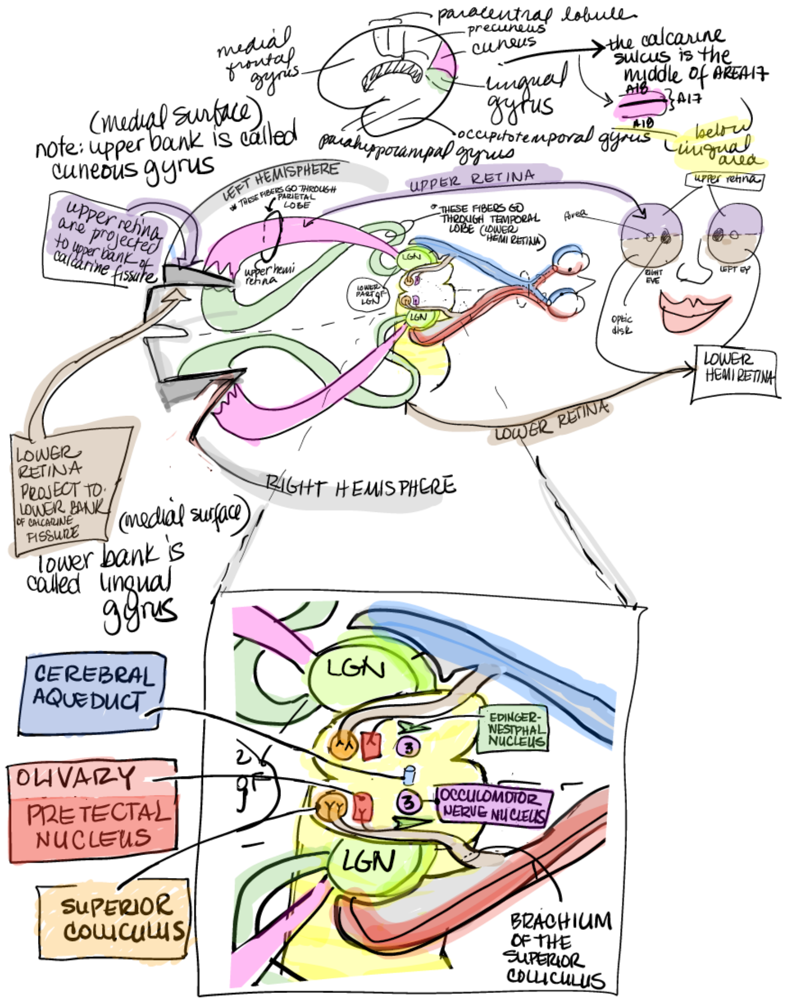



IPSILATERAL FIBERS:
LAYERS 2,3,5
LAYERS OF LGN
LAYERS OF LGN
CONTRALATERAL FIBERS LAYERS 1,4,6



paracentral lobule
precuneus
cuneus
medial frontal gyrus
lingual gyrus
the calcarine sulcus is the middle of AREA17
A18
A17
A18
below lingual area
parahippocampal gyrus
occipitotemporal gyrus
(medial surface)
note: upper bank is called cuneous gyrus
LEFT HEMISPHERE
THESE FIBERS GO THROUGH PARIETAL LOBE
UPPER RETINA
upper retina are projected to upper bank of calcarine fissure
upper hemi retina
THESE FIBERS GO THROUGH TEMPORAL LOBE (LOWER HEMI RETINA)
LGN
LOWER PART OF LGN
LGN
fovea
upper retina
RIGHT EYE
LEFT EY
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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(medial surface)
