

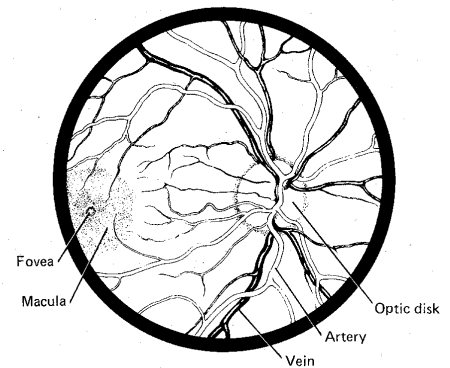
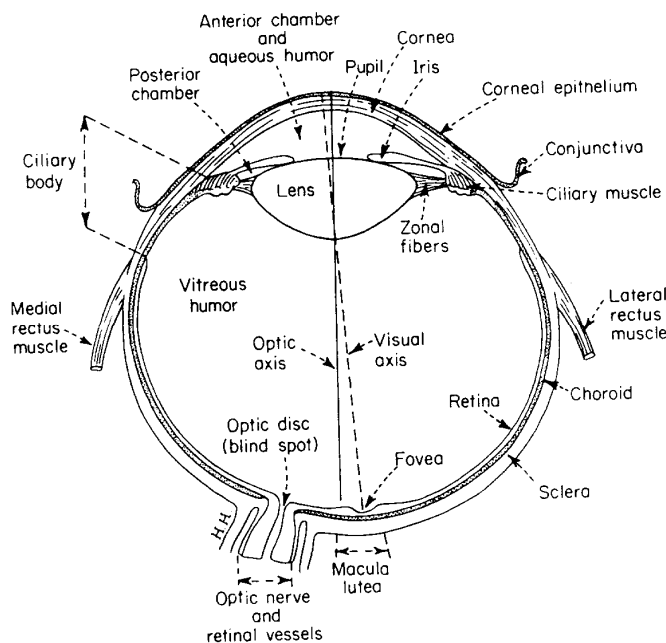
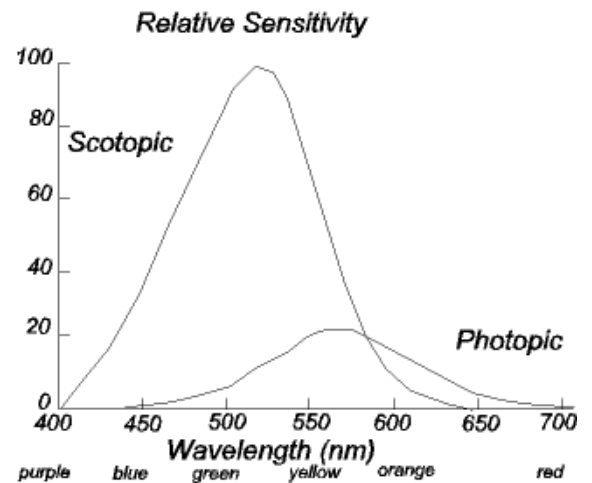
INTRODUCTION

A. Role of the visual system: sense photons emitted by or reflected from objects in the environment and to interpret the resulting afferent input. This is accomplished by four processes:

1. Formation of a small image of the environment on retina (which contains the photoreceptor afferent neurons) by the optical apparatus of the eye
2. Transduction of the image into a pattern of action potential discharge by retinal neurons (retinal transduction)

Note: Transduction is possible only for light within a limited wavelength range, approximately 400-700 nm (nanometers); the exact range depends on whether the eye is light adapted (photopic vision) or dark adapted (scotopic vision)

3. Conduction of the resulting action potentials to regions of the central nervous system (CNS) responsible for conscious sensation of visual input (visual pathways)
4. Extraction of the properties of the visual image: shape, color, brightness, movement, etc. (visual cortex)



OPTICS

A. Image Formation in the Eye

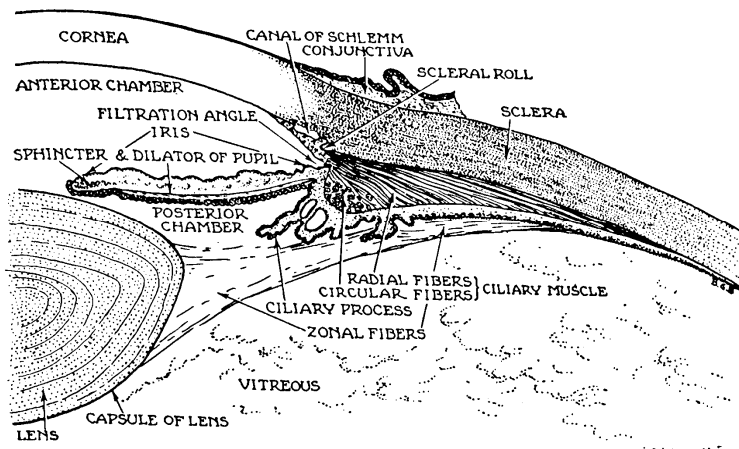
Note: image formation depends on focusing the light rays by bending (refraction) as the light passes through spherical surfaces.

