

# The Visual System

## Retinal Anatomy

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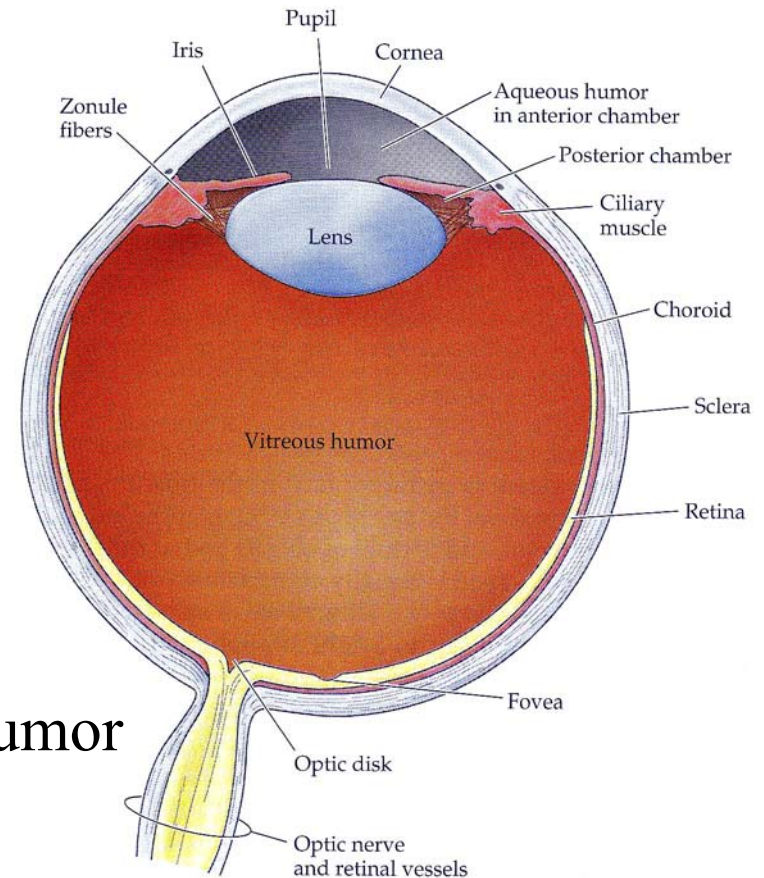
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# Reading assignments and Good Web Sites

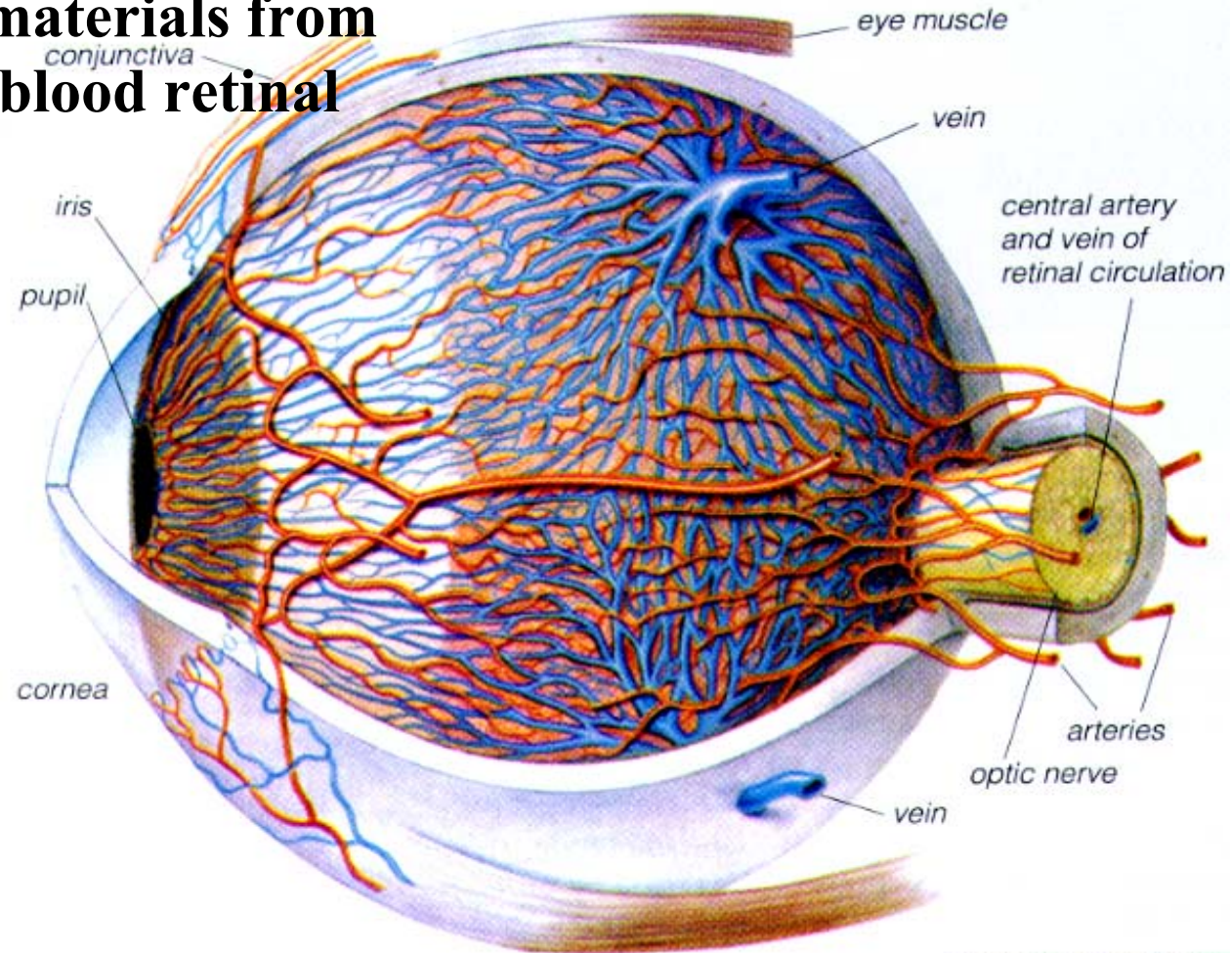
- Chapter 2 in Tovée,
- Chapter 6 in McIlwain.
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- <http://www.yorku.ca/eye/thejoy.htm>
- <http://retina.umh.es/Webvision/index.html>

# Anatomy of the Eye

- Fluid-filled sphere
- 3 tissue layers
  - Sclera
  - Iris, ciliary body, choroid
  - Retina – neural
- Light Path
  - Cornea - refraction
  - Anterior chamber, aqueous humor
  - Lens – refraction
  - Vitreous humor
  - Retina



**The retina is nourished on both sides by two separate blood supplies the retinal and the choroidal. As in the brain the blood vessels limit the transport of materials from the blood forming the blood retinal barrier.**



