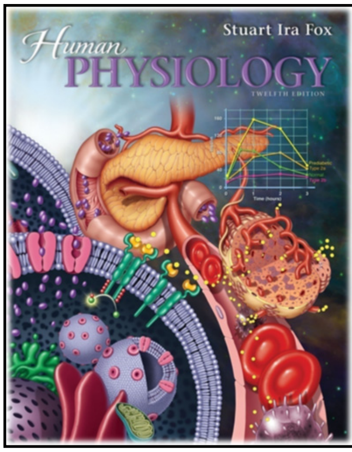
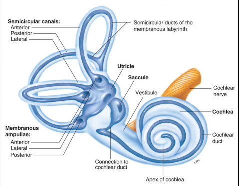


CHAPTER 10

Sensory Physiology



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Chapter 10 Outline

- Characteristics of Sensory Receptors
- Cutaneous Sensations
- Taste and Smell
- Vestublar Apparatus and Equilibrium
- The Ears and Hearing
- The Eyes and Vision
- Retina
- Neural processing of Visual Information

2

Sensory Receptors

10-3

3

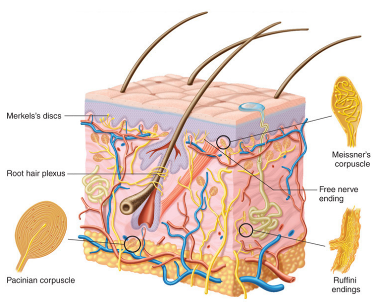
Sensory Receptors

- Transduce (=change) environmental info changed into APs -- the common language of NS
- Each type responds to a particular modality (=form of info, e.g. sound, light, pressure)
  - Different modalities perceived as different because of CNS pathways they stimulate

4

Sensory Receptors

- Can be simple dendritic endings of neurons
- Or specialized endings of neurons or non-neuronal cells



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Sensory Receptors

- Are grouped according to type of stimulus they transduce
  - Chemoreceptors sense chemical stimuli
  - Photoreceptors transduce light
  - Thermoreceptors respond to temperature changes
  - Mechanoreceptors respond to deformation of their cell membrane
  - Nociceptors respond to intense stimuli by signaling pain
  - Proprioceptors signal positional info of body parts

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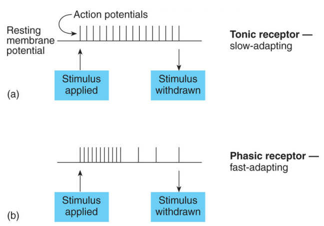
Sensory Receptors

- Also can be categorized according to location:
  - Cutaneous receptors are near an epithelial surface
    - Respond to touch, pressure, temperature or pain
  - Special sense receptors are part of a sensory organ
    - Such as hearing, sight, equilibrium

7

Sensory Receptor Responses

- Tonic receptors respond at constant rate as long as stimulus is applied
  - e.g. pain
- Phasic receptors respond with burst of activity but quickly reduce firing rate to constant stimulation (=adaptation)
  - e.g. smell, touch



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Law of Specific Nerve Energies

- Stimulation of sensory fiber evokes only the sensation of its modality
  - Adequate stimulus is normal stimulus
    - Requires least energy to activate its receptor

Table 10.1 Classification of Receptors Based on Their Normal (or "Adequate") Stimulus

Receptor	Normal Stimulus	Mechanisms	Examples
Mechanoreceptors	Mechanical force	Deforms cell membranes of sensory dendrites or deforms hair cells that activate sensory nerve endings	Cutaneous touch and pressure receptors; vestibular apparatus and cochlea
Pain receptors	Tissue damage	Damaged tissues release chemicals that excite sensory endings	Cutaneous pain receptors
Chemoreceptors	Dissolved chemicals	Chemical interaction affects ionic permeability of sensory cells	Smell and taste (exteroceptors) osmoreceptors and carotid body chemoreceptors (interoceptors)
Photoreceptors	Light	Photochemical reaction affects ionic permeability of receptor cell	Rods and cones in retina of eye

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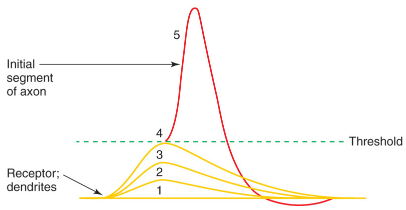
Generator Potentials