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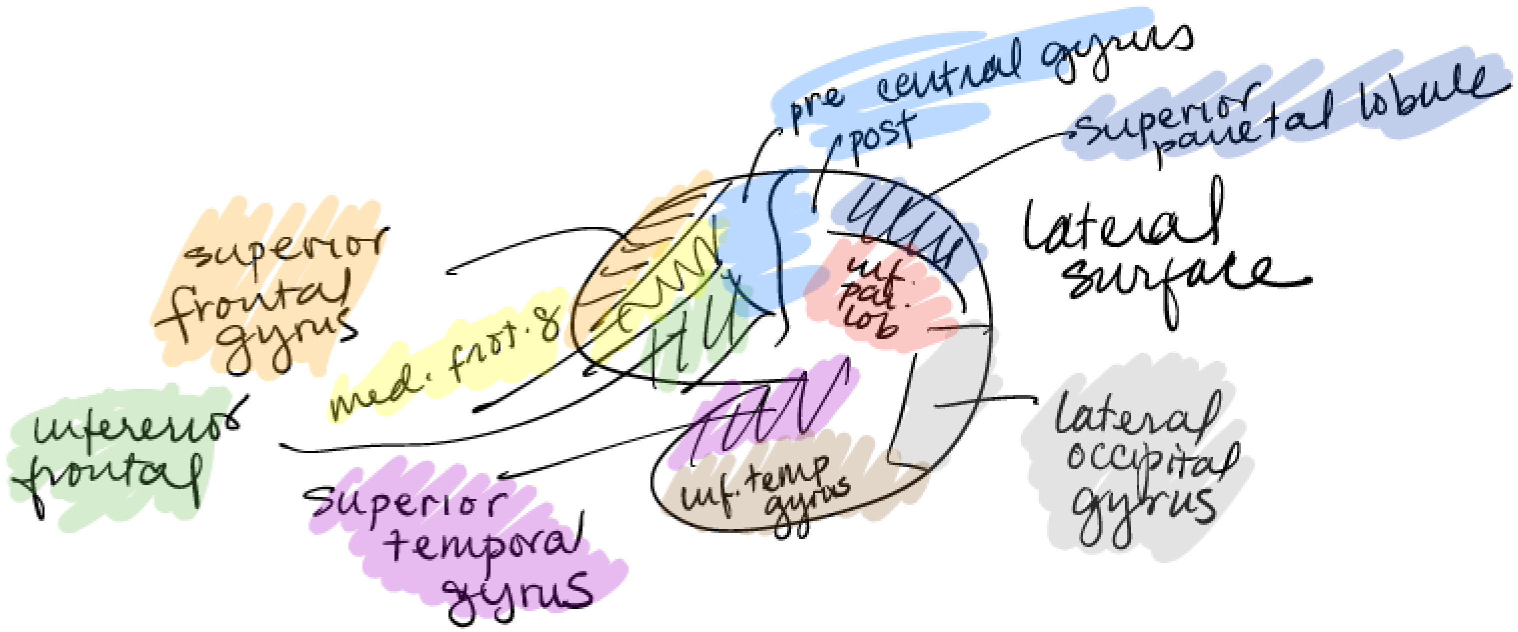
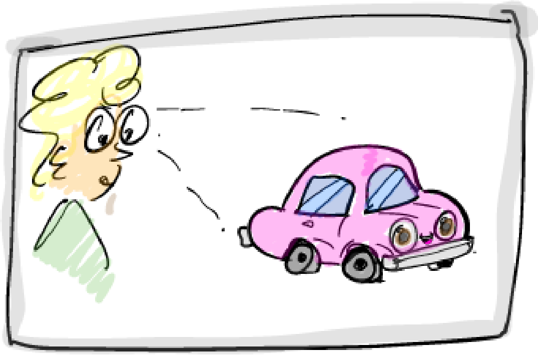
parahippocampal gyrus
occipitotemporal gyrus
below lingual area
LEFT HEMISPHERE
UPPER RETINA
upper retina are projected to upper bank of calcarine fissure
upper retina
LOWER HEMI RETINA
LOWER RETINA
LOWER RETINA PROJECT TO LOWER BANK OF CALCARINE FISSURE
RIGHT HEMISPHERE
(medial surface)
lower bank is called lingual gyrus
CEREBRAL AQUEDUCT
OLIVARY
PRETECTAL NUCLEUS
SUPERIOR COLLICULUS
LGN
EDINGER-WESTPHAL NUCLEUS
OCCULOMOTOR NERVE NUCLEUS
LGN
BRACHIUM OF THE SUPERIOR COLLICULUS



pre central gyrus
post
superior parietal lobule
lateral surface
superior frontal gyrus
med. frot. 8
inf. pat. lob
inferenor frontal
superior temporal gyrus
inf. temp gyrus
lateral occipital gyrus

