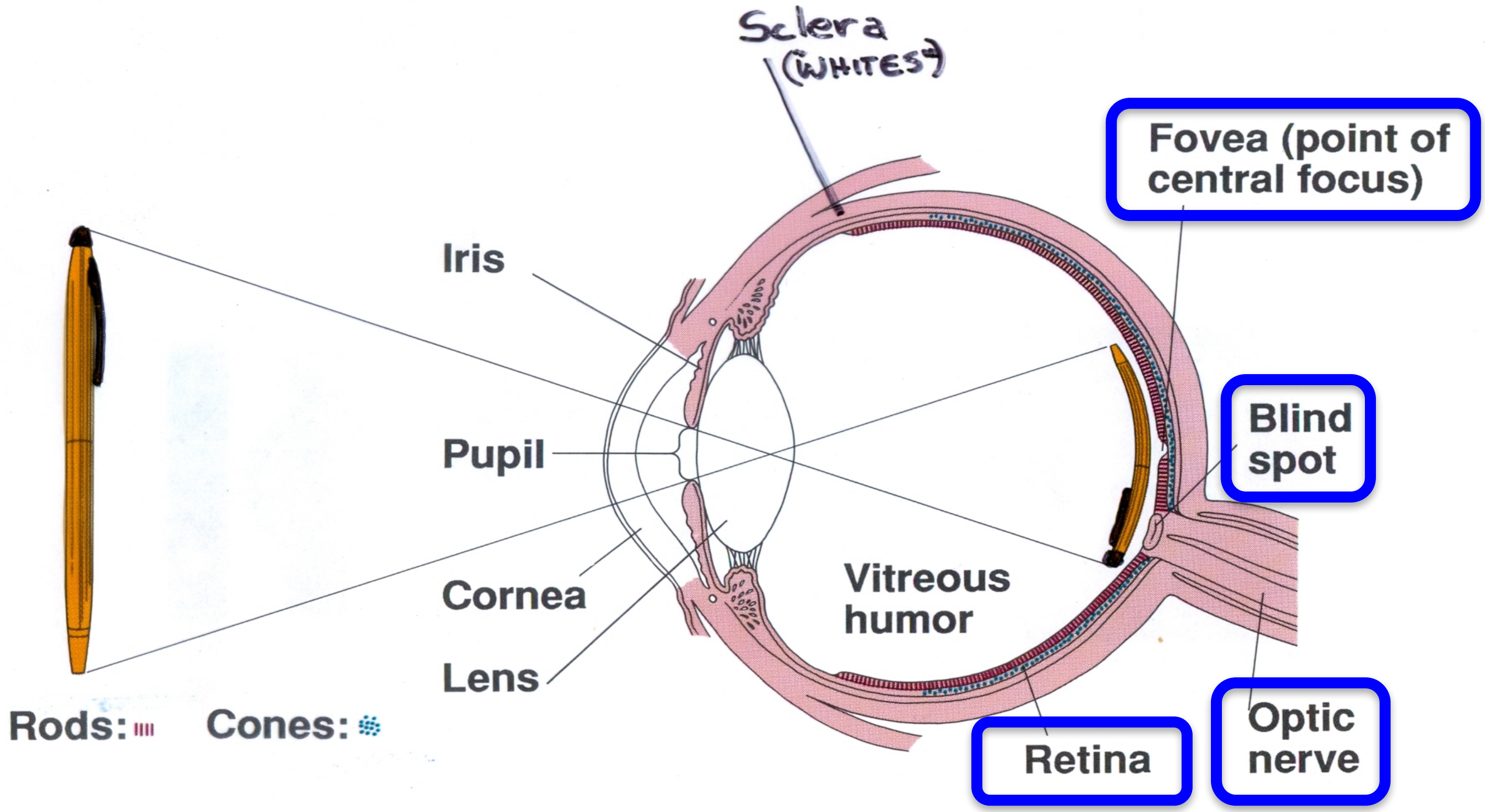
Lecture 4.1

Vision

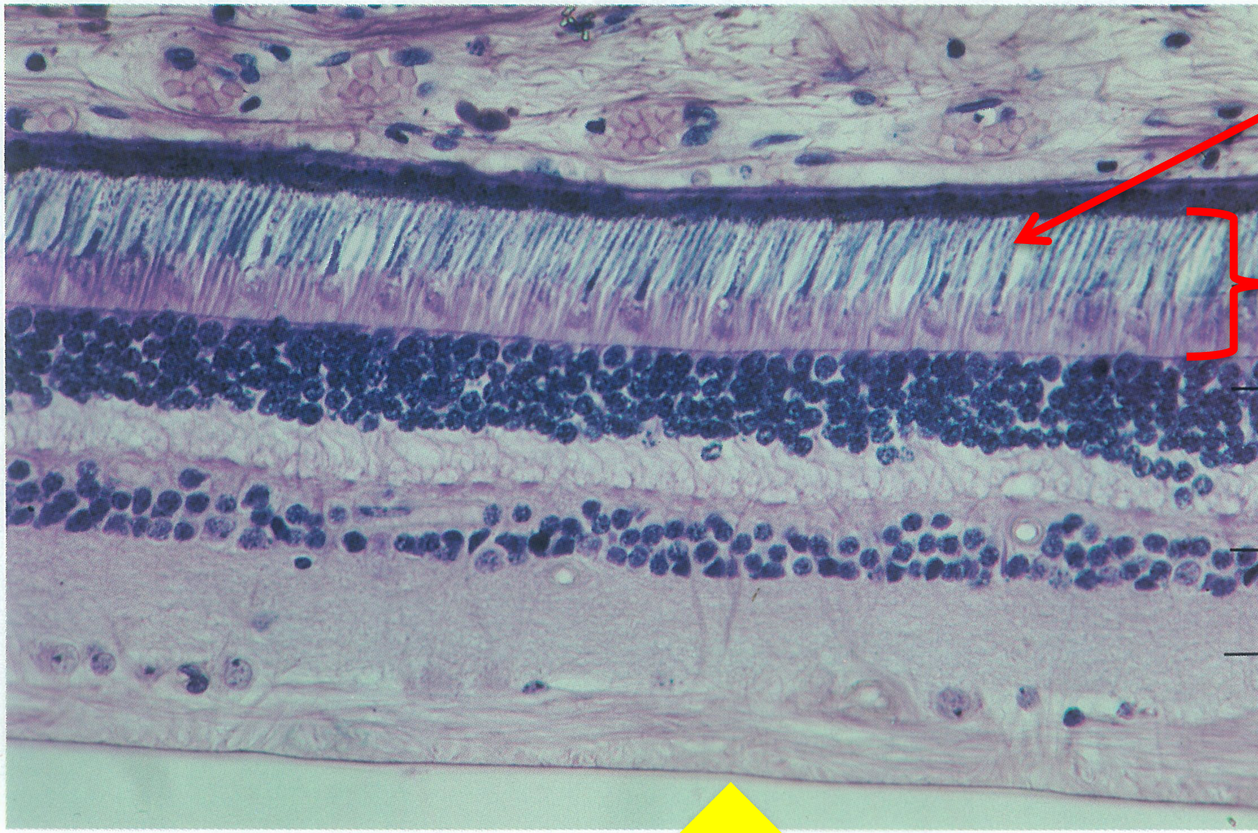
Cogs17 * UCSD

The Eye



Structure of the eye

The Retina

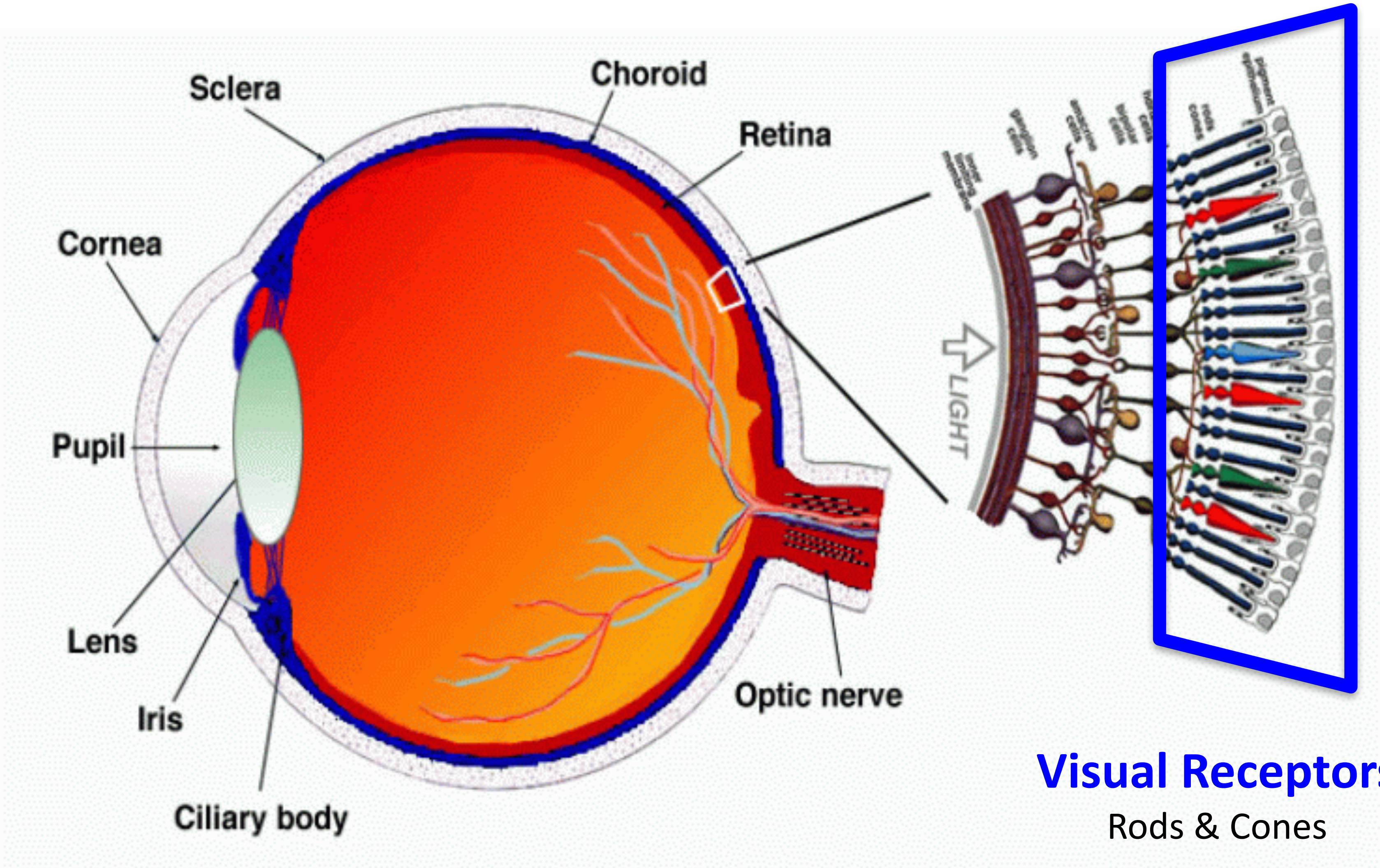


Cross section of the retina

Photo by Ed Reschke

NOTE:
Not a particularly "intelligent design" !

The Retina



Visual Receptors

Rods & Cones

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)

Visual Receptors: Rods & Cones

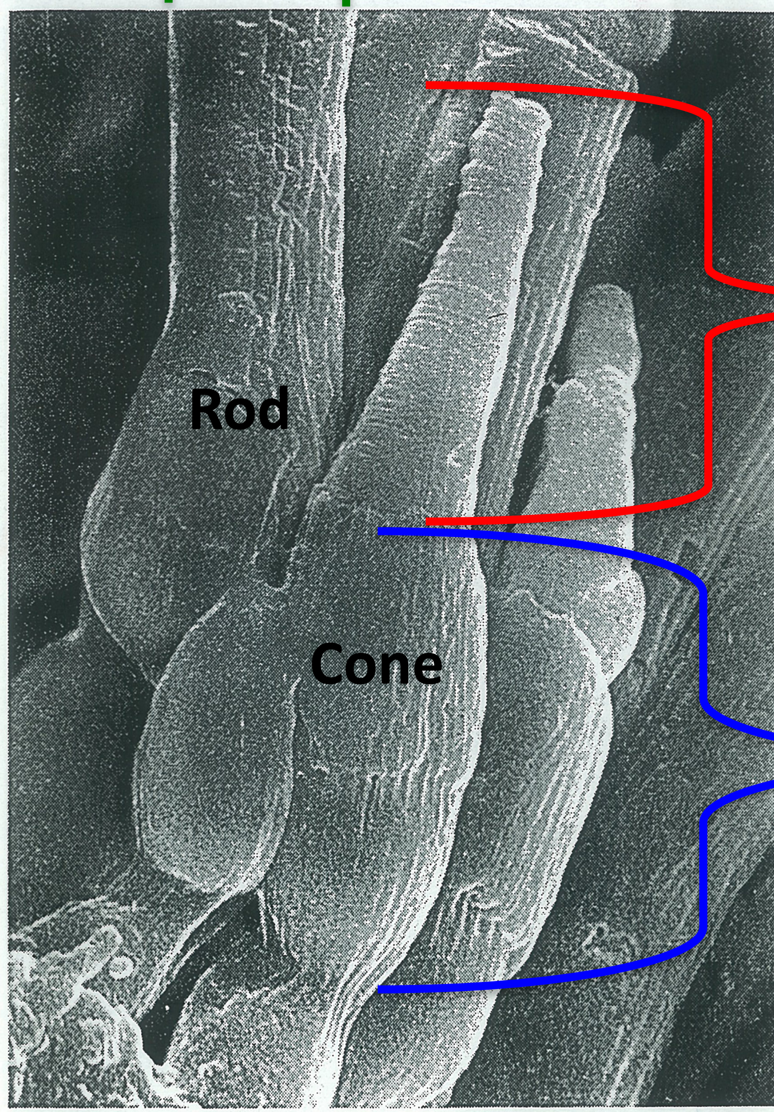
Rod's
Outer Segment
much larger
than Cone's

Rods, being larger, have MORE Photo-pigment

Also differ in #:

Rods ~120 million/eye

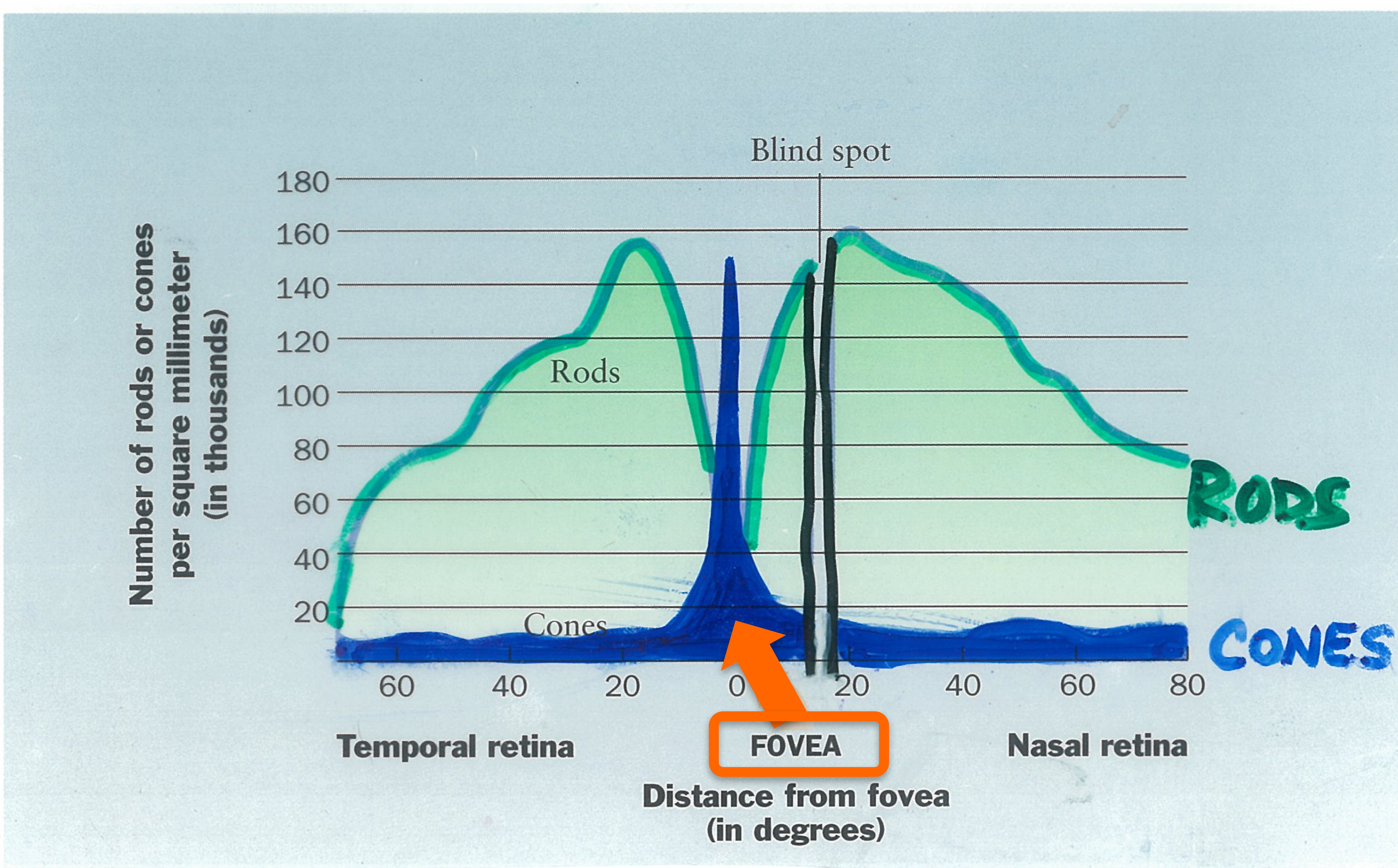
Cones ~6 million/eye



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

Cell body

Distribution of Rods & Cones across Retina



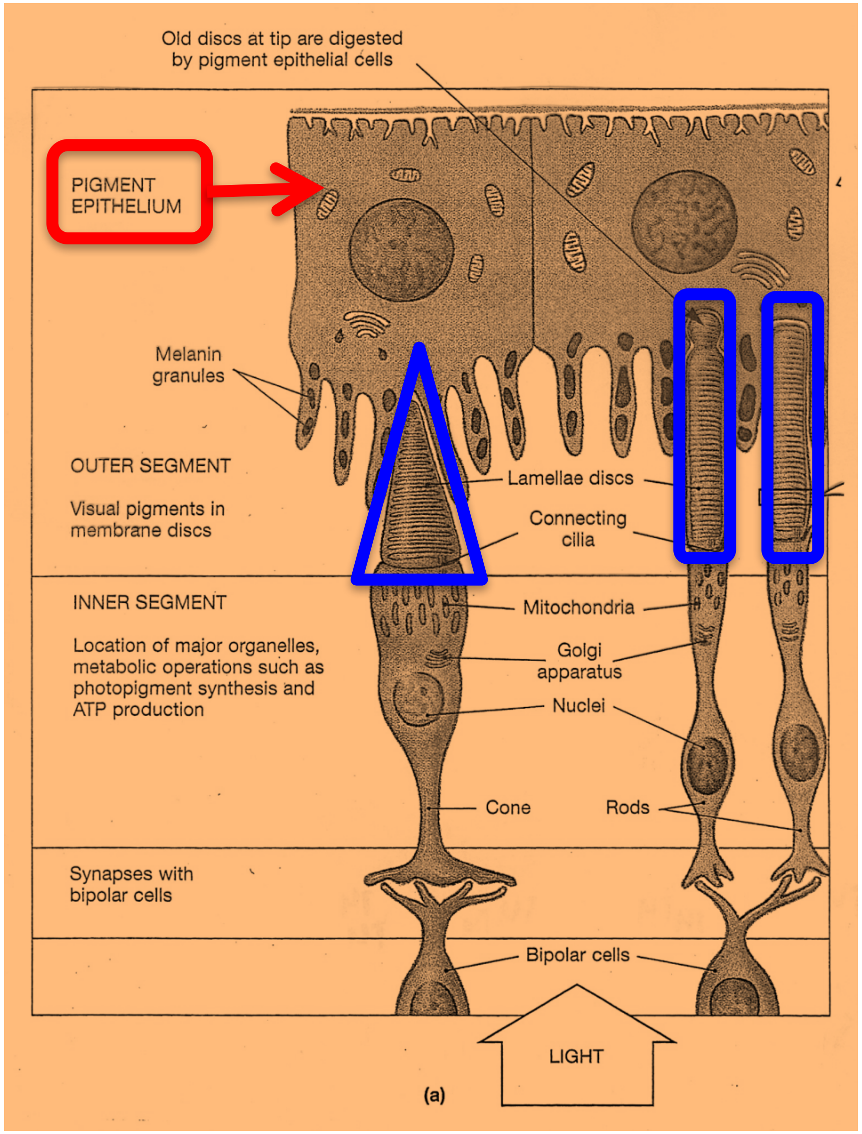
CONES – Concentrated in Fovea, Dispersed in lesser numbers throughout retina

RODS – None in Fovea, In abundance throughout retina

Visual Receptors: Rods & Cones

SIMILARITIES

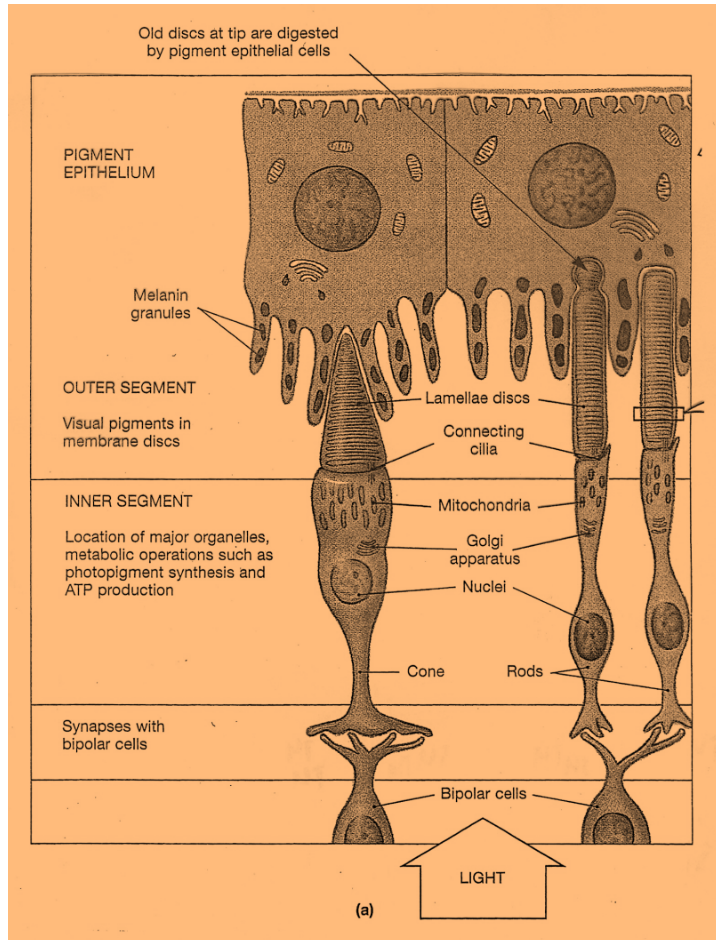
- Molecules of photo-pigment embedded in outer segments
- Outer segments embedded in "Pigment epithelium"
- Graded Potentials
- Release Inhibitory NT



