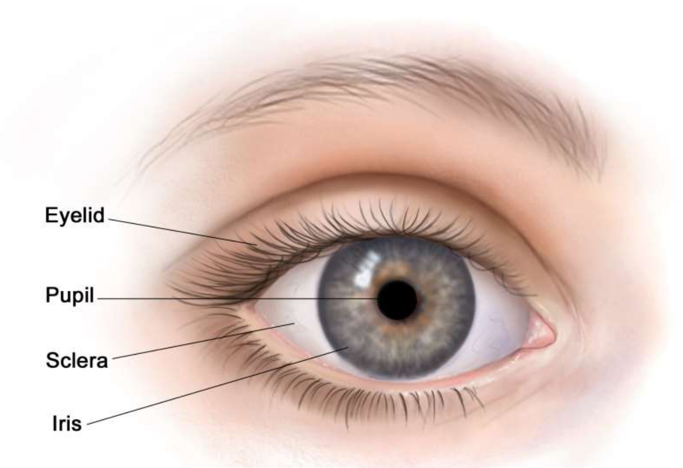
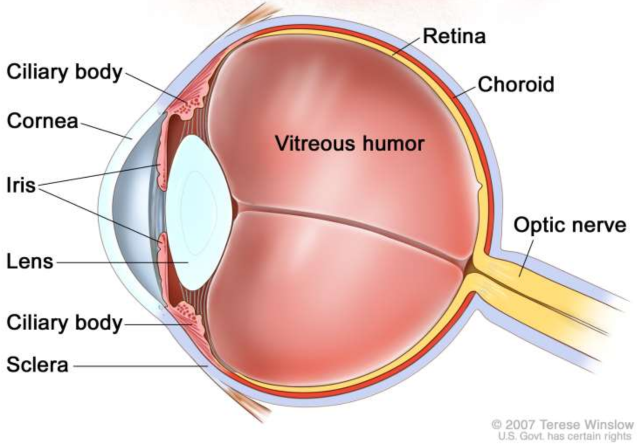
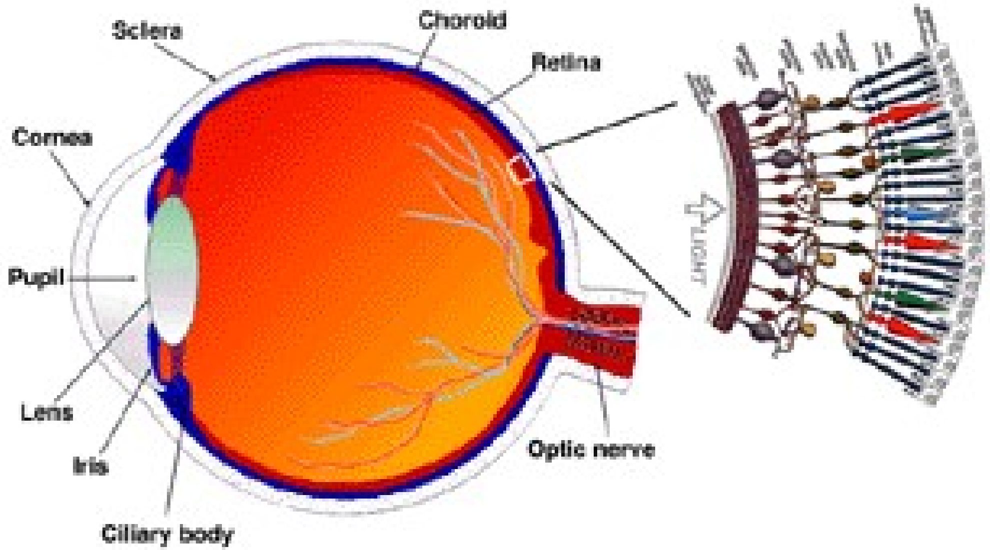
Vision System

Retina and Visual Receptors





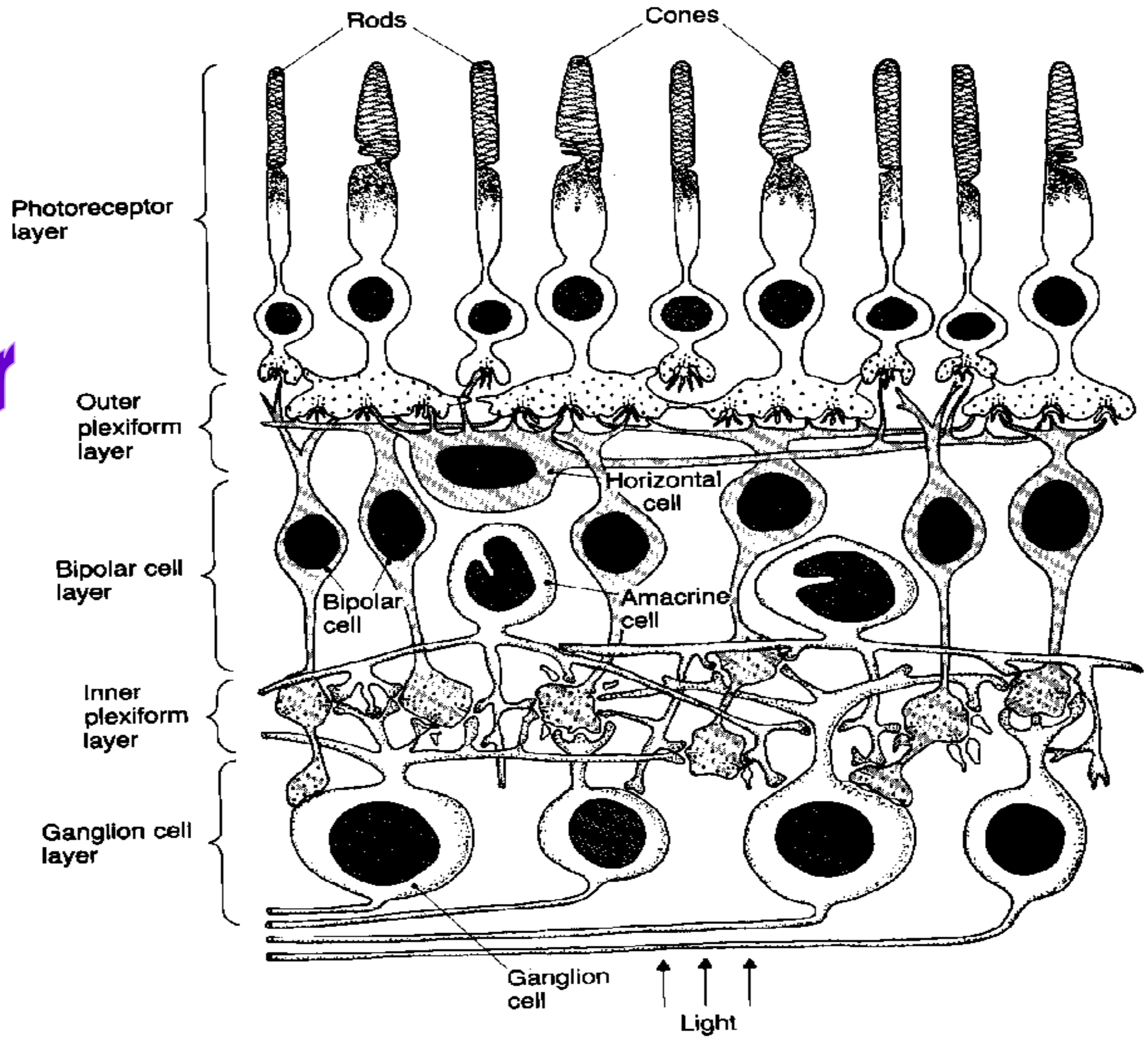


The retina has three major layers:

