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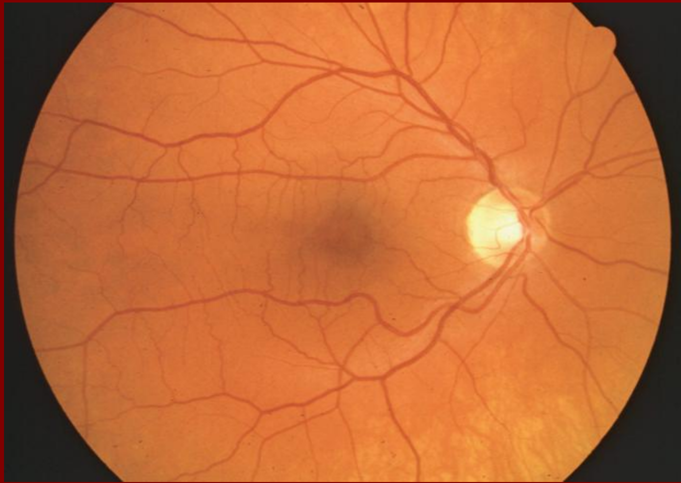
The First Steps in Vision: From Light to Neural Signals



Chapter 2 The First Steps in Vision: From Light to Neural Signals

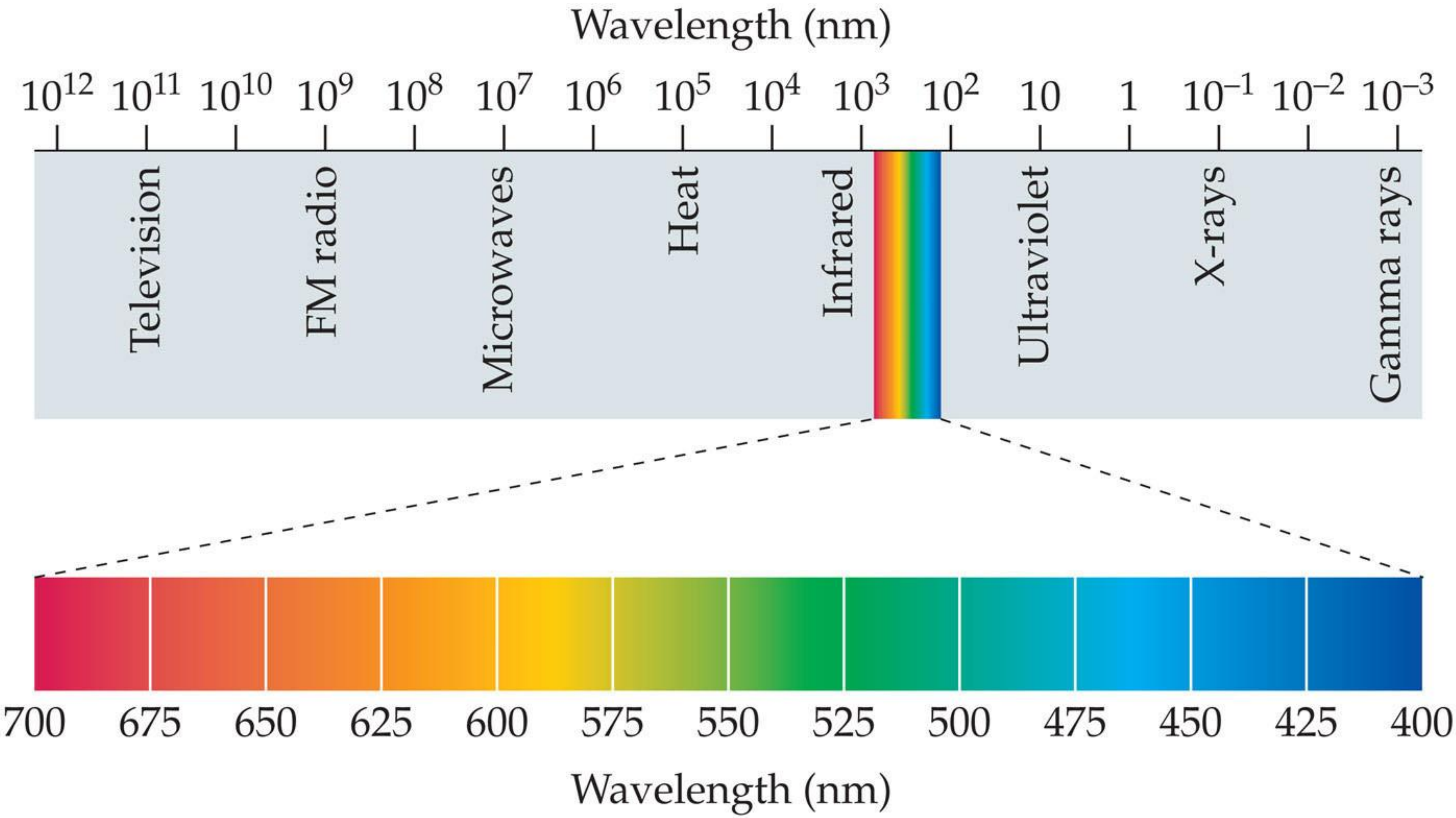
- A Little Light Physics
- Eyes That Capture Light
- Retinal Information Processing
- Dark and Light Adaptation

A Little Light Physics

Light: A narrow band of electromagnetic radiation that can be conceptualized as a wave or a stream of photons.

Photon: A quantum of visible light (or other form of electromagnetic radiation) demonstrating both particle and wave properties.

Figure 2.1 The spectrum of electromagnetic energy, with the visible spectrum expanded below



***SENSATION & PERCEPTION 4e*, Figure 2.1**

A Little Light Physics

Light can be absorbed, scattered, reflected, transmitted, or refracted.

- Absorbed: Energy (e.g., light) that is taken up and is not transmitted at all.
- Scattered: Energy that is dispersed in an irregular fashion.
  - When light enters the atmosphere, much of it is absorbed or scattered and never makes it to the perceiver.

A Little Light Physics

- Reflected: Energy that is redirected when it strikes a surface, usually back to its point of origin.
- Transmitted: Energy that is passed on through a surface (when it is neither reflected nor absorbed by the surface).
- Refracted: Energy that is altered as it passes into another medium.

Eyes That Capture Light

The human eye is made up of various parts

- Cornea: The transparent “window” into the eyeball.
- Aqueous humor: The watery fluid in the anterior chamber.
- Crystalline lens: The lens inside the eye, which focuses light onto the back of the eye.

Eyes That Capture Light

The human eye is made up of various parts (*continued*)

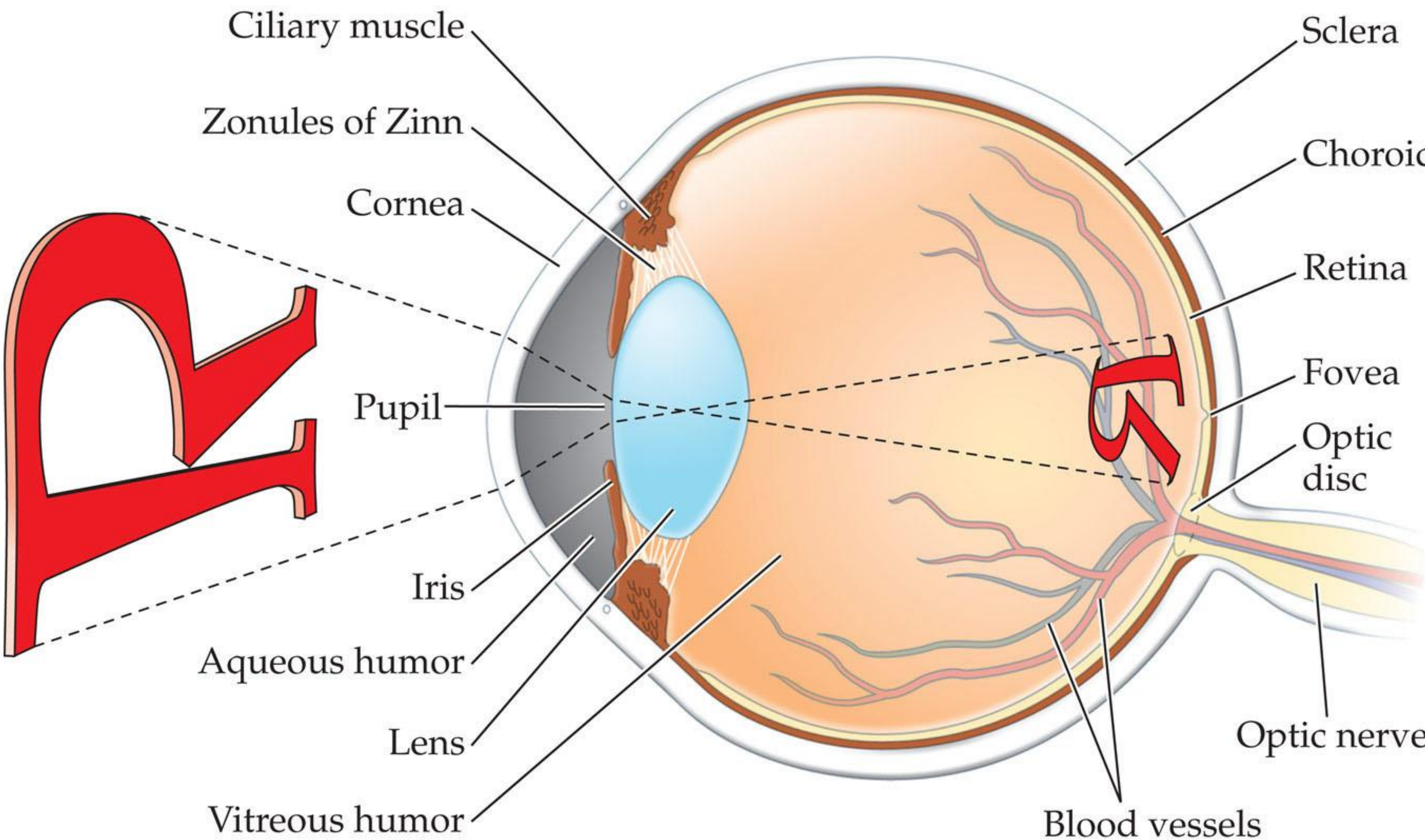
- Pupil: The dark circular opening at the center of the iris in the eye, where light enters the eye.
- Iris: The colored part of the eye, a muscular diaphragm, that regulates light entering the eye by expanding and contracting the pupil.

Eyes That Capture Light

The human eye is made up of various parts (*continued*)

- Vitreous humor: The transparent fluid that fills the large chamber in the posterior part of the eye.
- Retina: A light-sensitive membrane in the back of the eye that contains rods and cones. The lens focuses an image on the retina, which then sends signals to the brain through the optic nerve.

