Special Senses: Vision

Dr. DeCoster Fall 2023

Some Materials Adapted from

Dr. Stan Cronk, Louisiana Tech

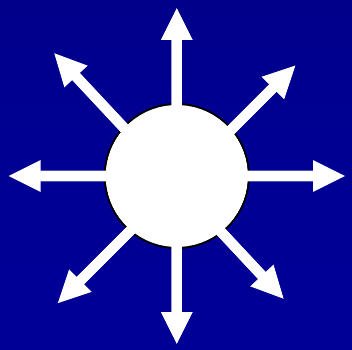
Suggested readings: Hall & Guyton (13th edition), chapters 50 & 51

VISION

Physical Stimulus: Light

Light = electromagnetic radiation of a wavelength detectable by the visual receptors of the eye

(~ 380 to 770 nm)



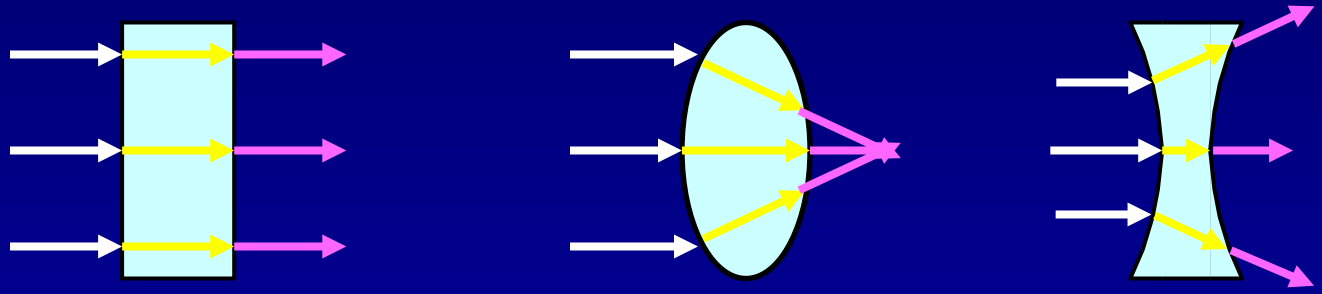
Light rays are reflected from an object in all directions, but only those passing through the lens of the eye are used to form an image.

THE STIMULUS FOR VISION: LIGHT

- Characteristics of light: wavelength (color) and amplitude (brightness)
- most perceived light is a mixture of wavelengths, i.e. a light composed of blue and red only would be perceived as purple
-

REFRACTION: PROCESS OF BENDING LIGHT RAYS

$$\text{Refractive index of substance x} = \frac{\text{Velocity of light in air}}{\text{Velocity of light in substance x}}$$



Perpendicular interface

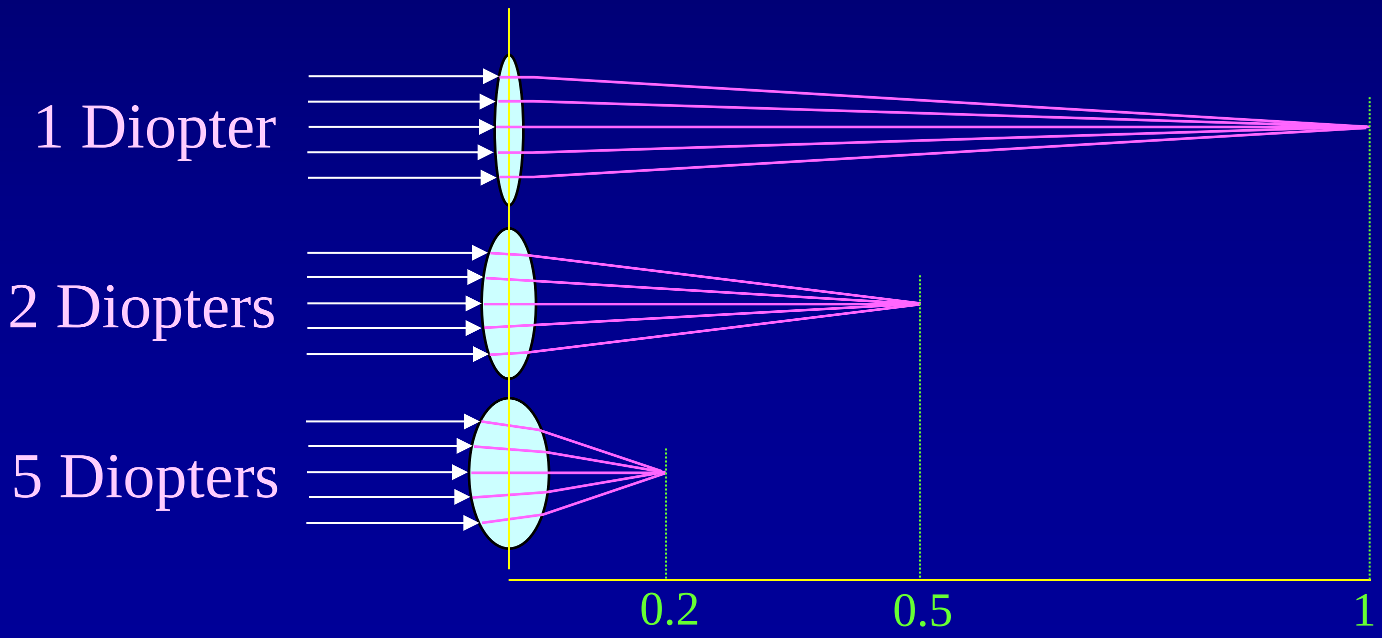
Convex spherical surface

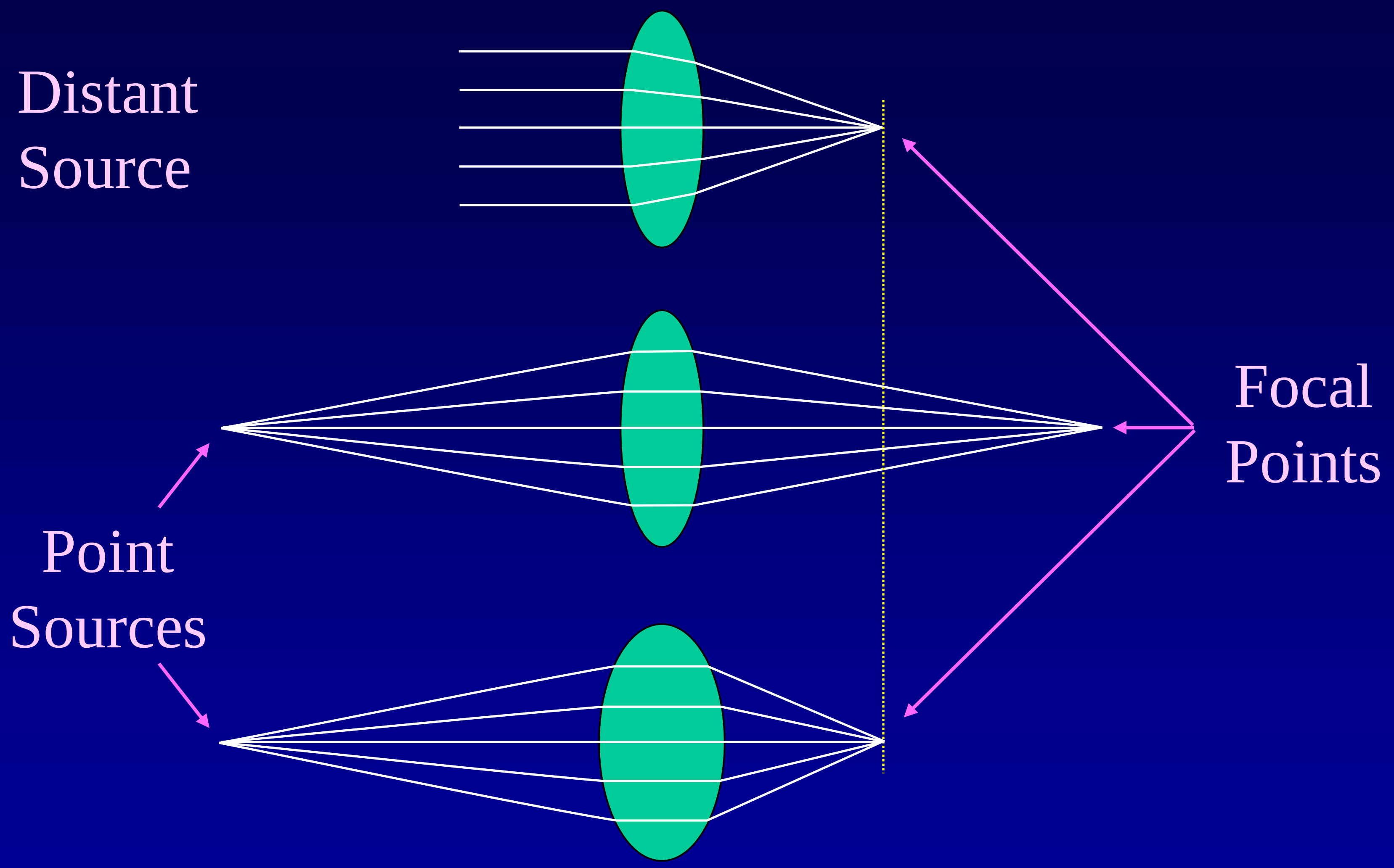
Concave spherical surface

FOCAL LENGTH

Focal Length of a convex lens: characteristic distance on the image side of lens where light rays converge