source: Hogan et al., 1971

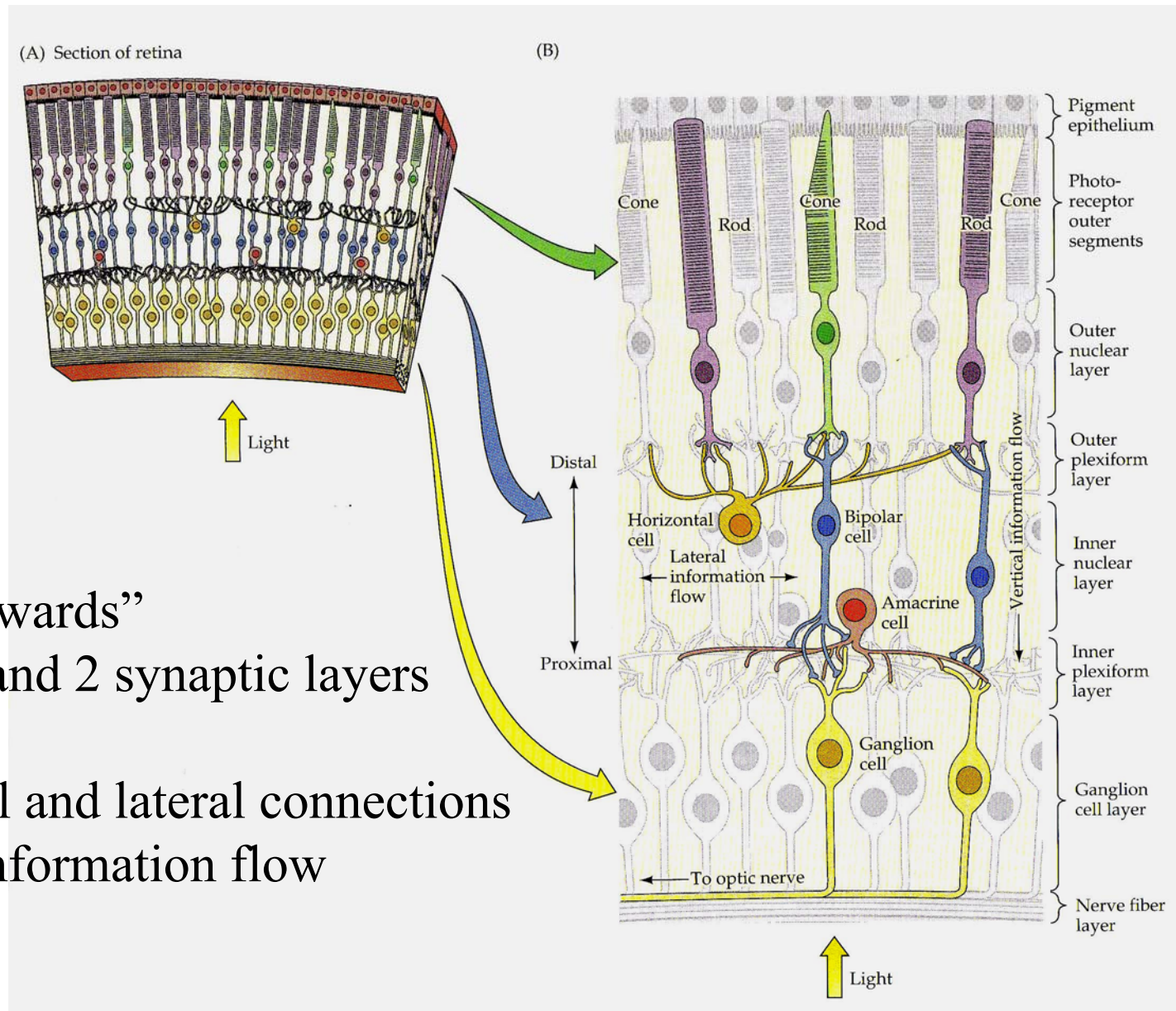
What is the tapetum and where is it located?

What pathological condition arises when the normal flow of the aqueous humor is blocked?

What are the 3 cell layers of the neural retina called?



# Retinal Structure and Cell Types



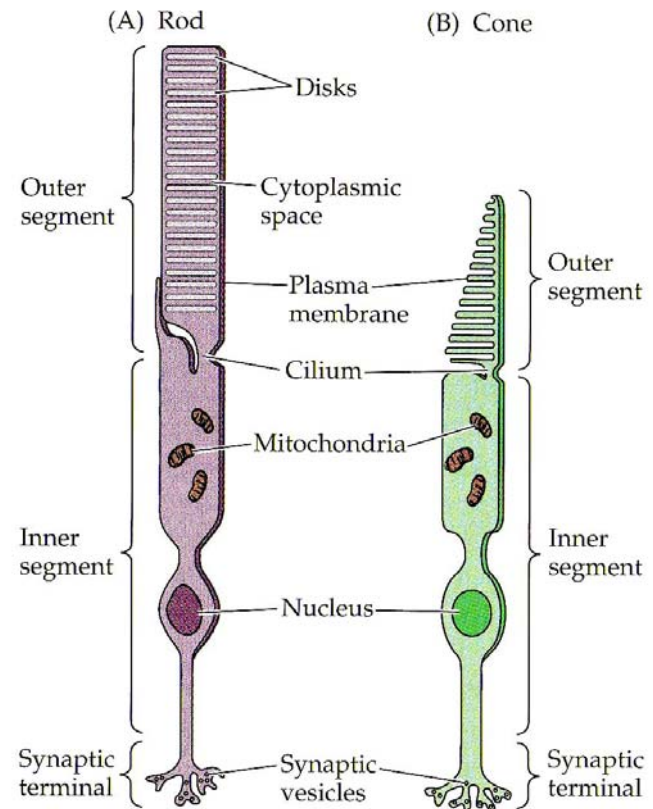
- Faces “backwards”
- 3 cell body and 2 synaptic layers
- 6 cell-types
- Both vertical and lateral connections and information flow



# Rods and Cones

Two types of photoreceptors distinguished by:

- Shape
- Type of photopigment they contain.
- Distribution across the retina.
- Pattern of synaptic connections
- Functional range of light intensities.