receptor layer

bipolar layer

ganglion cell layer



Layers of the retina: Fig. 50-1

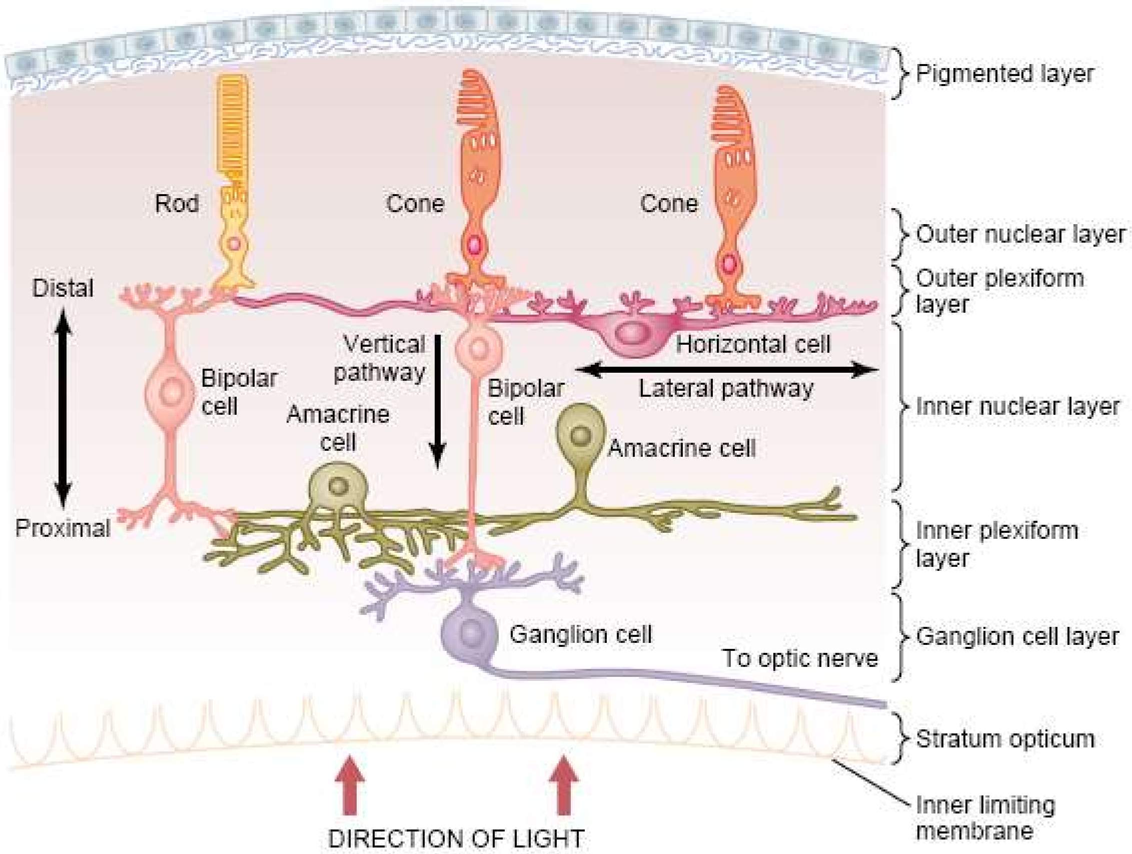
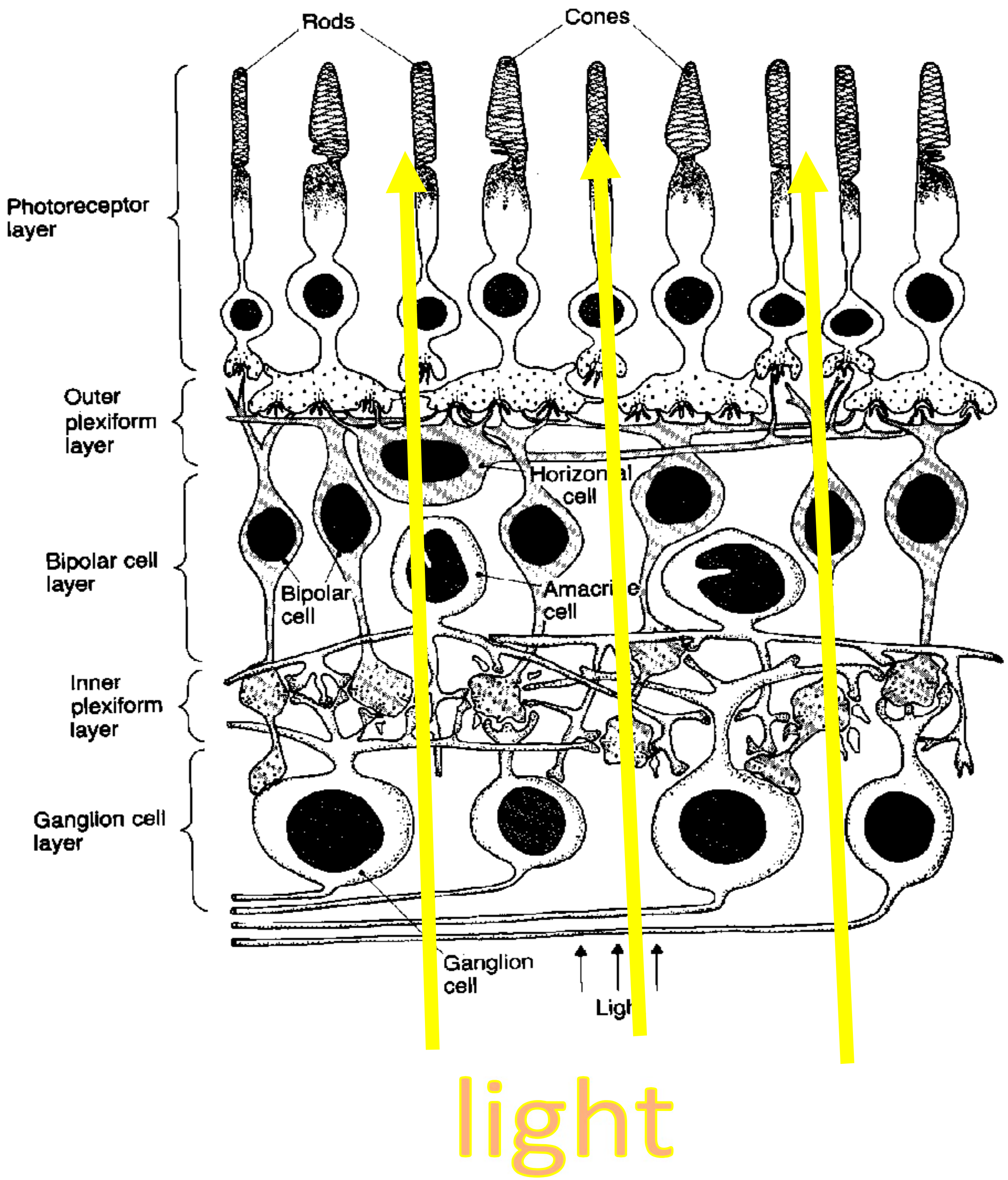


Figure 50–1

Layers of retina.

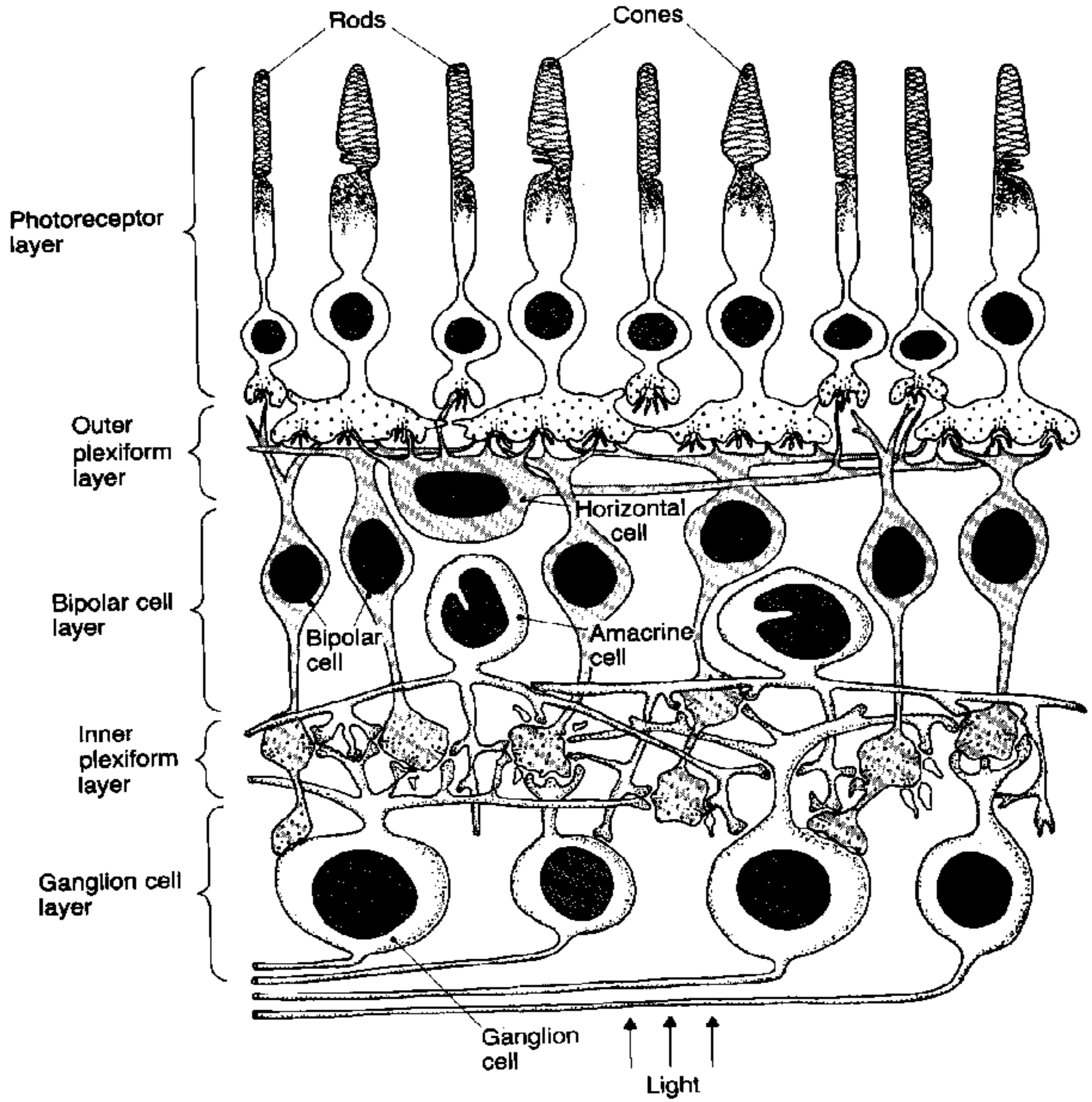
Note that the retina appears to be backward from what we would expect....

...as the light must pass through all the other neural tissue before it arrives at the receptors.



Interaction among most of the retinal neurons is by means of graded potentials.

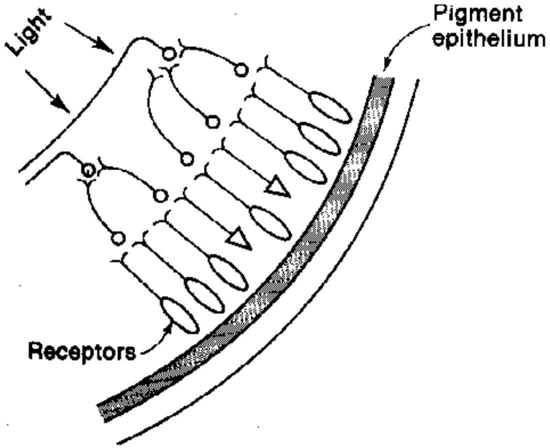
The influence is passed to the ganglion cells, which produce spikes.

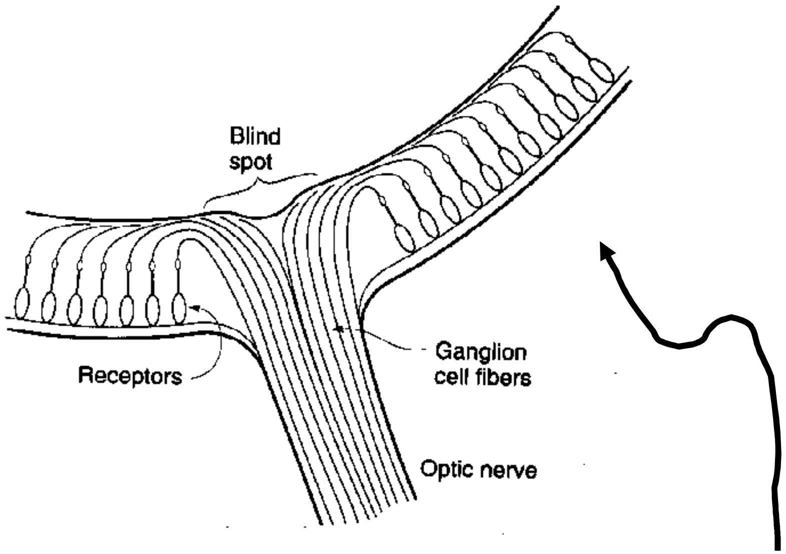


The axons of ganglion cells converge to become the fibers of the optic nerve.