- Are sensory receptor equivalents of EPSPs (1-4)
- Produced in response to adequate stimulus
- If threshold reached, generates and action potential (5)



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Generator Potentials

- Are proportional to stimulus intensity
  - After threshold is reached AP frequency is proportional to amplitude of generator potential
- In phasic receptors the generator potential adapts to a constant stimulus and quickly diminishes in amplitude

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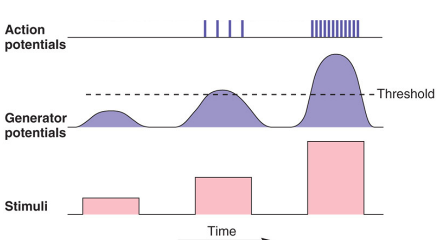
Generator Potentials

- In tonic receptors generator potential does not adapt to a constant stimulus



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Receptive Field

- Is area of skin whose stimulation results in changes in firing rate of sensory neuron
  - Area varies inversely with density of receptors
  - e.g. back, legs have low density of sensory receptors
    - Receptive fields are large
  - Fingertips have high density of receptors
    - Receptive fields are small

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Two-Point Touch Threshold

- Is minimum distance at which 2 points of touch can be perceived as separate
  - Measure of tactile acuity or distance between receptive fields

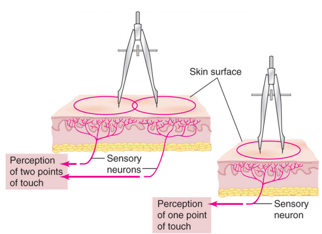

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Table 10.3 | The Two-Point Touch Threshold for Different Regions of the Body

Body Region	Two-Point Touch Threshold (mm)
Big toe	10
Sole of foot	22
Calf	48
Thigh	46
Back	42
Abdomen	36
Upper arm	47
Forehead	18
Palm of hand	13
Thumb	3
First finger	2

Source: From S. Weinstein and D.R. Kenshalo, editors, *The Skin Senses*, © 1968. Courtesy of Charles C. Thomas, Publisher, Ltd., Springfield, Illinois.

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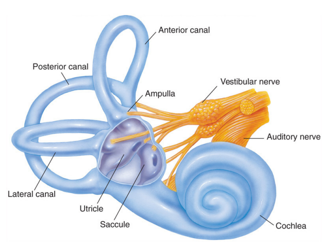
Ears and Hearing

16

Vestibular Apparatus

- Provides sense of equilibrium
  - =orientation to gravity
- Vestibular apparatus and cochlea form inner ear
- V. apparatus consists of otolith organs (utricle and saccule) and semicircular canals



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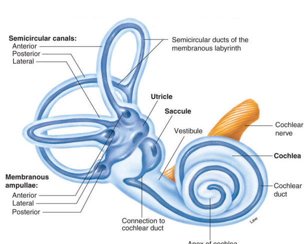
Vestibular Apparatus

- Sensory structures located with membranous labyrinth
  - Which is filled with endolymph
  - And located within bony labyrinth



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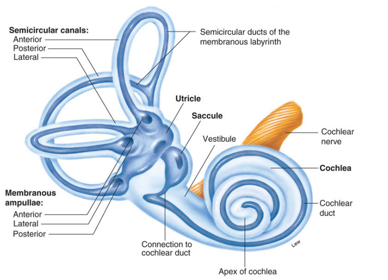
Vestibular Apparatus

- **Utricle and saccule** provide info about linear acceleration
- **Semicircular canals**, oriented in 3 planes, give sense of angular acceleration



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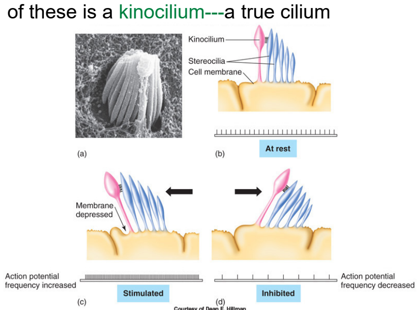
Vestibular Apparatus

- Hair cells are receptors for equilibrium
  - Each contains 20-50 hairlike extensions called stereocilia
    - 1 of these is a kinocilium---a true cilium



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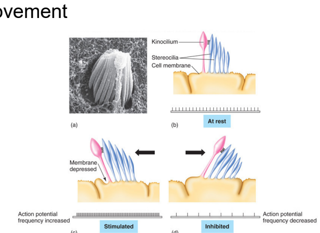
Vestibular Apparatus

