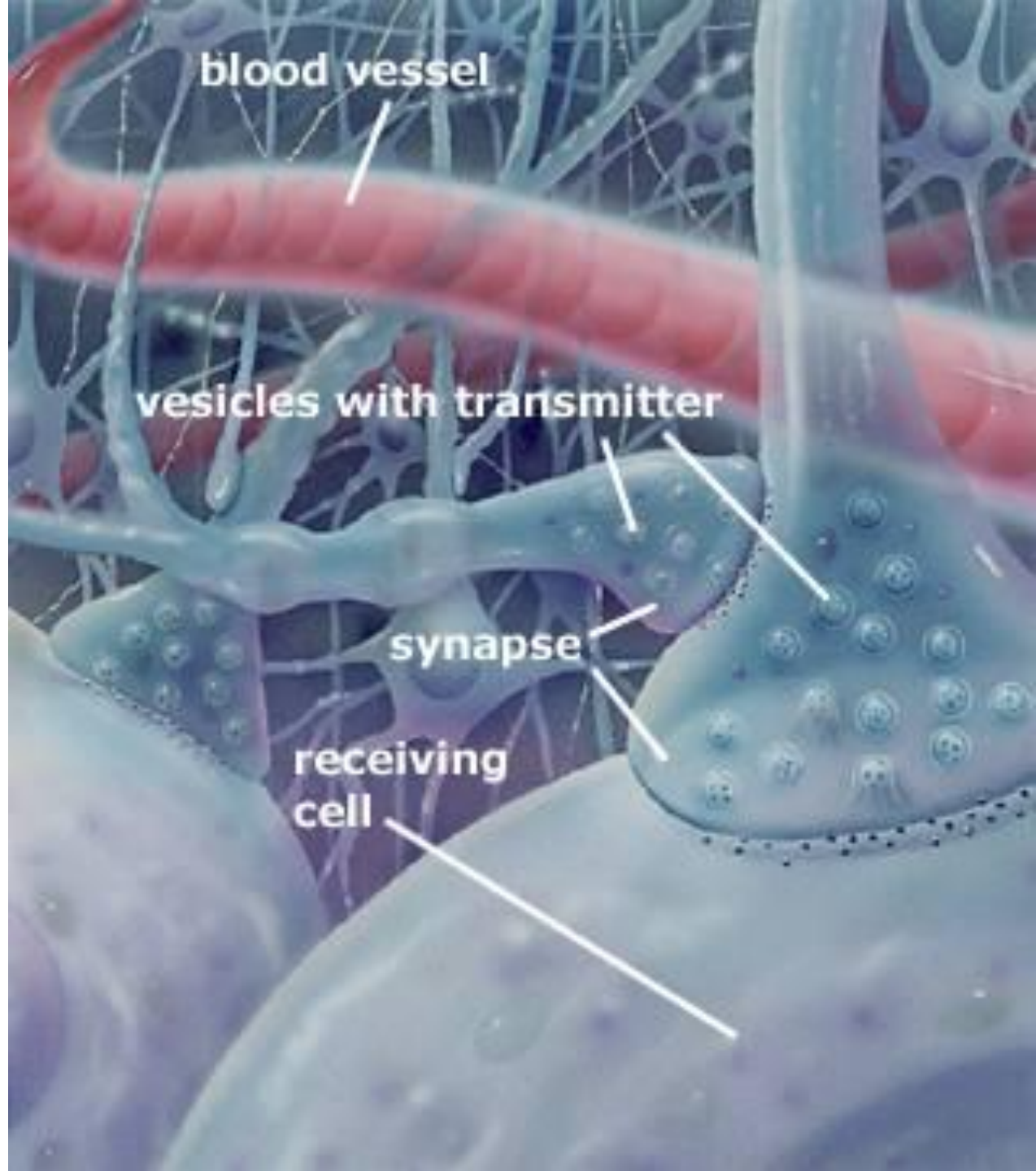


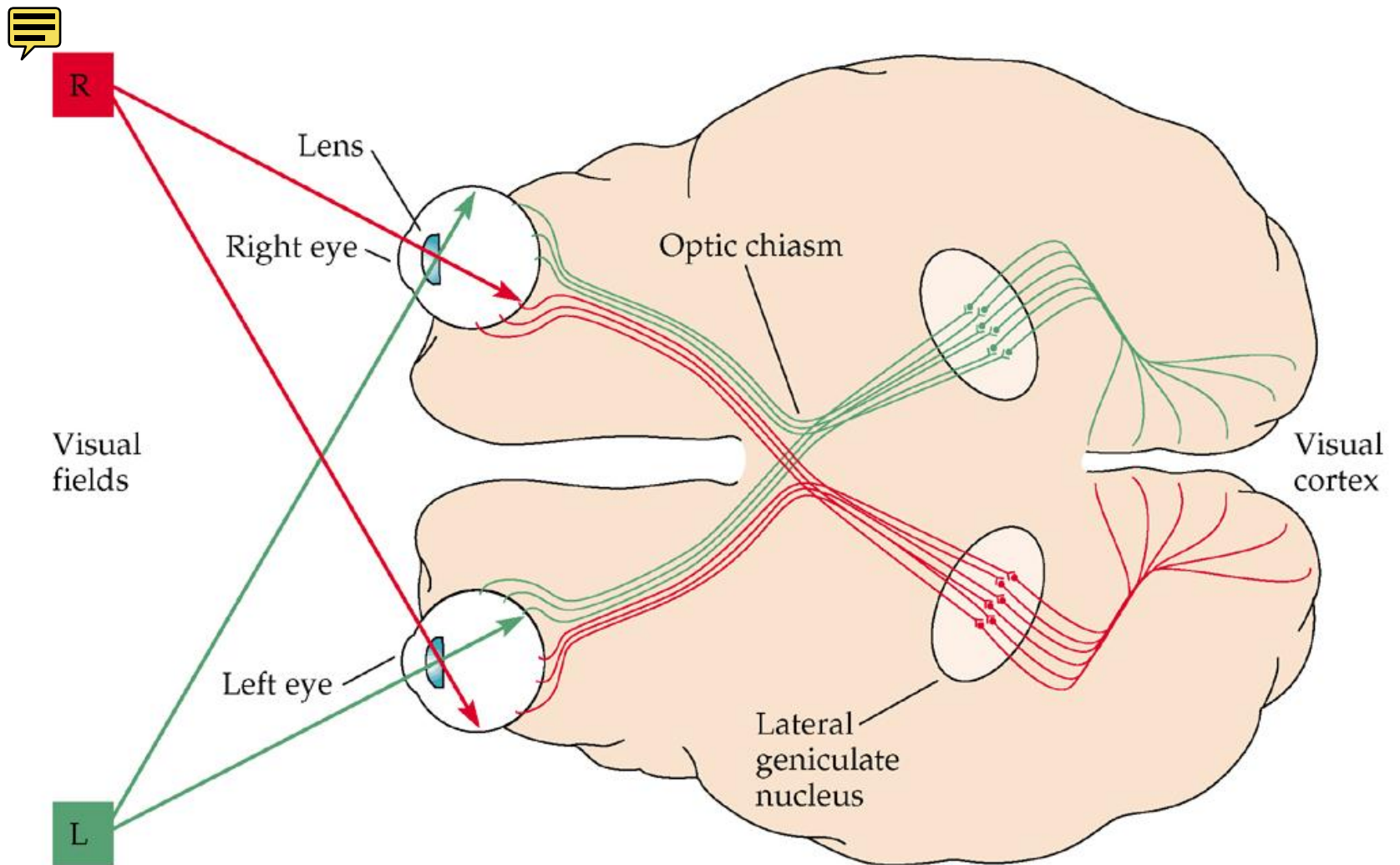
CSB 332

Neurobiology of the Synapse

Melanie A. Woodin
January 2012

Lecture 21
Sensory Systems
Chpts 2, 20







Anatomical Pathways in the Visual System

- Optic nerve fibers arise from ganglion cells in the retina and end in the LGN (lateral geniculate nucleus – part of the thalamus)
- LGN axons project to the cerebral cortex
- Output from each retina divides at the optic chiasm to supply the LGN on each side
- The R side of each retina projects to the right LGN, thus the R visual cortex receives information exclusively from the left half of the visual field
- E.g. people with damaged R cortex are blind in the left visual field





