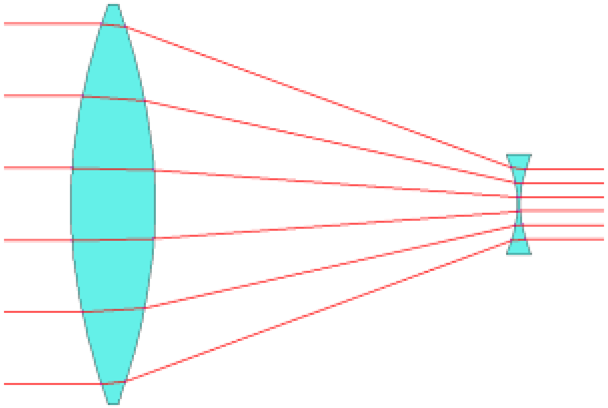
OPAC 101
Introduction to Optics

Topic 8

Optics of the Eye



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Eye (Perfect Light Detector)

- The majority of optical systems utilize the eye as the final element of the system
- A normal eye focuses light and produces a sharp image better than a camera.
- Human eye can detect even a few photons in dark.
- Eye forms images of a continuum of objects, at distances of a 25 cm to infinity.

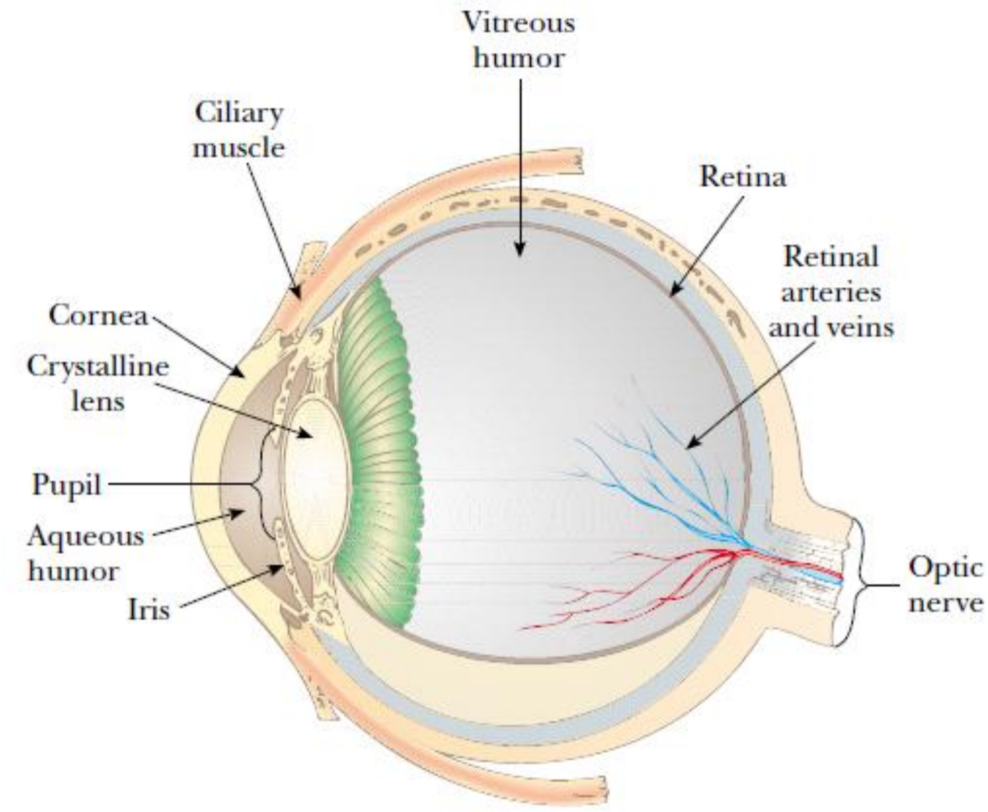
Eye (Perfect Light Detector)

We will see:

- *Biological structure of eye*
- *Photometry*
- *Optical representation of Eye*
- *Functions (Conditions) of Eye and corrections*

Biological Structure of Eye

1. Light entering the eye passes through a transparent structure called the cornea.
2. Pupils are opening in the iris.
3. Crystalline lens focuses light onto the back surface of the eye, the retina which consists of millions of sensitive receptors called *rods* and *cones*.
4. The receptors send light impulses via the optic nerve to the brain, where an image is perceived.



From Feynman Lecture Notes

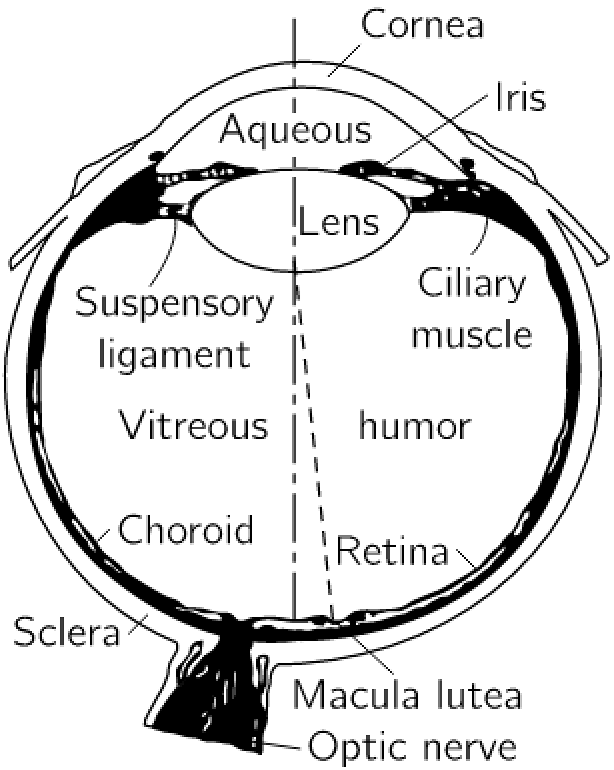


Fig. 35–1. The eye.