- When stereocilia are bent toward kinocilium, hair cell depolarizes and releases NT that stimulates 8th cranial nerve
- When bent away from kinocilium, hair cell hyperpolarizes
  - In this way, frequency of APs in hair cells carries information about movement



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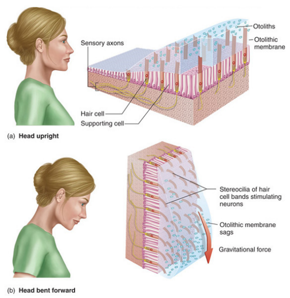
Utricle and Saccule

- Have a macula containing hair cells
  - Hair cells embedded in gelatinous otolithic membrane
    - Which contains calcium carbonate crystals (=otoliths) that resist change in movement



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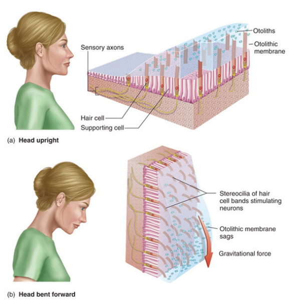
Utricle and Saccule

- Utricle sensitive to horizontal acceleration
  - Hairs pushed backward during forward acceleration
- Saccule sensitive to vertical acceleration
    - Hairs pushed upward when person descends



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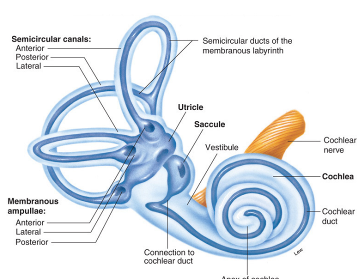
Semicircular Canals

- Provide information about rotational acceleration
- Project in 3 different planes
- Each contains a semicircular duct
- At base is crista ampullaris where sensory hair cells are located



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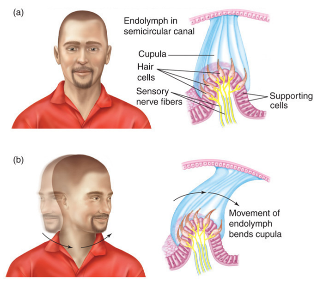
Semicircular Canals continued

- Hair cell processes are embedded in cupula of crista ampullaris
- When endolymph moves cupula moves
  - Sensory processes bend in opposite direction of angular acceleration



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Ears and Hearing

- Sound waves travel in all directions from source
- Waves characterized by frequency and intensity
  - Frequency is measured in hertz (cycles/sec)
    - Pitch is directly related to frequency
  - Intensity (loudness) is directly related to amplitude of waves
    - Measured in decibels

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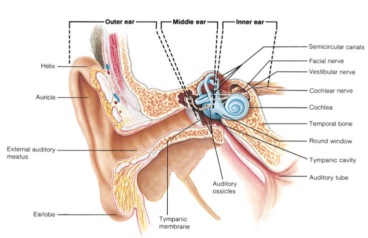
Ears and Hearing - Outer Ear

- Sound waves funneled by pinna (auricle) into external auditory meatus
- External auditory meatus channels sound waves to tympanic membrane



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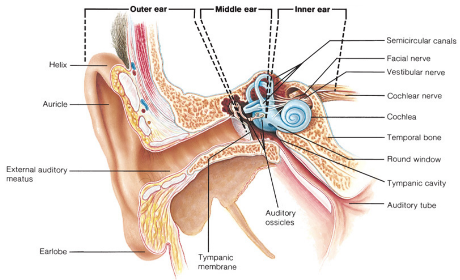
Ears and Hearing - Middle Ear

- Middle ear is between tympanic membrane and cochlea; holds ossicles



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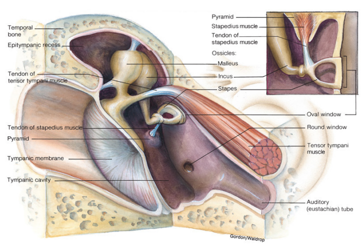
Ears and Hearing - Middle Ear continued

- Malleus (hammer) is attached to tympanic membrane
  - Carries vibrations to incus (anvil)
  - Stapes (stirrup) receives vibrations from incus, transmits to oval window



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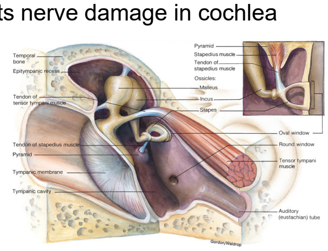
Ears and Hearing - Middle Ear