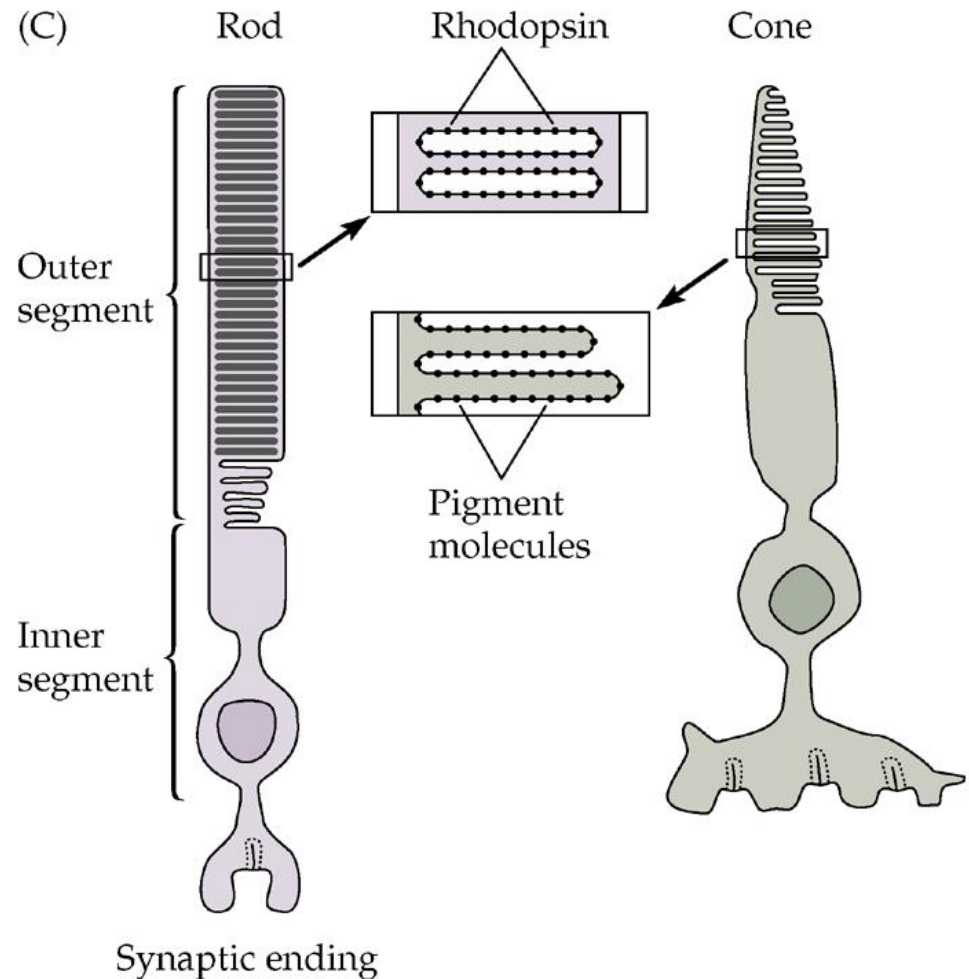
Convergence and Divergence of Connections

- Neurons converge and diverge extensively at every stage e.g. human eye contains 100 million rods and cones but only 1 million ganglion cell axons
- Thus there must be extensive funneling of information in the eye
- Each ganglion cell axon supplies many geniculate cells

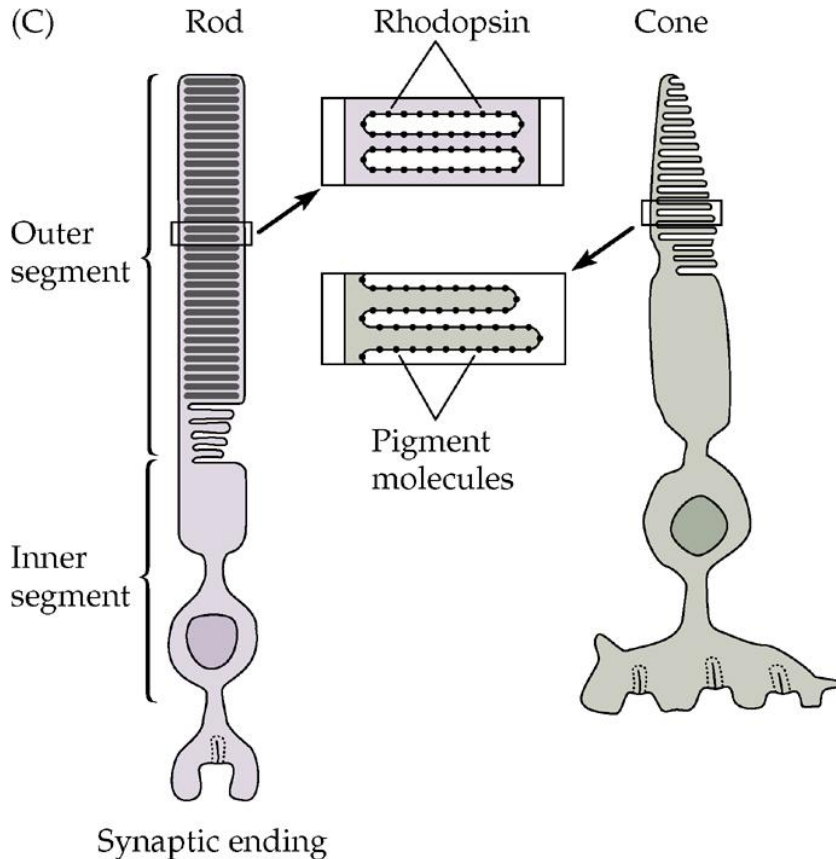
3 Principal Feature of Photoreceptor Structure:



1. An outer segment where light is absorbed by the visual pigment
2. Inner segment containing nucleus, ion pumps, transporters, ribosomes, mitochondria and ER
3. Synaptic terminal which releases glutamate; it is a highly specialized terminal characterized by “ribbon” structures that contain the transmitter vesicles