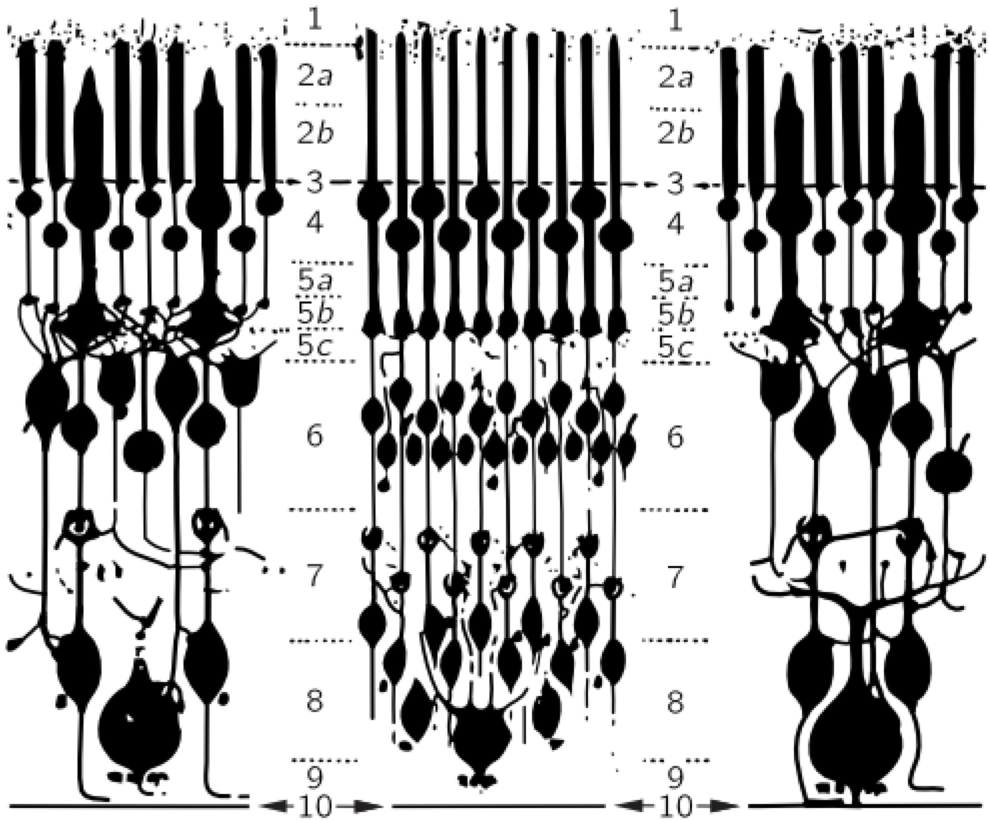


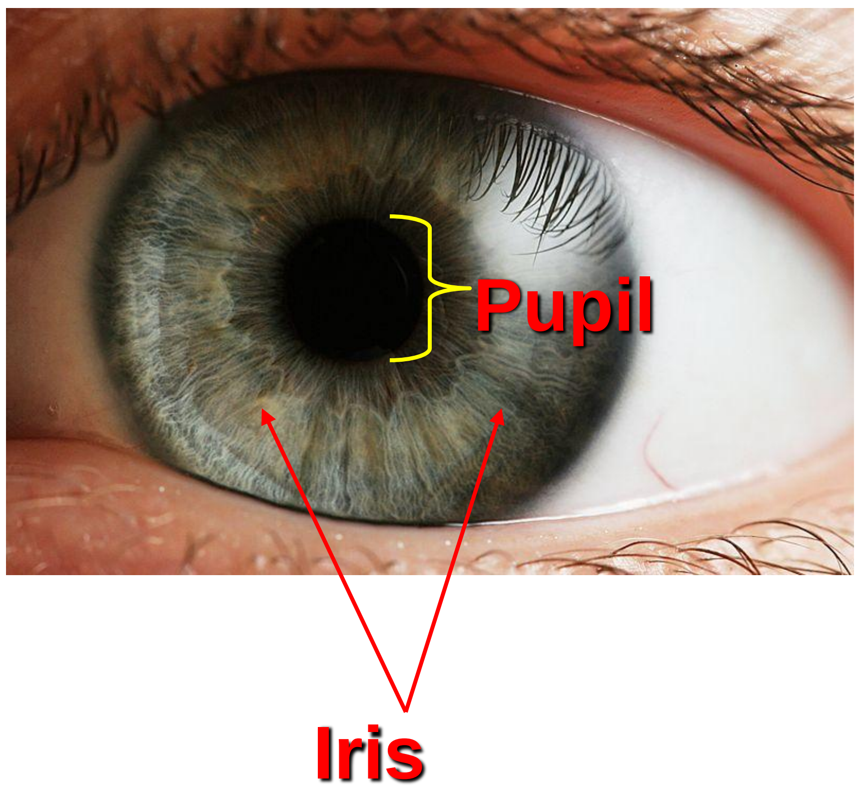
Fig. 35–2. The structure of the retina. (Light enters from below.)