- Stapedius muscle, attached to stapes, provides protection from loud noises
  - Can contract and dampen large vibrations
  - Prevents nerve damage in cochlea



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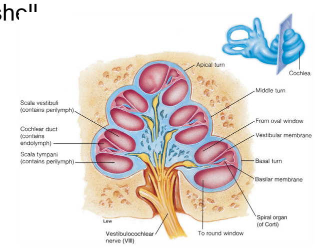
Ears and Hearing - Cochlea

- Consists of a tube wound 3 turns and tapered so looks like snail shell



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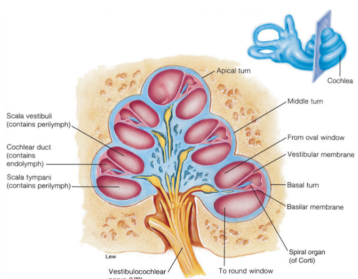
Ears and Hearing - Cochlea

- Tube is divided into 3 fluid-filled chambers
  - Scala vestibuli, cochlear duct, scala tympani



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Ears and Hearing - Cochlea

- Oval window attached to scala vestibuli (at base of cochlea)
- Vibrations at oval window induce pressure waves in perilymph fluid of scala vestibuli
- Scalas vestibuli and tympani are continuous at apex
  - So waves in vestibuli pass to tympani and displace round window (at base of cochlea)
    - Necessary because fluids are incompressible and waves would not be possible without round window

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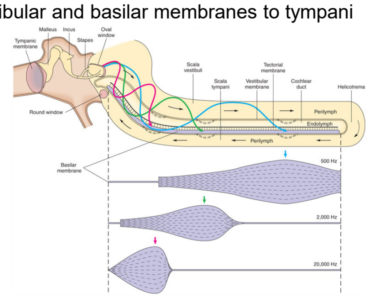
Ears and Hearing - Cochlea

- Low frequencies can travel all way thru vestibuli and back in tympani
- As frequencies increase they travel less before passing directly thru vestibular and basilar membranes to tympani



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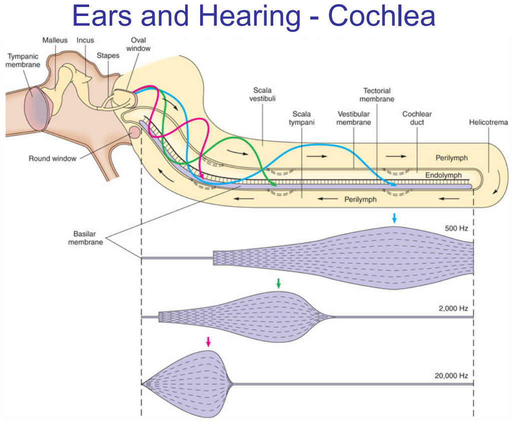
Ears and Hearing - Cochlea



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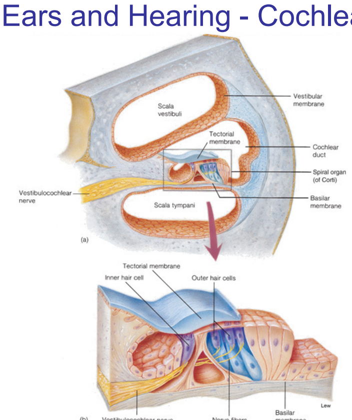
Ears and Hearing - Cochlea



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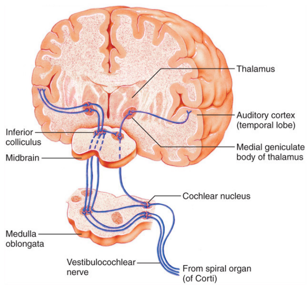
Neural Pathway for Hearing

- Info from 8th nerve goes to medulla, then to inferior colliculus, then to thalamus, and on to auditory cortex



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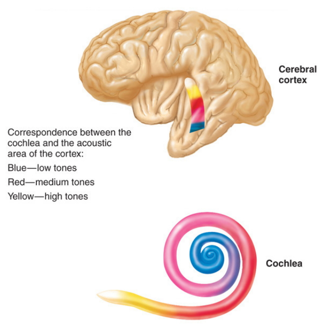
Neural Pathways for Hearing