1. Refracting surfaces
 - a. cornea
 - b. front lens surface
 - b. rear lens surface

Note: The most refraction occurs at the cornea. However, the lens surfaces are important because the lens can change its power, thereby permitting focusing on near objects.

2. Eye aqueous and vitreous humors
 - a. secreted by the ciliary bodies; drained by the canal of Schlemm
 - b. normally at a positive pressure of 15 ± 3 mmHg; positive pressure helps to maintain shape of eye
 - c. excess pressure (due, for example, to blockage of fluid drainage) is termed *glaucoma*, and can interfere with retinal circulation and axoplasmic transport, leading to retinal degeneration and blindness
3. Result: small, inverted image of the external world is formed on the retina

Note: light incident on the retina that is not absorbed by the retinal photoreceptors is absorbed by *melanin* in the pigment epithelium in back of the retina, preventing photons that pass through the retina from being reflected back into the eye, which would otherwise blur the retinal image

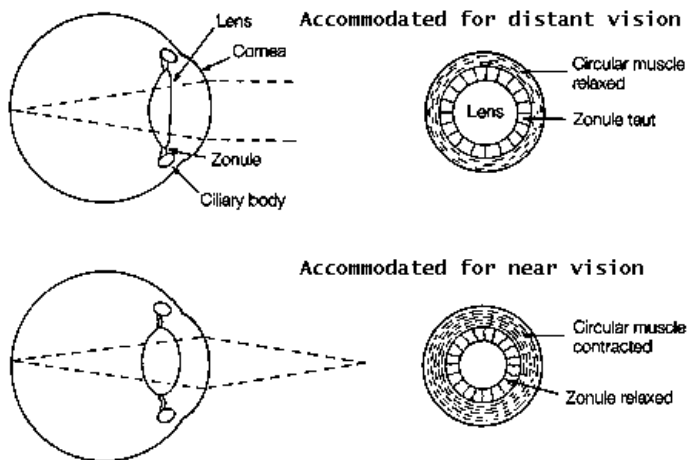


Note: The lens is normally transparent but if protein precipitation occurs, light passing through the lens is scattered (*cataract*), resulting in blurring; major causes: aging, UV exposure, diabetes (diabetes also can cause diabetic retinopathy due to small artery disease)

OPTICS (continued)

B. Accommodation

1. Definition: variations in eye refracting power in order to focus objects at different distances onto the retina
2. Mechanism



When the ciliary muscles of the lens are relaxed, the tension developed by the zonule fibers of the suspensor ligament flatten the lens, reducing its power to a minimum. When the ciliary muscles contract, they take up some of the suspensory ligament force, permitting the lens to bulge passively, thereby increasing its bending power.

3. Maximum power increase

The ability of the lens to bulge upon ciliary muscle contraction depends upon lens elasticity. The lens becomes less elastic with age, leading to decreased ability to accommodate for near objects.

4. Innervation: Autonomic

- a. parasympathetic: excite ciliary muscles; cholinergic (muscarinic); accommodate for near vision
- b. sympathetic: inhibit ciliary muscles; adrenergic (β_2); accommodate for distant vision

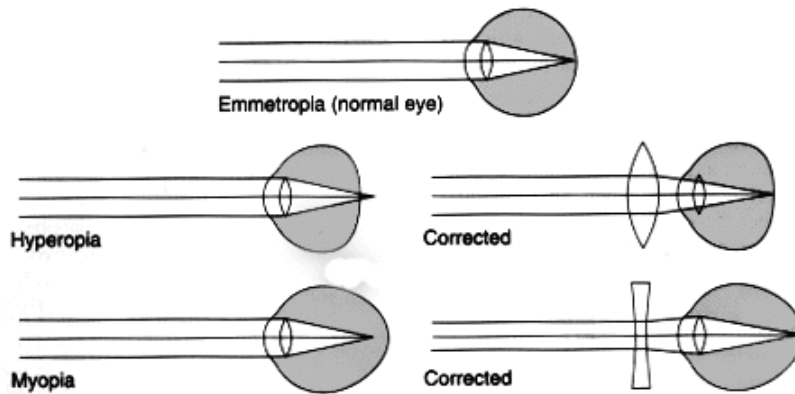
C. Normal Refraction and Refraction Pathophysiology

1. Emmetropia: With no accommodation (ciliary muscles relaxed; minimum optical power), images from distant objects come to a focus on the retina. This is the "normal" condition. Far point is infinity (distant objects) and near point depends on maximum power of accommodation (about 20 cm for a 40 yo adult).

