

Visual Optics

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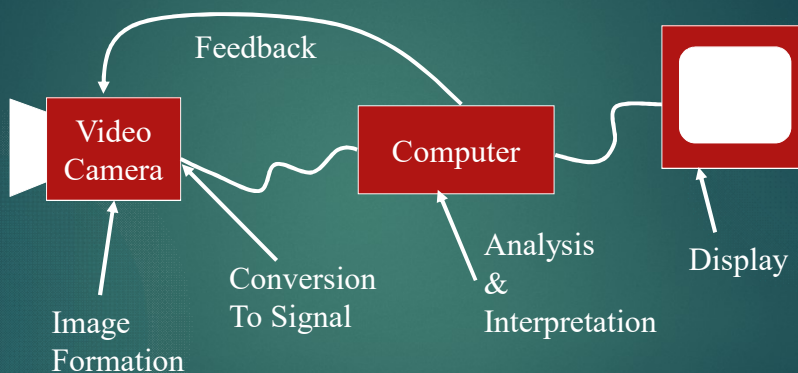
Visual Optics - Introduction

- ▶ In this course, the optical principals behind the workings of the eye and visual system will be explained.
- ▶ Furthermore, descriptions of different devices used to measure the properties and functioning of the eye will be described.
- ▶ Goals are a general understanding of how the visual system works and exposure to an array of different optical instrumentation.

What is Vision?

- ▶ Three pieces are needed for a visual system
 - ▶ Eye needs to form an “Image”. Image is loosely defined because it can be severely degraded and still provide information.
 - ▶ Image needs to be converted to a neural signal and sent to the brain.
 - ▶ Brain needs to interpret and process the image.

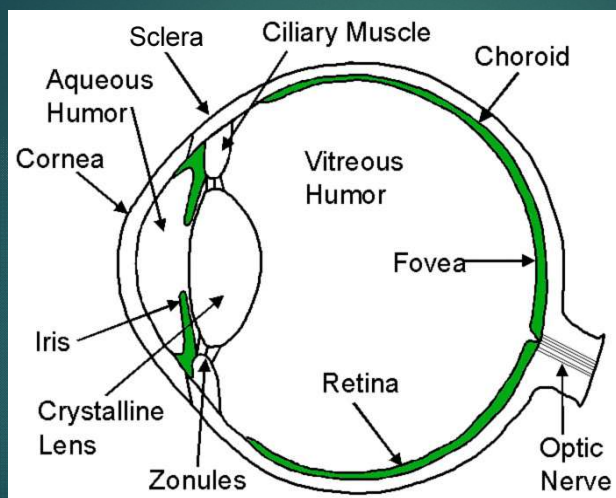
Analogous Vision System



Engineering Analysis

- ▶ **Optics** – Aberrations and raytracing are used to determine the optical properties of the eye. Note that the eye is non-rotationally symmetric, so analysis is more complex than systems normally discussed in lens design. Fourier theory can also be used to determine retinal image with the point spread function and optical transfer function.
- ▶ **Neural** – Sampling occurs by the photoreceptors (both spatial and quantification), noise reduction, edge filtering, color separation and image compression all occur in this stage.
- ▶ **Brain** – Motion analysis, pattern recognition, object recognition and other processing occur in the brain.

Anatomy of the Eye



Anterior Chamber – front portion of the eye

Cornea – Clear membrane on the front of the eye.

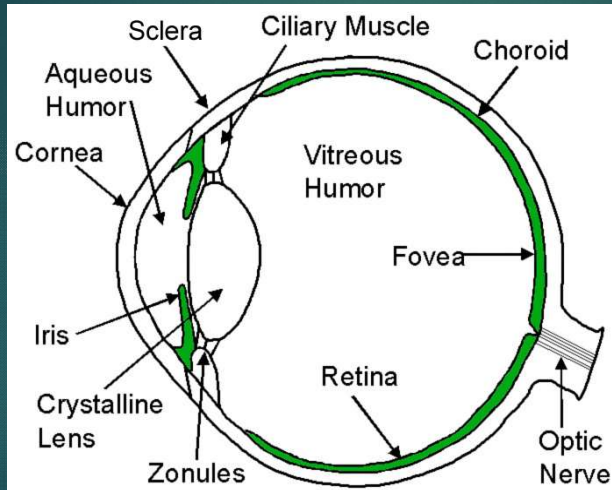
Aqueous – water-like fluid behind cornea.

