The ON and OFF Channels

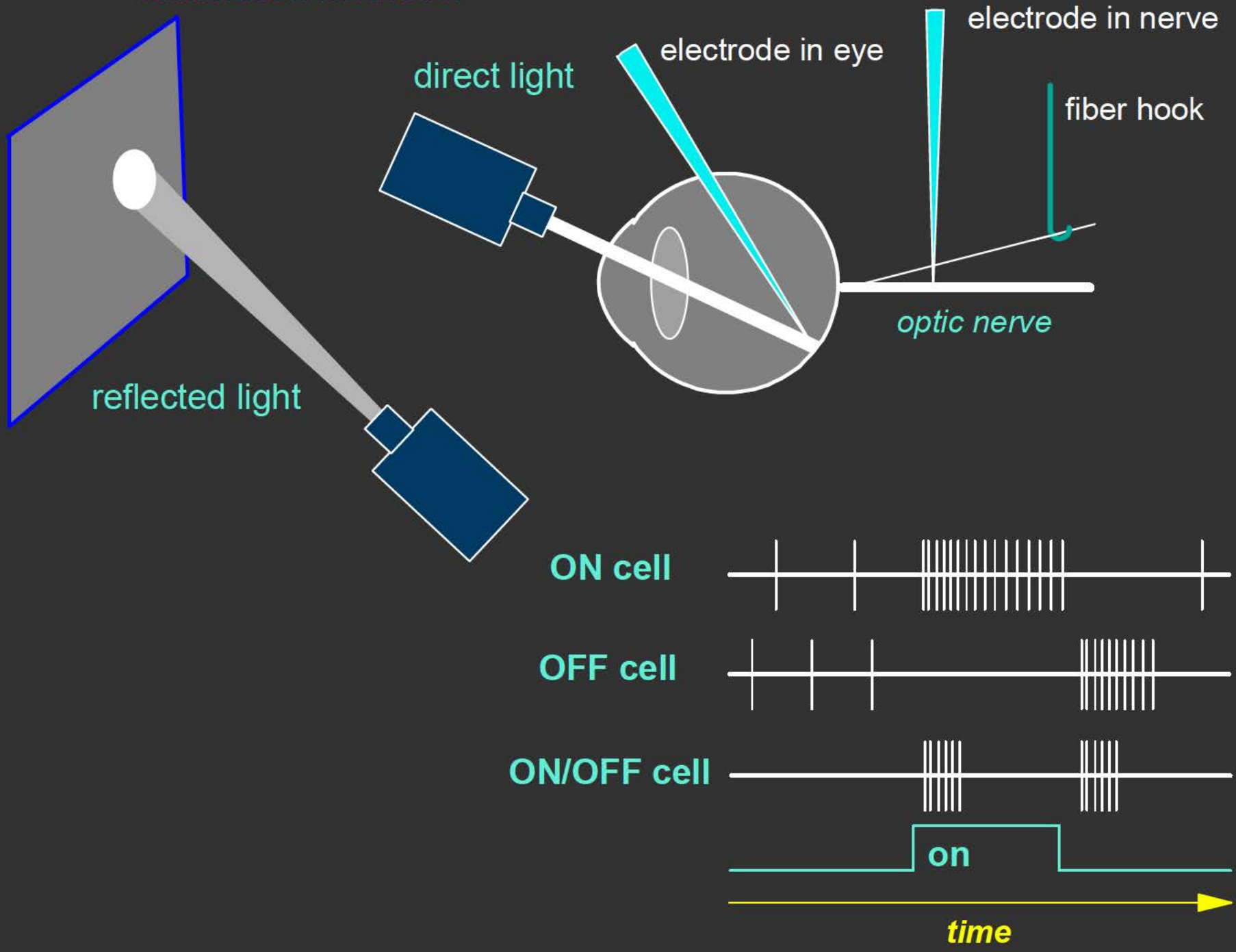
Questions:

1. Why do we have ON and OFF channels that originate in the retina?
2. How are the ON and OFF channels created for the cones and rods?
3. How do the ON and OFF channels contribute to the center-surround organization of RGCs?
4. What role do the ON and OFF channels play in giving rise to the transforms seen in visual cortex?
5. What are the consequences of blocking the ON channel on neuronal activity and on perception?

The neural responses of the ON and OFF retinal ganglion cells

Stimulation Methods:

Recording Methods:



The receptive fields of three major classes of retinal ganglion cells

Action potentials discharged by an ON and an OFF retinal ganglion cell

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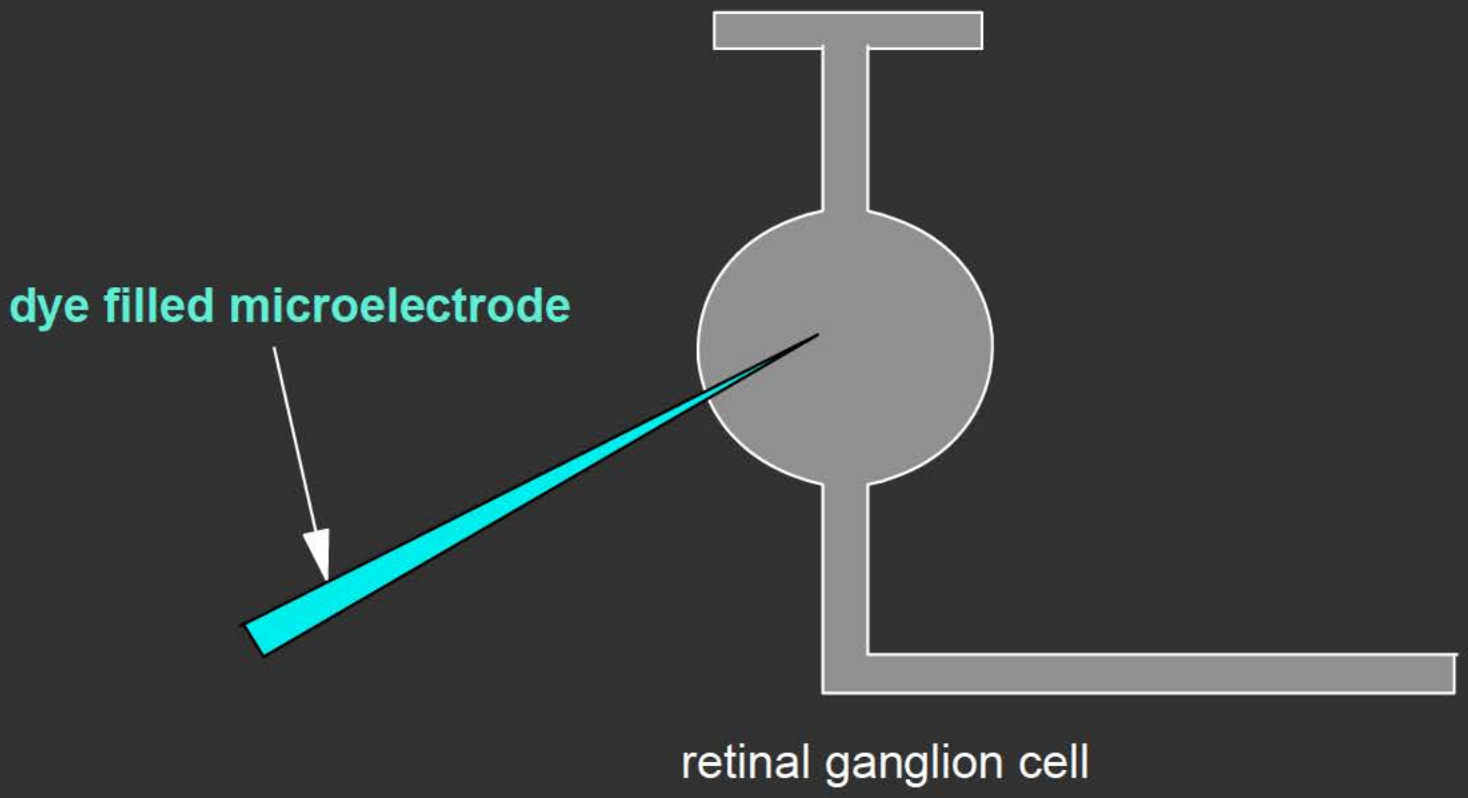
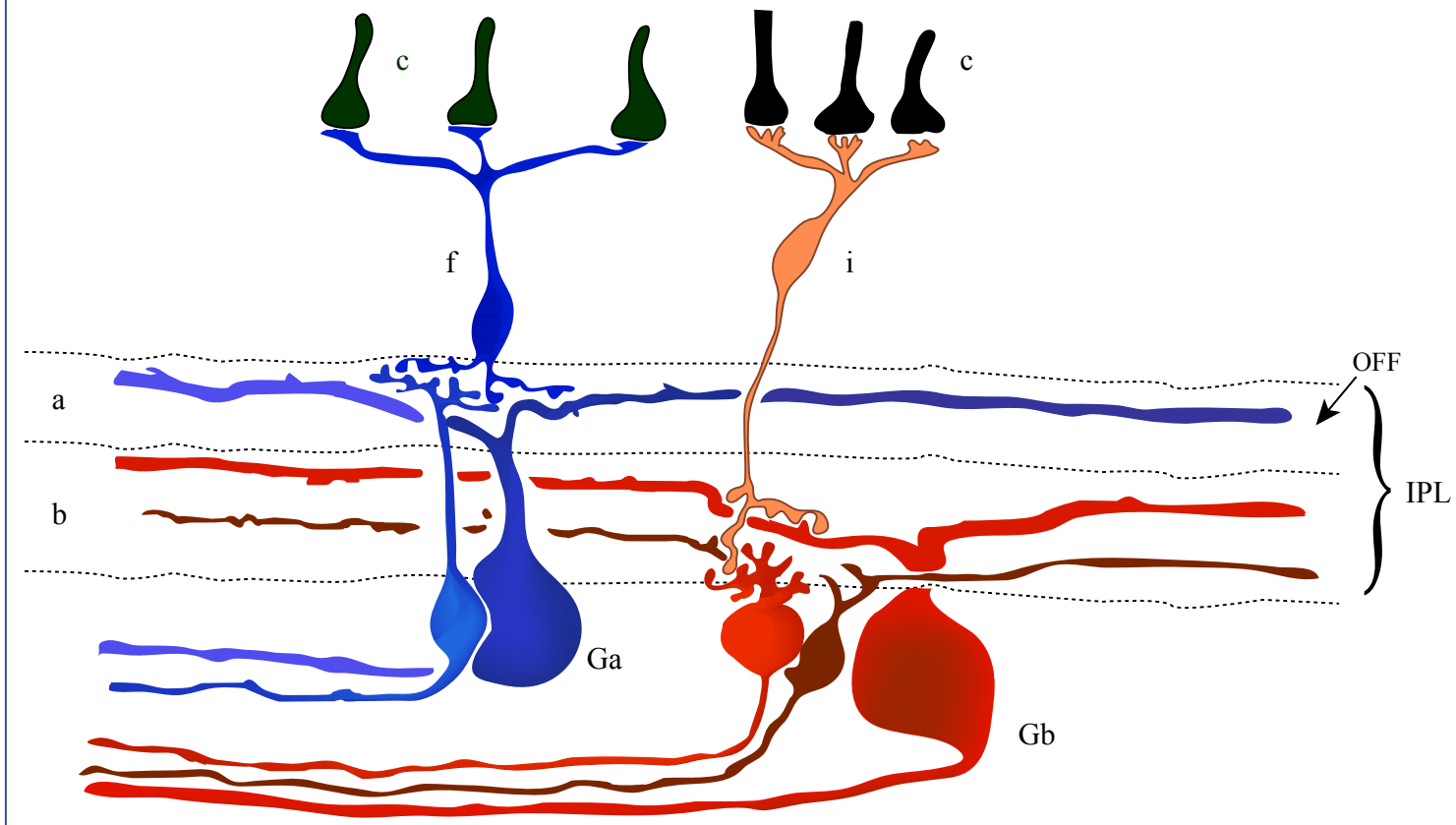
Please refer to lecture video or)LJXUH $ RI 6FKLOHU 3HWHU + DQG (GZDUG - 7HKRYQLN 9LVXDO SURVWKHVLV *3HUFHSWLRQ* QR

Anatomy of the ON and OFF retinal ganglion cells

Intracellular recording and labeling method



The dendritic arborization pattern of ON and OFF retinal ganglion cells



Organization of cone bipolar cells and ganglion cells in the IPL of the cat retina. Flat cone bipolar cells (f) have axon terminals ending in sublamina a contacting the dendrites of a-type ganglion cells (Ga). Invaginating cone bipolar cells (i) have axon terminals which ramify lower in the IPL in sublamina b where they contact b-type ganglion cell dendrites (Gb). Ganglion cells of various morphologies branch either in sublamina a or sublamina b; these prove to be off-center and on-center, respectively, c, cones.

