Crown 85: Visual Perception:
A Window to Brain and Behavior

Lecture 4: Light, the Eye, and Visual Transduction

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lecture 4 outline

Crown 85 Winter 2016

Visual Perception: A Window to Brain and Behavior

Lecture 4- Light, the Eye, and Visual Transduction

Reading: Joy of Perception Master Eye Diagram
Eye Brain and Vision
Web Vision

Looking: Structure and Working of Human Eye
Anatomy of the Eye (Sinauer)
Phototransduction (Sunauer)
Several Werblin Videos on Retinal Function

OVERVIEW: In all sensory systems, stimuli originating in the "outside world" convey information about the environment to the organism. Common to the study of all sensory processes is the need to know (a) *how information (e.g., pitch, color, odor, etc.) is coded in the physical properties of the stimulus,* (b) *how the organism captures the physical stimulus (e.g., via the eye, the ear, the nose)*, and (c) *how the organism converts the physical information into electrical signals (sensory transduction) which lead to perception*. The objectives of this lecture are to understand how the physical properties of light are related to the information used in vision, how the various structural parts of the eye convey this information to the retina, and how chemicals in the receptor cells convert light to electrical responses.

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sensory information

1. **What kinds of information about objects in the environment are conveyed by light and coded by the visual system? What types of information present in light are lost in visual processing (examples of such "lost" information will be discussed in later lectures)?**

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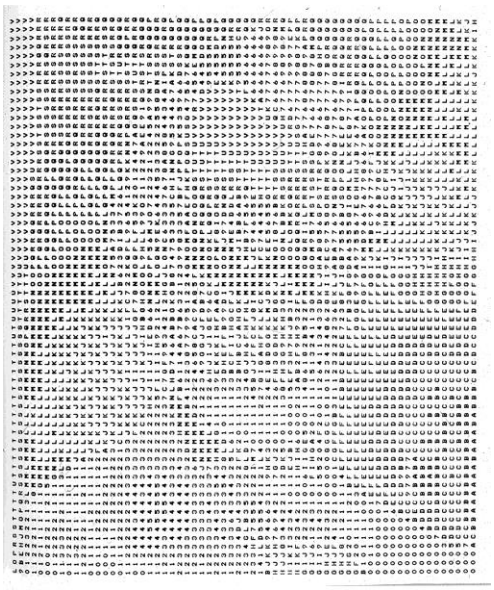
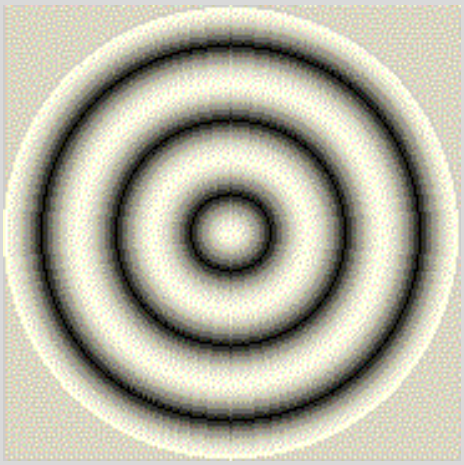


intensity vs spatial position (image formation)

color

motion



depth (monocular)

depth (binocular)

depth (binocular)

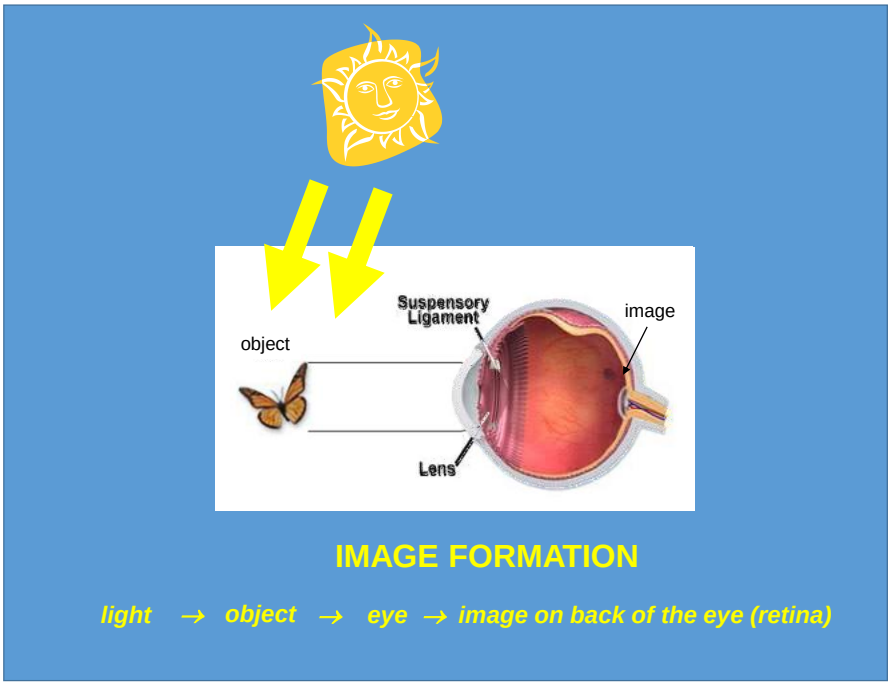


IMAGE FORMATION

light → object → eye → image on back of the eye (retina)

properties of light

2. **Understand the properties of light and how they are related to brightness and color perception.**
   a. **Wavelength**
   b. **Intensity**
   c. **Luminance**

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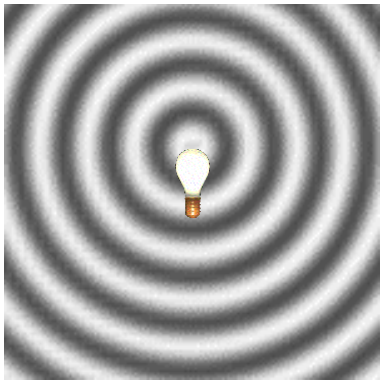
light waves



ELECTROMAGNETIC WAVE

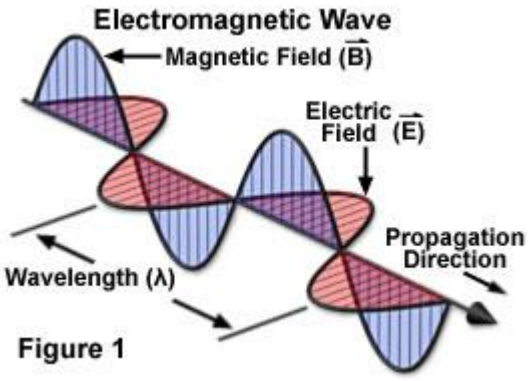
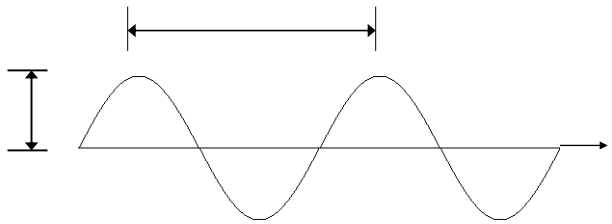


Figure 1

properties of a light wave



amplitude

wavelength

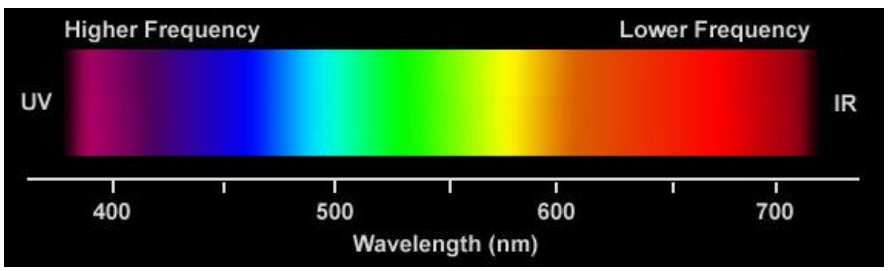
color

brightness

frequency= speed of light / wavelength

spectrum of visible light

V I B G Y O R



R O Y G B I V

full electromagnetic spectrum

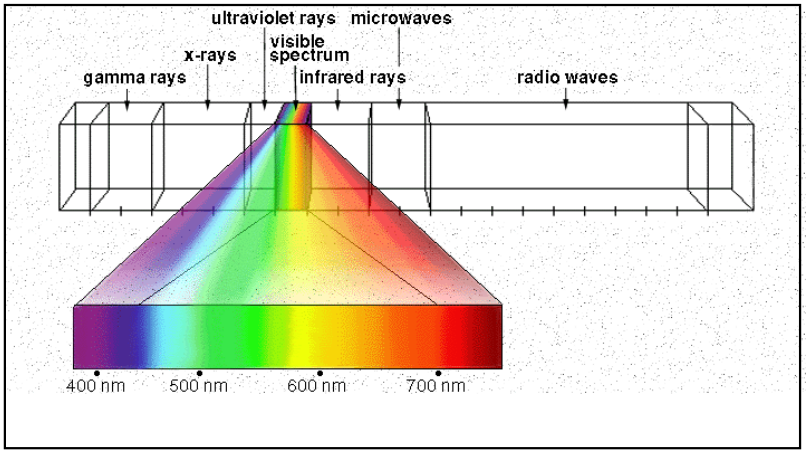
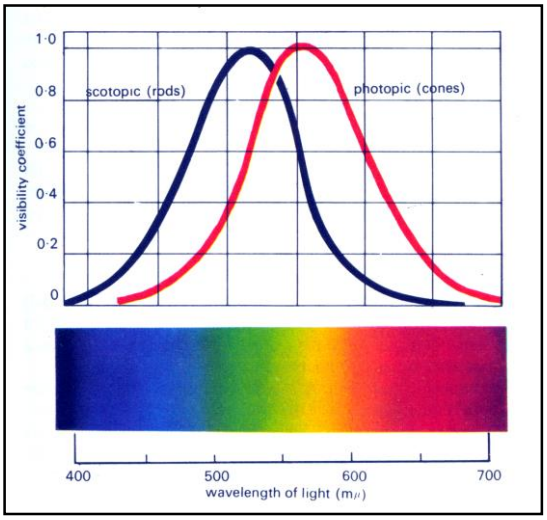
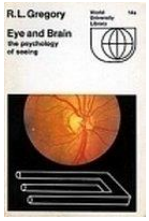


Figure 5.4 Eye & Brain (luminance or luminosity)





properties of light

2. **Understand the properties of light and how they are related to brightness and color perception.**
   - ✓ **a. Wavelength**
   - ✓ **b. Intensity**
   - ✓ **c. Luminance**