Note: near point is the closest a person can focus, far point is the furthest a person can focus for clear vision

OPTICS

C. Normal Refraction and Refraction Pathophysiology (continued)



2. Myopia (near sighted): With the ciliary muscles relaxed, images from distant objects come to a focus in front of the retina, and only nearby objects are focused clearly. Far and near points are closer than normal.

Correction: negative lens (diverging) or contact lens with less curved surface (compared to cornea)

3. Hyperopia (far sighted): With the ciliary muscles relaxed, images from distant objects come to a focus behind the retina; some or all of accommodation power must be used to see distant objects clearly and, with severe hyperopia, even maximum accommodation may be insufficient. Near point further than normal and far point infinity, at best.

Correction: positive lens (converging) or contact lens with more curved surface (compared to cornea)

4. Presbyopia: Reduction in maximum accommodation of lens. Characteristic of aging. Near point becomes further away.

Correction: bifocals or trifocals (lenses with different amounts of correction depending on viewing direction)

5. Astigmatism: Differing refractive power at different orientation angles (e.g. differing horizontal and vertical power). Result: there is no distance at which an image is in focus at all angles.

Correction: Asymmetric lens, with different refractive power at different angles

OPTICS

D. Iris and Pupil

1. Structures

- a. Iris: structure blocking light from passing through lens; similar to diaphragm on camera
- b. Pupil: clear area not blocked by iris; size controlled by contraction of circular and radial muscles of iris, of which extreme states are
 - 1) dilated pupil: radial (dilator) muscles contracted, circular (constrictor, **sphincter**) muscles relaxed; maximum diameter about 7 mm
 - 2) constricted pupil: radial muscles relaxed, circular muscles contracted; minimum diameter about 1-2 mm

2. Innervation of iris smooth muscle

- a. sympathetic (adrenergic, α_1): cause dilation by exciting radial muscle fibers (mydriasis)
- b. parasympathetic (cholinergic, muscarinic): cause constriction by exciting circular muscle fibers (miosis)

3. Roles

- a. Regulate amount of light reaching retina
 - 1) light reflex: when light incident on the eye increases, the pupil constricts, tending to reduce the variation in the intensity of light reaching the retina

Incident light \uparrow → Retinal stimulation \uparrow → Reflex integration → Parasympathetic \uparrow → Pupil \downarrow
Sympathetic \downarrow

- 2) consensual light reflex: if only one eye is stimulated by increased light, both the pupil of the stimulated eye and the contralateral pupil constrict
- b. Reduce the effects of optical defects by constricting pupil (increase acuity)
 - 1) near reflex: accommodation for near vision leads to reflex pupil constriction

E. Visual Acuity

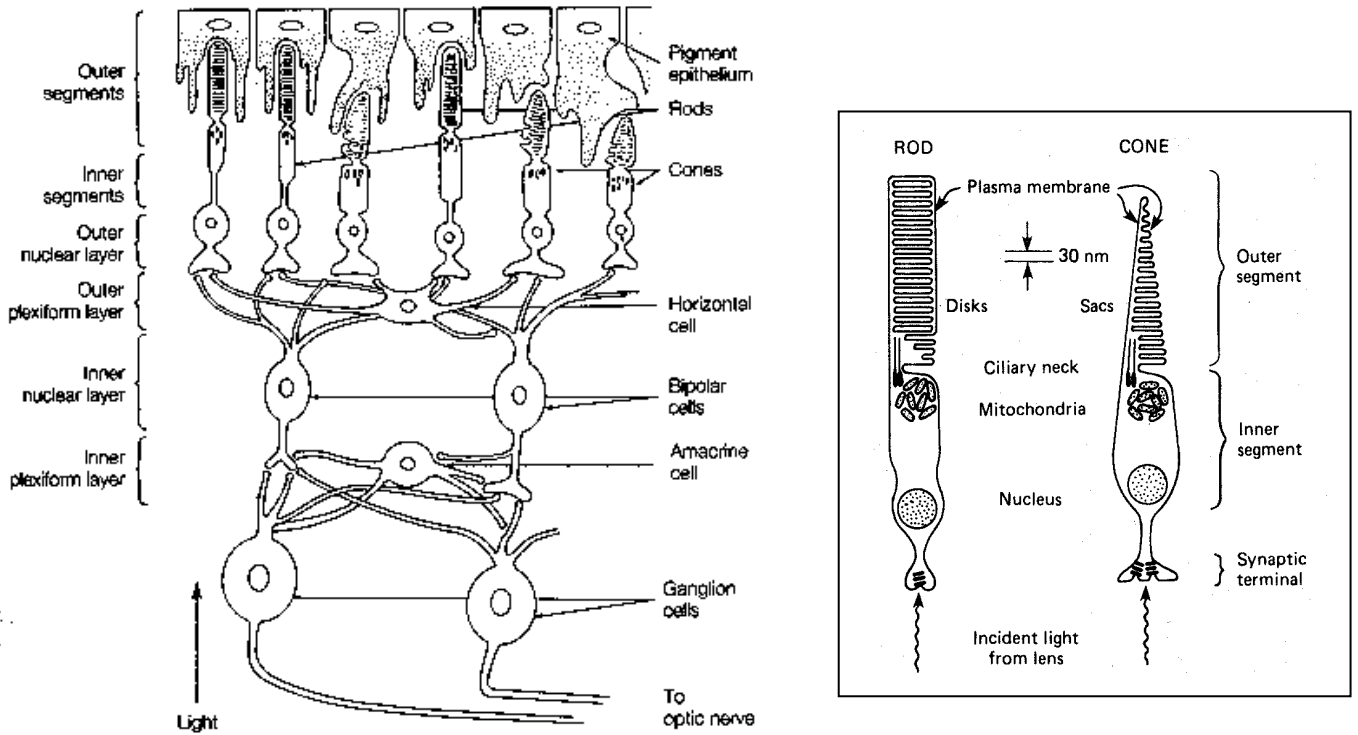
1. Define: ability to distinguish fine visual detail
2. Clinical test: place a well-lighted target with letters or figures of various sizes the standard distance of 20 feet (6 meters) away from the subject and note the smallest letters the subject can distinguish