Iris – colored diaphragm that acts as the aperture stop of the eye.

Sclera – white of the eye.

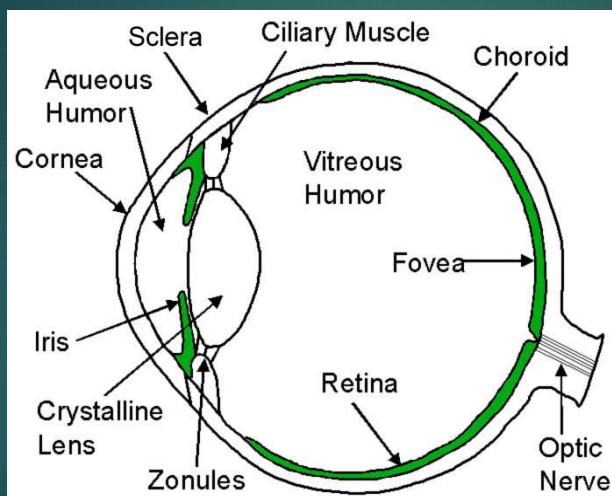
Limbus – boundary between sclera and cornea.

Anatomy of the Eye



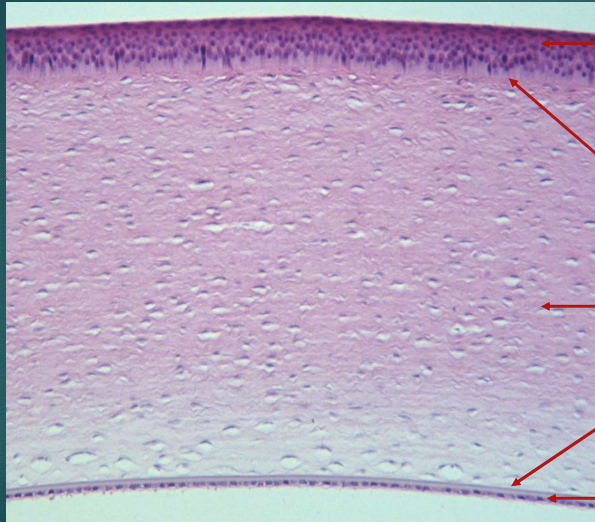
- Posterior Chamber** – rear portion of the eye
- Crystalline Lens** – Gradient index lens that can change shape to alter focus.
- Vitreous** – jelly-like fluid behind crystalline lens.
- Zonules** – Ligaments that support the crystalline lens.
- Ciliary Body** – tissue that generates aqueous

Anatomy of the Eye



- Choroid** – tough membrane that forms the eyeball
- Retina** – Photosensitive inner lining of eye
- Fovea** – central region of retina with sharpest vision.
- Optic Nerve** – bundle of nerve fibers that carry information to the brain.