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

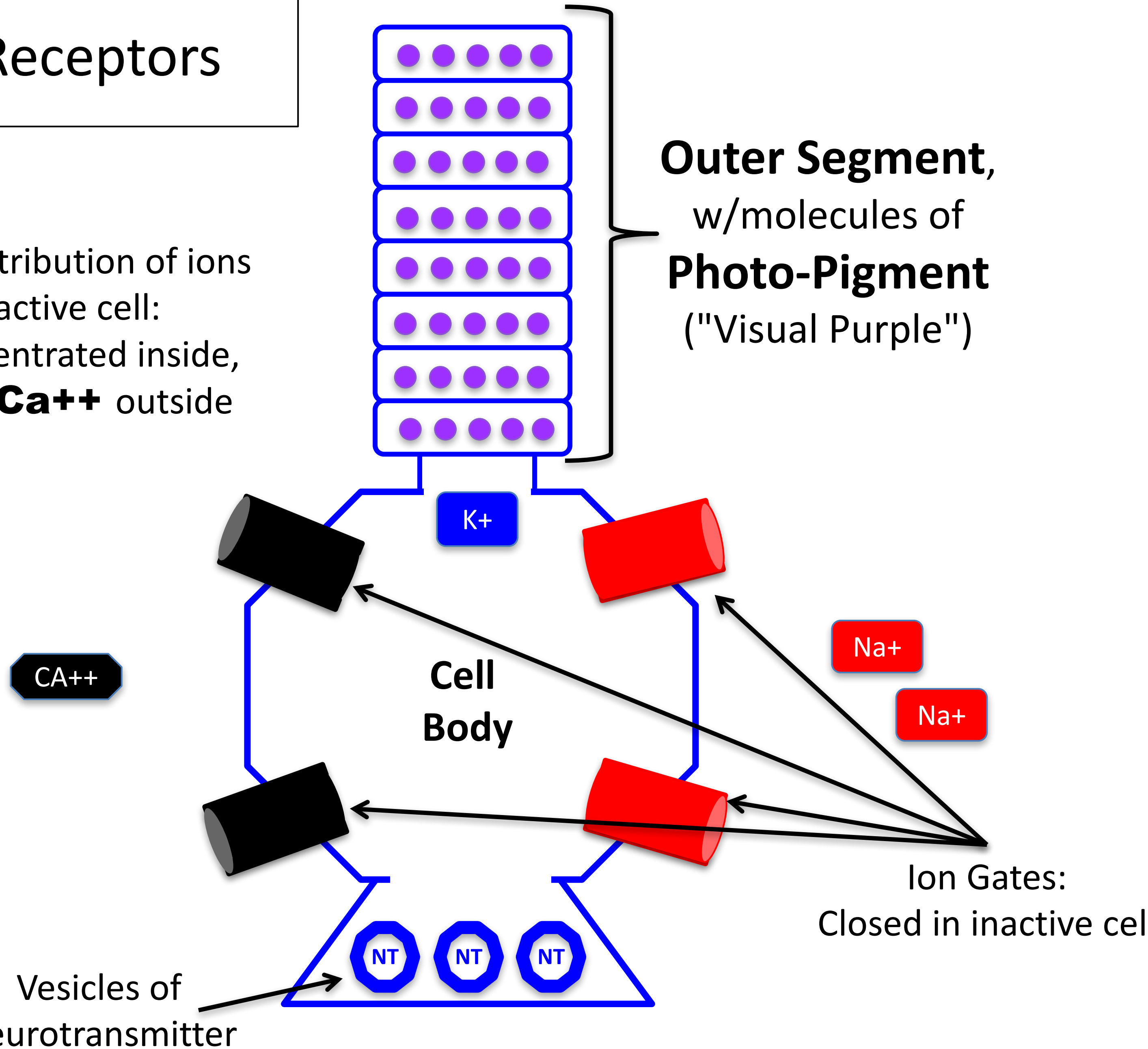


RODS

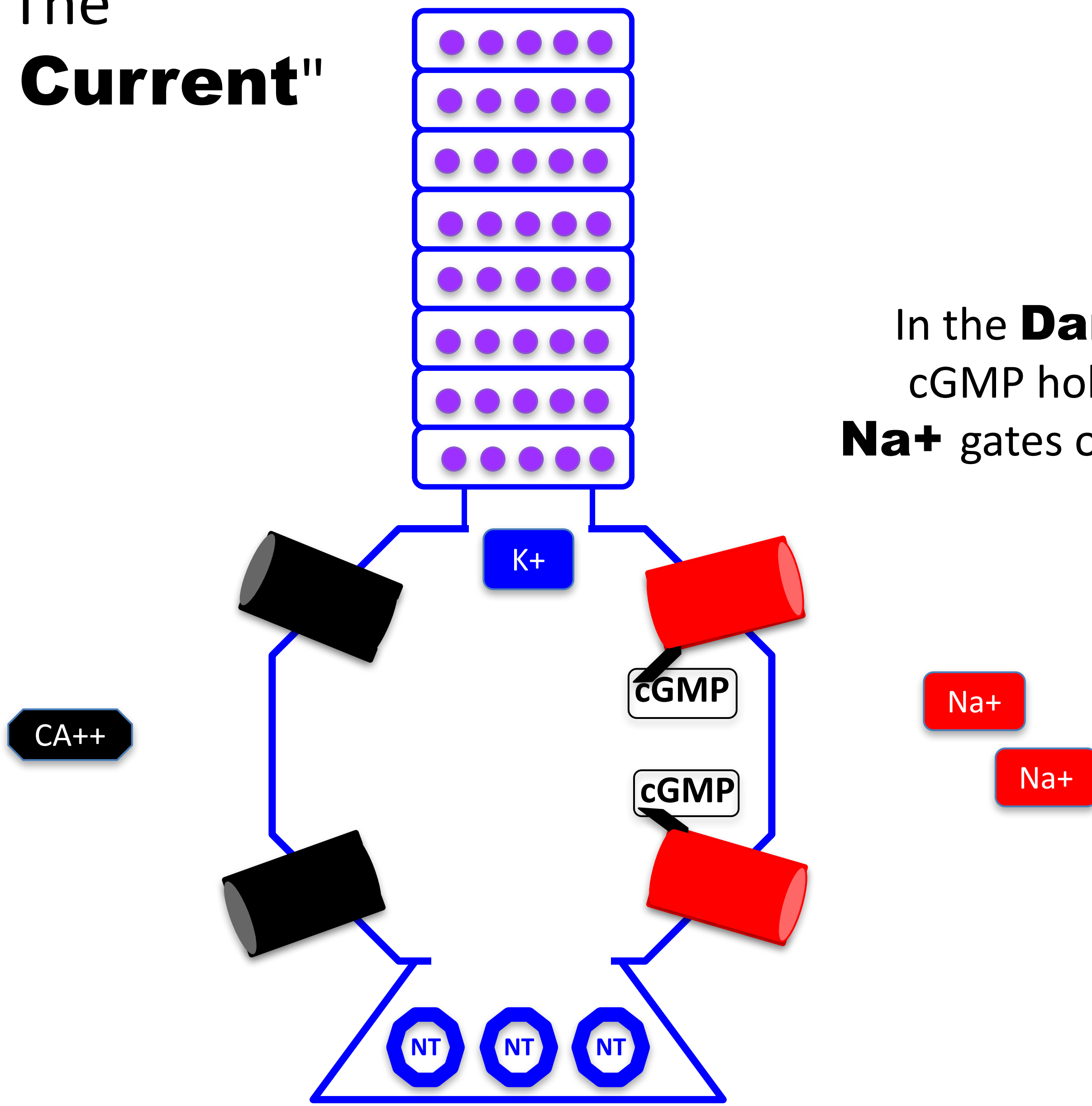
- 1 kind of photopigment
- Do not code color
- Excellent for **motion** detection
- Poor acuity
- High **sensitivity** (operate in dim light)
- Mainly **Dorsal** Path

Visual Receptors

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

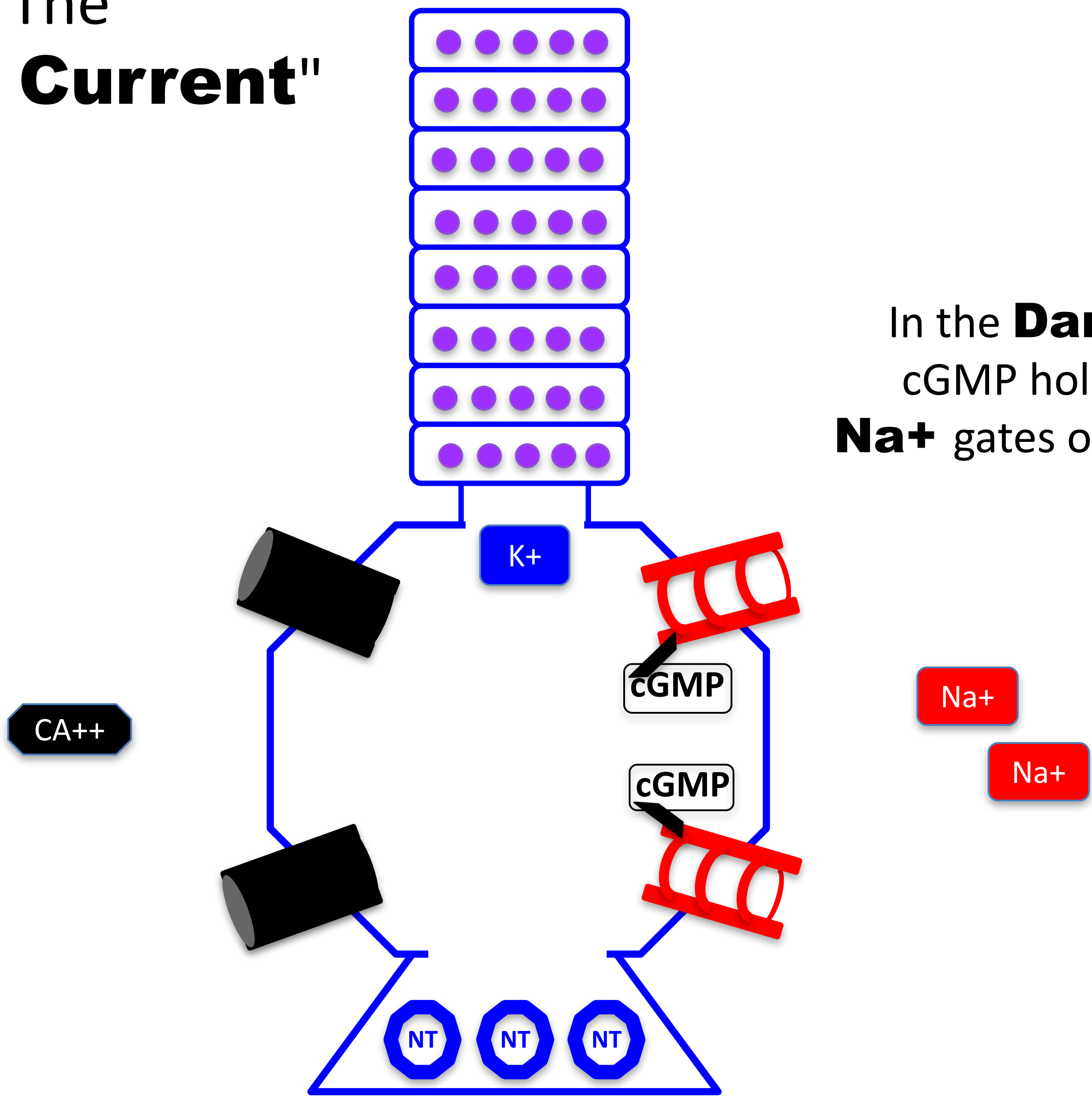


The "**Dark Current**"



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

The "**Dark Current**"

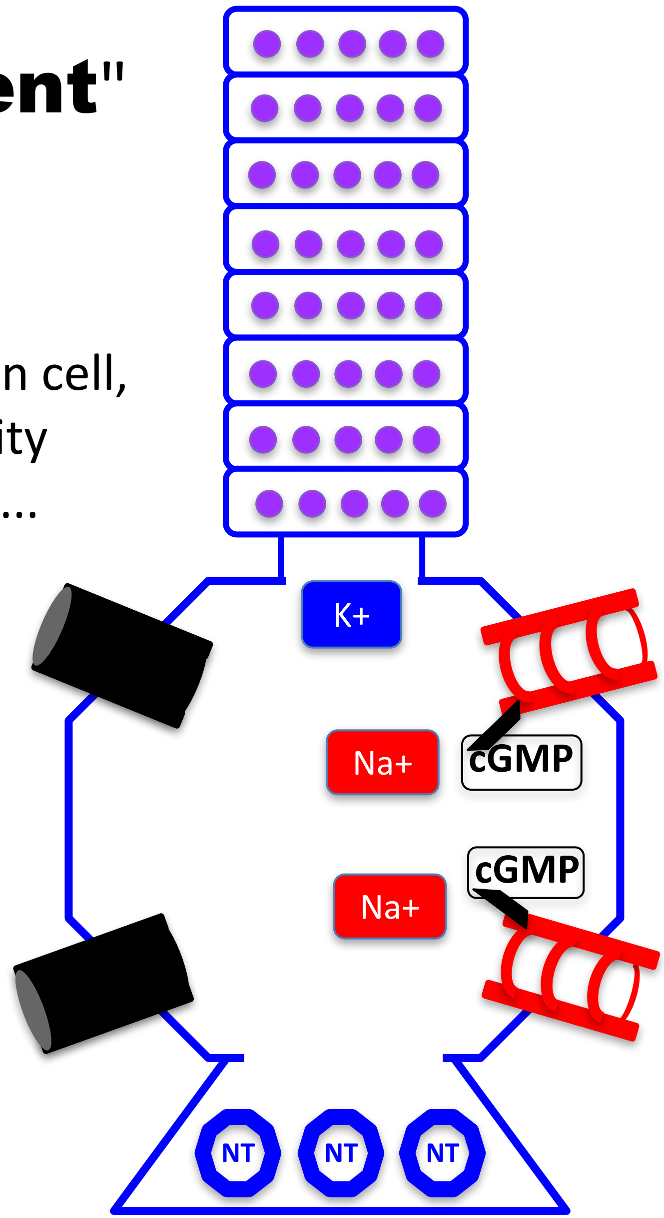


In the **Dark**,
cGMP holds
Na+ gates open...

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

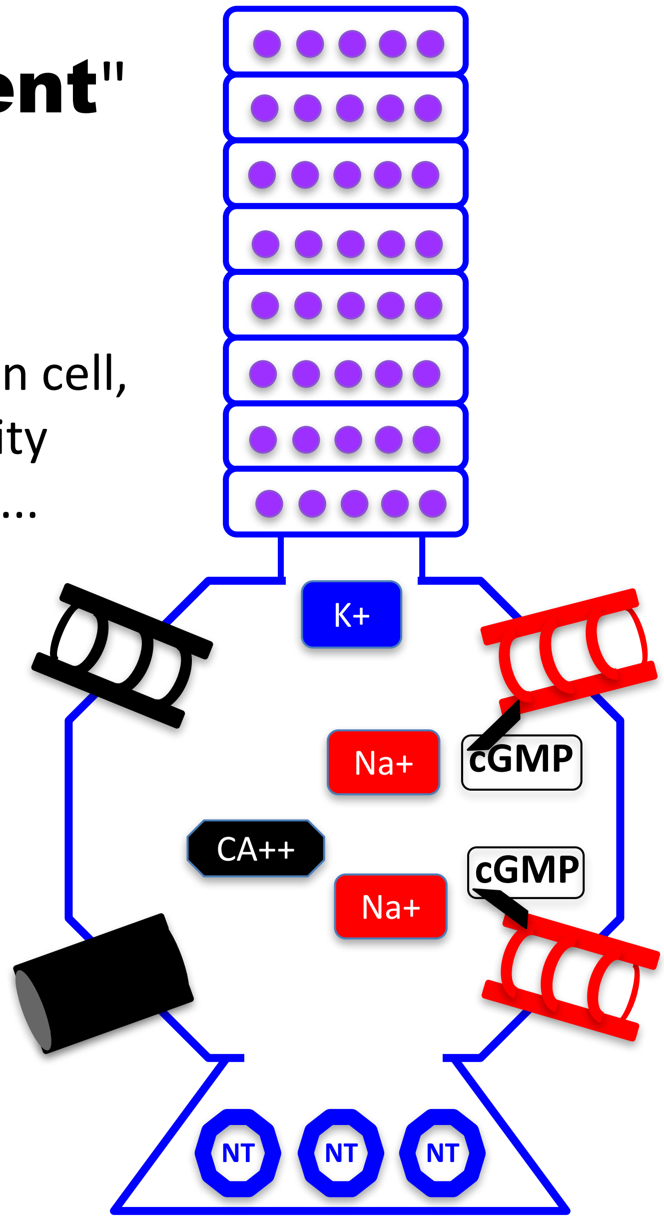
The "**Dark Current**"

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

... **Ca++** enters

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

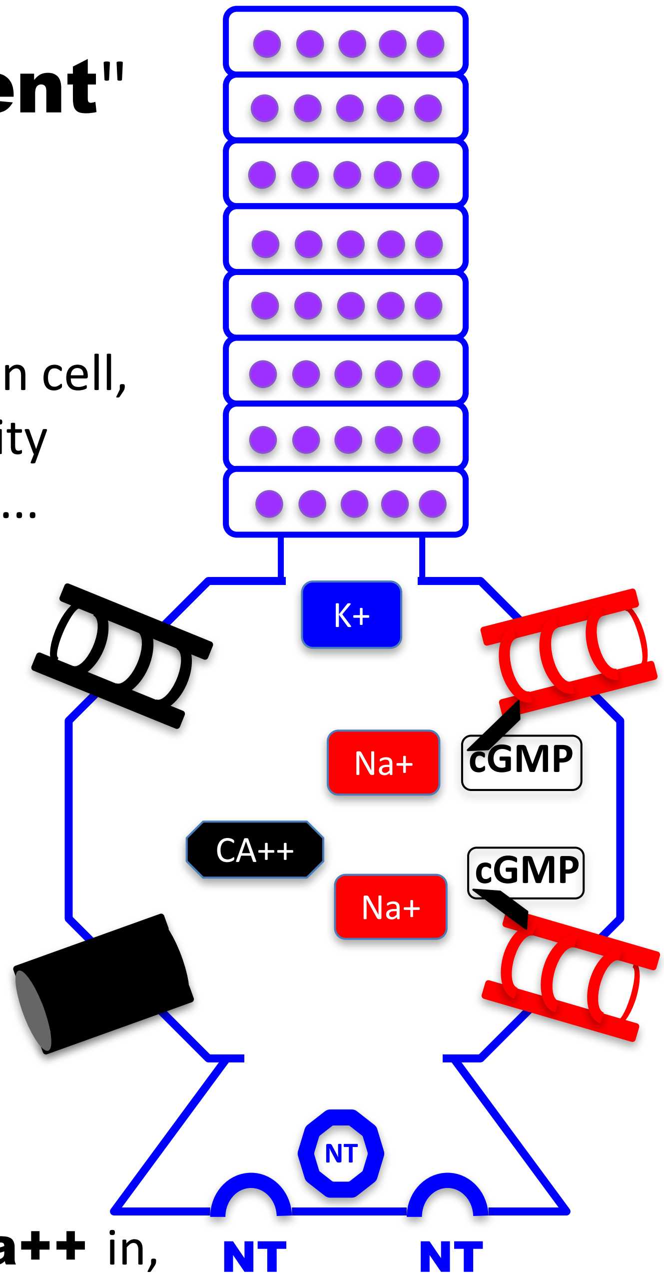
...**Na+** enters



The "**Dark Current**"

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

... **Ca++** enters



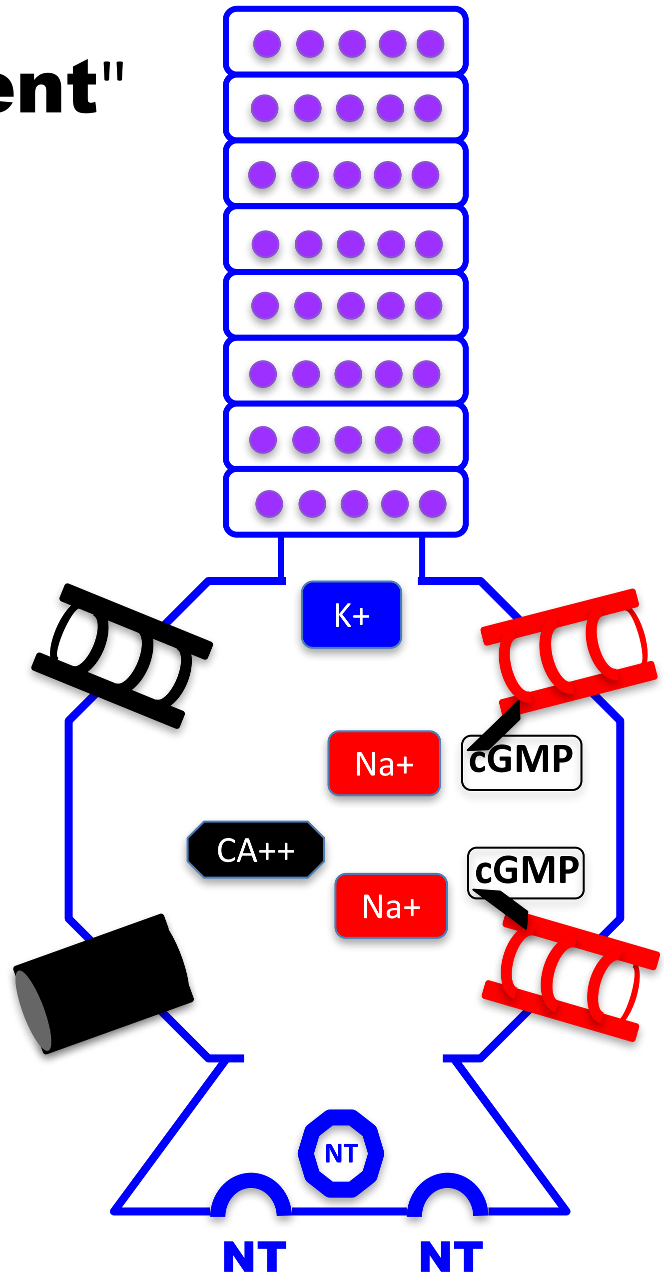
Ca++ in, **NT** out

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

...**Na+** enters

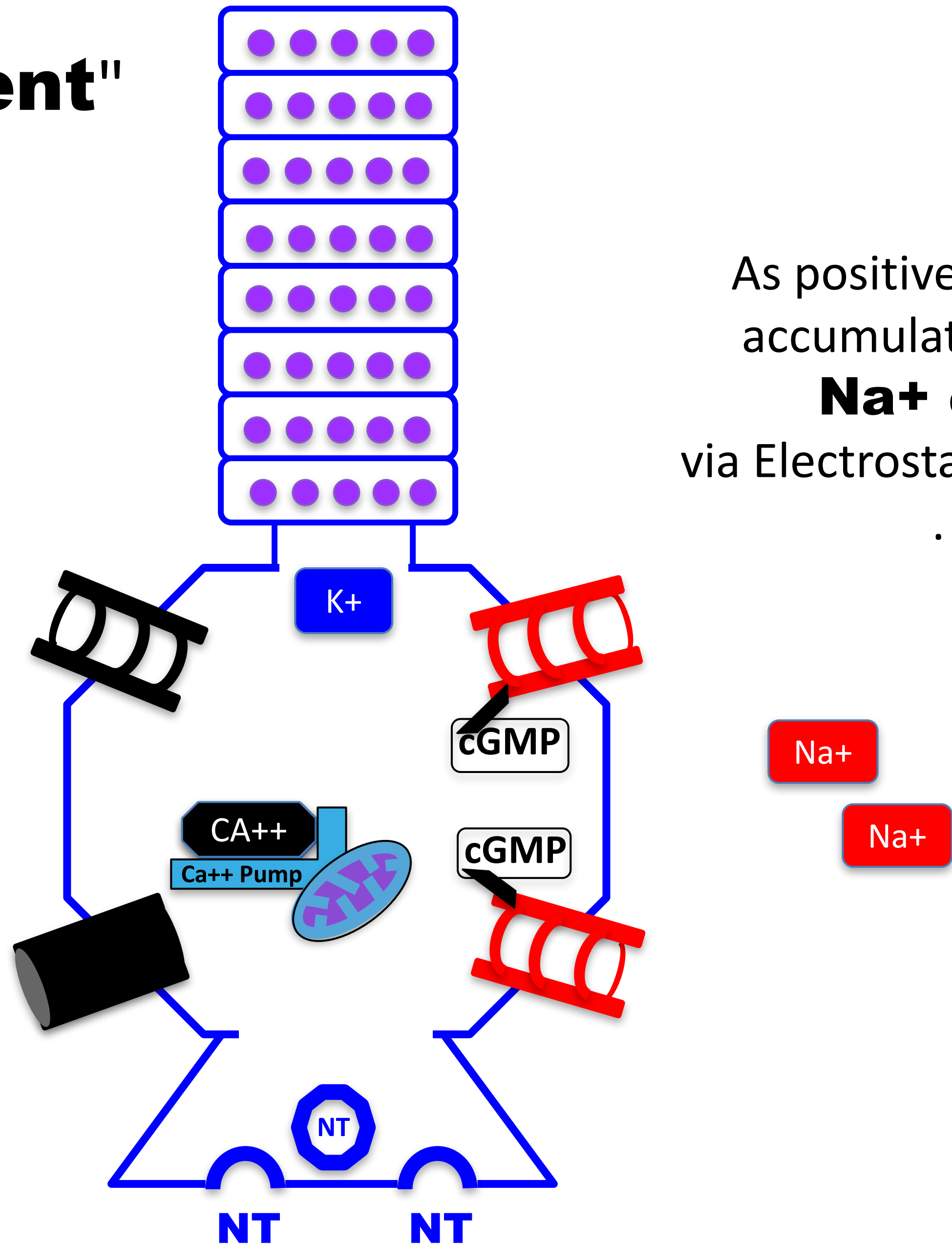
Visual Receptors fire in the dark!