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from outline

3. Patterns of light coming from an object must be focused to form an image. Know the following terms related to image formation:

a. refraction
b. accommodation
c. diopter
d. pupillary reflex
e. depth of focus

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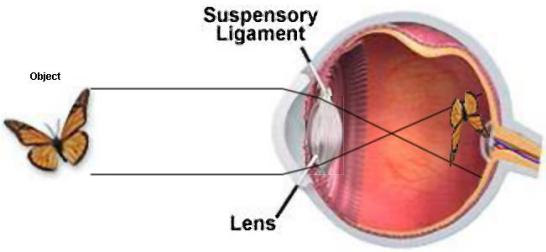
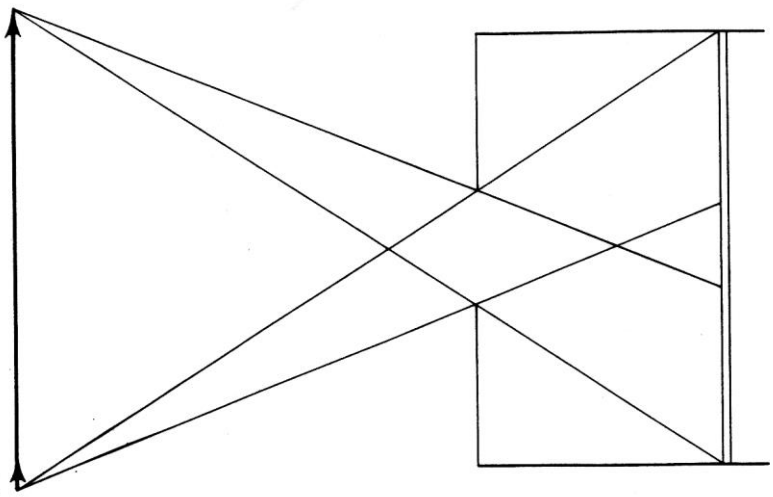
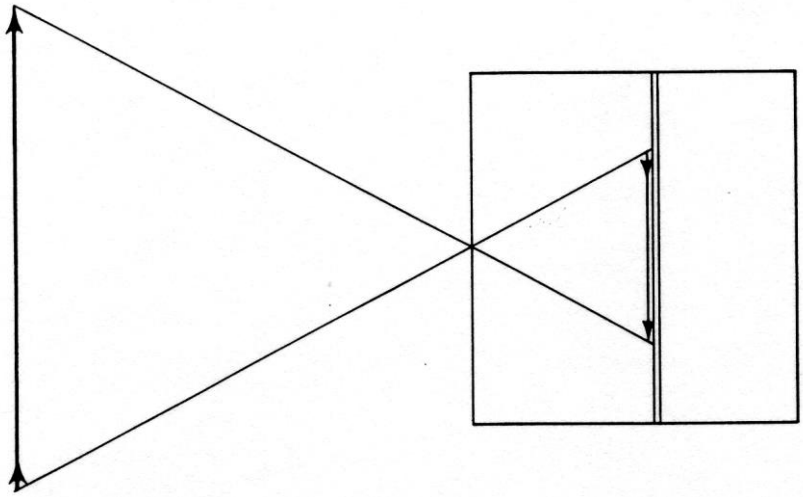
image formation





no image



pinhole image

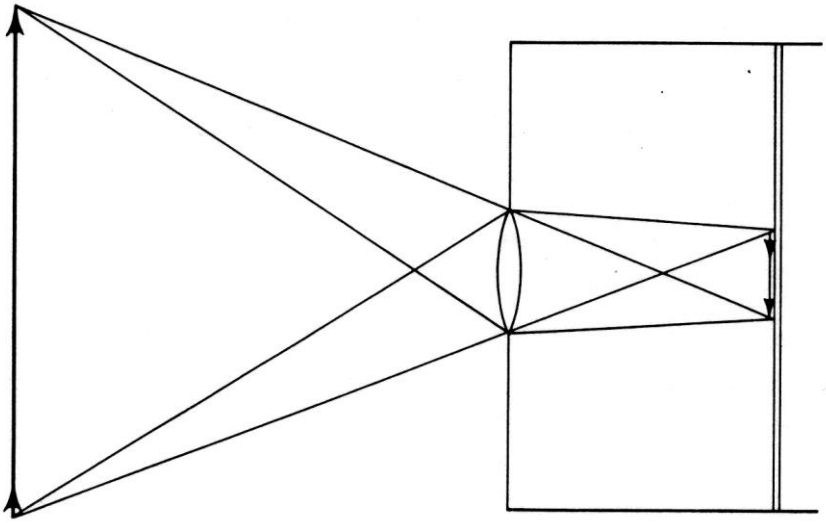
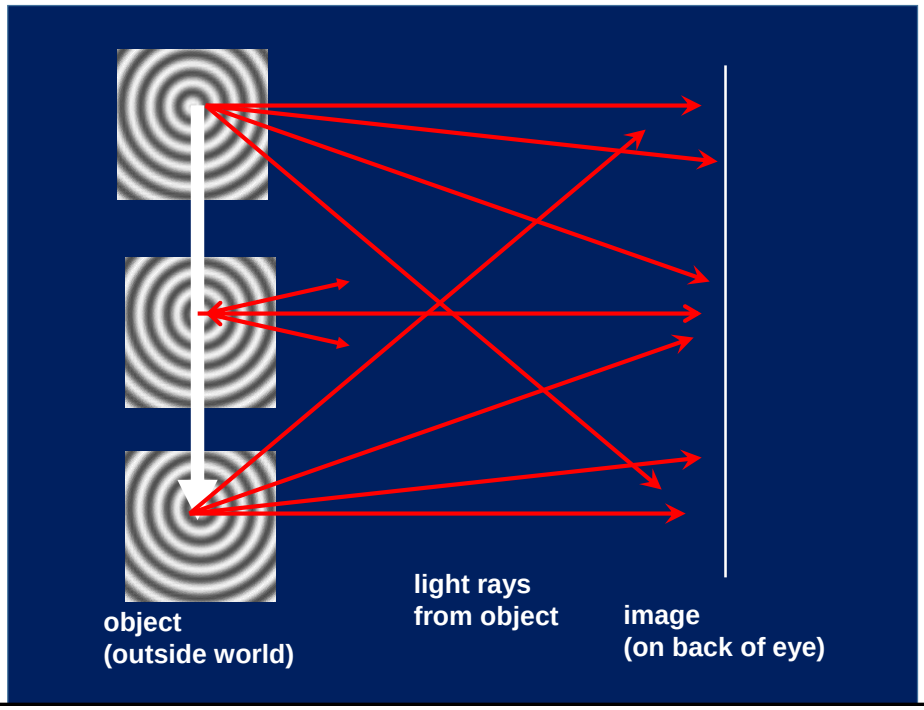
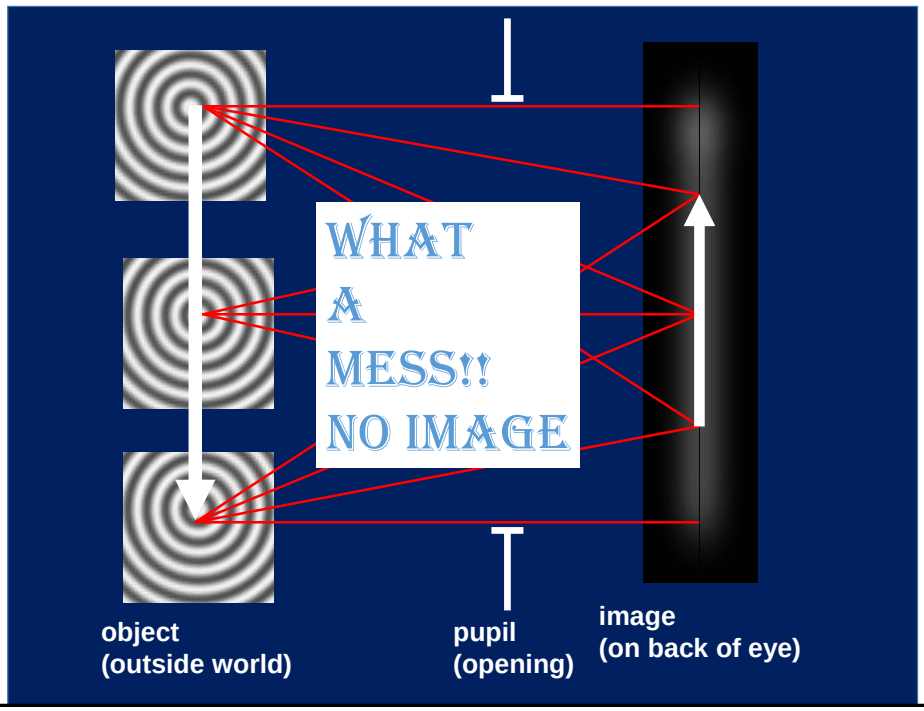


image formation using a lens (refraction)


object
(outside world)
light rays
from object
image
(on back of eye)


WHAT
A
MESS!!
NO IMAGE
object
(outside world)
pupil
(opening)
image
(on back of eye)

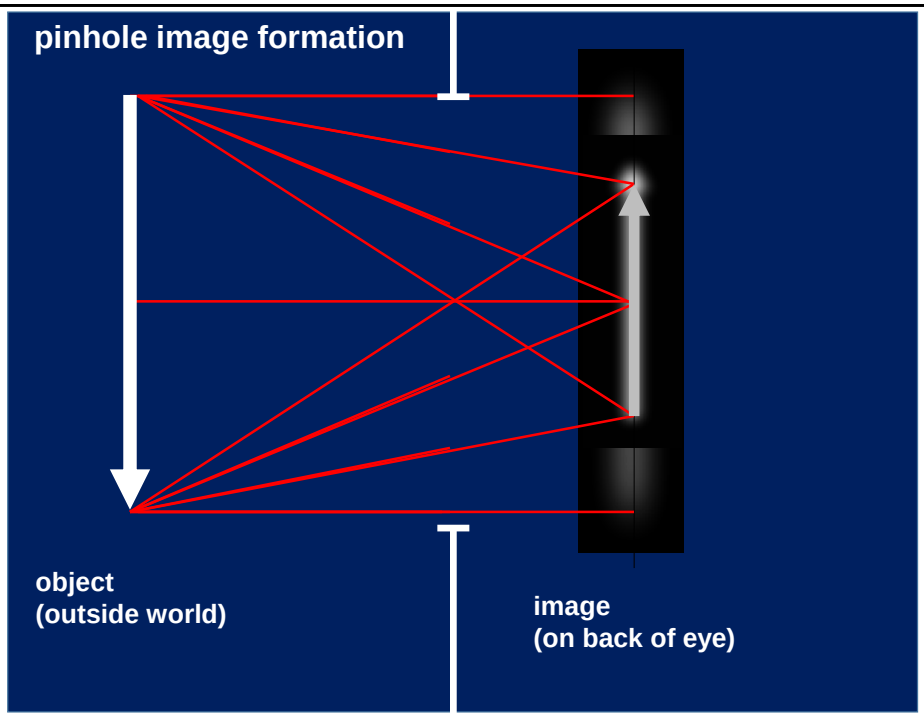
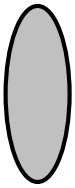


image formation

OK,
so pinholes can form images
but very dim (loose a lot of light).