Rods & Cones



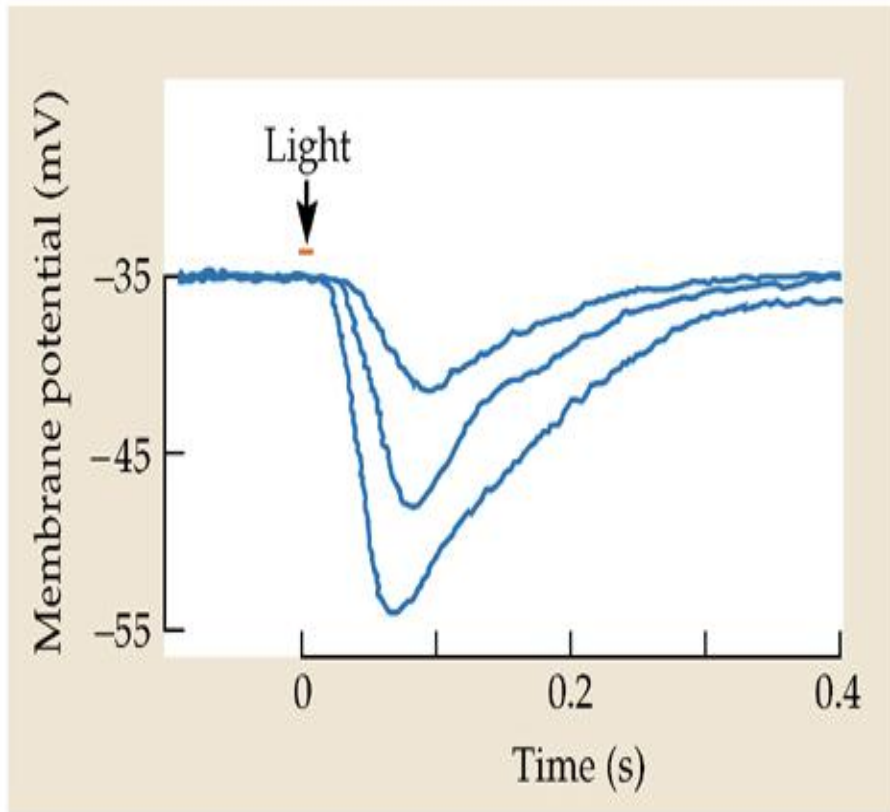
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- Rods contains rhodopsin embedded in membranes arranged as disks (separate from the outer membrane)
- Cones contain pigment molecules on infolded membranes continuous with the surface
- Outer segment is connected to the inner segment by a narrow stalk
- Synaptic endings continuously release glutamate in the dark



Responses of Photoreceptors

(B) Vertebrate photoreceptor

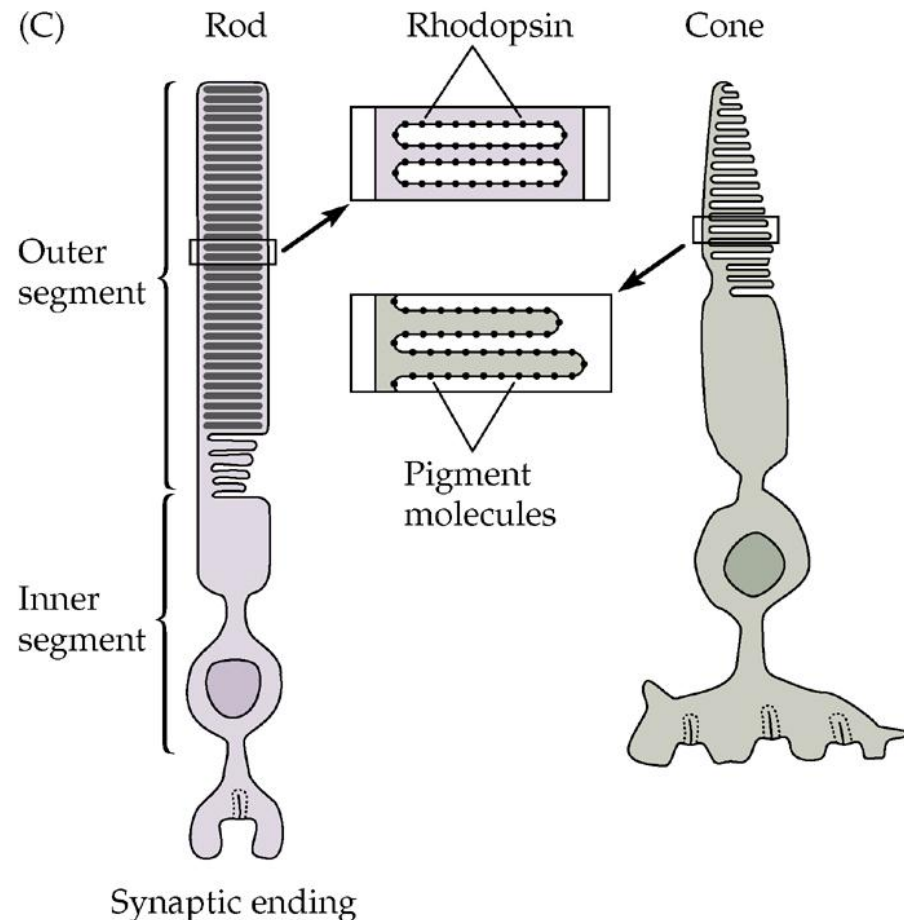


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- In the dark (rest) inward current into the outer segment results in depolarization
- Light turns off the ongoing inward current
- Vertebrate photoreceptors respond with a hyperpolarization that is graded according to the intensity of the flash

Visual Pigments

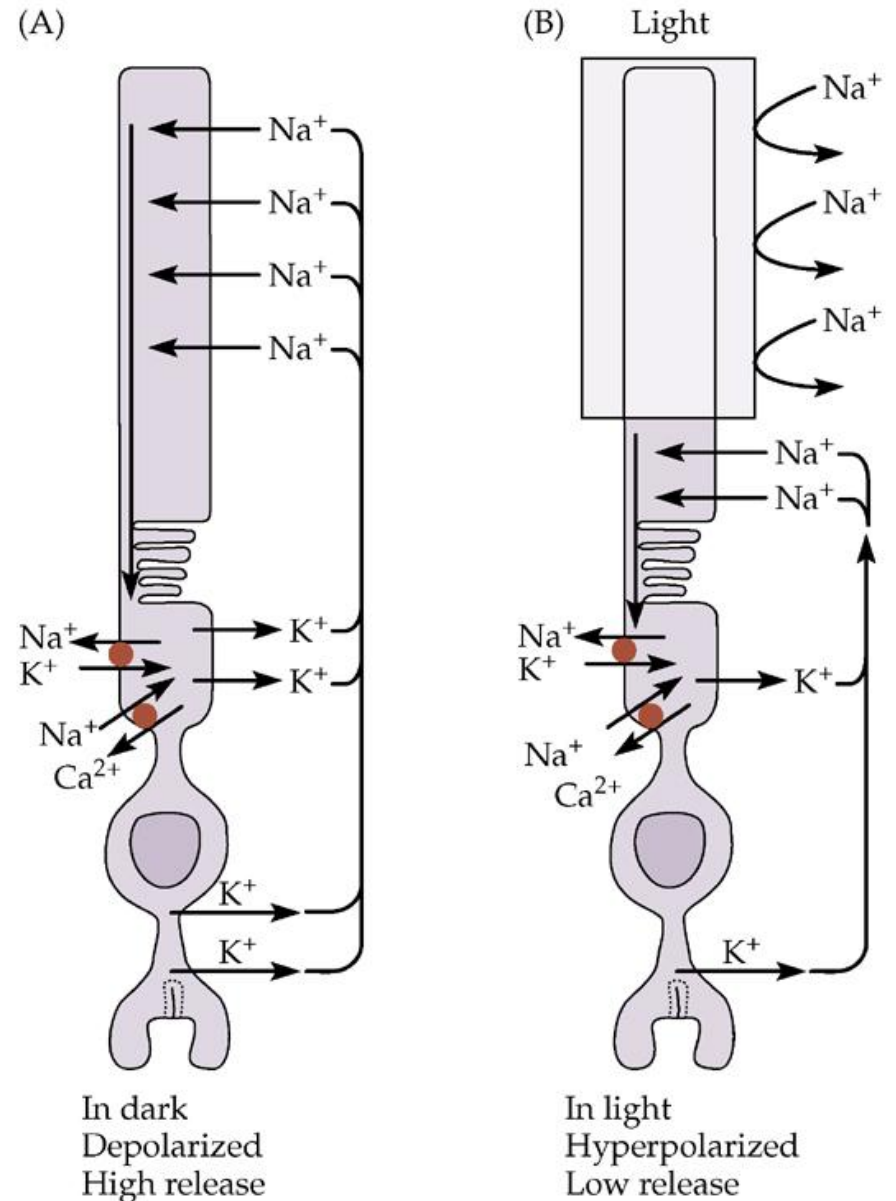
- Visual pigments are concentrated in membranes of the outer segments
- The dense packing of these sensitive molecules in layers traversed by light enhances the probability that a photon will be trapped on its way through the outer segment