Feature Detection

"EXTRACTING INFORMATION" when we look at an object:



PARALLEL PROCESSING

1. COLOR INFO.
   → CONES

RED	GREEN	BLUE
60%	30%	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

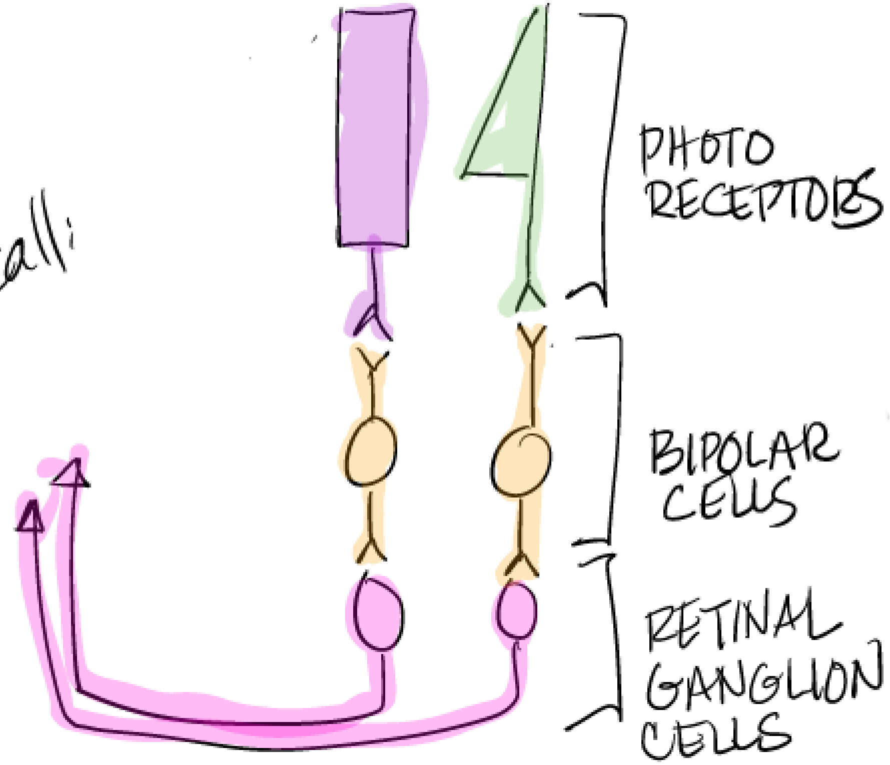
③ MOTION

* Magno (MAGNOCELLULAR PATHWAY)
  M-PATHWAY

M-CELL

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

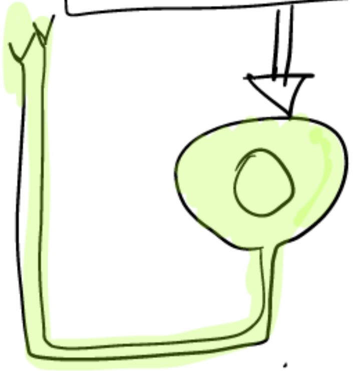
Recall:



⊛ NOTE

The M- & P- pathways respond to different stimuli

THE DIFFERENCE BETWEEN: [MAGNO (M) PATHWAY / PARVO (P) PATHWAY]