Figure 2.2 The human right eye in cross section



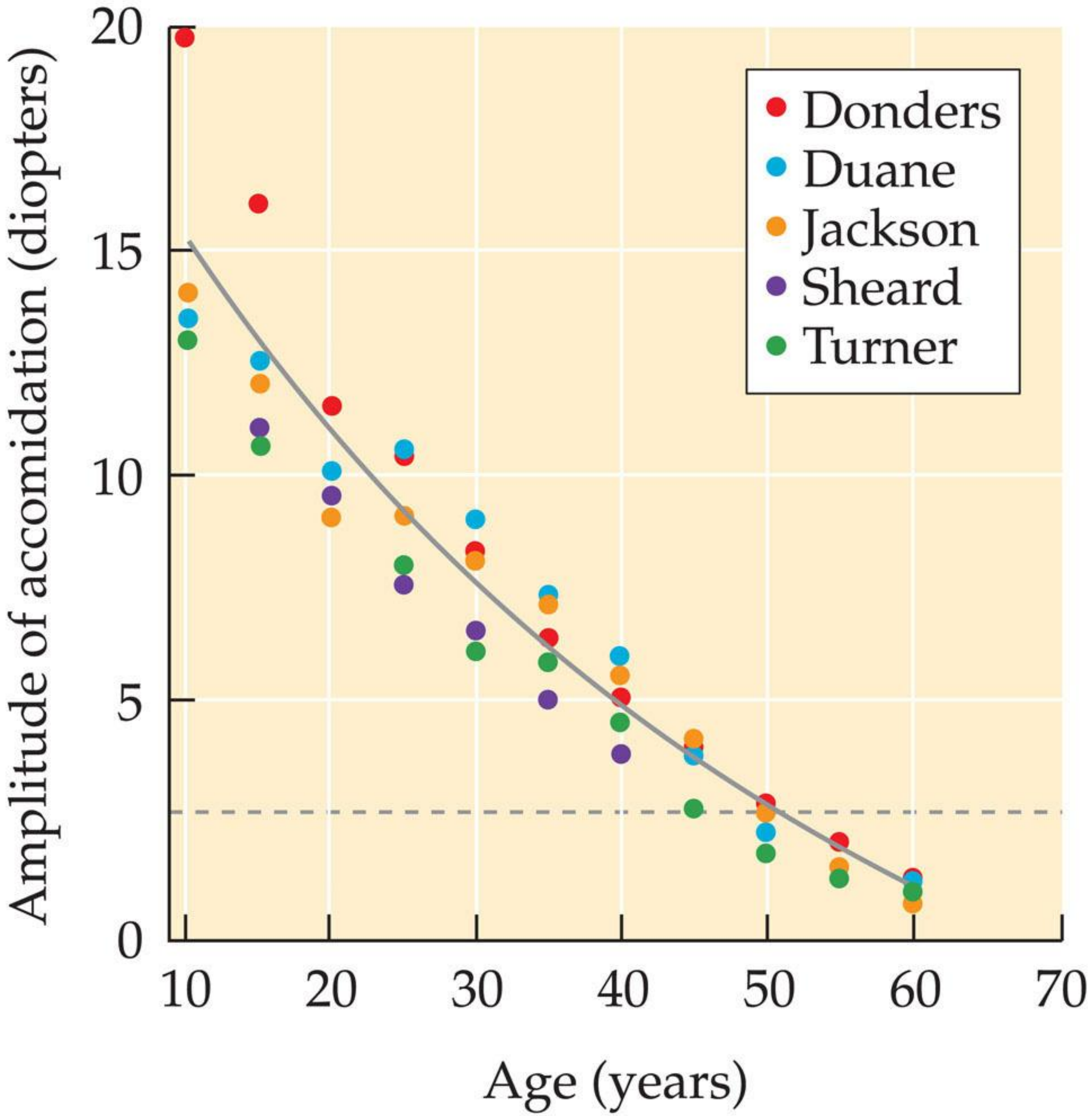
SENSATION & PERCEPTION 4e, Figure 2.2

Eyes That Capture Light

Refraction is necessary to focus light rays onto the retina and this is accomplished by the lens.

- Accommodation: The process in which the lens changes its shape, thus altering its refractive power.
- Emmetropia: The happy condition of no refractive error.

Figure 2.5 The precipitous drop in amplitude of accommodation with age



SENSATION & PERCEPTION 4e, Figure 2.5

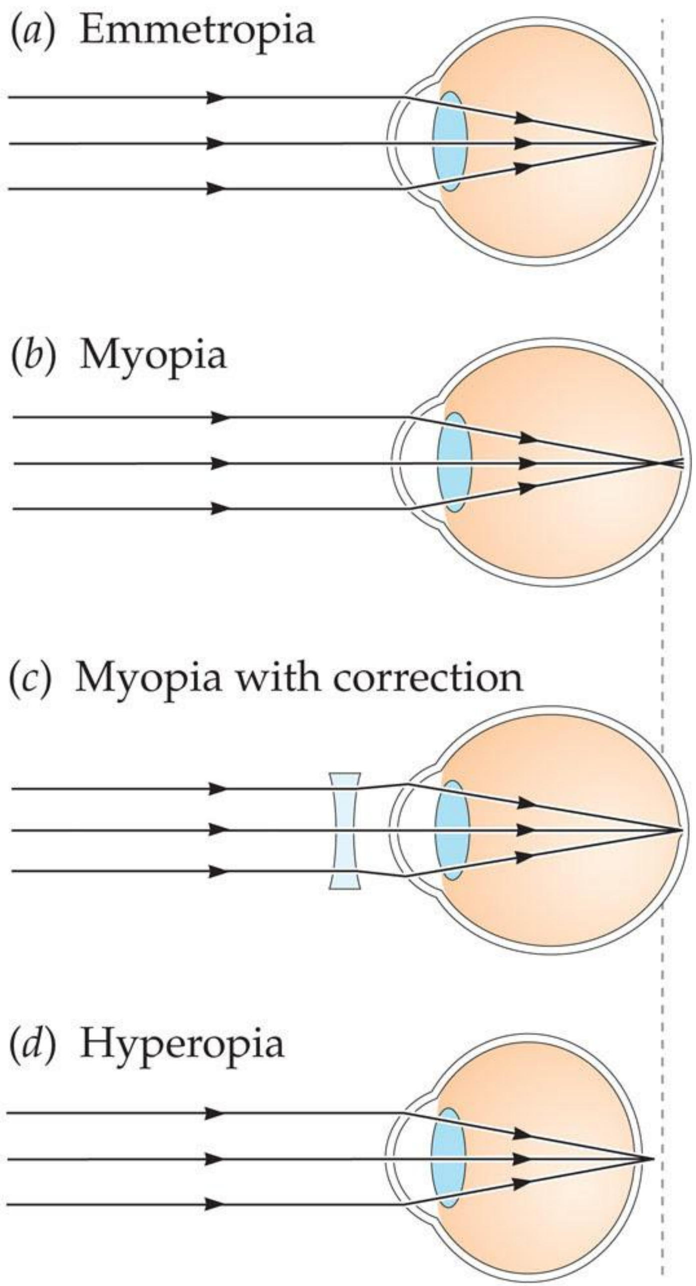
Problems of refraction

- The lens may focus the image either in front of or behind the retina. In these cases, corrective lenses are needed for normal vision.
- Myopia: When light is focused in front of the retina and distant objects cannot be seen sharply; *nearsightedness*.

Problems of refraction (*continued*)

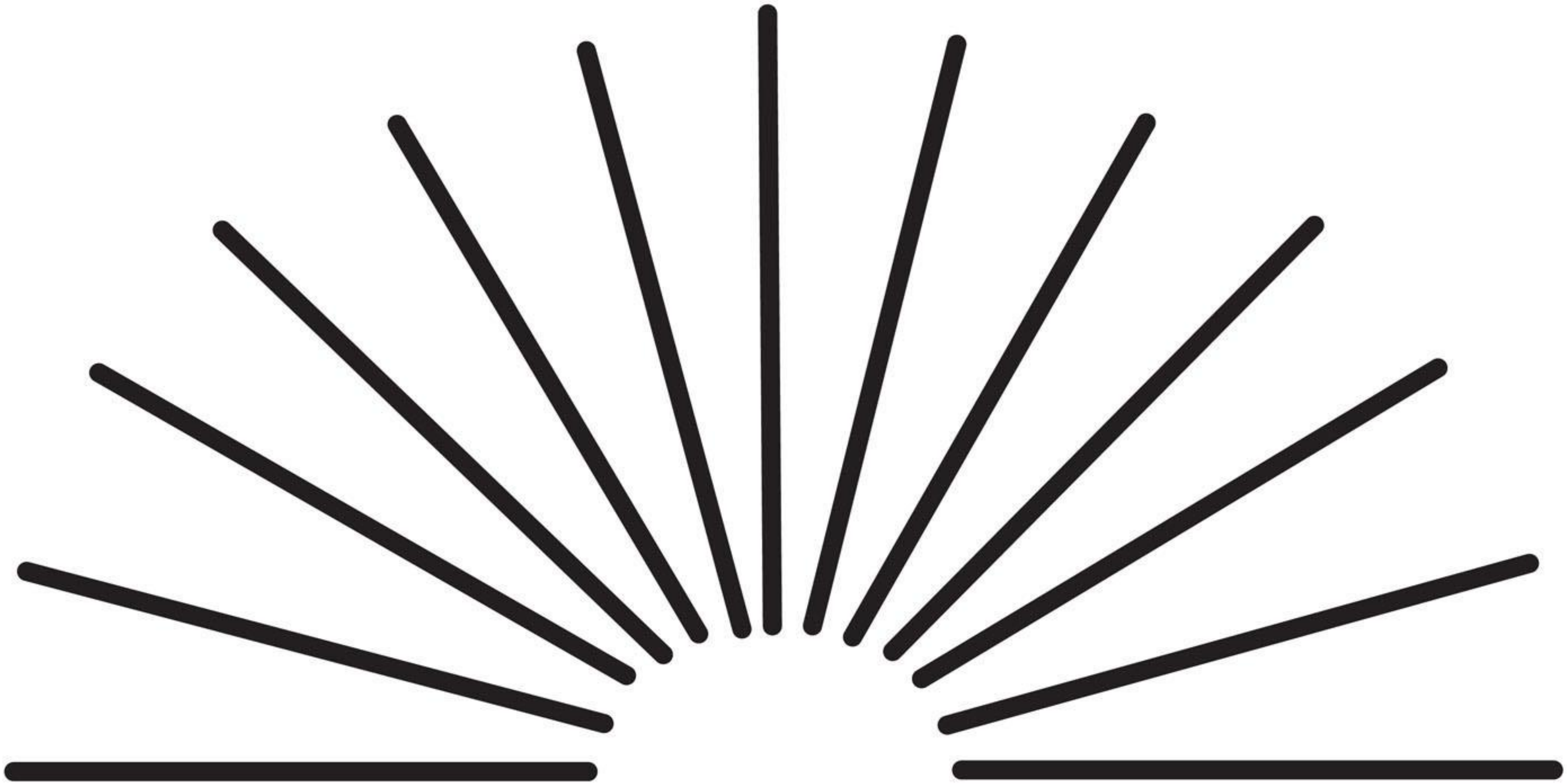
- Hyperopia: When light is focused behind the retina and near objects cannot be seen sharply; *farsightedness*.
- Astigmatism: Unequal curving of one or more of the refractive surfaces of the eye, usually the cornea.