From Feynman Lecture Notes

Light enters the eye through the cornea; we have already discussed how it is bent and is imaged on a layer called the retina in the back of the eye, so that different parts of the retina receive light from different parts of the visual field outside. The retina is not absolutely uniform: there is a place, a spot, in the center of our field of view which we use when we are trying to see things very carefully, and at which we have the greatest acuity of vision; it is called the fovea or macula. The side parts of the eye, as we can immediately appreciate from our experience in looking at things, are not as effective for seeing detail as is the center of the eye. <u>There is also a spot in the retina where the nerves carrying all the information run out; that is a blind spot.</u> There is no sensitive part of the retina here, and it is possible to demonstrate that if we close, say, the left eye and look straight at something, and then move a finger or another small object slowly out of the field of view it suddenly disappears somewhere. The only practical use of this fact that we know of is that some physiologist became quite a favorite in the court of a king of France by pointing this out to him; in the boring sessions that he had with his courtiers, the king could amuse himself by "cutting off their heads" by looking at one and watching another's head disappear.

From Feynman Lecture Notes

Figure 35-2 shows a magnified view of the inside of the retina in somewhat schematic form. In different parts of the retina there are different kinds of structures. The objects that occur more densely near the periphery of the retina are called *rods*. Closer to the fovea, we find, besides these rod cells, also *cone* cells. We shall describe the structure of these cells later. As we get close to the fovea, the number of cones increases, and in the fovea itself there are in fact nothing but cone cells, packed very tightly, so tightly that the cone cells are much finer, or narrower here than anywhere else. So we must appreciate that we see with the cones right in the middle of the field of view, but as we go to the periphery we have the other cells, the rods. Now the interesting thing is that in the retina each of the cells which is sensitive to light is not connected by a fiber directly to the optic nerve, but is connected to many other cells, which are themselves connected to each other. There are several kinds of cells: there are cells that carry the information toward the optic nerve, but there are others that are mainly interconnected "horizontally." There are essentially four kinds of cells, but we shall not go into these details now. The main thing we emphasize is that the light signal is already being "thought about." That is to say, the information from the various cells does not immediately go to the brain, spot for spot, but in the retina a certain amount of the information has already been digested, by a combining of the information from several visual receptors. It is important to understand that some brain-function phenomena occur in the eye itself.