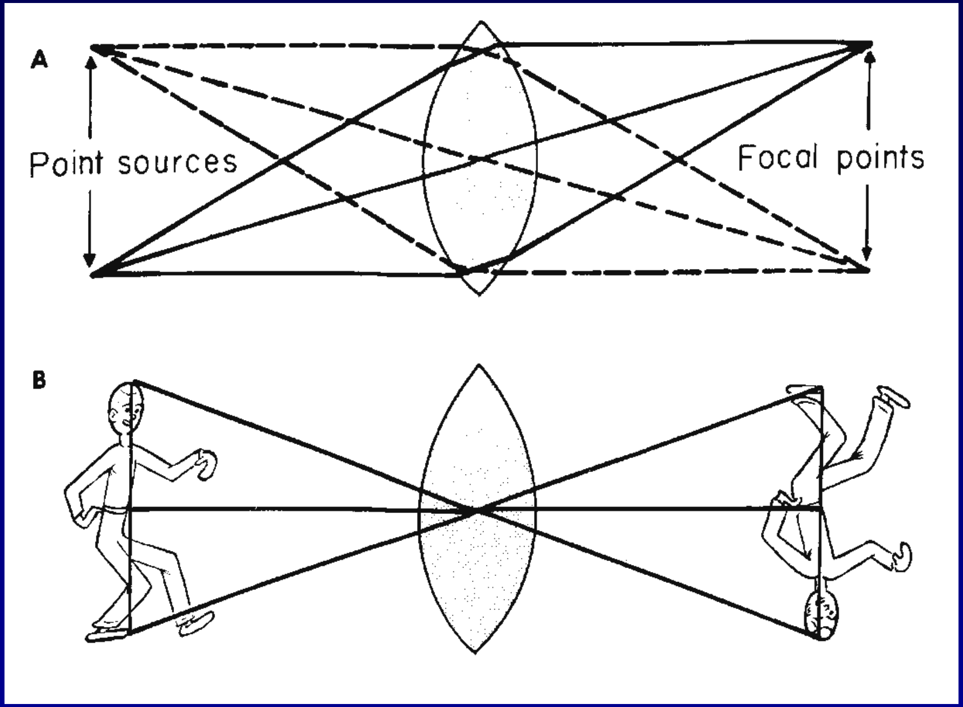
$$\text{Refractive Power } (\textbf{diopters}) = \frac{1}{\text{Focal Length}}$$





Adapted from: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

Real Life: Light rays reflected by an object form a mosiac of point sources.



These point sources focus on the focal plane of the lens with the image formed being inverted.

Adapted from: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

Anatomy of the eye:

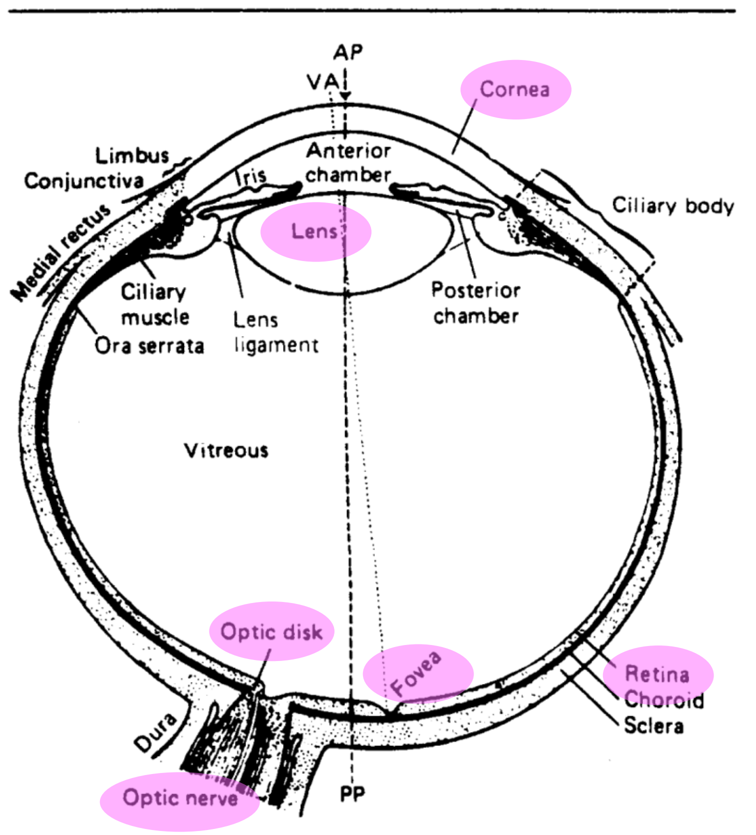


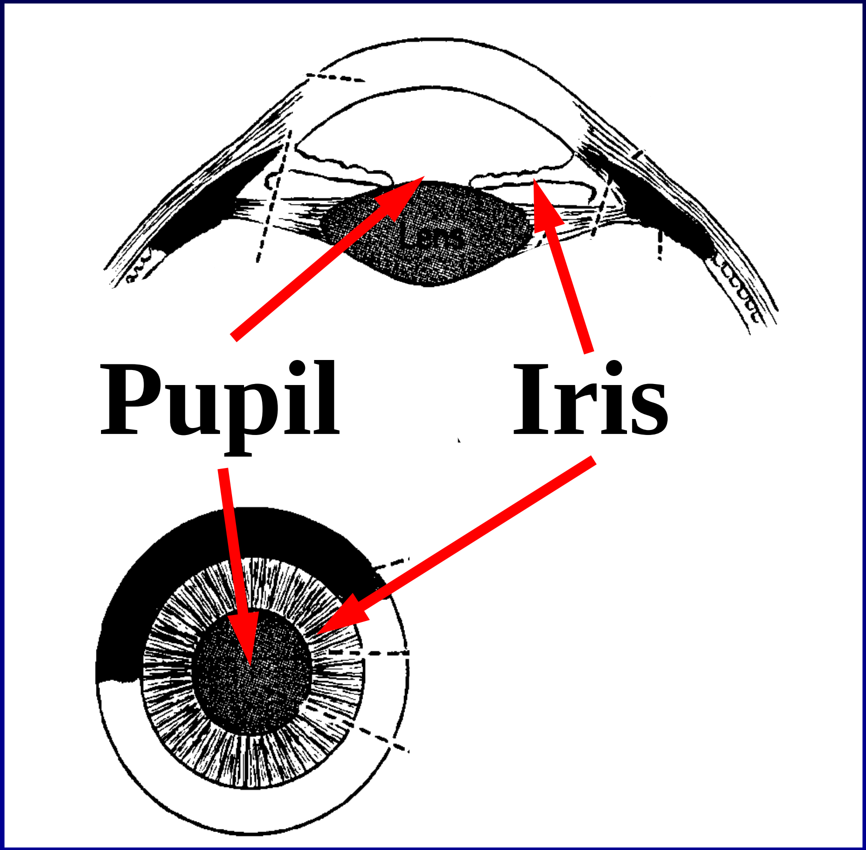
Figure 8–1. Horizontal section of the right eye. AP, anterior pole; PP, posterior pole; VA, visual axis. (Reproduced, with permission, from Warwick R: *Eugene Wolff's Anatomy of the Eye and Orbit*, 7th ed. Saunders, 1977.)

From: W.F. Ganong, *Review of Medical Physiology*, 19th ed. Appleton & Lange, 1999

Parts of the Eye

- Cornea: protective surface for eye; absorbs some light energy, especially with age
- Pupil: hole in center of eye allowing light to pass through; size controlled by the iris
- Iris: ring of muscle fibers between cornea and lens; the “colored” part of the eye (brown, green, etc.) that lets light pass through to lens
- Lens: focuses light on the back of the eyeball (retina)
- Retina: back of the eyeball containing rods and cones
- Fovea: center of retina containing most of the cones
- Optic Nerve: carries signals from eye to brain

Control of Light Entrance into Eye



Light must pass through 4 refractive interfaces to reach the retina:

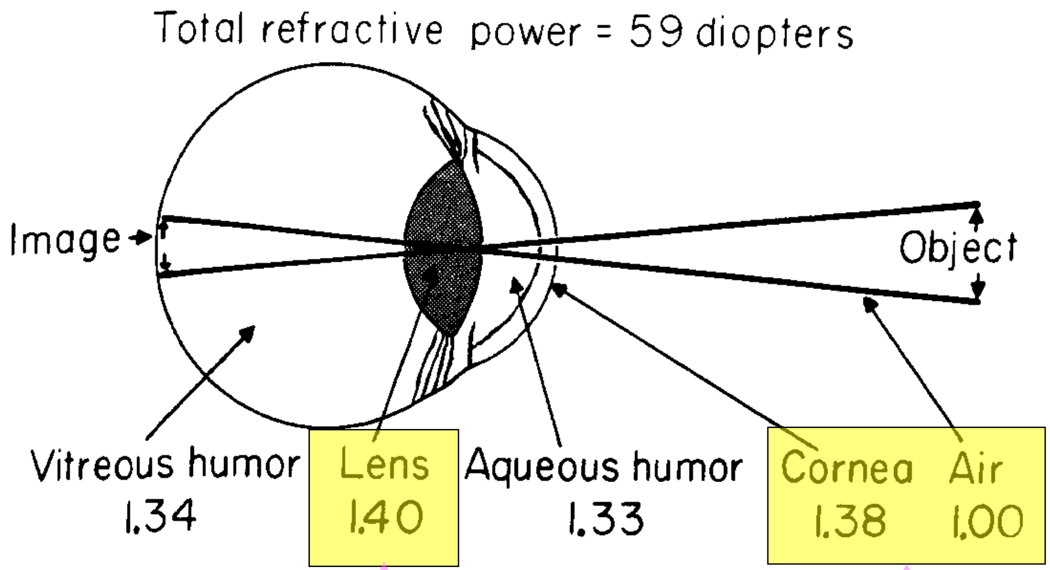


Figure 58–9. The eye as a camera. The numbers are the refractive indices.

The convexivity of the lens can be changed, allowing the overall refractive power of the eye to be altered (**accommodation**).

Most of the refractive power of the eye is achieved at the air / cornea interface due to the large refractive index difference.