Figure 2.3 Optics of the human eye



SENSATION & PERCEPTION 4e, Figure 2.3

Figure 2.4 Fan chart for astigmatism



SENSATION & PERCEPTION 4e, Figure 2.4

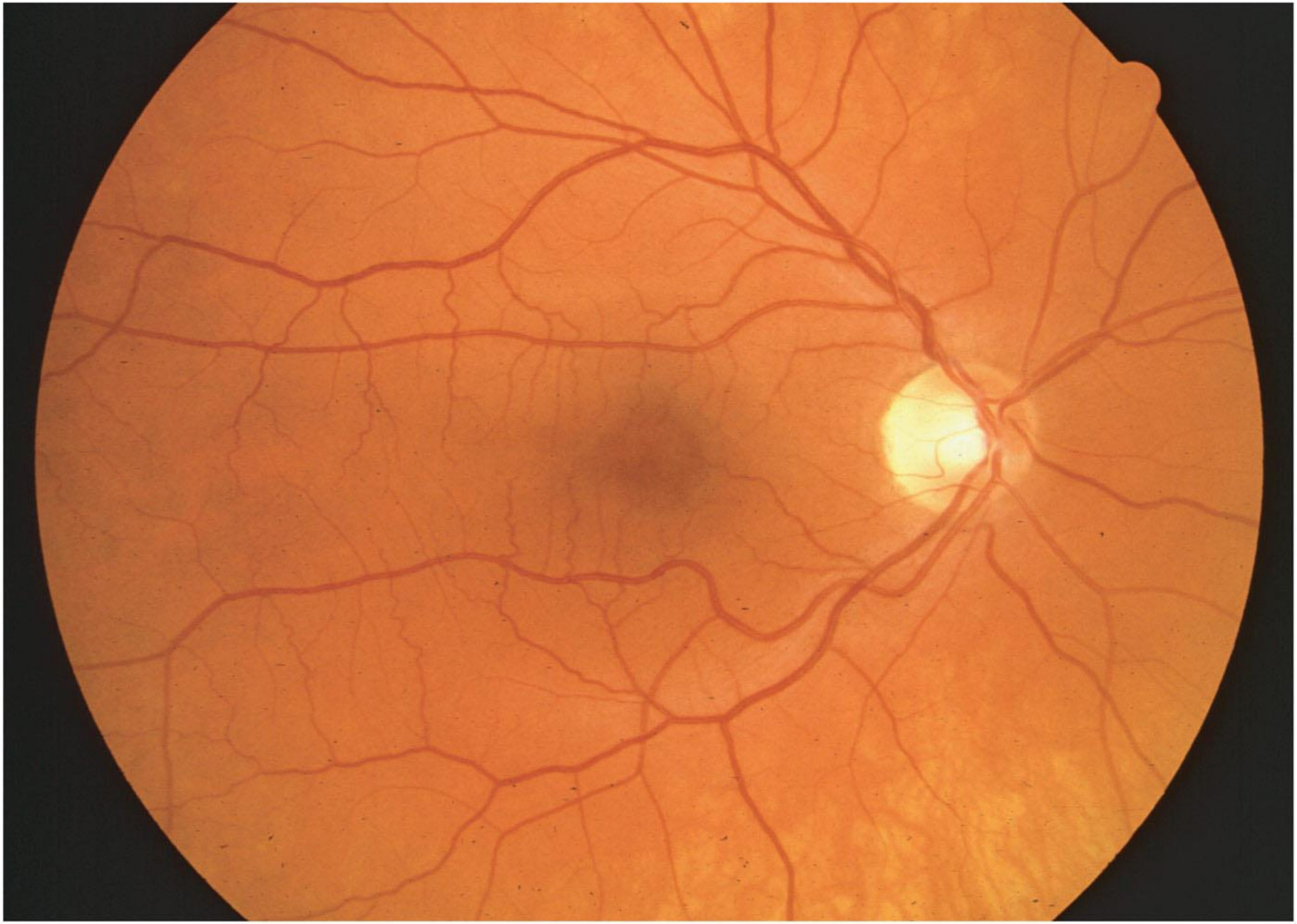
Camera analogy for the eye.

- F-stop: Iris/pupil—regulates the amount of light coming into the eye
- Focus: Lens—changes shape to change focus
- Film: Retina—records the image

Eyes That Capture Light

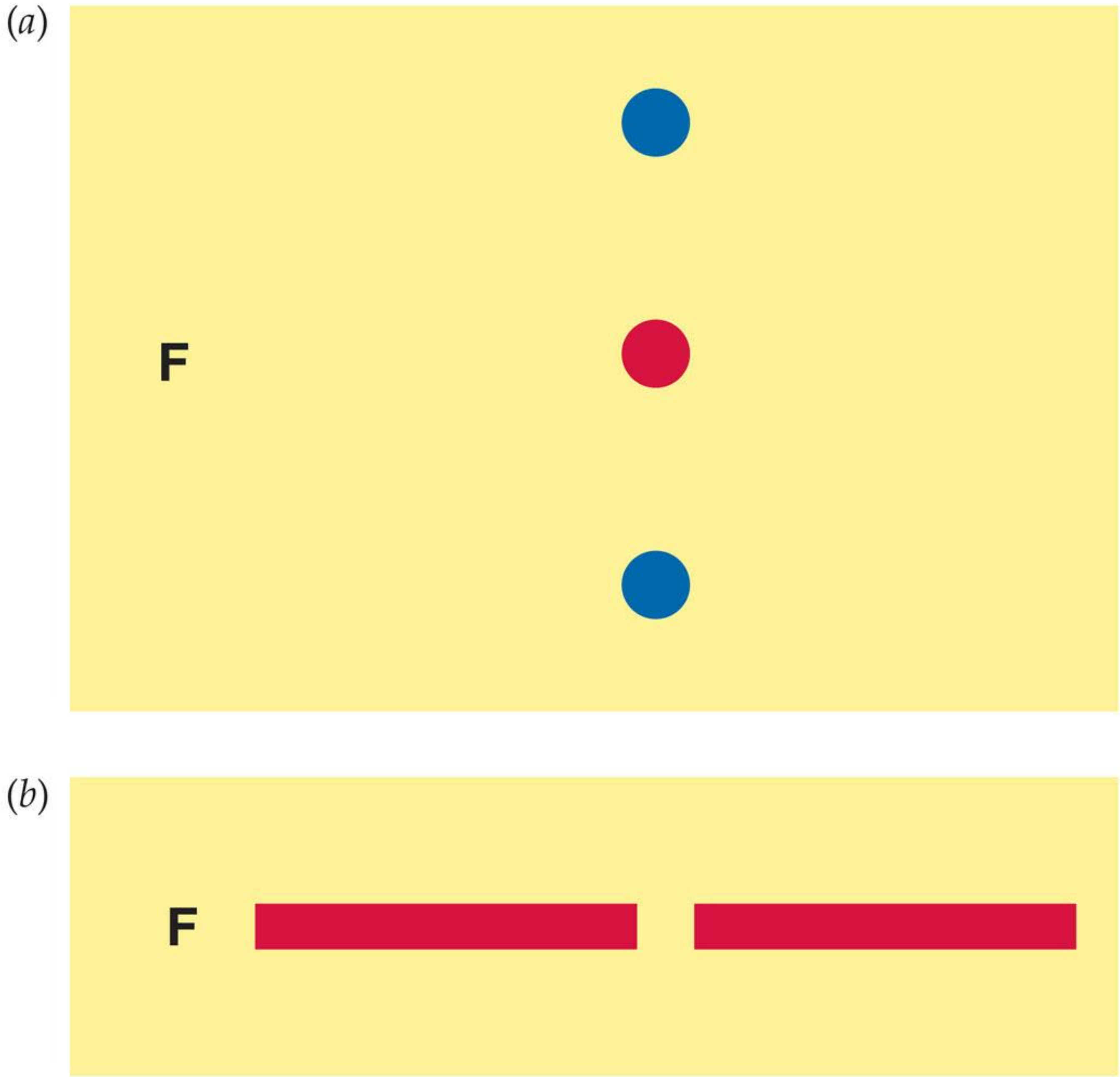
Using the ophthalmoscope, doctors can view the back surface of patients' eyes, called the *fundus*.

Figure 2.6 Fundus of the right eye of a human



SENSATION & PERCEPTION 4e, Figure 2.6

Figure 2.7 Blind spot



SENSATION & PERCEPTION 4e, Figure 2.7

Photoreceptors: Cells in the retina that initially transduce light energy into neural energy.

- Rods: Photoreceptors specialized for night vision.
  - Respond well in low luminance conditions
  - Do not process color

Eyes That Capture Light

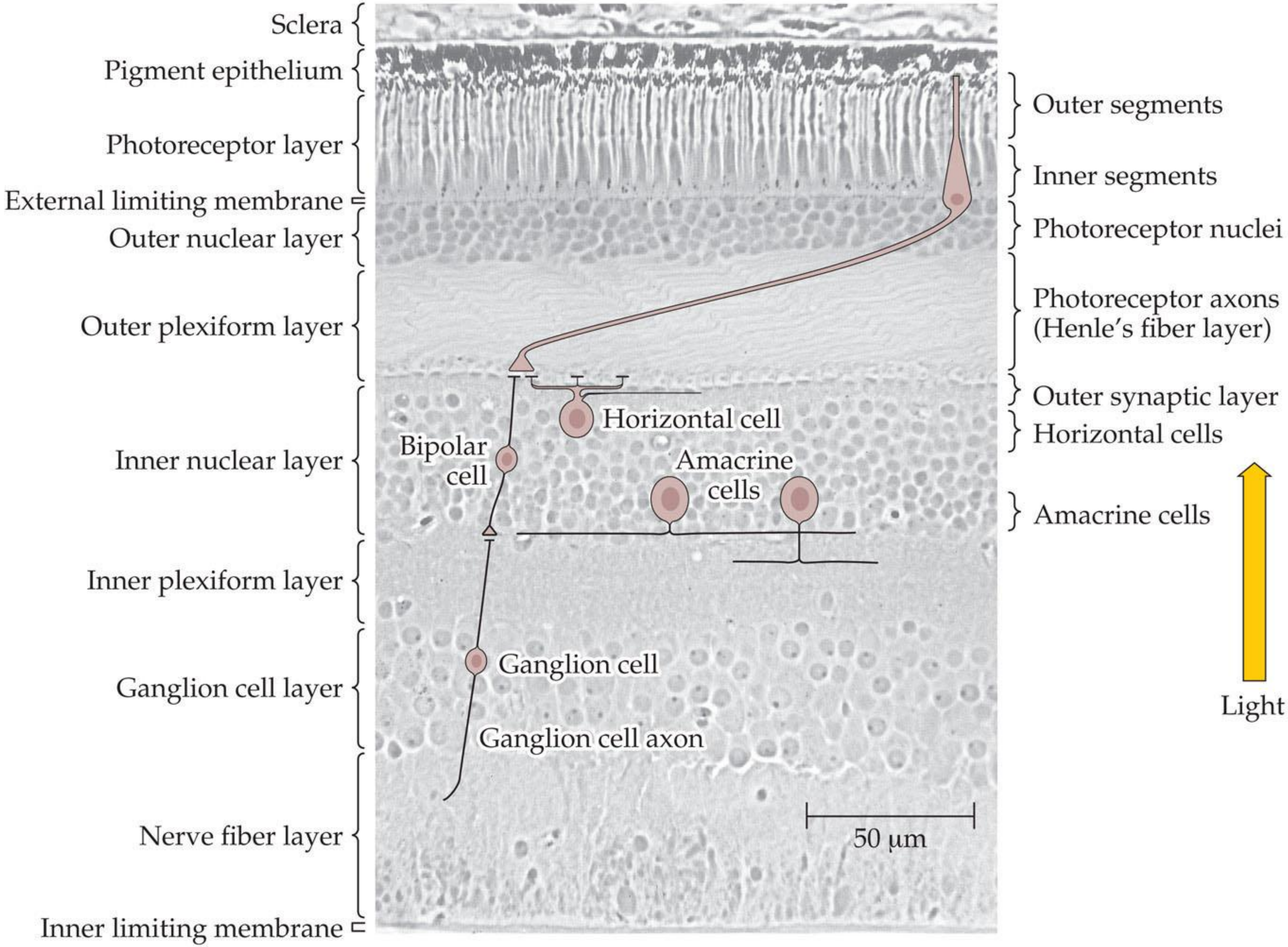
- Cones: Photoreceptors specialized daytime vision, fine visual acuity, and color.
  - Respond best in high luminance conditions

Eyes That Capture Light

Light passes through several layers of cells before reaching rods and cones.