Pupil
Iris

Optical Represeantation of Eye

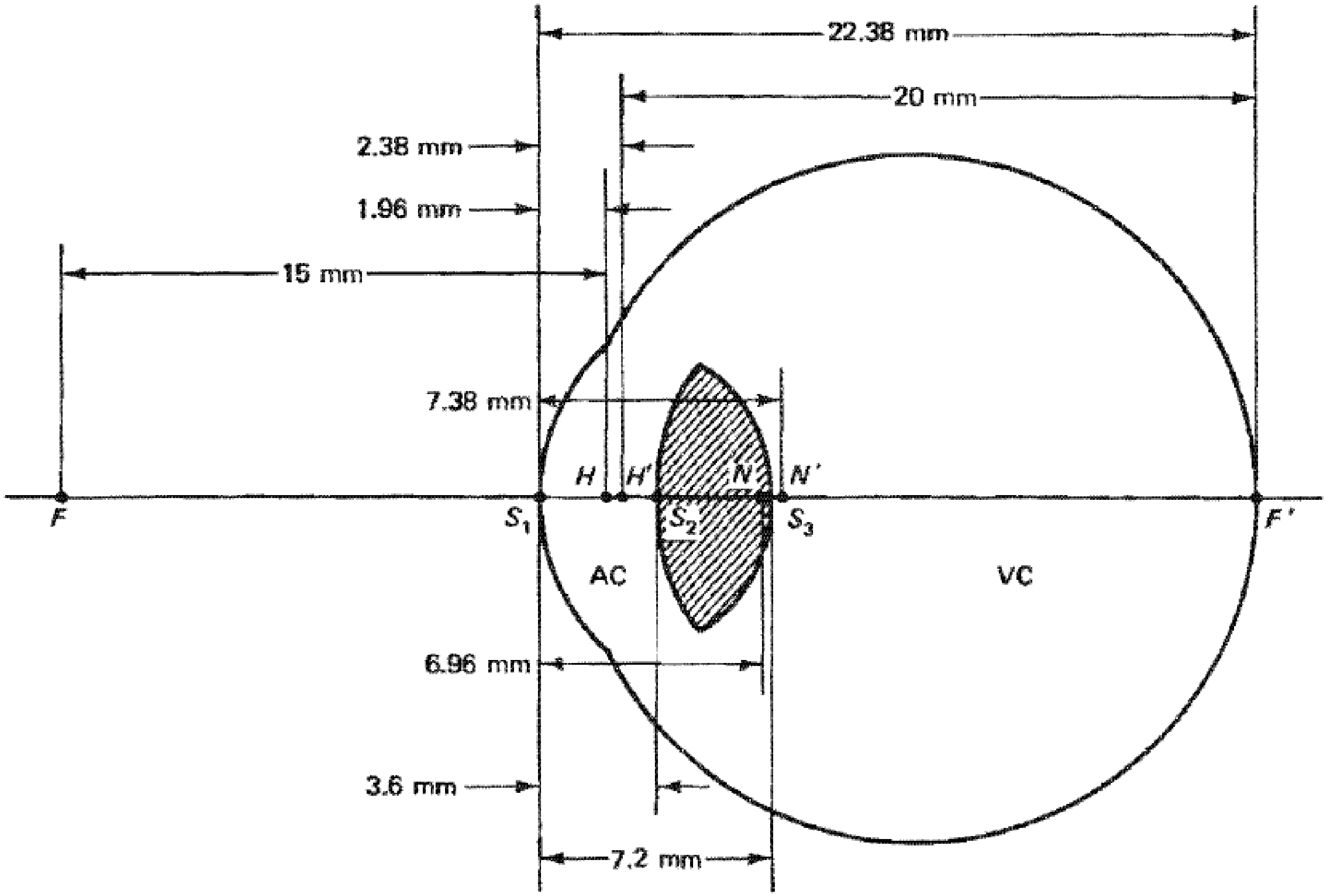


Figure 7-2 Representation of H. V. Helmholtz's schematic eye 1, as modified by L. Laurance. For definition of symbols, refer to Table 7-1. (Adapted with permission from Mathew Alpern, "The Eyes and Vision," Section 12 in *Handbook of Optics*, New York: McGraw-Hill, 1978.)

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	—	—	—

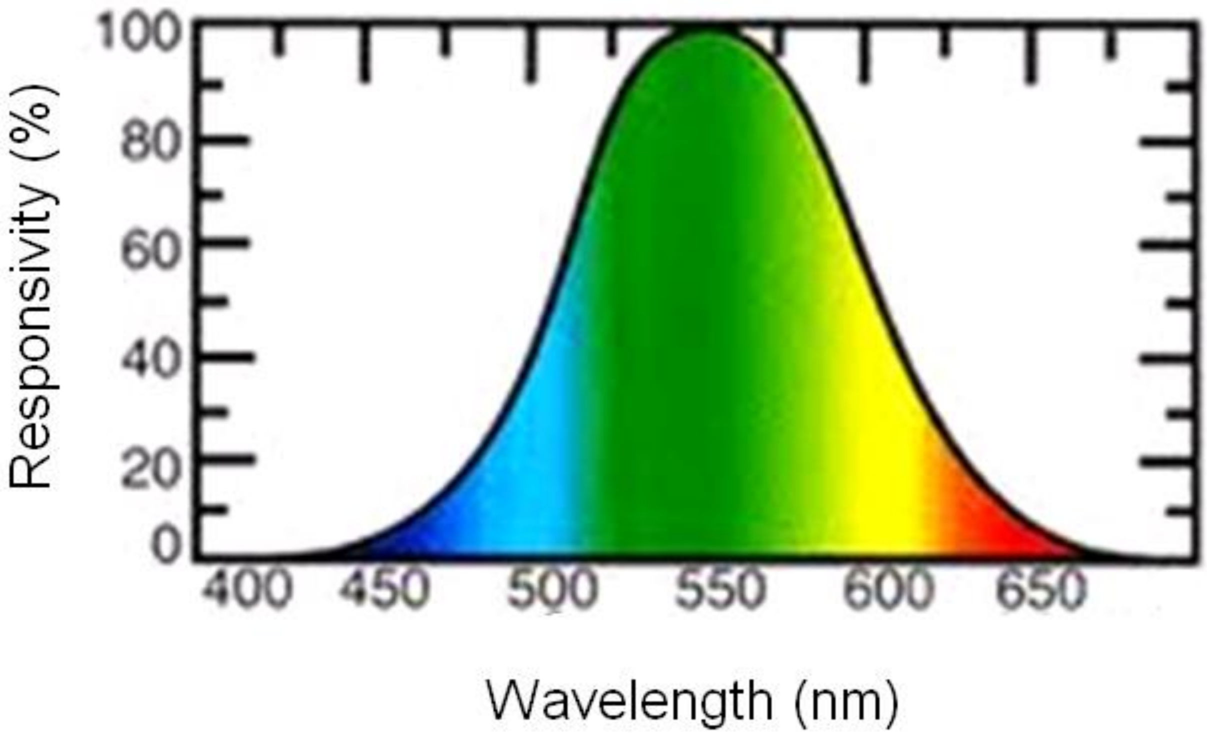
SOURCE: Adapted with permission from Mathew Alpern, "The Eyes and Vision," Table 1, Section 12, in *Handbook of Optics*, New York: McGraw-Hill Book Company, 1978.