Retrogradely labeled cat Y retinal ganglion cells

Images removed due to copyright restrictions.

Please refer to lecture video or)LJXUH D F RI 3HLFK0 / DQG % % %R\FRWW $ VSDWLD0 DQD0\VLV RI RQ DQG RII JDQJ0LRQ FH00V LQ WKH FDW UHWLQD *9LVLRQ UHVHDUFK* QR .

Overview of retinal connections

Photoreceptor basics:

1. All photoreceptors hyperpolarize to light.

2. Depolarization of the photoreceptor releases glutamate.

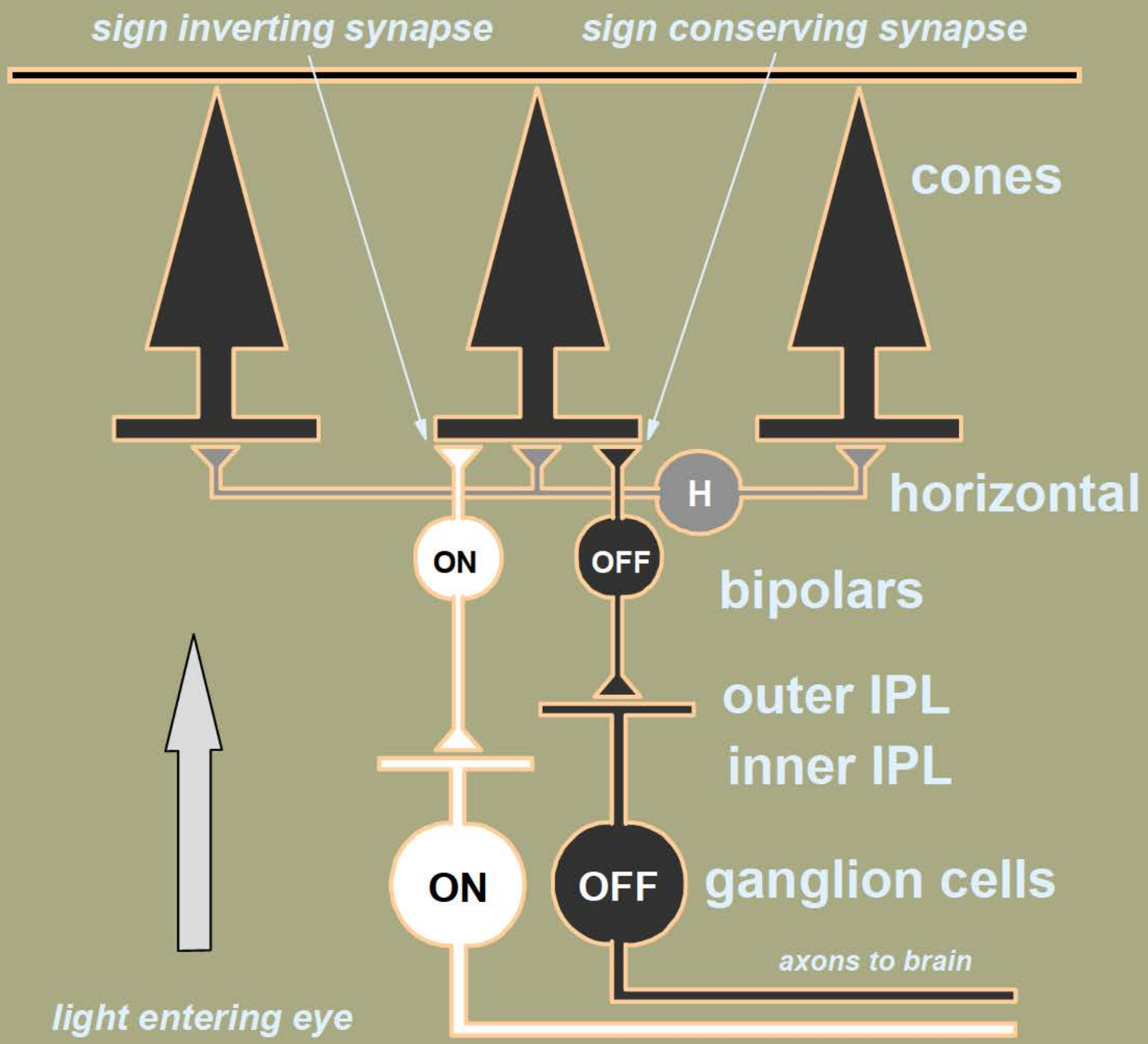
3. Photon absorption by the photopigment results in isomerization of the chromophore from 11-cis to all-trans. This causes hyperpolarization thereby reducing neurotransmitter release.

4. Two classes of bipolars are the ON and the OFF. The synaptic junction of OFF bipolars is sign conserving; that of the ON bipolar is sign inverting.

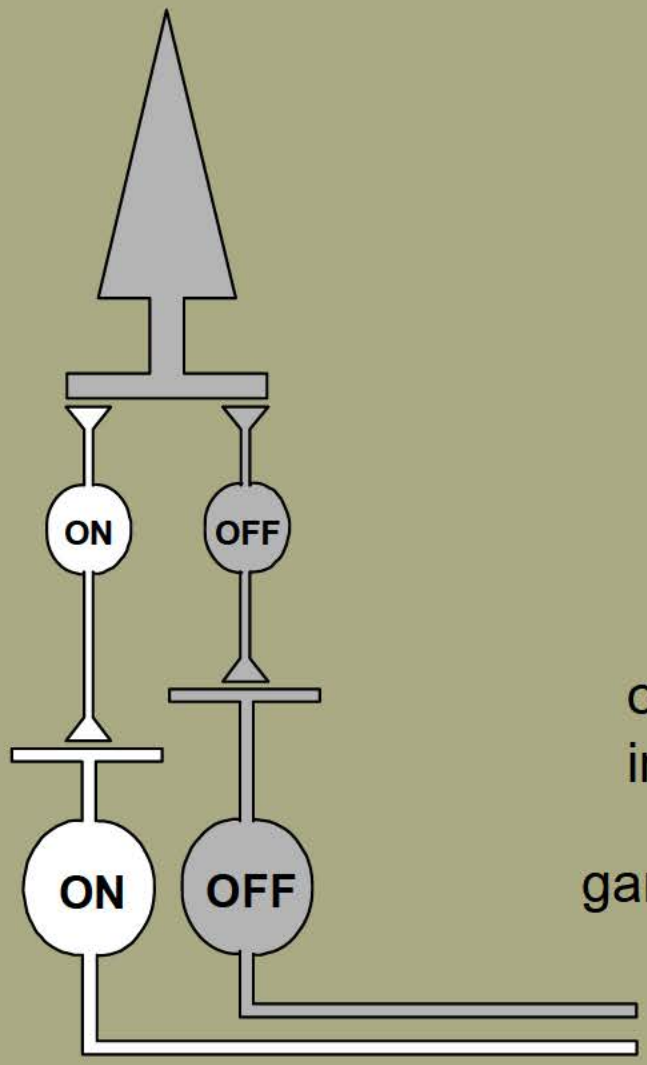
5. The ON bipolar receptor is mGluR6. Its activation leads to closing of channels causing hyperpolarization.

6. The OFF bipolar receptors are mGluR1 & 2. Their activation leads to the opening of channels causing depolarization.

Retinal wiring of the ON and OFF systems



The ON and OFF systems



cones

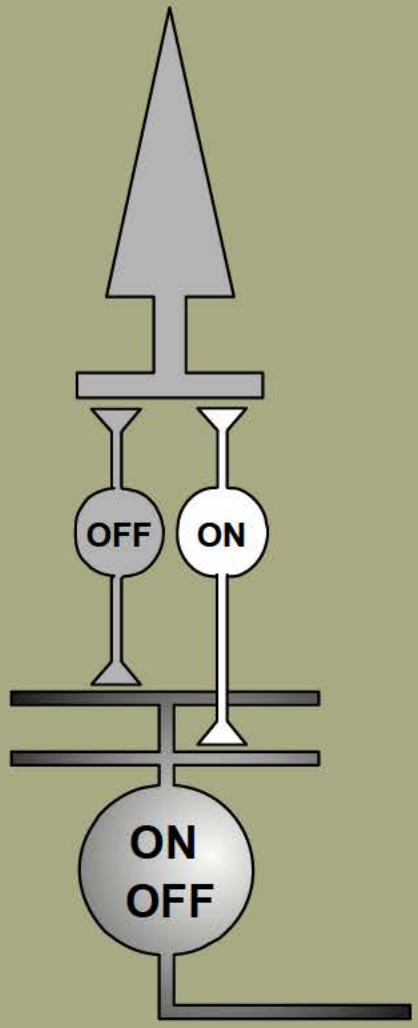
bipolars

outer IPL

inner IPL

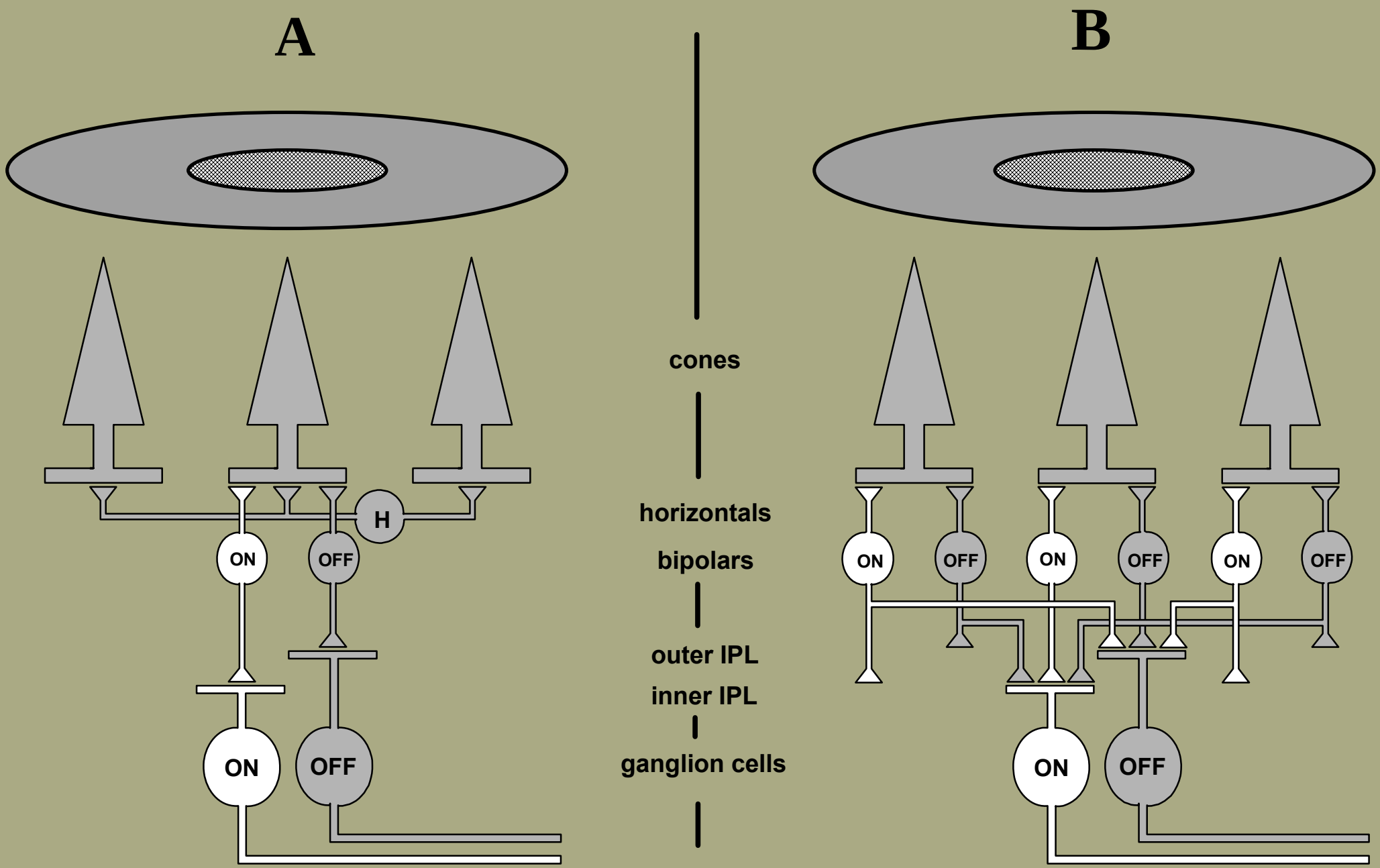
ganglion cells

The ON/OFF system



How is the surround mechanism created?