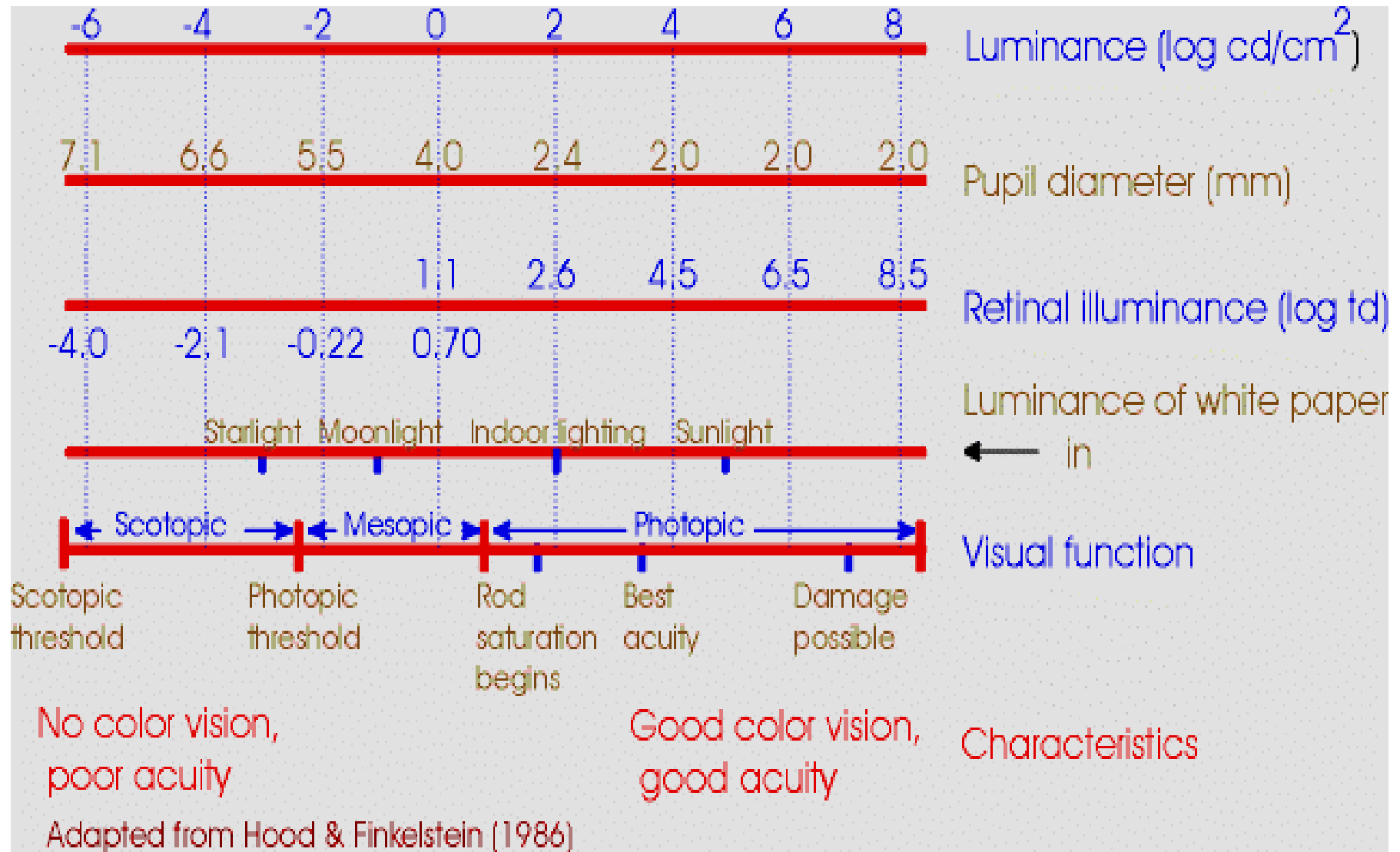
# Morphology of photoreceptors

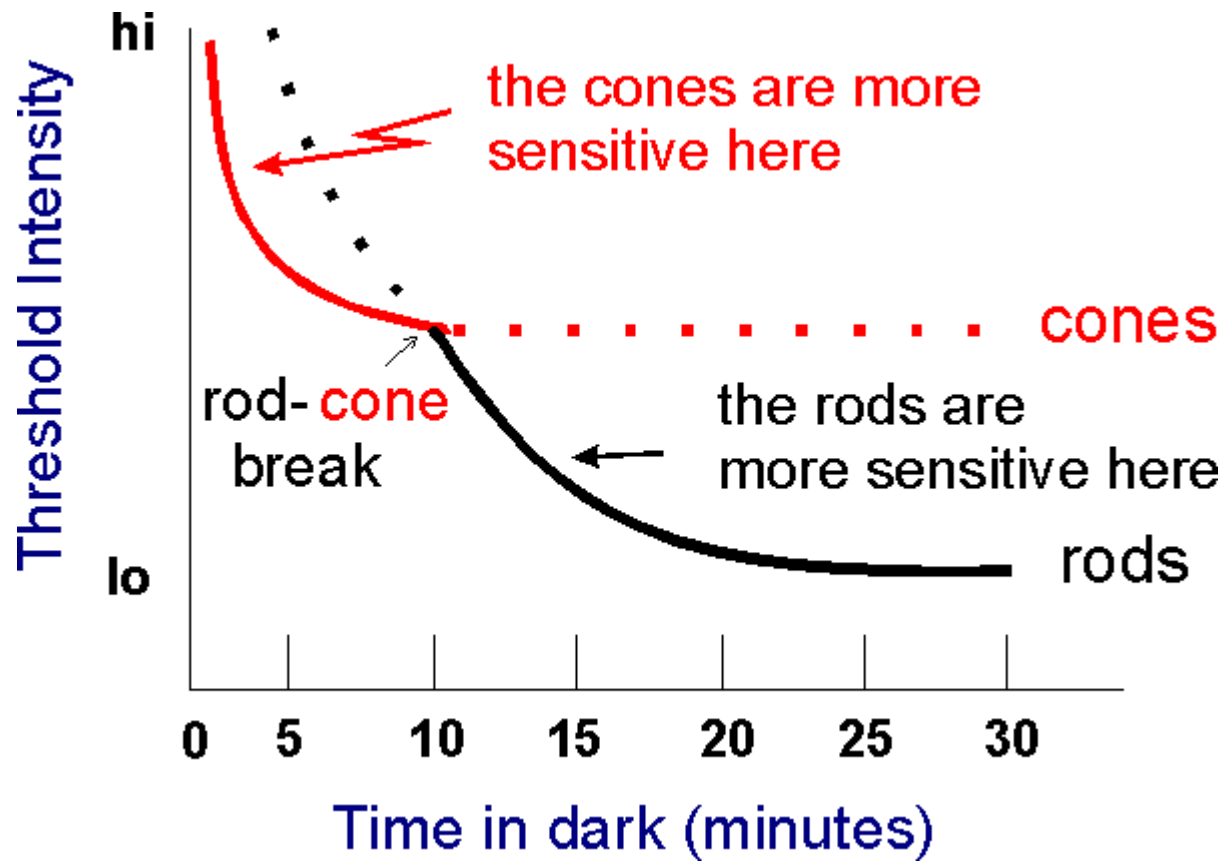
- **Rods:** have long cylindrical outer segments containing many membranous. Rod disks contain  $10^8$  rhodopsin molecules in their membranes. The outer segments of disks are shed into the pigment epithelium and new ones take their place. If this renewal process does not take place due to some defect rods can die (e.g., retinitis pigmentosa)
- **Cones:** Cones are more tapered than rods with infolded plasma membranes within their outer segments. There are 3 types of cones sensitive to short, medium and long wavelengths of light

Scotopic vision – very dim light, purely rod-mediated.

Mesopic vision – dim light, rod and cone mediated.