120 millions receptors

to 1.5 million optic nerve fibers

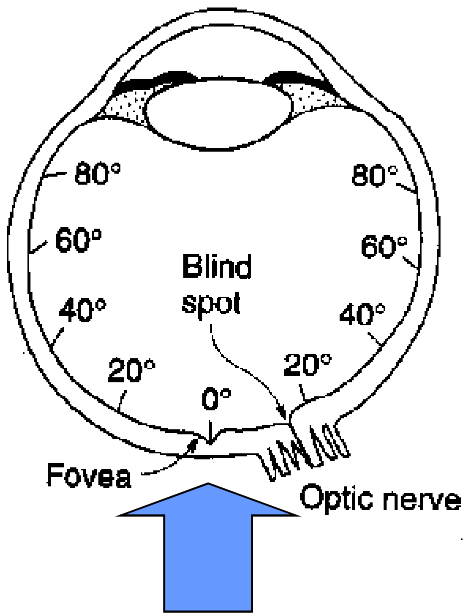


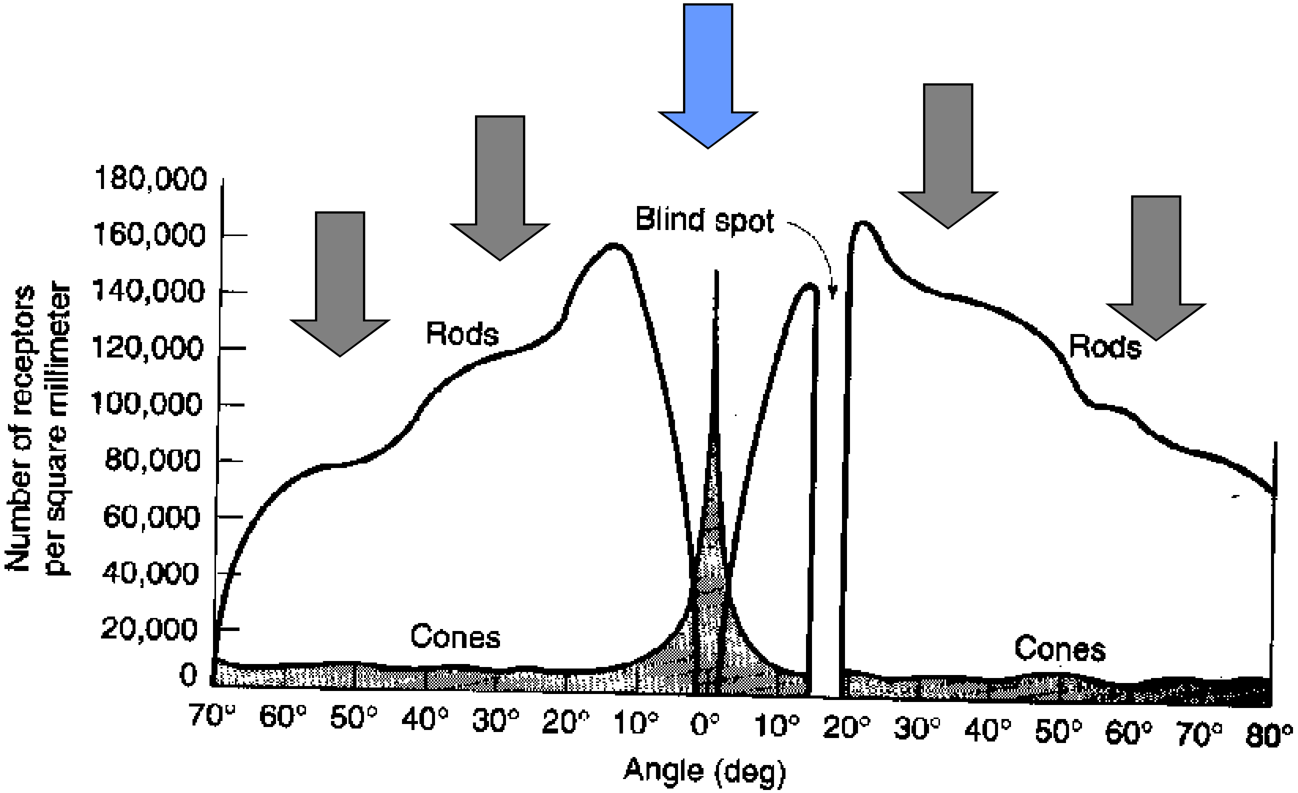


And the flow of axons from the ganglion cells into the optic nerve is shown here.

- Cones: responsible for color vision
- Rods: responsible for dark vision

• Rods are most abundant in the periphery of the retina (gray arrows), while cones are most abundant in the vicinity of the fovea (blue arrow).





The fovea lies at the center of vision.

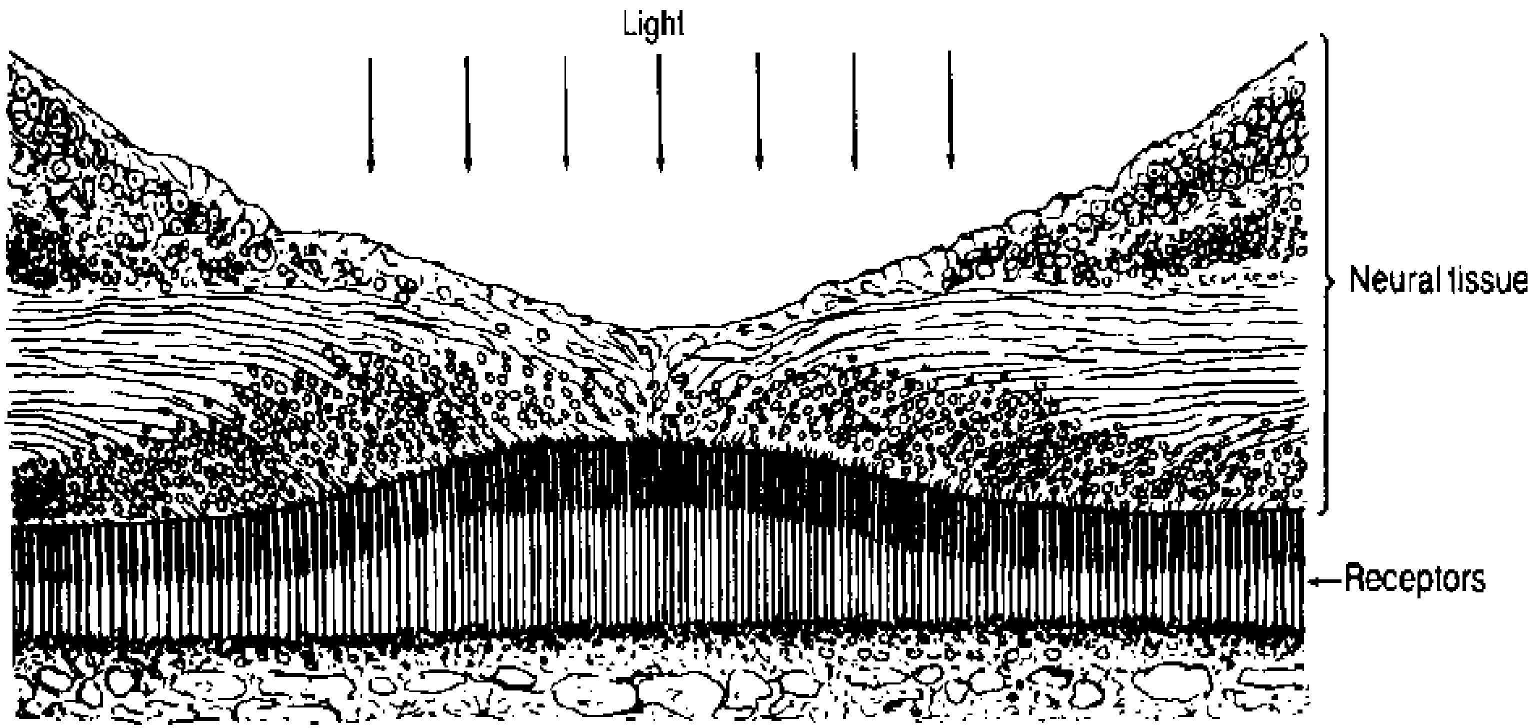


Fig. 50-2

There is better **acuity** i.e., detailed vision, in the fovea.

This is partly because the other neural tissue has shifted to one side, providing an unobstructed path for the light.