The
"**Dark Current**"



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

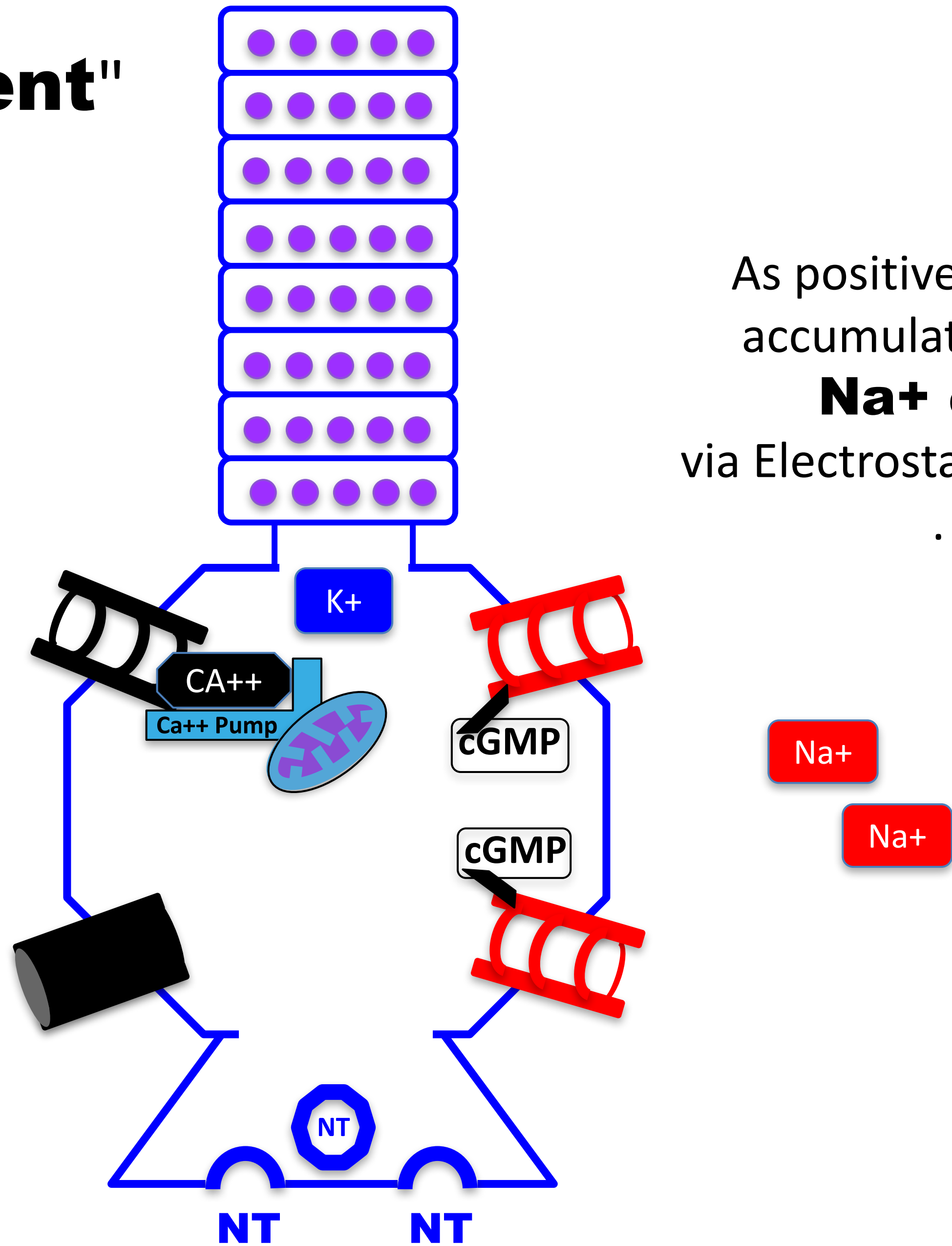
The
"**Dark Current**"



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

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

The "**Dark Current**"



As positive charges accumulate in cell, **Na+** exits, via Electrostatic Pressure
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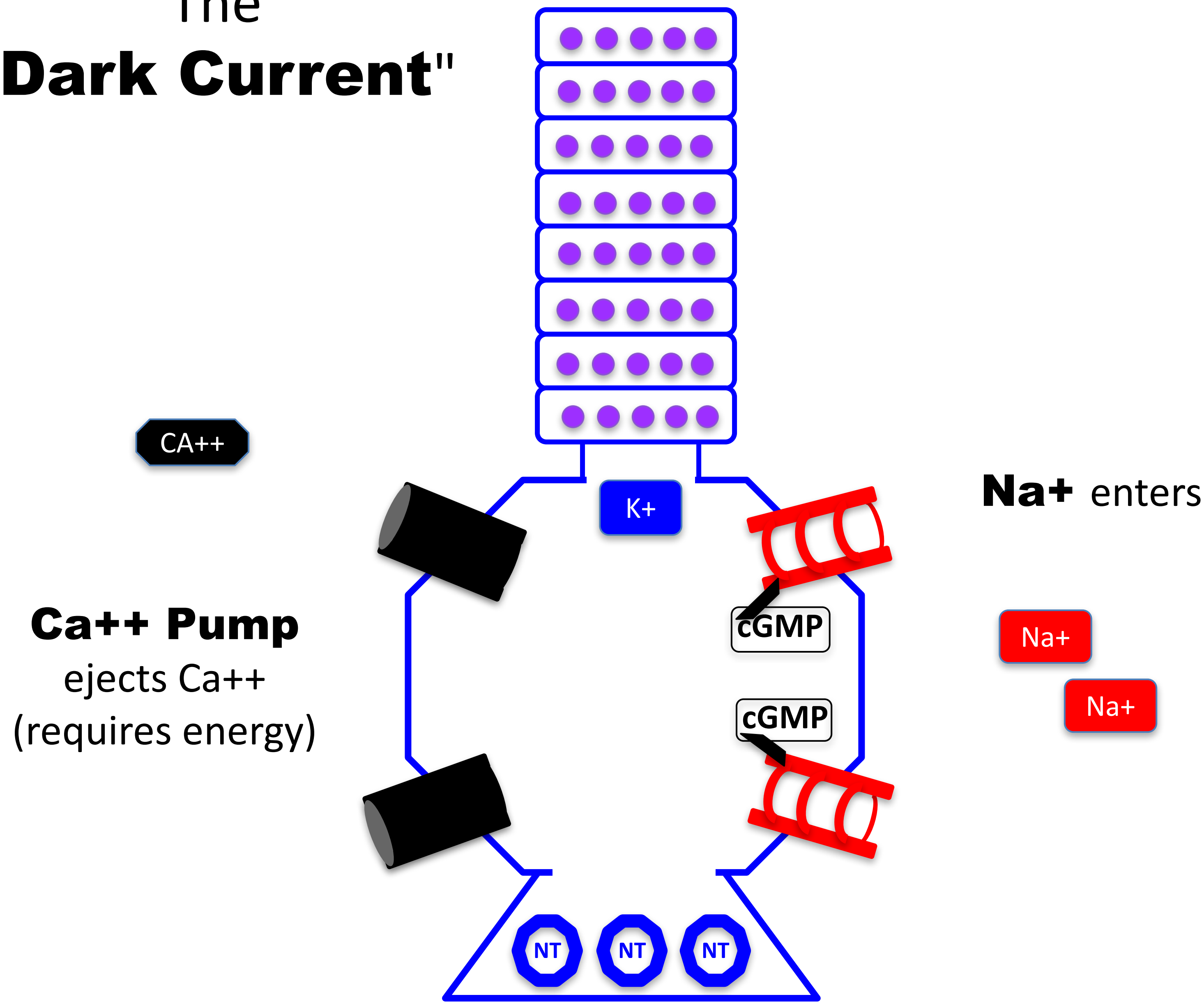
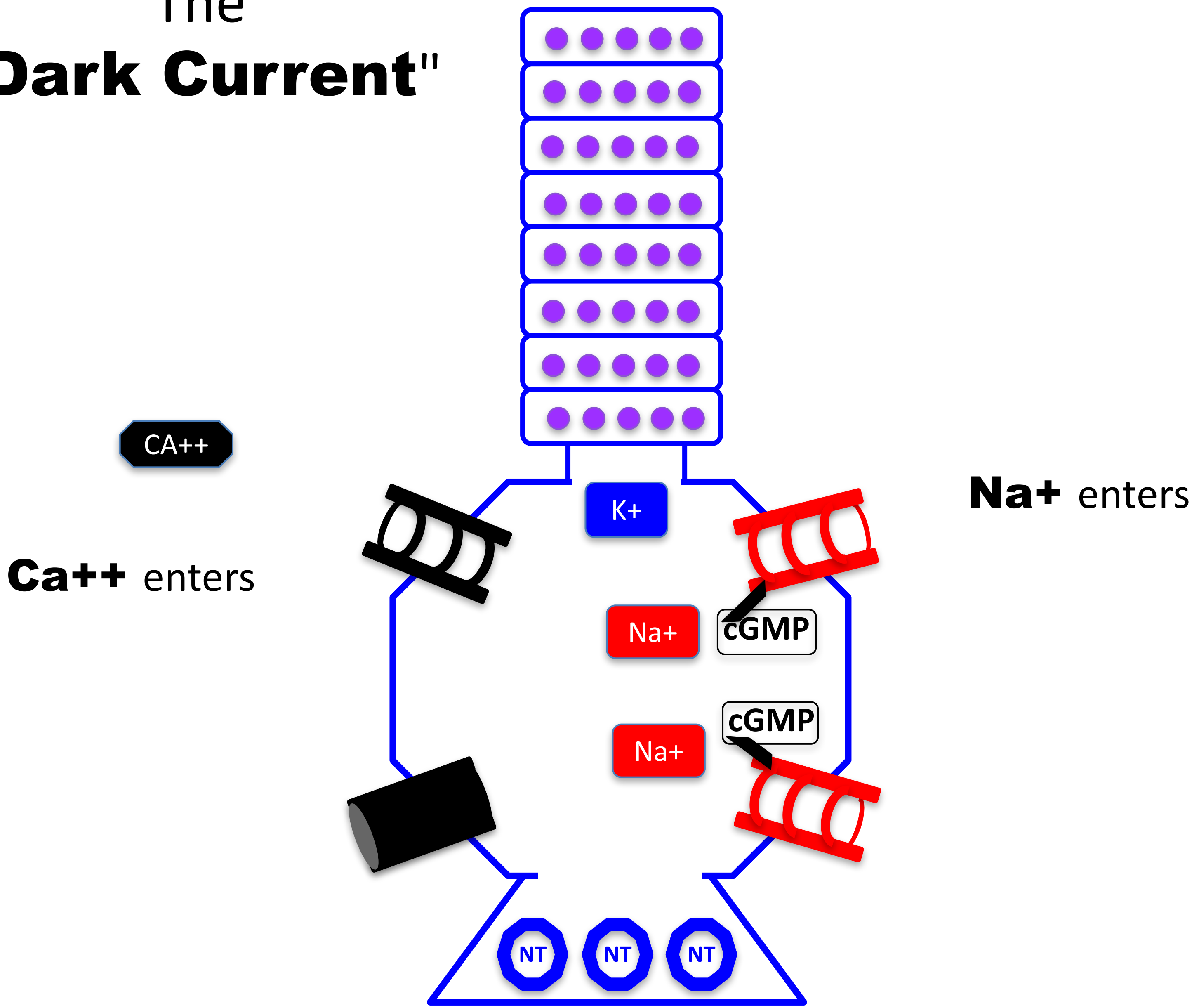
The "**Dark Current**"



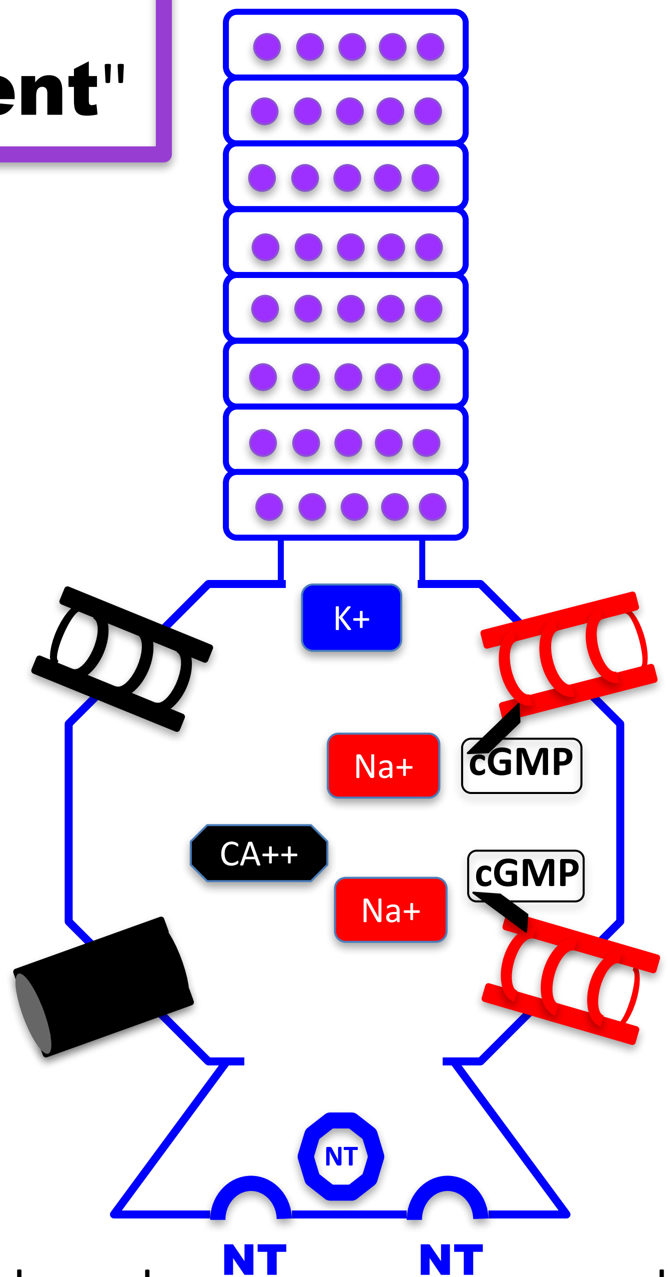
Ejection of **Ca++** should end **NT** release, but whole cycle begins again . . .

The "**Dark Current**"



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

The "**Dark Current**"



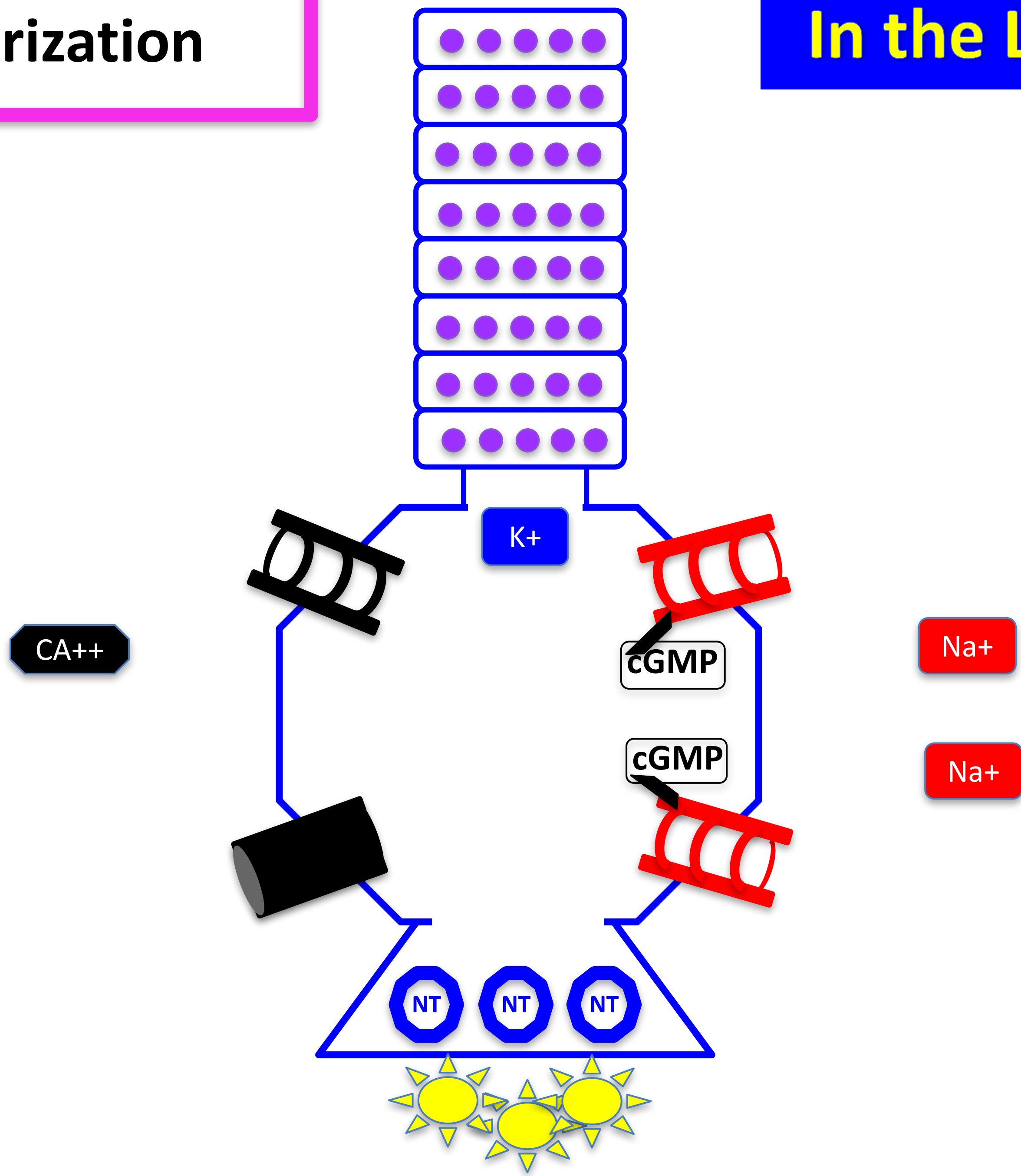
Ca++ enters

Na+ enters

NT is repeatedly released... ... as long as there is <u>no light</u>.