Adapted from: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

Adjustable Lens System: **Accommodation**

Lens refractive power is adjustable from ~15 to 29 diopters (range of **~14 diopters**)

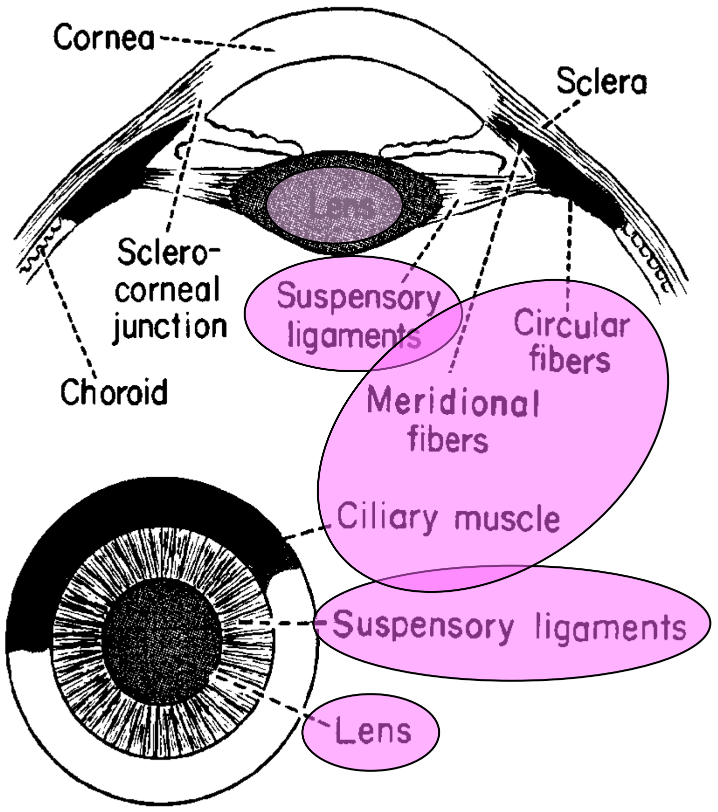


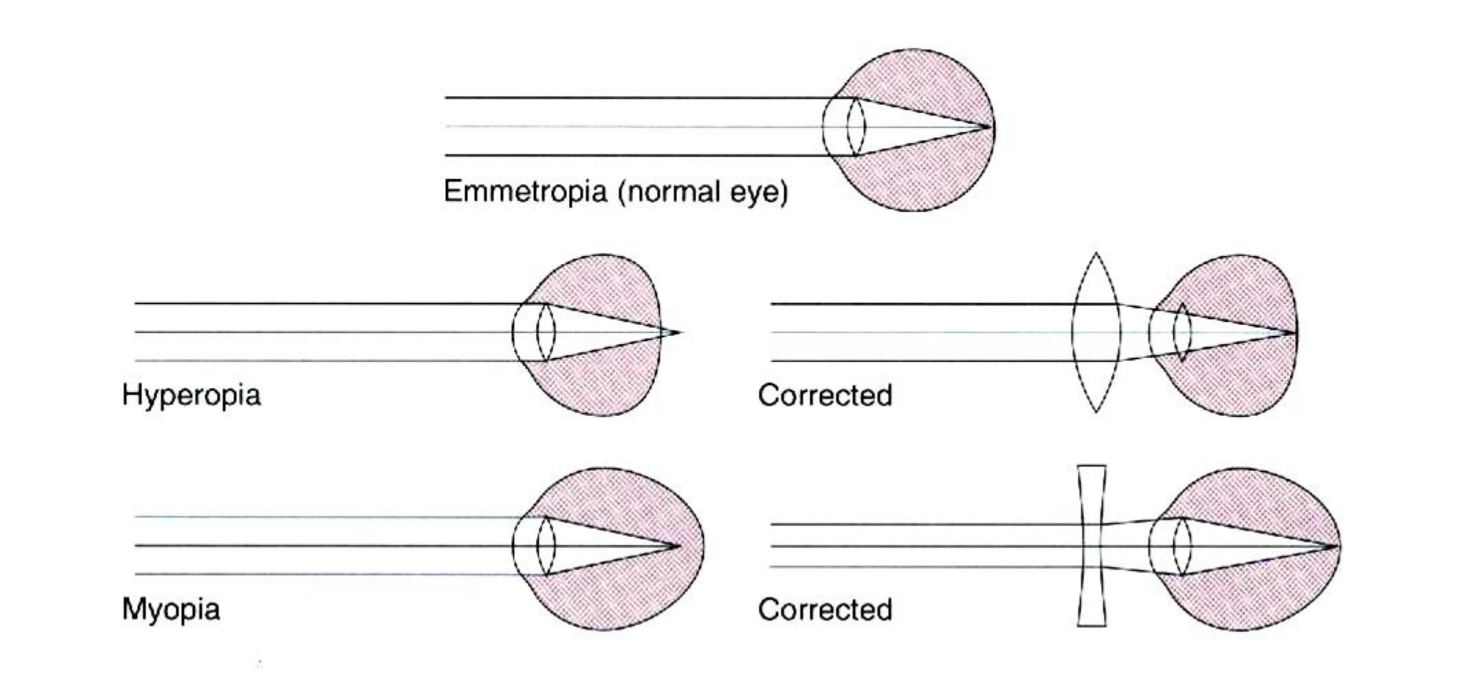
Figure 58–10. Mechanism of accommodation.

Adapted from: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

How the Eye Works

- The iris controls the size of the pupil by responding to brightness; pupil dilates in darkness and constricts in bright conditions
- The lens adjusts (accommodates) its shape to bring image into focus
  - Lens becomes rounder for close objects and flattens to focus distant objects
  - Resting state of accommodation (focusing objects about 1 m); point at which eye muscles do little work = our “comfortable setpoint”.
- Common eye conditions limiting ability of lens to accommodate: myopia (nearsightedness) and presbyopia (farsightedness)
  - Farsightedness becomes more pronounced with age

Defects in the Optical System of the Eye



From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

DEPTH PERCEPTION

- To judge distance in 3D space, we use depth cues:
  - **Accommodation**: out-of-focus image triggers change in lens shape; signal from ciliary muscles tells brain the extent of accommodation
  - **Convergence**: corresponding to accommodation, brain receives amount of inward rotation the muscles in the eyeball must turn to bring an image to rest on corresponding parts of the retina; closer objects require more inward rotation
  - **Binocular disparity**: results because the closer an object is to an observer, the greater the amount of disparity between the view of the object received by the eyeball
- All 3 bottom-up cues are effective for judging distance, slant, and speed for objects within a few meters of viewer

Depth Perception – Distant Objects

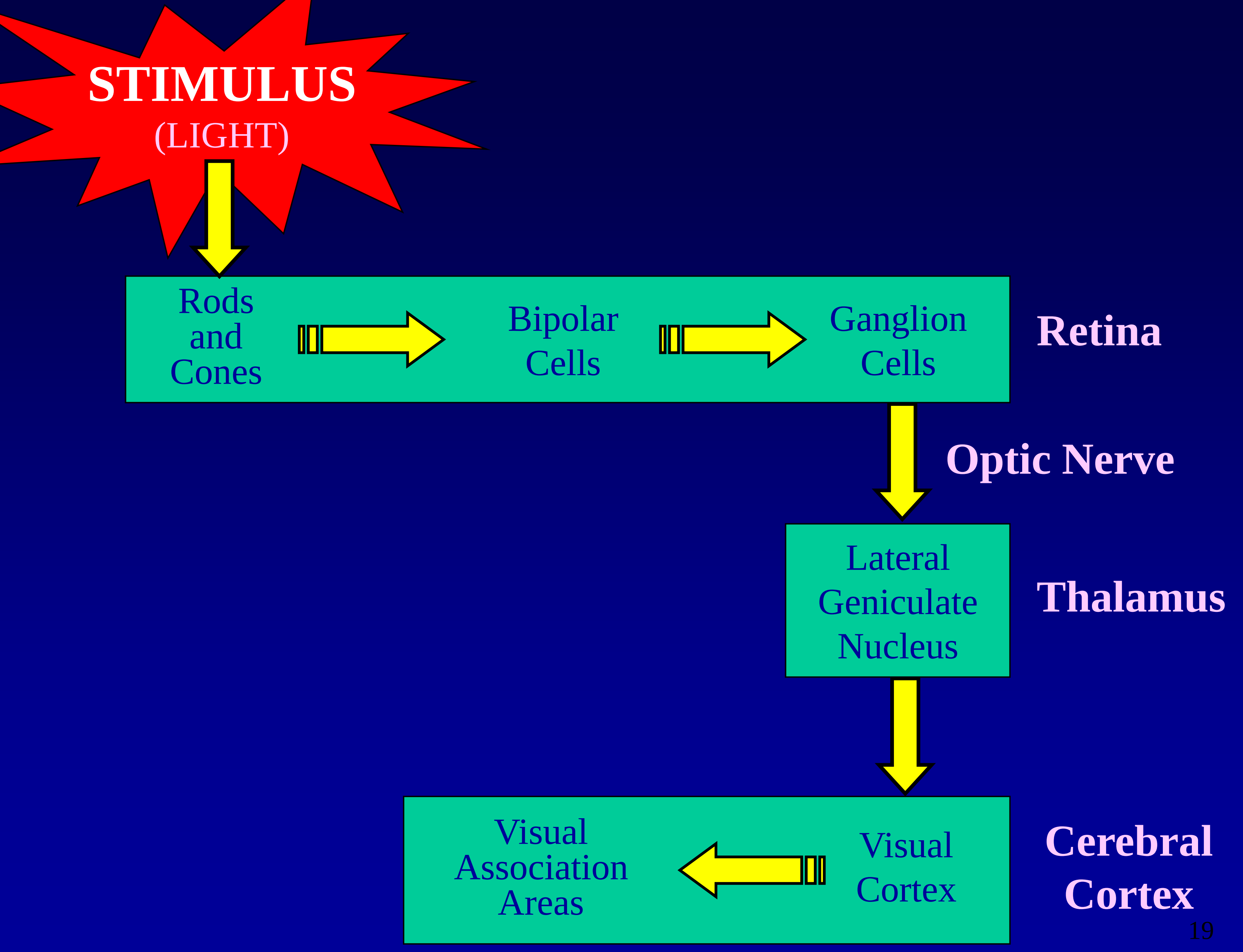
- For objects > a few meters away, pictorial cues help us judge distance
  - Linear perspective: converging lines toward distant points
  - Relative size: judging distance by comparing sizes of objects that should be close in size; smaller objects must be farther away
  - Interposition: objects obscuring parts of other objects must be nearer
  - Light and shading: shadows from and reflections on objects give evidence of location and form
  - Textural gradients: texture changes give distance cues; finer texture indicates more distance
- Relative motion (motion parallax): more distant objects exhibit smaller movement across visual field; also objects moving toward us provide the retina with increasingly larger images