Two models for the creation of receptive field surround



Surround by horizontal cell network

Surround by ON/OFF interconnection

The effects of APB on the responses of neurons in the visual system

APB is a glutamate analog specific for the mGluR6 receptor of the ON bipolar cells.

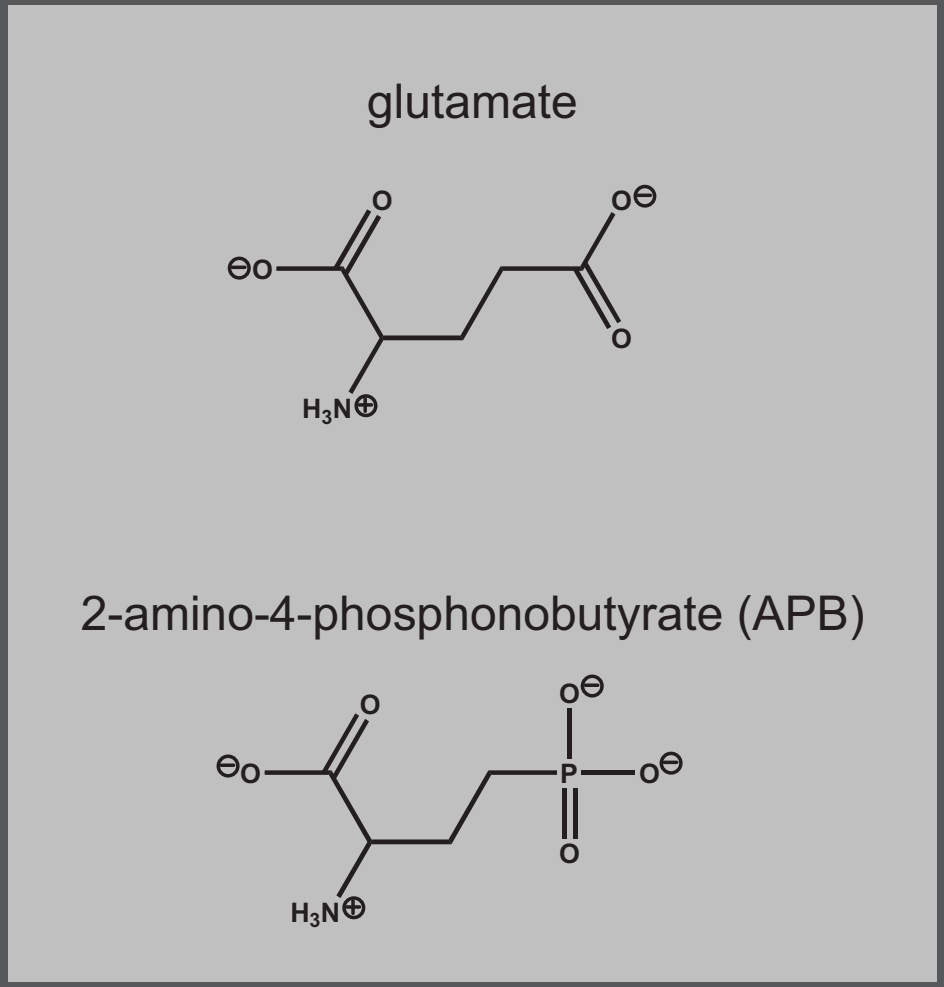


Image by MIT OpenCourseWare.

Method for infusing APB into the eye while recording in various brain structures

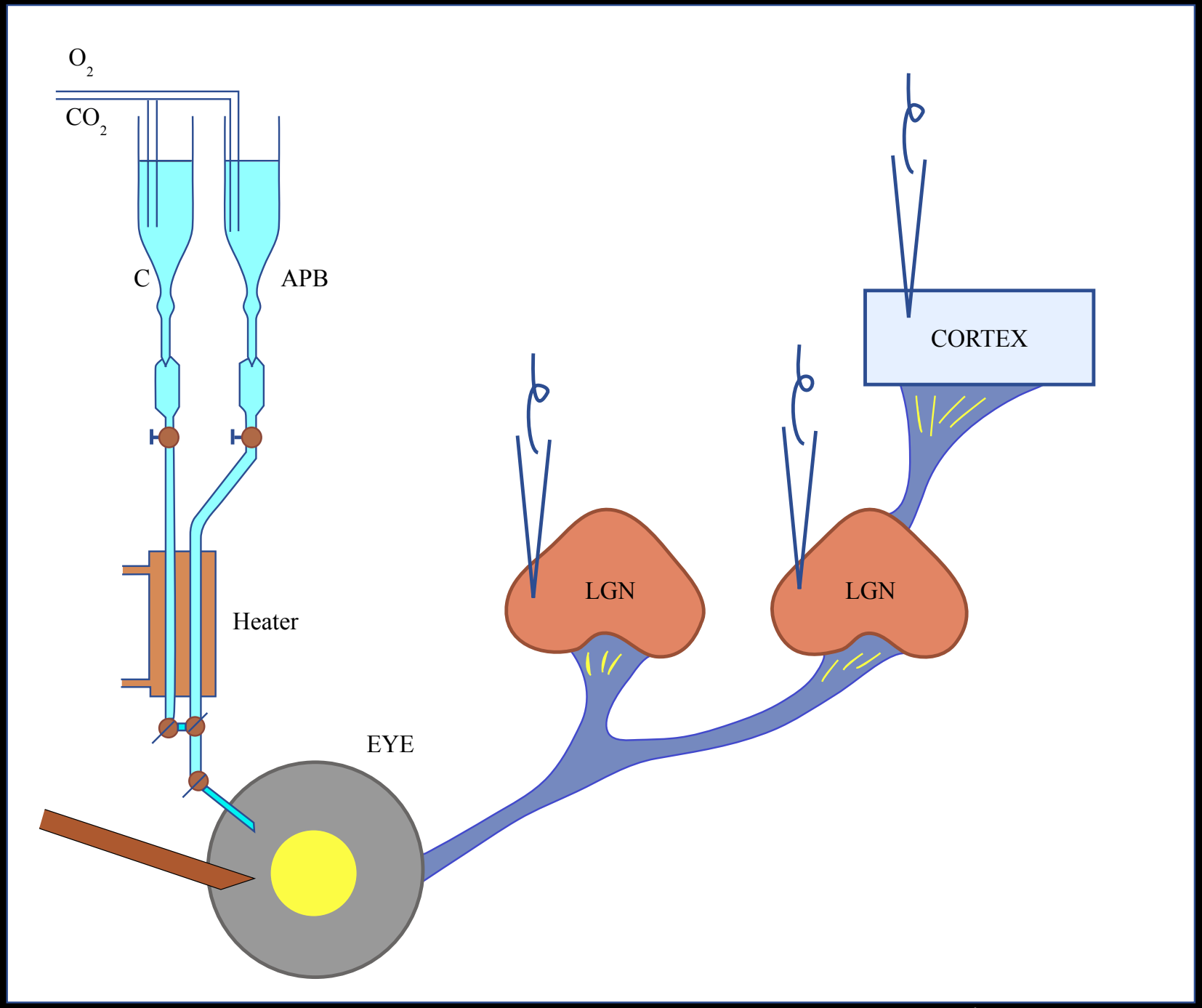


Image by MIT OpenCourseWare.