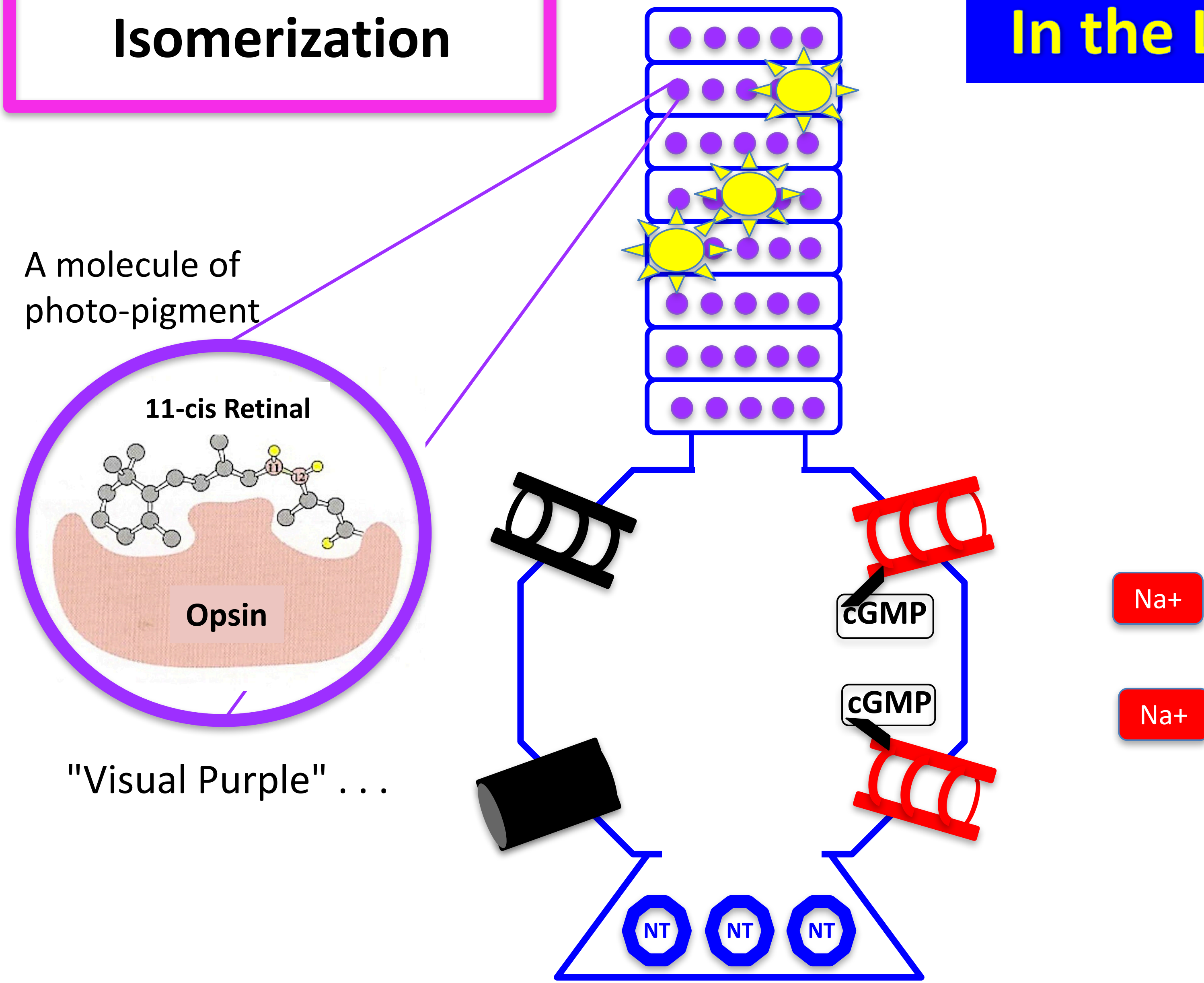
Isomerization

In the Light



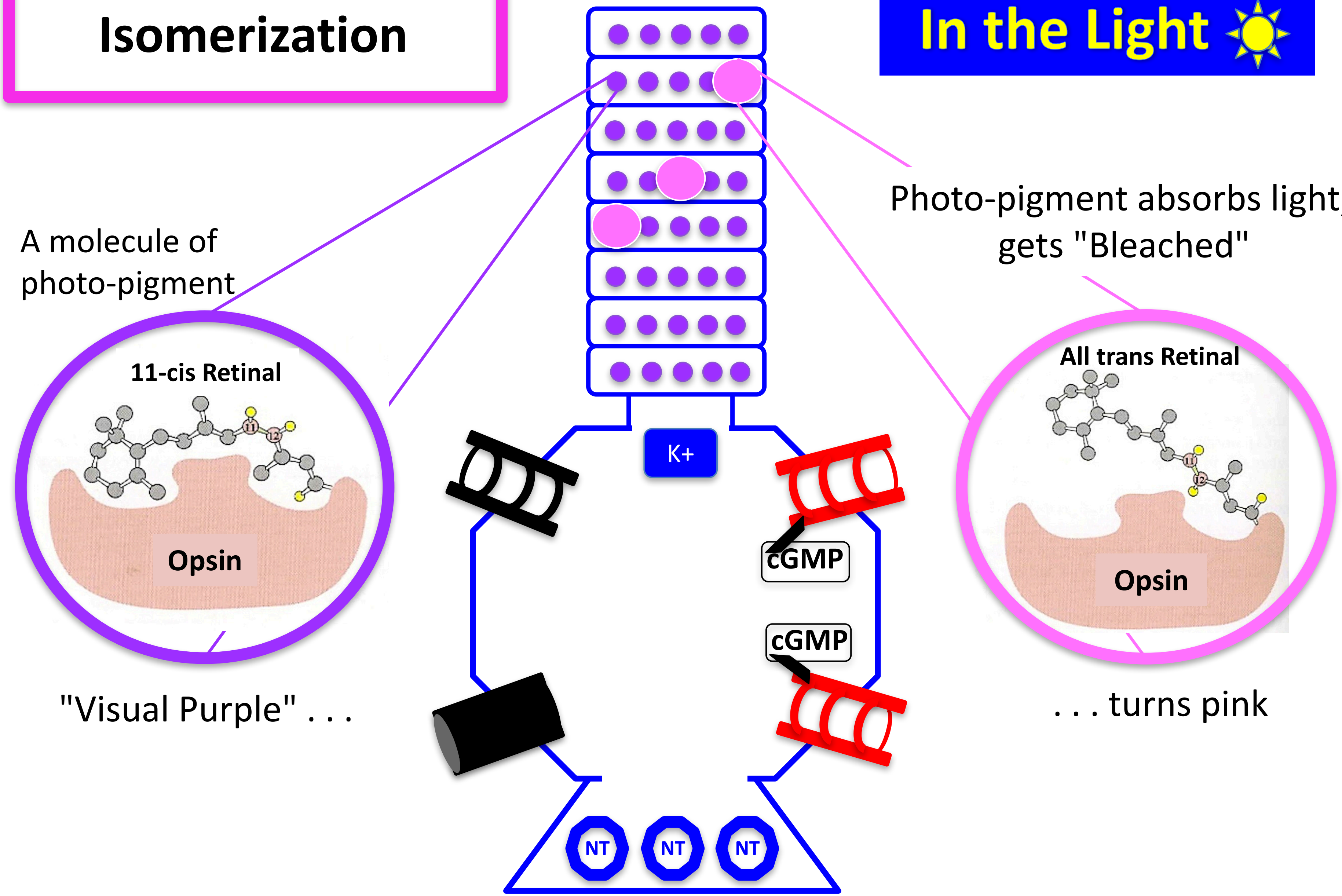
Isomerization

In the Light



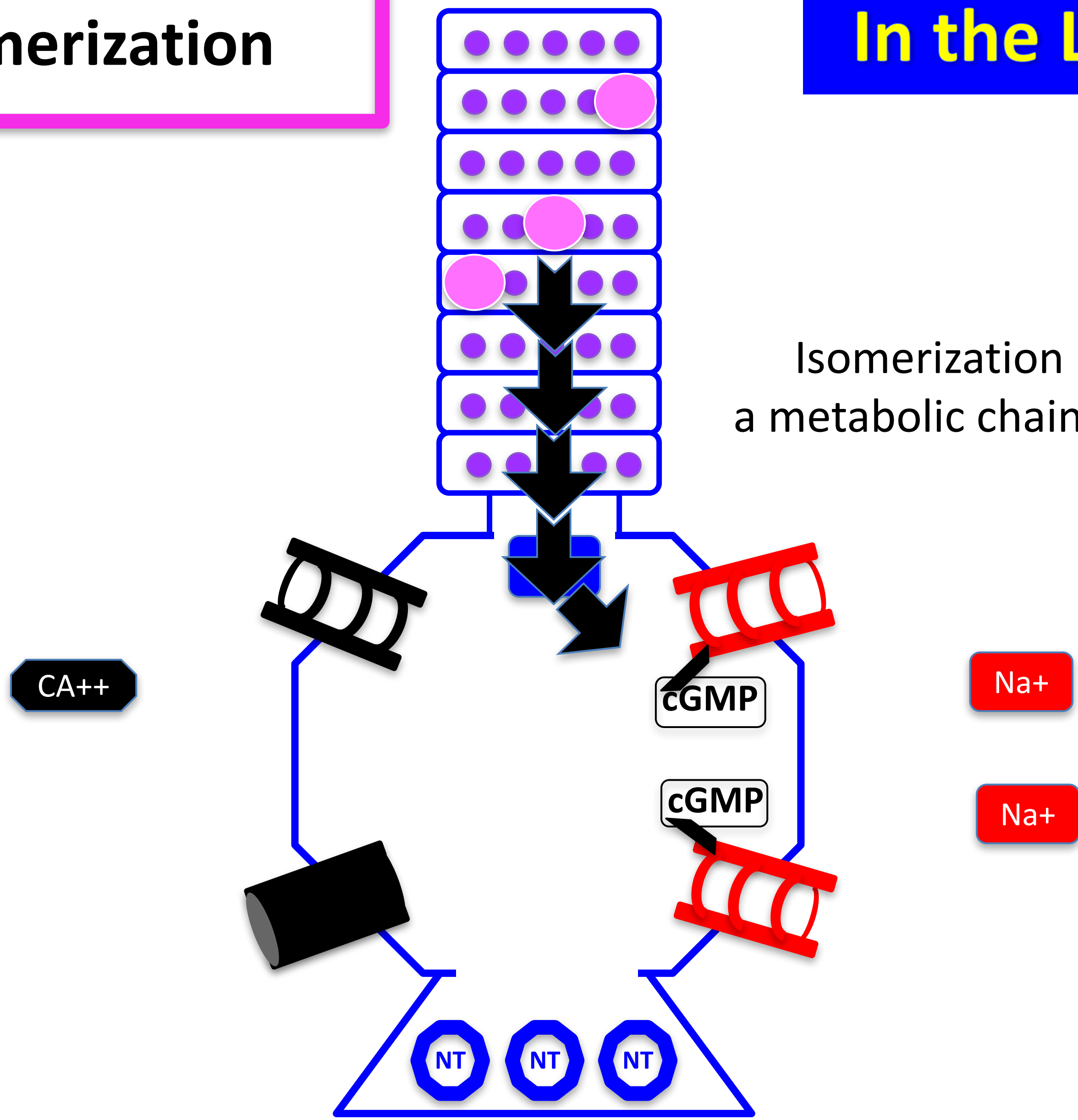
Isomerization

In the Light ☀



Isomerization

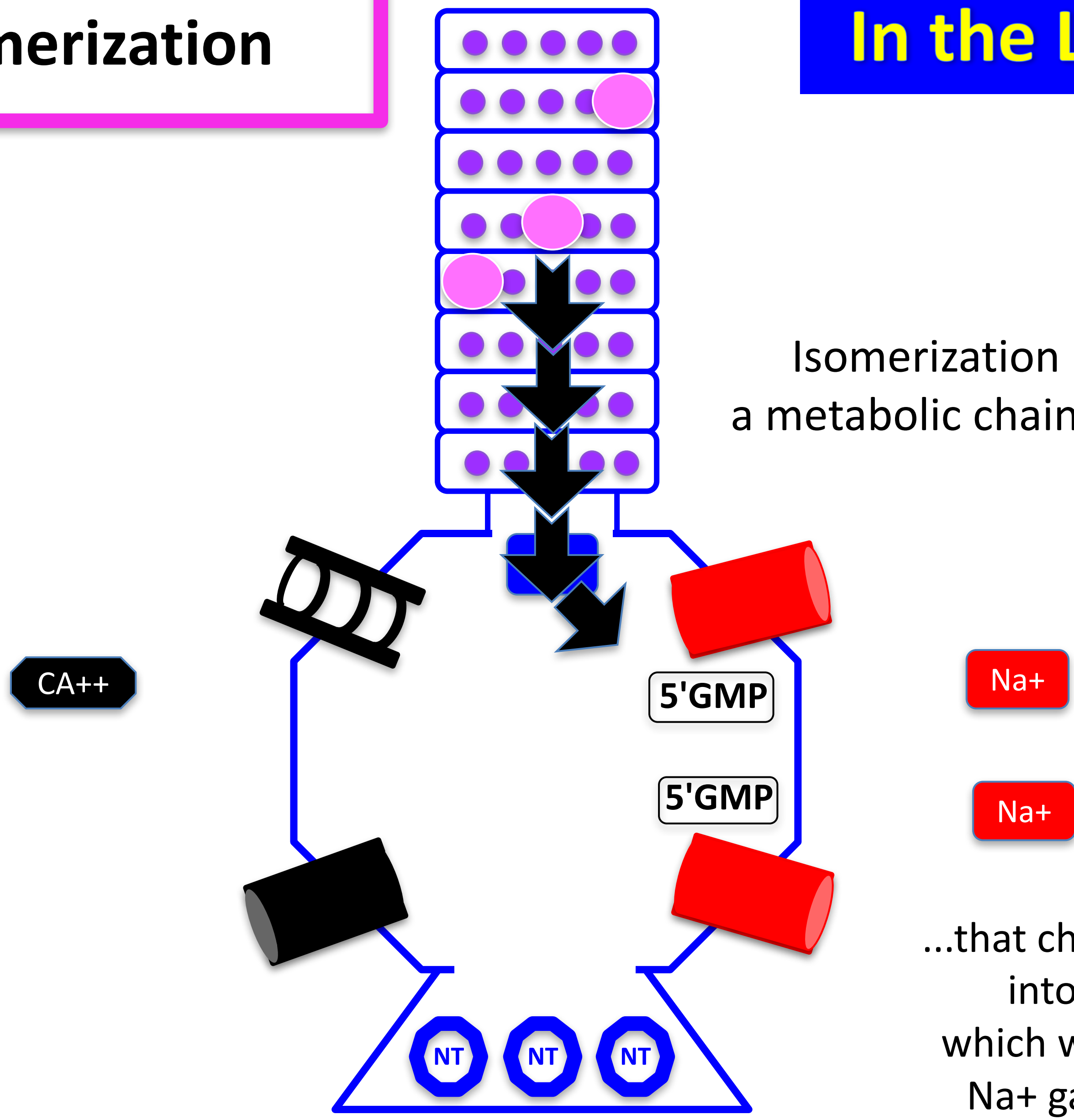
In the Light



Isomerization initiates
a metabolic chain reaction...

Isomerization

In the Light

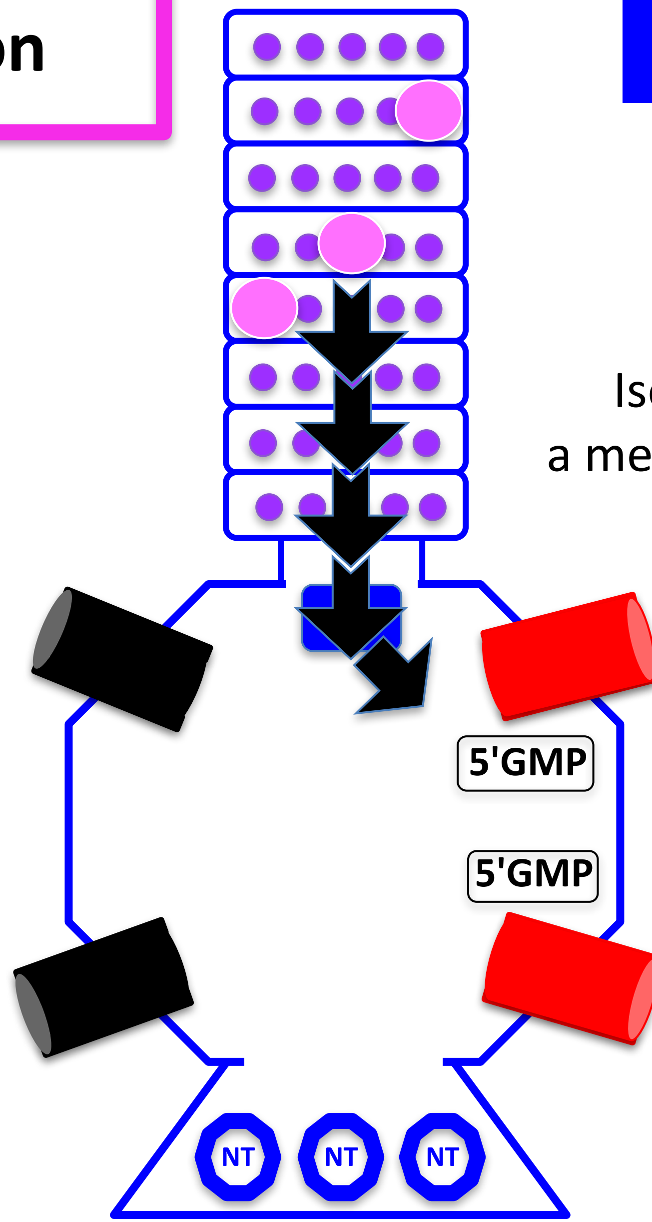


Isomerization initiates
a metabolic chain reaction...

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

Isomerization

In the Light



CA++

Na+

Na+

Isomerization initiates
a metabolic chain reaction...

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

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

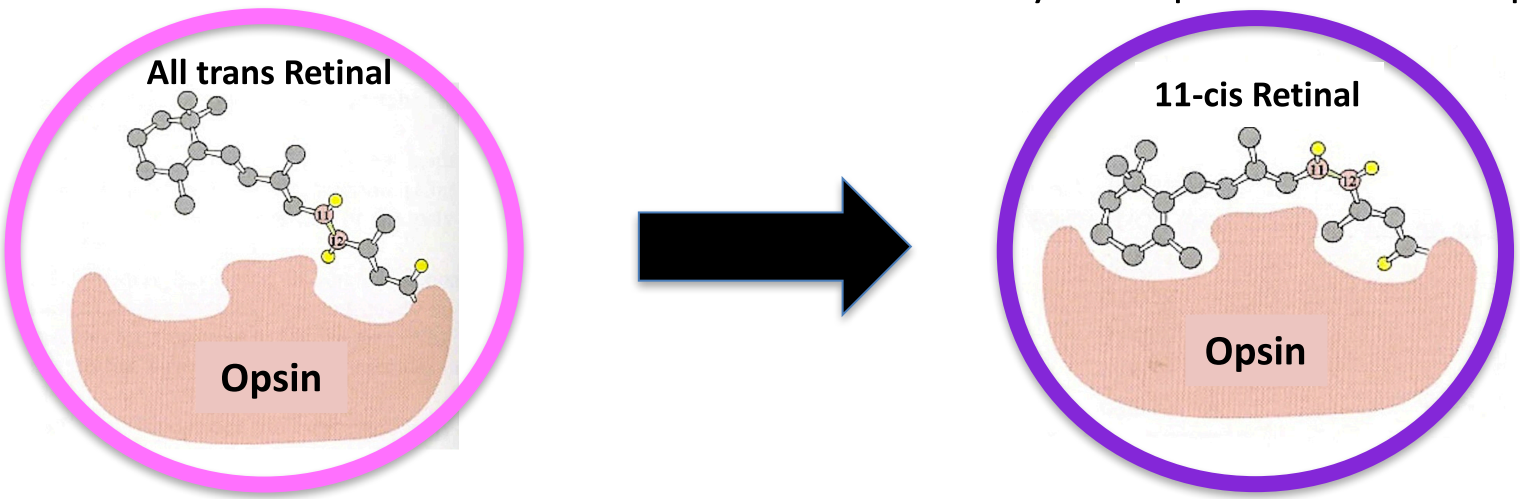
So, in the Light,
the "Dark Current"
is shut down

No NT is released

Isomerization & Re-Generation of Photo-Pigment

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

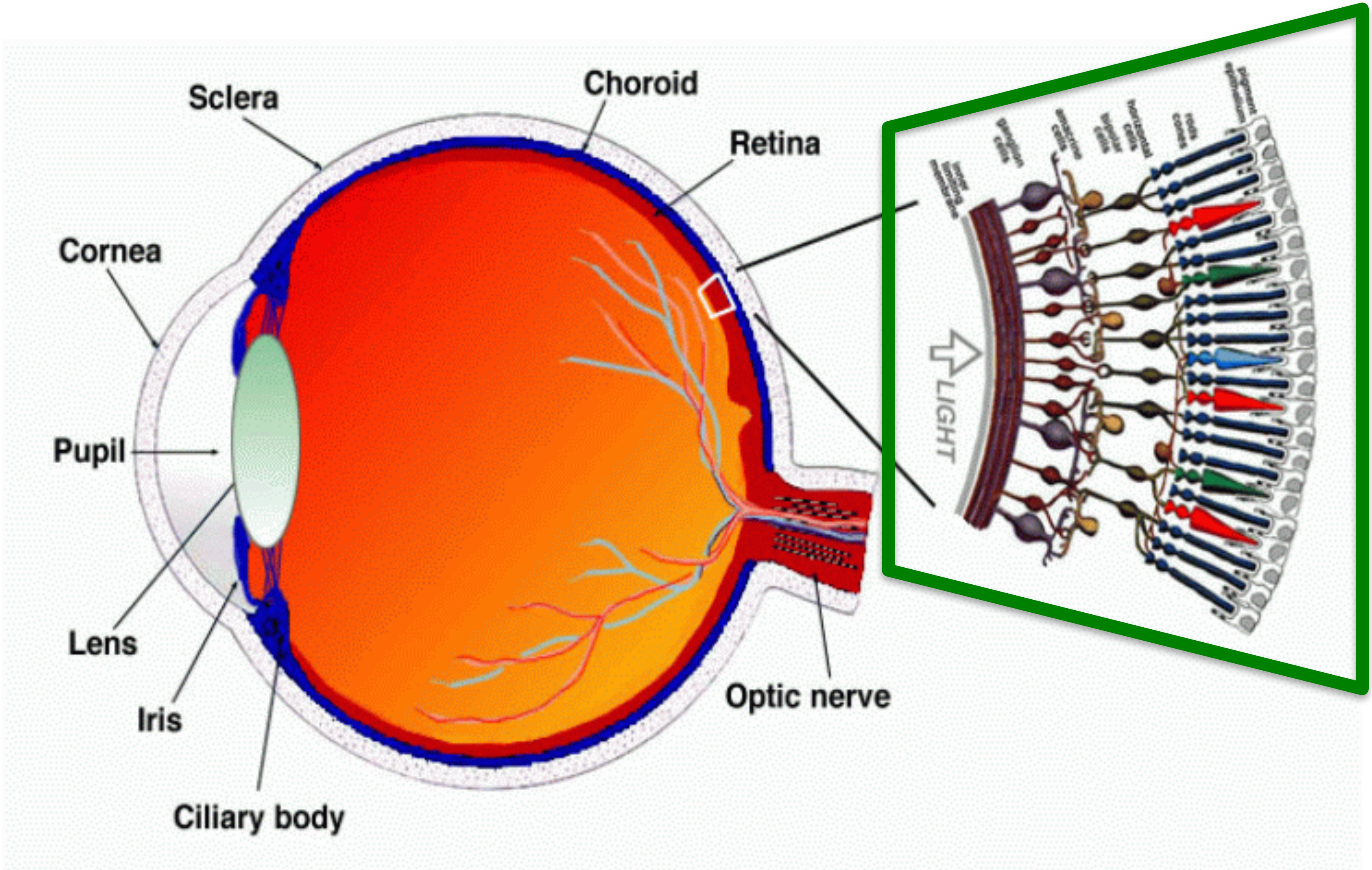
...it will soon regenerate into its original form, so it is ready to respond to the next photon.