- Neurons in different regions of cochlea stimulate neurons in corresponding areas of auditory cortex
  - This is called tonotopic organization where each area of the cortex represents a different part of cochlea and thus a different pitch



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Hearing Impairments

- Conduction deafness occurs when transmission of sound waves to oval window is impaired
  - Impacts all frequencies
  - Helped by hearing aids
- Sensorineural (perceptive) deafness is impaired transmission of nerve impulses
  - Often impacts some pitches more than others
  - Helped by cochlear implants
    - Which stimulate fibers of 8th in response to sounds

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Vision

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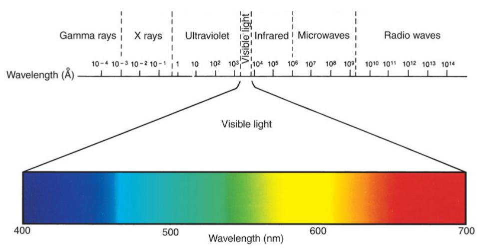
Vision

- Eyes transduce energy in small part of electromagnetic spectrum into Action Potentials
- Only wavelengths of 400 – 700 nm constitute visible light



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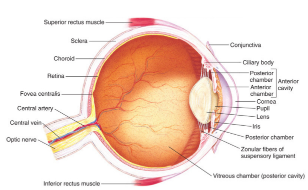
Structure of Eye

- The sclera (white of eyes) is outermost layer
- The transparent cornea is continuous with sclera
  - Light passes thru it into anterior chamber
    - Then thru pupil which is formed by iris
      - Then thru lens and vitreous to retina



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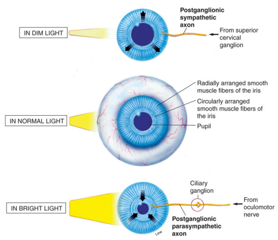
Structure of Eye

- The iris (a pigmented muscle) controls size of pupil
- Pupil constricts by contraction of circular muscles
  - Under parasympathetic control
- Dilation is via contraction of radial muscles



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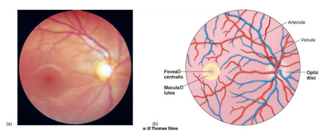
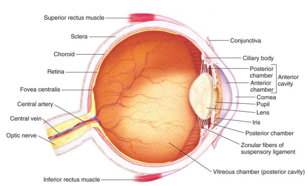
Structure of Eye

- Photoreceptors are in retina
- Retina absorbs some light
  - Rest is absorbed by the dark choroid layer
- Axons of retinal neurons gather at the optic disc (blind spot) and exit eye in optic nerve





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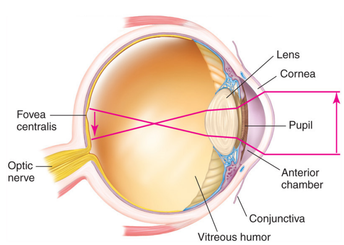
Visual Field

- Image projected onto retina is upside down and backward



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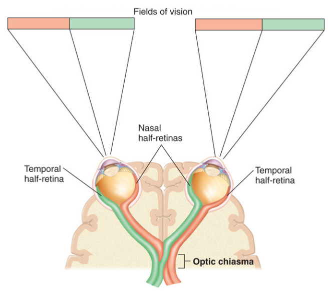
Visual Field

- Cornea and lens focus right part of visual field on left half of retina
- Left half of visual field focuses on right half of each retina



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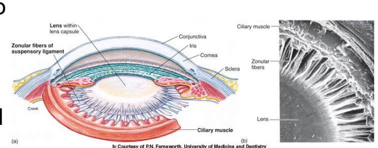
Accommodation

- Is ability of eyes to keep image focused on retina as distance between eyes and object varies
- Results from contraction of ciliary muscle



b: Courtesy of P.N. Farnsworth, University of Medicine and Dentistry

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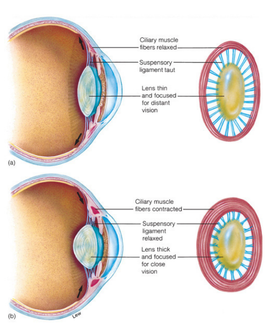
Accommodation

- **At distances > 20 ft** ciliary relaxation places tension on suspensory ligament
  - Pulls lens taut; is least convex
- **As distance decreases** ciliary muscles contract reducing tension on suspensory ligament
  - Lens becomes more convex