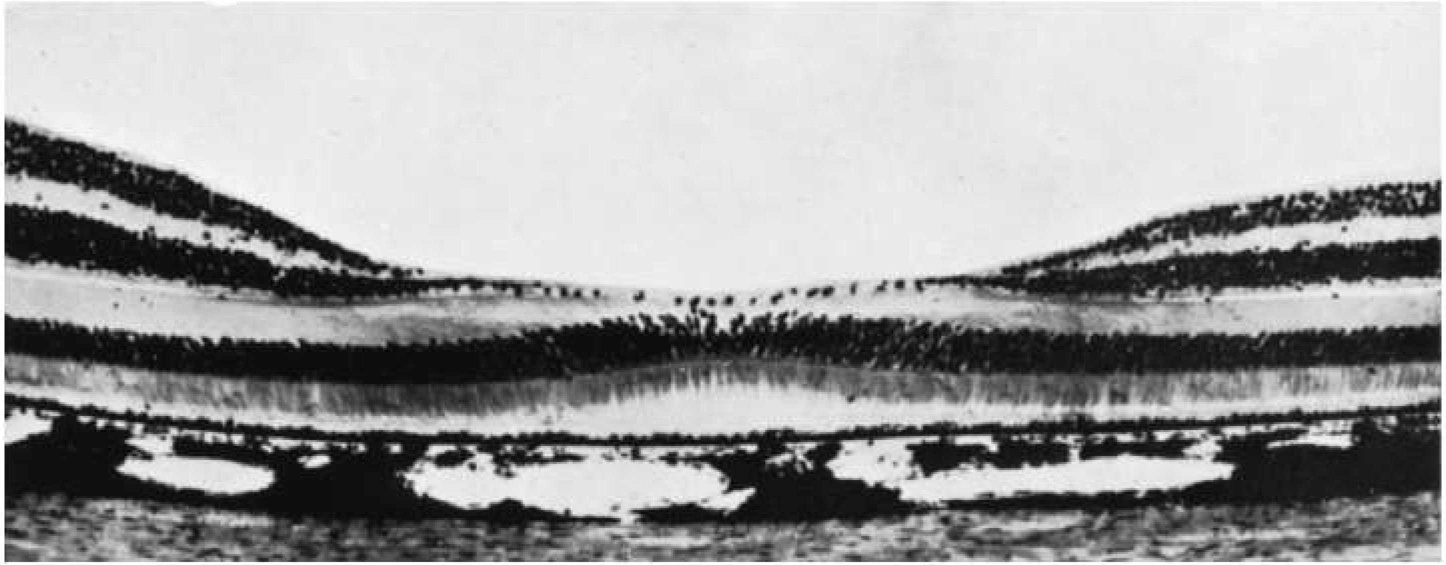
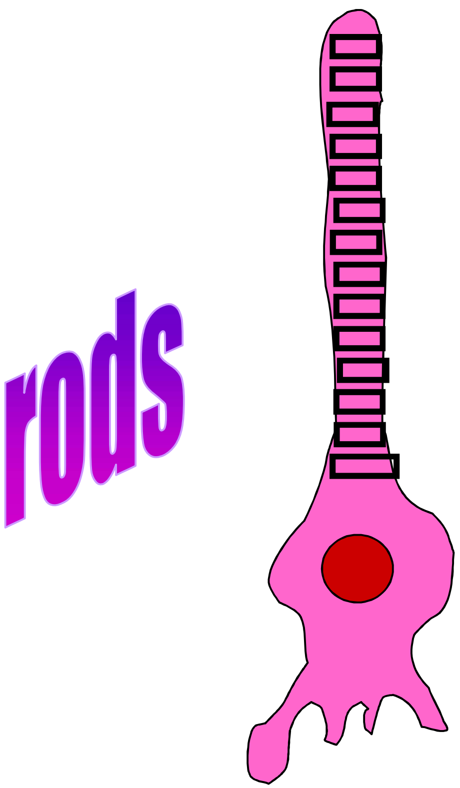


Figure 50–2

Photomicrograph of the macula and of the fovea in its center. Note that the inner layers of the retina are pulled to the side to decrease interference with light transmission. (From Fawcett DW: Bloom and Fawcett: A Textbook of Histology, 11th ed. Philadelphia: WB Saunders, 1986; courtesy H. Mizoguchi.)

Anatomists discovered that humans (and a few other species*) have a special kind of receptor --

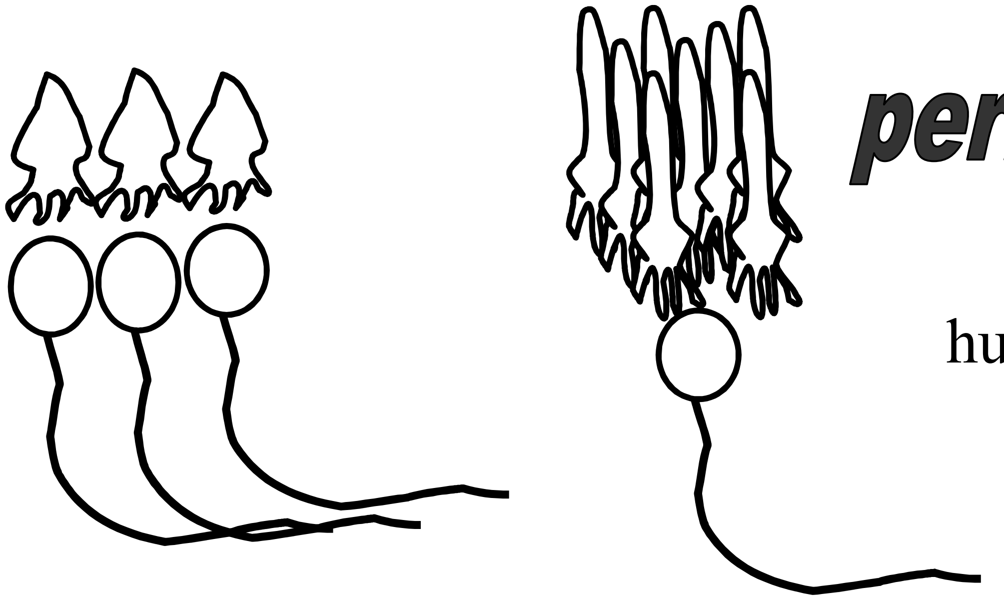


found mostly in the periphery of vision

found mostly in central vision

* now known to be more extensive among vertebrates than previously thought

But more important, each receptor in the fovea connects to a single ganglion cell, while a great many receptors in the periphery may have only one ganglion cell as their channel to the brain.



fovea

1 to 1

(higher acuity)

periphery

hundreds to 1

(lower acuity)

receptive field of ganglion cell

Is there any benefit?

- Rods and Cones
  - Fig. 50-3: Essential components of a photoreceptor
  - Fig. 50-4: rod and cone
  - Discs: 1000 discs in each rod or cone
  - Light sensitive photochemical
    - Rods: rhodopsion
    - Cones: red, green, blue color pigments or cone pigments
    - Chemicals decompose on exposure to light, excite the nerve fibers leading from the eye
  - Rhodopsin and its decomposition by light energy: Fig. 50-5
  - One of three types of color pigments is present in each of the different cones, making the cones selectively sensitive to different colors
  - Light wavelengths: Fig. 50-7, Blue (445 nanometers) Green (535), and Red (570)

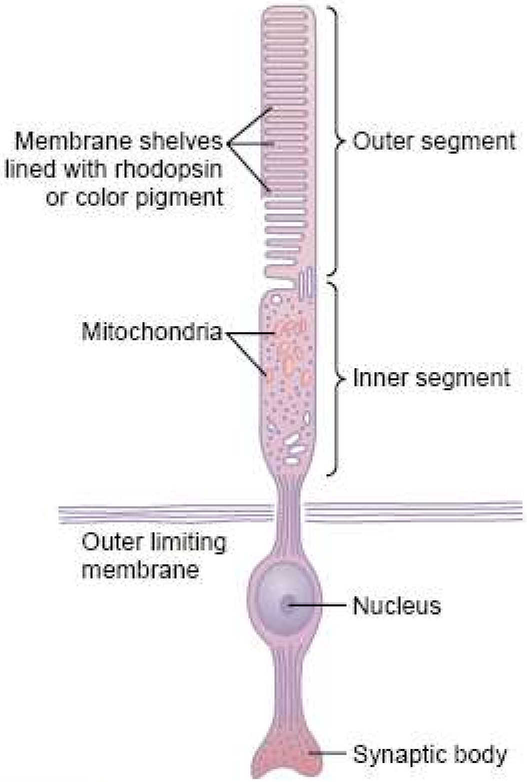


Figure 50–3

Schematic drawing of the functional parts of the rods and cones.

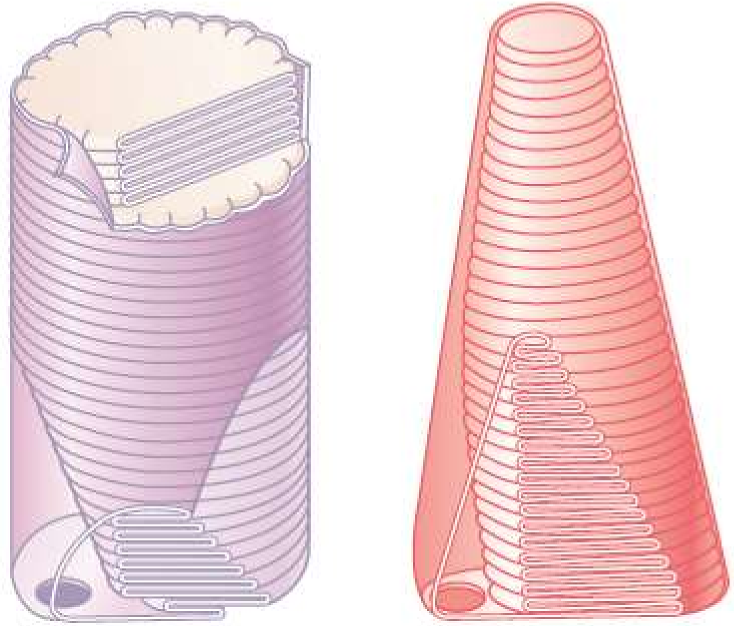


Figure 50–4

Membranous structures of the outer segments of a rod *(left)* and a cone *(right)*. (Courtesy Dr. Richard Young.)

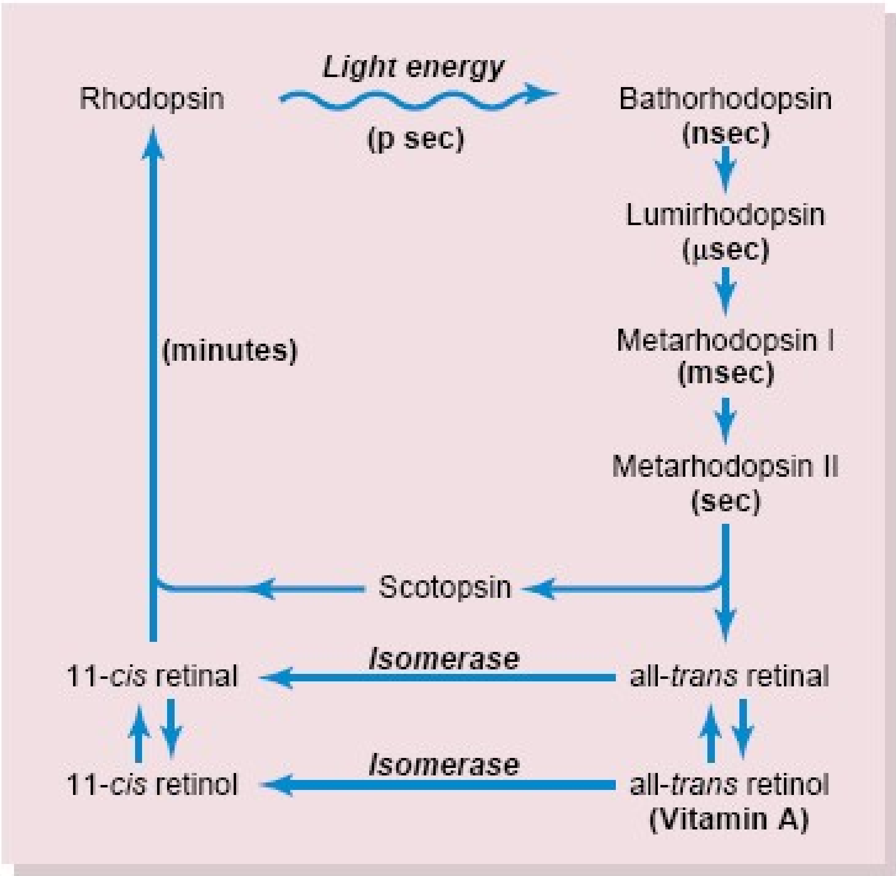


Figure 50–5

Rhodopsin-retinal visual cycle in the rod, showing decomposition of rhodopsin during exposure to light and subsequent slow re-formation of rhodopsin by the chemical processes.