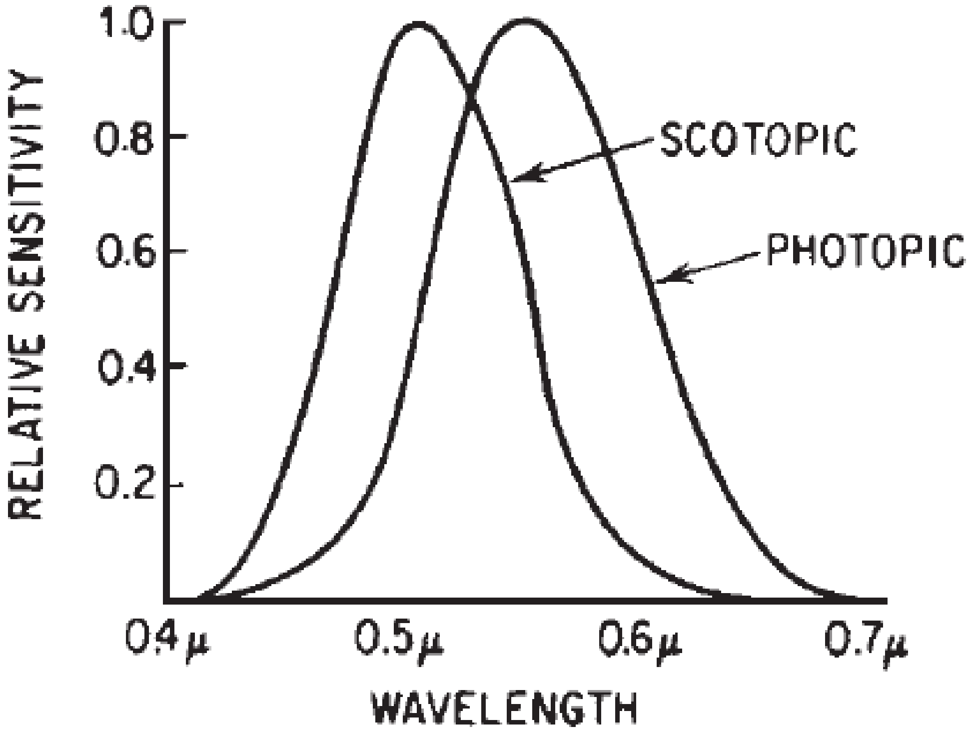
[a] The cornea is assumed to be infinitely thin.

[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.

Spectral Response of Eye

The human eye is not equally sensitive to all wavelengths of visible light.
(See Topic 3 Photometry)

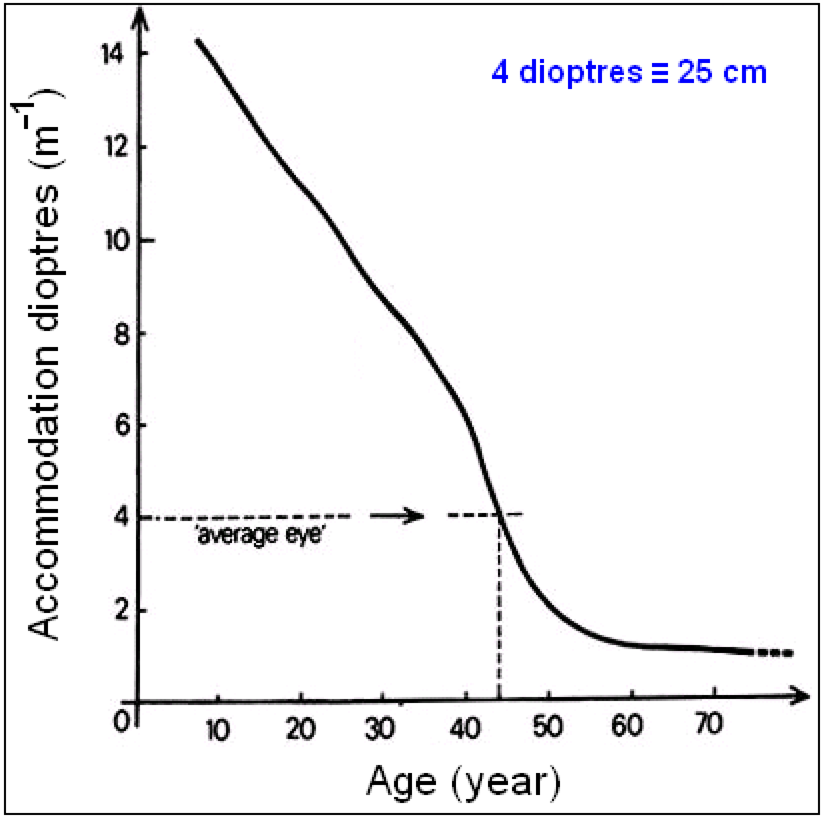




The relative sensitivity of the eye to different wavelengths for normal levels of illumination (photopic vision) and under conditions of dark adaptation (scotopic vision).

Accomodation

- The eye focuses on an object by varying the shape of the pliable crystalline lens (by ciliary muscle) through an amazing process called **accommodation** (*göz uyumu*).



- The **near point** is the closest distance for which the lens can accommodate to focus light on the retina.

  This distance usually increases with age and has an average value of 25 cm = 0.25 m.