Transduction



- In darkness a current (mostly Na^+) flows into the outer segment of both rods and cones; $V_m \sim 40 \text{ mV}$
- Light closes these cation channels allowing V_m to move towards E_K ($\sim -80 \text{ mV}$); thus hyperpolarizing the photoreceptor



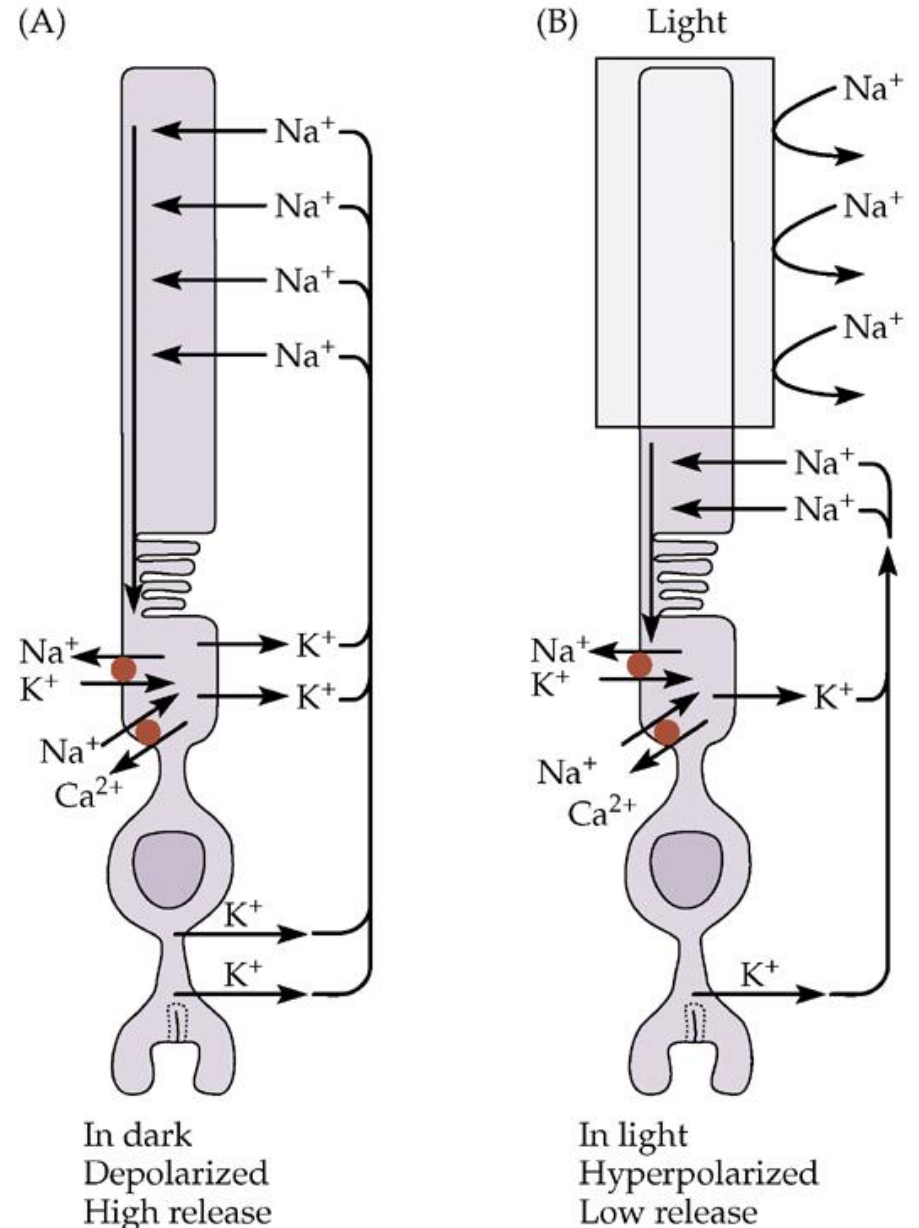


Transduction by Photoreceptors

- A high cytoplasmic [cGMP] keeps the cation channels in an open state
- The [cGMP] is inversely related to the intensity of ambient light
- Increasing light decreases [cGMP] and decreases the fraction of open channels

Transduction

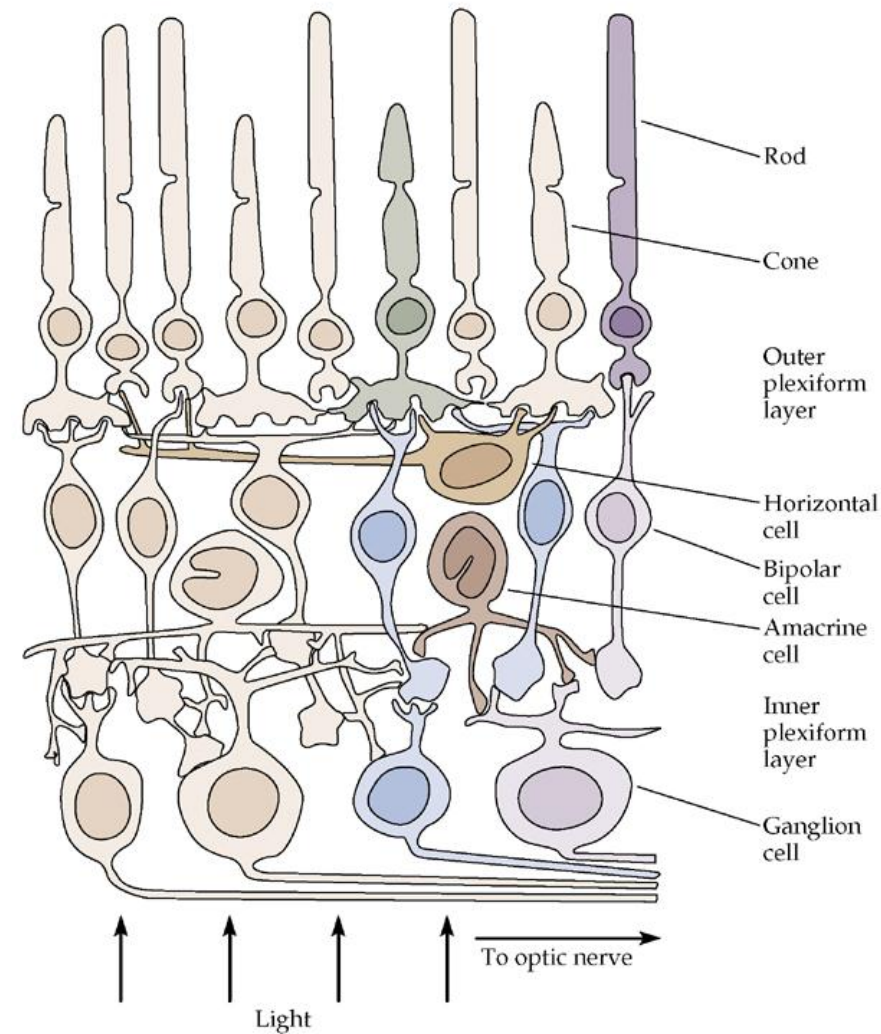
- (A) in dark, Na^+ in via cation channels on outer segment – depolarization; current loop is completed in neck of rod with outward movement of K^+ through inner segment membrane
- (B) in light, cGMP decreased closing channels, rod is now hyperpolarized; hyperpolarization decreases transmitter release
- Na^+ , K^+ and Ca^{2+} []'s are maintained by pumps and exchangers in the inner segment