CAN THE EYE DO BETTER
IN
IMAGE FORMATION ???



LENSES
and
REFRACTION

refraction

- **refraction: light waves bend when they go between different materials (glass and air; air and water)**

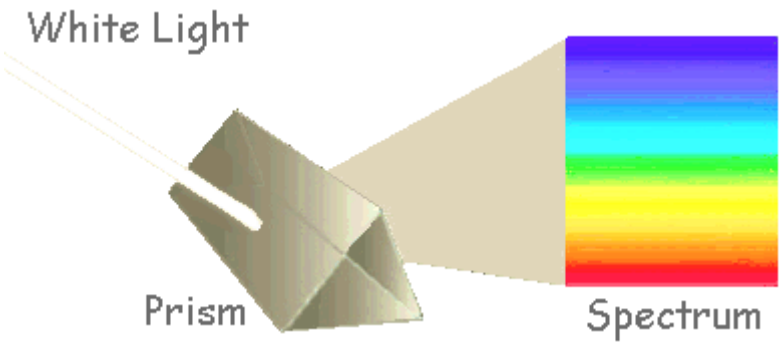
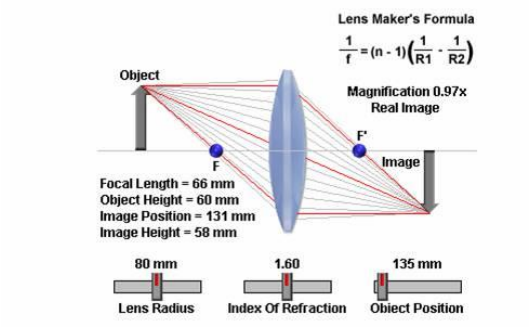


image formation by a lens

By bending light rays a lens enables ALL the light from one point in the **OBJECT** (e.g. head of arrow) to be **FOCUSED** to one point in the **IMAGE**



http://www.micro.magnet.fsu.edu/primer/java/lenses/lensvariations/

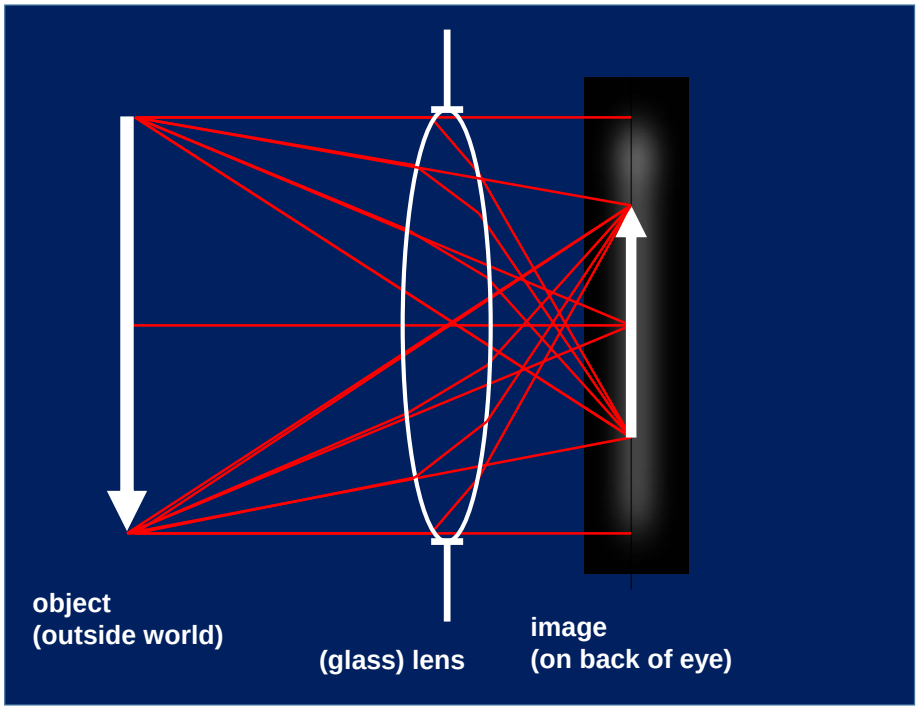
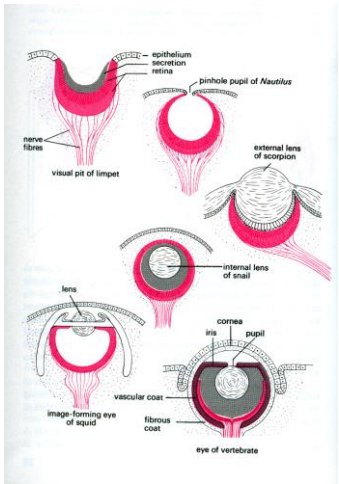
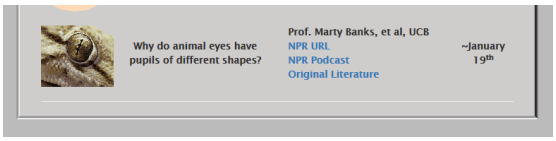


image formation through evolution: figure 3.1 Eye & Brain

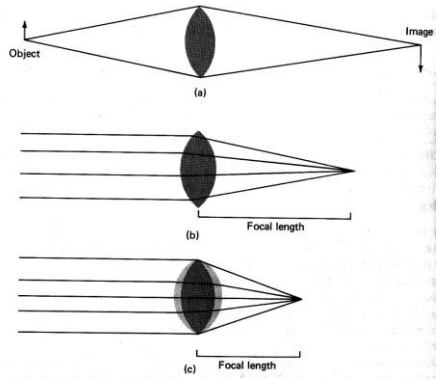




refraction by a lens; strength of a lens

$$\text{diopters} = \frac{1}{\text{focal length [meters]}}$$

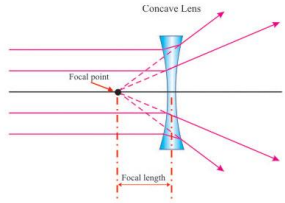
convex



shorter fl (greater curvature, fatter)

stronger (more diopters)

concave



negative diopters !!

from outline

3. Patterns of light coming from an object must be focused to form an image. Know the following terms related to image formation:

- ✓ **a. refraction**
- **b. accommodation**
- ✓ **c. diopter**
- **d. pupillary reflex**
- **e. depth of focus**

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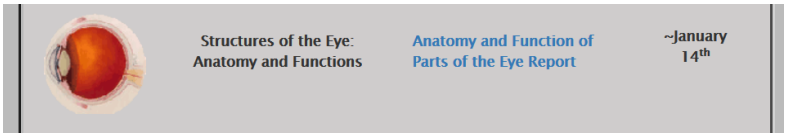
from outline

4. Be able to identify and discuss the function of the various parts of the eye

a. cornea
b. iris-pupil
c. aqueous humor
d. lens
e. ciliary muscle
f. zonula (suspensory ligament)
g. vitreous humor
h. retina
i. choroid
j. sclera
k. fovea
l. macula
m. blind spot
n. optic nerve



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Anatomy and Function of Parts of the Eye

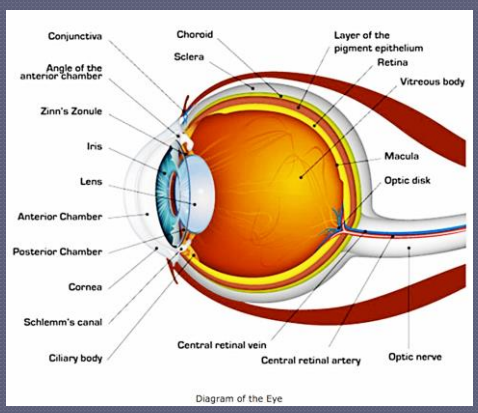
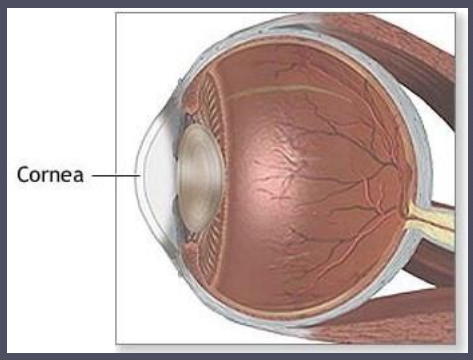


Diagram of the Eye

Ashwin Krishnan
Crown 85

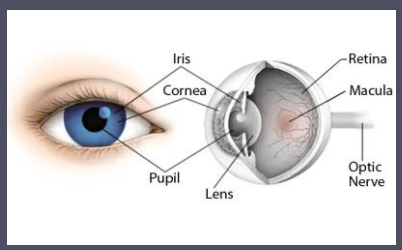
The Cornea

- Protects the eye
- 2/3 of the eye's refractive power at ~43 diopters
- Made of layers of protein called collagen
- Continuous with the sclera
- Avascular – no blood vessels

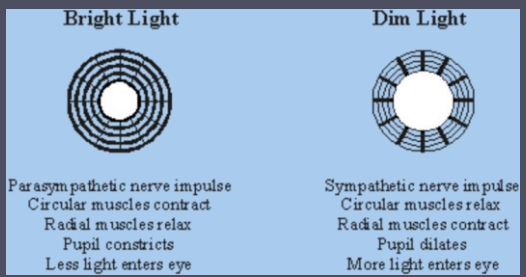


The Iris and the Pupil

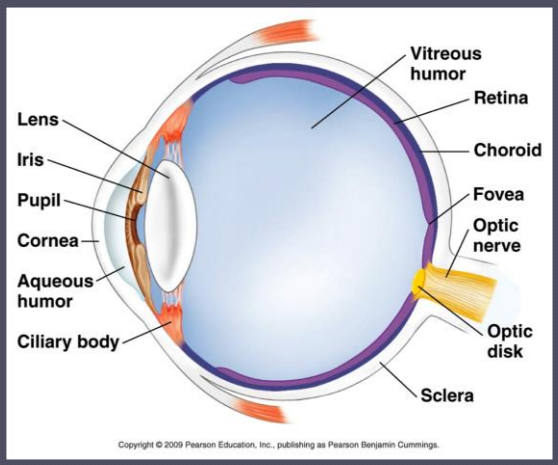
- The IRIS is a ring-shaped, pigmented muscle group around the pupil
- Its biggest job is in light-adaptation
- It also varies the depth of vision by changing the size of the pupil