Photopic vision – bright light, rods saturated, cone-mediated

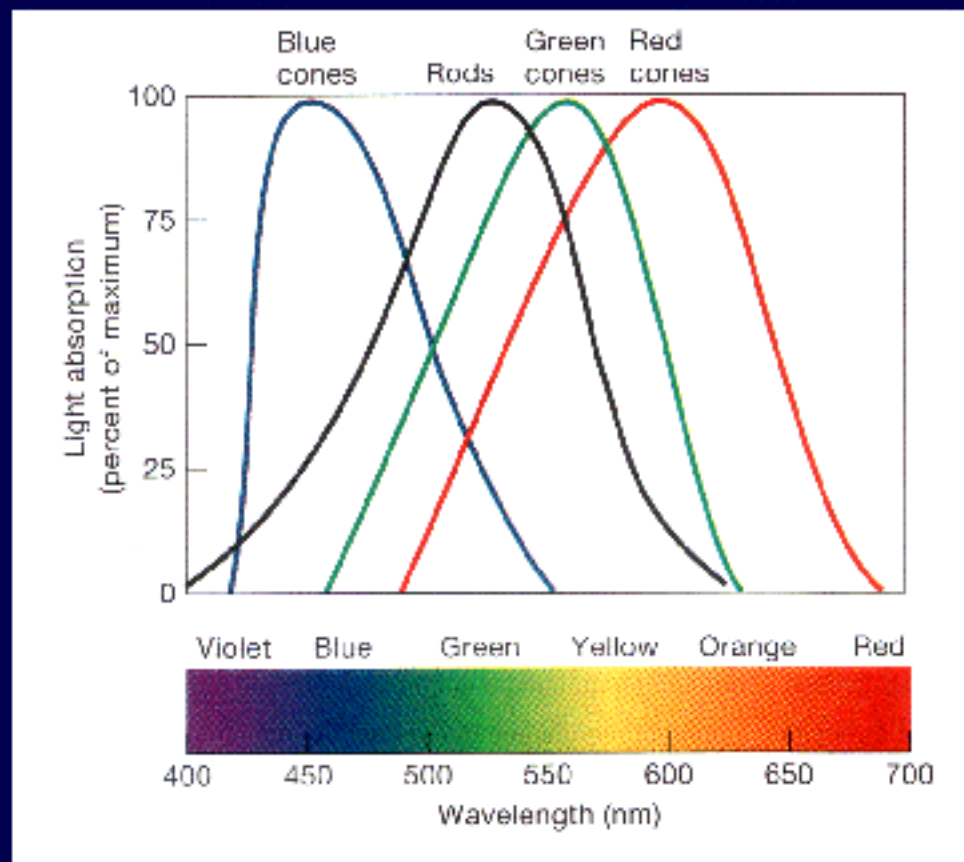


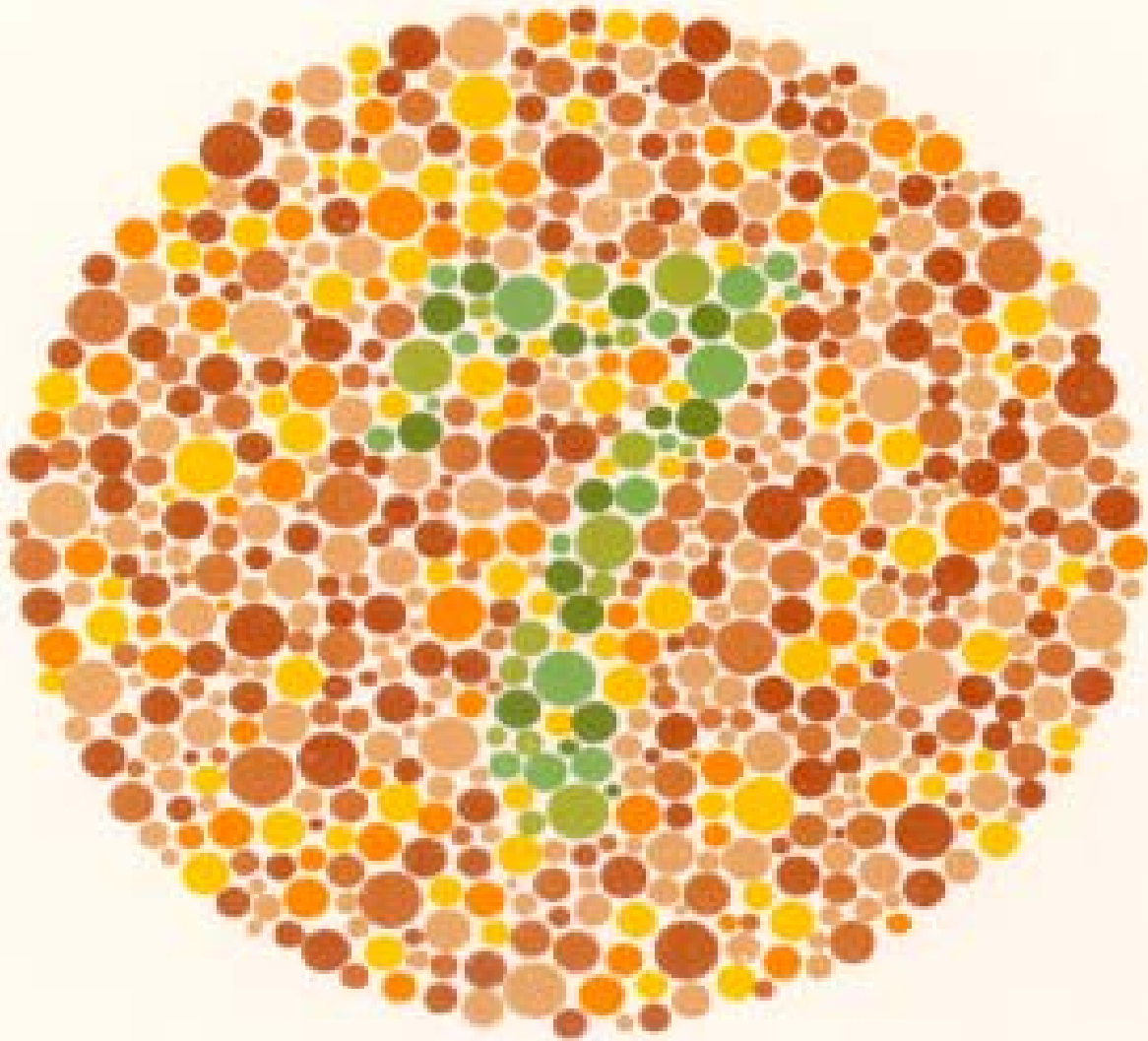


Photopic  
scotopic

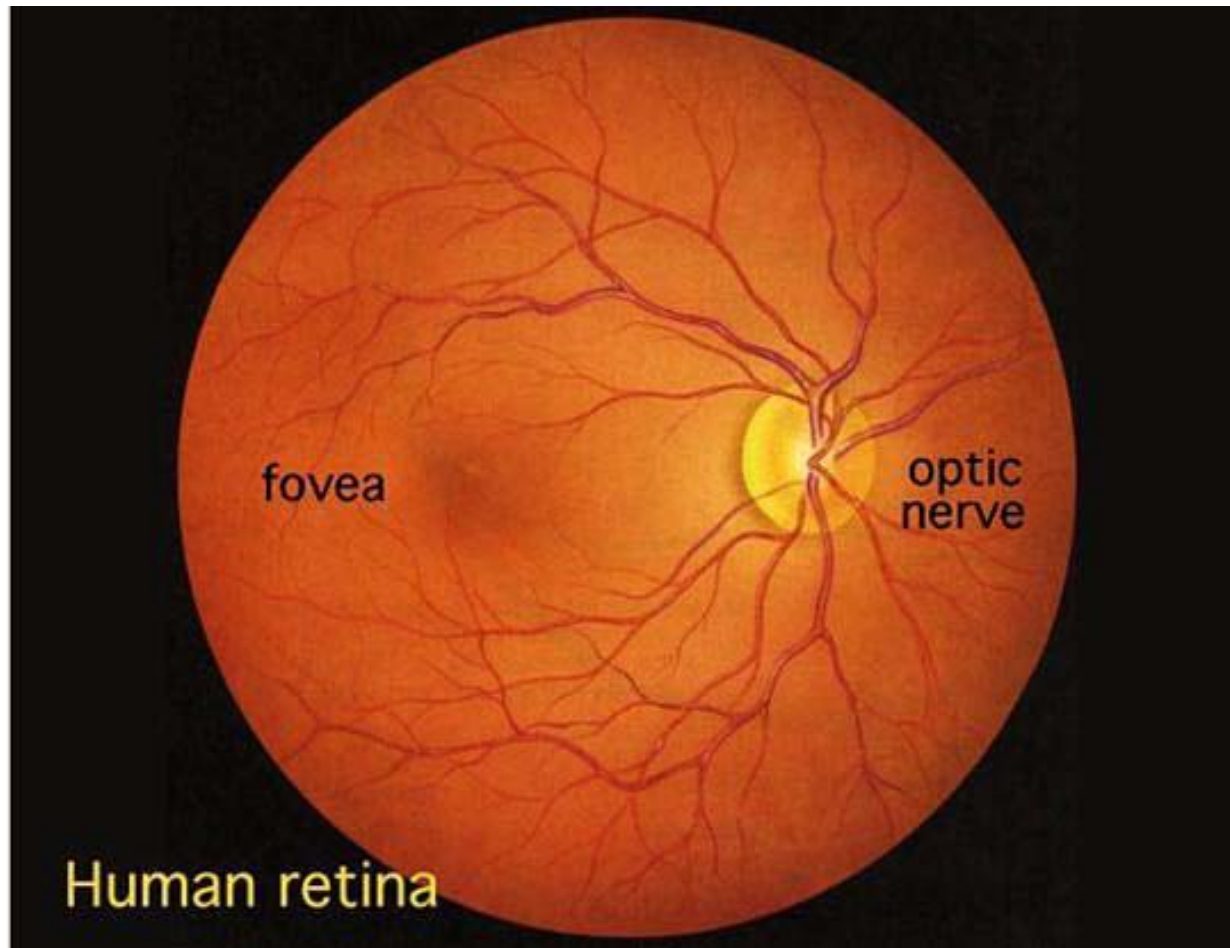
# Photoreceptor Photopigment Spectral Sensitivities