Retinal Processing

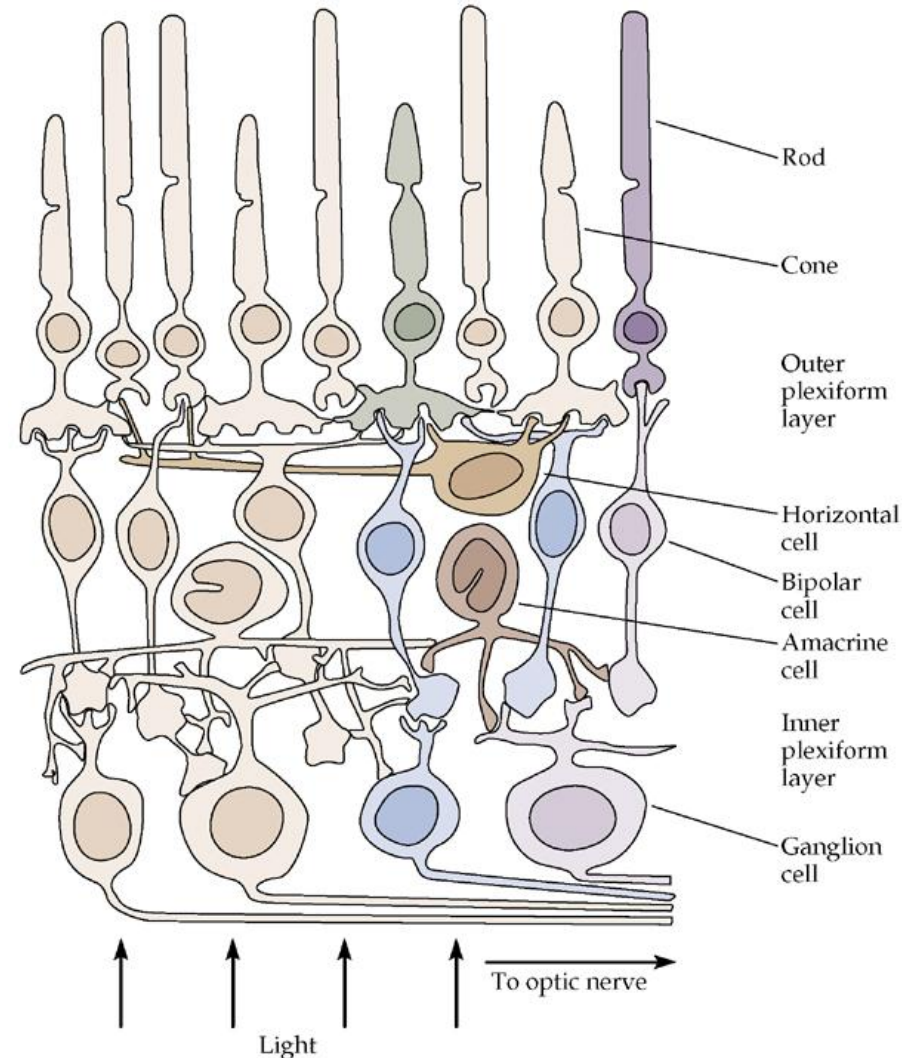
Photoreceptors communicate via bipolar cells with ganglion cells; these interactions are mediated by amacrine and horizontal cells (e.g. the horizontal and amacrine cells transmit and modify signals traveling through the retina); Thus the output of the eye is the result of highly complex integrative processes



Retinal Processing



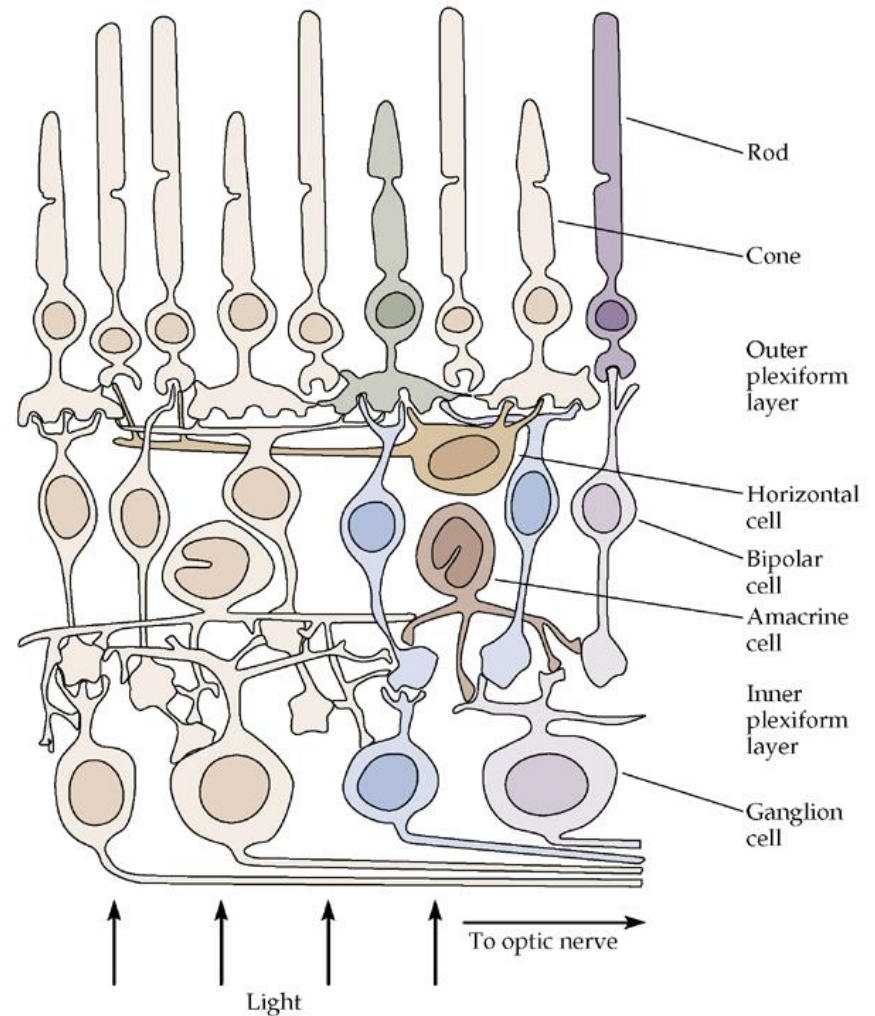
- Nearly all known transmitters have been found in the retina
- Photoreceptors and bipolar cells release glutamate
- Horizontal cells release GABA
- Amacrine cells often release either dopamine or ACh

