Optics of the eye

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Contents

- Source

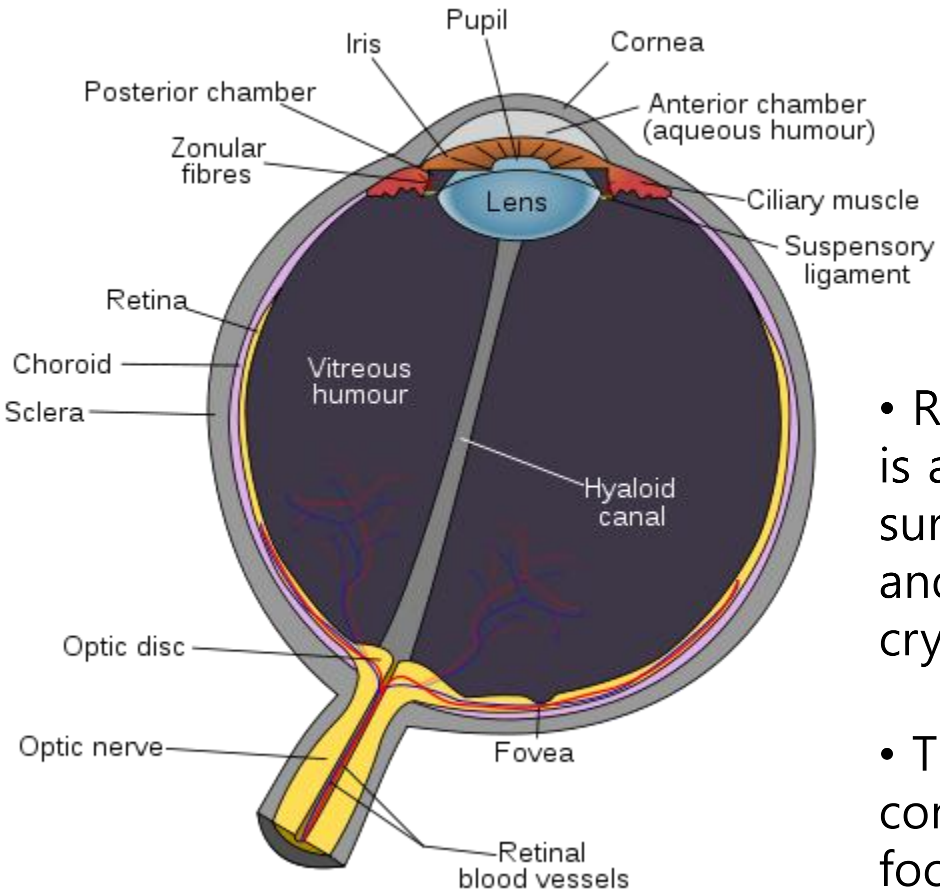
1) Optics and vision

   Leno S. Pedrotti, Frank L. Pedrotti, S.J.,1998, Prentice-Hall

2) Wikipedia

1. Biological structure

Biological structure



• Refraction of light rays entering the eye is accomplished primarily by a single-surface spherical refraction at the cornea and also, to some extend, by the crystalline lens of the eye.

• The lens can be made more or less convex in shape, thereby varying its focusing power. This adjustment, which occurs automatically in the act of looking at things, is called **accommodation**.

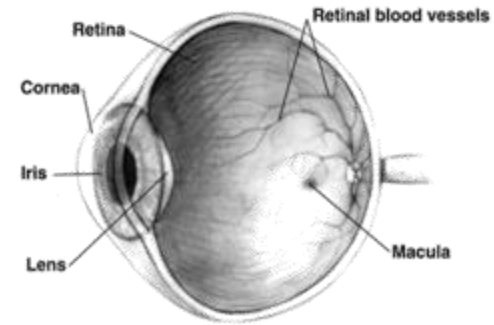
Terminology

- Ophthalmic[afθǽlmik] 눈의,안과의
- Optometrist[aptάmətrist] 검안사

  optometrist가 의사? optometrist는 시력(vision)을 측정하여 안경·콘택트 렌즈의 처방전 (prescription)을 발행해 주는 검안사임. 이 처방전에 따라 안경을 만들어 주거나 콘택트 렌즈를 판매하는 사람은 optician이라 하고 안과 질환의 치료나 수술을 담당하는 의사는 ophthalmologist이며 흔히들 eye doctor라고 말함. (미)에서는 optometrist를 (비격식)으로 eye doctor라고 말하기도 하는데 이것은 사실은 틀린 말임. optometrist는 의사(doctor)가 아닌 특수 기능인으로 optometry school을 졸업하며, ophthalmologist가 되려면 medical school에 가야 하기 때문임.