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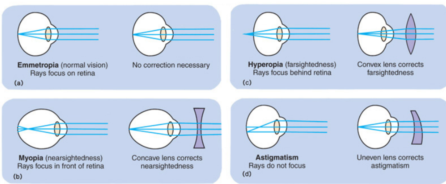
Visual Acuity

- Is sharpness of vision
- Depends upon resolving power =ability to resolve 2 closely spaced dots
- With myopia (nearsightedness) image is focused in front of retina because eyeball is too long
- With hyperopia (farsightedness) image is focused behind retina because eyeball too short



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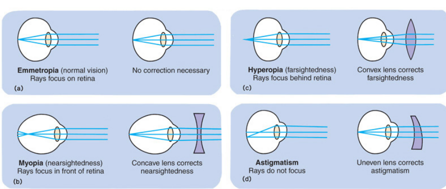
Visual Acuity continued

- With astigmatism cornea or lens is not symmetrical
  - Light is bent unevenly
  - Causing uneven focus



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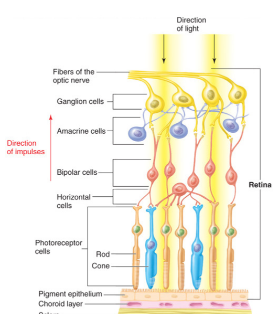
Retina

- Is a multilayered epithelium consisting of neurons, pigmented epithelium, and photoreceptors (rods and cones)
  - Neural layers are an extension of brain
  - Light must pass through several neural layers before striking rods and cones



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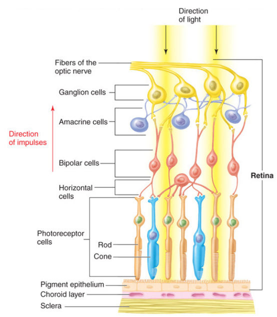
Retina continued

- Rods and cones face away from pupil
  - send sensory info to bipolar cells
- Bipolars send electrical activity to ganglion cells
- Ganglion cells project axons thru optic nerve to brain
- Horizontal cells and amacrine cells are interneurons involved in visual processing in retina



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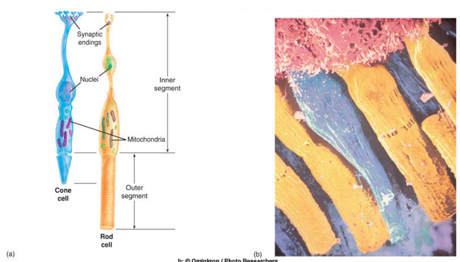
Rods and Cones

- Have inner and outer segments
  - Outer segments contain stacks of photopigment discs
  - New discs added at base and removed at tip



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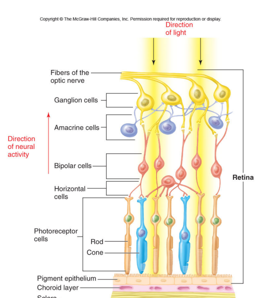
Rods and Cones continued

- Retinal pigment epithelium phagocytizes old discs from tips
  - also absorbs excess light
  - delivers nutrients from blood to the photoreceptors
  - suppresses potential immune attack on retina
  - stabilizes ion levels for photoreceptors



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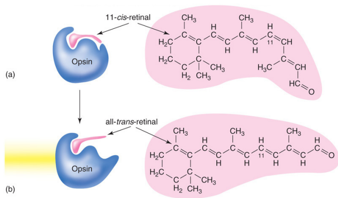
Effect of Light on Rods

- Rods are activated when light produces chemical change in rhodopsin
  - Causing it to dissociate into retinal and opsin
    - = bleaching reaction
    - Causes changes in permeability, resulting in APs in ganglion cells



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Dark Adaptation

- Is a gradual increase in photoreceptor sensitivity when entering a dark room
  - Maximal sensitivity reached in 20 min
- Increased amounts of visual pigments produced in the dark
  - Increased pigment in cones produces slight dark adaptation in 1st 5 min
  - Increased rhodopsin in rods allows light sensitivity to increase up to 100,000-fold

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Electrical Activity of Retinal Cells

- Ganglion and amacrine cells produce APs; rods, cones, bipolar and horizontal cells produce graded potential changes
- Visual transduction is inverse of other sensory systems
  - In dark, photoreceptors release inhibitory NT that hyperpolarizes bipolars
  - Light inhibits photoreceptors from releasing inhibitory NT, thus stimulating bipolars