acuity measure = distance of the chart / distance at which a normal subject can distinguish figure

e.g. acuity = $\frac{20}{20}$ (6/6m) → normal
 $\frac{20}{200}$ (6/60m) → poor vision (1/10 normal acuity)
 $\frac{20}{10}$ (6/3m) → better than normal

RETINAL TRANSDUCTION (ACTION POTENTIAL GENERATION)

A. Retinal Neural Organization



Note: Incident photons must pass through all neural and vascular structures before striking visual pigments except in fovea

B. Rod and Cone Function

1. General characteristics of rods and cones

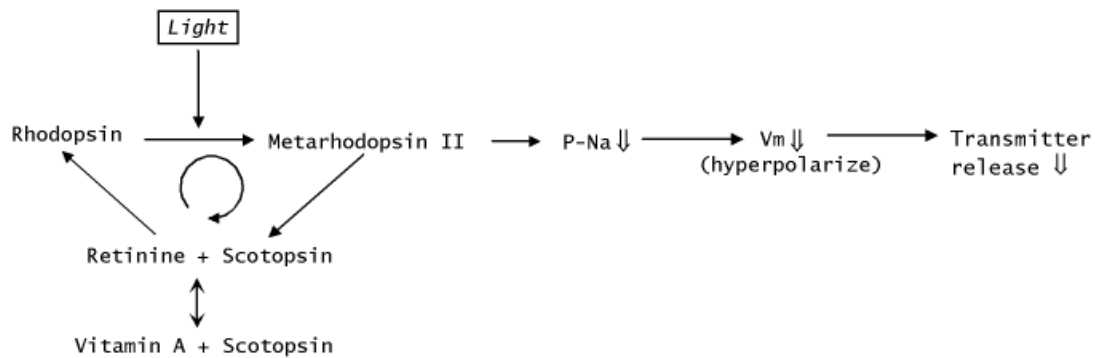
<i>Rods</i>	<i>Cones</i>
120,000,000 per eye	6,000,000 per eye
Uniformly distributed throughout retina, except not found in fovea	Mainly confined to fovea
High light sensitivity (function at low light levels)	Lower sensitivity (function limited to higher light levels)
Night vision (scotopic)	Daytime vision (photopic)
Lower acuity, due in part to great convergence of neurons innervating rods along visual pathway	Higher acuity, due in part to minimal convergence
Visual pigment is rhodopsin	Three separate visual pigments
Monochromatic vision	Color vision

Note: Absorption of light photons by the rod and cone pigments is the first step in the transduction process

RETINAL TRANSDUCTION (continued)