Corneal Anatomy



Epithelium

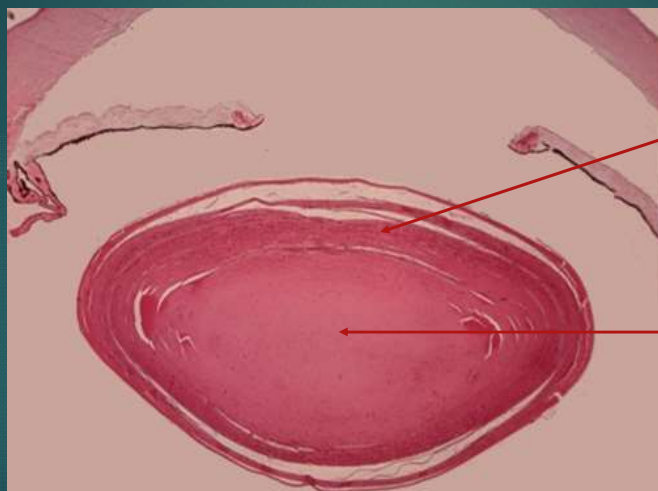
Bowman's Membrane

Stroma

Descemet's Membrane

Endothelium

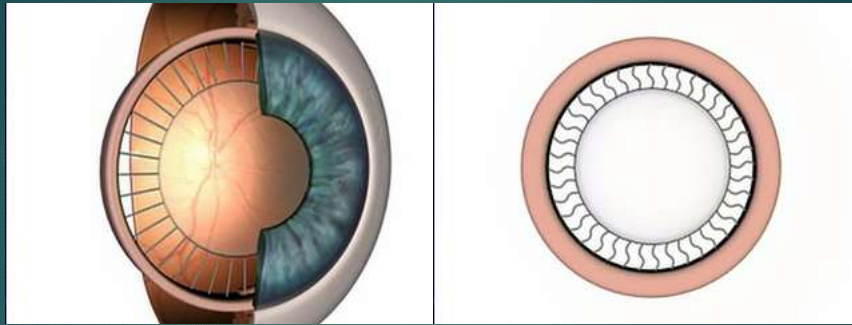
Crystalline Lens Anatomy



Cortex

Nucleus

Accommodation



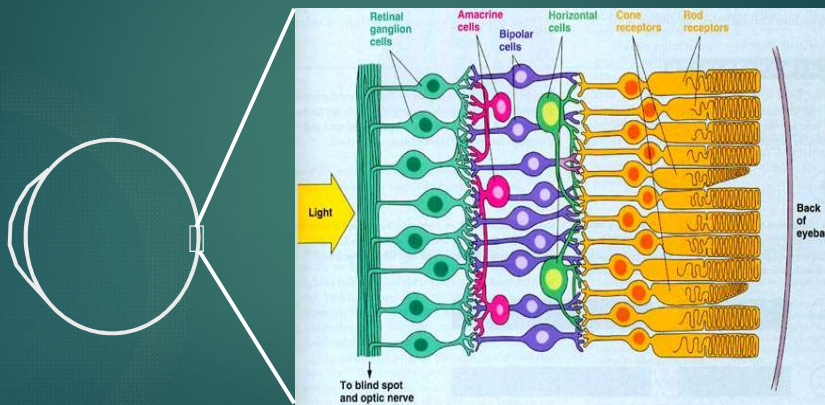
Relaxed ciliary muscle pulls zonules taut and flattens crystalline lens.



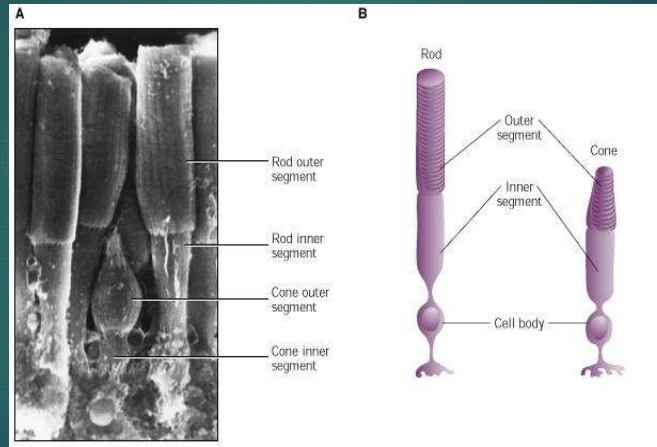
Constrict ciliary muscle releases tension on zonules and crystalline lens bulges.