- Light activates a photoreceptor, which signals the horizontal and bipolar cells that synapse with it.
- Bipolar cells are connected to amacrine cells and ganglion cells.
- Ganglion cells have axons that leave the retina through the optic disc (blind spot).

Figure 2.8 Photomicrograph of the retina

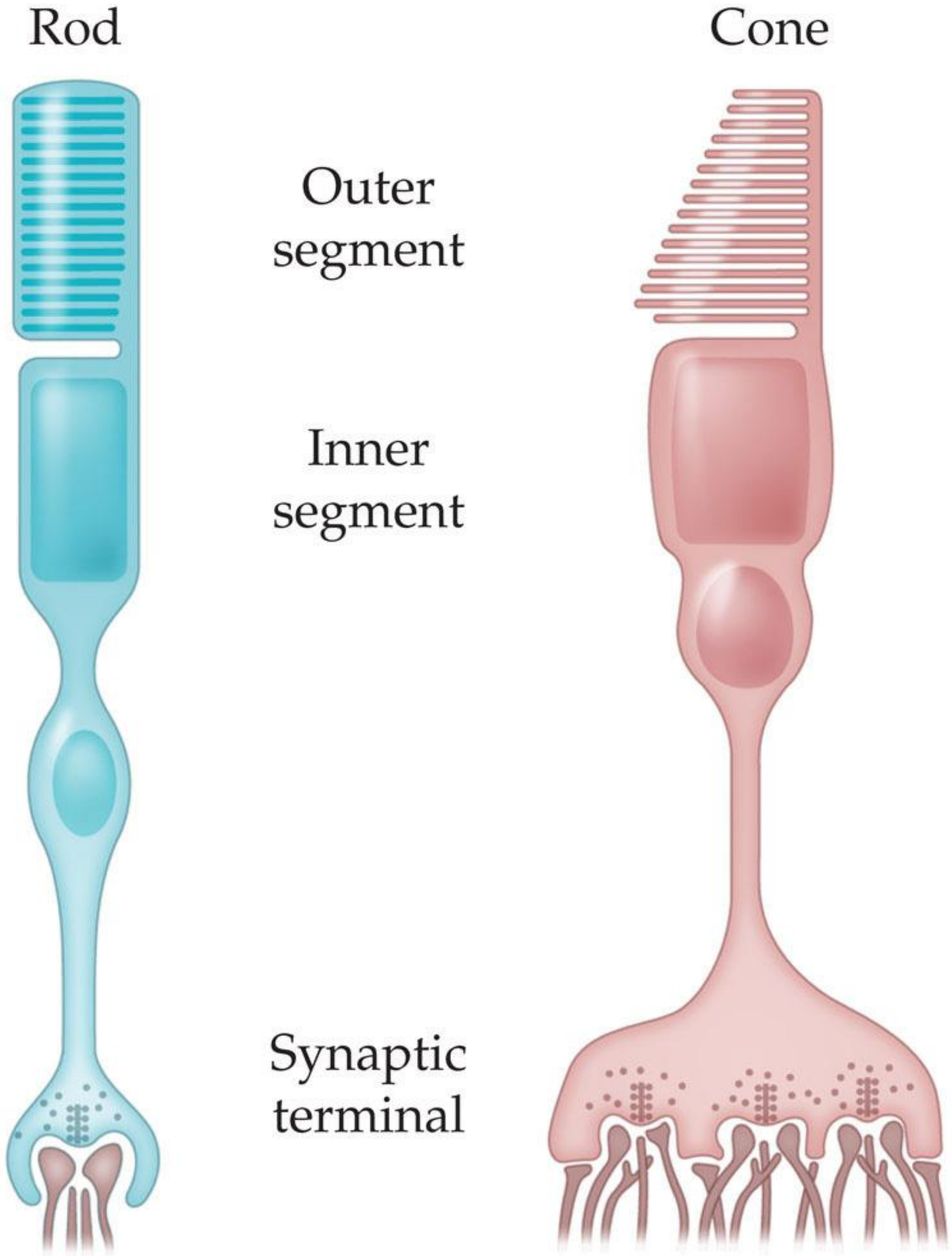


SENSATION & PERCEPTION 4e, Figure 2.8

Eyes That Capture Light

Rods and cones are so named because of their respective shapes.

Figure 2.9 Rod and cone



SENSATION & PERCEPTION 4e, **Figure 2.9**

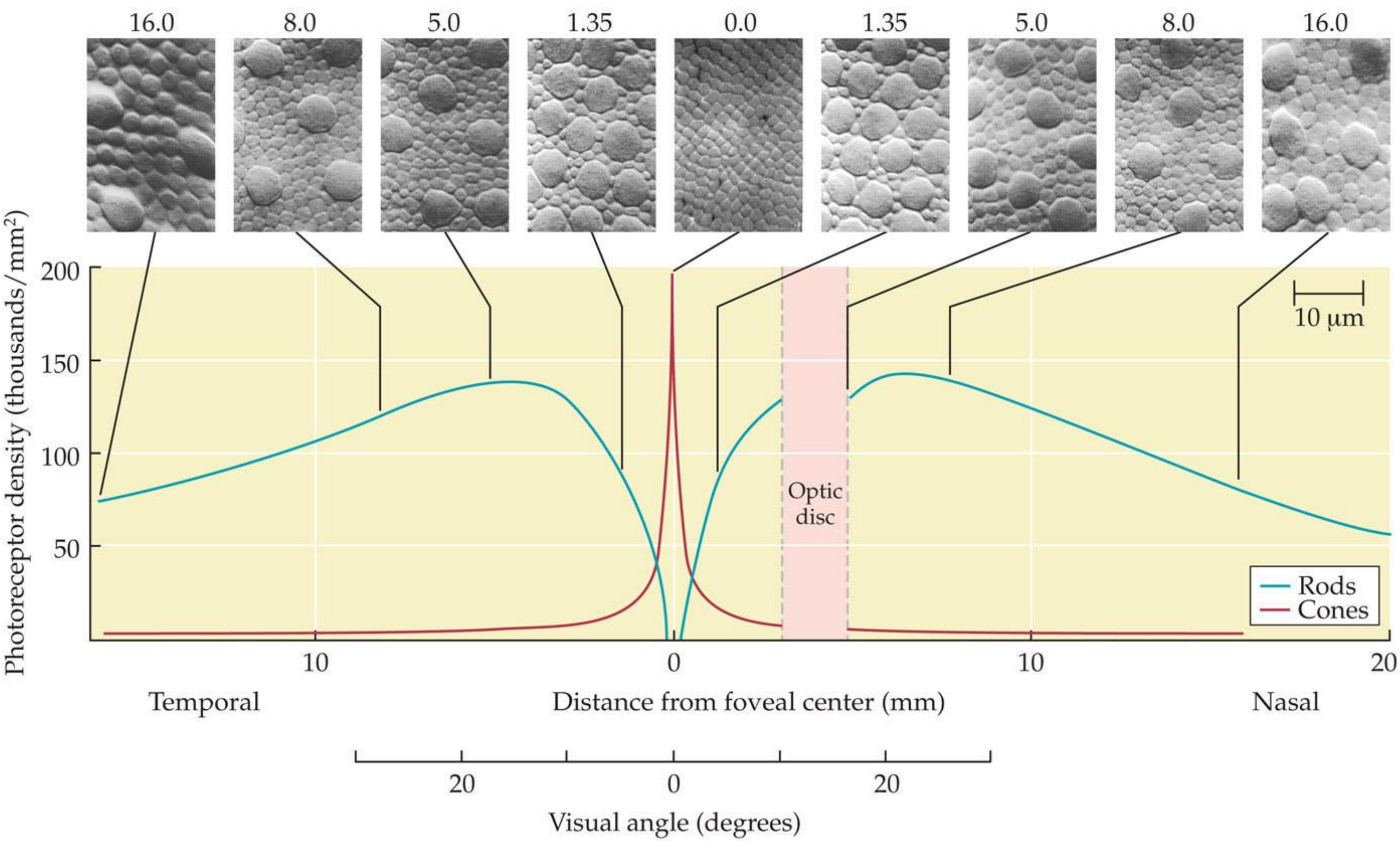
Eyes That Capture Light

The distribution of rods and cones is not constant over the retina.

Cones process color; rods do not.

This means that you have very poor color vision in your periphery. It may seem as if your entire field of view has full-resolution color, but it does not.

Figure 2.10 Photoreceptor density across the retina



SENSATION & PERCEPTION 4e, Figure 2.10

Eyes That Capture Light

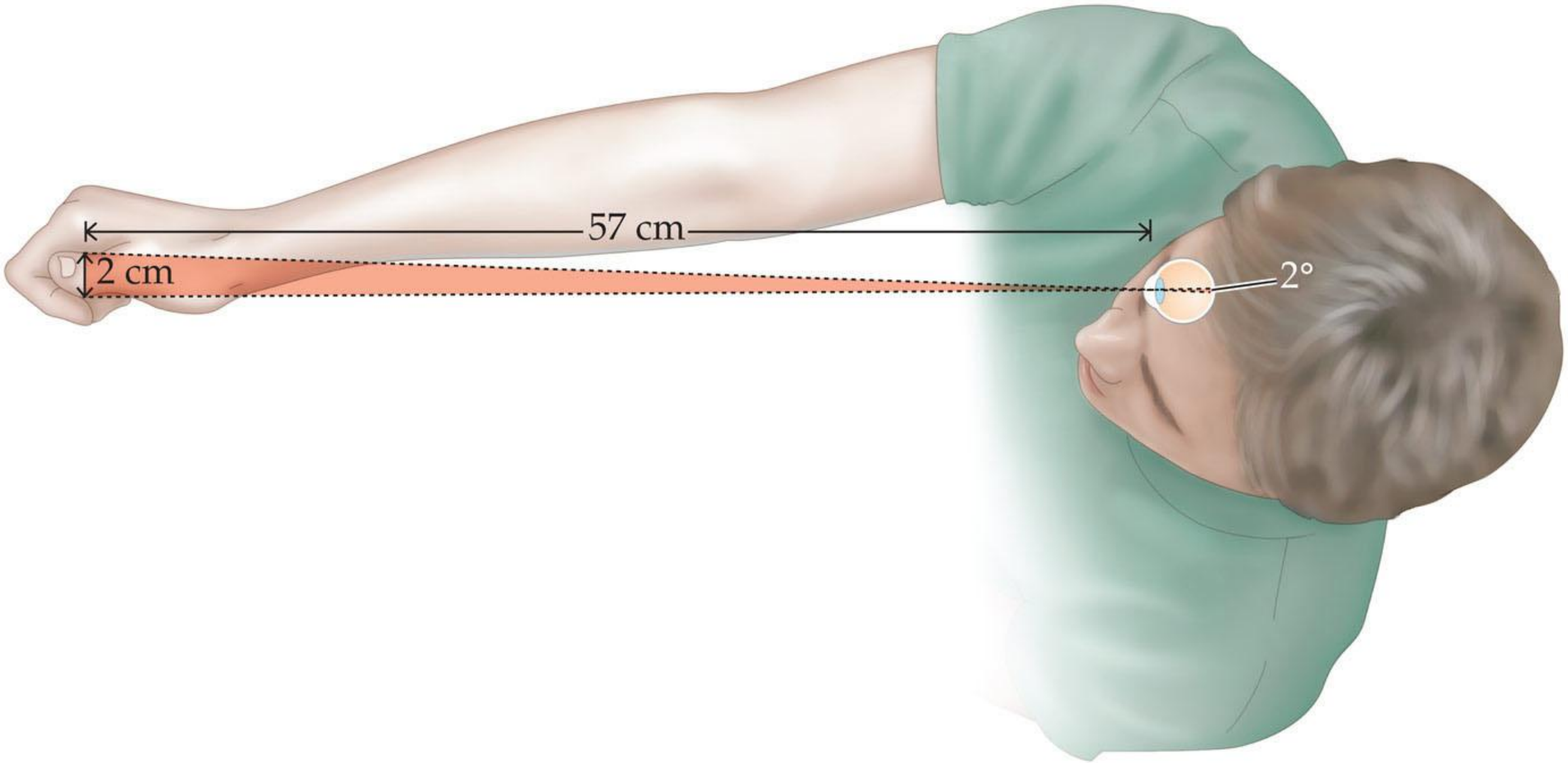
Vision scientists measure the size of visual stimuli by how large an image appears on the retina, not by how large the object is.