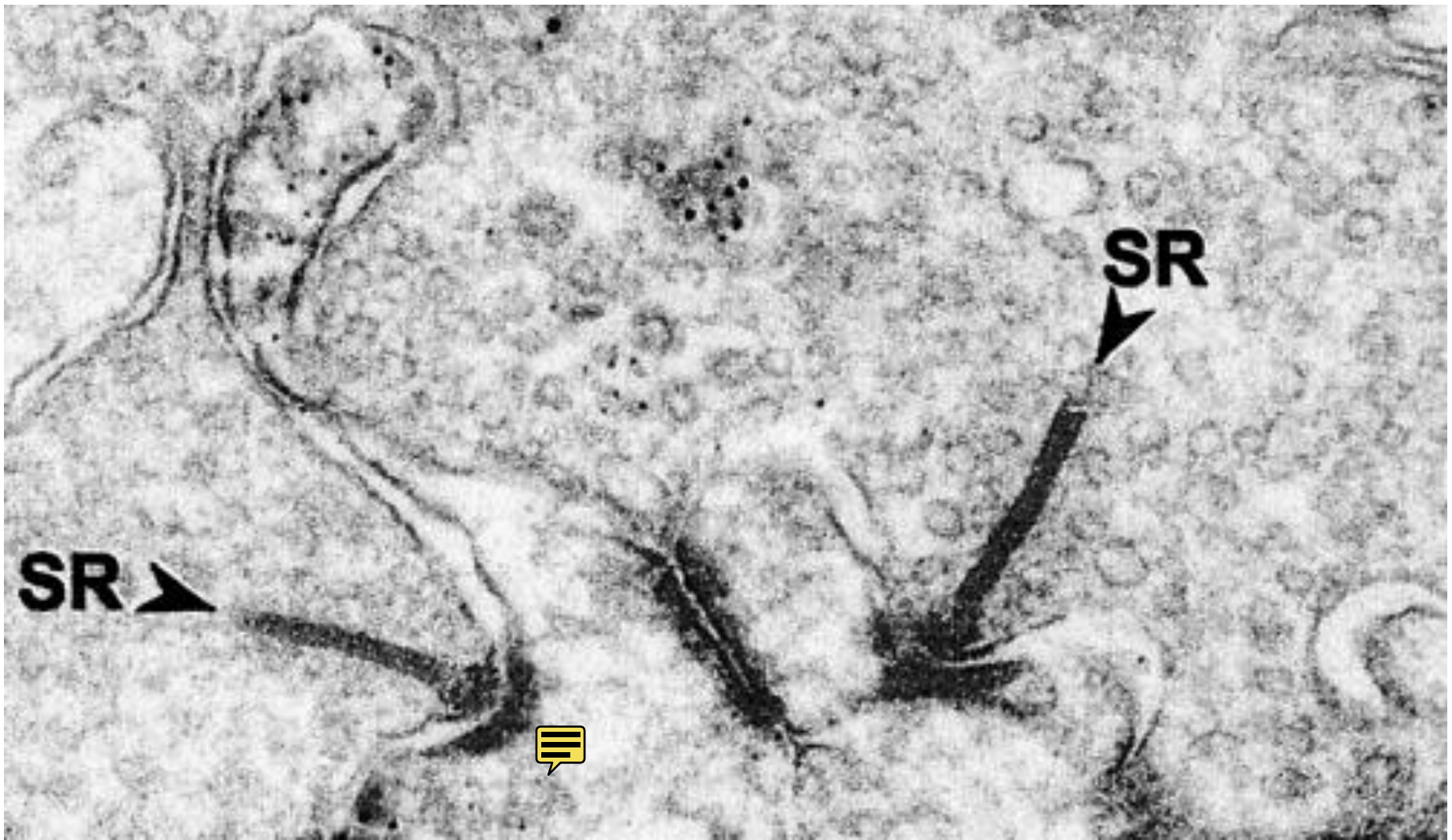


Ribbon Synapses



- Ribbon synapses: specialized endings that allow the continuous release of transmitter
- These synaptic terminals, found in rods and cones, contain vesicles that are docked and ready for release, along a long flat organelle called the ribbon





Synaptic Ribbons (SR) from a photoreceptor of rat retina.

Immunology and Cell Biology 78 (4), 442-446



Receptive Fields

- Receptive field of a neuron in the visual system is the restricted area of the retinal surface that enhances or inhibits signaling in that cell when it is illuminated – or more simply, *the area of the retina from which the activity of a neuron can be influenced by light*
- The concept of receptive fields applies to many neuronal types in the visual system (including the cortex)
- The receptive field of a retinal ganglion cell is a small circular area on the retina
- e.g. a recording from a neuron in the optic nerve shows that the rate of firing increases or decreases only if the illumination is changed over a defined area of the retina; illumination outside a receptive field produces no effect on firing
- The receptive field is further subdivided into regions which either increase or decrease firing



Bipolar Cells

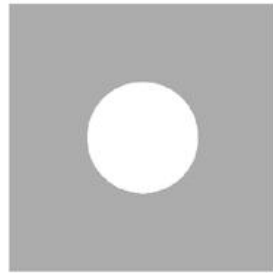
- Each bipolar cell receives its direct input either from rods or cones
- Rod bipolar cells are supplied by 15-45 photoreceptors
- In contrast, midget bipolar cells of the fovea (where acuity is highest) receives its input from a single cone
- Bipolar cells and horizontal cells respond to illumination with graded depolarizations or hyperpolarizations
- The continuous release of glutamate from photoreceptors in the dark keeps some bipolar cells depolarized and others hyperpolarized, depending on whether the cells have excitatory or inhibitory glutamate receptors

H and D Bipolar cells

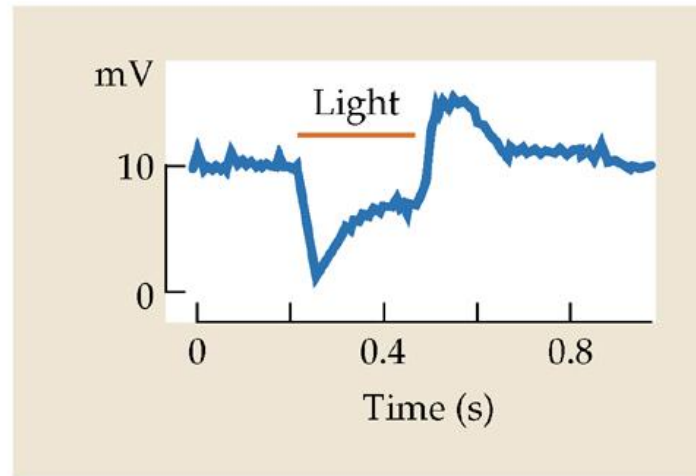


- Decreased tonic release of illuminated photoreceptors will decrease the excitatory response of bipolar cells that have excitatory receptors (thus they will hyperpolarize) – ***H bipolar cells***
- In contrast, decreased tonic release will give rise to depolarization of bipolar cells with inhibitory receptors – ***D bipolar cells***