- Rods
  - Green
- Cones
  - Red
  - Green
  - Blue

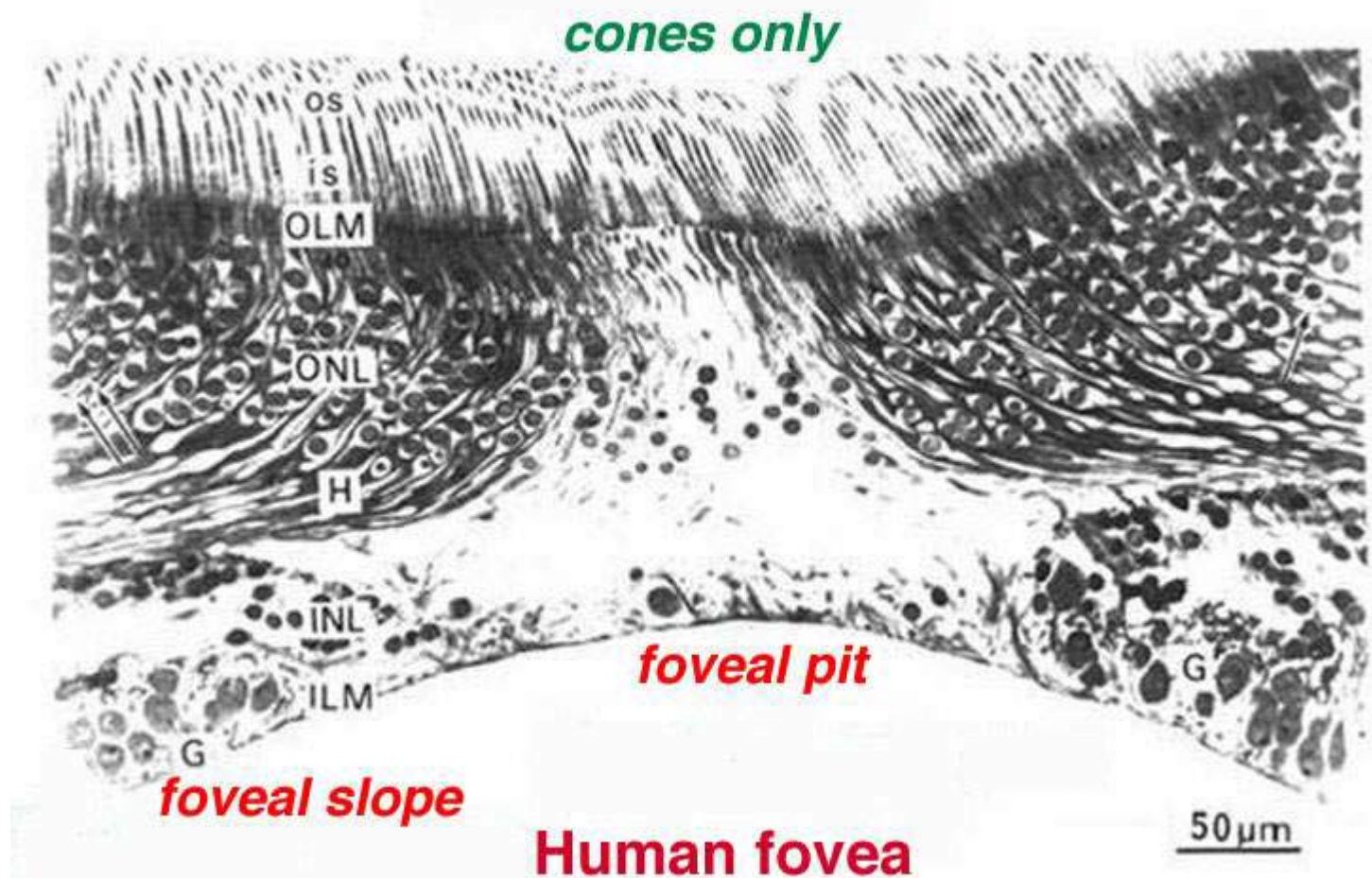




**Different parts of the retina are functionally specialized. The fovea contains all cones which are less sensitive to light. The fovea has the highest density of receptors and highest resolution. Outside the fovea rods dominate and the retina is more sensitive to light but resolution is lower.**



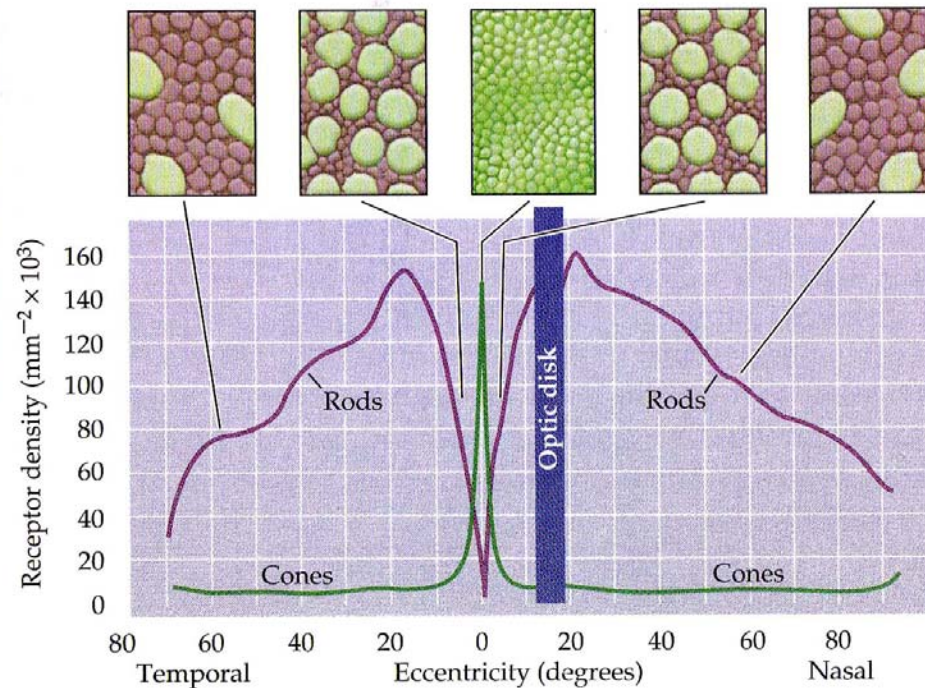




fovea: 1.5mm, (5.2 deg)central pit = 0.5mm has no overlying cells or blood vessels

# Anatomical Distribution of Rods and Cones

- Rods are for high sensitivity but low spatial and temporal resolution and are distributed in the peripheral retina.
- Cones are for low sensitivity but high spatial and temporal resolution and are concentrated in the central retina.



[illegible]

$2.5 \times 10^6$  cones  $10^8$  rods

fovea: 1.5mm, (5.2 deg) central pit = 0.5mm  
cones only; no overlying cells or blood vessels  
receptor to ganglion  
cell ratio 1:3 **high acuity, low sensitivity**

peripheral retina  
Rods outnumber cones  
receptor to ganglion cell ratio 125:1  
**high sensitivity, low acuity**

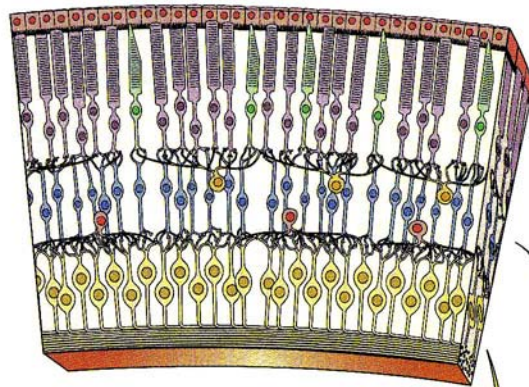
# Retinal Circuits

- Following light activation the most direct path for visual signals to travel from the eye to the brain is from the **photoreceptors** to the **bipolar** cells to the **ganglion** cells.
- The ganglion cells send axons to the brain
- **Horizontal** and **Amacrine** cells integrate signals horizontally across the retina.
- The retina also has glial cells or supporting cells important from maintaining the environment of the retina. One glial cell found only in the retina is the **Mueller** glial cell

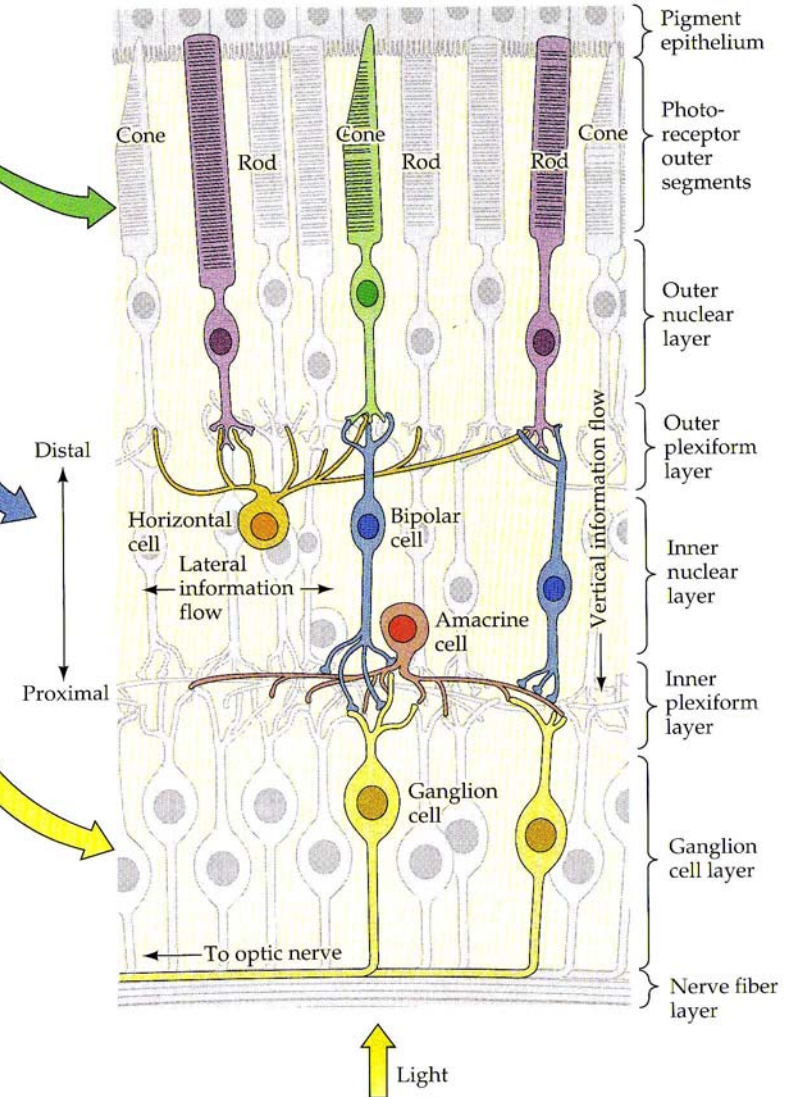


# Retinal Circuits: How do they Work?

(A) Section of retina



(B)