Retinal Anatomy

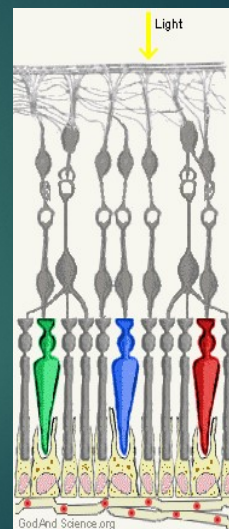


Rods and Cones

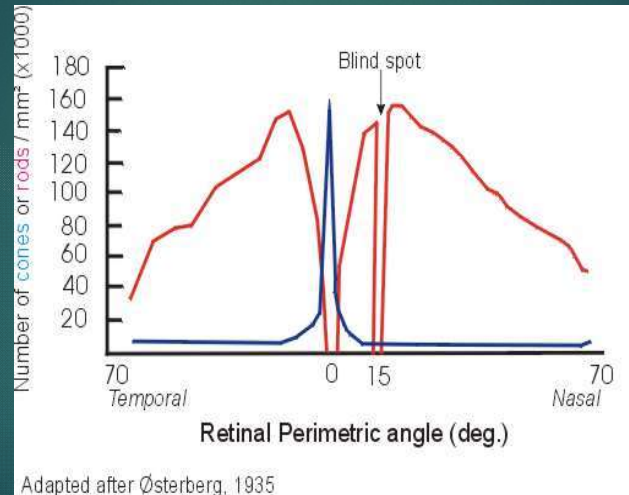


Retinal Pigment Epithelium (RPE)

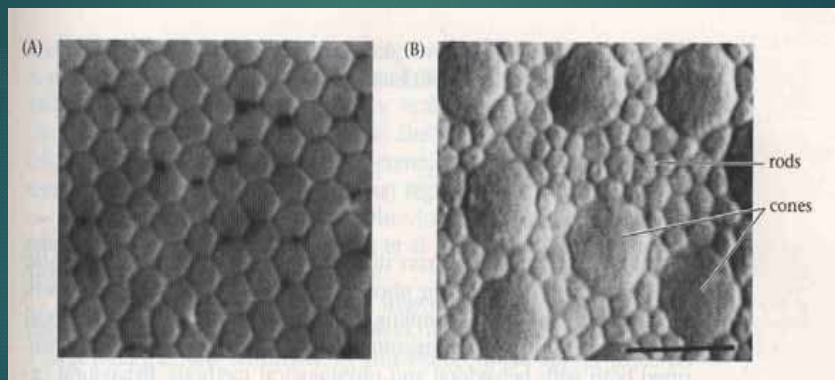
- ▶ Contains Melanin to absorb stray photons to reduce false stimulation of photoreceptors. Some animals (eg cats) have instead a tapetum lucidum which reflects light back giving a second chance at absorption and superior vision under dark conditions
- ▶ Digests old photopigment disks and provides nutrients for their regeneration. This is the reason why the wiring is in front of the pixel.



Rod and Cone Density



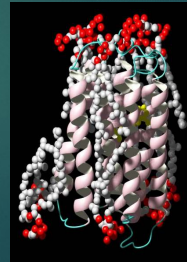
Rod and Cone Mosaic



Photopigments

In 1877, Franz Boll looked into a frog's eye that he had just taken from a dark closet and noticed a reddish pigment that faded under exposure to light. By placing the eye back in the dark and removing again, the fading pigment was seen again. Boll was seeing Rhodopsin, which is a molecule that changes state when it absorbs light.

Rods are sensitive to the blue end of the spectrum. (Scotopic curve) There are 3 types of cones that have similar photopigments to Rhodopsin that are sensitive to the red, green and blue portions of the spectrum. (L, M, and S cones)



Photoreceptor Comparison

Rods

- ▶ Monochromatic – transmit only luminance information to the brain
- ▶ High efficiency in dark lighting conditions
- ▶ Bleached in daytime conditions
- ▶ Fast temporal response
- ▶ Mostly in periphery; none in fovea
- ▶ Low visual acuity
- ▶ Many rods to one neuron

Cones

- ▶ Color Sensitive
- ▶ No efficiency in dark
- ▶ High efficiency in daylight conditions
- ▶ Slow temporal response
- ▶ Mostly in fovea; some in periphery
- ▶ high visual acuity in macula
- ▶ In fovea one to one neuron

Ocular Component Dimensions

Name	Mean	Range
Anterior Cornea	7.86 mm	7.00-8.65 mm
Posterior Cornea	6.50 mm	6.20-6.60 mm
Anterior Chamber Depth	3.68 mm	2.80-4.60 mm
Crystalline Lens Power	20.35 D	15.50-25.00 D
Crystalline Lens Thickness	~ 4 mm	
Anterior Lens Surface	10.2 mm	8.8-11.9 mm
Posterior Lens Surface	6.0 mm	
Axial Length	24.0 mm	20.0-29.5 mm
Total Power	59.63 D	54-65 D