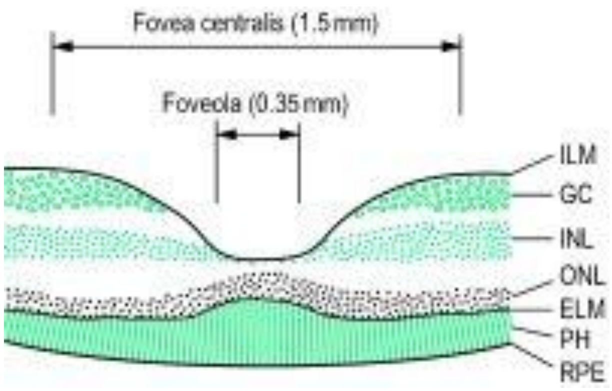
- Ophthalmologist[àfθælmάlədʒist] 안과의사
- Cornea[kɔ́ːrniə] (눈의) 각막 n=1.376
- Aqueous humor (안구의) 수양액(水樣液) n=1.336
- Iris[áiəris] (안구의) 홍채(虹彩). Pupil 2mm~8mm
- Ciliary[sílièri] muscle 모양체근(毛樣體筋) n=1.336
- Crystalline lens **(안구의)** 수정체 n=1.41(core), 1.39(periphery)
- Vitreous[vítriəs] humor (안구의) 유리체액.
- Retina [rétənə] (눈의) 망막.

Terminology



- Rod cell 막대세포
- Cones 원추세포
- Macula 황반(黃斑)

  눈의 망막 중앙에 있는 누르스름한 점. 지름이 약 3밀리미터쯤 되는 타원형으로 시각 세포가 잘 발달되어 있어 시력과 색각이 가장 뛰어나다.
- Sclera[sklíərə] (눈의)공막(鞏膜)
- Forvea[fóuviə] 와(窩) = forvea centralis
- Choroid[kɔ́ːrɔid, -riɔid] 맥락막(脈絡膜)



- Myopia [maióupiə] 근시
- Myope [máioup] 근시인 사람
- Hyperopia [hàipəróupiə]원시
- Hyperope [háipəròup]원시인 사람
- Emmetropia [èmitróupiə] 정시안(正視眼)
- Ametropia [æmitróupiə] 비정시안, 굴절이상

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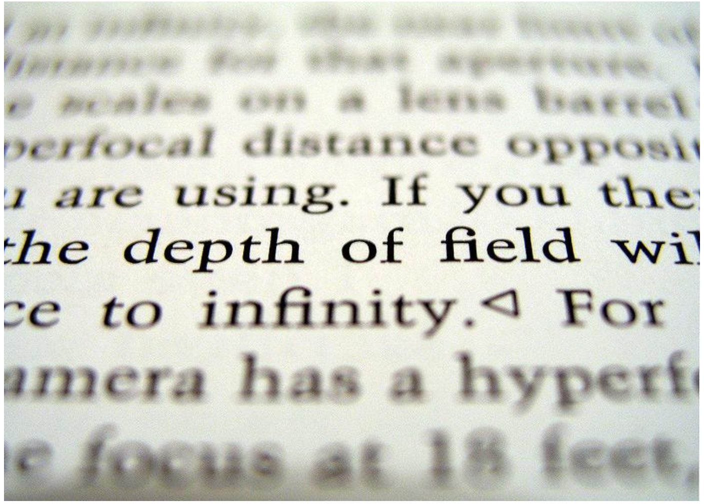
2. Functions

Functions

(1) To focus on objects nearby and far away, the eye ***accommodates***.