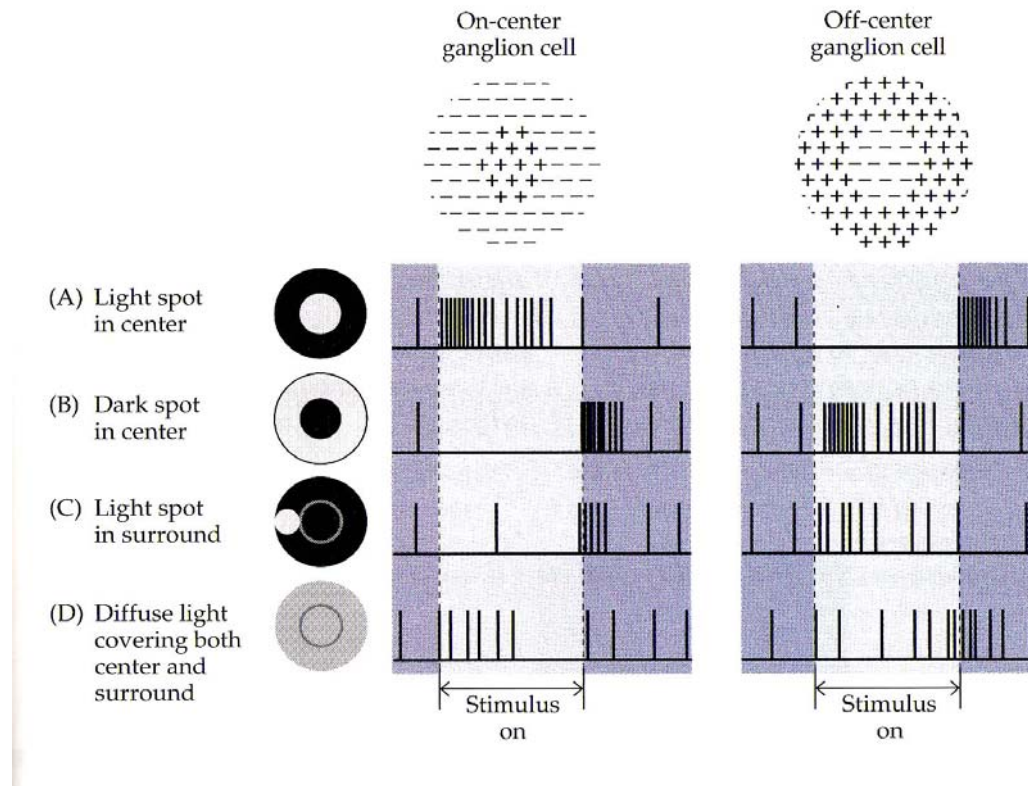


## **STRUCTURE AND TRANSFORMATIONS IN THE OUTER PLEXIFORM LAYER:** interactions between photoreceptors, horizontal cells and bipolar cells

- A. cones and rods form specialized **chemical synapses** with bipolar cells and horizontal cells and employ both **electrical and chemical synapses** with each other.
- B. **Bipolar cells** have two processes that connect receptors to ganglion cells. They come in two flavors: **ON center and OFF center**. Light leads to hyperpolarization of cones which leads to depolarization of ON center bipolar cells and hyperpolarization of OFF bipolar cells
- C. **Horizontal cells synapse reciprocally with many photoreceptors**. Horizontal cells are responsible for the sign reversing of bipolar cells when the surround is stimulated with light

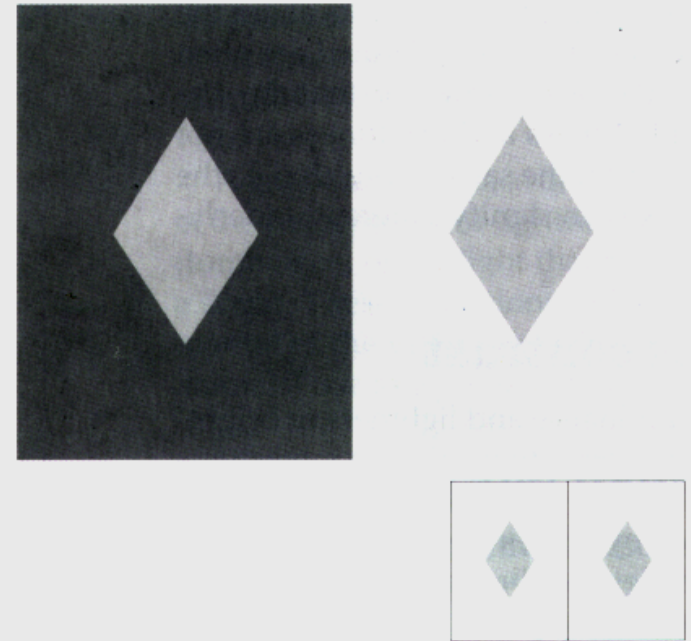


# Ganglion Cell Recordings Reveal Antagonistic Center/Surround Receptive Fields

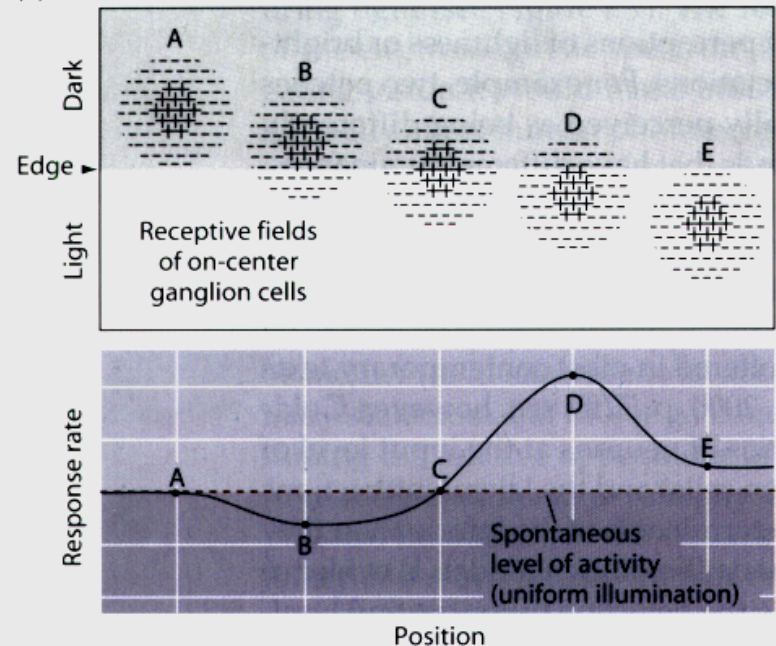


- Lateral Inhibition in ganglion cell (GC) receptive fields enhances contrast and edge detection.
- The modest difference in GC activity from a light region (A) and a dark region (E) is enhanced at the edge (B and D).
- Lateral inhibition is thought to underlie illusions such as the simultaneous brightness-contrast illusion in the upper panels.

(A)

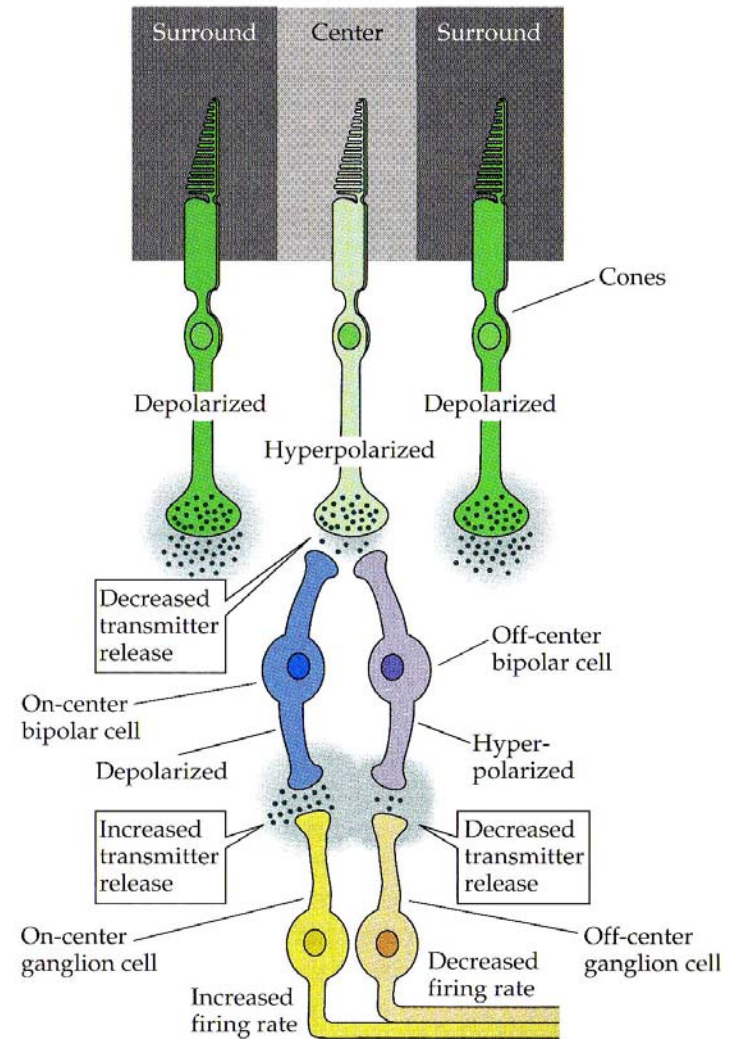


(B)