Use of Cues

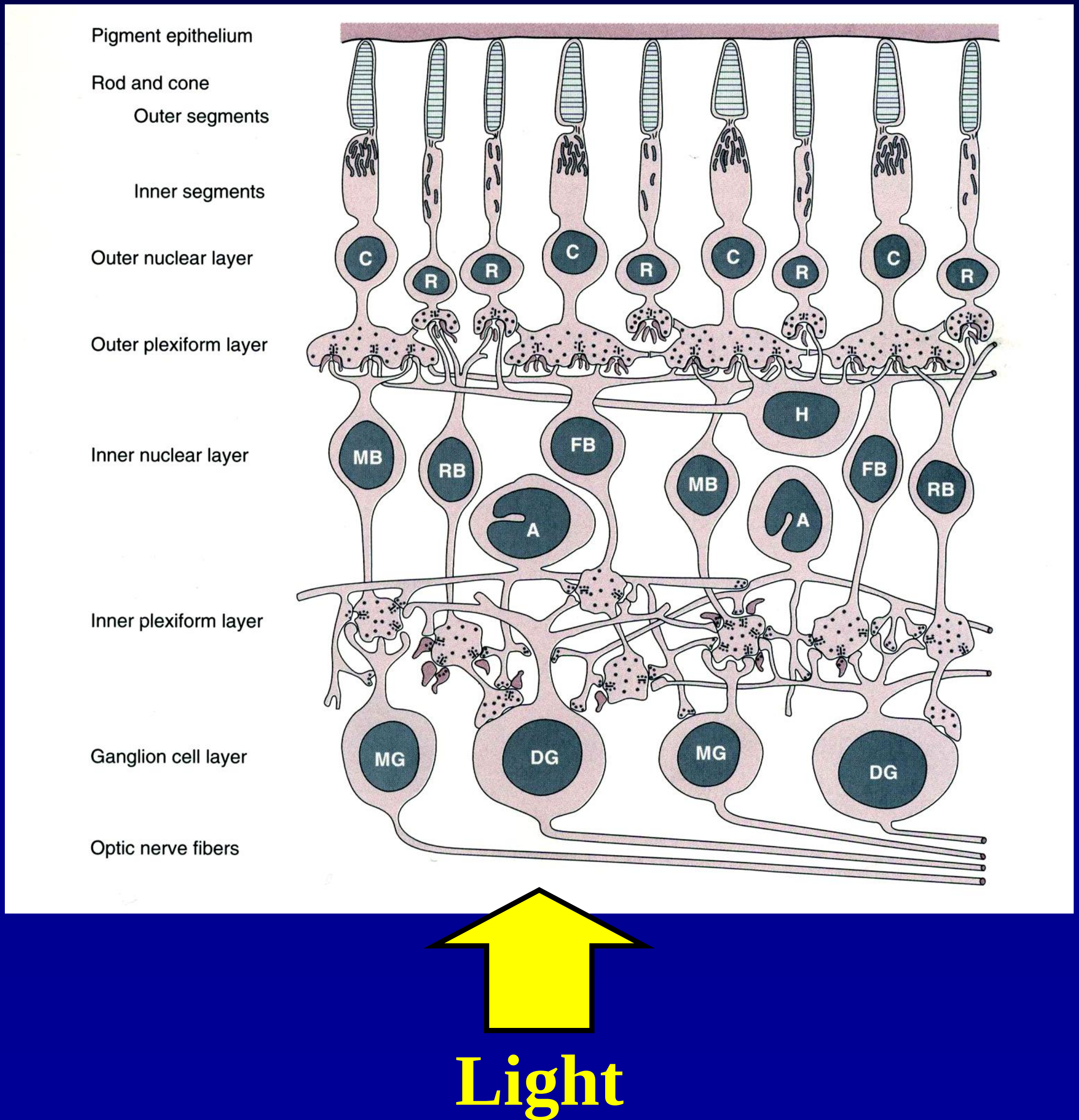
- Collectively, pictorial cues provide lots of info about object sizes, relative positions, and movement within 3D space
- Removal of some cues may cause confusion, as a pilot flying over featureless land covered by snow
- Removal of cues may also cause distortion of perception
  - Example: small cars hit from behind more often because drivers in cars behind them think they are farther away

Bottom Line

- What we see is often what we expect to see.


STIMULUS
(LIGHT)
Rods and Cones
Bipolar Cells
Ganglion Cells
Retina
Optic Nerve
Lateral Geniculate Nucleus
Thalamus
Visual Cortex
Visual Association Areas
Cerebral Cortex

Neural Components of the Retina



From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

CENTRAL RETINA

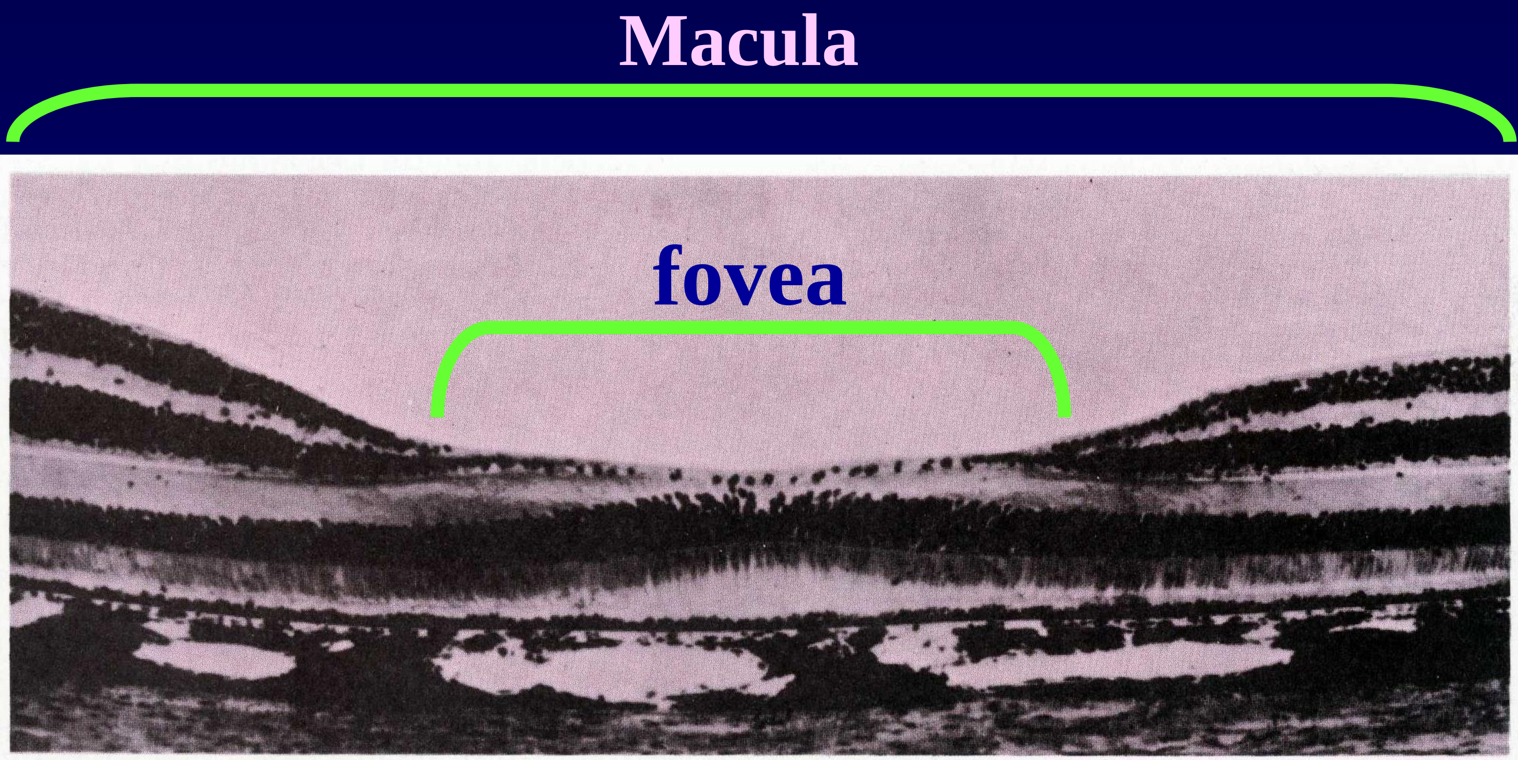


Figure 50–2. Photomicrograph of the macula and of the fovea in its center. Note that the inner layers of the retina are pulled to the side to decrease the interference with light transmission. (From Fawcett: Bloom and Fawcett: A Textbook of Histology. 11th ed. Philadelphia, W. B. Saunders Company, 1986; courtesy of H. Mizoguchi.)