- 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

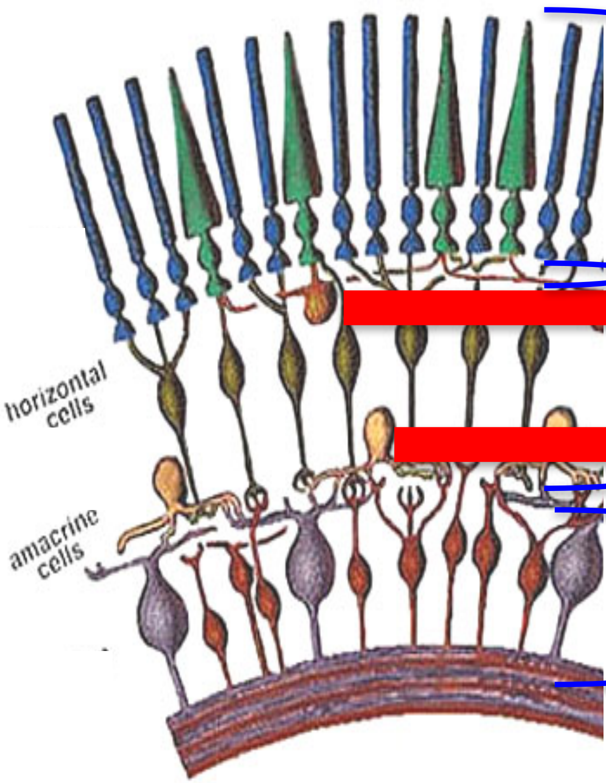
- We are "**Dark Adapted**" after spending time in the dark
  - At first, when you turn out the light, you cannot see anything
  - But in time, as your photo-pigment regenerates, you can see faint shapes etc in the dark

The Retina



Sclera
Choroid
Retina
Cornea
Pupil
Lens
Iris
Ciliary body
Optic nerve
LIGHT

The Retina - Five Layers of Neurons



Visual Pathway

Receptors
(Rods & Cones)

Bipolars

Ganglions

Inter-Neurons
(Lateral Inhibitors)

Horizontals

Amacrines

The Retina

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

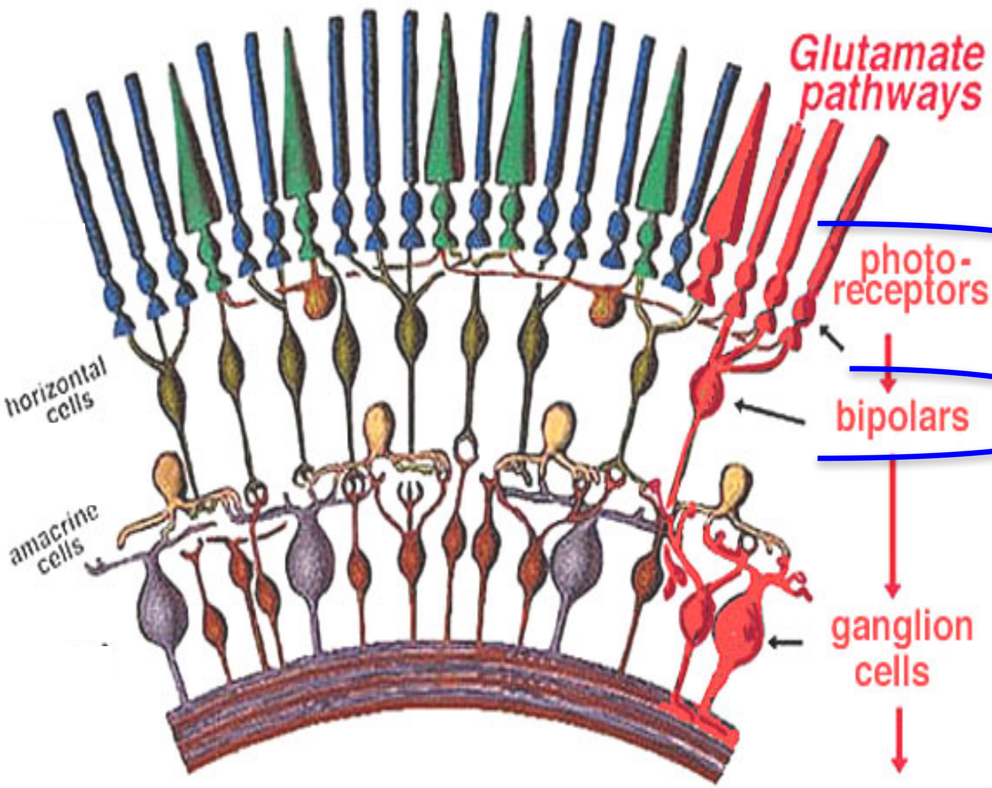


Fig. 13. The types of neurons in the vertebrate retina that use glutamate as a neurotransmitter (red).

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)

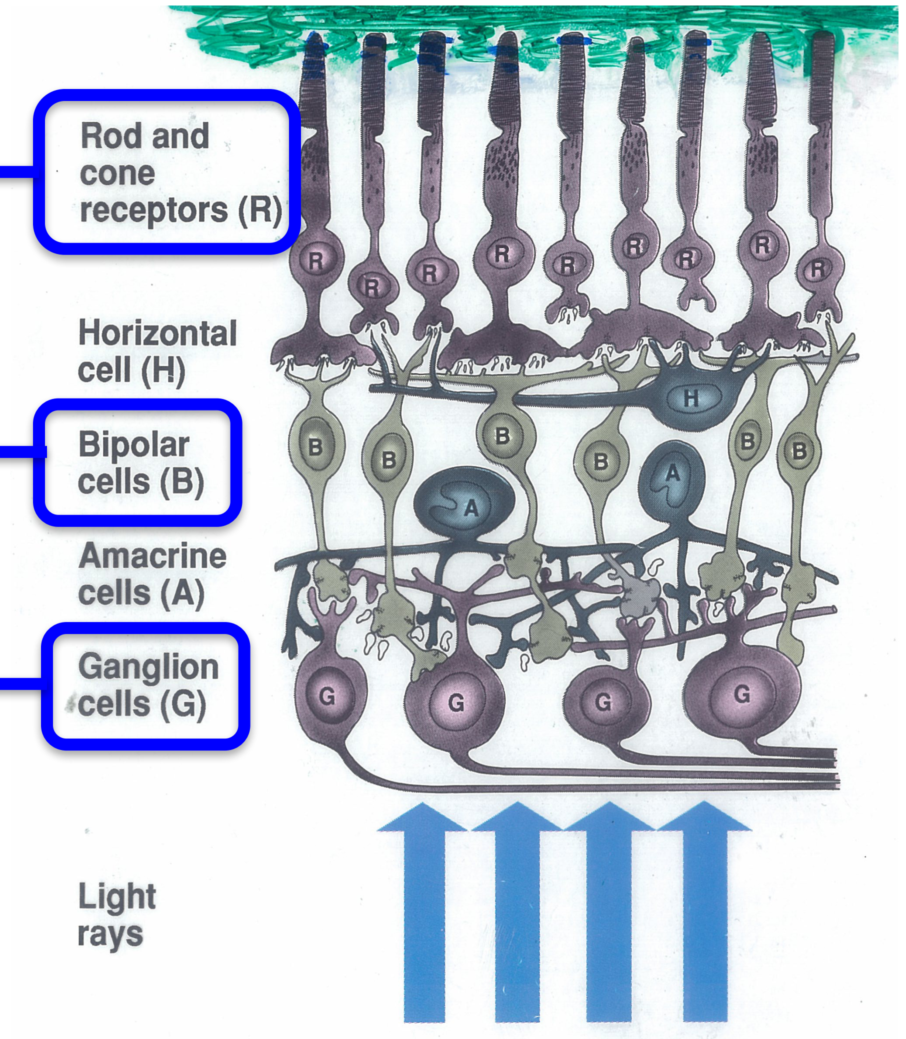
The Retina

Visual Pathway

Spontaneous,
Graded,
& Inhibitory

Spontaneous,
Graded,
& Excitatory

Action Potentials
& Excitatory



The Retina

Visual Pathway

Spontaneous,
Graded,
& **Inhibitory**

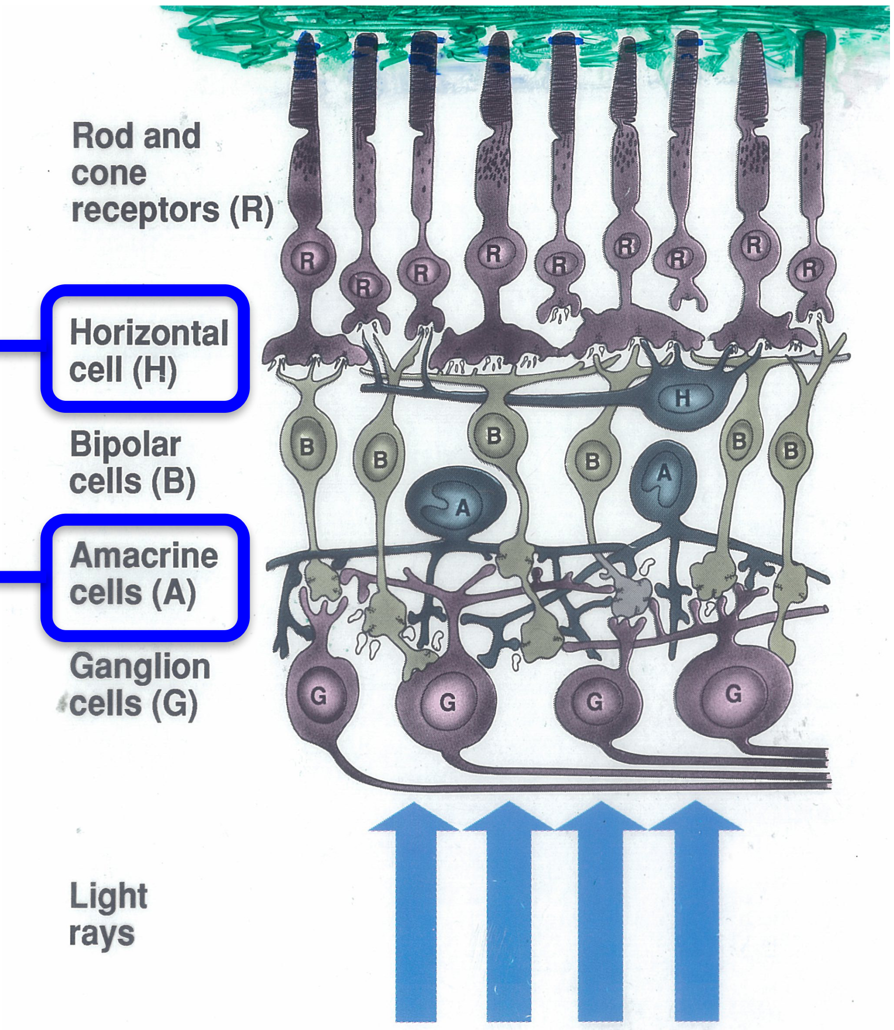
Inter-Neurons

Spontaneous,
Graded,
& **Inhibitory**

Spontaneous,
Graded,
& **Excitatory**

Graded
& **Inhibitory**

Action Potentials
& **Excitatory**



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

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)

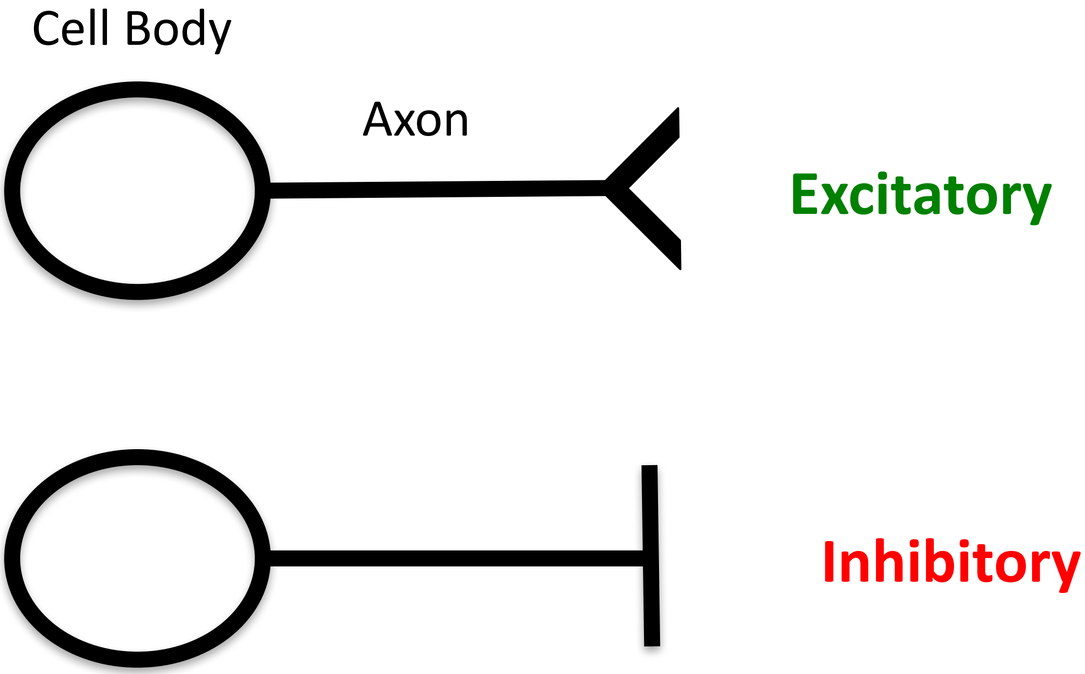
(i.e. If Dark Current is reduced by incoming light)

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 . . .



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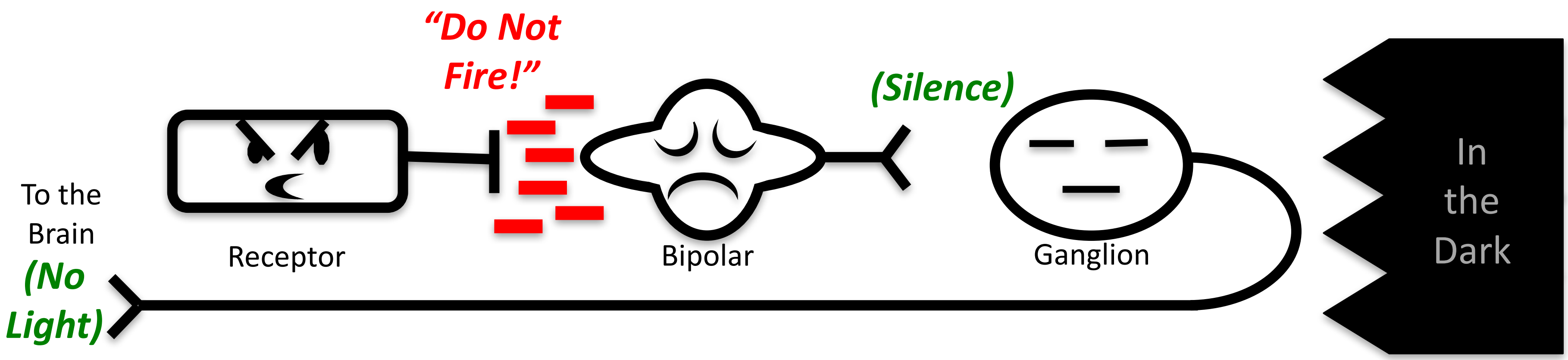

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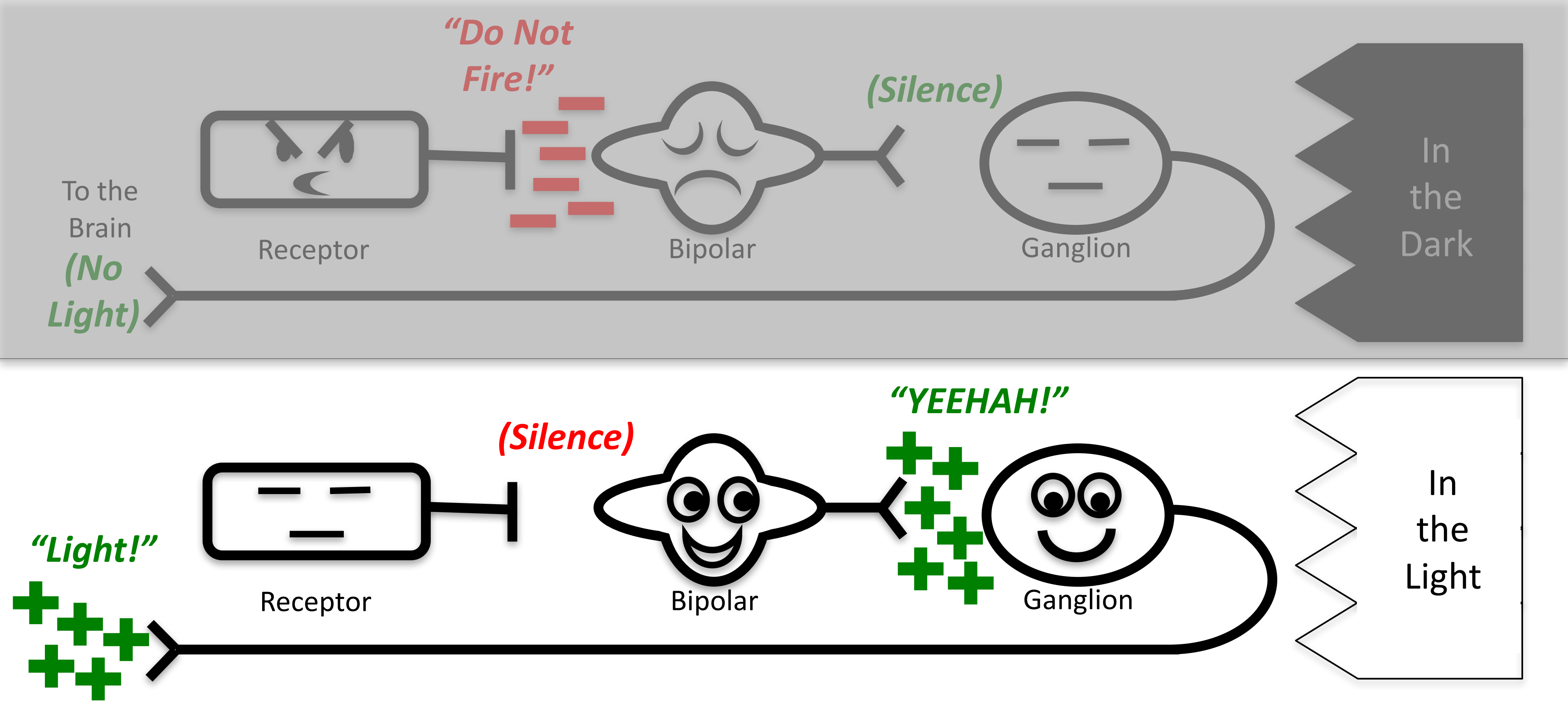

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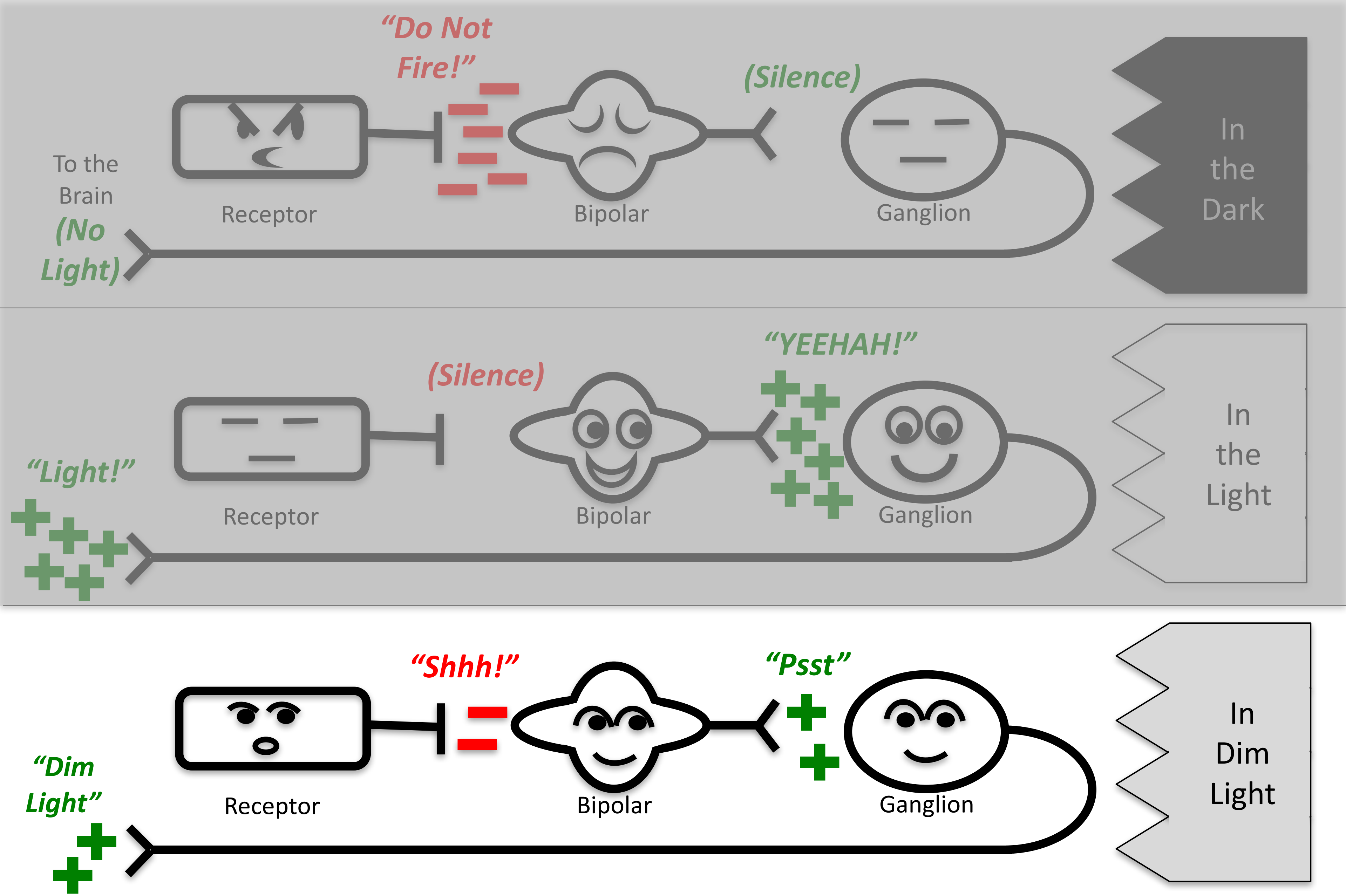