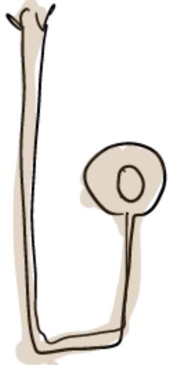


M-Ganglion cells

* 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

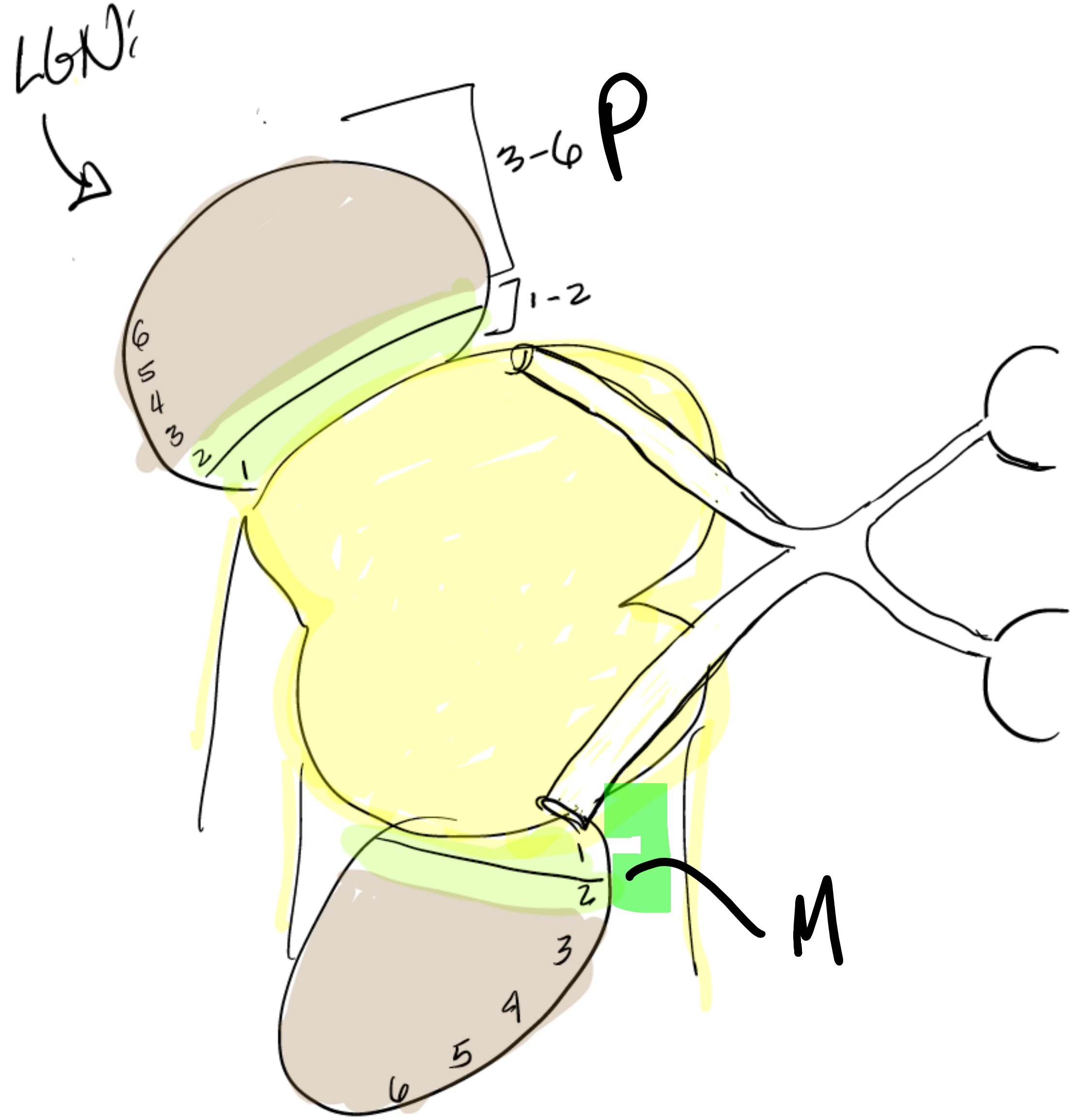


P-Ganglion cells

* 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
P
1-2
6
5
4
3
2
1
M

Slide from Dr. Christine Johnson