Night Blindness?

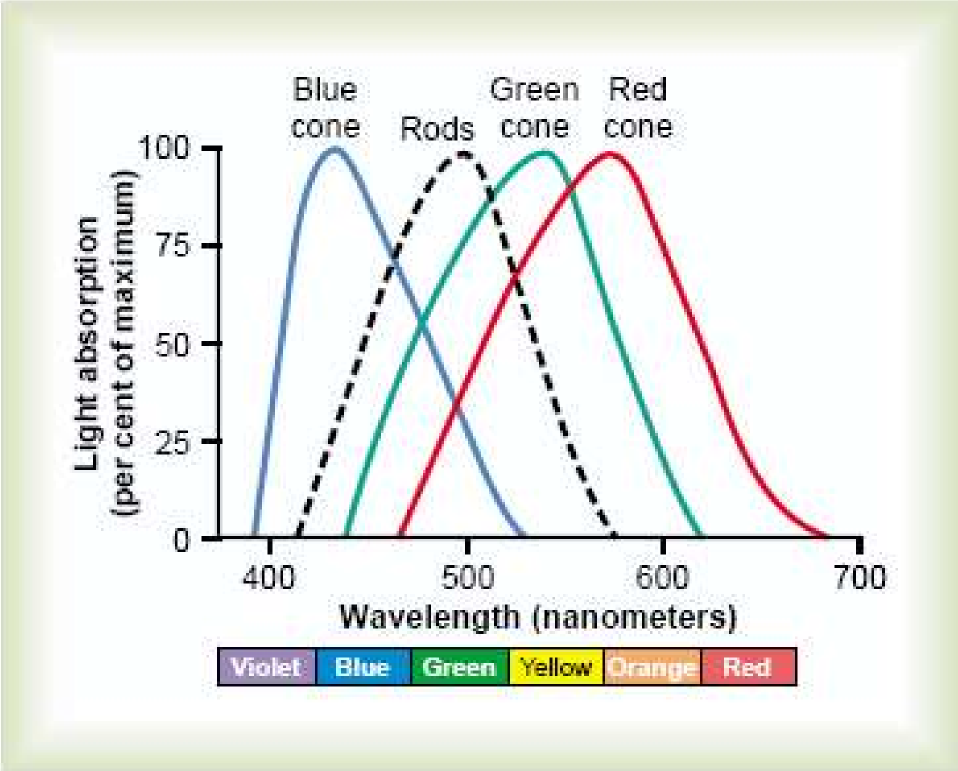


Figure 50–7

Light absorption by the pigment of the rods and by the pigments of the three color-receptive cones of the human retina. (Drawn from curves recorded by Marks WB, Dobelle WH, MacNichol EF Jr: Visual pigments of single primate cones. Science 143:1181, 1964, and by Brown PK, Wald G: Visual pigments in single rods and cones of the human retina: direct measurements reveal mechanisms of human night and color vision. Science 144:45, 1964. ® 1964 by the American Association for the Advancement of Science.)

- Excitation of the Rod When Rhodopsin is Activated
  - Rod receptor potential is hyperpolarizing, not depolarizing
  - Under light condition, Na+ pumped out of the inner segment and pumped back via the outer segment (Fig. 50-6).
  - Rod membrane is leaky to Na+ in the dark state
  - Light → rhodopsin decomposes → decreases the outer segment membrane conductance of Na+ → more Na+ ions leave the rod than leak back in → inside becomes more negative → This is hyperpolarization, opposite to depolarization
- How can a small amount of light cause such great excitation? Photoreceptors have an extremely sensitive chemical cascade that amplifies the stimulatory effects about a million-fold
- Light and dark adaptation
  - Light adaptation: in bright light, photochemicals turn into retinal and opsins. The sensitivity of the eye to light is reduced.
  - Dark adaptation: in darkness, the retinal and opsins turn back into light-sensitive pigments. The sensitivity adapts to the darkness
  - Value of light and dark adaptation in vision
    - Eye can change its sensitivity to light as much as 500,000 to 1,000,000 times.

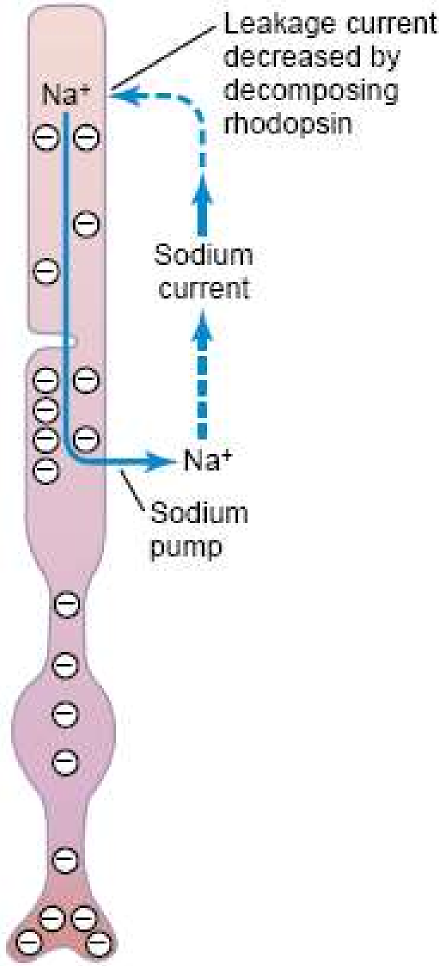


Figure 50–6

Theoretical basis for generation of a "hyperpolarization receptor potential" caused by rhodopsin decomposition, which *decreases the flow of positively charged sodium ions* into the outer segment of the rod.

- Neural circuitry of the retina
  - Fig. 50-11: neural organization of the retina
  - Visual pathway of the cones and rods
    - Fig. 50-11 right side: cones → bipolar cells → ganglion cells
    - Fig. 50-11 left side: rods → bipolar cells → amacrine cells → ganglion cells
  - Transmission of most signals occurs in the retinal neurons by electronic conduction, not by action potentials
    - Light → hyperpolarization → electronic conduction (direct electric current flow) → synaptic body (no action potentials)
    - Why ? Allowing graded potentials (i.e., more light stronger response)
  - Function of horizontal cells: lateral inhibition to enhance visual contrast. Stops the excitatory signal's spreading into other areas. Why? Essential for high visual accuracy of edge detection
  - Bipolar cells:
    - Two types: depolarizing and hyperpolarizing. Why?
    - Generate both positive and negative signals in transmitting visual information
    - Second mechanism to lateral inhibition, therefore edge detection
  - Amacrine cells: 30 types. Direct pathway for rod vision, Most importantly directional sensitive