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Electrical Activity of Retinal Cells

- Rods and cones contain many Na^+ channels that are open in dark
  - This depolarizing Na^+ influx is the dark current
  - Light hyperpolarizes by closing Na^+ channels

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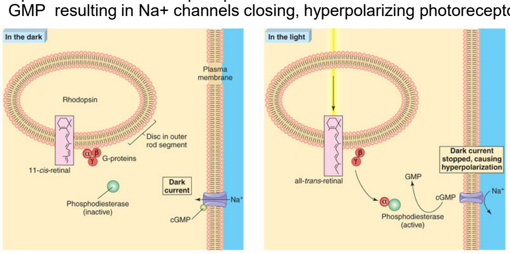
Electrical Activity of Retinal Cells continued

- In the light, 11-cis-retinal converted to all-trans retinal
  - As shown, this causes G-proteins associated with opsin to dissociate; alpha subunits activates phosphodiesterase which converts cGMP to GMP resulting in Na+ channels closing, hyperpolarizing photoreceptors.



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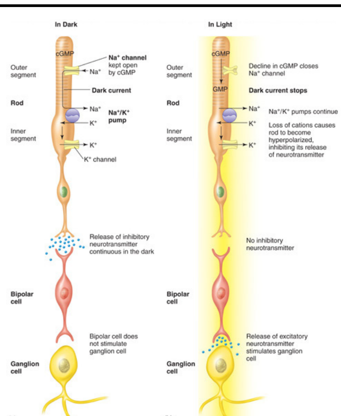


60

Cones and Color Vision

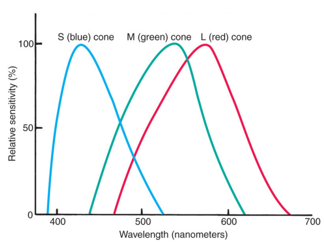
- Cones less sensitive than rods to light
  - Provide color vision and greater visual acuity
- In day, high light intensity bleaches out rods, and high acuity color vision is provided by cones

10-85

61

Cones and Color Vision continued

- Humans have trichromatic color vision
- All colors created by stimulation of 3 types of cones
  - Blue, green, red
  - According to region of visual spectrum they absorb

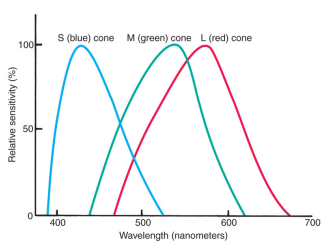


10-86

62

Cones and Color Vision continued

- Instead of opsin, cones have photopsins
  - A different photopsin for each type of cone
    - Causing each to absorb at different wavelengths

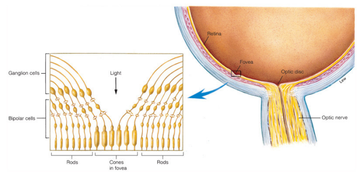


10-87

63

Visual Acuity and Sensitivity

- Eyes oriented so that object of attention is focused on fovea centralis
  - Pin-sized pit within yellow macula lutea
  - Contain only cones
  - Neural layers displaced to sides so light strikes cones directly

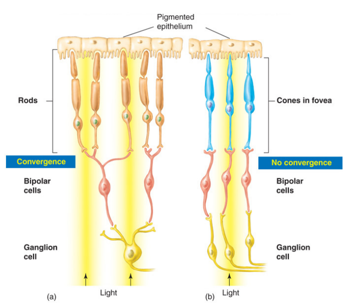


10-88

64

Visual Acuity and Sensitivity continued

- In fovea each cone supplies 1 ganglion cell
  - Allows high acuity
- Peripheral regions contain both rods and cones
  - Degree of convergence of rods on ganglions is much greater
    - Allows high sensitivity, low acuity

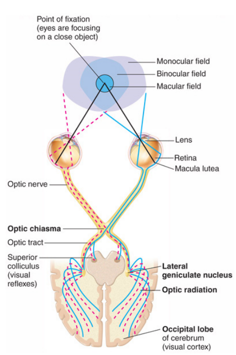


10-89

65

Neural Pathways from Retina

- Right half of visual field projects to left half of retina
- Left half of visual field projects to right half of retina
- Left lateral geniculate nucleus receives input from right half of visual field of both eyes
- Right Lat geniculate body receives input from both eyes from left half of visual field



10-90

66