Responses of an ON and OFF LGN cell before, during and after APB infusion

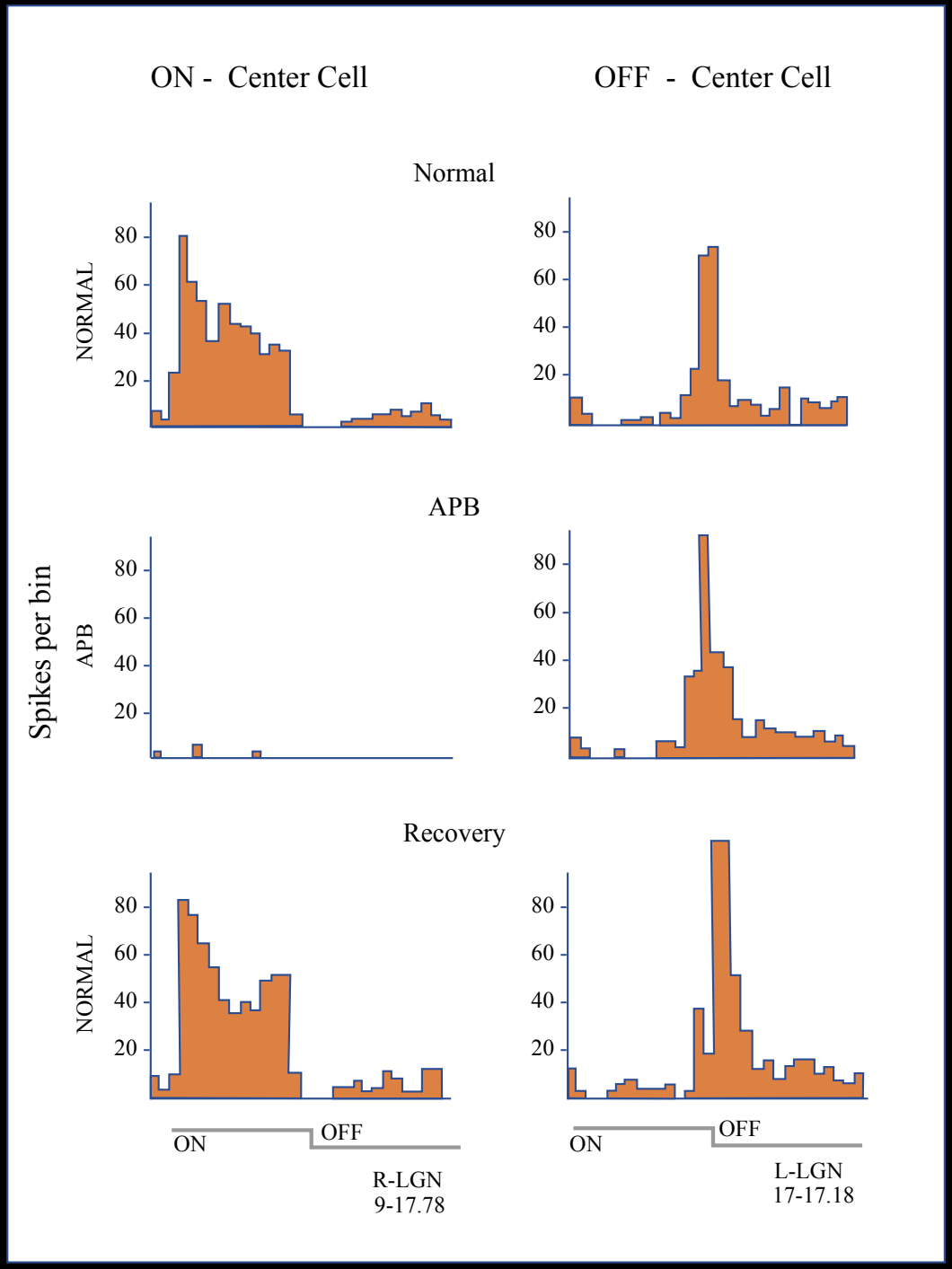
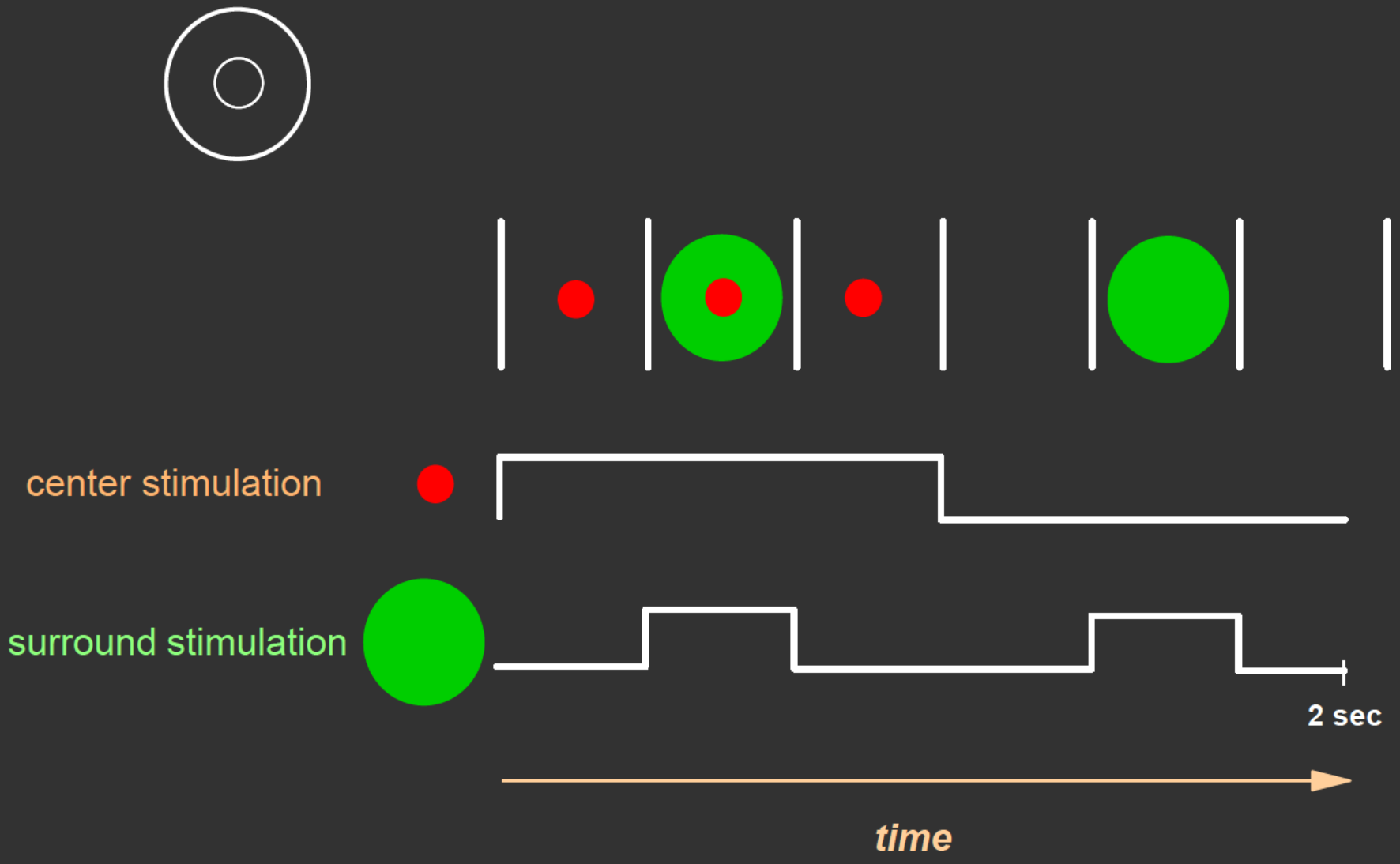
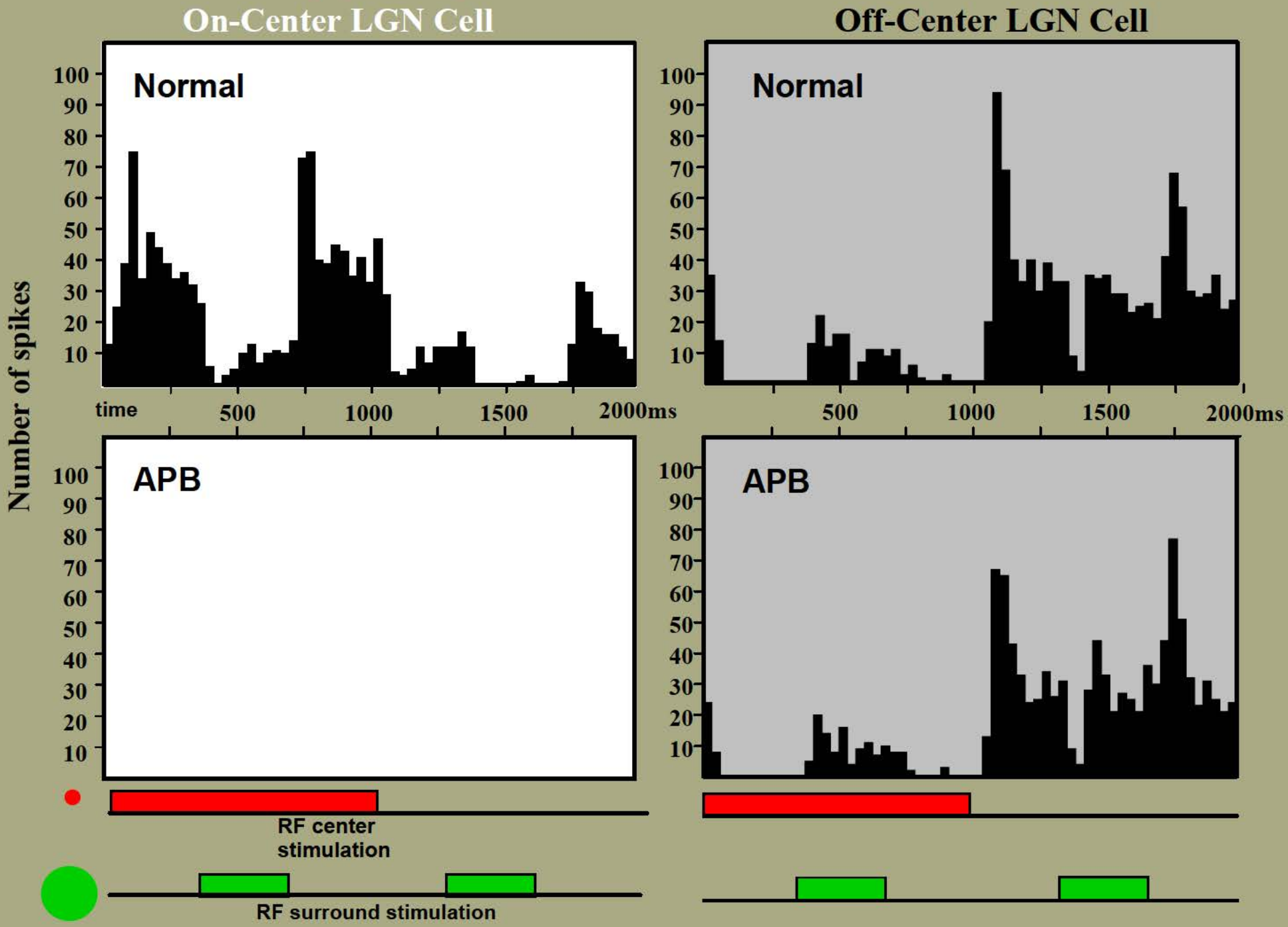


Image by MIT OpenCourseWare.

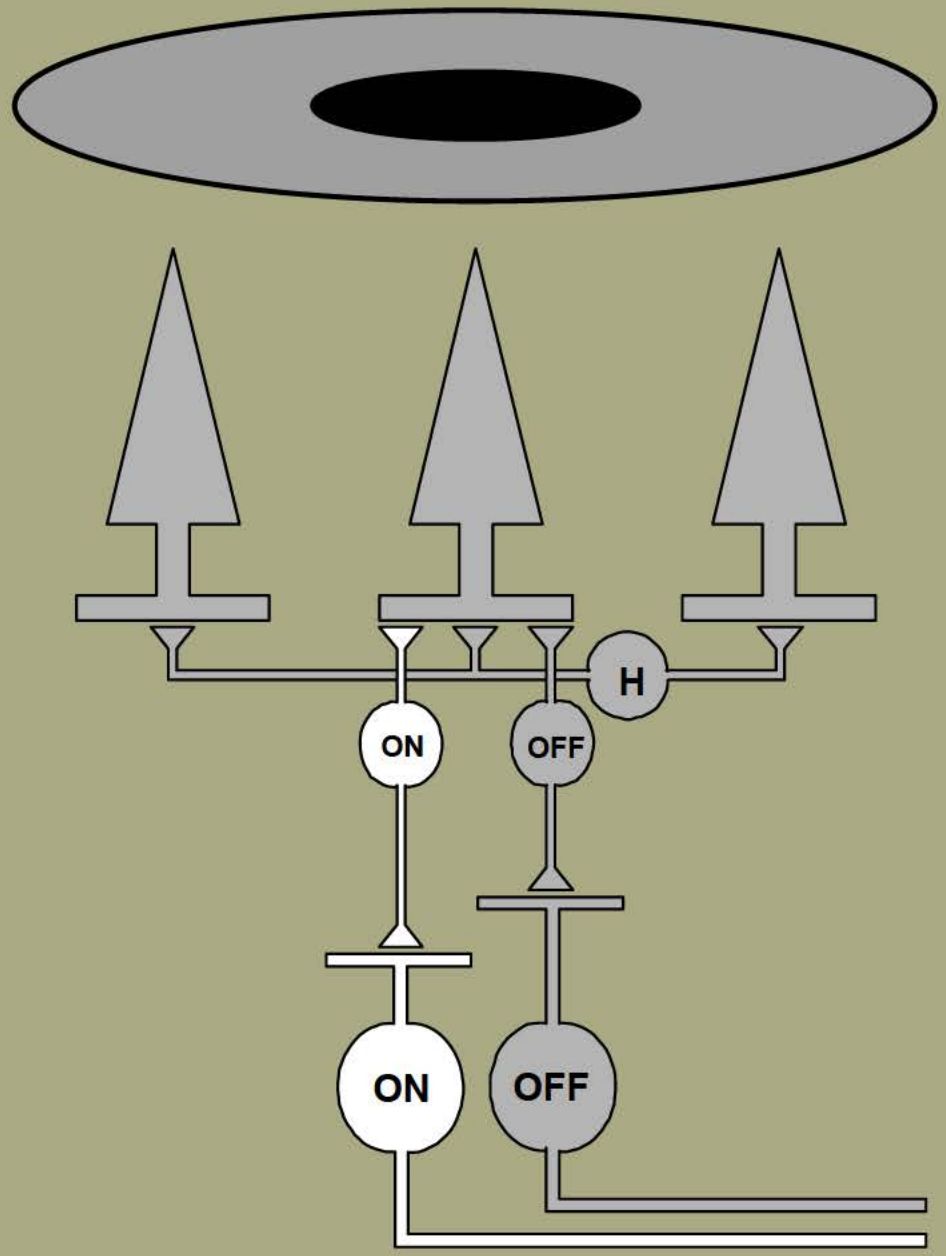
Selective center/surround activation of a red/green LGN cell



The effect of APB on ON and OFF LGN cells



The receptive field surround of retinal ganglion cells is created predominantly by the horizonal cell system.



What happens in V1 when APB is delivered to the retina?