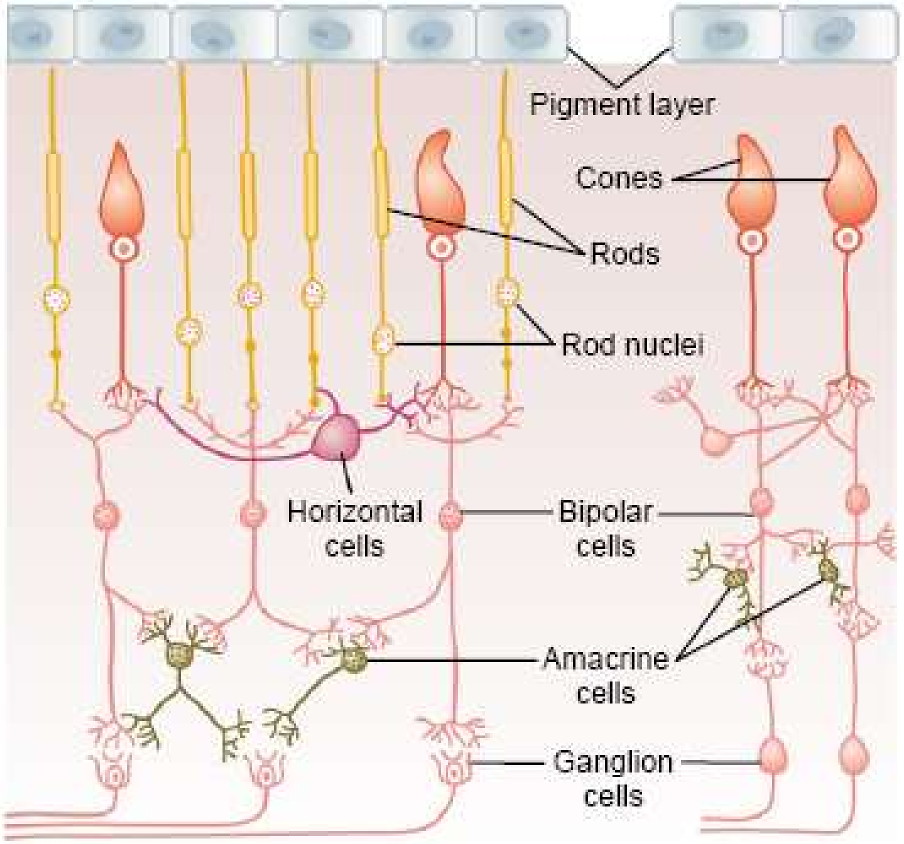
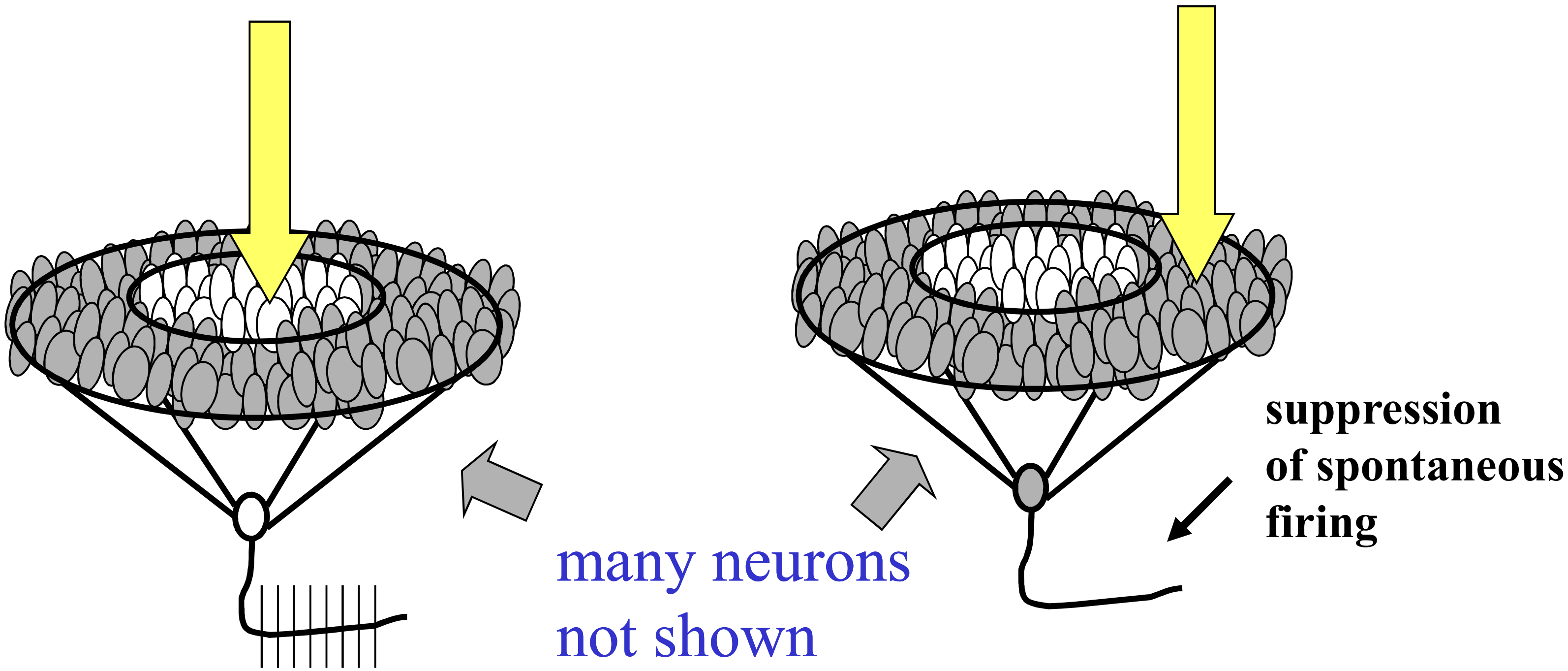


Figure 50–11

Neural organization of the retina: peripheral area to the left, foveal area to the right.

- Ganglion Cells
  - In the central fovea, no. of optic fibers match no. of cones, thus high acuity
  - Greater sensitivity of the peripheral retina to weak light
    - Rods are 30 to 300 times more sensitive to light than the cones
    - Many as 200 rods converge on a single optic fiber so that more signals from the rods summate to give more intense stimulation of the peripheral ganglion cells
  - Three types of ganglion cells
    - W cell: receive most of excitation from rods, thus transmission of rod vision
    - X cell: transmission of visual image and color
    - Y cell: transmit instantaneous changes in the visual image
  - Excitation of ganglion cells
    - From the ganglion cells to the brain, electronic conduction is no longer appropriate due to its travel distance. Use action potentials that are spontaneous and continuous
    - On-off or off-on response of ganglion cells: transmission of changes in light intensity by the on-off response
    - Transmission of signals depicting contrasts in the visual scene – the role of lateral inhibition



Many believe that the basis for this selective response can be found in the design of **receptive fields**

In vertebrates, the receptive fields of ganglion cells commonly have a "center/surround" design.

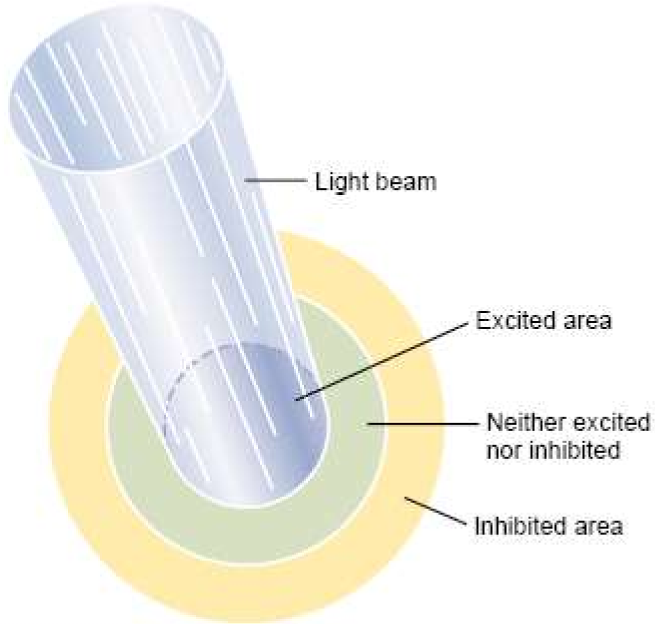
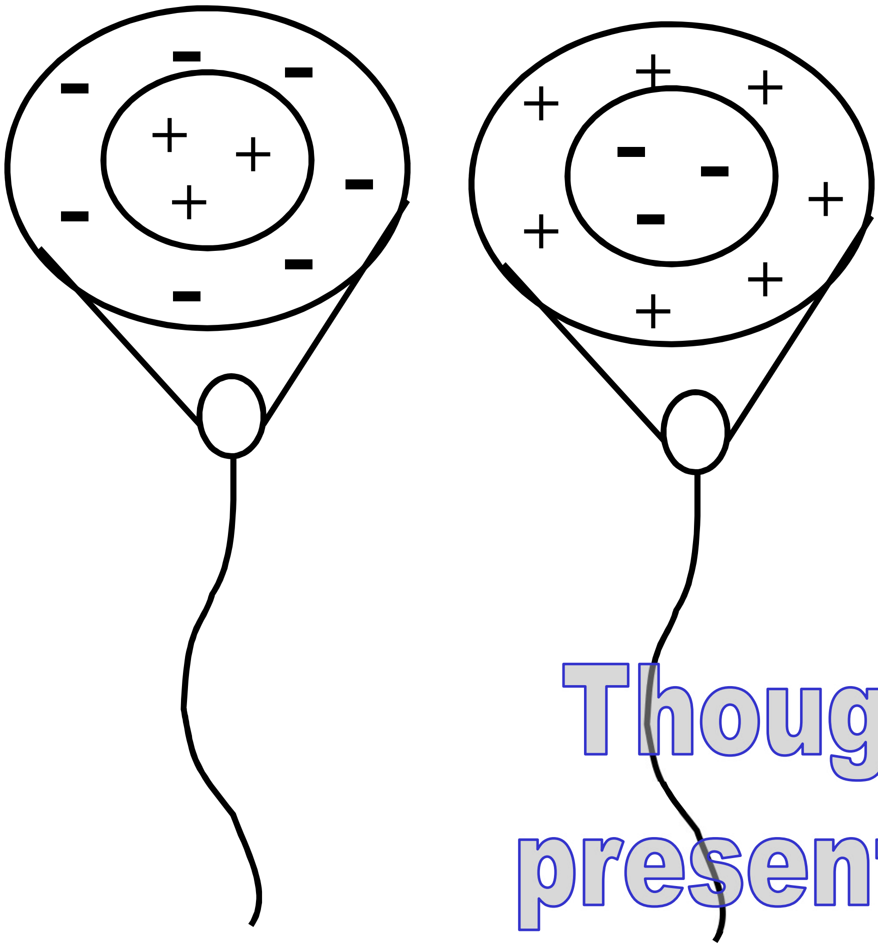


Figure 50–12

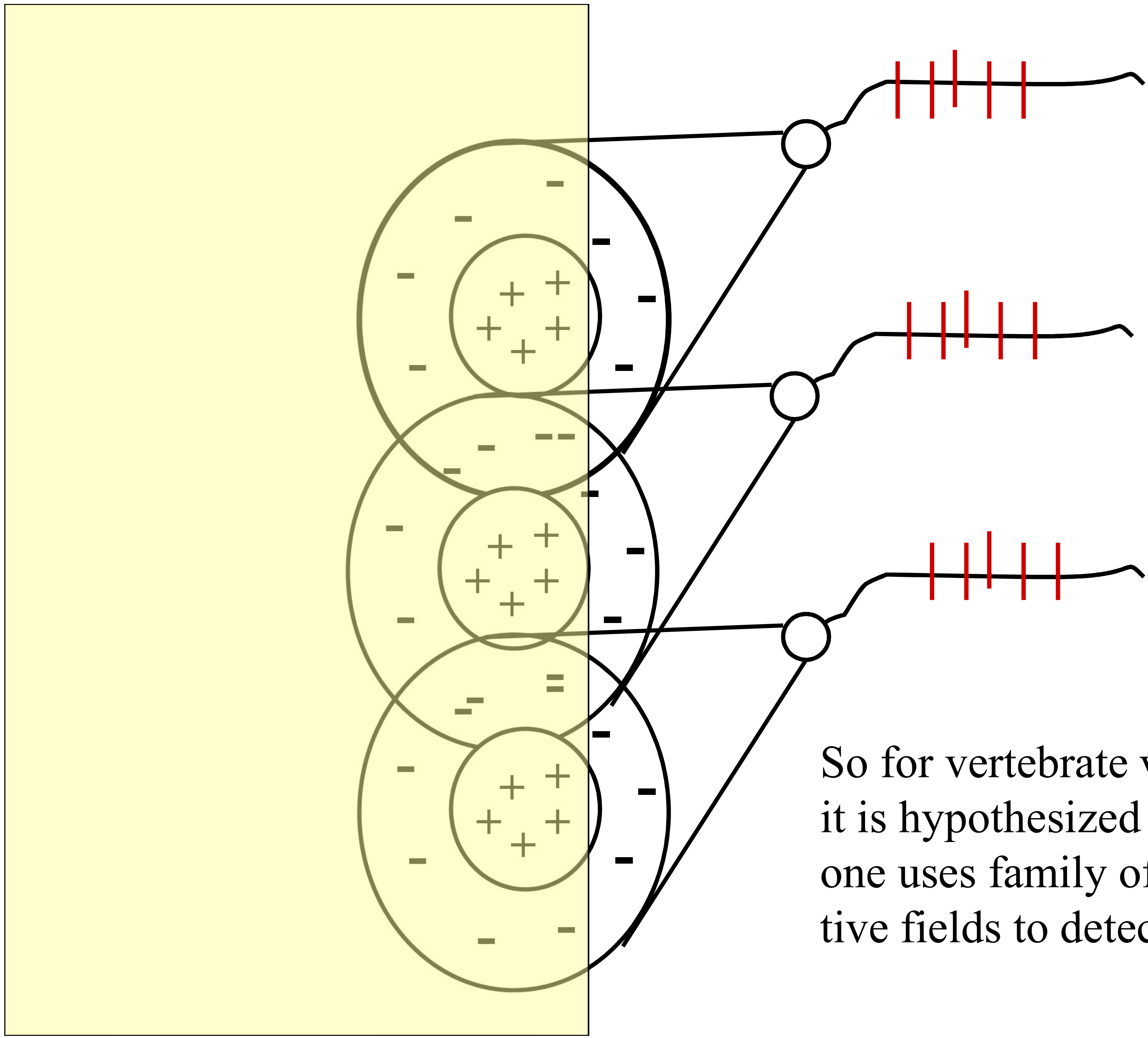
Excitation and inhibition of a retinal area caused by a small beam of light, demonstrating the principle of lateral inhibition.