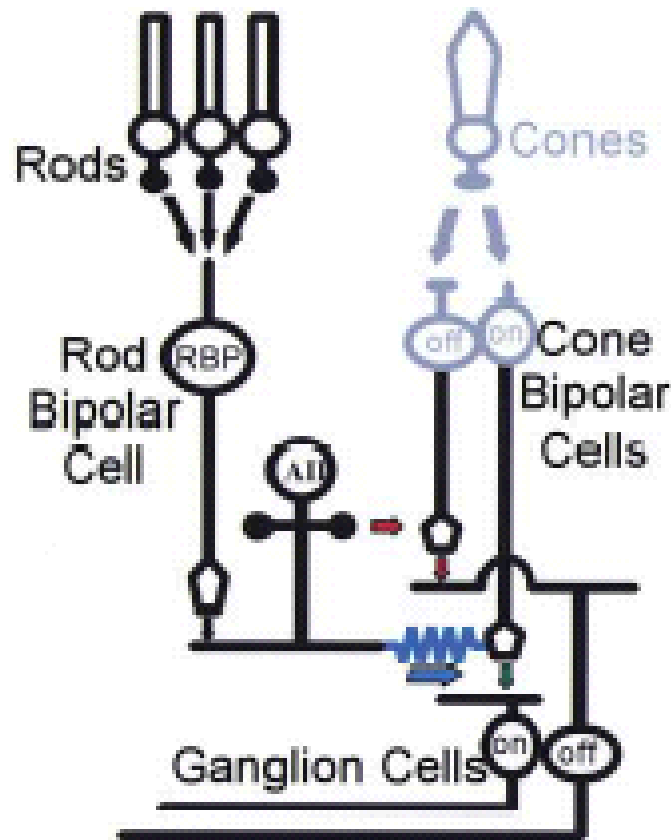
## Vertical pathways carry the “Center” signal.

- On-center vs. Off-center receptive fields are determined at the bipolar cell level.
- The receptor transmitter is glutamate.
- Off-center bipolar cells have AMPA type glutamate receptors that preserve the sign of the PR signal.
- On-center bipolar cells have metabotropic GluRs that invert the PR signal.
- Ganglion cells follow their bipolar cell input



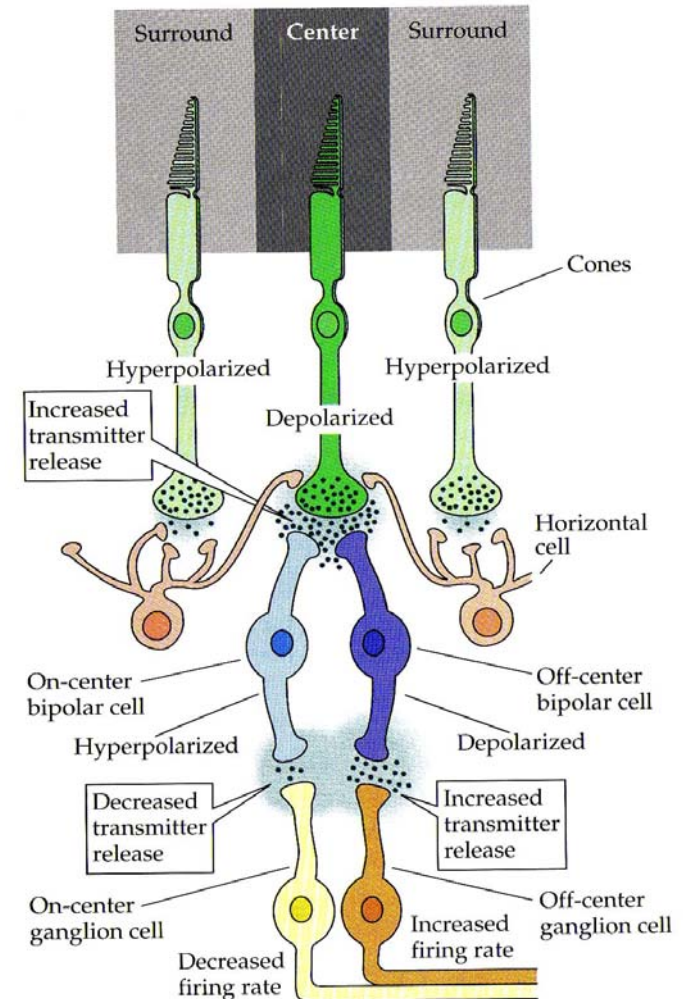
# Rods and Cones: Synaptic Connections

- Rods converge on bipolar cells that do not access ganglion cells directly.
- Cones diverge onto bipolar cells that directly drive ganglion cells.



## Lateral Interactions mediate the “Surround”.

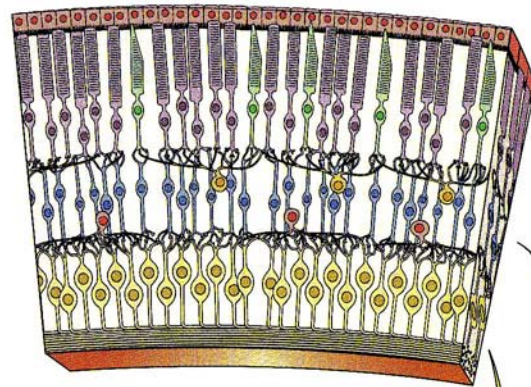
- Horizontal cells are critical for spatial aspects of visual signals.
- Lateral inhibition from horizontal cells produce the antagonistic surround of GC receptive fields.
- The horizontal cells form an electrically coupled network in the OPL.