From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

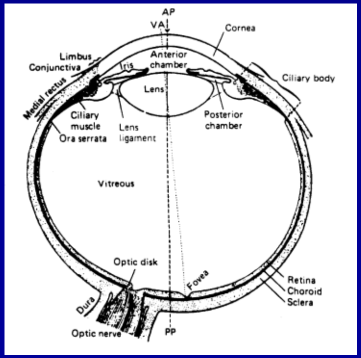
PERIPHERAL VS. CENTRAL RETINA

Periphery:

- more **rods**

- more rods and cones converge on each ganglion cell (200 rods : 1 ganglion cell)

- high sensitivity to weak light



Center:

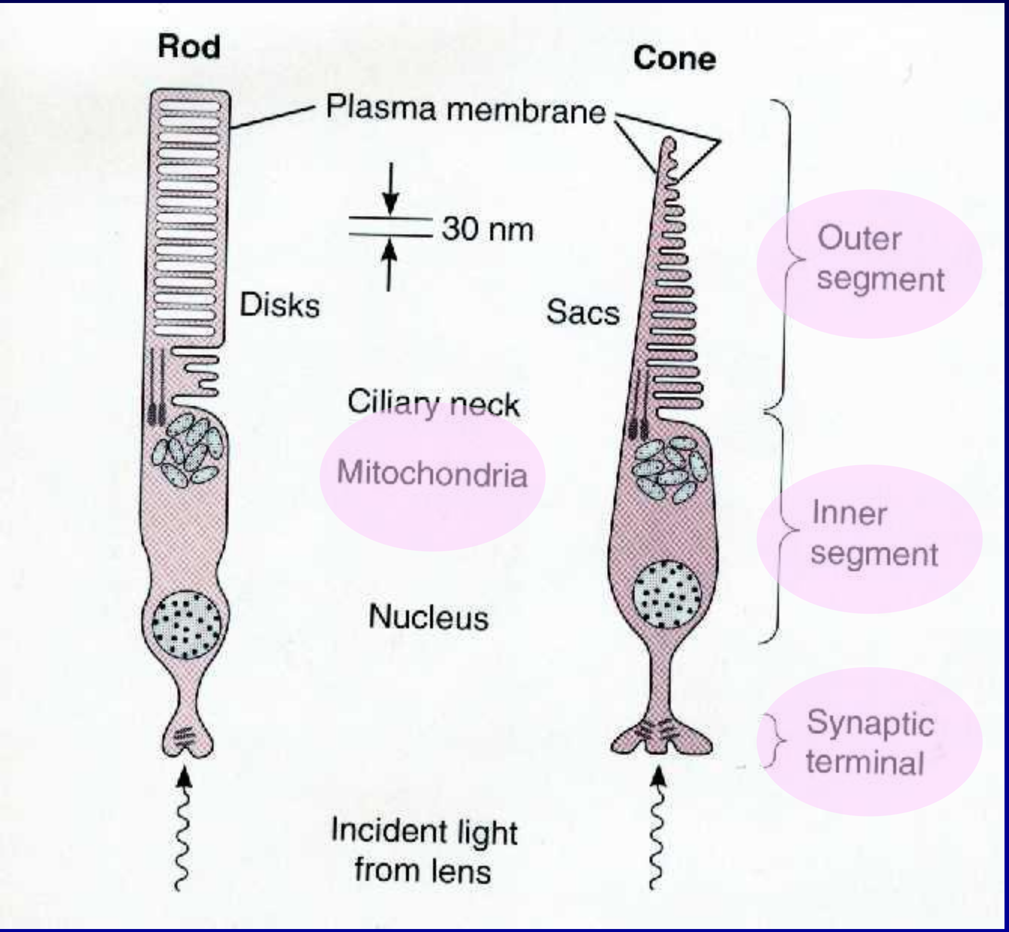
- more **cones**

- fewer rods and cones converge on each ganglion cell (1 cone : 1 ganglion cell)

- high visual acuity

- only **cones** are in the fovea

ANATOMY OF VISUAL CELLS



From: W.F. Ganong, *Review of Medical Physiology*, 19th ed. Appleton & Lange, 1999

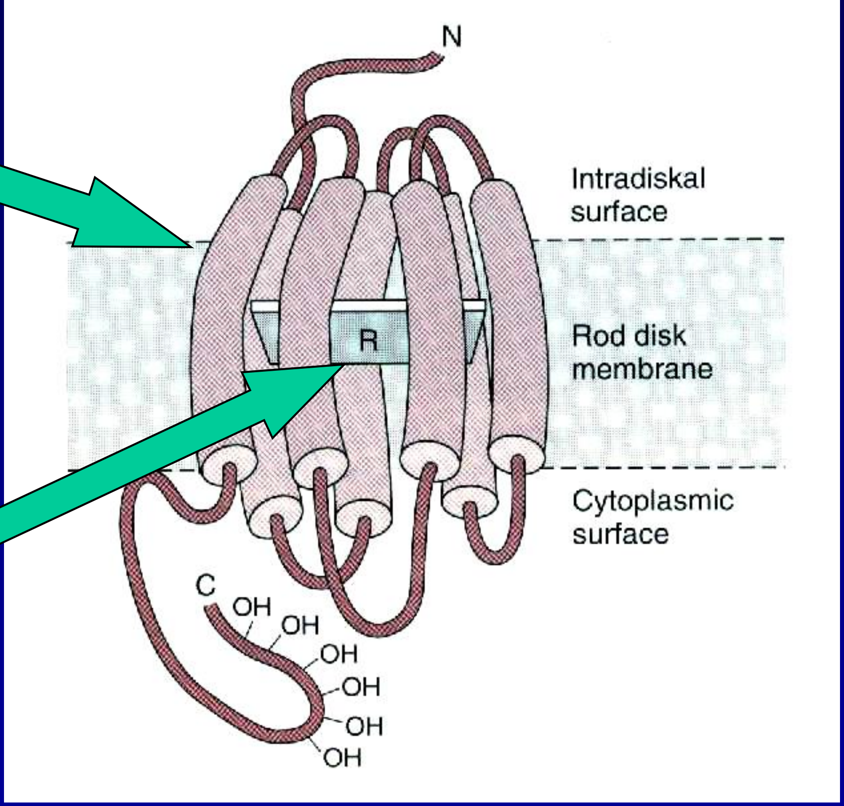
ROD VS. CONE VISION

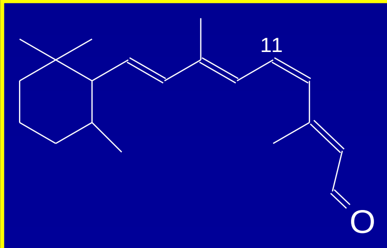
Rod Vision	Cone Vision
- **high** level of convergence	- **low** level of convergence
- high sensitivity to light (for **night** vision)	- low sensitivity to light (for **daytime** vision)
- **low** visual acuity	- **high** visual acuity
- **black / white** vision	- **color** vision

Rhodopsin, the visual pigment in rods, is an integral membrane protein complex

Opsin: 40 kDa, 7 TM helix protein

11-cis-Retinal: chromophore, covalently bound to opsin at lys-296





11-cis-Retinal

From: W.F. Ganong, *Review of Medical Physiology*, 19th ed. Appleton & Lange, 1999

Light

↓

Rhodopsin activation

↓

Transducin activation

↓

cGMP PDE activation

↓

cGMP hydrolysis ↑

↓

Free [cGMP] ↓

↓

cGMP dissociates from cGMP-activated cation channel

↓

Cation channel closes

↓

Influx of Na^+ and Ca^{++} ↓

↓

Rod plasma membrane **hyperpolarizes**

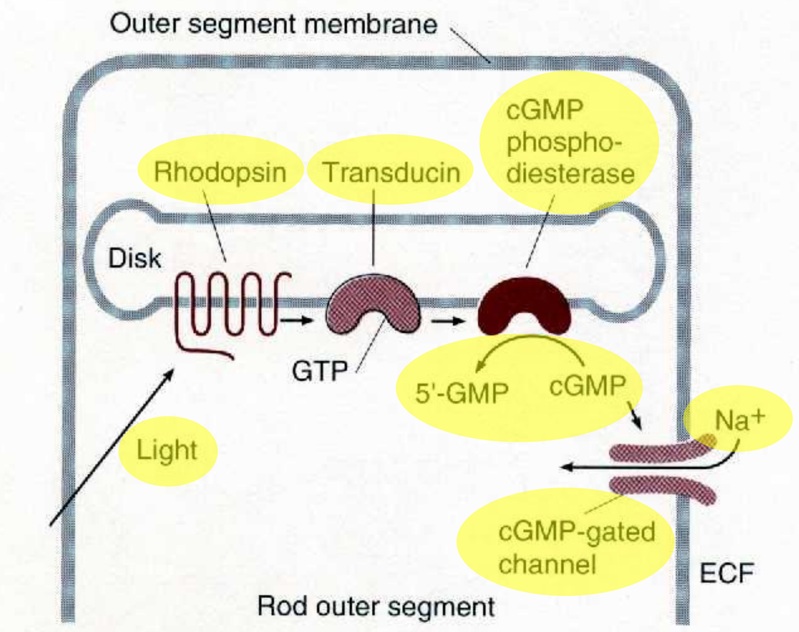


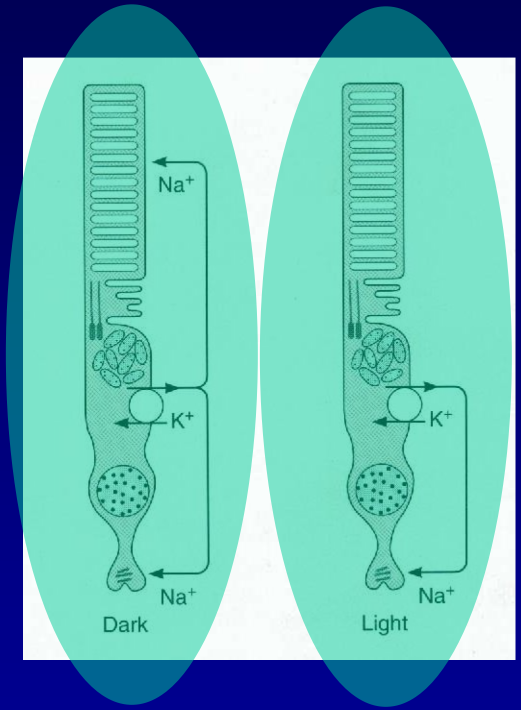
Figure 8–18. Initial steps in phototransduction in rods. Light activates rhodopsin, which activates transducin to bind GTP. This activates phosphodiesterase, which catalyzes the conversion of cGMP to 5′-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels to close.