Response of a V1 complex cell to a drifting light bar

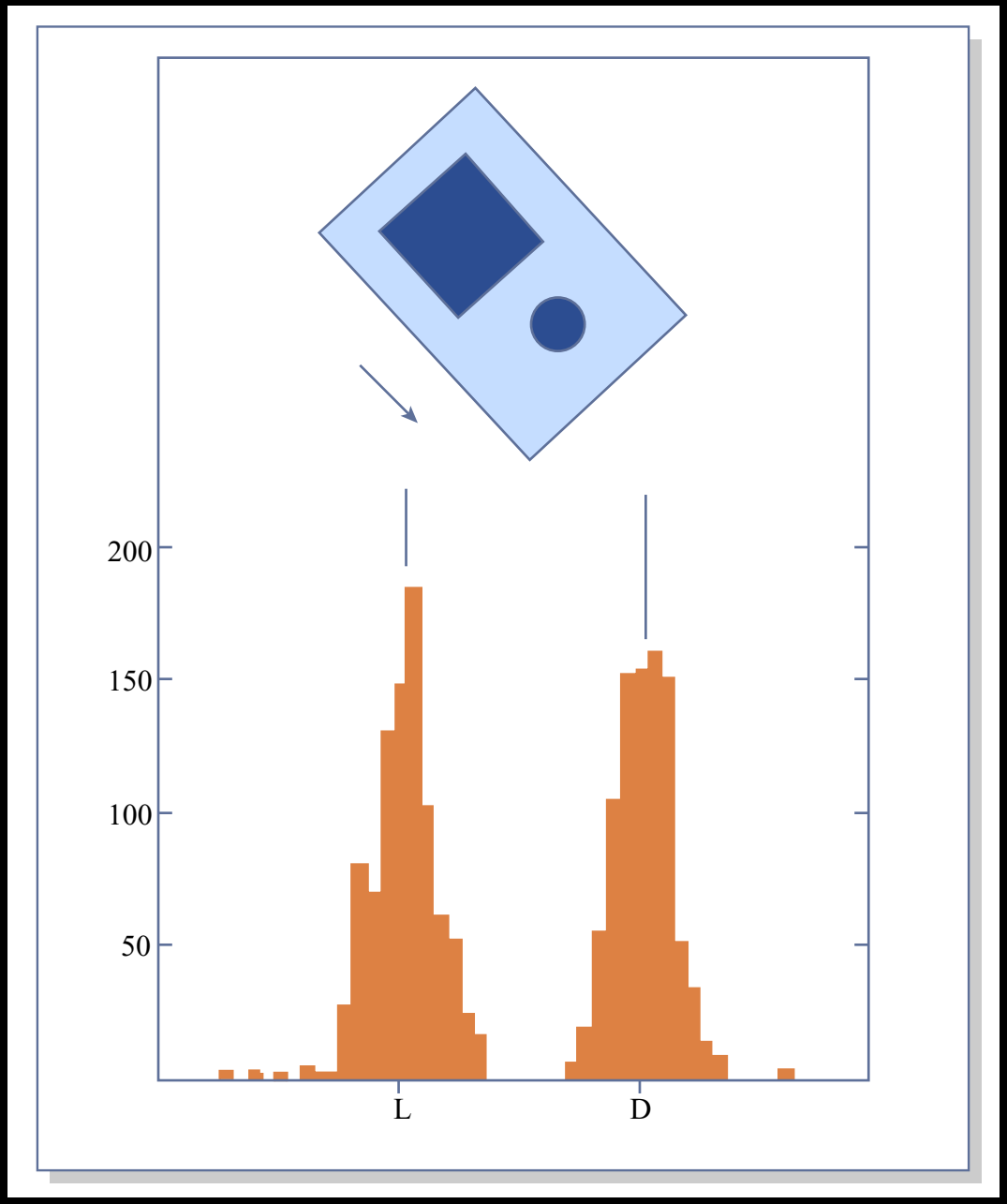
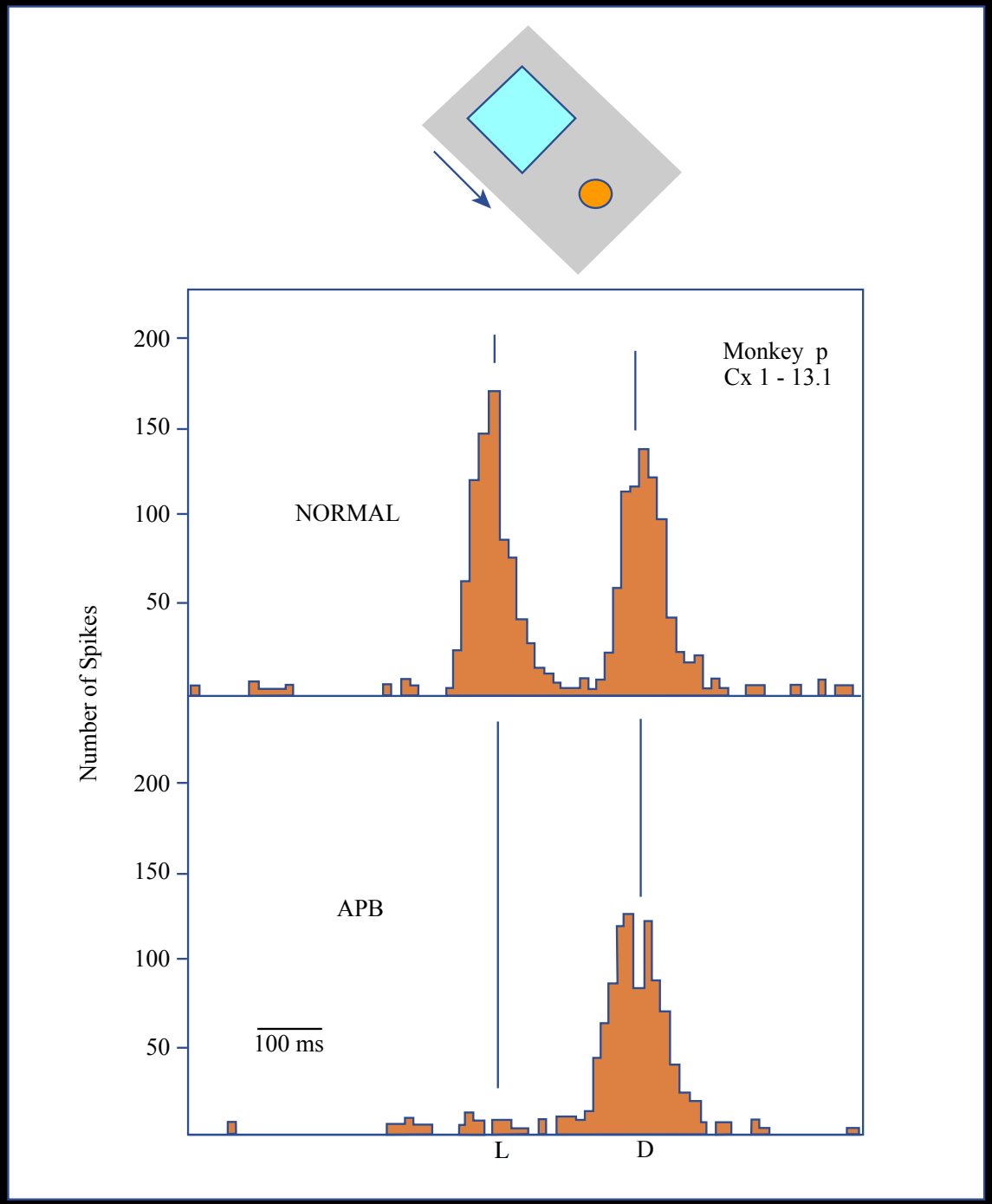


Image by MIT OpenCourseWare.

Response of a V1 complex cell to a drifting light bar before and during APB infusion



Response of a V1 complex cell to a drifting light bar before, during and after APB infusion