- In a normal eye, accommodation permits faithful retinal images of objects anywhere from distant points(at infinity) to nearby points about one foot away.
- The near point(closest point of accommodation) recedes from the eye with advancing age, starting at a position of 7 to 10 cm from the eye for a teenager, increasing to 20 to 40 cm for a middle-aged adult, and extending to as far as 200 cm in later years.



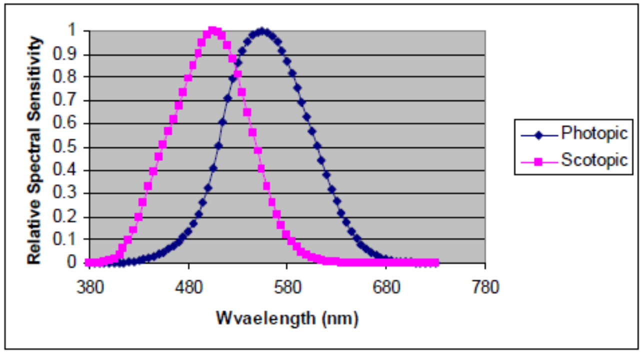
An image that is partially in focus, but mostly out of focus in varying degrees.

Functions

(2) To process light signals of varying brightness, the eye ***adapts***.

- The ability of the eye to respond to light signals that range from very dim to very bright, a range of light intensities that differ by an astonishing factor of about 10^5, is referred to as adaptation.
- The rods, stimulated by low-level light signals(scotopic vision), contain pigment of only one kind, called visual purple. The cones, sensitive to light signals of high intensity and variable color composition(photopic vision), each contain one of three different kinds of visual pigment.

Schematic Eyes - Spectral Sensitivity



Scotopic - Low light level
Peak around 505 nm

Photopic - High light level
Peak around 555 nm

Mesopic - In between

To include in raytracing code, weight wavelengths by appropriate curve.