Some fields are excited by light which falls on the center, and inhibited by light which falls on the surround.

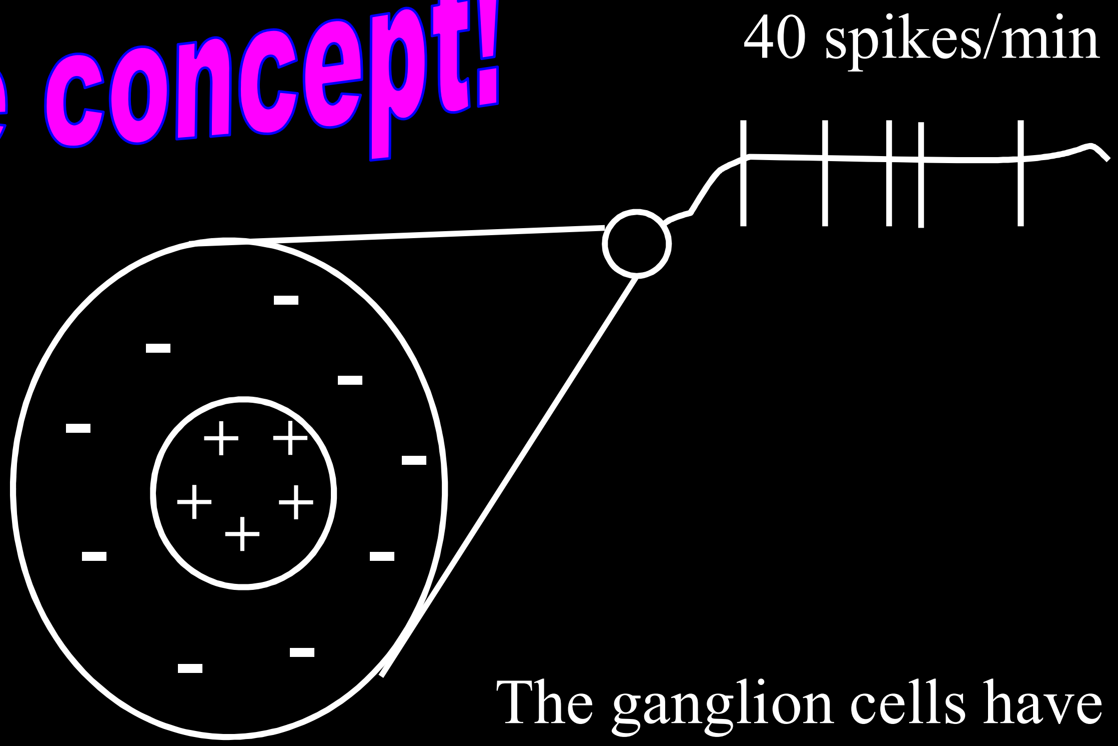
Others respond in the reverse.

Though both kinds are present, explanations of vision tend to focus on the former.

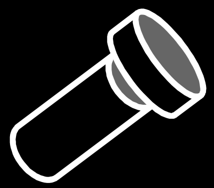


So for vertebrate vision,
it is hypothesized that
one uses family of receptive fields to detect edges.

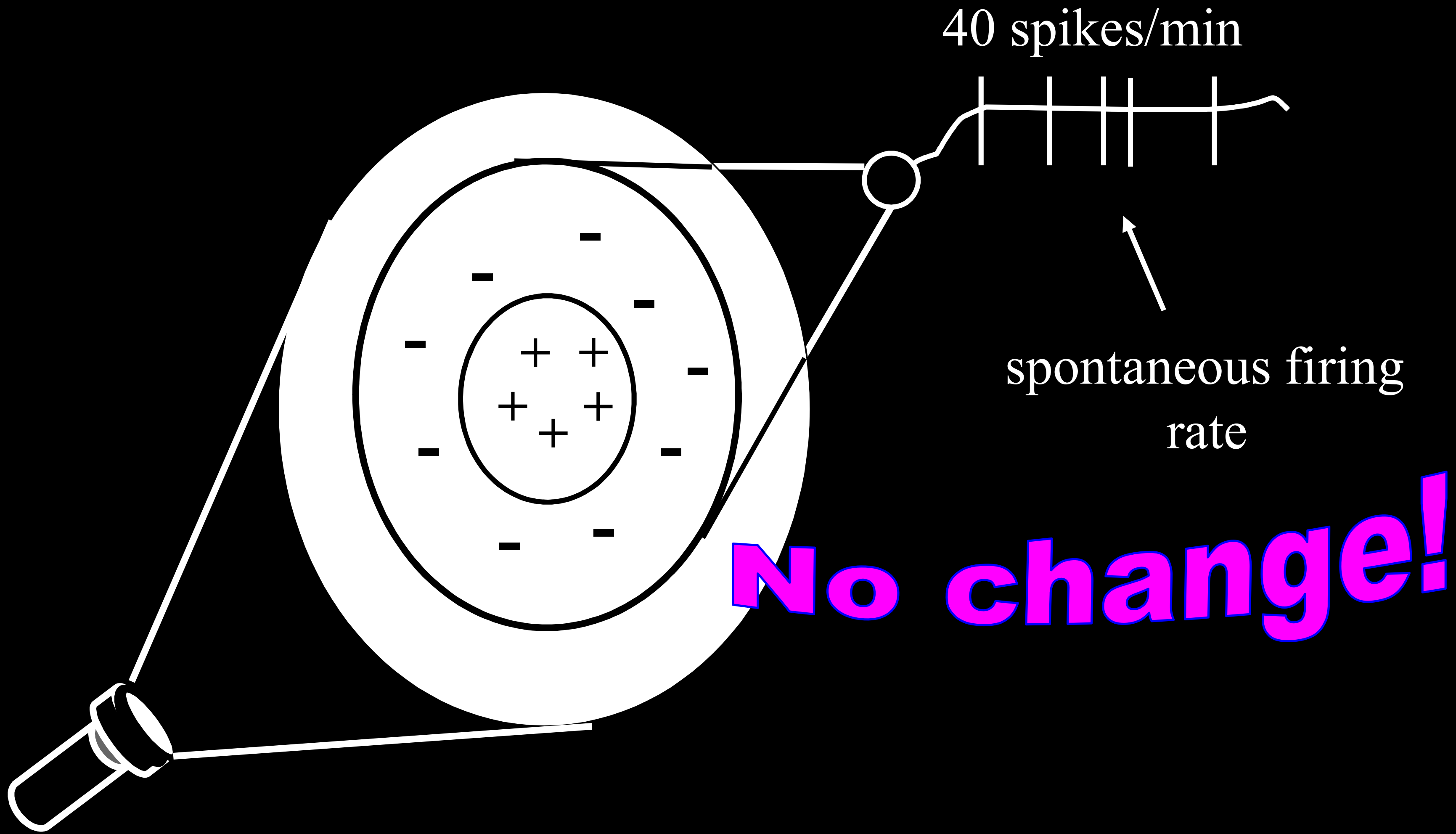
Here's the concept!