C. Photoreceptors

1. Signaling sequence in rods



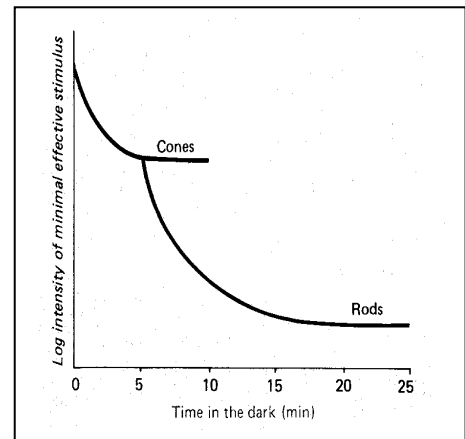
- a. in rods, the photochemical pigment is rhodopsin (“visual purple”), which is formed from retinine and an opsin; for rhodopsin, the opsin is scotopsin
- b. effect of light
 - 1) light => absorbed by rhodopsin => bleach products
 - 2). bleach products activate intermediates which cause Na channels to close
 - 3) reduced Na⁺ influx causes hyperpolarization
 - 4) bleach products eventually break down into retinine and scotopsin; some of the retinine combines with scotopsin to form new rhodopsin, some is broken down into Vitamin A₁, and some is lost (note: rod outer segments are continuously broken down and regenerated); the amount lost is replaced by Vitamin A₁ from dietary sources (note effect of Vitamin A deficiency)
- d. receptor cells release neurotransmitter continuously to bipolar cells in the dark; hyperpolarization reduces the rate of transmitter release

RETINAL TRANSDUCTION

C. Photoreceptors (continued)

2. Light and Dark adaptation

- a. define: Light adaptation: decrease sensitivity with continued exposure to light; Dark adaptation: increase sensitivity in the absence of light
- b. mechanisms
 - 1) bleaching of rhodopsin and cone pigments by light (reducing photo-sensitivity) and the accumulation of pigment in the dark (increasing photo-sensitivity) is responsible in part for dark and light adaptation
 - 2) intracellular calcium increases in the dark and increases photoreceptor sensitivity, Ca decreases in the light which decreases sensitivity (note: Ca ions can enter the cell through Na channels)

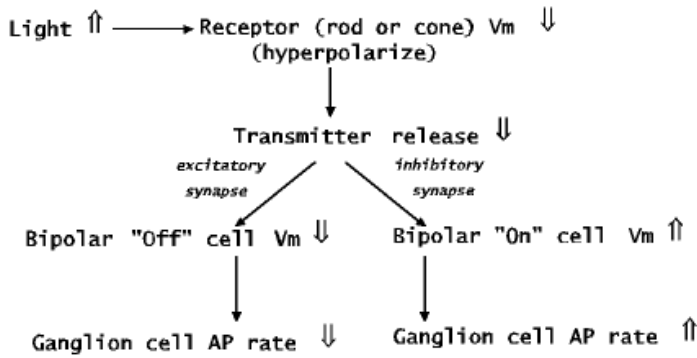


Note: Dark and light adaptation permit the eye to function over a very wide range of light intensities

RETINAL TRANSDUCTION (continued)

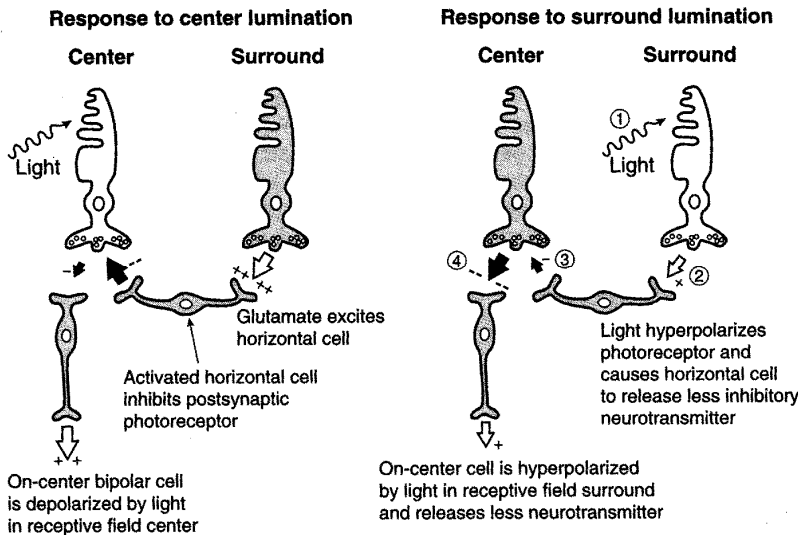
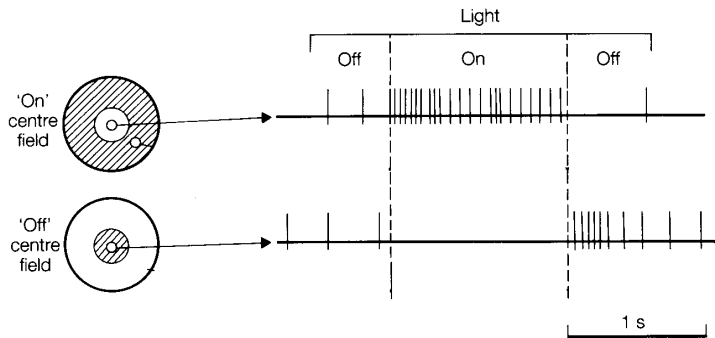
D. Bipolar Cell Function