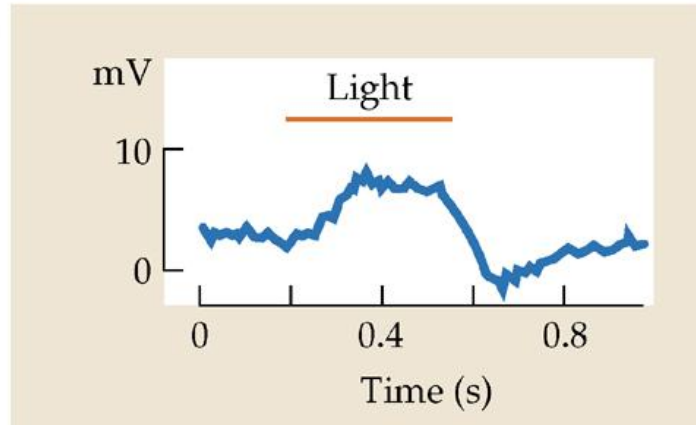
(A) Central illumination



1 mm



(B) Annular illumination

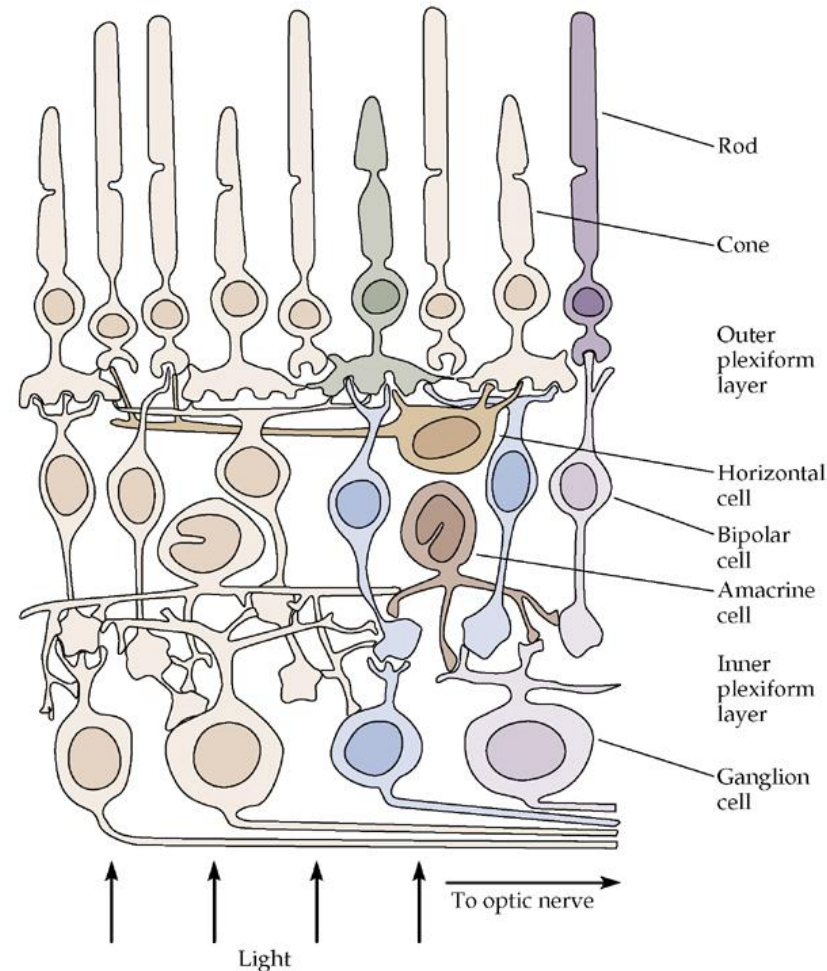


A small spot of light on the central part of the field causes an H bipolar cell to hyperpolarize; illumination around the centre (centre remains dark) causes depolarization
Thus the H bipolar cell has an “off” centre receptive field (it is depolarized when light goes off)



Horizontal Cells

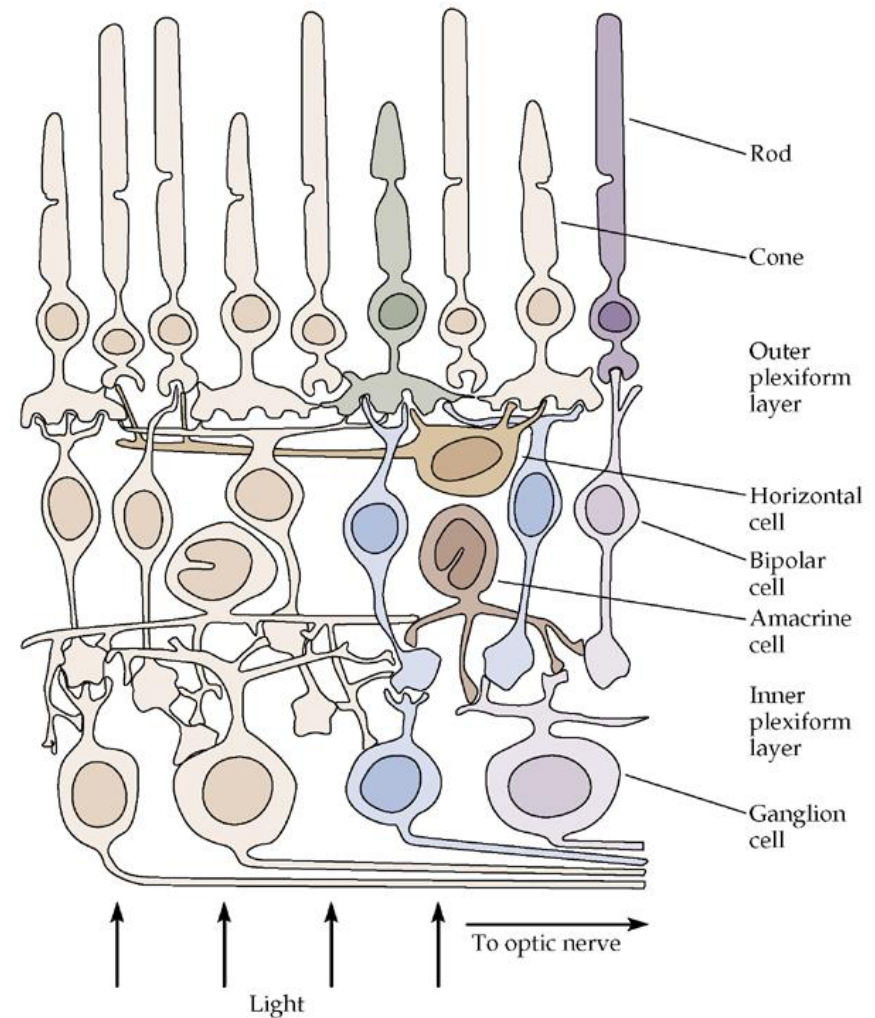
- The responses of bipolar cells to illumination are mediated by horizontal cells
- Each horizontal cell receives inputs from many photoreceptors
- Horizontal cells respond to illumination of photoreceptors by hyperpolarization (like H bipolar cells)
- Horizontal cells are electrically coupled to each other
- Thus, any one horizontal cell is influenced by light shone on a large area of retina because of current flow from its neighbours



Horizontal Cells



- In the dark, horizontal cells release GABA back onto the photoreceptors and onto bipolar cells
- Thus, in the dark, horizontal cells provide negative feedback onto photoreceptors
- Thus depolarization of photoreceptors in the dark is antagonized by inhibitory input from horizontal cells