From: W.F. Ganong, *Review of Medical Physiology*, 19th ed. Appleton & Lange, 1999

Summary: effect of light on cation current flow in rods

Dark → ↑cGMP → cation channel open → rod depolarized (Vm ~ -30 mV)

Light → ↓cGMP → cation channel closed → rod hyperpolarized (Vm ~ -90 mV)



From: W.F. Ganong, *Review of Medical Physiology*, 19th ed. Appleton & Lange, 1999

Cones vs. Rods

Similarities:

- overall biochemical signal transduction cascade
    - opsin + retinal (receptor)
    - transducin (G-protein)
    - cGMP phosphodiesterase
    - cGMP-gated cation channel
- hyperpolarization in response to light

Differences:

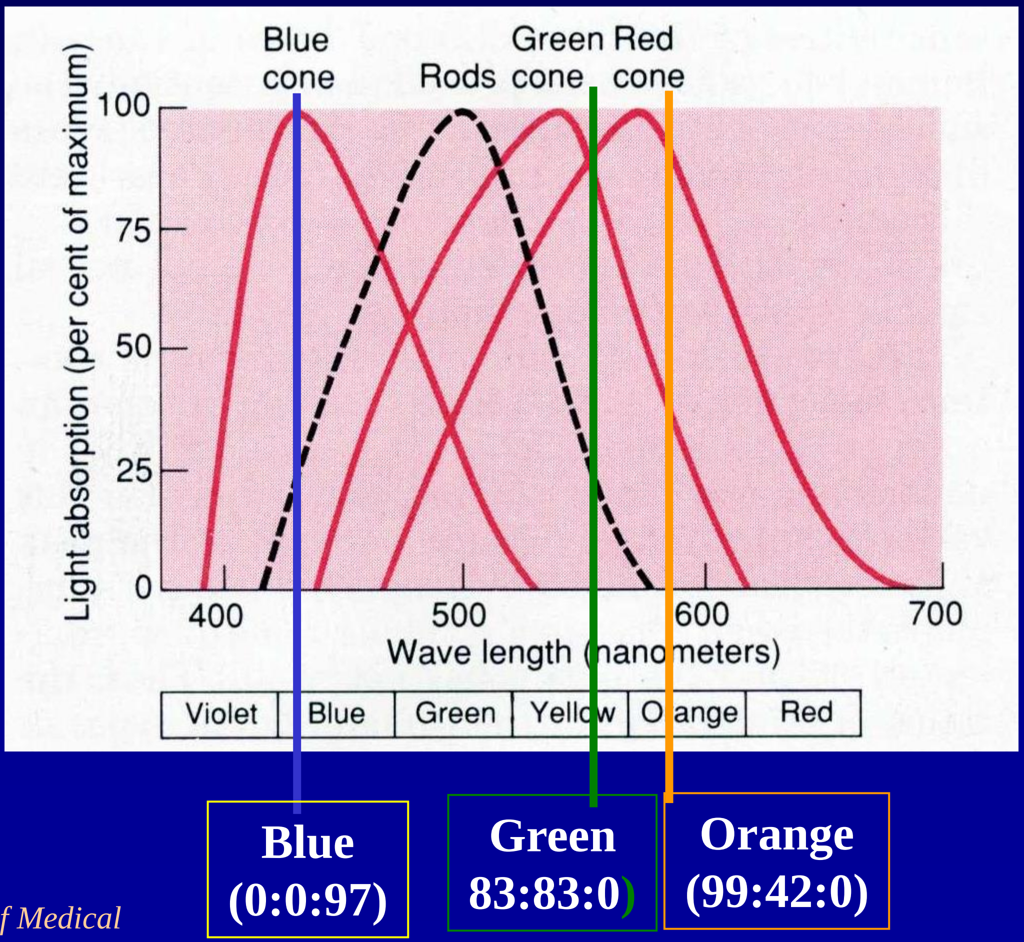
- opsin (receptor)
    - cones can have 1 of 3 opsin / retinal complexes

1) blue - 443 nm
2) green - 535 nm
3) red - 570 nm

} For color

    -rods have rhodopsin

Spectral Sensitivity of Opsins



From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

How Computers “See”: Image Analysis-1

Bit Depth

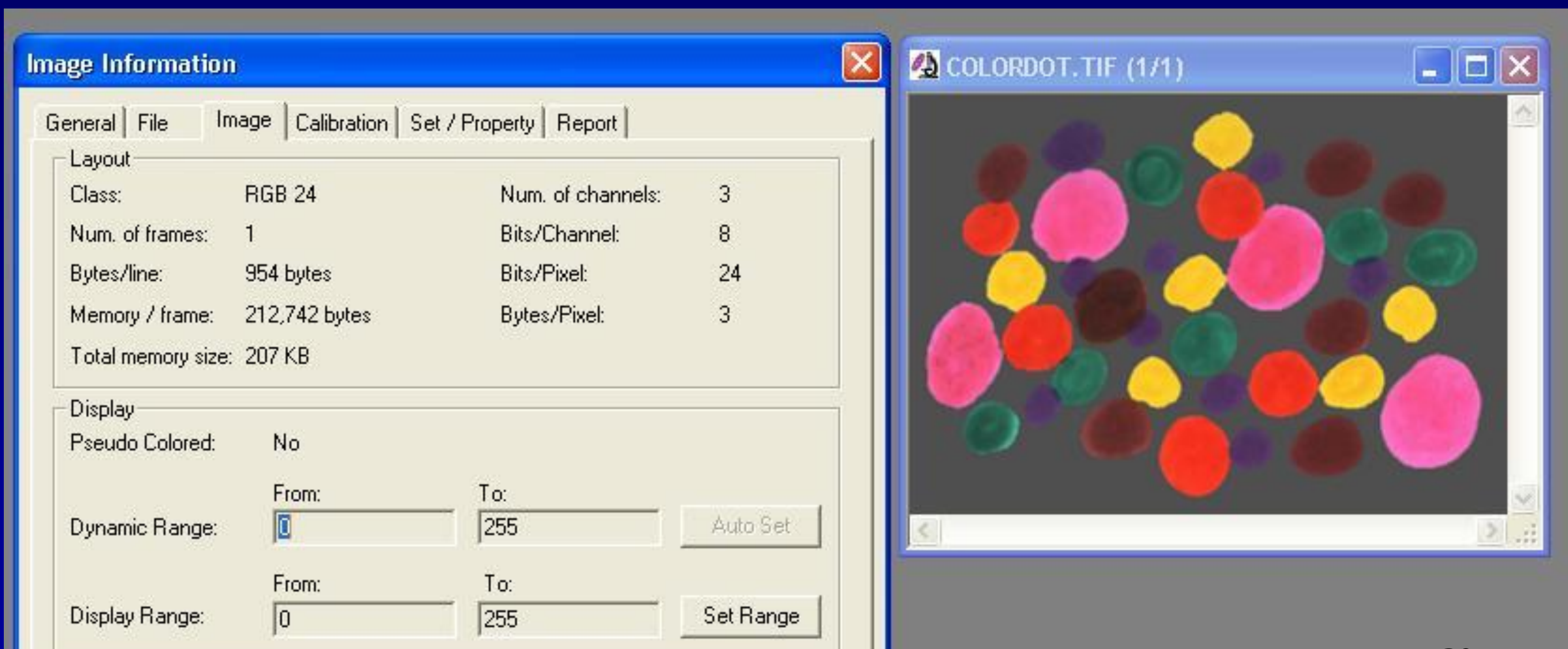
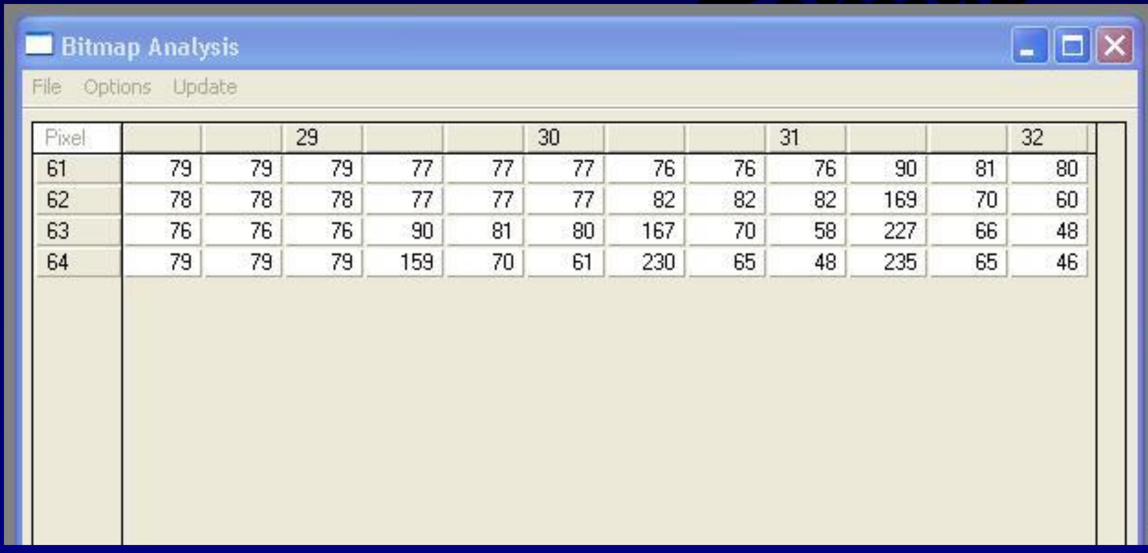
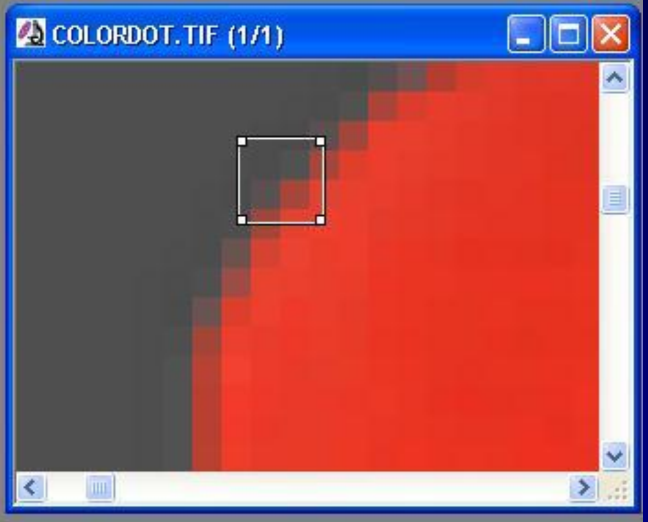