1. Reduced release of rod or cone synaptic transmitter may cause depolarization or hyperpolarization of bipolar cell, depending upon type of synapse with bipolar cell



2. Upon depolarization, bipolar cells release excitatory (depolarizing) transmitter, causing ganglion cells to increase their resting action potential discharge rate
3. Thus, the response to light of bipolar cells that respond to transmitter by hyperpolarizing is to cause the associated ganglion cells to increase AP frequency (ON cell or "center on" cell)

The response to light of bipolar cells that respond to transmitter by depolarizing is to cause the associated ganglion cells to decrease AP frequency (OFF cell or "center off" cell)



RETINAL TRANSDUCTION (continued)

E. Horizontal and Amacrine Cell Function

1. Horizontal cells

- a. stimulated by photoreceptor cells
- b. synapse with near-by receptor cells and bipolar cells
- c. output generally inhibitory
- d. contribute to surround (lateral) inhibition
- e. increase spatial contrast of image (edge detection)

2. Amacrine cells

- a. receive information from bipolar cells
- b. synapse on ganglion cells
- c. multiple subtypes, with various image processing functions, including
 - 1) signal onset, cessation, or change in illumination
 - 2) sequence of receptor cell stimulation (movement and direction detection)

E. Ganglion Cells

1. Receive input from bipolar and amacrine cells
2. Generate the action potentials which propagate into the CNS

Note: receptors (rods and cones), bipolar cells, horizontal cells, and (for the most part) amacrine cells can depolarize or hyperpolarize, but do not generate action potentials; ganglion cells are the first cells in the chain that generate APs

3. Two channels

- a. M (or *magno*-, large) channel, characterized by
 - 1) large receptive fields (& extensive dendritic trees)
 - 2) adapting response to sustained stimulus
 - 3) respond to large (course) features and movement
- b. P (or *parvo*-, small) channel, characterized by
 - 1) smaller receptive fields
 - 2) support color vision
 - 3) respond to fine detail

Note: this organization carried up to the thalamus and primary visual cortex

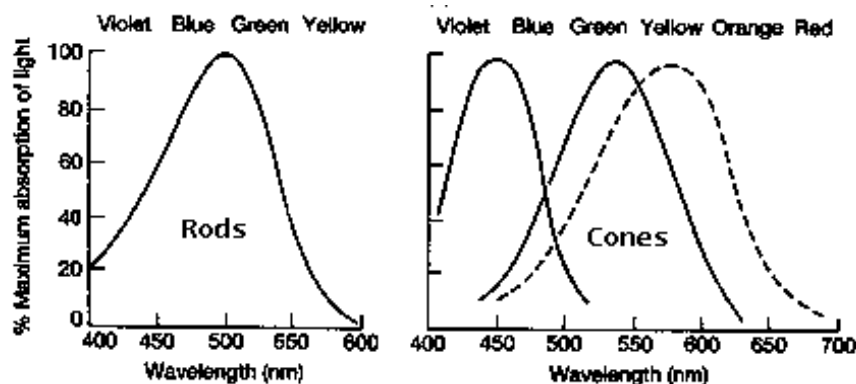
COLOR VISION

A. Basis: Cone Sensitivity

1. three types of cones, each characterized by the spectral sensitivity of the photopigment it contains
 - a. peak sensitivity 405 nm ("blue" cone)
 - b. peak sensitivity 535 nm ("green" cone)
 - c. peak sensitivity 565 nm ("red" cone)
2. each photopigment is composed of retinene and an opsin which determines the type of cone
3. the general conversion of light to membrane potential change and transmitter release is the same as in rods

Note: sensitivity depends upon absorption efficiency of each visual pigment

- B. Trichromatic Theory: the color sensed depends upon the ratio of stimulation of the red, green, and blue cones