- The PUPIL is the hole in the middle of the iris through which light enters the eye
- Appears black because all light that enters it is absorbed by the retina
- Magnified by the cornea so it appears larger than it is



The Aqueous Humor

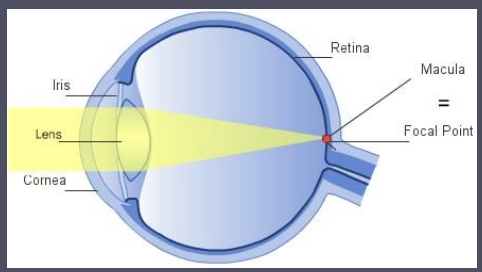


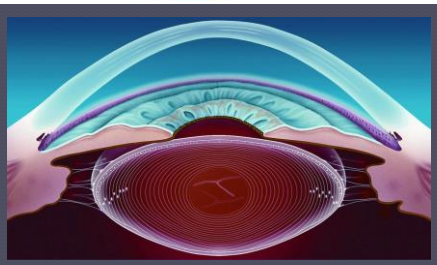
- Transparent fluid that provides nutrients for the anterior cavity of the eye
- Provides pressure for the cornea and anterior cavity
- Drains through canals of Schlemm
- Mostly proteins and water
  - 98% water
  - rest: amino acids, electrolytes, ascorbic acid, immunoglobulins

The Lens

- Flexible, transparent, round orb structure that refracts light onto the retina
- Changes shape to focus on objects at varying distances from the eye

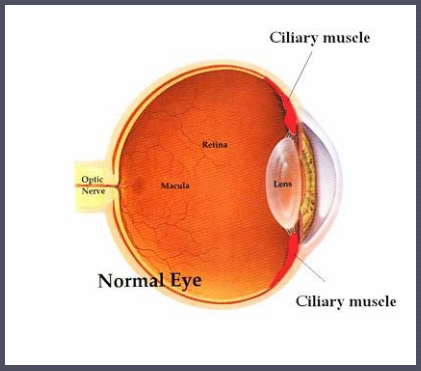
ACCOMMODATION – a reflex response of the eye when shifting focus from an object close to the eye to one further away. This involves changing the shape of the lens to increase the <u>focal distance</u>.
- Further away – flatter lens
- Closer up – rounder lens





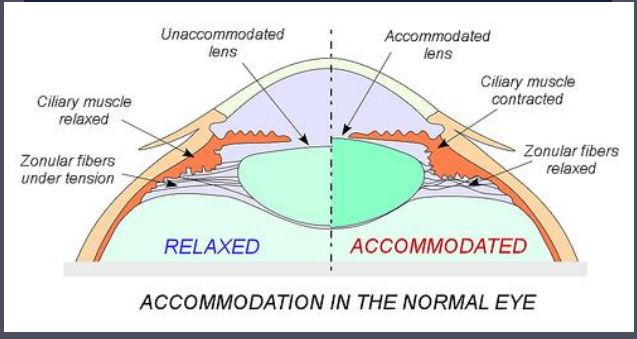
The Ciliary Muscle

- A ring of smooth muscle around the lens whose main function is in accommodation of the lens
- Part of the ciliary body
- Plays a role in the drainage of the aqueous humor
- Connected to the zonula
- When the Ciliary muscle contracts, the zonula lose their tension

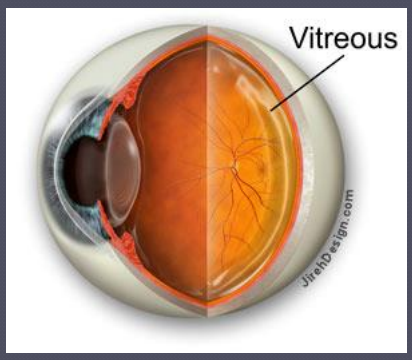


The Zonula (Suspensory Ligaments)

- Ligaments that suspend the lens from the ciliary muscle whose main function is also in accommodation
- Extend from the lens radially, like the spokes of a wheel
- Made of fibrillin (glycoprotein essential for elastic/connective tissues)

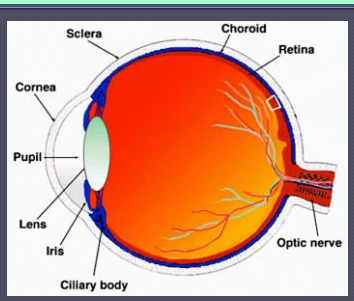


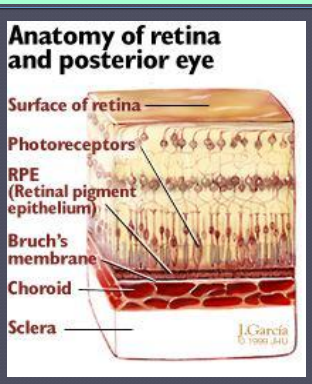
The Vitreous Humor



- A clear, viscous liquid that fills the inside of the posterior cavity of the eye
- Keeps the retina in place
- Stagnant, unlike the aqueous humor
- Any blood, other cells, or debris that gets in stays as "floaters"

The Retina



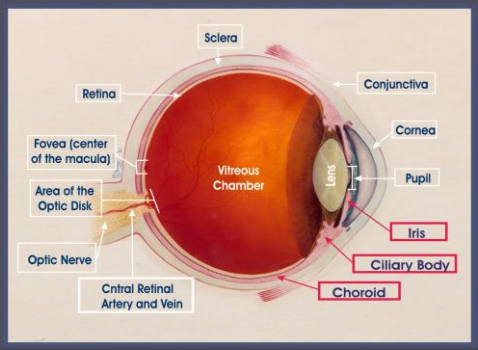


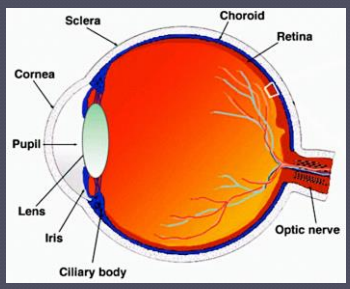
- A layer of light-sensitive cells in the back of the posterior cavity that take in refracted light and convert it into electrical signals sent to the brain via the optic nerve
- Forms the optic nerve at the blind spot
- Contains photoreceptors (rods and cones)

- Rods: used in low light and for black-and-white vision
- Cones: used for color vision and sharp vision; less sensitive to light

The Choroid

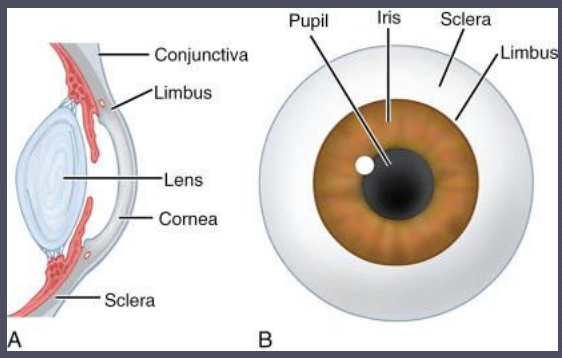
- The vascular layer of the posterior cavity located between the retina and the sclera
- Forms the uveal treact with the iris and ciliary body
- Supplies outer layers of the retina with blood



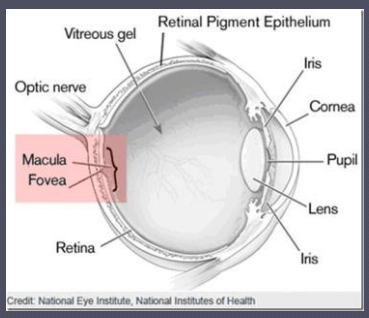


The Sclera

- Opaque outer layer of collagen and elastic fiber that protects the eye
- Connects to the 6 extra ocular muscles humans use to move their eyes
- Continuous with the cornea
- Connects with the dura mater (outermost membrane of the brain and spinal cord)
- "white of the eye"

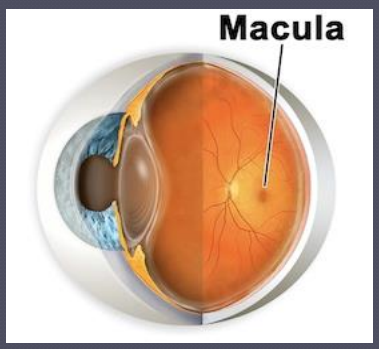


The Fovea

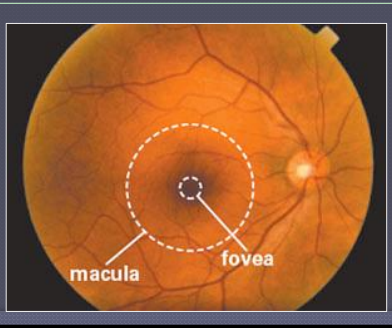


- A closely packed pit of cones with a diameter of 1.5 mm in the center of the macula that is responsible for visual acuity
- Density of 50 cones per 100 micrometers (147,000 cones per mm^2
- Sees the central 2˚ of visual field

The Macula

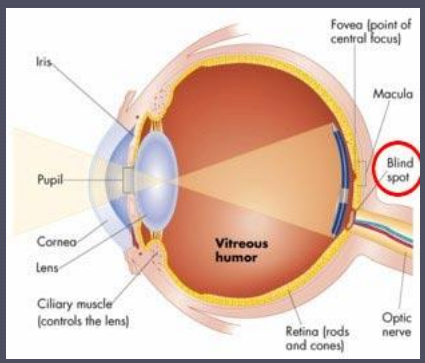


- Oval, highly pigmented center of the human retina with a diameter of ~5.5 mm
- Consists of the fovea, parafoveal belt (immediately around the fovea), and the perifovea
- Prevalence of carotenoid pigments lend a yellow look