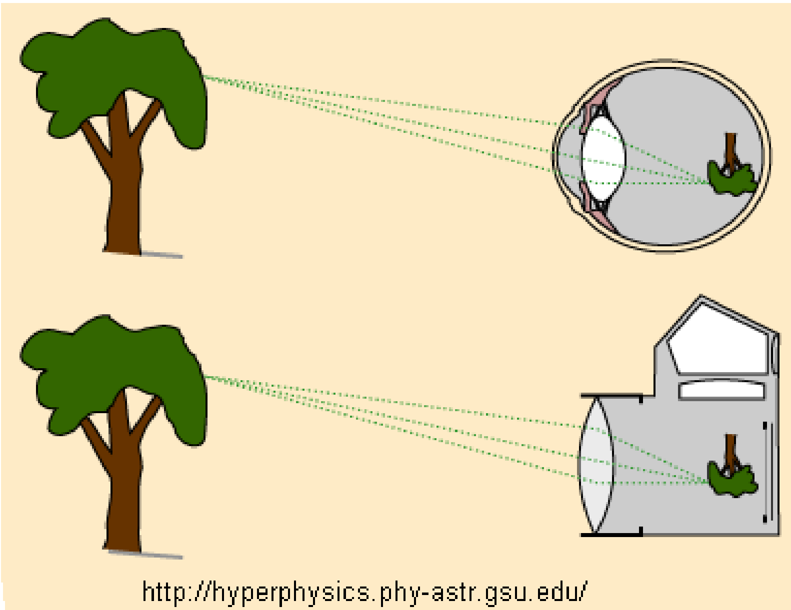
$$P = \frac{1}{0.25\,\mathrm{m}} = 4\,\mathrm{m}^{-1} = 4\,\mathrm{D}$$

- The **far point** of the eye represents the greatest distance for which the lens of the relaxed eye can focus light on the retina. For normal vision "far point –> ∞"

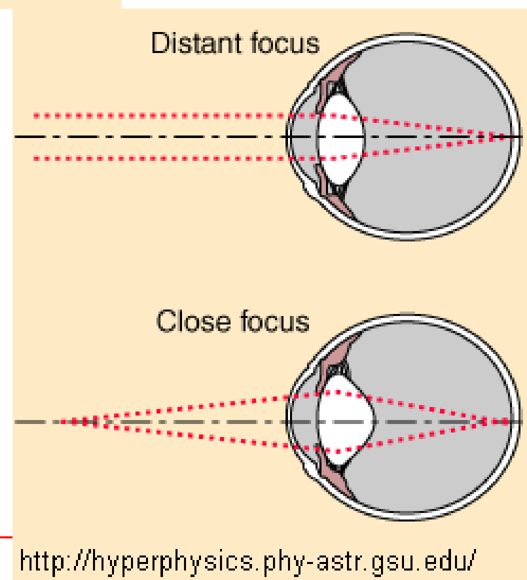
- *For normal eye, range accommodation is between 25 cm and ∞.*

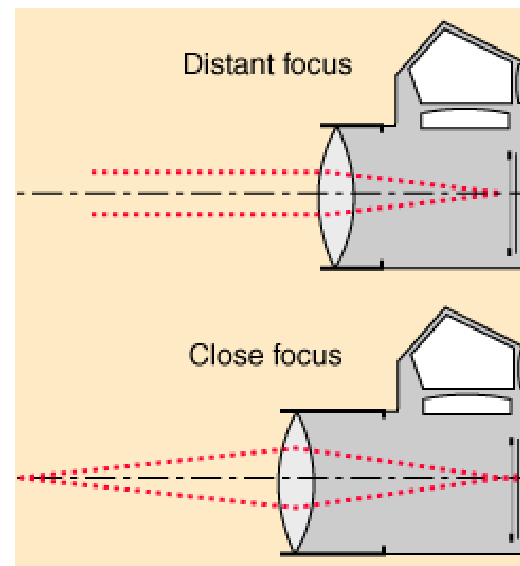
Eye and Camera

Image formation



Accommodation in Eye and Camera





(Eye) Glasses

- Glasses or eyeglass are frames bearing lenses worn in front of the eyes.

- They are normally used for vision correction.