The standard way to measure retinal size is in terms of "degrees of visual angle."

Rule of thumb: If you hold your thumb out at arms length, the width of your thumbnail is about 2 degrees of visual angle.

In summary: The visual angle of an object is a function of both its actual size and distance from the observer.

Figure 2.11 The “rule of thumb”: when viewed at arm’s length, your thumb subtends an angle of about 2 degrees on the retina



SENSATION & PERCEPTION 4e, Figure 2.11

TABLE 2.1
Properties of the fovea and periphery in human vision

Property	Fovea	Periphery
Photoreceptor type	Mostly cones	Mostly rods
Bipolar cell type	Midget	Diffuse
Convergence	Low	High
Receptive-field size	Small	Large
Acuity (detail)	High	Low
Light sensitivity	Low	High

SENSATION & PERCEPTION 4e, Table 2.1

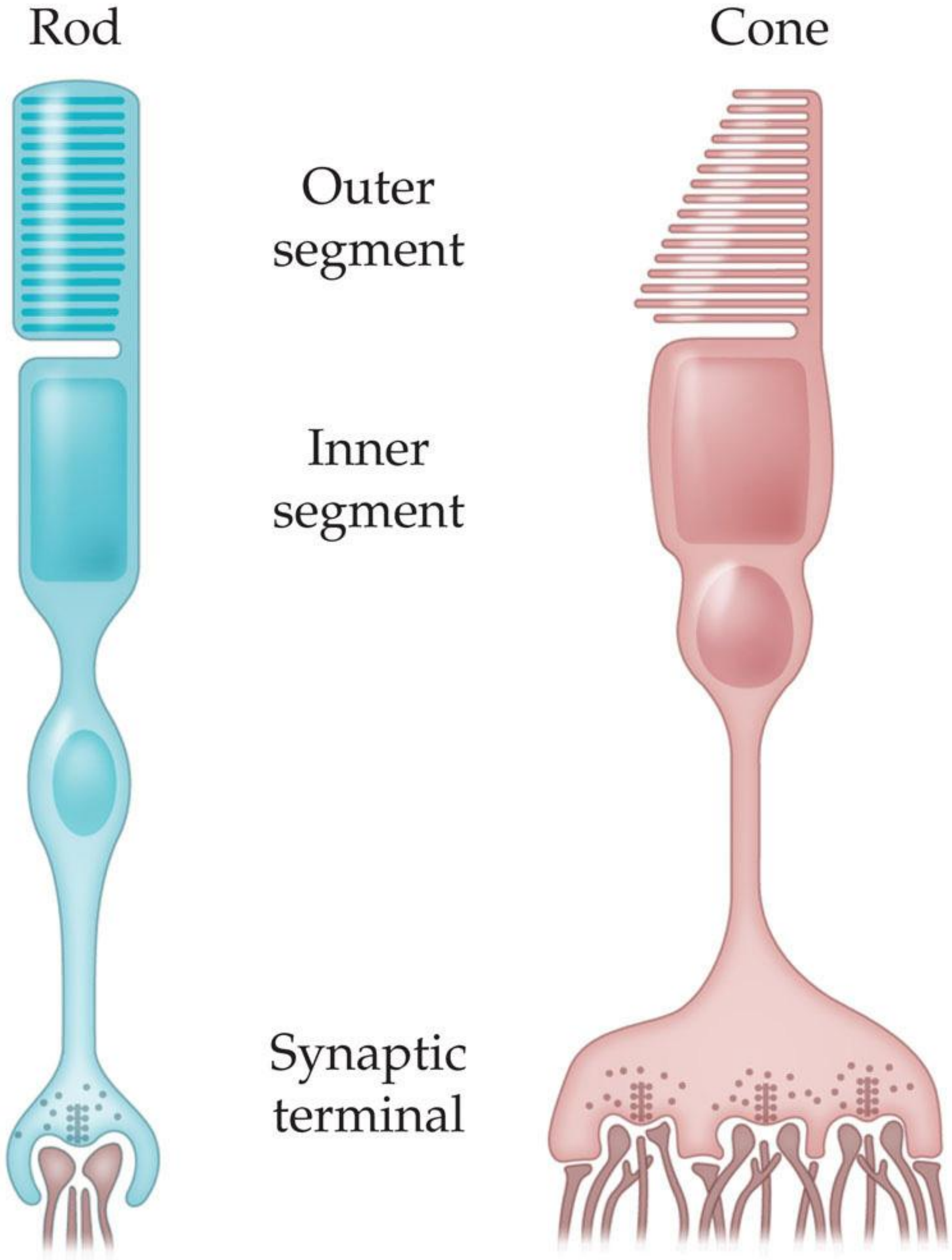
Retinal Information Processing

Capturing a photon: When light hits a photoreceptor, the process of photoactivation begins.

Photoreceptors

- Contain an outer segment (adjacent to the pigment epithelium), an inner segment, and a synaptic terminal.
- Visual pigments are manufactured in the inner segment and then stored in the outer segment.

Figure 2.9 Rod and cone



SENSATION & PERCEPTION 4e, Figure 2.9

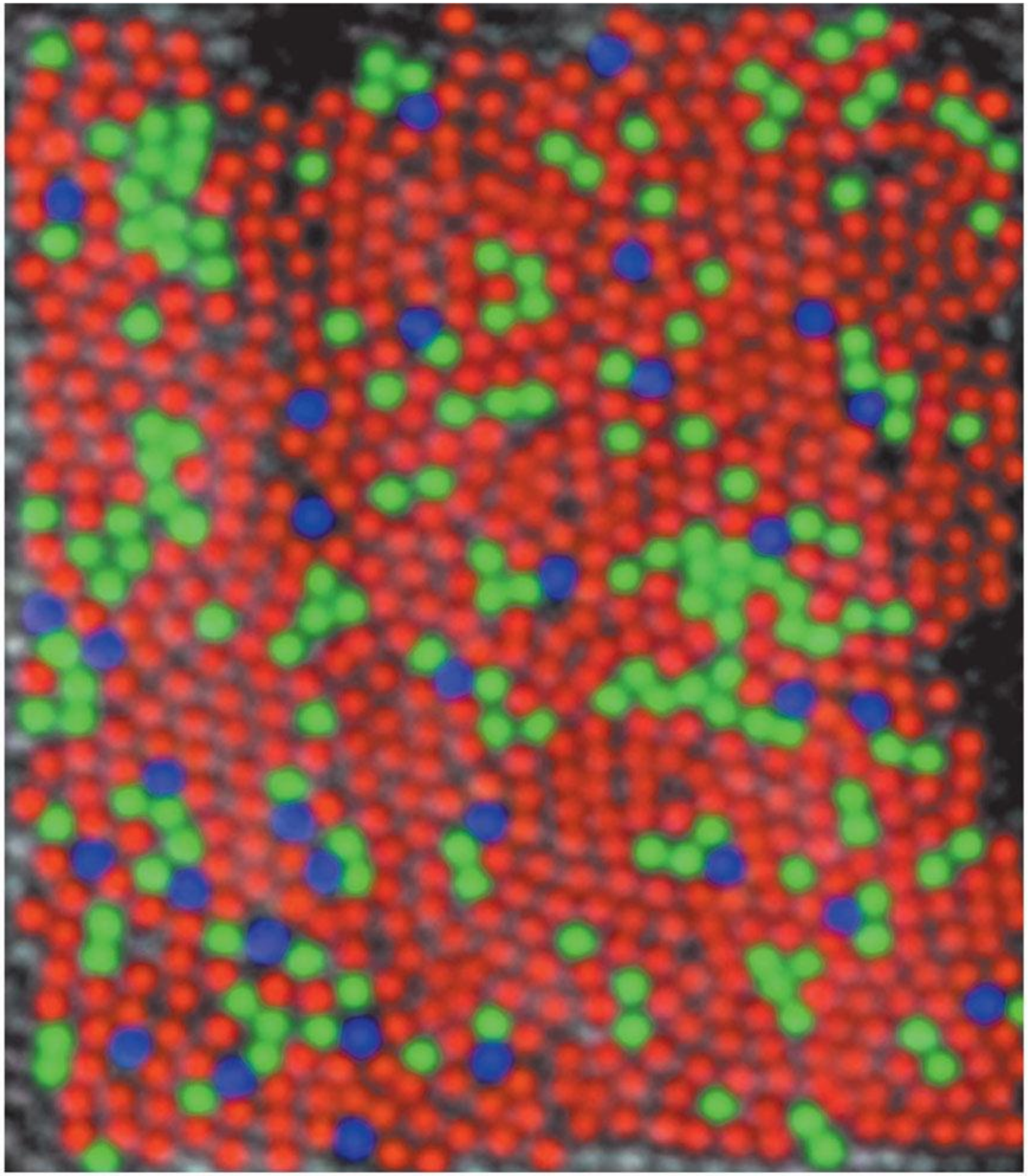
Photoreceptors (*continued*)

- Contain a chromophore that captures photons and a protein, called an opsin, whose structure determines the wavelength of light to which the photoreceptor responds
  - Rods have rhodopsin.
  - Cones have three different opsins, which respond to long, medium or short wavelengths.

Photoreceptors (*continued*)

- Some photoreceptors contain melanopsin and can monitor ambient light levels and influence our sleep/wake cycle.

Figure 2.12 Blue, green, and red represent the S-, M-, and L-cones, respectively, of a living human being in a patch of retina at 1 degree from the fovea



SENSATION & PERCEPTION 4e, Figure 2.12

Retinal Information Processing

Once photoactivation starts, photoreceptors become hyperpolarized (negatively charged).

Changes in photoreceptor activation are communicated to the bipolar cells in the form of graded potentials.

- Graded potentials vary continuously in their amplitudes.

Retinal Information Processing

Bipolar cells synapse with retinal ganglion cells, which fire in an all-or-none fashion rather than in graded potentials.

Retinal Information Processing

Cones work best in photopic (high-illumination) situations.

Rods work best in scotopic (low-illumination) situations.

TABLE 2.2
Properties of human photopic and scotopic vision

Property	Photopic system	Scotopic system
Photoreceptors	4–5 million cones	90 million rods
Location in retina	Throughout retina, with highest concentration close to fovea	Outside of fovea
Acuity (detail)	High	Low
Sensitivity	Low	High

SENSATION & PERCEPTION 4e, Table 2.2

Retinal Information Processing

The retina’s horizontal pathway: horizontal and amacrine cells

- Horizontal cells: Specialized retinal cells that run perpendicular to the photoreceptors and contact both photoreceptors and bipolar cells.
  - These cells are responsible for lateral inhibition, which creates the center-surround receptive field structure of retinal ganglion cells.