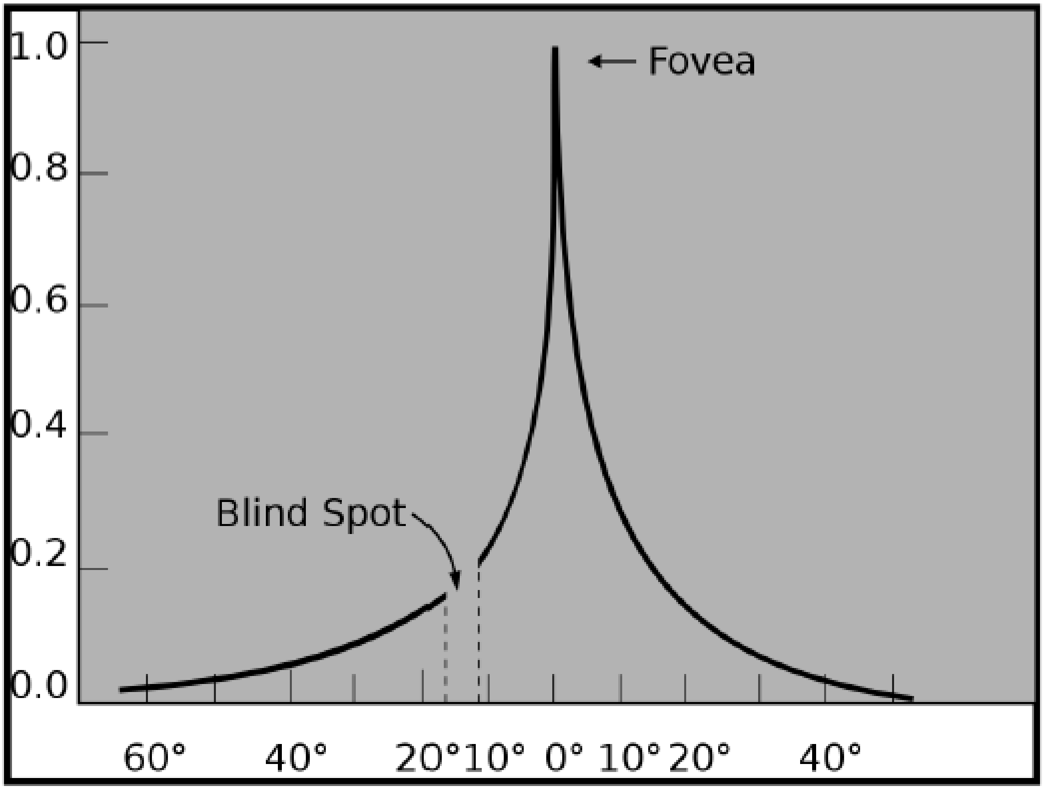
Functions

(3) To sense the spatial orientation of three-dimensional scenes, the eyes make use of ***stereoscopic vision***.

- The fusion by the brain of two distinct images into a single image is referred to as binocular vision. Nevertheless, the slight differences between the two images from the left and light eyes provide the basis for stereoscopic vision in humans.
- It should be noted that even monocular vision is not without some depth perception. This is due to visual clues like parallax, shadowing, and the particular perspective of familiar objects.

Functions

(4) To form a faithful, detailed image of the external object, the eye relies on its ***visual acuity***.



The diagram shows the relative acuity of the left human eye (horizontal section) in degrees from the fovea.[4]

Vergence

- A vergence is the simultaneous movement of both eyes in opposite directions to obtain or maintain single binocular vision.
- When a creature with binocular vision looks at an object, the eyes must rotate around a vertical axis so that the projection of the image is in the center of the retina in both eyes. To look at an object closer by, the eyes rotate towards each other(convergence), while for an object farther away they rotate away from each other(divergence).
- Vergence movements are closely connected to accommodation of the eye. Under normal conditions, changing the focus of the eyes to look at an object at a different distance will automatically cause vergence and accommodation.
- As opposed to the 500°/s velocity of saccade movements, vergence movement are far slower, around 25°/s

3. Optical models

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Helmholtz-Laurance schematic eye

- A schematic eye-after H.V.Helmholtz and L.Laurance- represents a biological eye with fair accuracy.

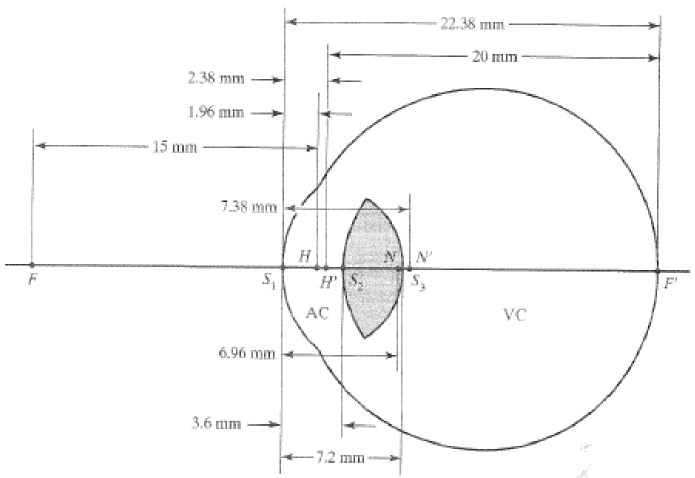


Figure 10-3 Representation of H. V. Helmholtz's schematic eye 1 as modified by L. Laurance. For definition of symbols, refer to Table 10-1. (Adapted with permission from Mathew Alpern, "The Eyes and Vision," Section 12 in *Handbook of Optics*, New York: McGraw Hill, 1978.)