- Lens powers:

```
Positive = {+0.25, +0.50, ..., +14.00}
Negative = {-0.25, -0.50, ..., -14.00}
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Remember Focal length is inverse of Power:

$$f = 1 / P$$

Eyeglass Materials

Glass Type	Refractive Index (nd)	Abbe Value (Vd)	Density (g/cm^3)	UV cutoff (nm)	Note
Optical crown glass	1.52288	58.5	2.55	320	the heaviest corrective lens material in common use, today
Plastic (CR-39)	1.498	59.3	1.31	355	The most commonly used lens material
Trivex	1.532	43–45	1.1	380	the lightest corrective lens material in common use
Polycarbonate	1.586	30	1.2	385	lighter weight than normal plastic
High-index plastics (thiourethanes)	1.600–1.740	42–32	1.3–1.5	380–400	higher indexes generally result in lower Abbe values

Coating & Ultraviolet Protection

- Anti-reflective coatings help to make the eye behind the lens more visible. (anti-reflective coating seen in the bottom)

- A UV coating is used to reduce the transmission of light in the ultraviolet spectrum.
  UV radiation increases the likelihood of cataracts.
  Long term exposure to UV radiation can damage the retina.

Vision Corrections with External Lenses

The errors of refraction of the eye lead to four well-known defects in vision:

- Myopia (nearsightedness)
- Hyperopia (farsightedness)
- Presbyopia
- Astigmatism

Read your book for the details.

Here we'll see summary.

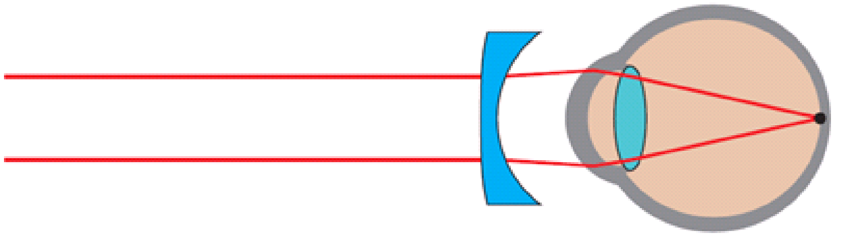
Myopia

- is a vision condition in which close objects are seen clearly, but objects farther away appear blurred.
- Nearsightedness occurs if the eyeball is too long or the cornea, as a result, the light entering the eye isn't focused correctly.
- Nearsightedness is corrected with a diverging lens.
- The far point (F.P.) of a nearsighted person is not infinity (~1 m).
- Near point (N.P) may be 15 cm.

- *The purpose of the lens is to "move" an object from infinity to a distance (x) where it can be seen clearly.*

$$\frac{1}{f} = \frac{1}{\infty} + \frac{1}{x}$$

where $f < 0$.



Example

A particular nearsighted person is unable to see objects clearly when they are beyond 2 m away. What should be the focal length and power of the lens ?

SOLUTION

$$\frac{1}{f} = \frac{1}{\infty} + \frac{1}{-2\text{ m}} \longrightarrow f = -2\text{ m}$$

$$P = \frac{1}{f} = \frac{1}{-2\ m} = -0.5\text{ m}^{-1} = -0.5\text{ dioptres}$$

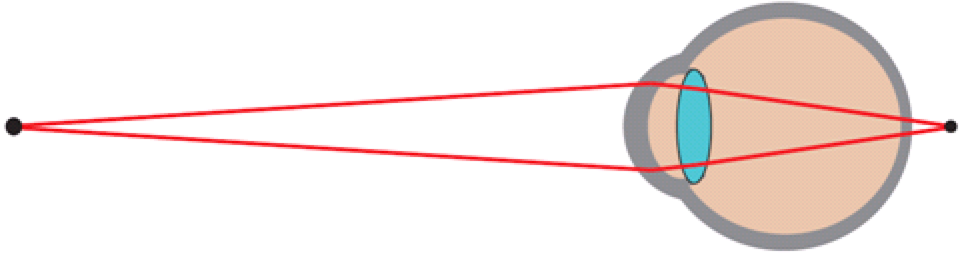
In Turkish -0.5 numara gözlük.

Example (Petrotti 3rd Ed)

A myopic person (without astigmatism) has a far point of 100 cm and a near point of 15 cm. (a) What power contact lens should an optometrist prescribe to move the myopic far point out to infinity? (b) With this correction, can the myopic person also read a book held at the normal near point, 25 cm from the eye? [Answer: (a) -1.00 D   (b), yes. since s'= -20 cm and |s'| > 15 cm]

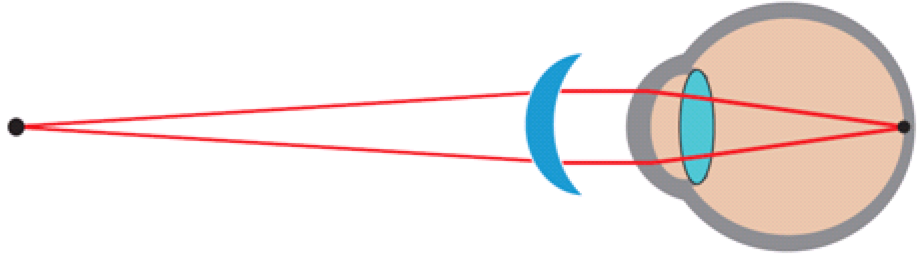
Far-sightedness (or hyperopia)

- is a vision condition in which distant objects are usually seen clearly, but close ones do not come into proper focus.
- Farsightedness occurs if your eyeball is too short or the cornea has too little curvature, so light entering your eye is not focused correctly.
- Farsightedness is corrected with a converging lens.
- The near point of a farsighted person is much farther away from 25 cm.



- *The purpose of the lens is to "move" an object from a distance (x) where it can be seen clearly to near point (in general 25 cm).*

$$\frac{1}{f} = \frac{1}{0.25\,\mathrm{m}} + \frac{1}{x}$$



where f > 0, and x<0

Example

A particular farsighted person is unable to see objects clearly when they are closer than 1 m. What should be the focal length and power of the lens?