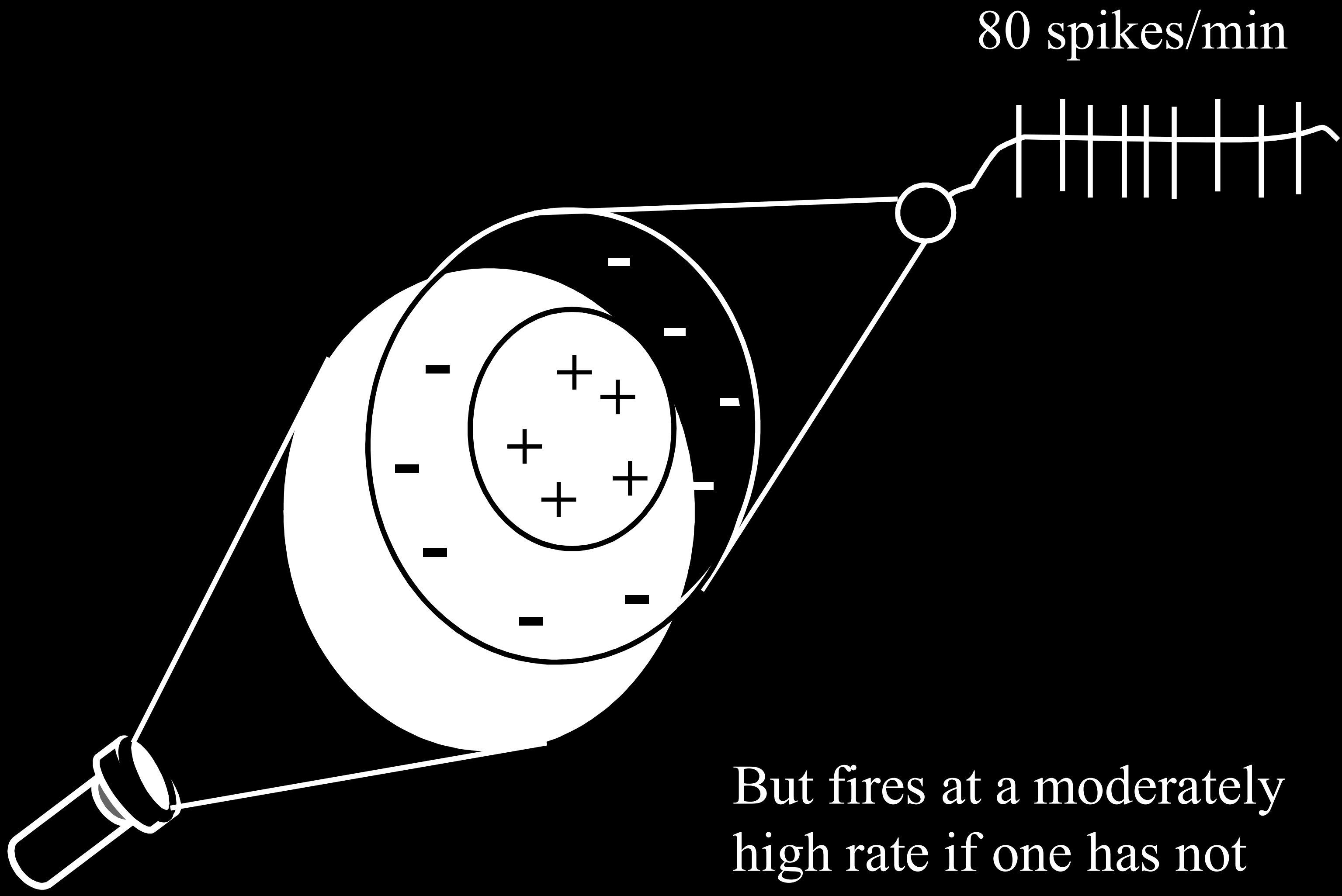
The ganglion cells have a low level of spontaneous firing ...



... so they generate spikes even in the dark.



Uniform light provides
equal amounts of excitatory
and inhibitory influence.

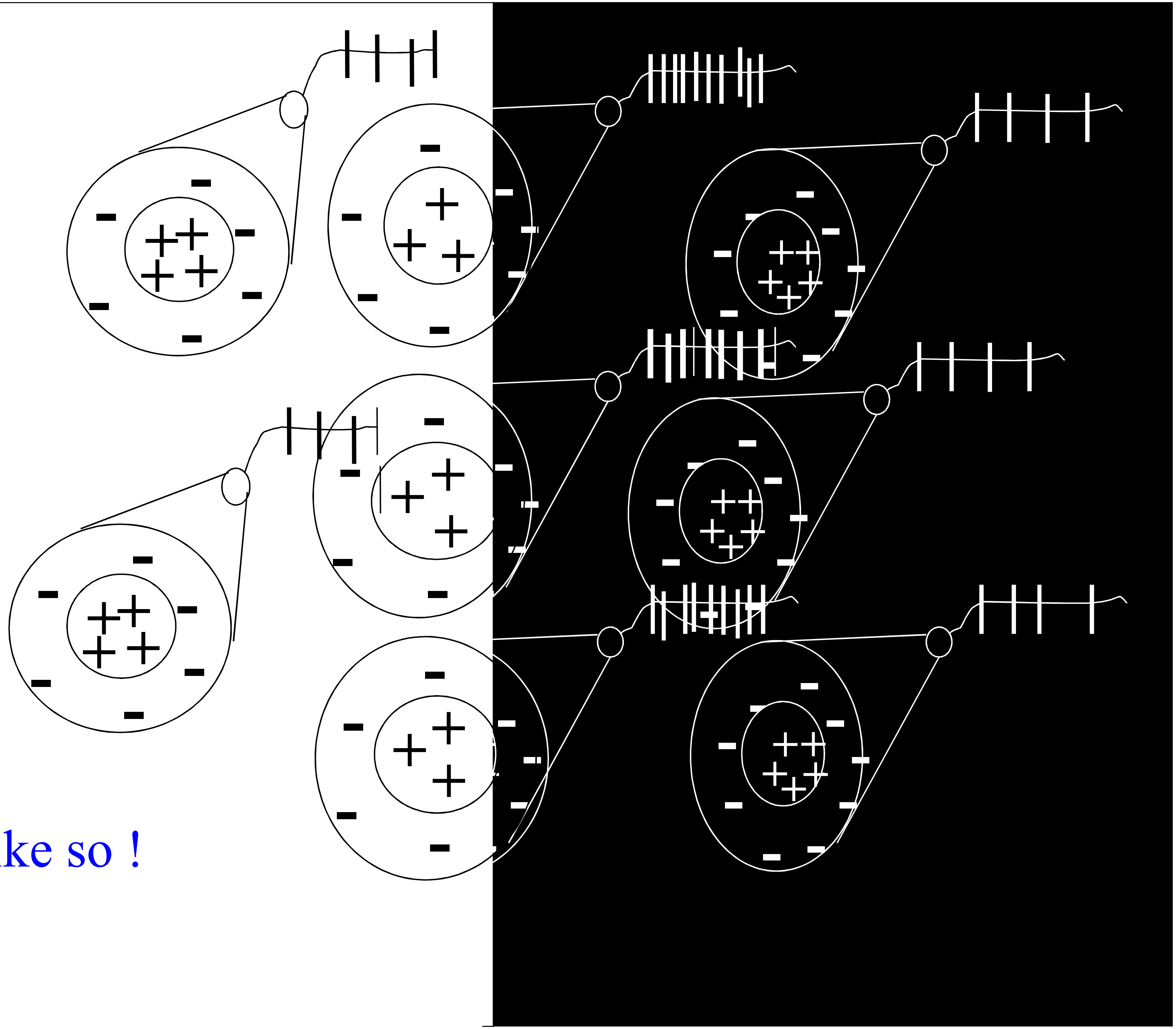


But fires at a moderately high rate if one has not covered all of the inhibitory field.

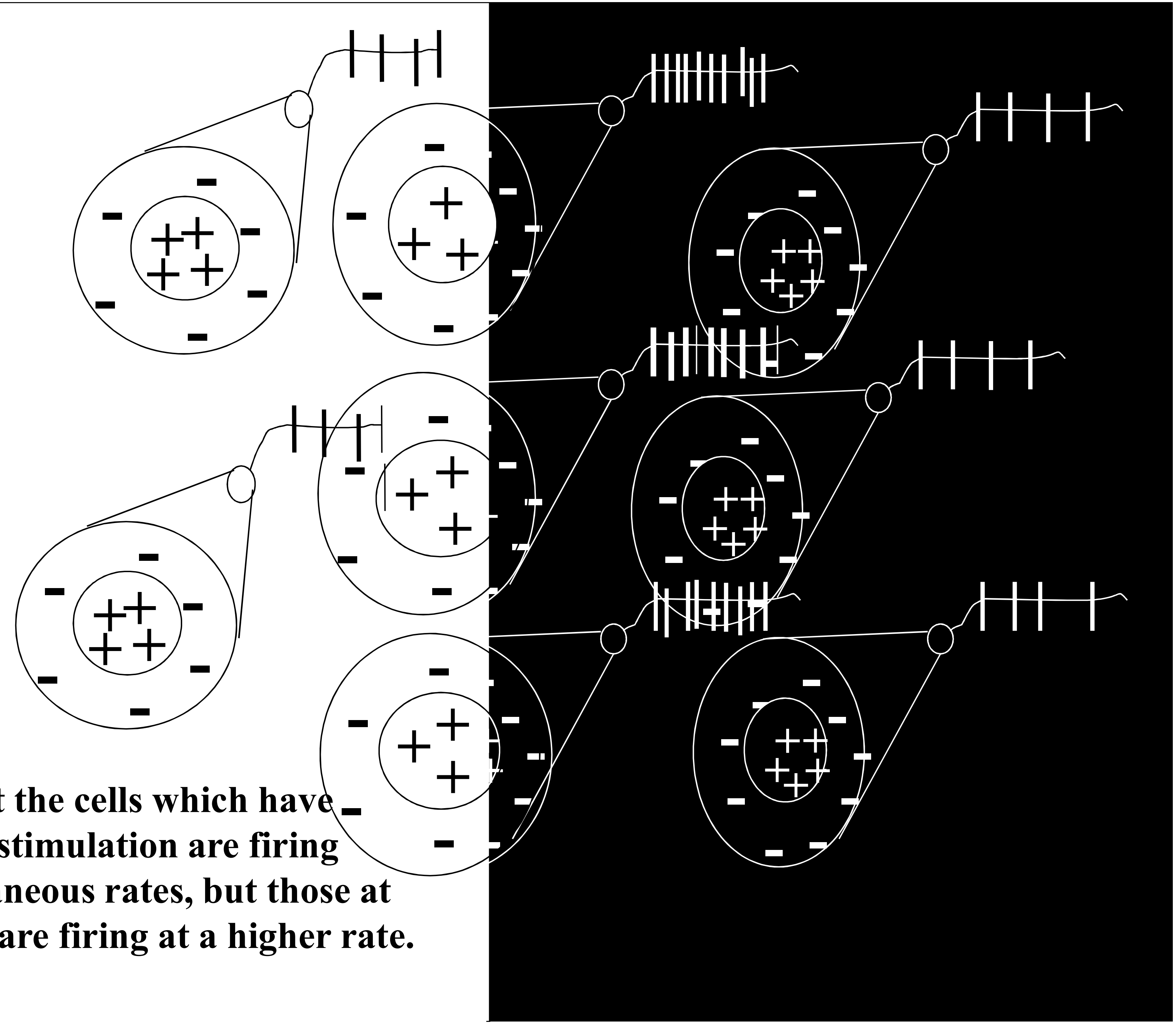
So theorists have suggested that these properties might be used for registering the transition between bright and dark ...

... in other words, detecting

EDGES



Like so !



Note that the cells which have uniform stimulation are firing at spontaneous rates, but those at the edge are firing at a higher rate.