TABLE 10-1 CONSTANTS OF A SCHEMATIC EYE (HELMHOLTZ-LAURANCE)

Optical surface or element	Defining symbol	Distance from corneal vertex (mm)	Radius of curvature of surface (mm)	Refractive index	Refractive power (diopters)
Cornea	S_1	—	+8[a]	—	+41.6
Lens (unit)	L	—	—	1.45	+30.5
Front surface	S_2	+3.6	+10[b]	—	+12.3
Back surface	S_3	+7.2	−6	—	+20.5
Eye (unit)	—	—	—	—	+66.6
Front focal plane	F	−13.04	—	—	—
Back focal plane	F'	+22.38	—	—	—
Front principal plane	H	+1.96	—	—	—
Back principal plane	H'	+2.38	—	—	—
Front nodal plane	N	+6.96	—	—	—
Back nodal plane	N'	+7.38	—	—	—
Anterior chamber	AC	—	—	1.333	—
Vitreous chamber	VC	—	—	1.333	—
Entrance pupil	E_nP	+3.04	—	—	—
Exit pupil	E_xP	+3.72	—	—	—

Source: Adapted with permission from Mathew Alpern, "The Eyes and Vision," Table 1, Section 12 in *Handbook of Optics*, New York: McGraw-Hill Book Company, 1978.

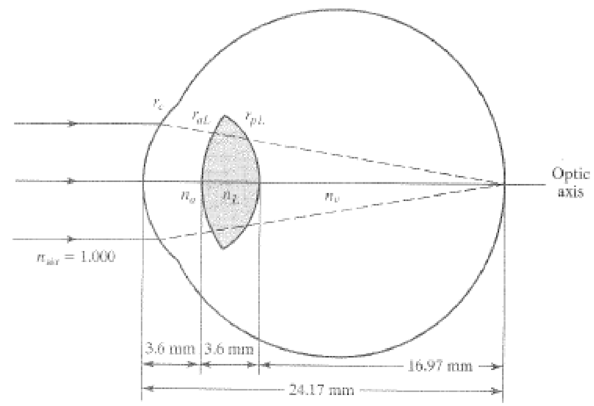
[a] In this model, the cornea is assumed to be infinitely thin. In Gullstrand's exact schematic eye, for example, the cornea is retained as a two-surface element of 0.5 mm thickness.

[b] Value given is for the relaxed eye. For the tensed or fully accommodated eye, the radius of curvature of the front surface is changed to +6 mm.

- Note carefully that the values for the refractive indices of various parts of the eye, as well as radii of curvature of various surfaces, may not agree with values of the biological eye itself.
- This "nearly exact" model is still far too complicated for calculations carried out by most of the ophthalmic community.

Gullstrand's three-surface simplified schematic eye

- Based on the historically significant work of Allvar Gullstrand(1862-1930), a Swedish ophthalmologist who received the Novel prize in 1911 for Physiology, specifically for his investigations of the eye as an image-forming optical system.



r_c = corneal radius = 7.8 mm
r_{aL} = anterior lens surface = 10 mm
r_{pL} = posterior lens surface = −6 mm
n_a = aqueous humor index = 1.336
n_L = average lens index = 1.413
n_v = vitreous humor index = 1.336

Figure 10-4 Gullstrand's three-surface, simplified schematic eye. The axial length of the eye (24.17 mm) is chosen to ensure the focusing of parallel rays on the retina (emmetropic eye). The radii of curvature r_{aL} and r_{pL} can be adjusted to represent a bulging lens during accommodation.

- While still not as simple as the standard, Gullstrand's three-surface model allows one to change the power of the lens to accommodate. Thus, this model is useful for calculating image positions when the natural lens is removed(during cataract surgery), or when an artificial lens of fixed shape replaces a cataractous lens.

Emsley standard reduced 60-diopter eye

- The axial distance of the eye is fixed at 22.22mm. Further, the principal points, H and H', and the two nodal points, N and N', are now coalesced into single principal points H and N, with fixed at the point where the corneal surface intersects the optic axis.