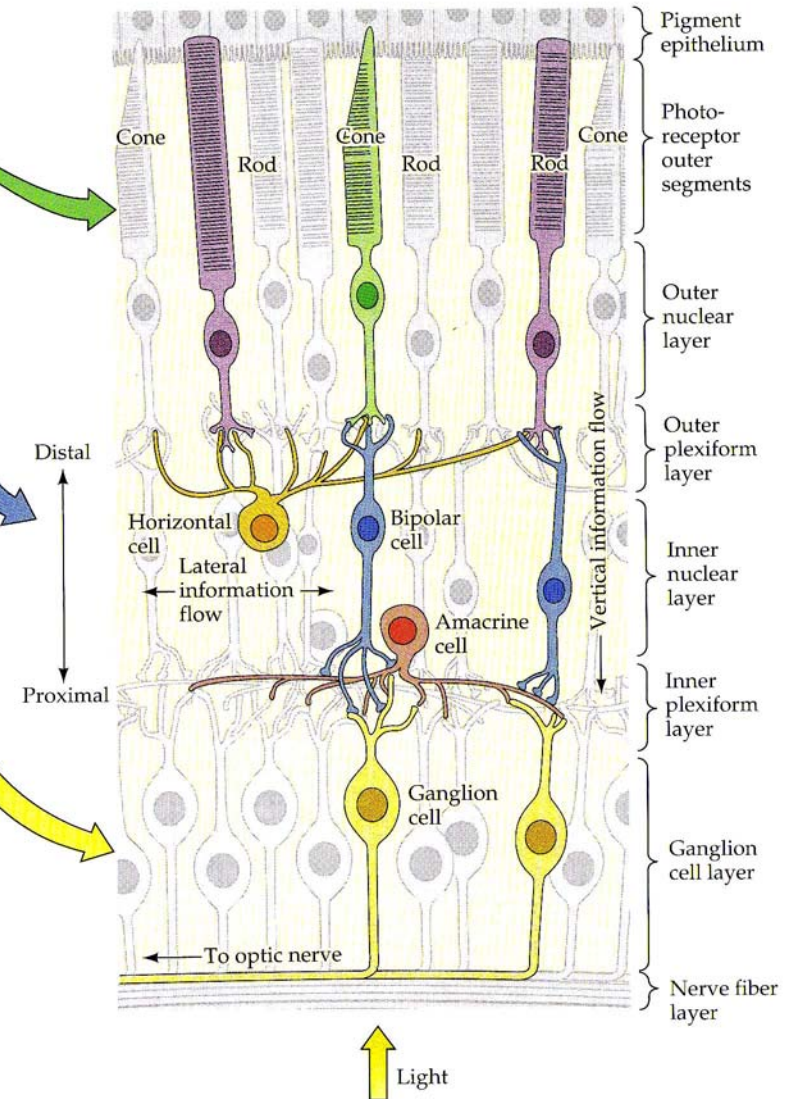


# Amacrine cells influence the temporal properties of ganglion cells

(A) Section of retina

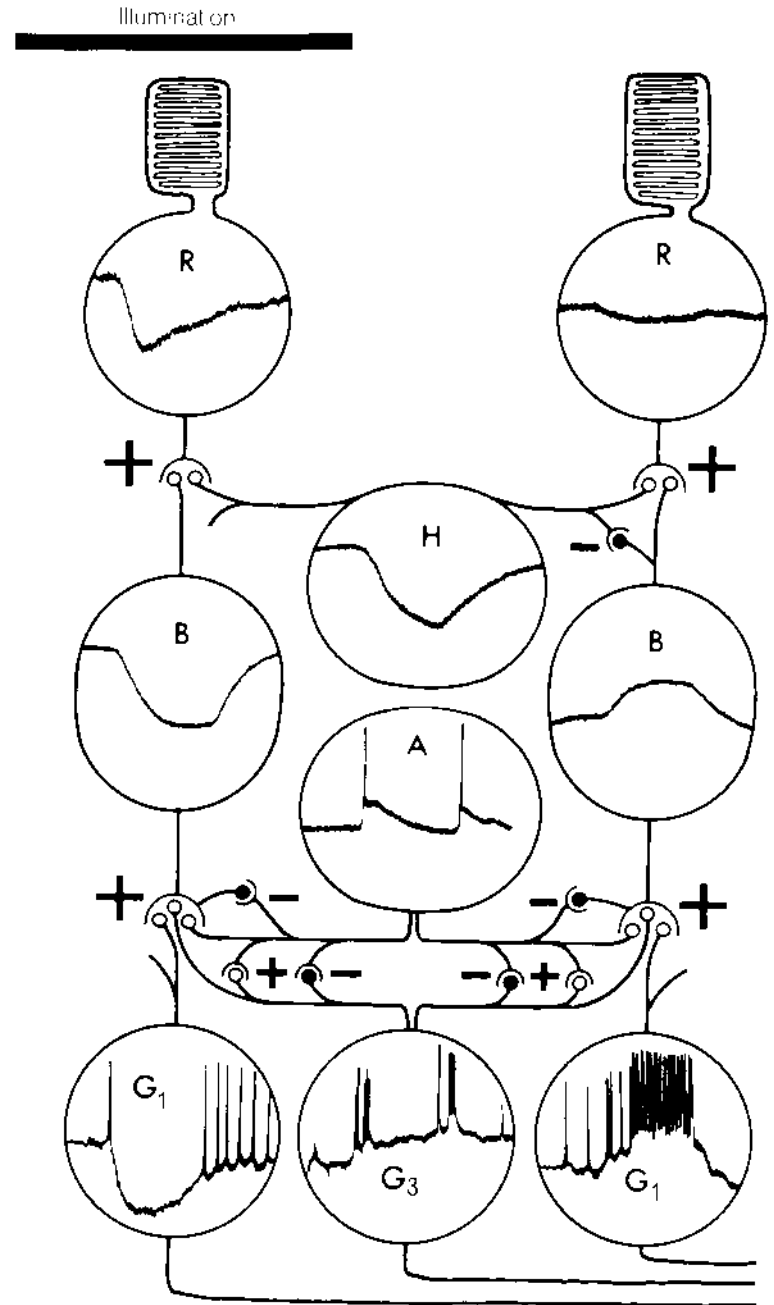


(B)



There are transient GC's that extract the timing of lights on and off, not spatial contrast.

- Amacrine cells shape the temporal aspects of visual signals by gating bipolar to GC transmission.
- Transient amacrine cells are wired to both ON and OFF bipolars with recurrent inhibitory synapses that quench bipolar drive to GCs.
- They make mostly inhibitory outputs to GCs (weak excitation).
- Many transient GCs are direction selective.

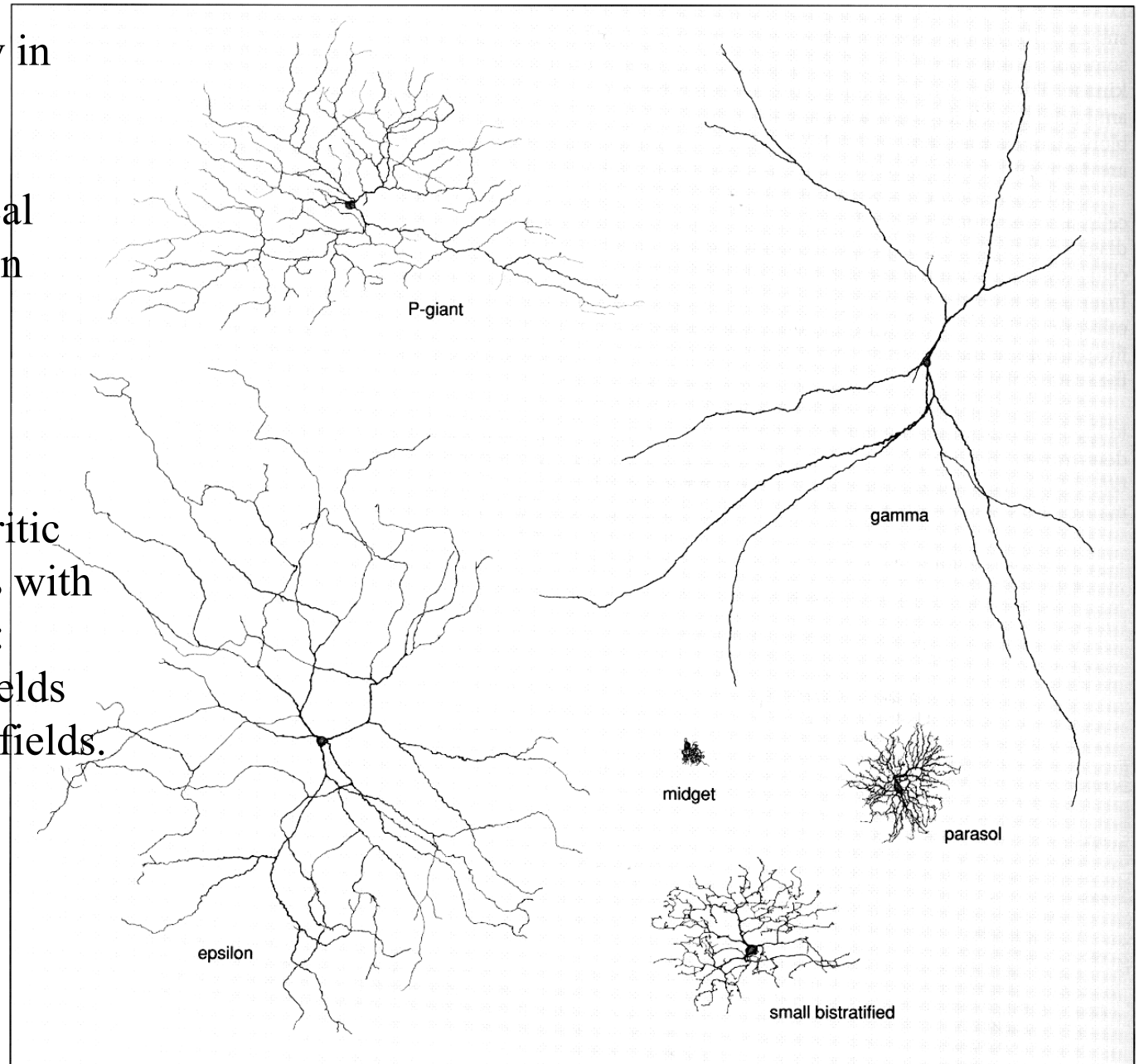




Ganglion cells vary in morphology.

These morphological variations have been related to physiological differences

For example, dendritic field size correlates with receptive field size:  
smaller dendritic fields  
=smaller receptive fields.



Ganglion cells send axons into the optic nerve.

Some axons cross at the optic chiasm while others remain uncrossed. Past the optic chiasm axons can terminate in several different brain areas that perform different functions.