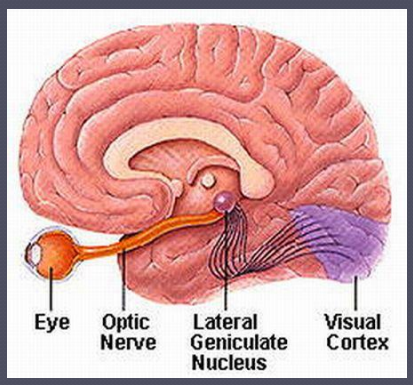


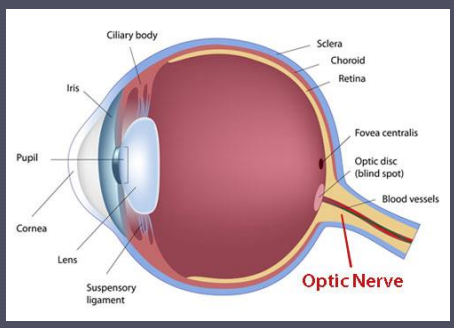
The Blind Spot

- The spot where all ganglion cell axons from the retina combine to form the optic nerve as they leave the eye
- Called the blind spot because there are no rods, cones, or light-sensitive ganglion photoreceptors
- On avg. carries 1-1.2 million neurons from the eye to the brain
- Part of the optic disc



The Optic Nerve



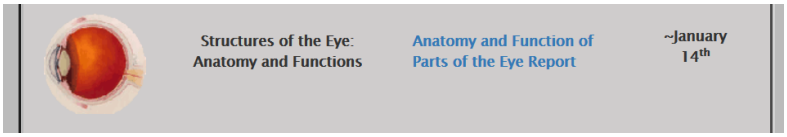


- Nerve (group) that transmits messages from the retina to the lateral geniculate nuclei
- Ganglion axons and glial cells
- Passes through lamina cribrosa (optic disc)

from outline

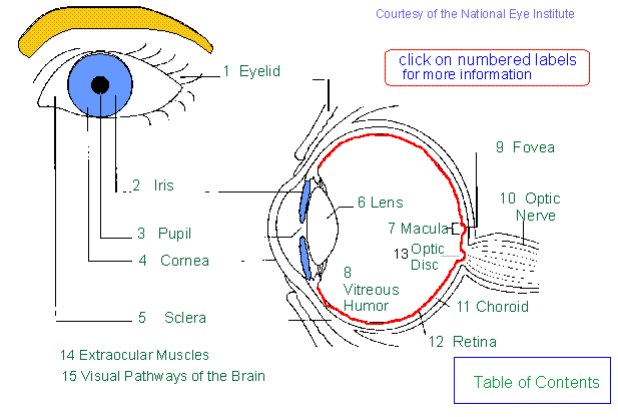
4. Be able to identify and discuss the function of the various parts of the eye

- ✓ a. cornea
- ✓ b. iris-pupil
- ✓ c. aqueous humor
- ✓ d. lens
- ✓ e. ciliary muscle
- ✓ f. zonula (suspensory ligament)
- ✓ g. vitreous humor
- ✓ h. retina
- ✓ i. choroid
- ✓ j. sclera
- ✓ k. fovea
- ✓ l. macula
- ✓ m. blind spot
- ✓ n. optic nerve



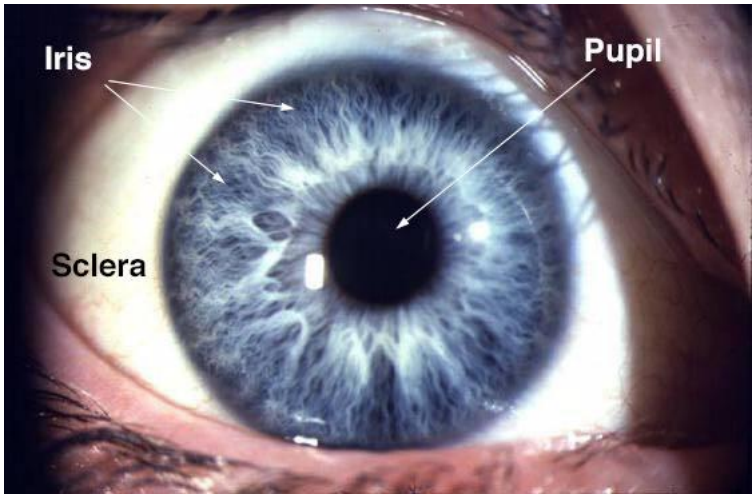
51

joy of perception

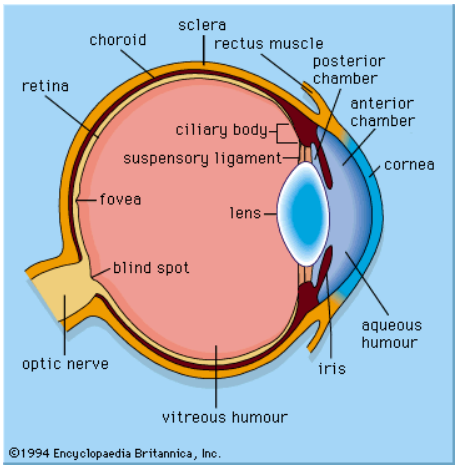


52

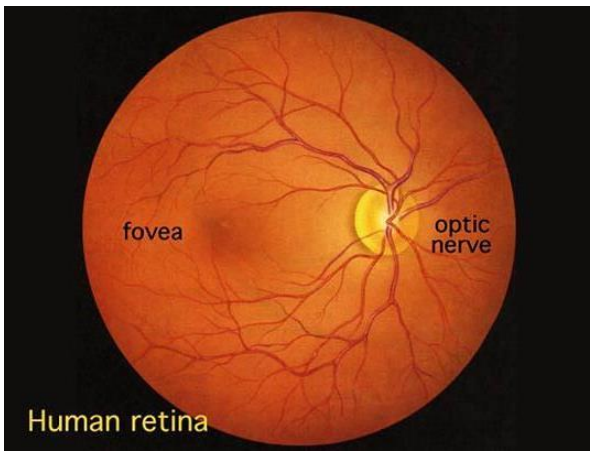
iris, pupil, sclera



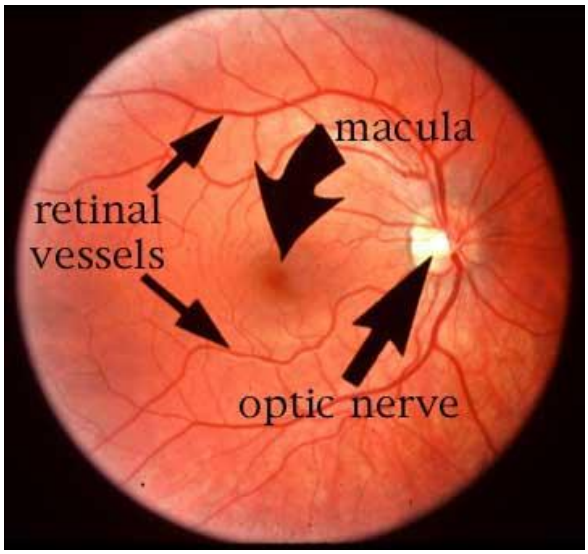
parts of the eye



fundus of the eye (fovea, macula, optic nerve, blind spot)



fundus photo



ciliary muscle and accommodation

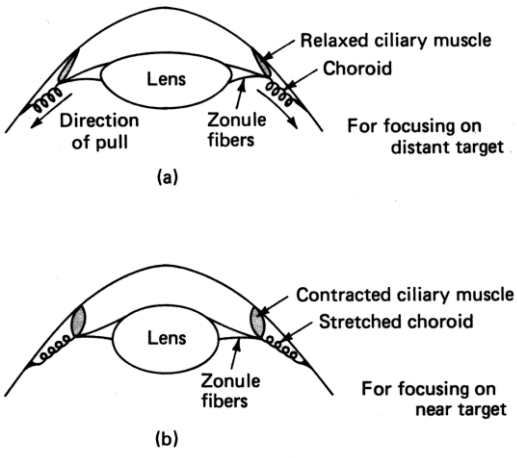
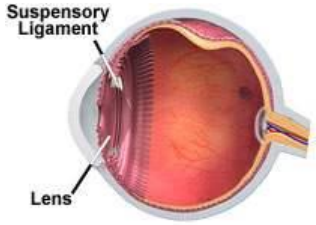


image formation and accommodation

accommodation and image formation



from outline

3. Patterns of light coming from an object must be focused to form an image. Know the following terms related to image formation:

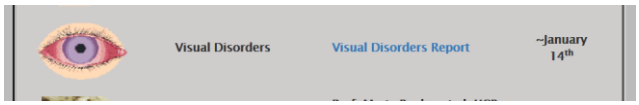
- ✓ **a. refraction**
- ✓ **b. accommodation**
- ✓ **c. diopter**
- ✓ **d. pupillary reflex**
- ✓ **e. depth of focus**

60

visual disorders of the eye (from outline)

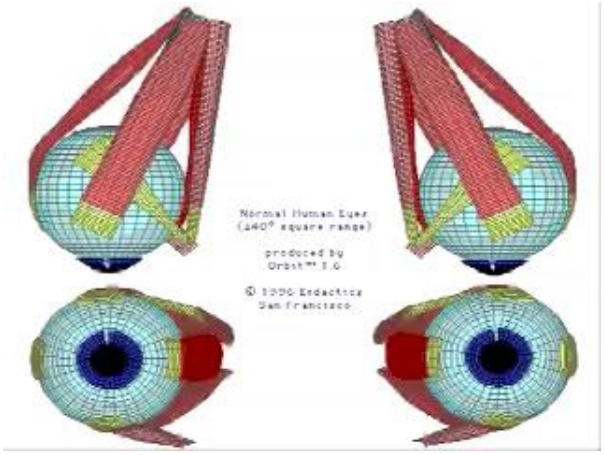
5. **What are the following optical and organic visual disorders:**

- **a. emmetropia**
- **b. myopia**
- **c. hyperopia**
- **d. astigmatism**
- **e. presbyopia**
- **f. Lasik surgery**
- **g. strabismus**
- **h. conjunctivitis**
- **i. cataract**
- **j. glaucoma**
- **k. detached retina**
- **l. keratoconus**
- **m. amblyopia**
- **n. diabetic retinopathy**
- **o. AMD (age related macular degeneration)**
- **p. Retinitis pigmentosa**



61

six muscles of the eye (class report later)



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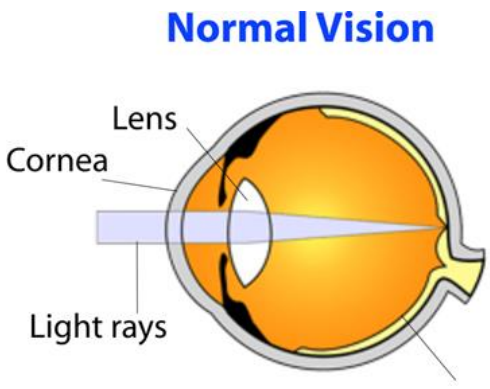
emmetropia