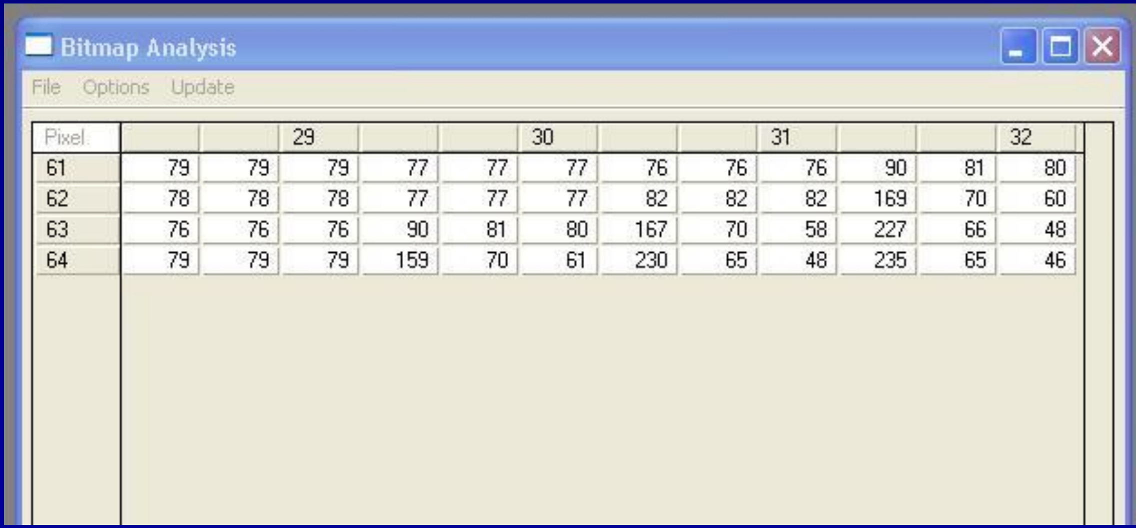
Image Analysis-2

Bitmap



Pixel			29			30			31			32
61	79	79	79	77	77	77	76	76	76	90	81	80
62	78	78	78	77	77	77	82	82	82	169	70	60
63	76	76	76	90	81	80	167	70	58	227	66	48
64	79	79	79	159	70	61	230	65	48	235	65	46





Pixel			29			30			31			32
61	79	79	79	77	77	77	76	76	76	90	81	80
62	78	78	78	77	77	77	82	82	82	169	70	60
63	76	76	76	90	81	80	167	70	58	227	66	48
64	79	79	79	159	70	61	230	65	48	235	65	46

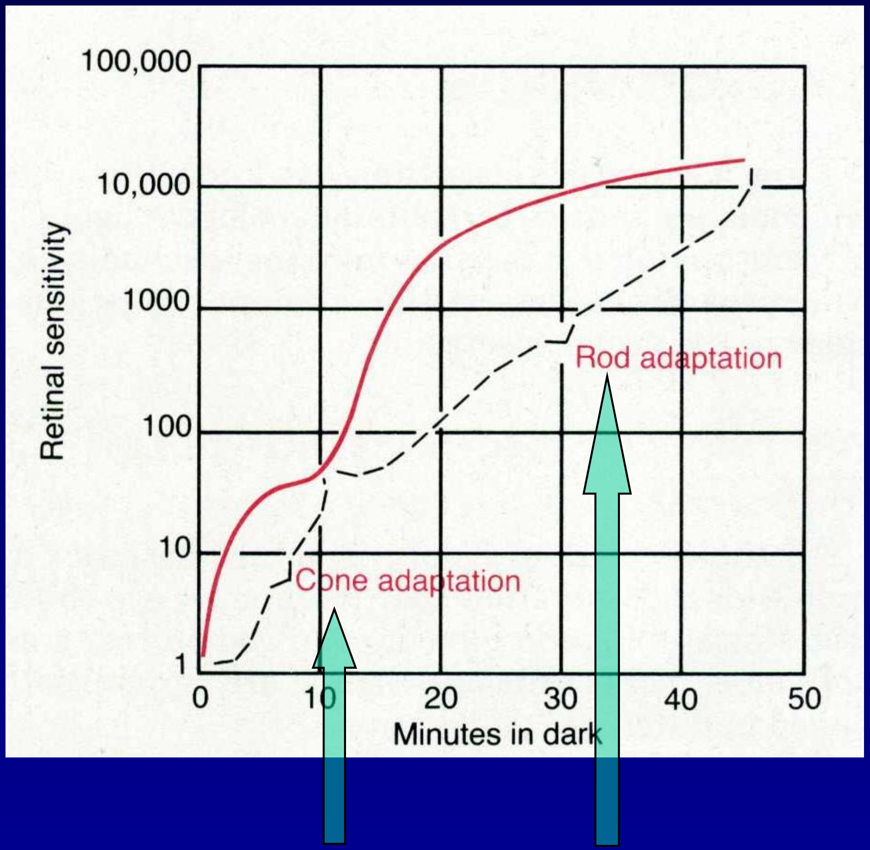
Dark and Light Adaptations

<u>Dark Adaptation:</u> accumulation of intact visual pigments and additional conversion of vitamin A into retinal while retina is kept in the dark.

<u>Light Adaptation:</u> Depletion of intact visual pigments due to extended exposure of the retina to light.

Other non-photochemical adaptations to changing light levels are **pupillary opening adjustment** and **neural adaptation**.

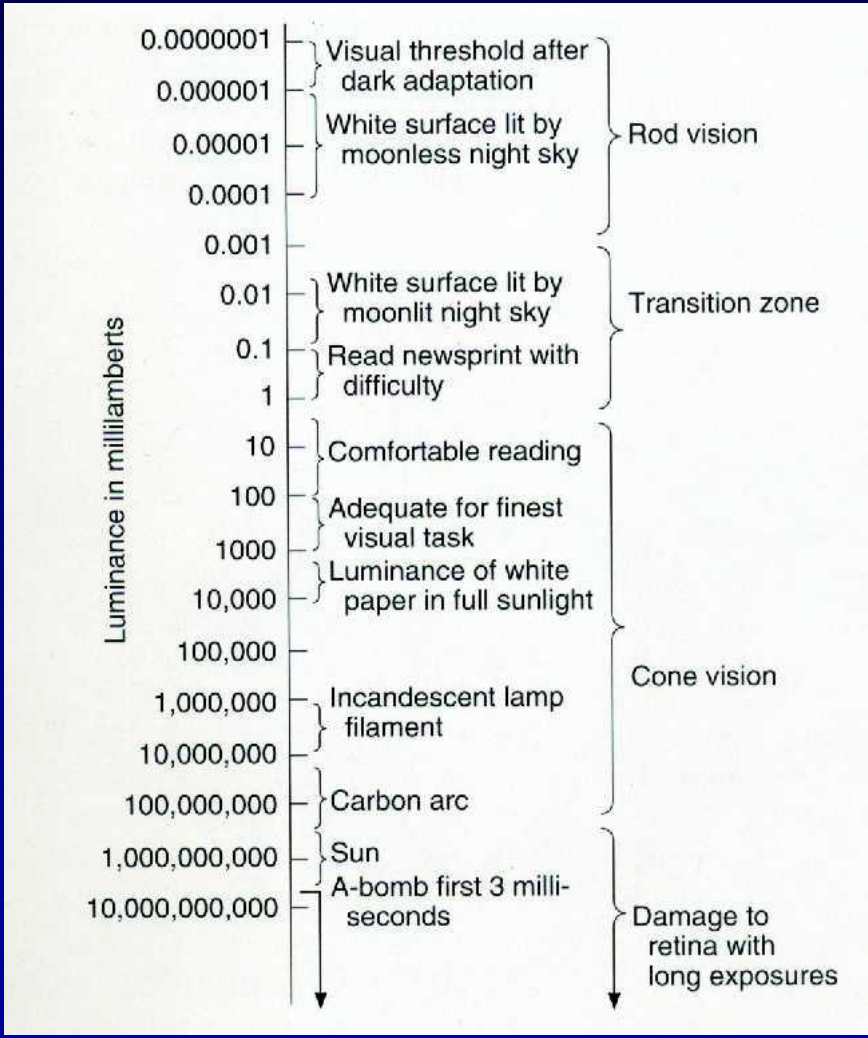
Question: Positive or Negative Feedback?