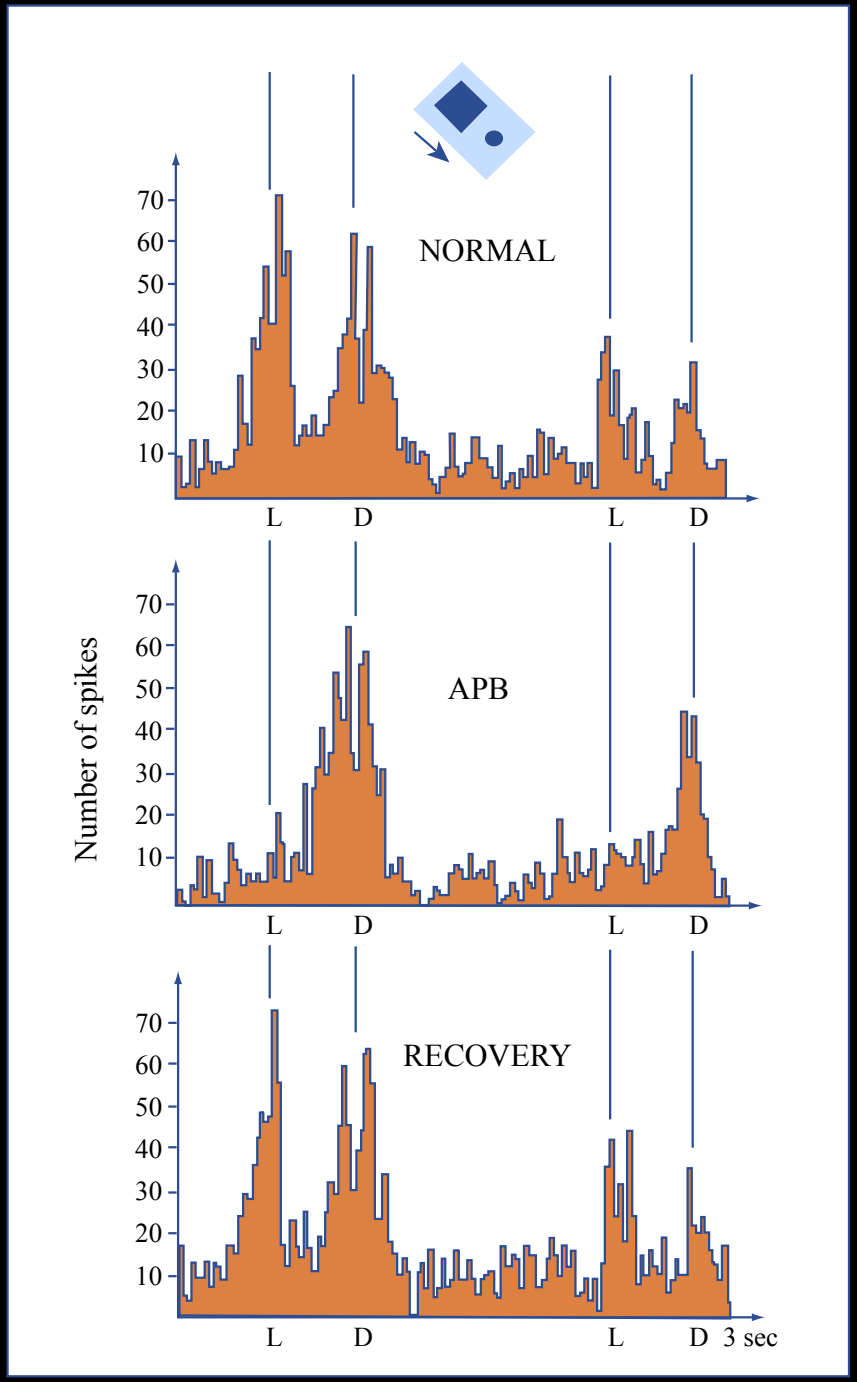
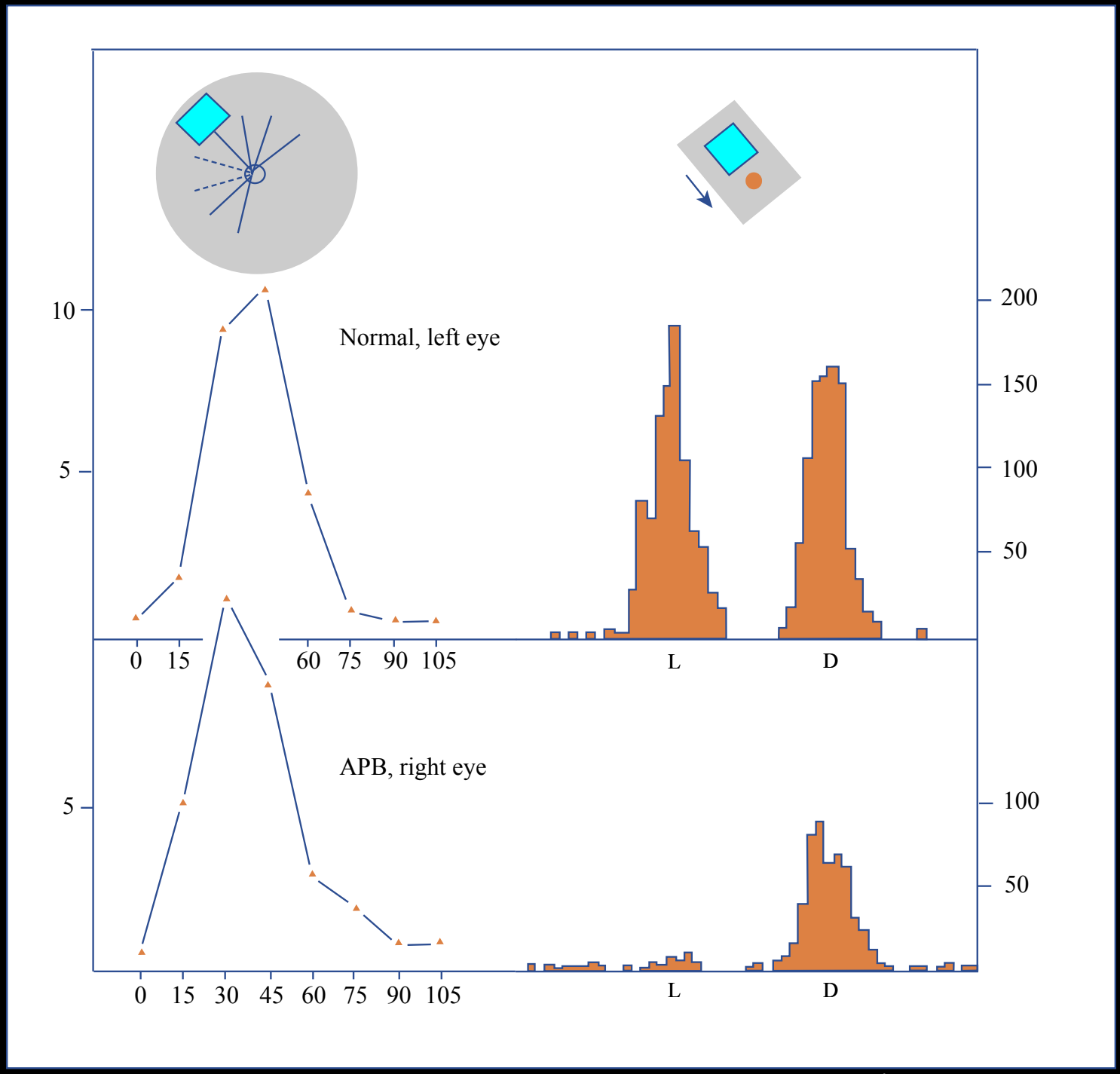
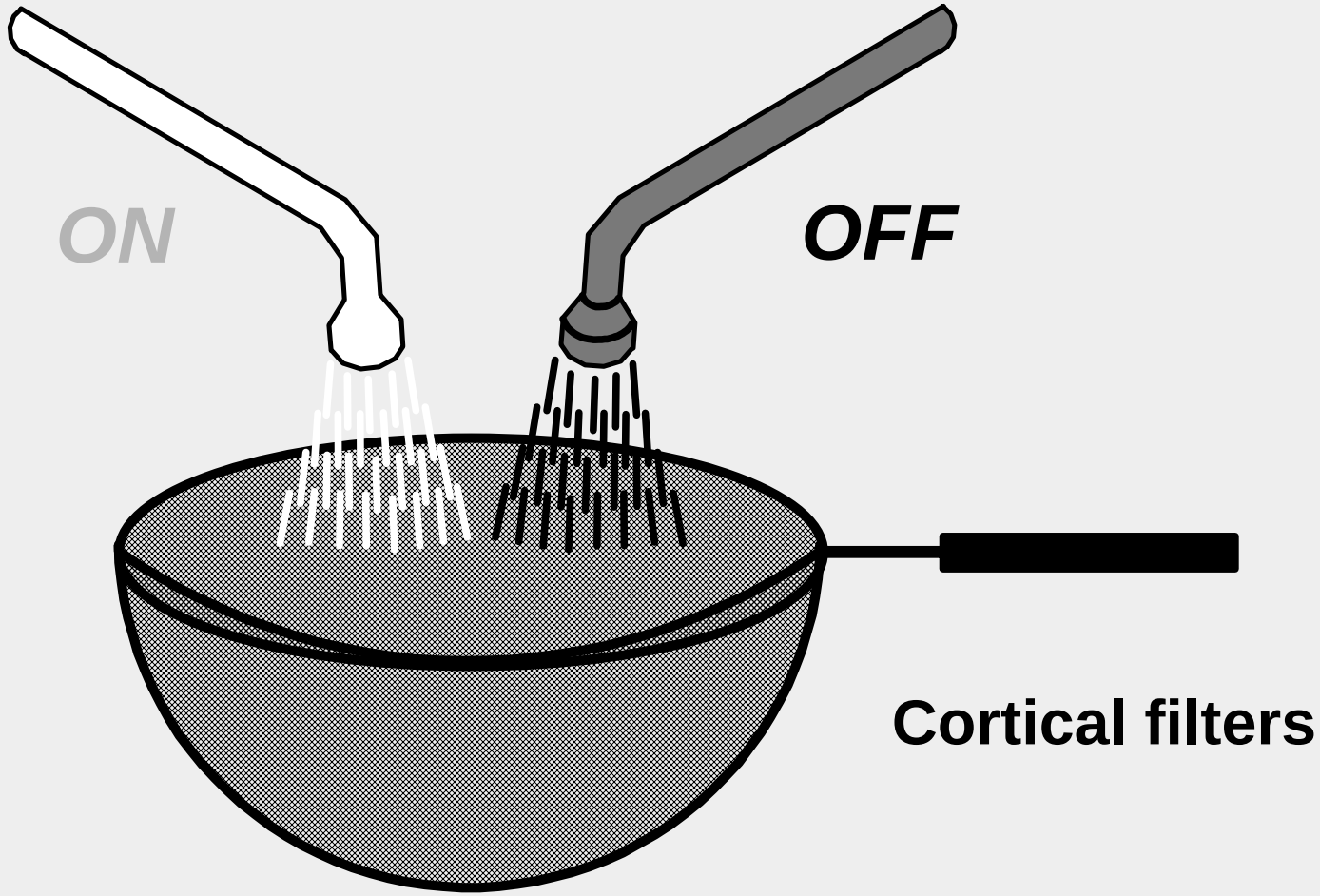


Image by MIT OpenCourseWare.

Response of a V1 complex cell to bars of different orientations before and during APB infusion