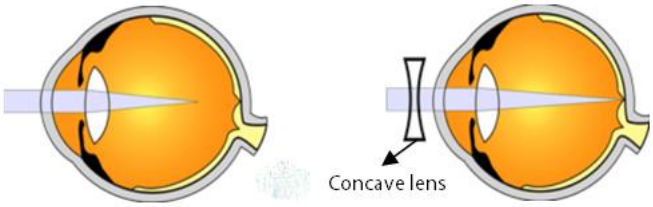


http://www.aravind.org/default/forpatientscontent/refractive

63

myopia: "near sightedness"

lens too strong or eye too long;
rays focus in front of retina



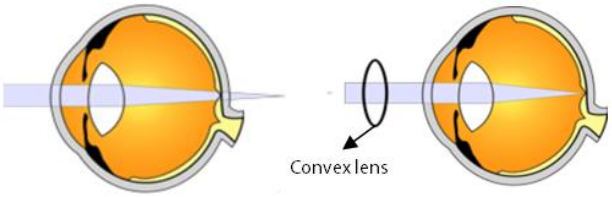
http://www.aravind.org/default/forpatientscontent/refractive

https://www.urmc.rochester.edu/eye-institute/lasik/about-vision.aspx

Near by images are clear

hyperopia: "far sightedness"

**lens too weak or eye too short;
rays focus behind retina**

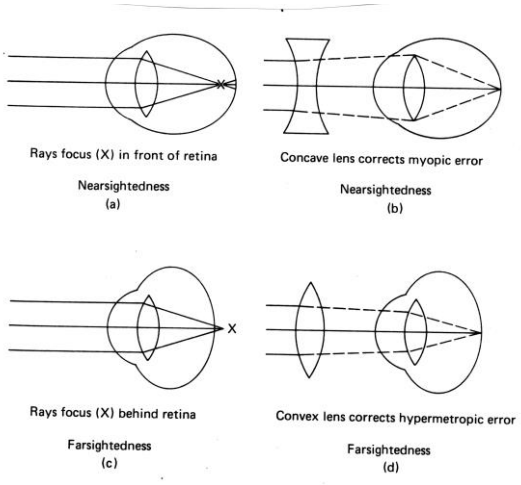


http://www.aravind.org/default/forpatientscontent/refractive

https://www.urmc.rochester.edu/eye-institute/lasik/about-vision.aspx

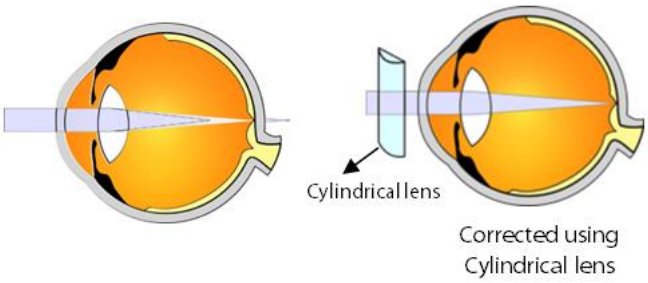
Far away images are clear

myopia and hyperopia



astigmatism

**cornea has different curvature along differing orientation;
shaped like a 'football'**



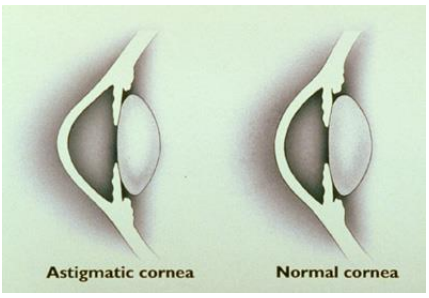
http://www.aravind.org/default/forpatientscontent/refractive

light rays focus on more than one point on the retina

https://www.urmc.rochester.edu/eye-institute/lasik/about-vision.aspx

Images are blurry

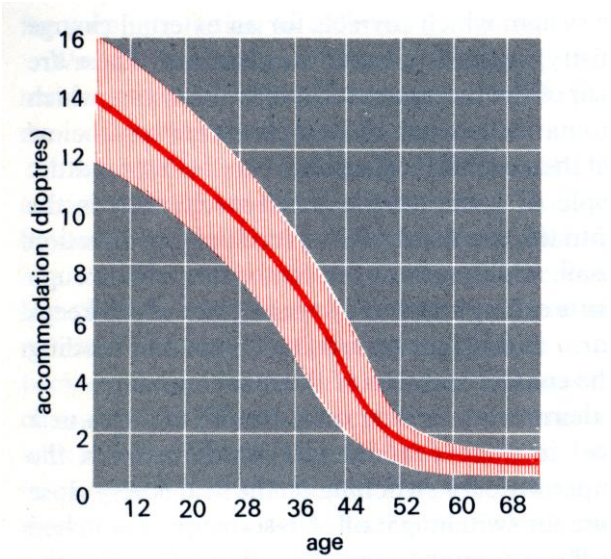
astigmatism



http://micro.magnet.fsu.edu/primer/java/aberrations/astigmatism/

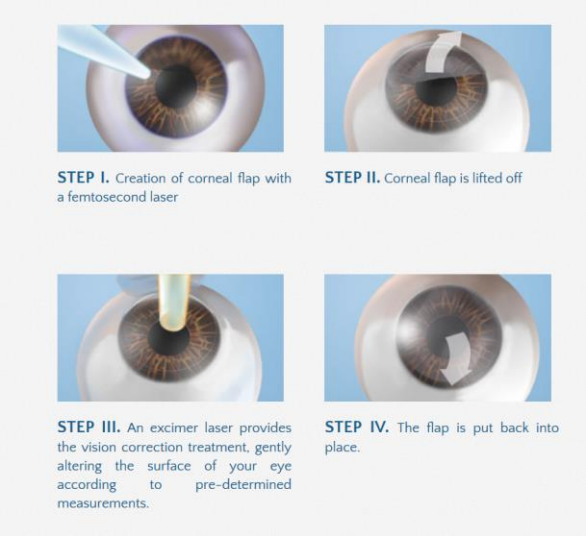
needs JAVA

presbyopia (figure 3.10 Eye & Brain)



lasik surgery

lasik surgery "bladeless"



http://www.manneye.com/blade-free-lasik-houston/

71

visual disorders of the eye (from outline)

5. **What are the following optical and organic visual disorders:**

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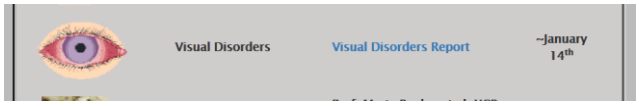
- **i. cataract**
- **j. glaucoma**
- **k. detached retina**
- **l. keratoconus**
- **m. amblyopia**
- **n. diabetic retinopathy**
- **o. AMD (age related macular degeneration)**
- **p. Retinitis pigmentosa**



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VISUAL DISORDERS

SARAH THORNBURG
CROWN 85
VISUAL PERCEPTION

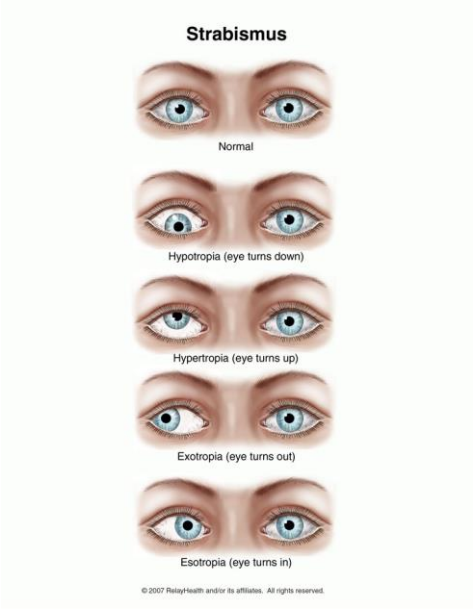
STRABISMUS

What is it? When both eyes are not aligned and so look in different directions.

What are the symptoms? Eyes turning outward, inward, upward, or downward consistently or sporadically causing the patient to see double. The eye turned incorrectly can alternate or remain the same or unilateral strabismus.

What causes it? Poor eye muscle control and extreme farsightedness caused by any number of the six muscles that control eye movements that are unaligned, feed the brain mixed signals, in turn causing the double vision. If this goes untreated long enough the brain will learn to ignore the visual input from the turned eye completely causing a permanent reduction in vision in this eye.

How should we treat it? Eyeglasses, prisms, vision therapy, or eye muscle surgery.

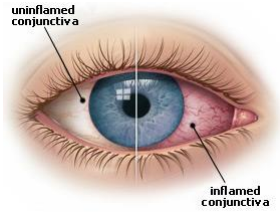


CONJUNCTIVITIS

What is it? The inflammation or infection of the conjunctiva or the outer layer of the eye and the inner eyelid, commonly referred to as pink eye. The conjunctiva is full of blood vessels along the whites of your eye so that it can routinely moisturize your eye, when it becomes inflamed the blood vessels expand causing the patient to appear bloodshot.

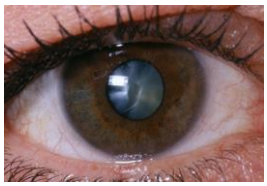
What are the symptoms? Conjunctivitis can cause burning, itching, excessive tearing, swelling, light sensitivity, redness, and bacterial discharge. Pinkeye usually doesn't affect your vision.

What causes it? Pinkeye is most routinely contracted through a viral or bacterial infection, an allergic reaction, or a substance that can cause eye irritation such as contact solution or eye ointments.



How should we treat it? Conjunctivitis is easily treatable and often goes away on its own, but if it was contracted through a bacterial infection then it requires antibacterial eye drops or ointment to treat it.

CATARACT

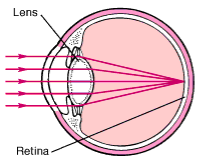


What is it? A cataracts is the clouding of the lens of one or both eyes that blurs your vision.

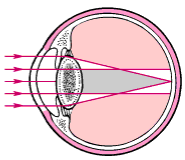
What are the symptoms? Common symptoms are blurry vision, double vision, glare, faded perception of colors, poor vision at night, and frequent eyeglass prescription changes.

What causes it? Most cataract cases are associated with age related changes in but some contributing factors are diabetes mellitus, alcohol, smoking, certain drugs, UV radiation and nutrient deficiency. While cataracts are almost always found in older patients, some infants are born with cataracts due to their mothers contracting inflections such as rubella during pregnancy.

Normal Lens



Lens with Cataract



How should we treat it? New glasses and brighter lighting can alleviate temporary symptoms, but surgery is the only option for a permanent solution. The procedure involves removing the cloudy lens and replacing it with an artificial lens called an intraocular lens or IOL.