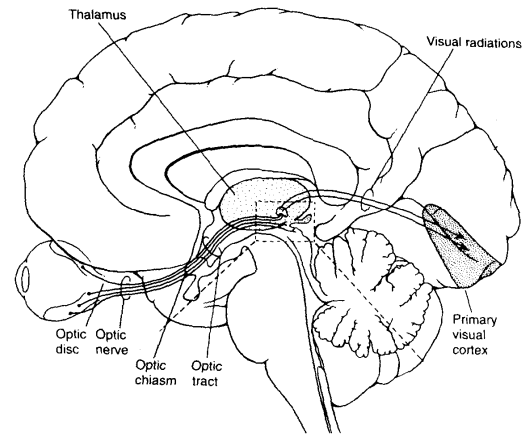
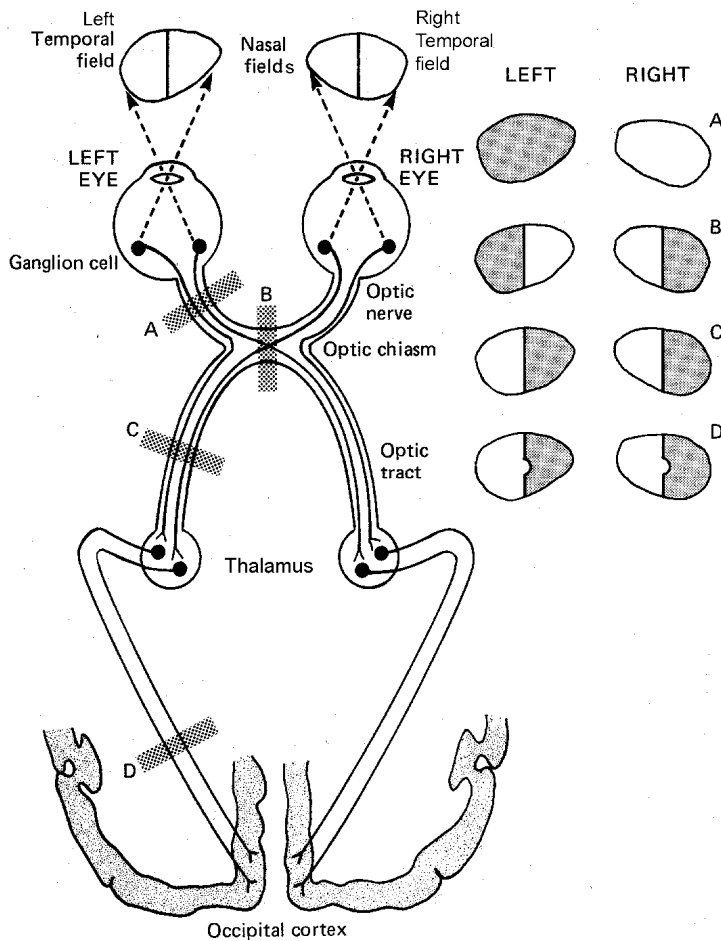
Examples:

<i>Cones stimulated</i>	<i>Color sensed</i>
Red only	Red
Red strongly, green less	Orange
Red and green equally	Yellow
Green mainly, less red and blue	Green
Blue mainly, less green	Blue
Blue only	Violet
Red and Green and Blue	White

- C. Color Blindness and Color Weakness: absence of one or more types of cones will lead to color blindness for one group or all colors; reduced function of one or more types of cones will lead to color weakness

Example: absence of red-sensing cones will lead to red-green color blindness; absence of both red and blue cones will lead to total color blindness (monochromatic vision)

VISUAL PATHWAYS



A. Optic nerve -- Optic Tract -- Thalamus -- Primary Visual Cortex

1. Optic nerve and tract

- a. ganglion cell axons form optic nerve
- b. optic nerve axons from the nasal half of each retina cross to the opposite side in the optic chiasm, while axons from the temporal half of each retina do not cross

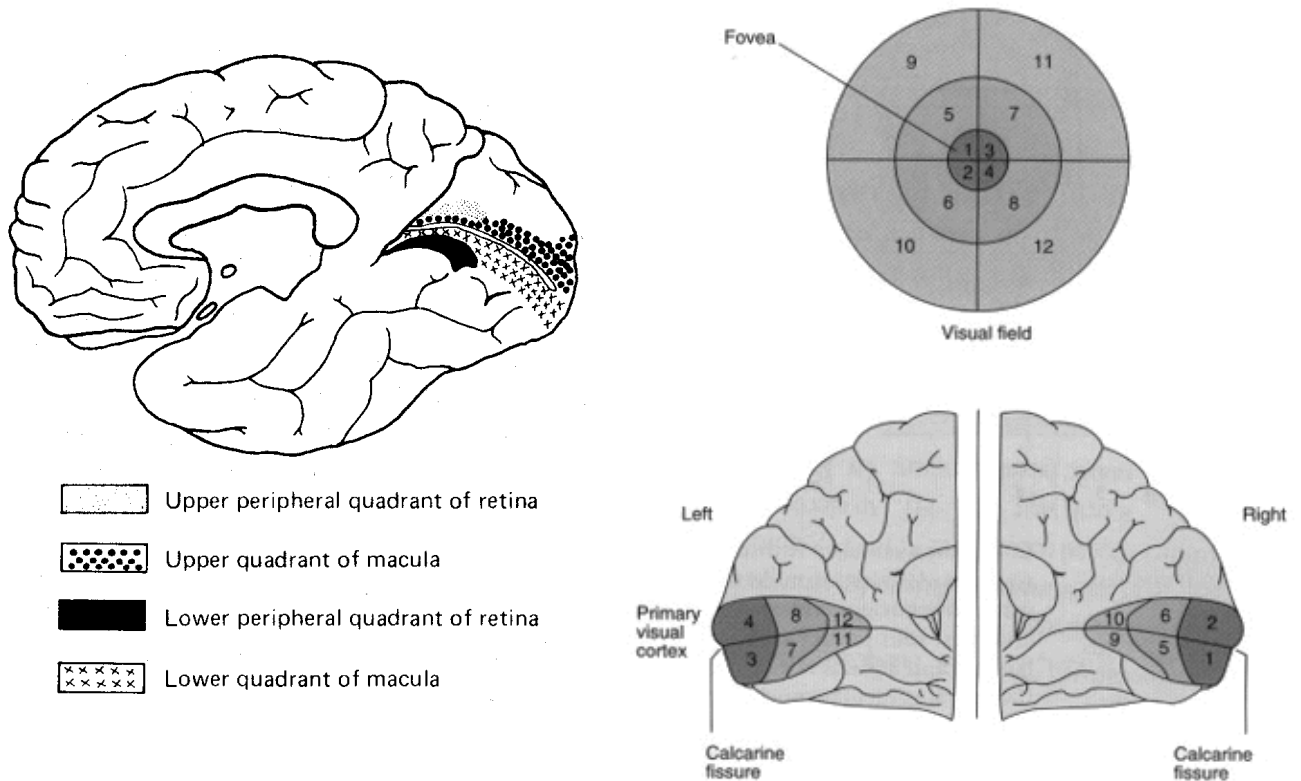
Note: after passing the chiasm, the ganglion cell axons are called the optic tract (same axons, different name)