The retina’s horizontal pathway: horizontal and amacrine cells (*continued*)

- Amacrine cells: These cells synapse horizontally between bipolar cells and retinal ganglion cells.
  - These cells have been implicated in contrast enhancement and temporal sensitivity (detecting light patterns that change over time).

Retinal Information Processing

The retina’s vertical pathway: photoreceptors, bipolar cells, and ganglion cells

- Bipolar cell: Synapses with one or more rods or cones and with horizontal cells, then passes the signals to ganglion cells.
  - Diffuse bipolar cell: Receives input from multiple photoreceptors.
  - Midget bipolar cell: Receives input from a single cone.

The retina’s vertical pathway: photoreceptors, bipolar cells, and ganglion cells (*continued*)

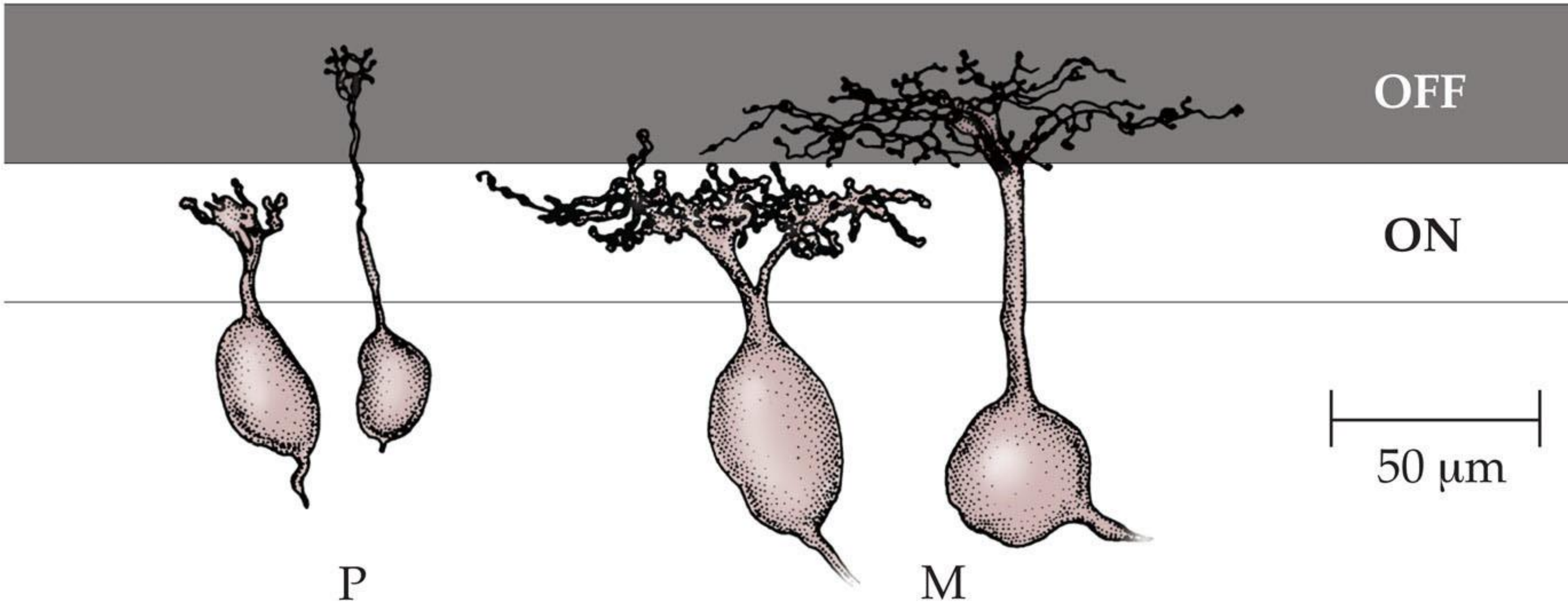
- P ganglion cells: Connect to the parvocellular pathway.
  - Receive input from midget bipolar cells
  - Parvocellular pathway is involved in fine visual acuity, color, and shape processing; poor temporal resolution but good spatial resolution.

Retinal Information Processing

The retina's vertical pathway: photoreceptors, bipolar cells, and ganglion cells (*continued*)

- M ganglion cells: Connect to the magnocellular pathway.
  - Receive input from diffuse bipolar cells
  - Magnocellular ("large cell") pathway is involved in motion processing; excellent temporal resolution but poor spatial resolution.

Figure 2.13 Different types of retinal P and M ganglion cells

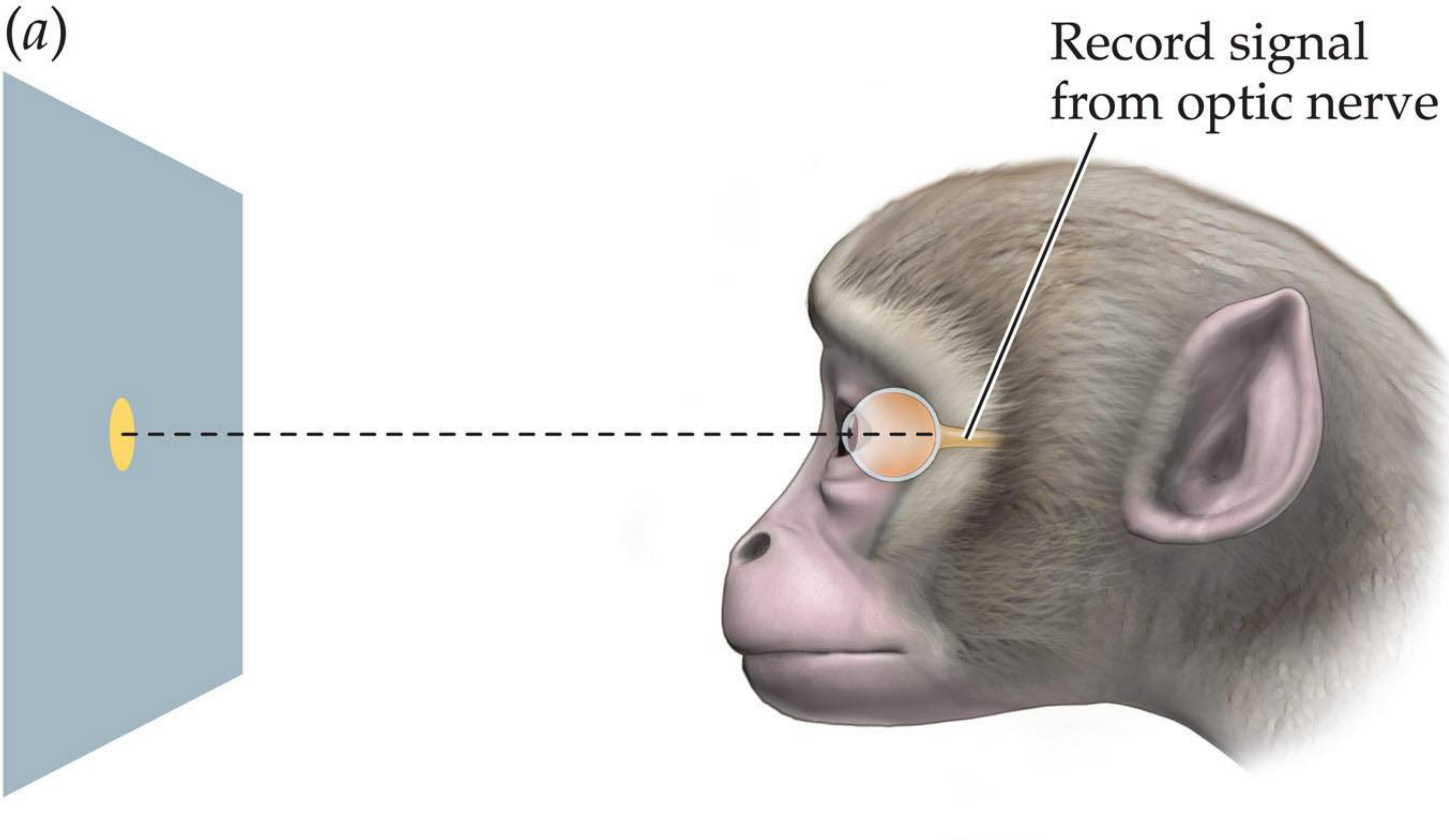


SENSATION & PERCEPTION 4e, Figure 2.13

Retinal Information Processing

Receptive field: The region on the retina in which stimuli influence a neuron's firing rate.

Figure 2.14 Retinal ganglion cell receptive fields (Part 1)



SENSATION & PERCEPTION 4e, **Figure 2.14 (Part 1)**

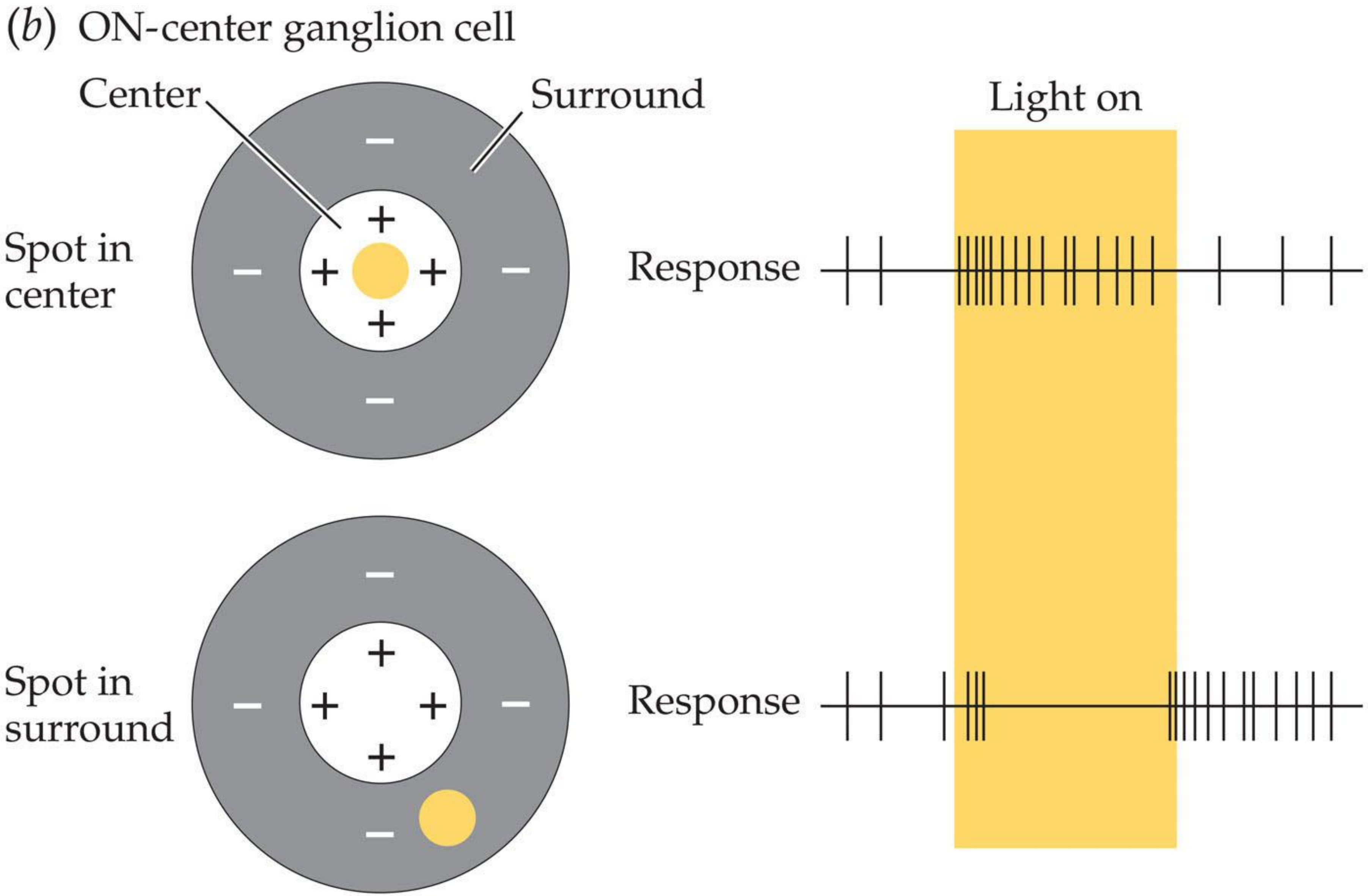
Retinal Information Processing

Kuffler mapped out the receptive fields of individual retinal ganglion cells in the cat.