Model for cortical input of the ON and OFF channels



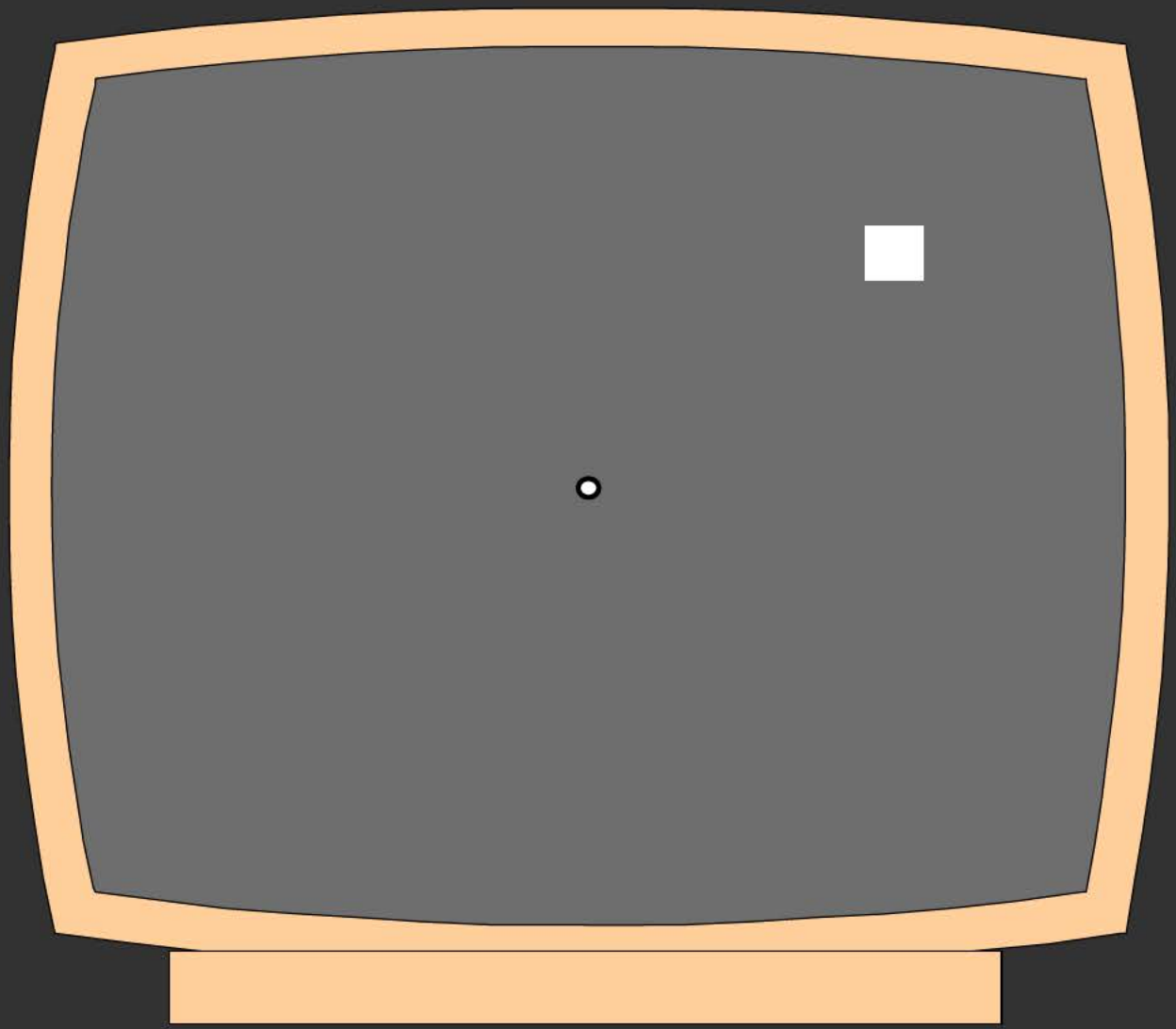
Orientation

Direction

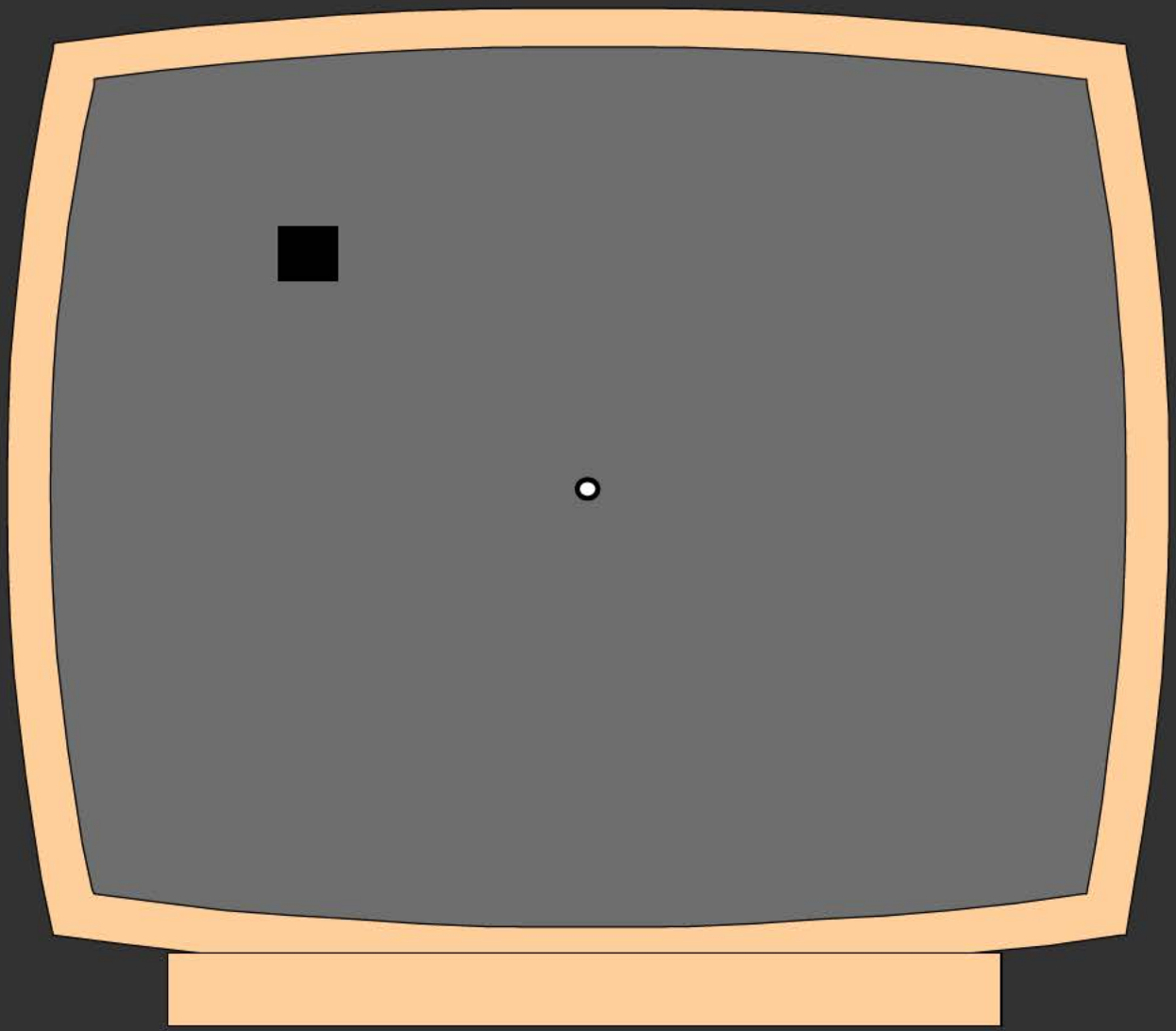
Spatial Frequency

The effects of APB on photopic vision

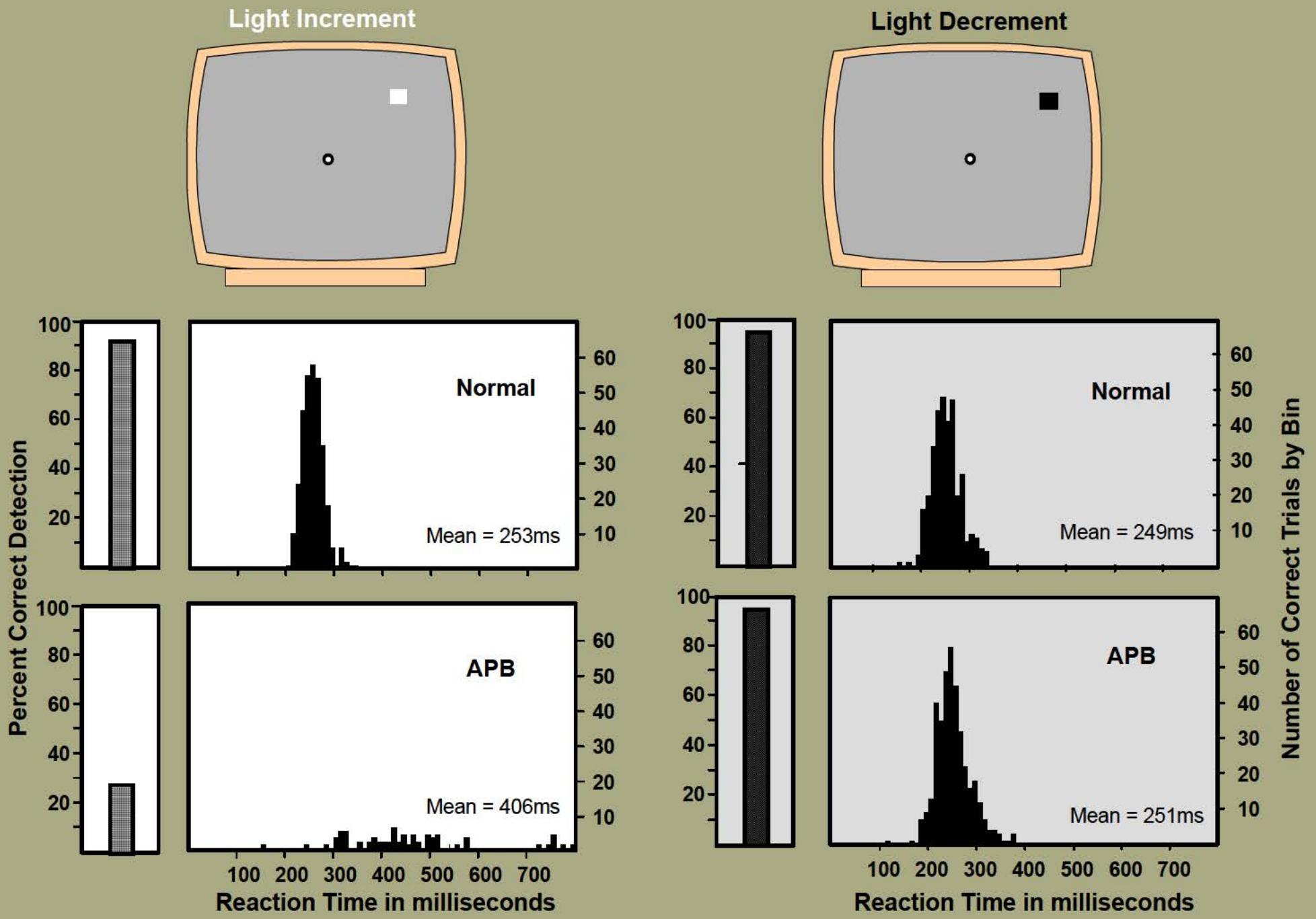
Light increment



Light decrement



The effect of APB on detection



Source: Schiller, Peter H., Julie H. Sandell, and John HR Maunsell. "Functions of the ON and OFF channels of the visual system." Nature 322 (1986): 824-825.

The effects of APB on scotopic vision

The effect of APB during light and dark adaptation

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Please refer to lecture video or 'R0DQ 5REHUW 3 DQG 3HWHU + 6FKLOOHU (YLGHQFH IRU RQ\ GHSR0DUL]LQJ URG ELSR0DU FH00V LQ WKH SUL P DWH UHWLQD *9LVXD0 QHXURVFLHQFH* QR .

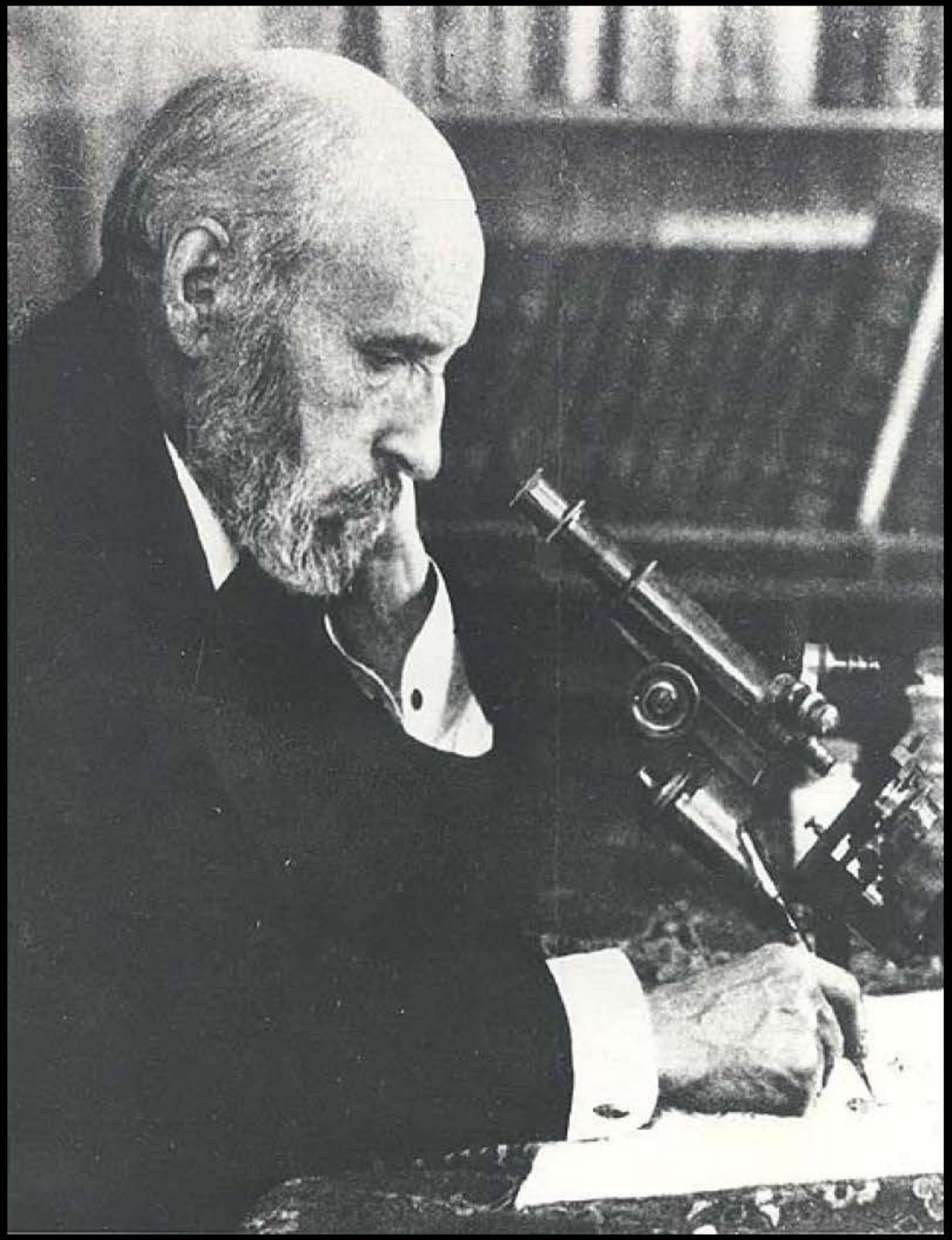
How are receptive fields altered by dark adaptation?

1. Color selective response disappears.
2. Receptive field becomes larger.

How can this be?

Rods and cones connect differently with the ganglion cells.

Santiago Ramon y Cajal



Photograph is in public domain.

Cajal on the connections of the rods and cones:

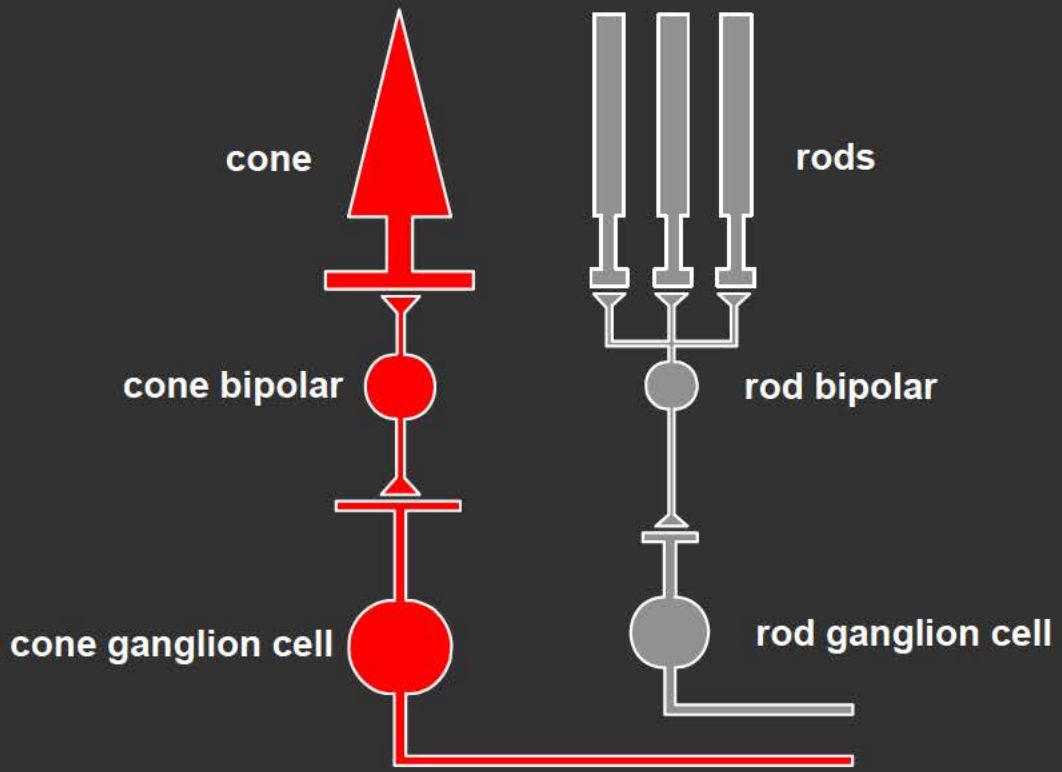
"Since the impression received by the rods is different from that taken up by the cone, it is necessary from every point of view that each of these specific impressions should be conveyed through the retina by a separate channel." (p.393, autobio)

"When we reason with common sense and lift the war club determined upon vigorous action, nature ultimately hears us. Knowing what I was looking for, I began to explore eagerly the retina of fishes and mammals...; finally, as the reward of my faith, there deigned to appear most clearly and brilliantly those two types of bipolar cells demanded by theory and guessed by reason."