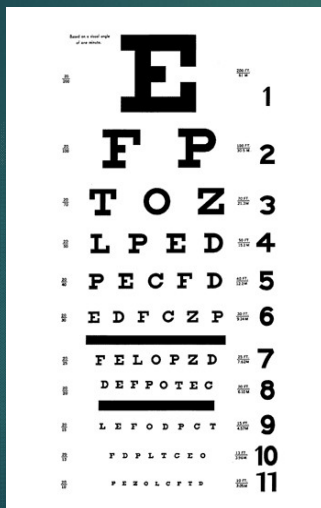
Indices of Refraction

Name	n
Cornea	1.377
Aqueous	1.3374
Lens	1.36→1.41 →1.36
Vitreous	1.336

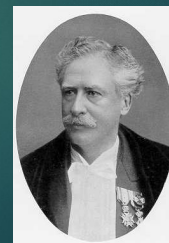
Optical Modeling

- ▶ Optical modeling of the eye attempts to use this information (i.e. radius of curvature, indices, spacing) for raytracing to determine the optical properties of the eye such as the cardinal points, imaging properties, aberrations, etc. Sophistication of the models range from very basic to very complex. In doing this modeling, we will see that the visual acuity (e.g. 20/20) is a limited measure of the performance of the optical system.

Visual Acuity (Snellen Acuity)

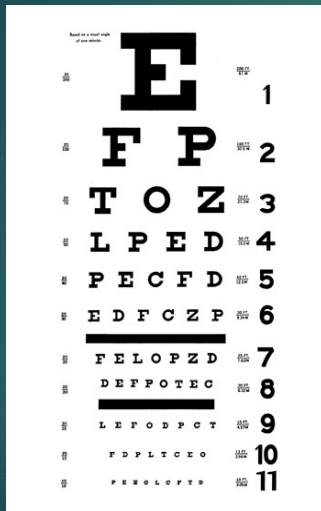


- ▶ Smallest resolvable black and white target. Many different types of tests, but the letter chart introduced by Snellen in 1862 is the most common. Snellen used a somewhat bizarre system from describing visual acuity, which is still in use today.



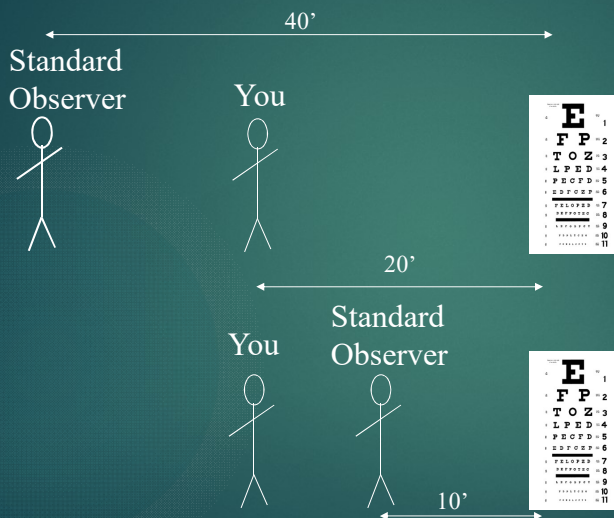
clendening.kumc.edu/dcfrcs.html

Snellen Fraction



- ▶ Visual Acuity is given as a fraction S (e.g. 20/40). The numerator is the distance the subject needs to be in order to resolve a given line on an eye chart (usually fixed to 20 feet in US). The denominator is the distance a standard observer (Snellen's assistant) needs to stand in order to see the same line on the eye chart.
- ▶ Many countries use 6 meters instead of 20 feet as the standard (6/12 is same as 20/40).

Snellen Fraction



$S=20/40$
Your eyesight is worse than the Standard Observer

$S=20/10$
Your eyesight is better than the Standard Observer

LogMAR Acuity

- ▶ Visual Acuity is sometimes given as a LogMAR (logarithm of the Minimum Angular Resolution) denoted by L. This is a continuous number instead of a fraction and is more convenient for doing statistics.

$$L = \log\left(\frac{1}{S}\right) \quad \text{e.g. } L = \log\left(\frac{1}{20/40}\right) = 0.3$$

ETDRS Chart

- ▶ Same number of letters on every line.
- ▶ Step sizes are in LogMAR, so the height of the letters decrease by the same amount from line to line.