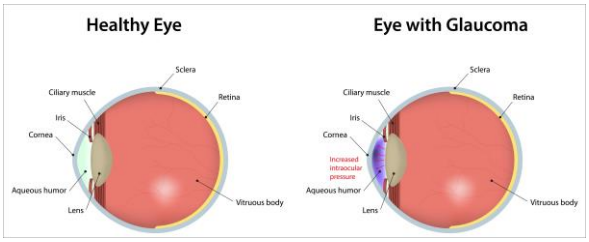
GLAUCOMA

What is it? Glaucoma is a group of diseases that damage the eye's optic nerve due to a loss of nerve tissue.

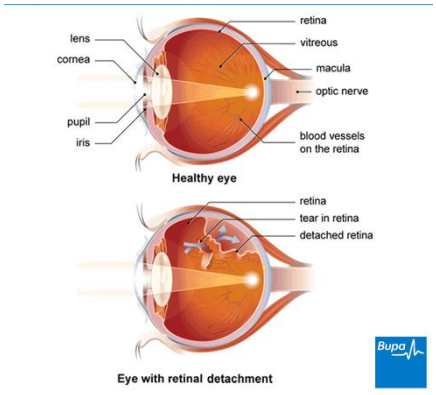
What are the symptoms? At first no symptoms are present until patients begin losing their peripheral vision causing them to experience permanent tunnel vision. Eventually straight ahead vision degrades into total blindness.

What causes it? When the fluid pressure in the eye slowly rises damaging the optic nerve.

How should we treat it? There is no cure for glaucoma but you can treat it by using prescription eye drops, medication to reduce intraocular pressure and possibly undergoing surgery.



DETATCHED RETINA



What is it? A tearing or separation of the retina, the light sensitive lining at the back of the eye, from the underlying tissue.

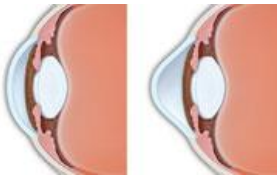
What are the symptoms? A detached retina can cause floaters and/or flashes of light to frequently enter your field of vision as well as induce the sensation of a curtain being drawn over your field of vision.

What causes it? There is a clear gel called vitreous in the center of your eye that is attached to the retina that when clumps form in it can cause floaters. As you age the vitreous might shrink and pull on the retina detaching it and possibly tearing it allowing fluid to seep into the eye.

How should we treat it? Retinal detachment is very serious and should be operated on immediately through retinal surgery so as to prevent blindness.

KERATOCONUS

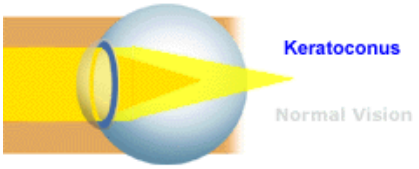
Normal Cornea Keratoconus



What is it? When the cornea of an eye becomes cone-shaped, thus distorting a persons vision by preventing light from entering the eye and being focused correctly.

What are the symptoms? Keratoconus can cause a slight blurring and distortion of vision at first, then after about 10-20 years the cone-shaped cornea becomes pronounced enough that it creates a small crack which is eventually replaced by scar tissue.

What causes it? The cause of keratoconus is almost always unknown, but sometimes it runs in families and is more common with patients with certain medical conditions.



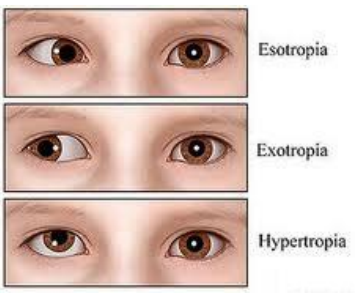
How should we treat it? There is no way to stop the disorder, but eyeglasses to correct vision during the initial period are often prescribed and in some cases a corneal transplant is necessary.

AMBLYOPIA

What is it? Amblyopia commonly referred to as lazy eye is the loss or lack of development of the central vision of one eye that is unrelated to any eye health problems and is not correctable with eyeglasses

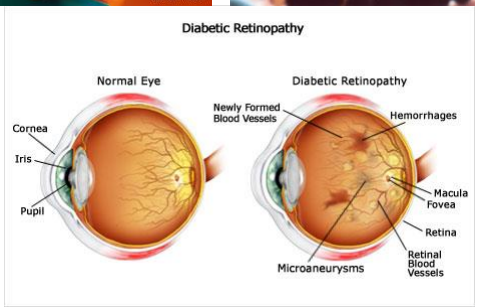
What are the symptoms? Symptoms are not always apparent but can include favoring one eye and/or bumping into things on one side repeatedly.

What causes it? A failure to use both eyes together often caused by a large degree of farsightedness or nearsightedness between eyes.



How should we treat it? Lazy eye can be treated with eyeglasses, prisms, vision therapy, and eye patching.

DIABETIC RETINOPATHY



What is it? A disease that patients with diabetes are it risk to develop which damages the light sensitive retina causing it leak fluid and induce blindness in both eyes.

What are the symptoms? Blurry or double vision, dark spots or floaters, rings, blank spots, or flashing lights, pain or pressure in one or both of your eyes, and trouble seeing out of the corner of you eye.

What causes it? When a diabetic's blood pressure remains high for too long it can damage the blood vessels in the retina.

How should we treat it? Diabetic Retinopathy can be treated with lasers or surgery with follow-up care.

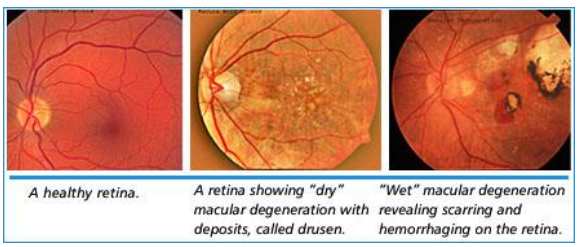
AGE RELATED MACULAR DEGENERATION (AMD)

What is it? The deterioration of the eye's macula the small part of your retina that is responsible for central vision and detail.

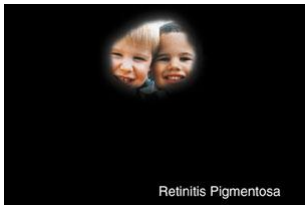
What are the symptoms? Blurriness, dark areas or distortion in your central vision, and possibly even permanent loss of your central vision.

What causes it? In Wet AMD, abnormal blood vessels grow under the macula and leak blood and fluid. The far more common Dry AMD manifests itself when the light sensitive cells in the macula break down causing you to gradually lose your central vision.

How should we treat it? Wet AMD can be treated with Photodynamic therapy (PDT) and Dry AMD can be treated through nutrition, but neither can be cured.

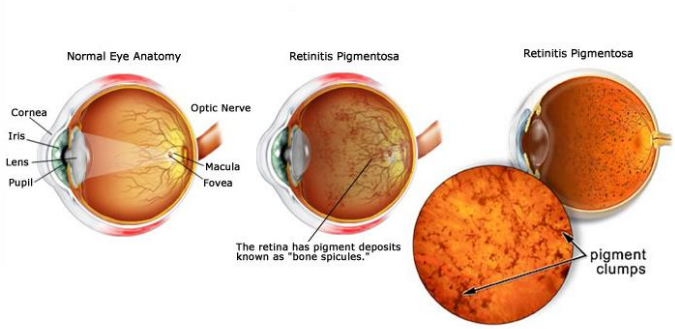


RETINITIS PIGMENTOSA



What is it? A group of inherited diseases that attack the light-sensitive rods and cones in the back of our eyes

What are the symptoms? At first, decreased night vision, loss of peripheral vision and eventual blindness. The initial loss of rods causes the loss of peripheral vision while the degeneration of the cones causes a loss of color perception and central reading vision



What causes it? Retinitis Pigmentosa is a genetic disease.

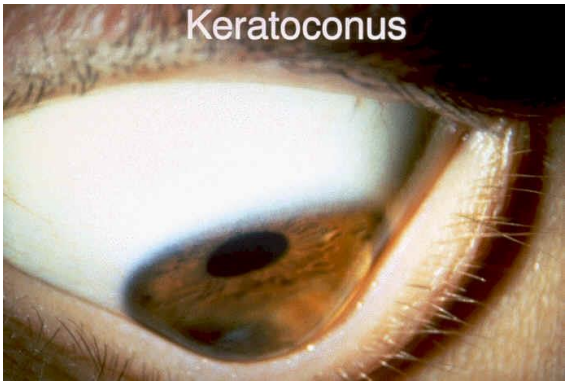
How should we treat it? Unfortunately there is no cure for Retinitis Pigmentosa, but patients often use low vision aids to guide them though day-to-day life.

cataracts

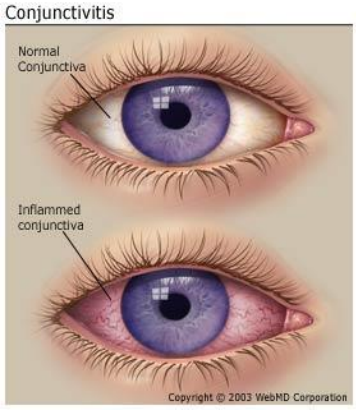
Normal

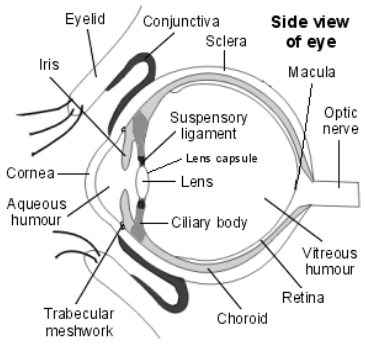
Cataract

keratoconus



conjunctivitis (conditions known as 'pink-eye')





http://www.patient.co.uk/showdoc/Pilsinl/113.gif

http://images.google.com/images?q=tbn:rw3EKTbHQ4VlZM:www.webmd.com/NR/rdonlyres/e2grguarjh
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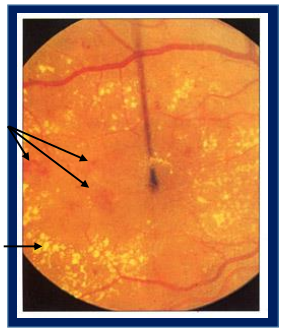
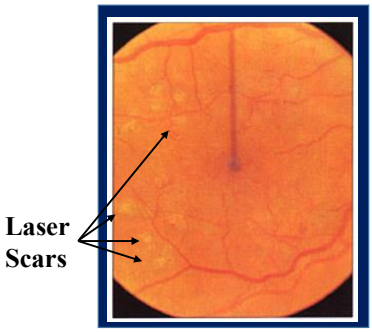
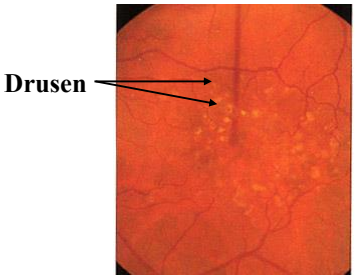
diabetic retinopathy