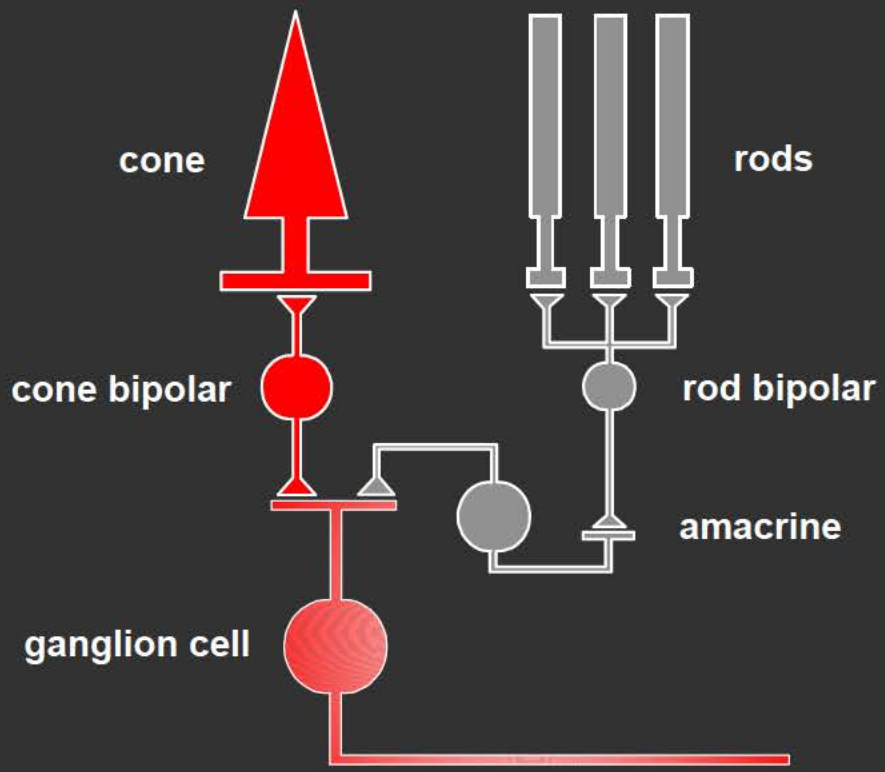
Cajal went on to state that these two kinds of bipolars then hooked up with two types of ganglion cells thereby forming separate channels to the brain.

The rod and cone connections

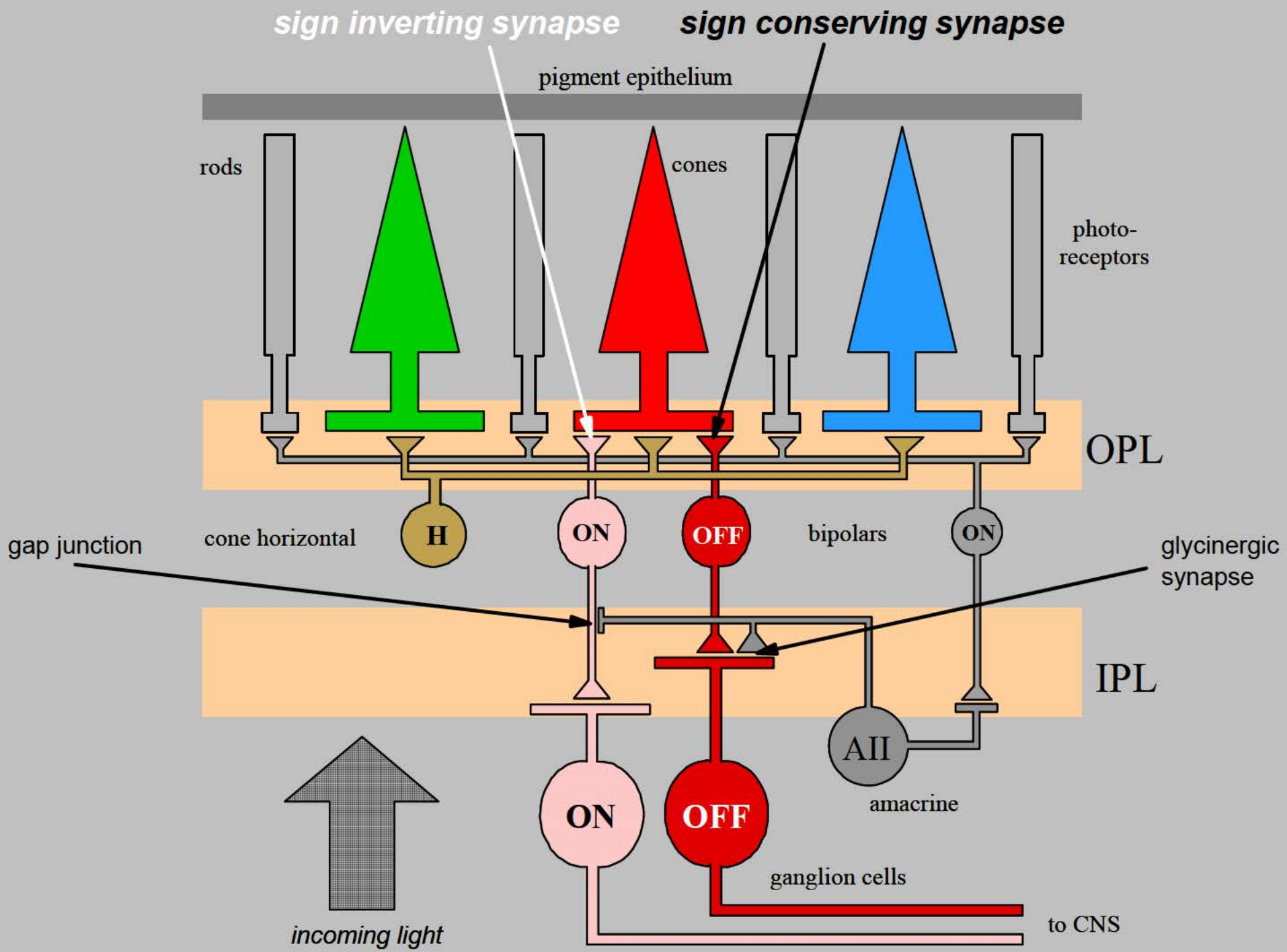
Separate channel model



Convergent channel model

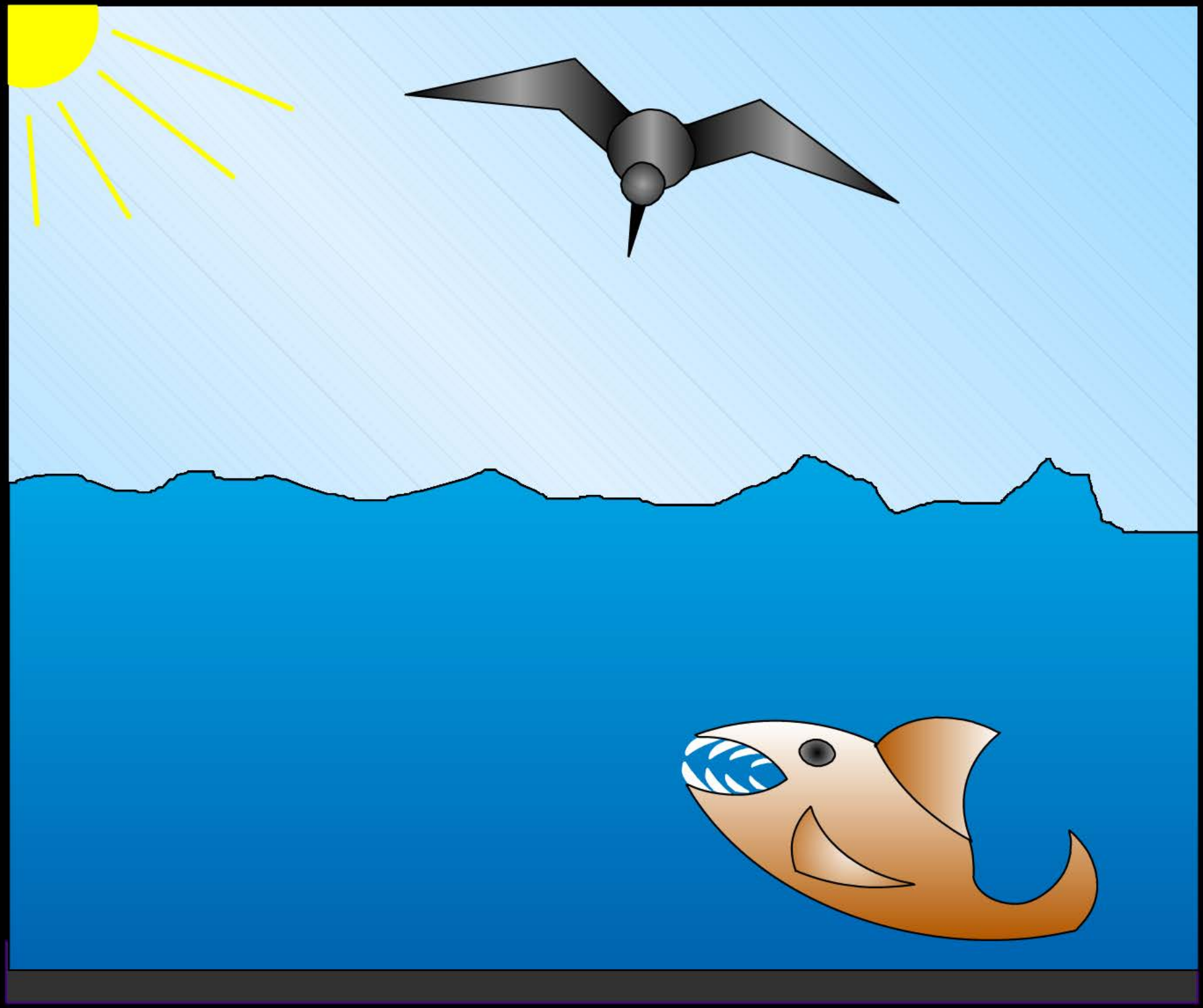


Overview of retinal connections


sign inverting synapse
sign conserving synapse
pigment epithelium
rods
cones
photo-
receptors
OPL
gap junction
cone horizontal
H
ON
OFF
bipolars
ON
glycinergic
synapse
IPL
AII
amacrine
ON
OFF
ganglion cells
to CNS
incoming light

The central conclusion:

The ON and OFF channels have emerged in the course of evolution to enable organisms to process both light incremental and light decremental information rapidly and effectively.



Summary:

1. All photoreceptors hyperpolarize to light.
2. The cone driven ON and OFF channels originate at the level of the retinal bipolar cells; sign inversion in ON bipolars is provided by the mGluR6 receptor.
3. APB is a glutamate analog that blocks the ON bipolar.
4. APB blocks the ON response in retinal ganglion cells; the OFF response and center/surround antagonism are unaffected.
5. APB blocks light edge response in cortex but has no effect on orientation, direction and spatial frequency selectivity.
6. APB reduces sensitivity for light increment.
7. The ON and OFF channels for rods arise in the inner retina.
8. In most primates there are only ON rod bipolars. The rod ON and OFF channels are created in the inner retina by amacrine cells.
9. Excitatory signals are generated for both light increment and light decrement by virtue of the ON and OFF channels.

9.04 Sensory Systems

Fall 2013