Cones adapt faster than rods, but are never as sensitive as rods

From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

Luminescence Intensity Response Range



From: W.F. Ganong, *Review of Medical Physiology*, 19th ed. Appleton & Lange, 1999

Photoreceptor cells synapse directly with 3 types of neurons

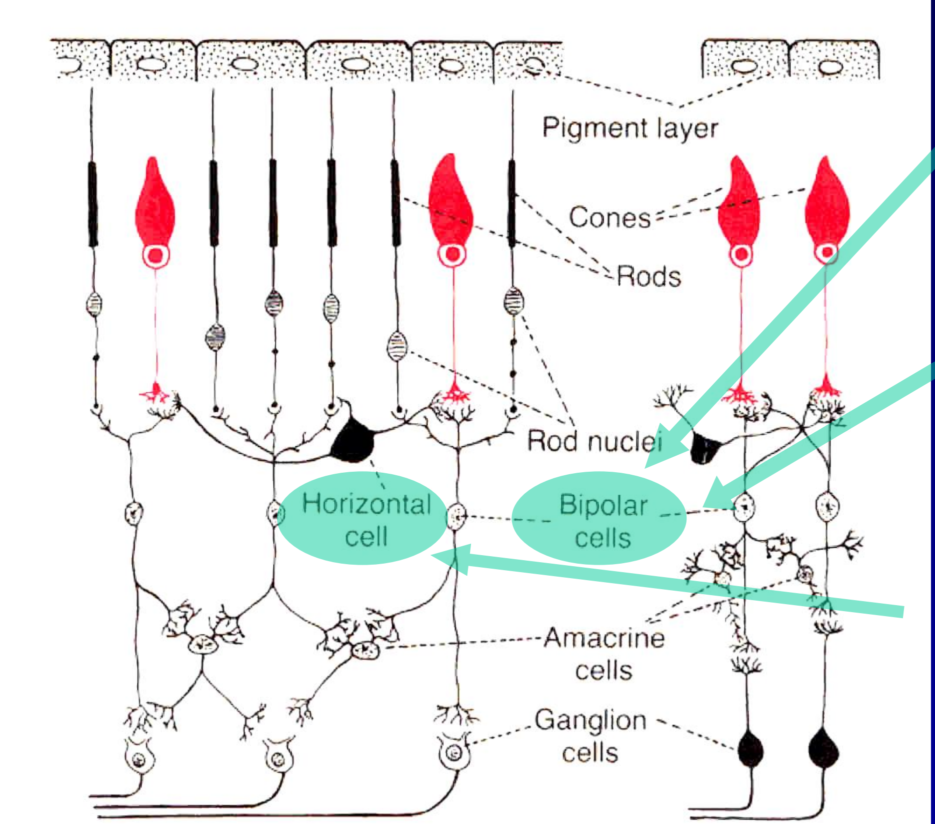


Figure 50 – 11. Neural organization of the retina: peripheral area to the left, foveal area to the right.

1. Depolarizing bipolar cells - depolarize with increased glutamate (released from rods and cones).
2. Hyperpolarizing bipolar cells - hyperpolarize with increased glutamate (from rods and cones)
3. Horizontal cells - always inhibitory
4. Two types of bipolar cells may allow for 2 types of control= "extra gas" and "emergency break". Also finer control in columns rather than lateral (= horizontal cells).

From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

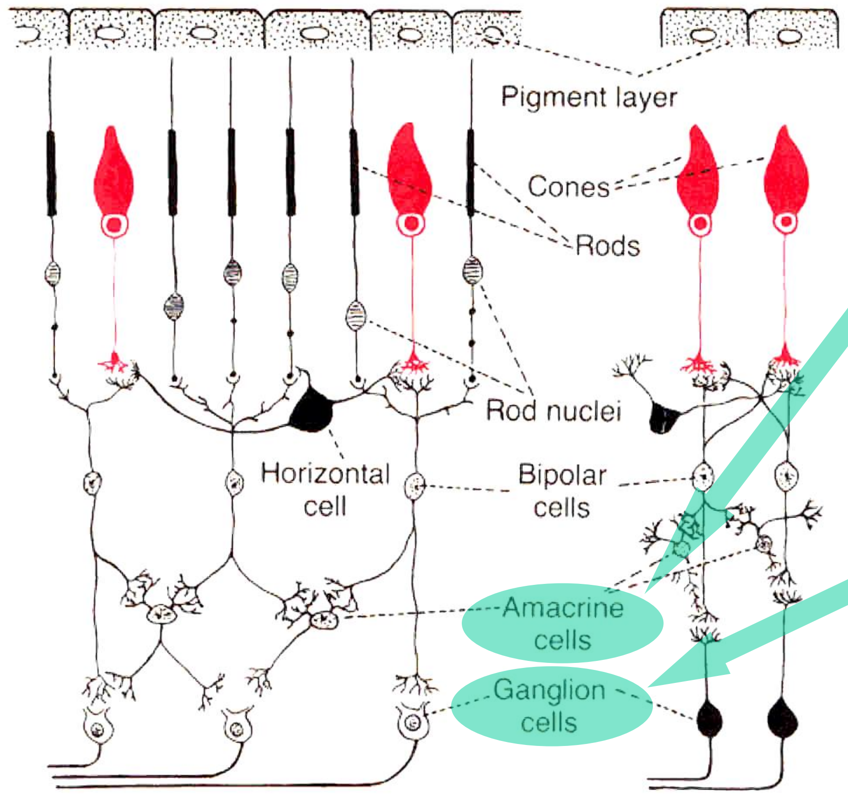


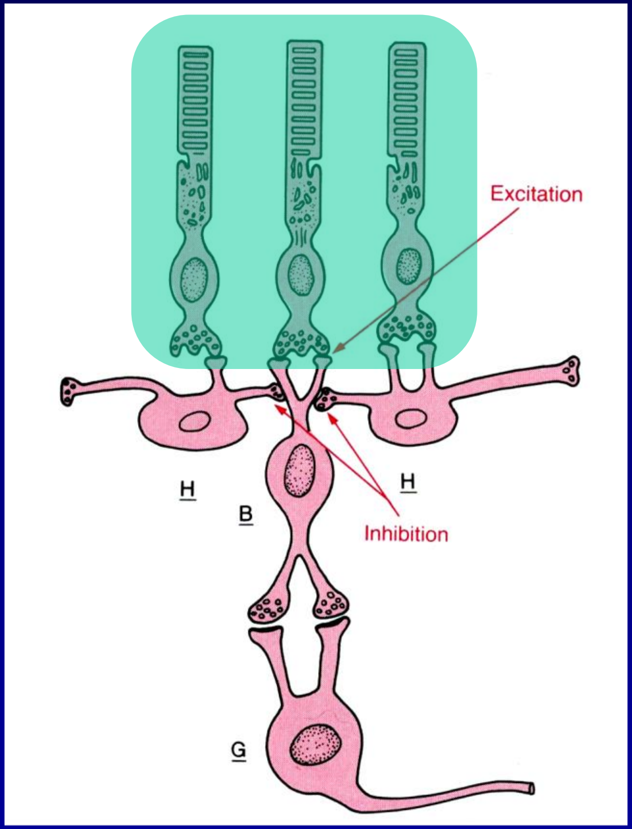
Figure 50 – 11. Neural organization of the retina: peripheral area to the left, foveal area to the right.

There are a variety of types of **amacrine cells** (interneurons) which modulate tramsmission of the signal from bipolar cells to ganglion cells.

Ganglion cells transmit an action potential to the CNS via their axons in the optic nerve

From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

Lateral Inhibition - complex interconnections of retinal neurons which enhance visual contrast.



Situation 1: Light impinges on all 3 photoreceptor cells

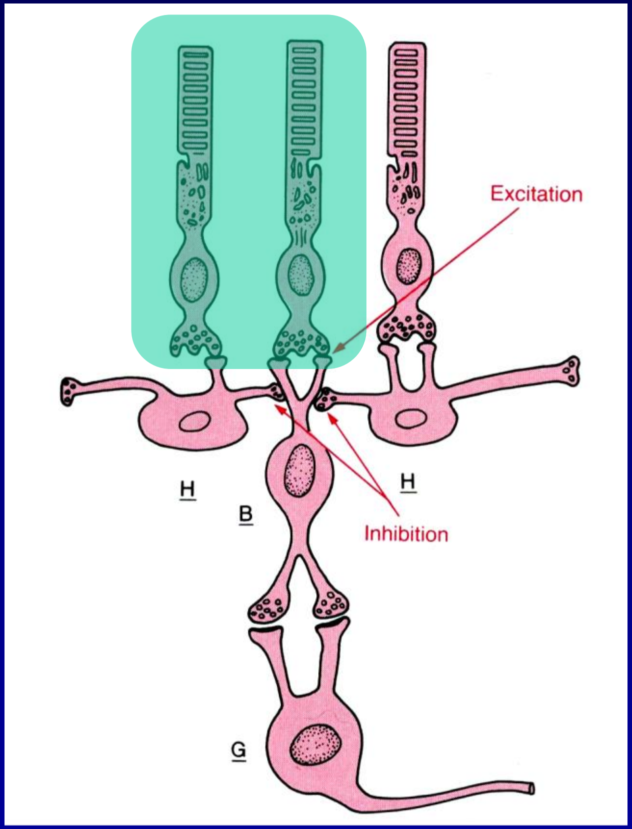
1. Central depolarizing B cell is excited, H cells inhibitory, therefore net signal is mixed

2. Depolarizing B cell inhibited by H cells but excited by photoreceptors

3. Excitation of G cell decreased= flat signal.

From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

<u>Lateral Inhibition</u> - complex interconnections of retinal neurons which enhance visual contrast.



Situation 2: Light impinges on the central and one lateral photoreceptor cells

1. Central depolarizing B cell is excited, one H cell active (inhibitory); one not active (less inhibition).
2. Depolarizing B cell inhibited half as much as Situation 1
3. Excitation of G cell enhanced relative to Situation 1

From: A.C. Guyton *Textbook of Medical Physiology*, 8th ed., Saunders, 1991.

Fixation Movements of Eyes

- Voluntary (search) and involuntary (lock) – function of visual cortex in brain
- During rapid change of visual scenes, eye experiences rapid jumps (saccades); visual stimuli during jumps are suppressed

Control of Accommodation (Focusing Eye)

- Results from contraction or relaxation of ciliary muscles to change lens shape
- Time to change focus: typically < 1 sec

Known features of accommodation system

- Lens always changes strength in proper direction
- Different clues help lens change its strength
  - Chromatic aberration: red focuses posterior to blue
  - As eyes converge for near objects, neural system simultaneously changes lens strength
  - Oscillation of accommodation (approximately twice per second)

Blindness

- Legal Blindness: no better than 20/200 vision (best correction) or 20° visual field
- Common Causes:
  - Cataracts (usually can be corrected)- clouding of the lens-
  - Macular Degeneration
  - Glaucoma- damage to the optic nerve
  - Diabetic Retinopathy- damage to blood vessels in back of eye-
  - Retinitis Pigmentosa-inherited and degenerative for light sensing cells of the retina.

Consequences of Blindness

- Mobility
- Reading
- Recreation
- Work / Schoolwork
- Tasks of Daily Living

END-