Before laser photocoagulation **After laser photocoagulation**

ARM (age-related macular degeneration)



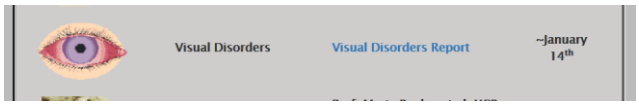
www.nei.nih.gov/health/images/normal_vision_color.jpg

http://www.nei.nih.gov/health/images/armd_color.jpg

visual disorders of the eye (from outline)

5. **What are the following optical and organic visual disorders:**

- ✓ **a. emmetropia**
- ✓ **b. myopia**
- ✓ **c. hyperopia**
- ✓ **d. astigmatism**
- ✓ **e. presbyopia**
- ✓ **f. Lasik surgery**
- ✓ **g. strabismus**
- ✓ **h. conjunctivitis**
- ✓ **i. cataract**
- ✓ **j. glaucoma**
- ✓ **k. detached retina**
- ✓ **l. keratoconus**
- ✓ **m. amblyopia**
- ✓ **n. diabetic retinopathy**
- ✓ **o. AMD (age related macular degeneration)**
- ✓ **p. Retinitis pigmentosa**



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visual transduction (light ⇒ electrical signals)

6. Describe the process of visual transduction, being sure to understand:

a. 11-cis and all-trans retinal
b. rhodopsin
c. vitamin A and regeneration

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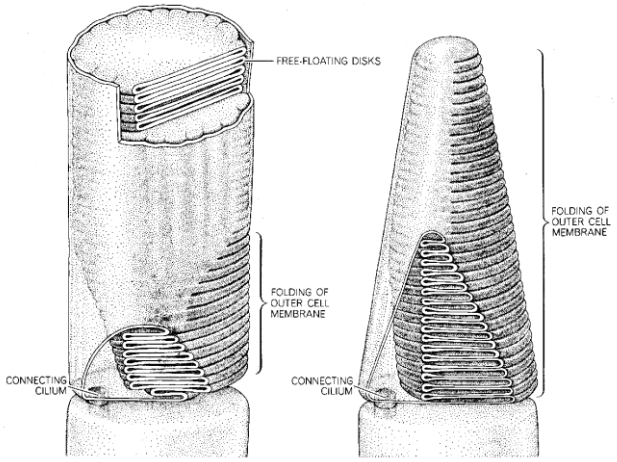
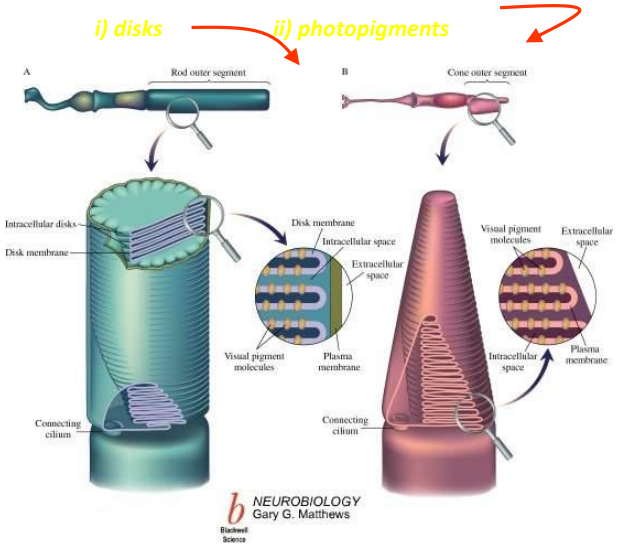
rod and cone



rod and cone

i) disks *ii) photopigments*



rhodopsin crystal structure

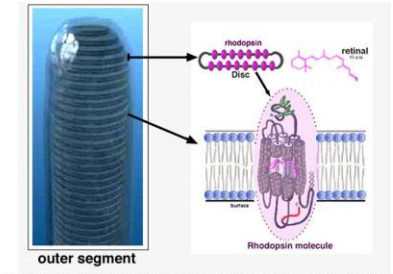
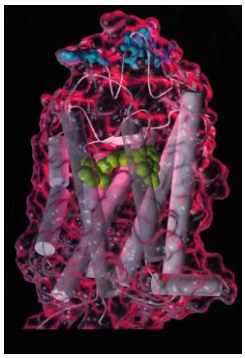


Fig. 3. Schematic diagram of Rhodopsin in the outer segment discs. When the outer segments are magnified further, stacked membrane disks are visible inside. The disks are studded with thousands of rhodopsin complexes. Each rhodopsin consists of a membrane-traversing protein with a retinal molecule embedded in its core.

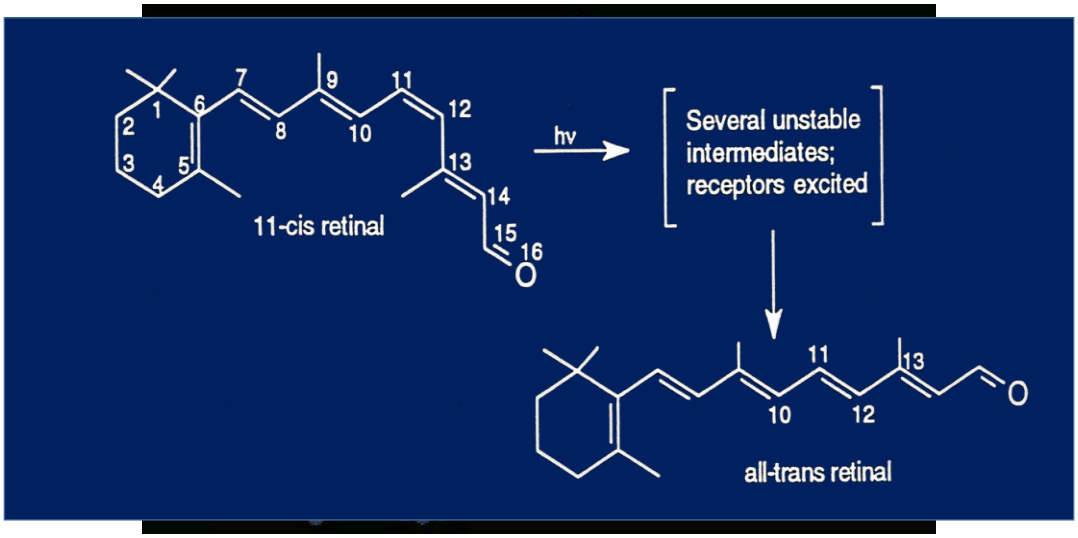
intradiscal side



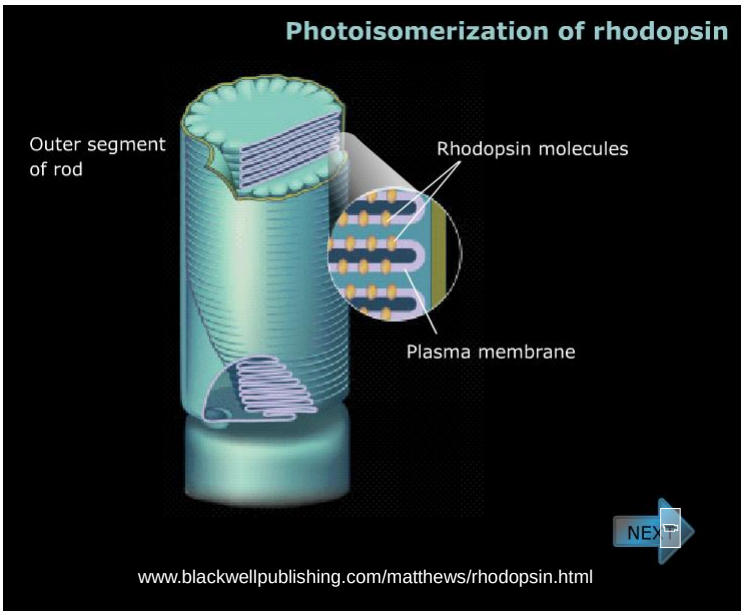
intracellular cytoplasmic side

Palczewski, et. al., (2000), *Science*, 289, 739-745.

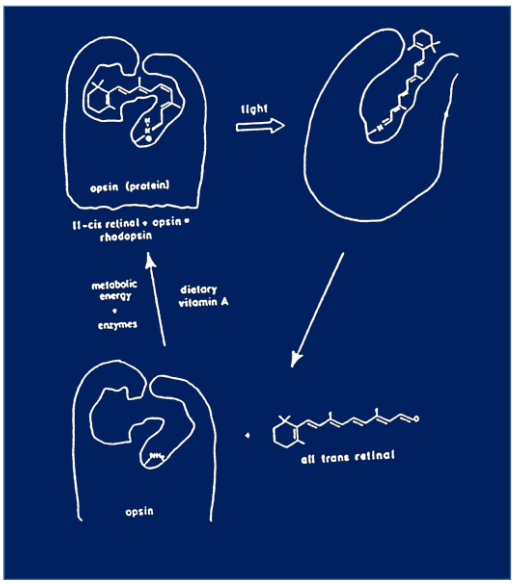
phototransduction: cis- to trans- photoisomerization of retinal

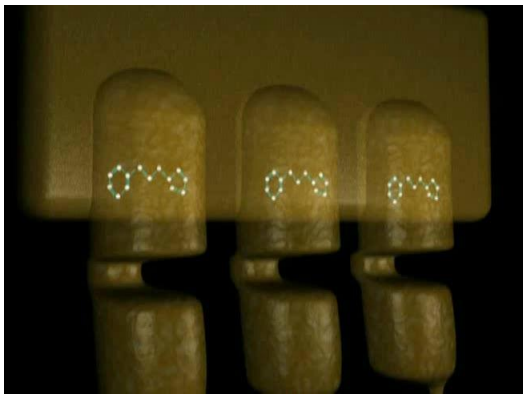


photoisomerization of rhodopsin



regeneration cycle





Rhodopsin Leaves Rods
Werblin, UCB

https://mcb.berkeley.edu/courses/mcb64/Retina.html

visual transduction (light ⇒ electrical signals)

6. Describe the process of visual transduction, being sure to understand:

- ✓ **a. 11-cis and all-trans retinal**
- ✓ **b. rhodopsin**
- ✓ **c. vitamin A and regeneration**

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Finis

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