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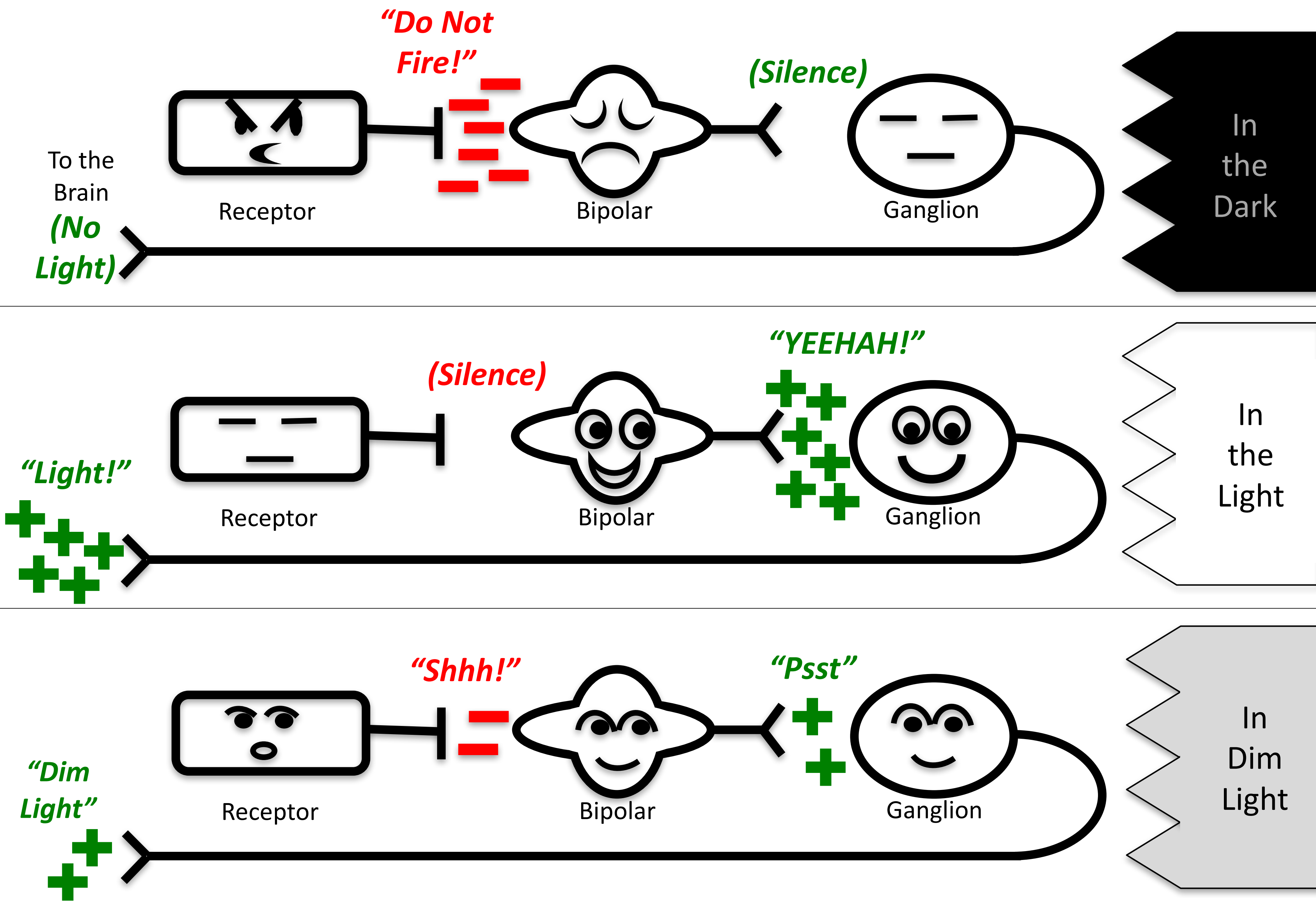


Connectivity Patterns

play a critical role in
information-transmission functions

e.g. Acuity in Cones

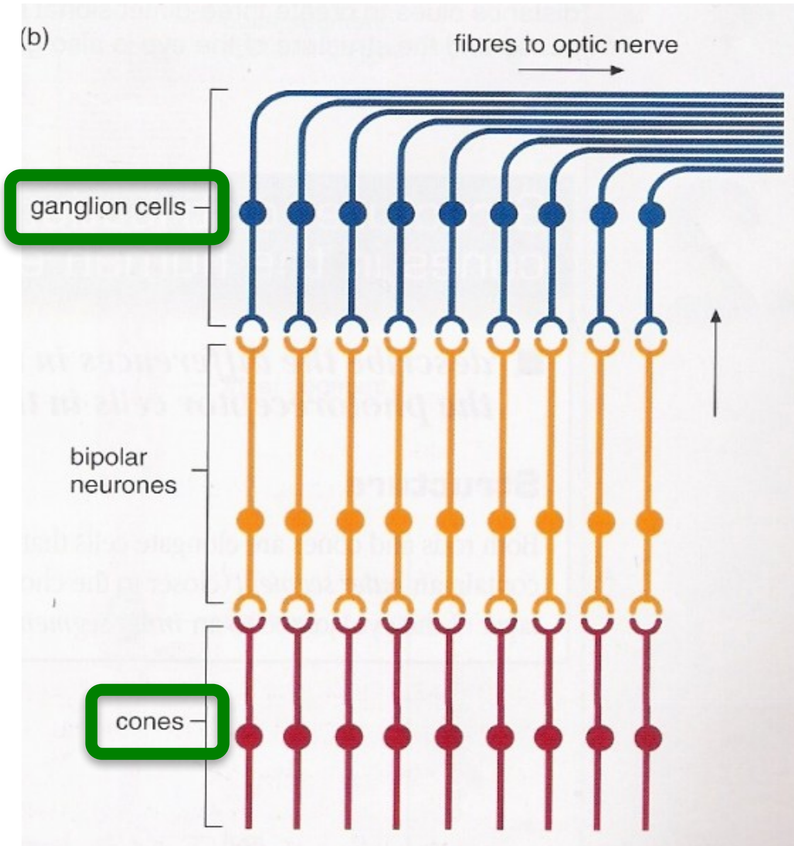
e.g. Sensitivity in Rods

e.g. Receptive Fields

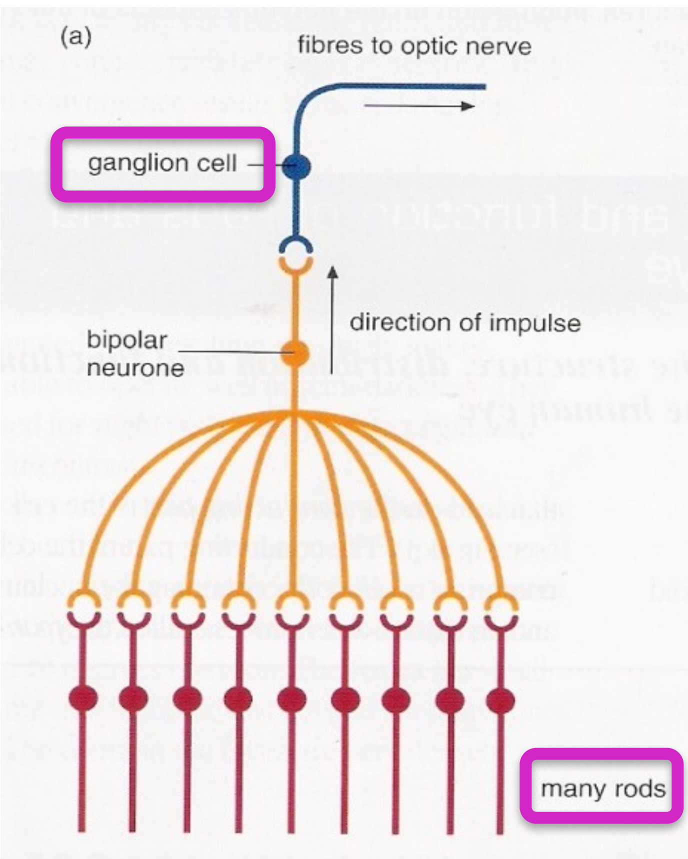
e.g. Simultaneous Contrast

Convergence

Cones show LOW convergence



Rods show HIGH convergence



Cones 1:1 or Few:1

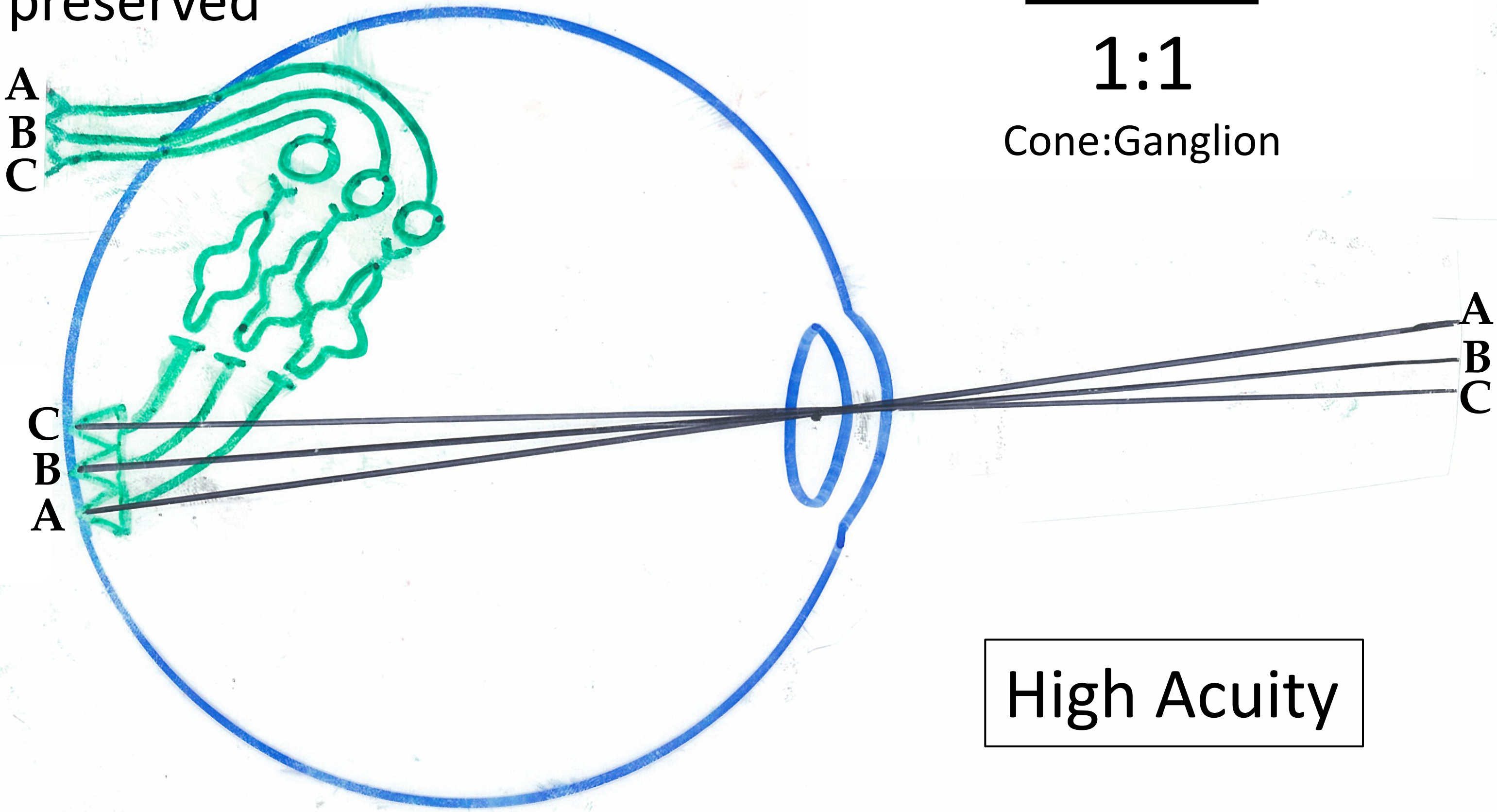
(Cones per Ganglion,
on average across retina, **6:1**)

Rods Many:1

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

Connectivity Matters

Due to connectivity pattern, details are preserved



CONES

1:1

Cone:Ganglion

High Acuity

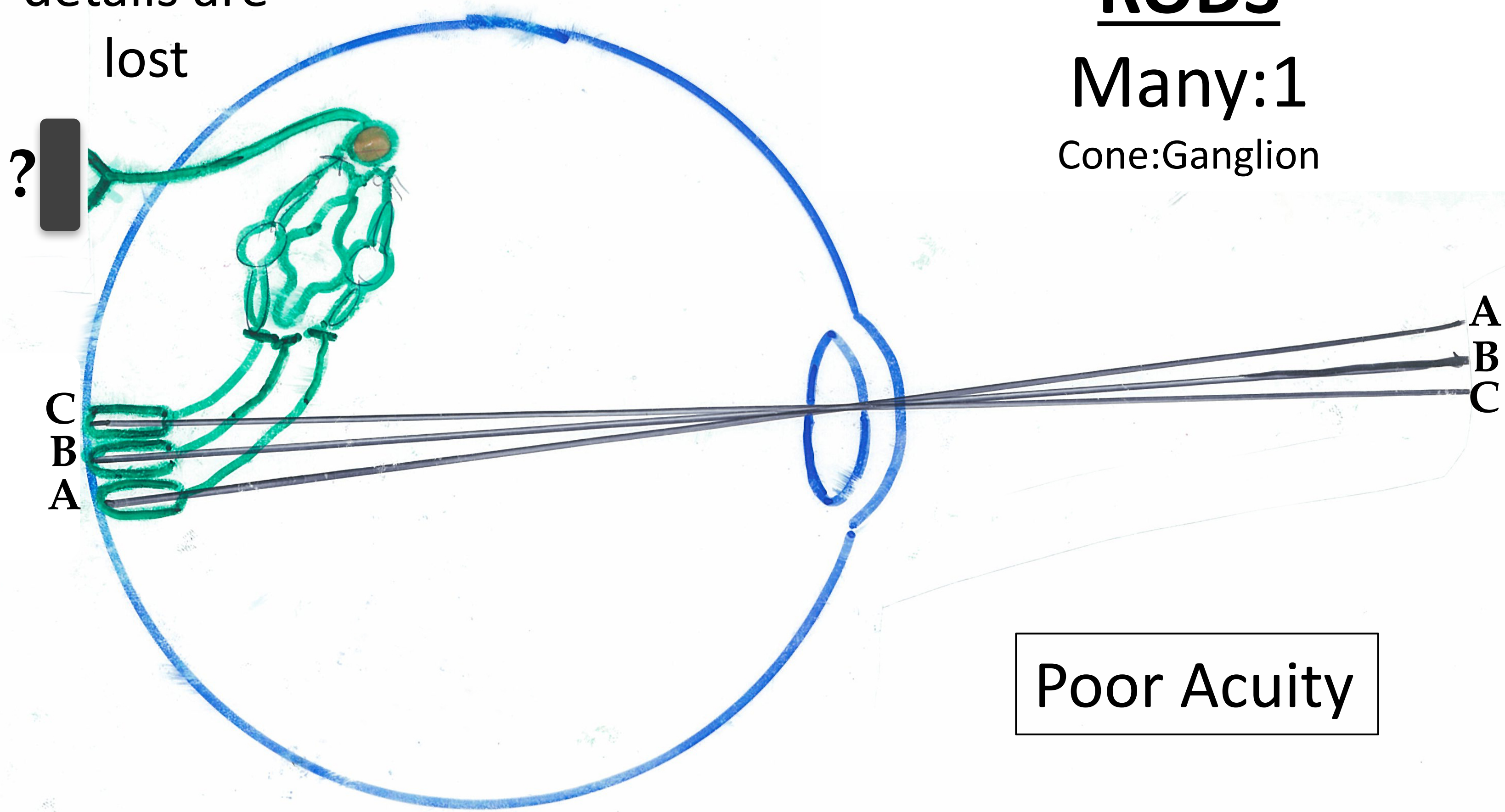
Connectivity Matters

Due to
Connectivity pattern,
details are
lost

RODS

Many:1

Cone:Ganglion



Poor Acuity

Connectivity Matters

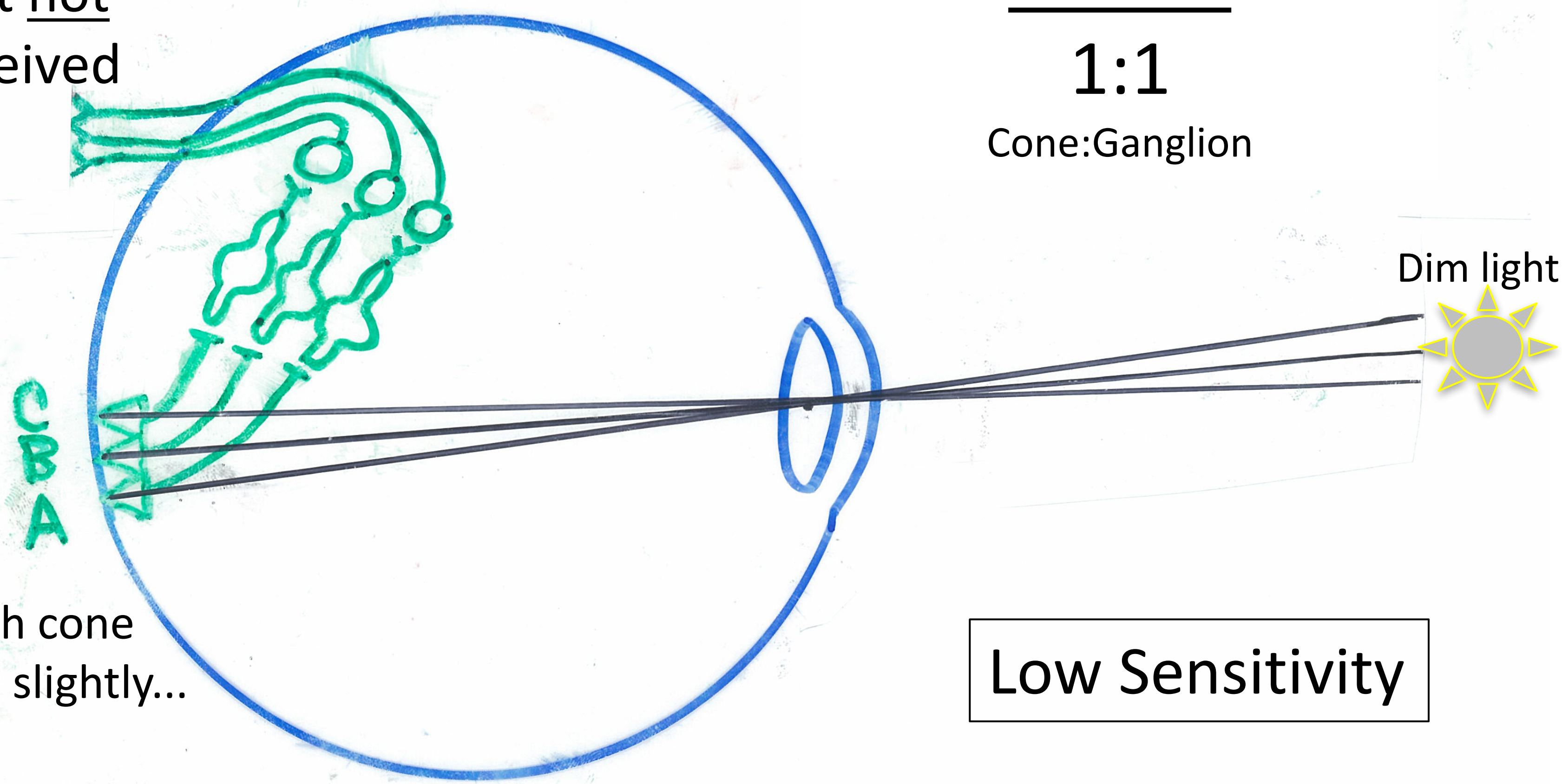
...but not enough activity from each Bipolar
to cross the threshold for
Ganglion to fire

Light <u>not</u>
perceived

<u>CONES</u>

1:1

Cone:Ganglion



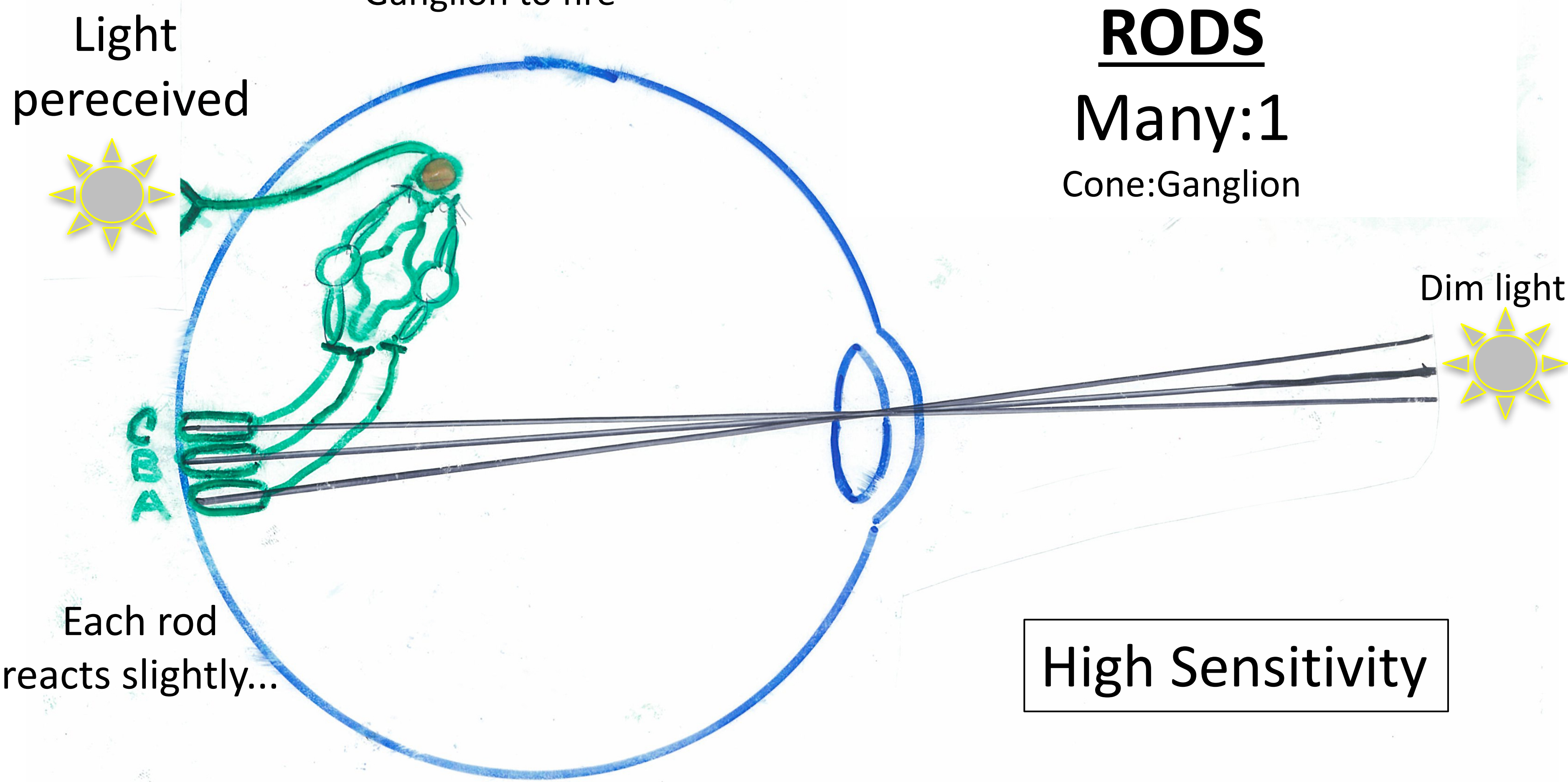
Dim light

Each cone
reacts slightly...