- c. thus, the right visual field is conveyed in the left optic tract and projects to the left side of the thalamus; the left visual field is conveyed in the right optic tract and projects to the right side of the thalamus

Note: Receptive field in the visual system is referred to the external world, and is termed the Visual Field (e.g. left, right, nasal, temporal)

VISUAL CORTEX

A. Primary Visual Cortex (synonyms: V1, striate cortex)



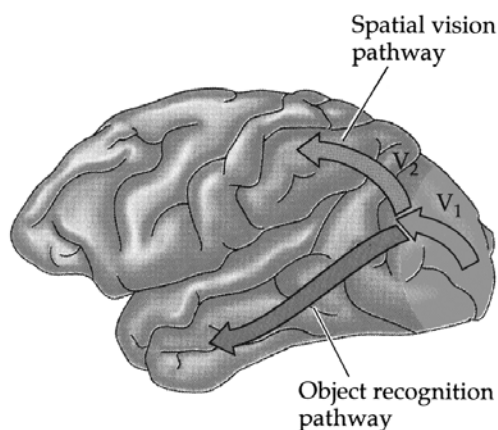
1. Located in occipital cortex
2. Visual field mapped on V1, with cortical area proportional to number of optic nerve fibers -- that is, relatively large area devoted to fovea/macula; ; map preserves spatial relations (inverted) of the visual fields; the left visual field is represented on the right occipital cortex and the right visual field on the left occipital cortex
3. Each region is organized as a groups of cells ("columns"), each of which represents a particular property (e.g. form, color) from a particular region of the retina of a given eye; some columns detect line orientation, some detect color, etc.
4. Columns are interconnected to extract properties
 - a. fuse images from the two eyes
 - b. detect color by comparing input from adjacent cones with differing visual pigments (blobs)
 - c. enhance contrast and detect edges
 - d. respond to movement
 - e. detect line orientation (e.g., horizontal or vertical) at a specific position ("simple" cells)
 - f. detect line orientation independent of position ("complex" cells)
 - g. detect lines of specific shapes or specific lengths ("hypercomplex" cells)

Note: If the eyes are not focused on the same objects, only the image from the **dominant eye** is perceived; the image from the non-dominant eye is suppressed

VISUAL CORTEX

B. Extrastriate Cortex

1. Define: areas of the cerebral cortex receiving projections from primary visual cortex (V1) columns and containing maps of aspects of the visual space; about 24 such areas have been identified
2. Location and function
 - a. parietal lobe visual areas; specialized for detection of motion, direction, spatial relations ("M channel")
 - b. temporal lobe visual areas; specialized for detection of color, detailed shape ("P channel")



Note: some cell columns very specialized; e.g. detect faces, detect hands

3. Conclusion: The various aspects of the visual image are decomposed and projected to a number of areas of the cortex for separate analysis (parallel processing)
4. Pathophysiology: Visual *agnosia* (inability to detect particular properties of visual images even though the optical apparatus, visual pathways, and primary visual cortex are normal); examples

OTHER VISUAL SYSTEM FUNCTIONS

- A. Hypothalamus: regulate body rhythms associated with day-night cycle (diurnal, circadian)
- B. Control of optical apparatus of eye (lens, pupil), e.g. pupillary light reflex, accommodation for near and far vision
- C. Coordination of head and eyes