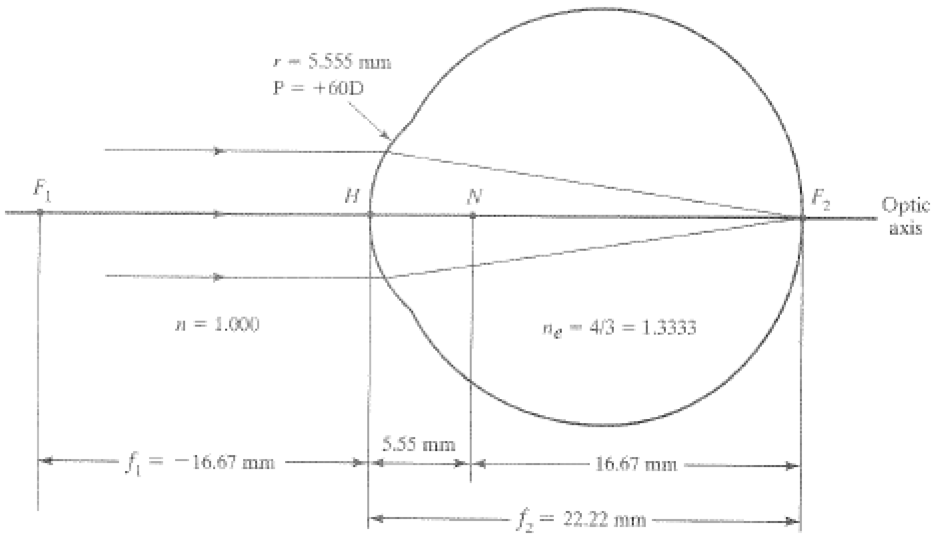
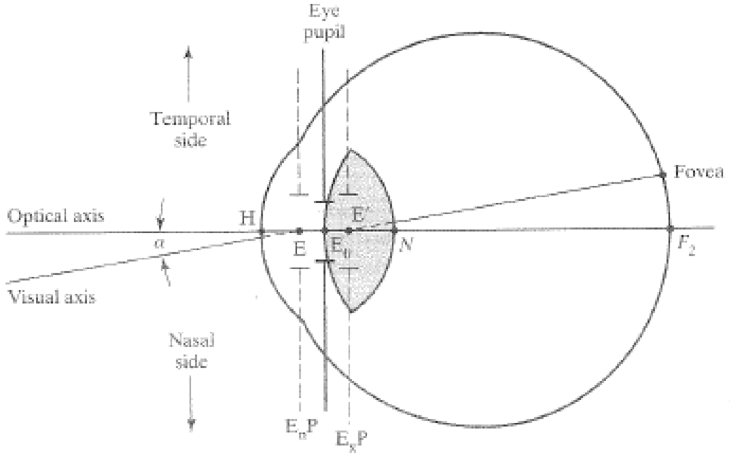


Figure 10-5 Emsley's standard reduced 60-diopter eye. Note that the model of this eye is represented by a single curved surface, where the two principal points *H* and *H'* and two nodal points *N* and *N'* (shown in Figure 10-3) coalesce into single points *H* and *N*, respectively. The focal points F_1 and F_2 are measured relative to the principal point *H*. Here the axial length of the emmetropic eye, from cornea to retina, is 22.22 mm, thereby ensuring that parallel rays for this model focus on the macula at the retinal surface.

Optical and visual axes

- The fovea centralis, the region of most distinct vision, is not located at F_2, the intersection of the retinal surface and the optical axis. Rather it is found in a region located somewhat temporally(horizontally away from the nose toward the side of the head) and downward(from top of head to bottom).
- Since the location of the fovea is on the temporal side of the focal point F_2 and somewhat downward, the visual axis in object space comes in at an angle 2° above the optical axis(thereby heading downward) and 5° to the nasal side(thereby heading outward).



Diopter

- A **dioptre**, or **diopter**, is a unit of measurement of the optical power of a lens or curved mirror, which is equal to the reciprocal of the focal length measured in meters (that is, 1/meters). It is thus a unit of reciprocal length. For example, a 3-dioptre lens brings parallel rays of light to focus at $^1/_3$ meter. The same unit is also sometimes used for other reciprocals of distance, particularly radii of curvature and the vergence of optical beams. The usage was proposed by French ophthalmologist Ferdinand Monoyer in 1872.

- One benefit of quantifying a lens in terms of its optical power rather than its focal length is that when relatively thin lenses are placed close together their powers approximately add. Thus a thin 2-dioptre lens placed close to a thin 0.5-dioptre lens yields almost the same focal length as a 2.5-dioptre lens would have.