Low Sensitivity

Connectivity Matters

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



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

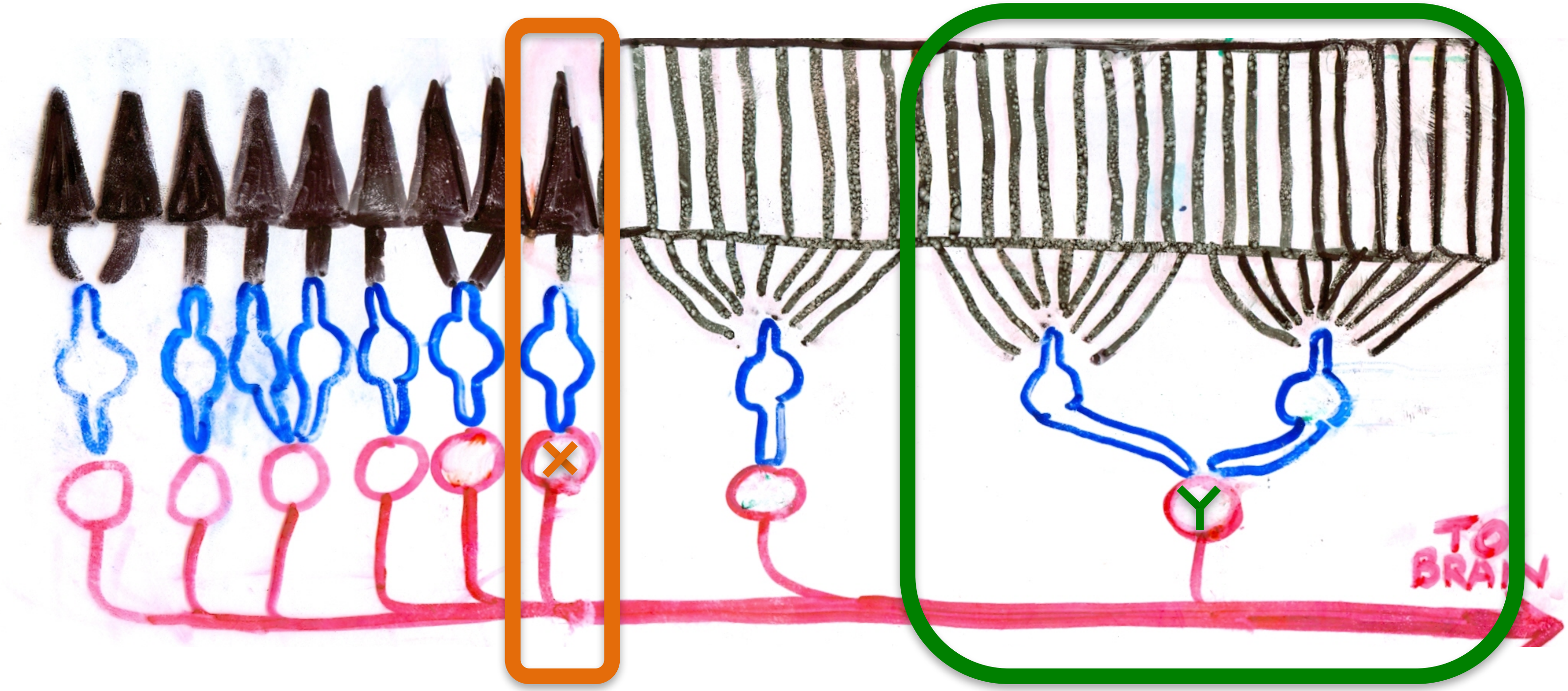
- That is, there is a better chance that a given photon of light will hit a Rod than a Cone, so in low light, Rods are more likely to be the receptors to respond

<u>MNEMONIC</u>

More and bigger rods,
Better the odds!

Receptive Field

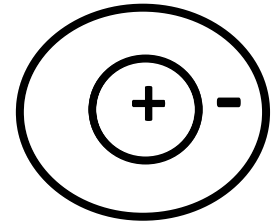
= Set of Receptors whose activity influences the activity of a "Target" cell

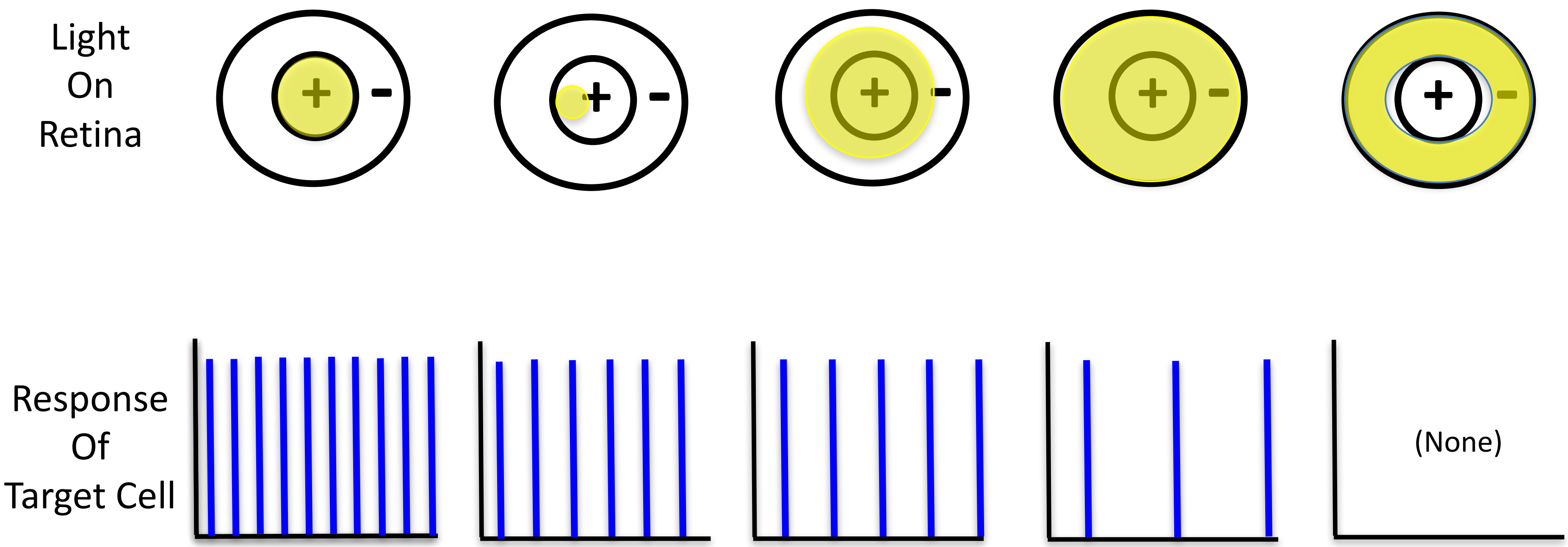


Ganglion X has a Small Receptive field

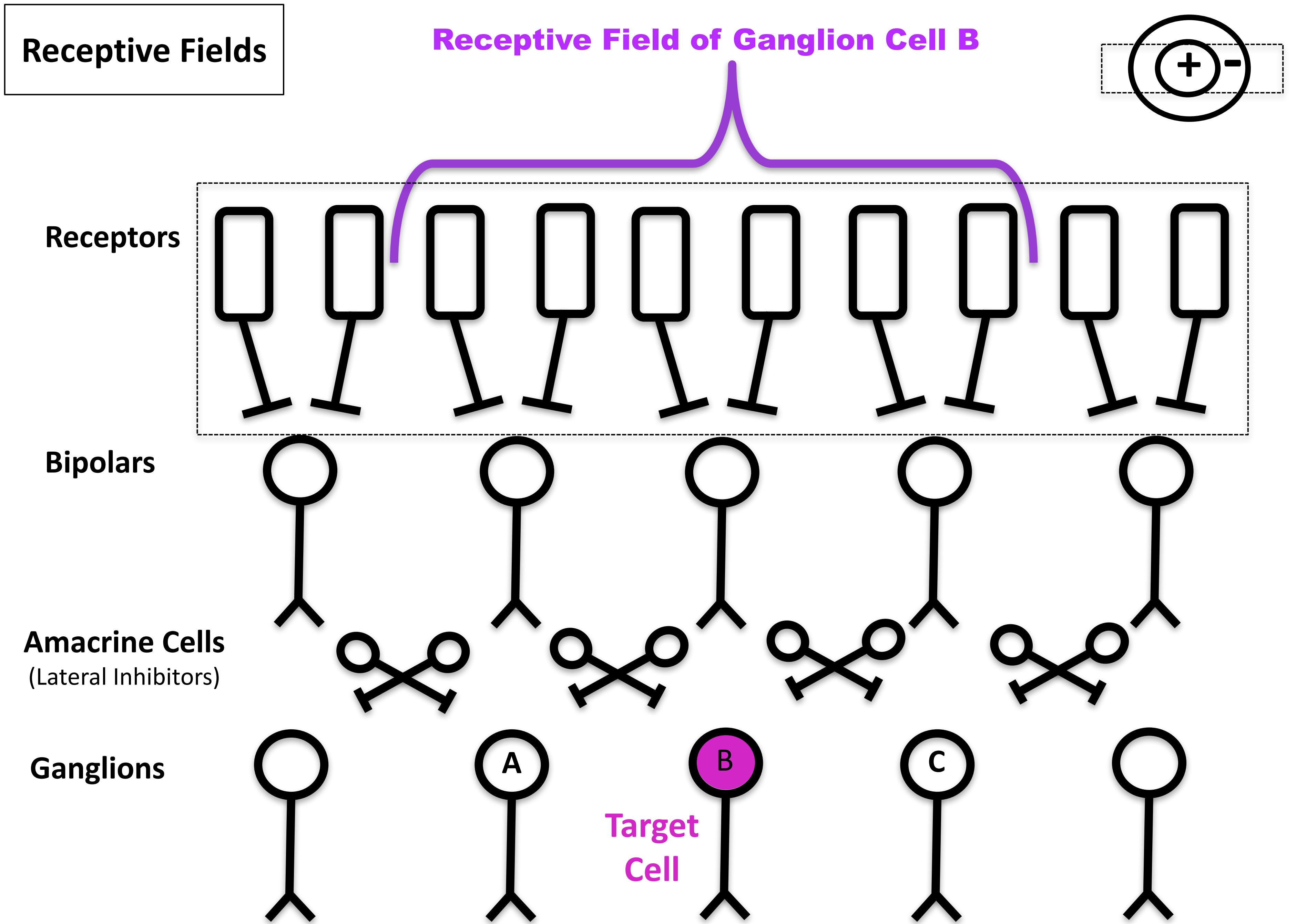
Ganglion Y has a Large Receptive field

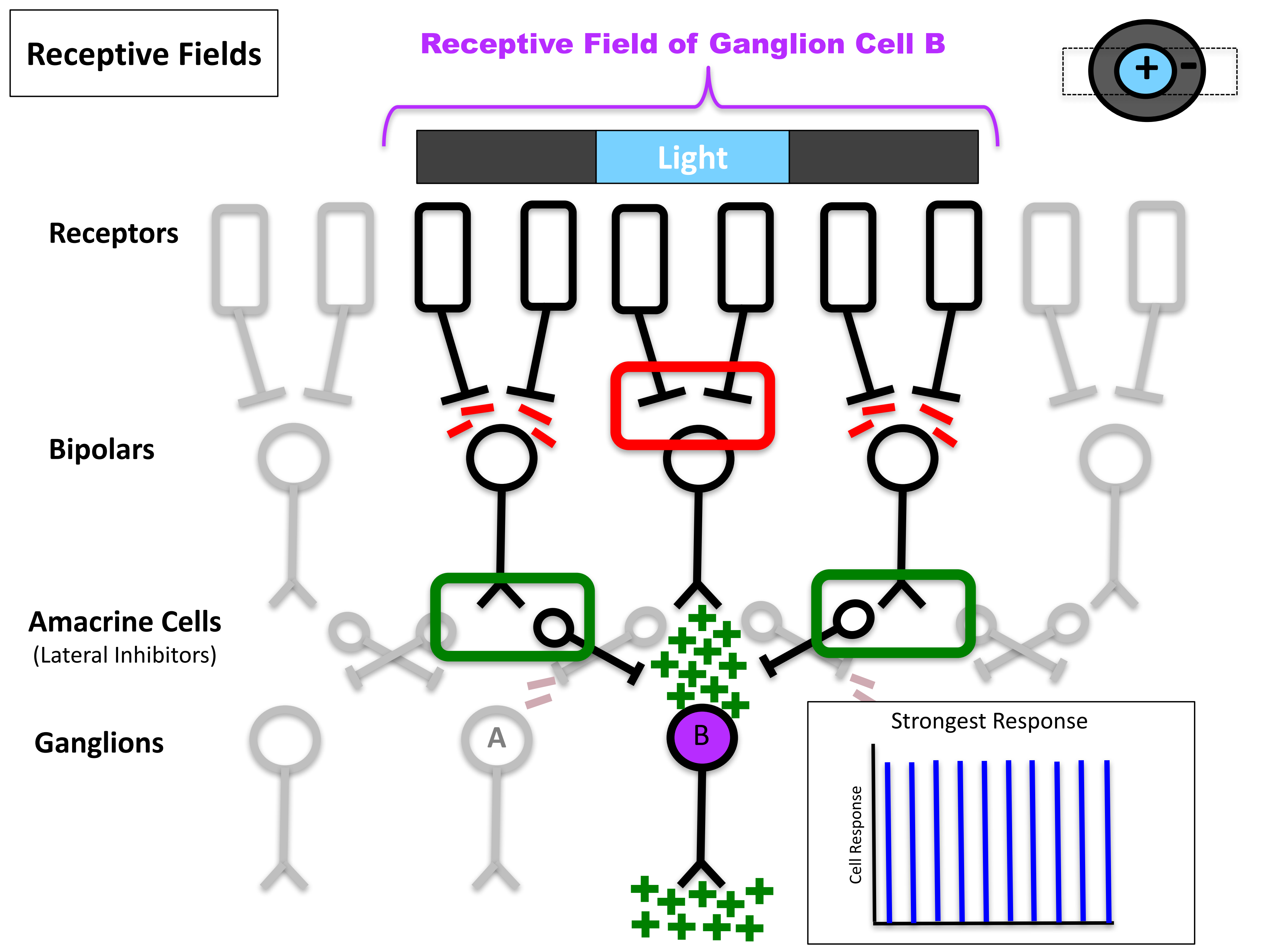
Excitatory Center- Inhibitory Surround Receptive Fields



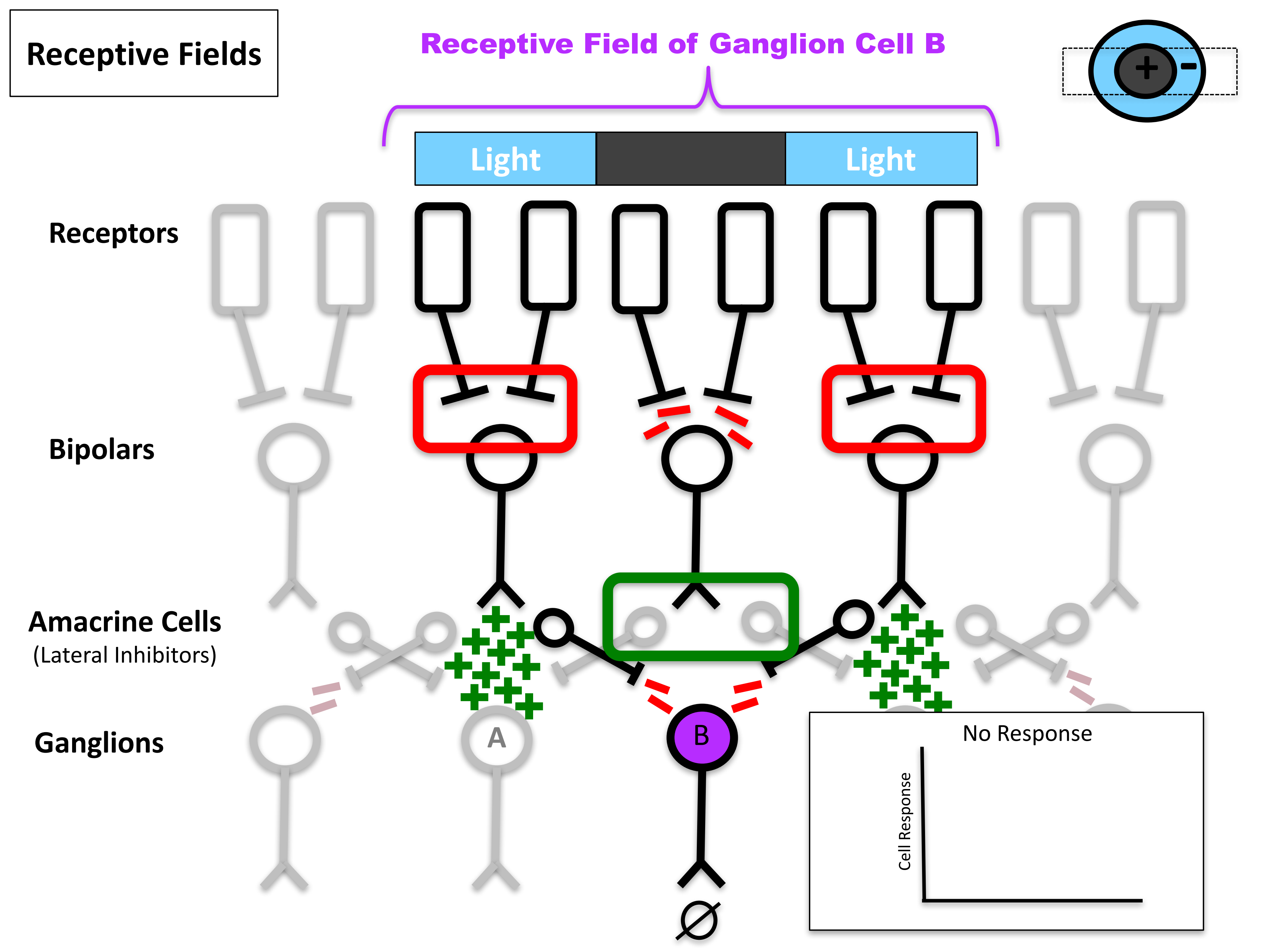


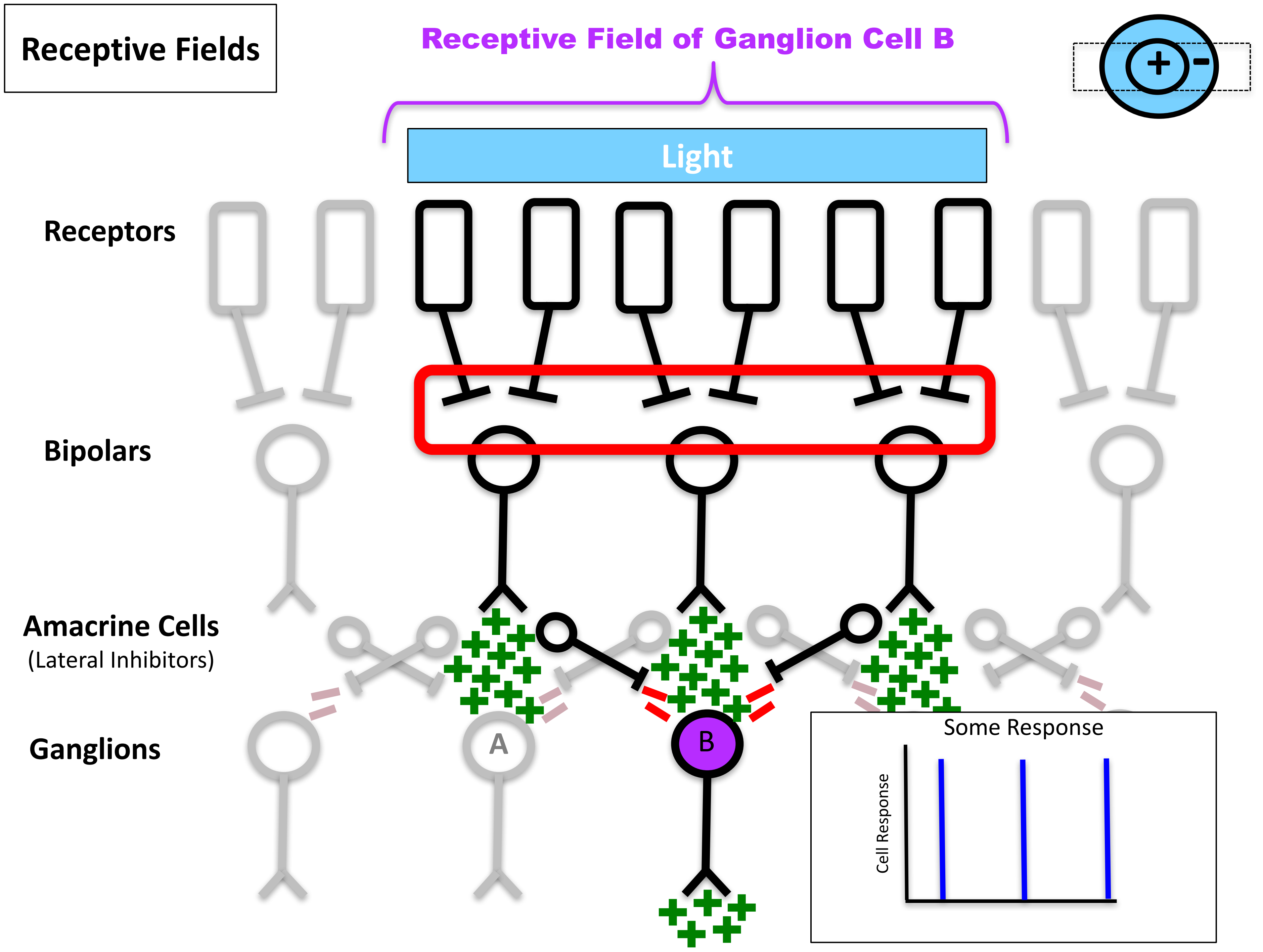
Let's look at the circuitry in the retina responsible for this . . .