ON-center ganglion cells—excited by light that falls on their center and inhibited by light that falls in their surround.

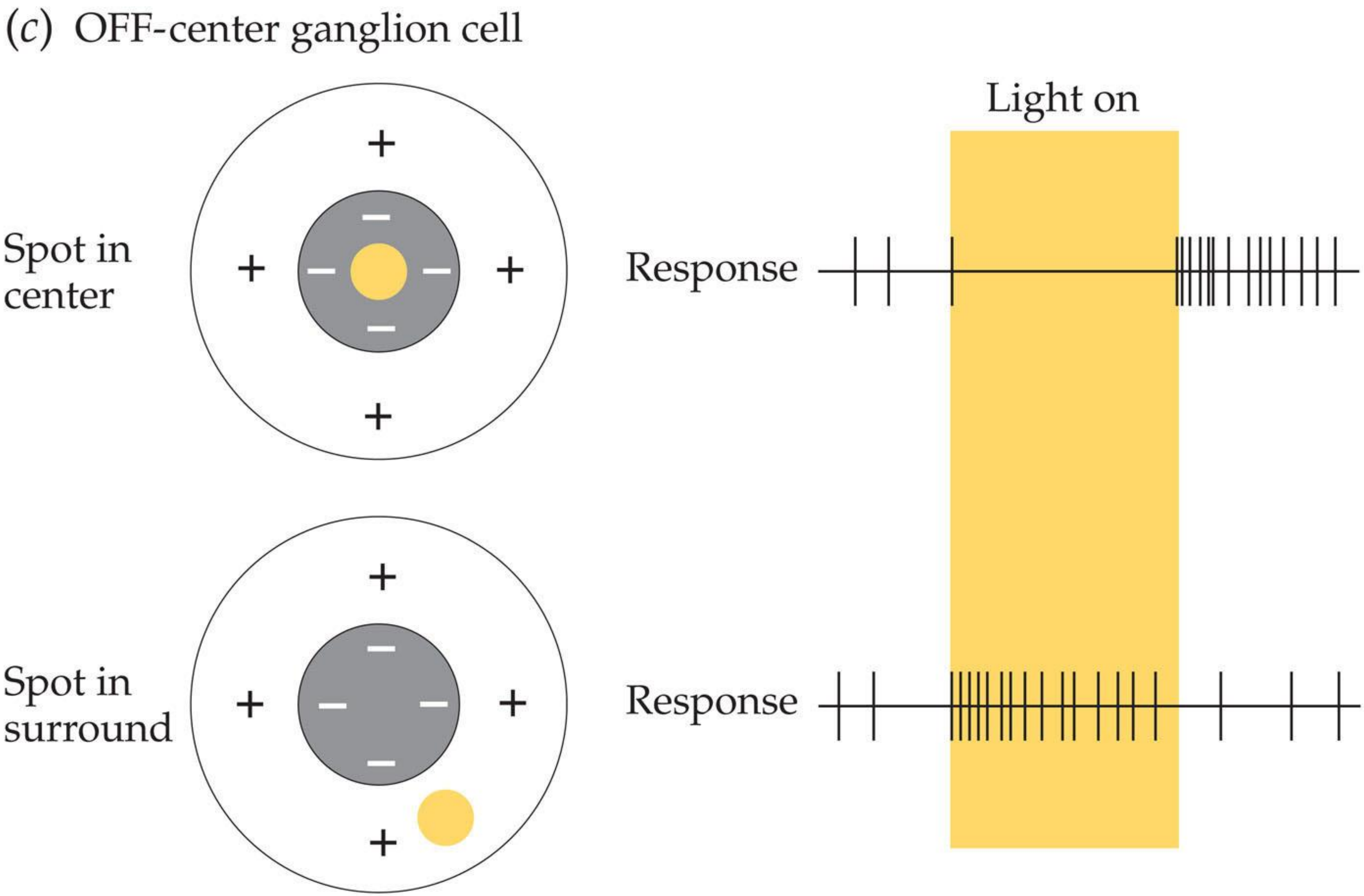
OFF-center ganglion—inhibited when light falls in their center and excited when light falls in their surround.

Figure 2.14 Retinal ganglion cell receptive fields (Part 2)



SENSATION & PERCEPTION 4e, Figure 2.14 (Part 2)

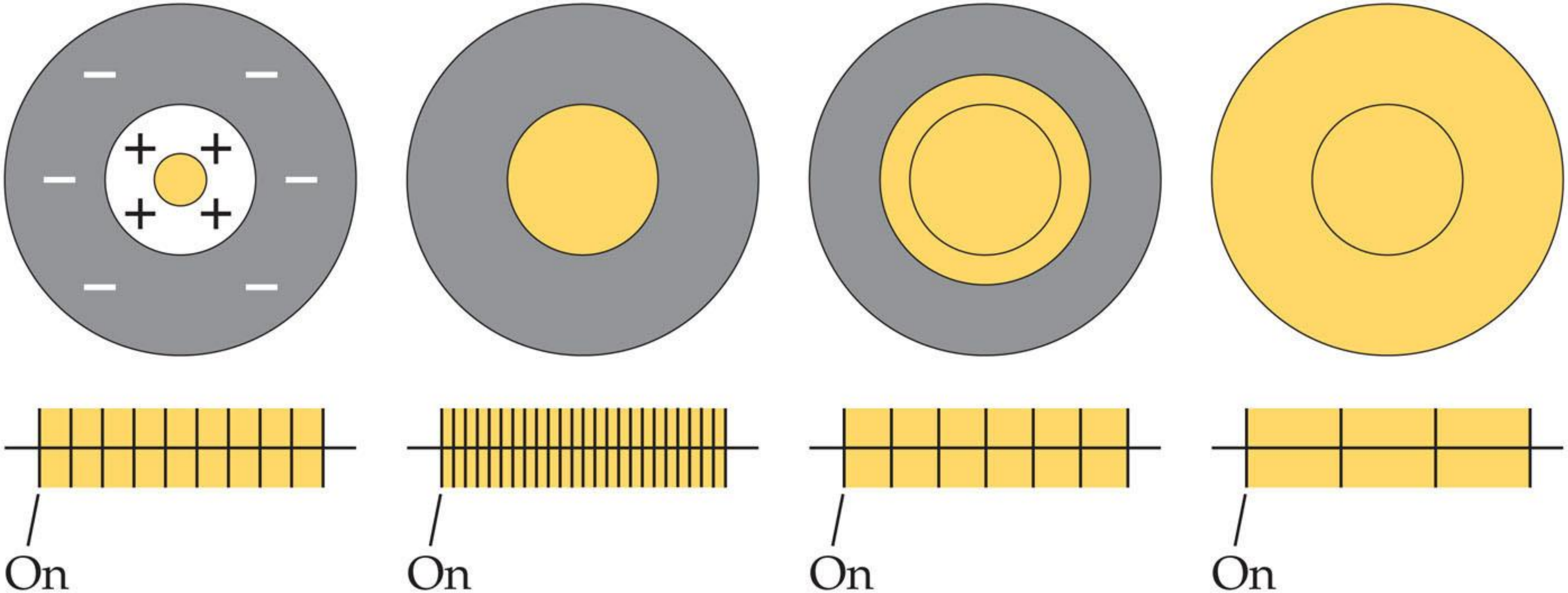
Figure 2.14 Retinal ganglion cell receptive fields (Part 3)



SENSATION & PERCEPTION 4e, Figure 2.14 (Part 3)

Figure 2.14 Retinal ganglion cell receptive fields (Part 4)

(*d*)



SENSATION & PERCEPTION 4e, Figure 2.14 (Part 4)

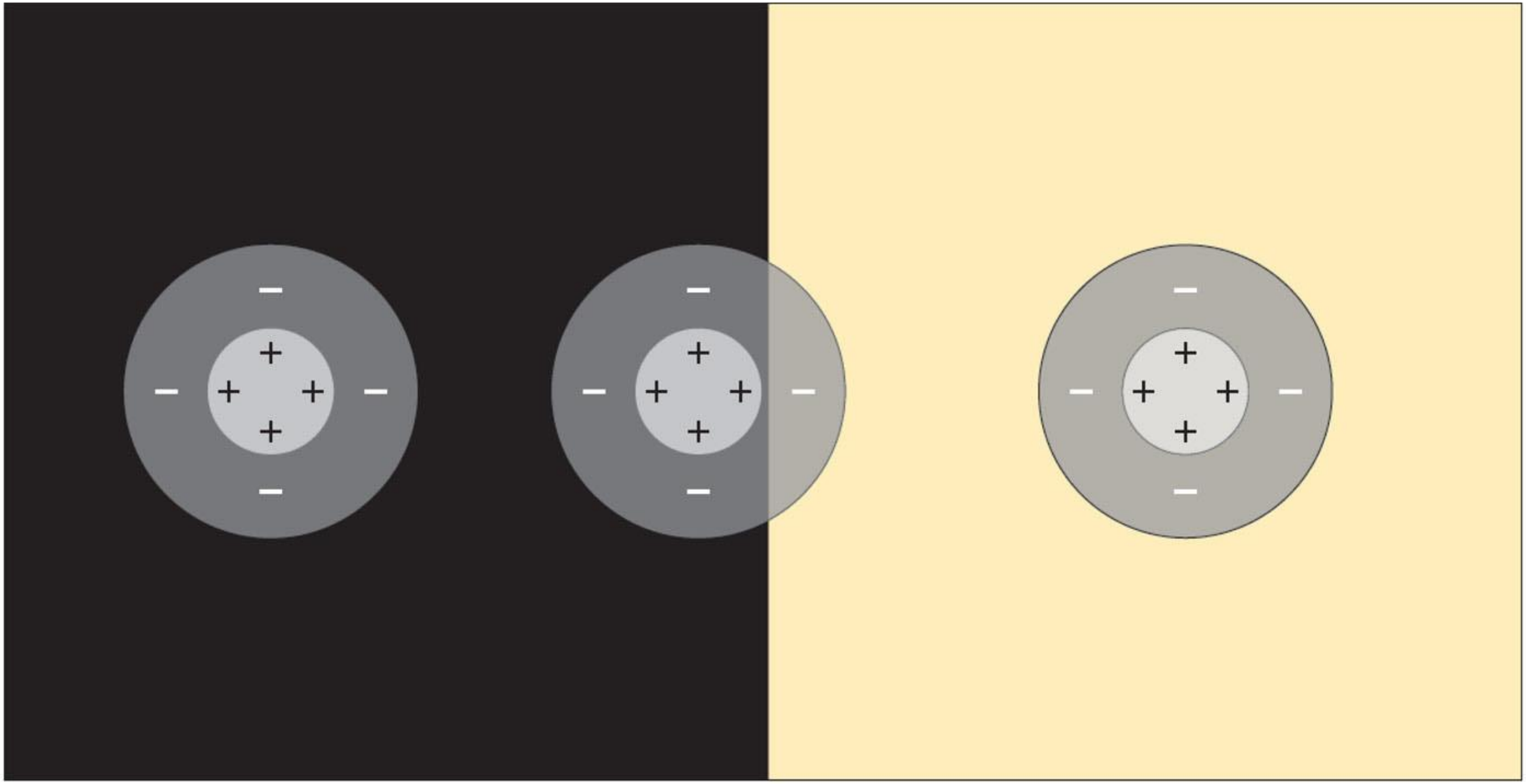
Why center-surround receptive fields?