Illumination



Photoreceptor hyperpolarization



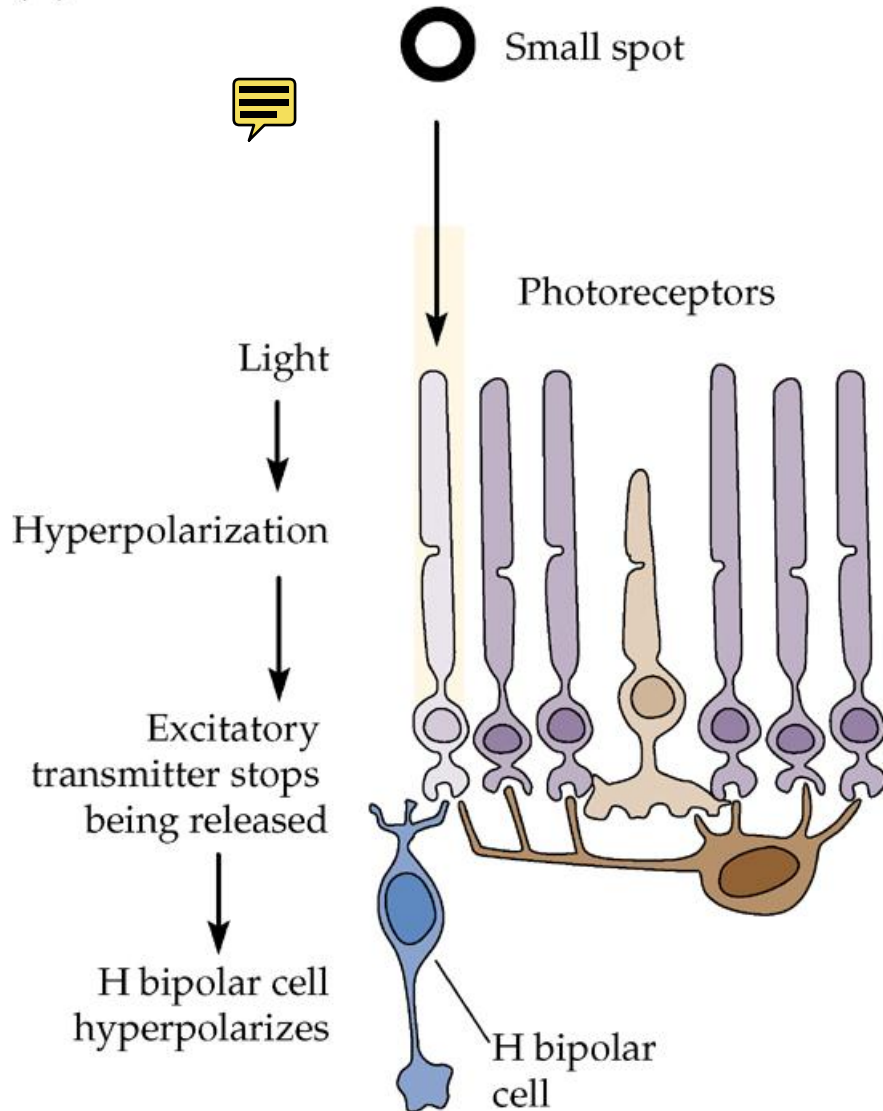
Horizontal cell hyperpolarization



Photoreceptor depolarization

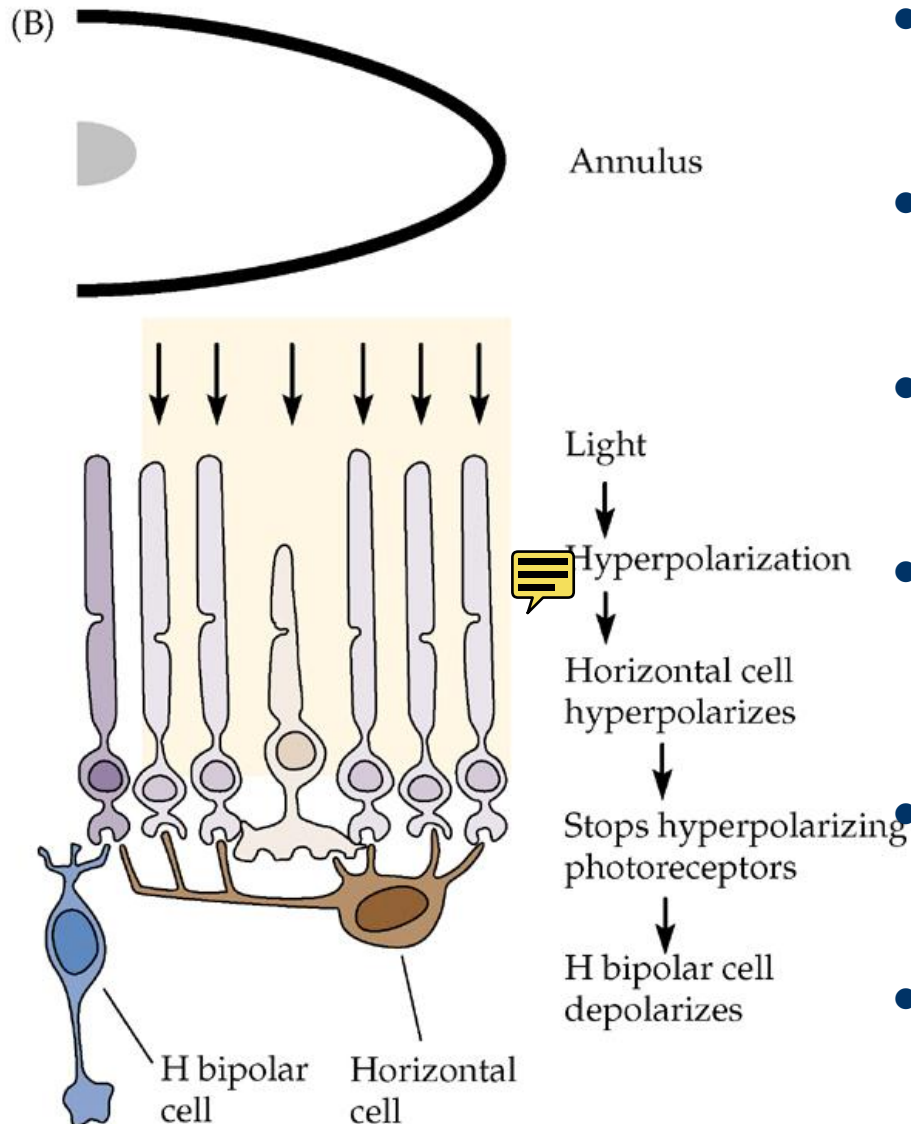
Horizontal Cells

(A)



- Light falls on a single photoreceptor and hyperpolarizes it decreasing glutamate release
- Through loss of excitation the H bipolar cell becomes hyperpolarized
- Horizontal cell also receives a hyperpolarizing input as well, but it is only from one photoreceptor and the effect is small, as is the negative feedback onto the central photoreceptor

Horizontal Cells



- Light falling on the surround area prevents glutamate from being released by photoreceptors
- This causes horizontal cells to be hyperpolarized preventing them from releasing GABA onto the photoreceptor
- Thus those photoreceptors become depolarized (through removal of inhibition)
- The depolarizing feedback is minimal on the surround receptors, which are being strongly hyperpolarized by illumination
- The central photoreceptor is receiving no illumination; thus it only loses horizontal cell inhibition
- So again it releases glutamate and depolarizes the bipolar cell