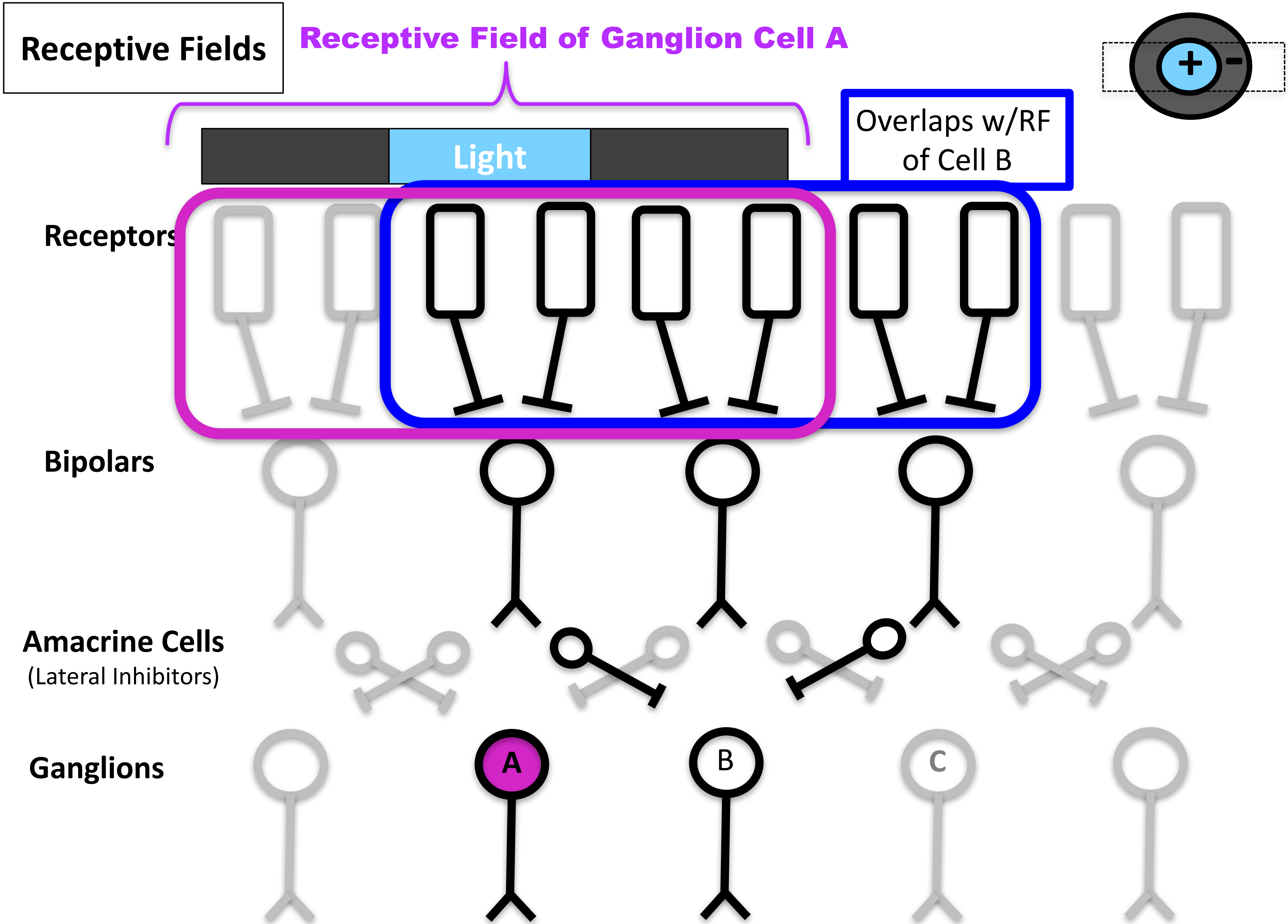

Receptive Fields
Receptive Field of Ganglion Cell B
+
-
Receptors
Bipolars
Amacrine Cells
(Lateral Inhibitors)
Ganglions
A
B
C
Target
Cell



Receptive Fields
Receptive Field of Ganglion Cell B
Light
Receptors
Bipolars
Amacrine Cells
(Lateral Inhibitors)
Ganglions
A
B
Strongest Response
Cell Response

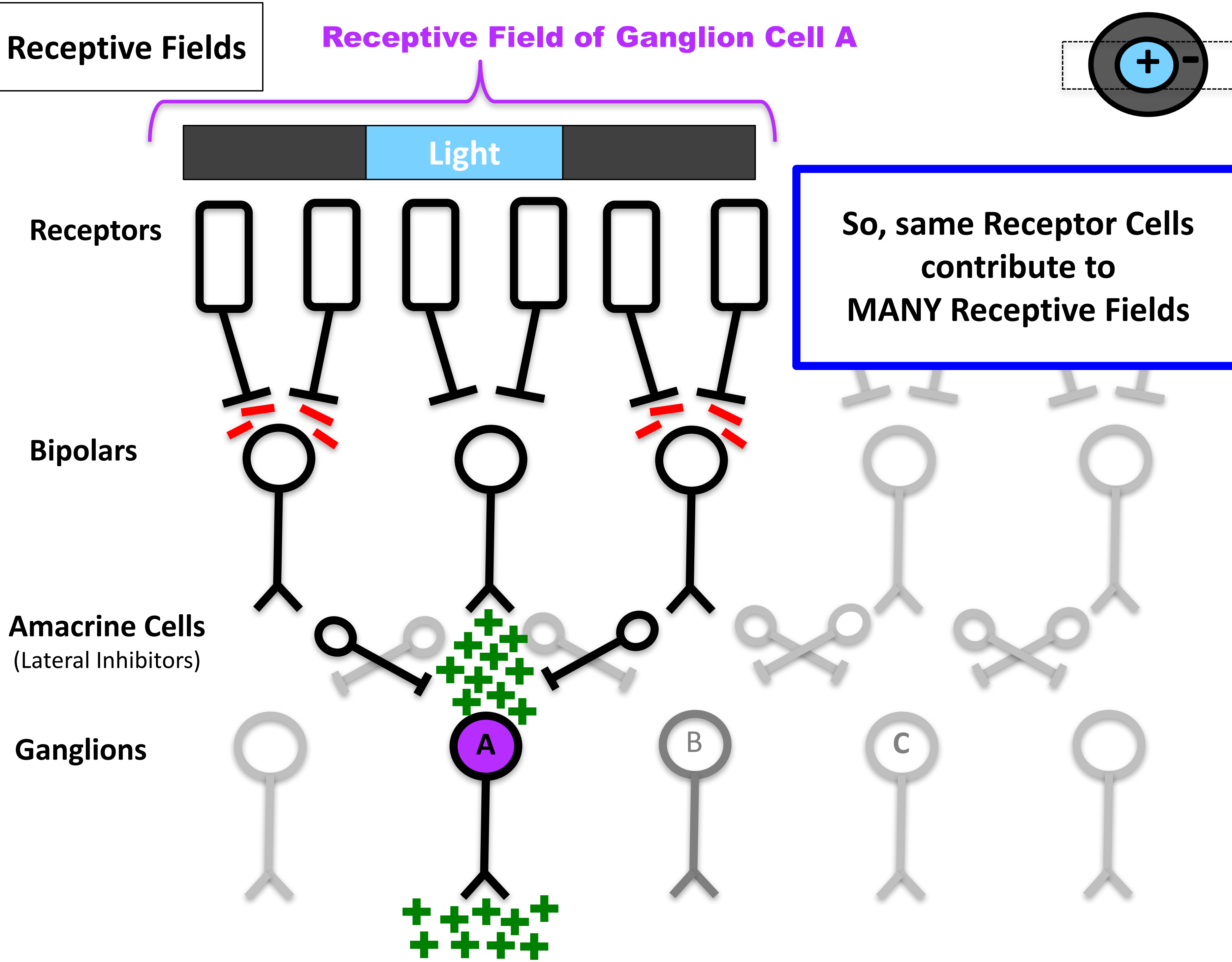

Receptive Fields
Receptive Field of Ganglion Cell B
+
-
Light
Light
Receptors
Bipolars
Amacrine Cells
(Lateral Inhibitors)
Ganglions
A
B
Ø
No Response
Cell Response


Receptive Fields
Receptive Field of Ganglion Cell B
+
-
Light
Receptors
Bipolars
Amacrine Cells
(Lateral Inhibitors)
Ganglions
A
B
Some Response
Cell Response



Receptive Fields
Receptive Field of Ganglion Cell A
Light
Overlaps w/RF of Cell B
+
-
Receptors
Bipolars
Amacrine Cells
(Lateral Inhibitors)
Ganglions
A
B
C

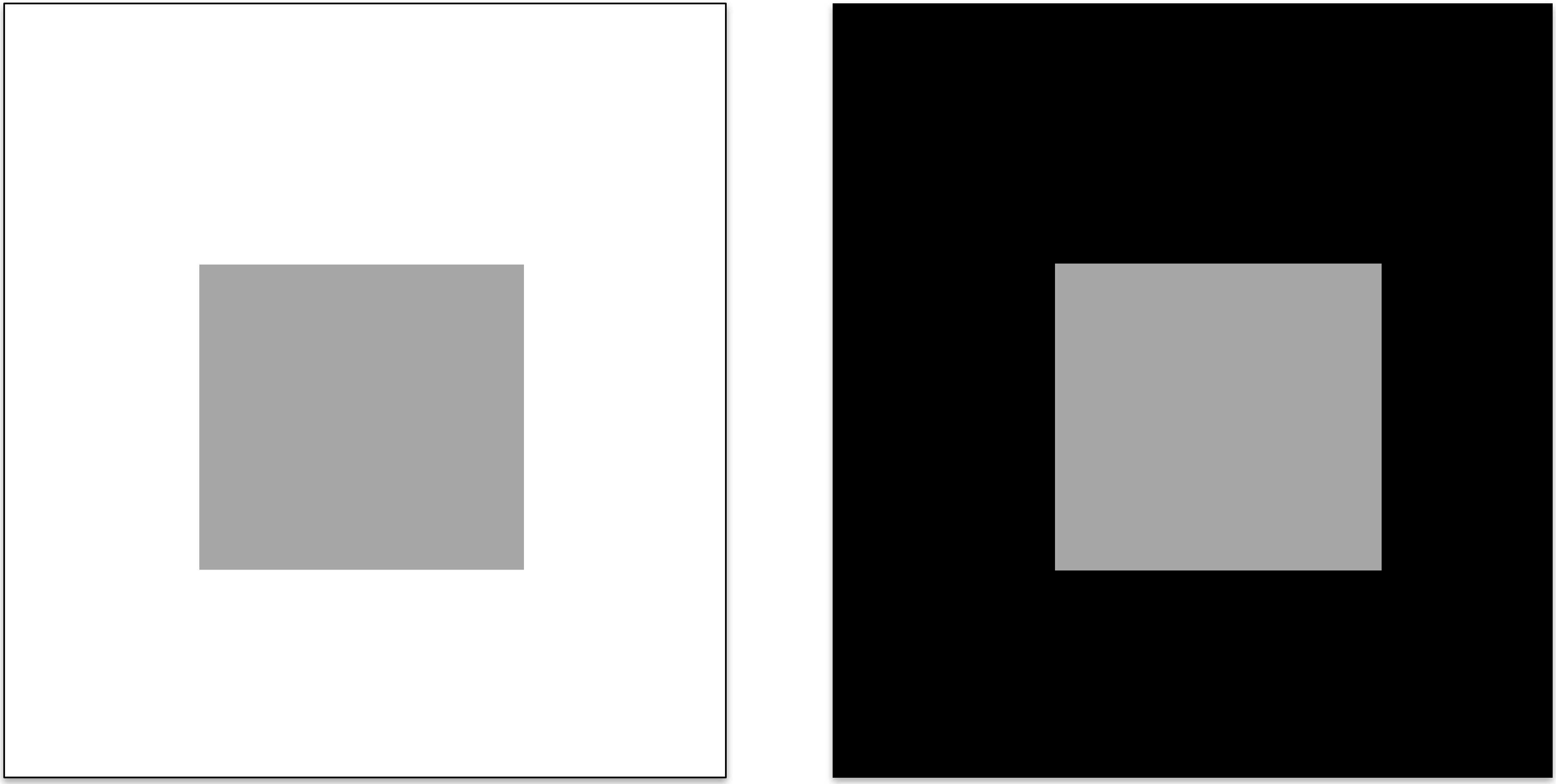
Receptive Fields



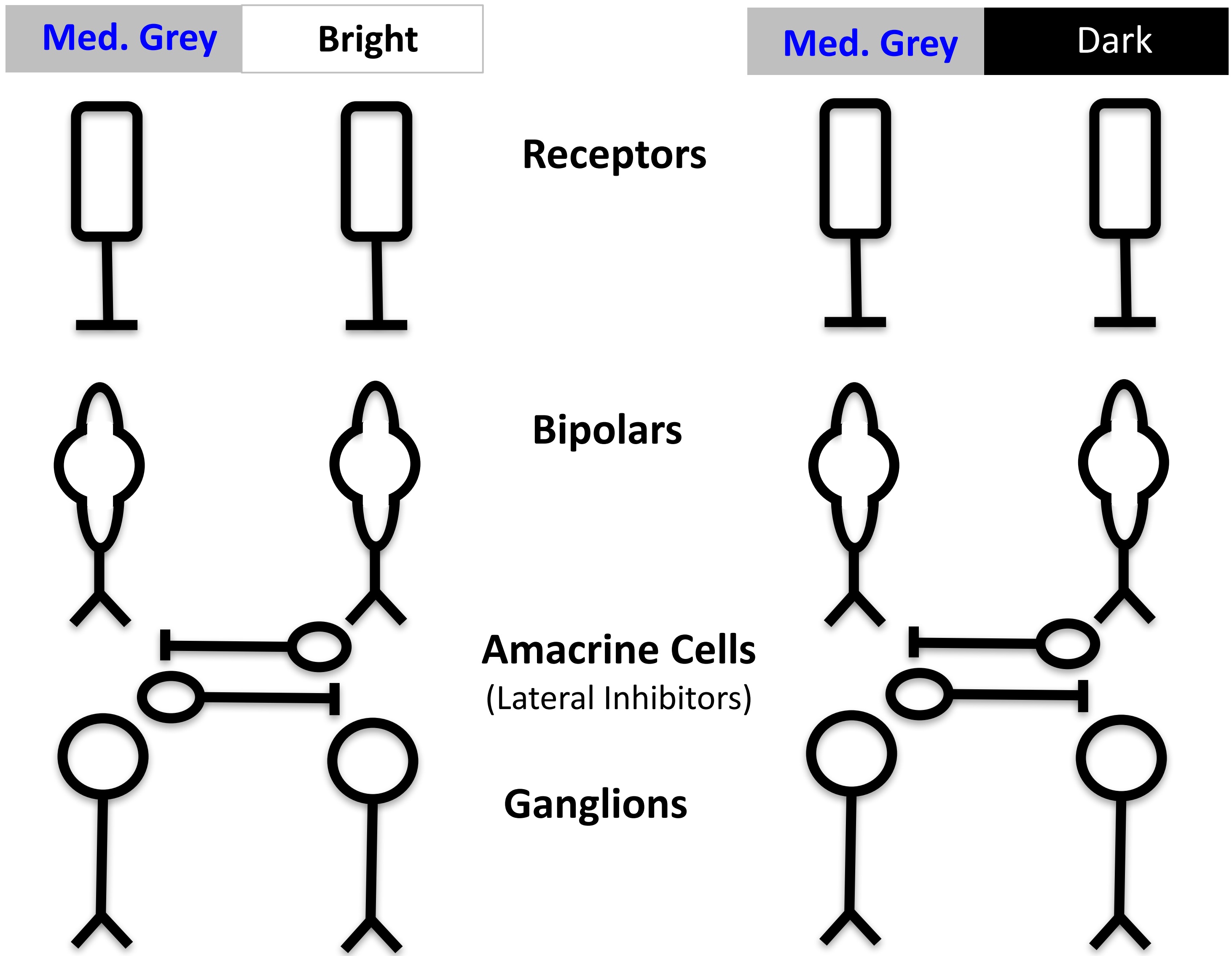
So, same Receptor Cells contribute to MANY Receptive Fields

Simultaneous Contrast in the Retina

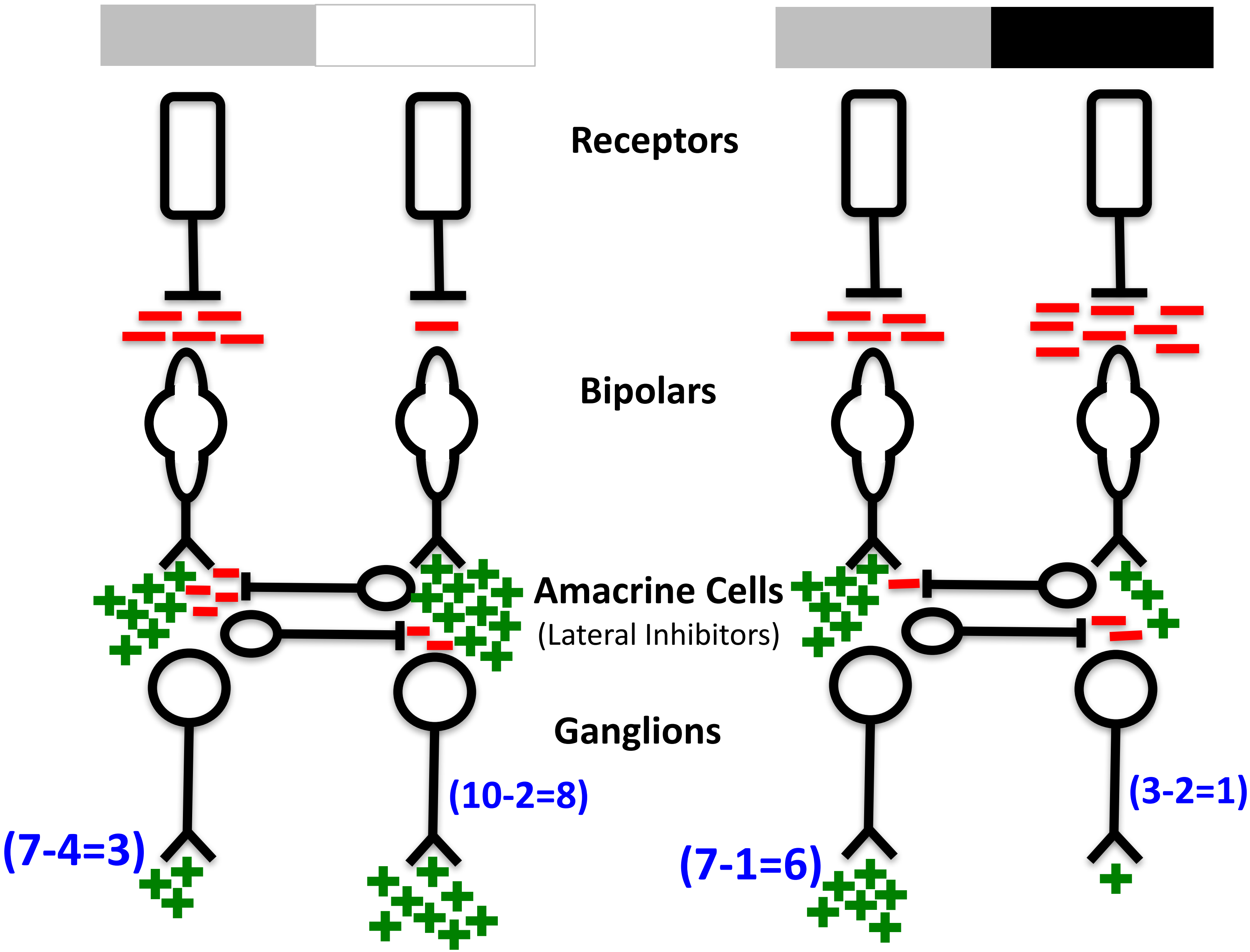
Simultaneous Contrast in the Retina



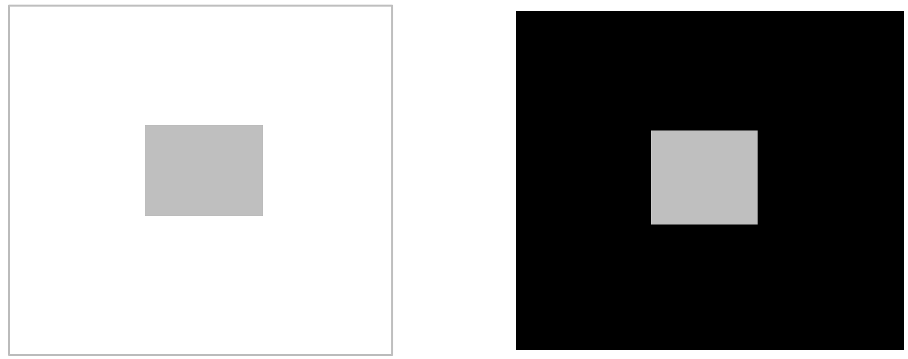
Simultaneous Contrast in Retina



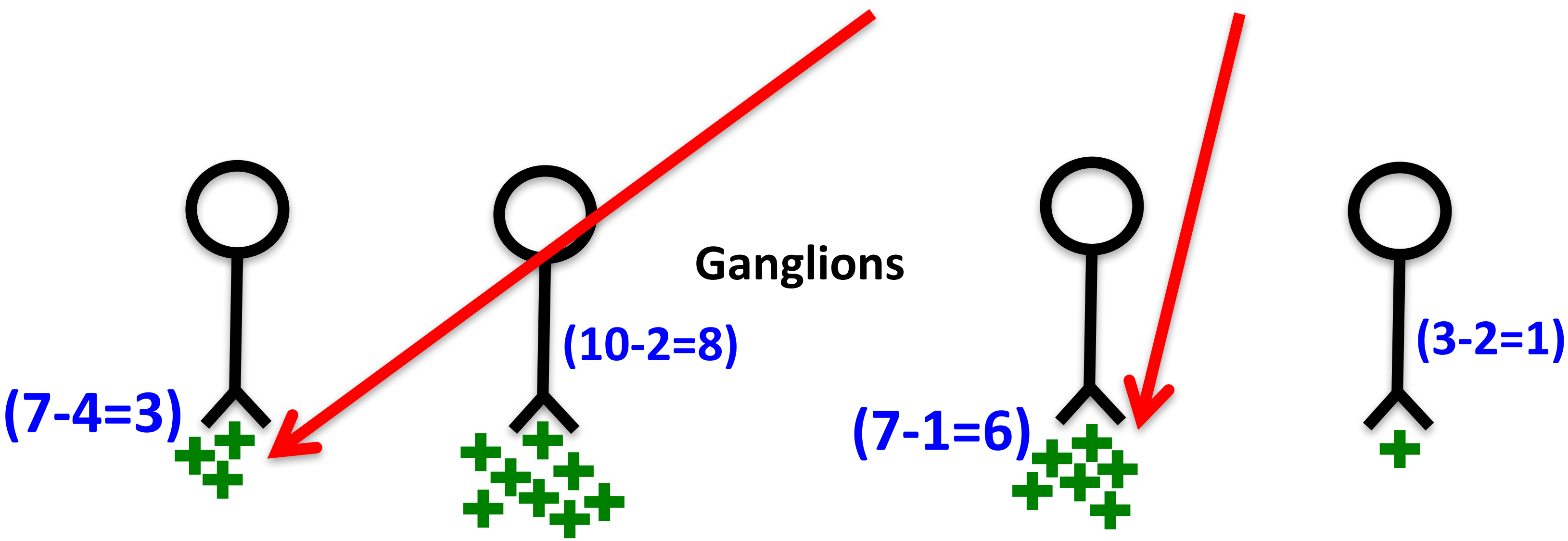
Simultaneous Contrast in Retina



Simultaneous Contrast in Retina



As a result of **Lateral Inhibition,**
Ganglions “lie” to brain about
Medium Grey –
So you Perceive one as <u>darker</u> and one as <u>lighter</u>



Simultaneous Contrast in Retina