- Each ganglion cell will respond best to spots of a particular size (and respond less to spots that are too big or too small).
  - Retinal ganglion cells act like a filter for information coming to the brain.

Why center-surround receptive fields? (*continued*)

- Retinal ganglion cells are most sensitive to differences in intensity of light between center and surround and relatively unaffected by average intensity.
  - Luminance variations tend to be smooth within objects and sharp between objects.
  - Thus, center-surround receptive fields help to emphasize object boundaries.

Figure 2.15 “Cartoon” showing a classic neuronal explanation for Mach bands



SENSATION & PERCEPTION 4e, **Figure 2.15**

P and M ganglion cells revisited

- P ganglion cells: Small receptive fields, high acuity, work best in high luminance situations, sustained firing.
    - Provide information mainly about the contrast in the retinal image
- M ganglion cells: Large receptive fields, low acuity, work best in low luminance situations, burst firing.
    - Provide information about how an image changes over time

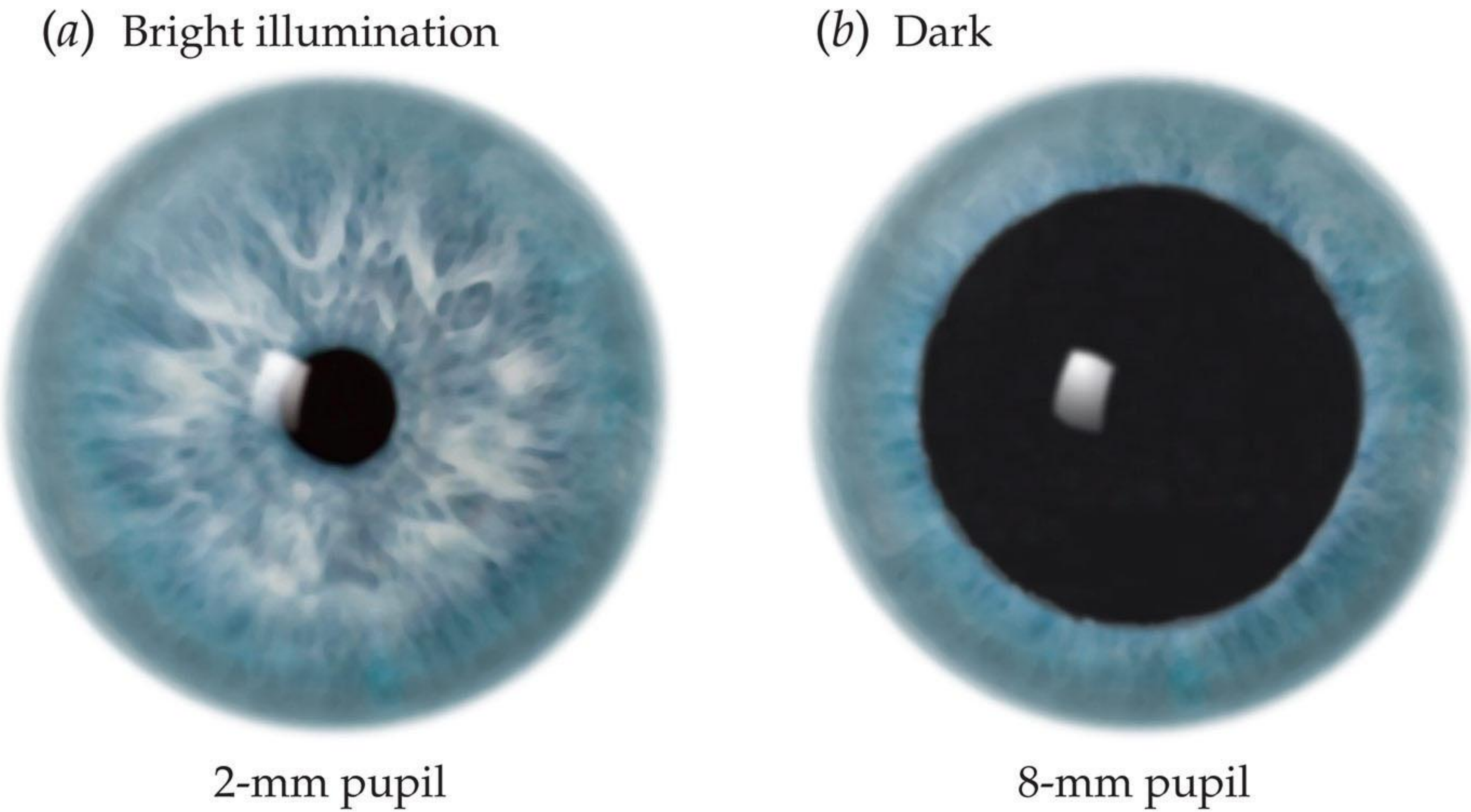
Dark and Light Adaptation

One of the most remarkable things about the human visual system is the incredible range of luminance levels we can adjust to.

Two mechanisms for dark and light adaptation:

- Pupil dilation
- Photoreceptors and their replacement

Figure 2.17 The black spots in the middle of these two irises show the possible range of pupil sizes as we go from bright illumination (*a*) into the dark (*b*)



***SENSATION & PERCEPTION* 4e, Figure 2.17**

Dark and Light Adaptation

Neural circuitry of the retina accounts for why we are not bothered by variations in overall light levels.

Dark and Light Adaptation

- The amount of photopigment available in photoreceptors changes over time.
    - The more light entering the retina, the faster the photopigments are used up, and the fewer photopigments there are to process more light.

Dark and Light Adaptation

- The amount of photopigment available in photoreceptors changes over time.
  - The less light entering the retina, the more slowly photopigments are used up, and the more photopigments there are to process what little light is there.

The visual system regulates the amount of light entering the eye and ignores whatever variation in overall light level is left over.

- In bright light, the pupil dilates, letting in less light.
- Next, the number of photopigments in the photoreceptors decreases over a few minutes.

Dark and Light Adaptation

- Being light-adapted means that even though there are more photons coming into the eye, there are fewer photopigments available to process them, so some of the light is “thrown away.”
- In this sense, the remaining variations in light are ignored, beyond whatever level of luminance the eye is adapted to.

Sensation & Perception in Everyday Life: When Good Retina Goes Bad

Imagine not being able to read, drive, or recognize faces. For some people, a specific type of retinal disease can rob them of their high acuity central vision.

Sensation & Perception in Everyday Life: When Good Retina Goes Bad

Age-related macular degeneration (AMD): A disease associated with aging that affects the macula. AMD gradually destroys sharp central vision.

- Macula: The central part of the retina containing the fovea.

AMD causes central vision loss, resulting in a blind spot in the visual field called a scotoma.

Sensation & Perception in Everyday Life: When Good Retina Goes Bad

Retinitis pigmentosa (RP): A family of hereditary diseases that involves the progressive death of photoreceptors and degeneration of the pigment epithelium

- Many people may not notice the onset of retinitis pigmentosa at first because it primarily affects peripheral vision.

Sensation & Perception in Everyday Life: When Good Retina Goes Bad

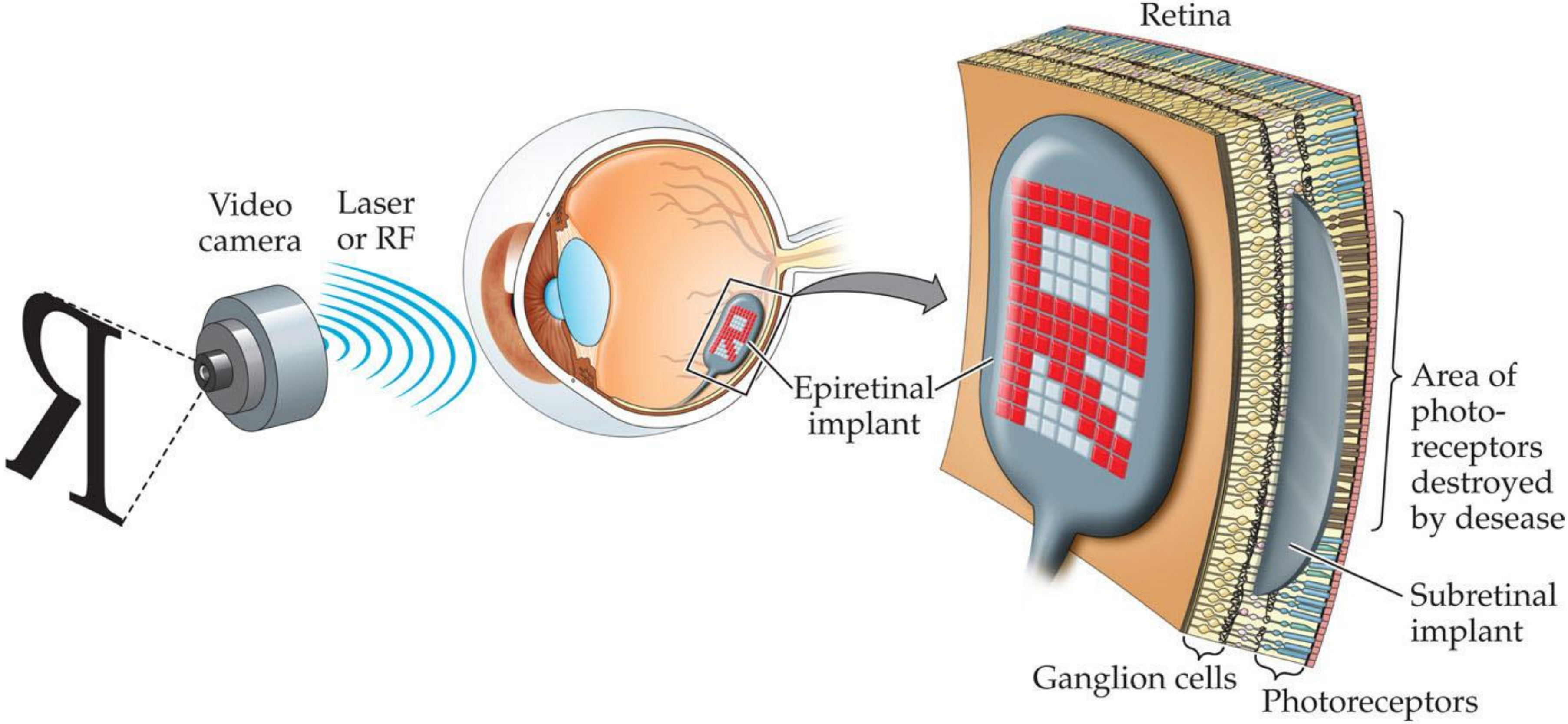
New technologies may help people with visual field loss

- Prosthetic retinas
  - May replace damaged photoreceptors with an implanted device

New technologies may help people with visual field loss (continued)

- Gene therapies
  - Can improve functioning of surviving photoreceptors
- Chemical therapies
  - Convert retinal ganglion cells into photoreceptors

Figure 2.18 Retinal Prostheses



SENSATION & PERCEPTION 4e, Figure 2.18