SOLUTION

$$\frac{1}{f} = \frac{1}{0.25\,\mathrm{m}} + \frac{1}{-1.0\,\mathrm{m}} \longrightarrow f = 0.333\,\mathrm{m}$$

$$P = \frac{1}{f} = \frac{1}{0.333\ \mathrm{m}} = 3.0\ \mathrm{m}^{-1} = +3\ \mathrm{D}$$

In Turkish +3 numara gözlük.

Example (Petrotti 3rd Ed)

A farsighted person is diagnosed to have a near point at 150 cm. It is found that a corrective lens of power 3.5 diopters placed 1.5 cm from the eye will allow this person to view objects at infinity with a relaxed eye.

What is the near point (with the corrective lens) for this eye?

SOLUTION

$$f = \frac{1}{P} = \frac{1}{3.5\ D} = 0.286\ \text{m} = 28.6\,\text{cm}$$

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'} \longrightarrow \frac{1}{28.6} = \frac{1}{s} + \frac{1}{-148.5} \longrightarrow s = 24\,\text{cm}$$

This object distance corresponds to a total distance of 25.5 cm from the eye. So, with the corrective lens, this person can see faraway objects with a relaxed eye and objects as near as 25.5 cm from the eye with a fully accommodated eye.

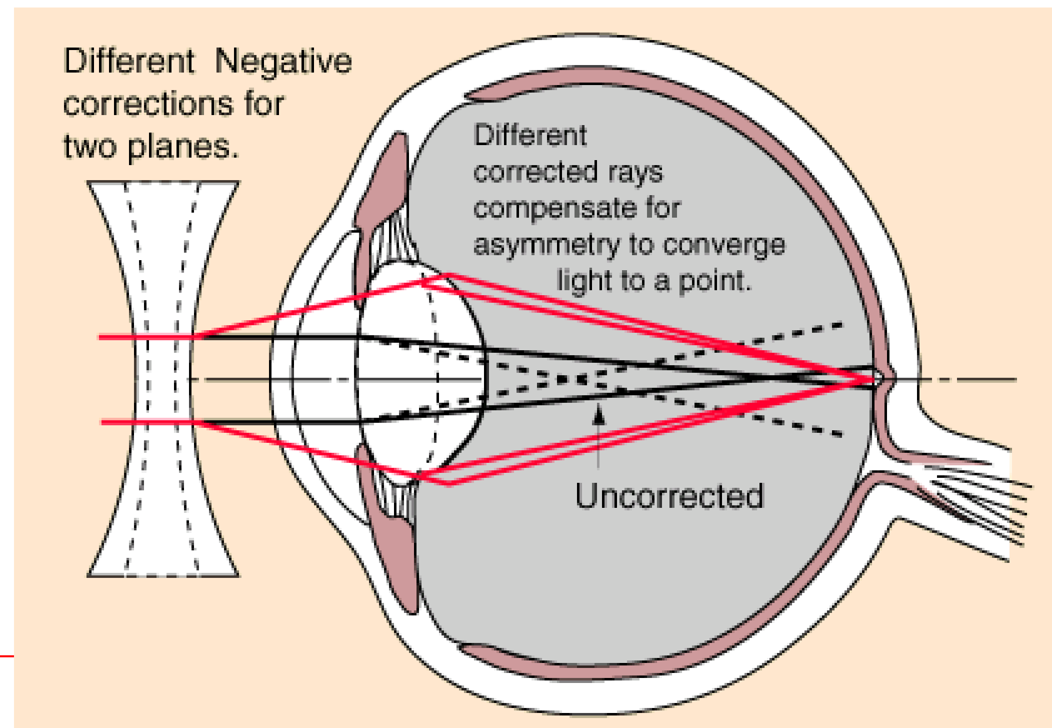
Astigmatism

- Astigmatizm is a vision condition that causes blurred vision due either to the irregular shape of the cornea, the clear front cover of the eye,
or sometimes the curvature of the lens inside the eye.

- Astigmatism frequently occurs with other vision conditions like nearsightedness (myopia) and farsightedness (hyperopia).

- Astigmatism can be corrected with lenses that have different curvatures in two mutually perpendicular directions.

- Laser surgery is also a possible treatment option for some types of astigmatism.



Presbyopia (old-age vision)

- Presbyopia is a vision condition in which the crystalline lens of your eye loses its flexibility, which makes it difficult for you to focus on close objects.

- Beginning in middle age, most people lose some of their accommodation ability as the *ciliary muscle* weakens and the lens hardens.

- Unlike farsightedness, which is a mismatch between focusing power and eye length, presbyopia is due to a reduction in accommodation ability.

Exercises

1. What is eye?
   (a) sensory organ mediating the sense of sight
   (b) A structure that detects light and converts it into neural responses that the brain interprets
   (c) A structure whose anatomy is designed to focus light rays so that an image is formed on the back of the retina
   (d) All of the above

2. Consider the phenomenon of accommodation. Under what condition do the ciliary muscles have to do the most work?
   (a)When shortening the focal length of the cornea-lens system to view far off objects
   (b) When lengthening the focal length of the cornea-lens system to view far off objects
   (c) When shortening the focal length of the cornea-lens system to view objects that are near.
   (d) When lengthening the focal length of the cornea-lens system to view objects that are near.

3. How does an optometrist correct for hyperopia?
   (a) Equips the eye with a diverging lens to shorten the focal length of the cornea-lens system
   (b) Equips the eye with a diverging lens to lengthen the focal length of the cornea-lens system
   (c) Equips the eye with a converging lens to shorten the focal length of the cornea-lens system
   (d) Equips the eye with a converging lens to lengthen the focal length of the cornea-lens system

4. A nearsighted person cannot see objects clearly beyond 50 cm (her far point). If she has no astigmatism and contact lenses are prescribed for her, what power and type of lens are required to correct her vision?

5. A farsighted person cannot see objects clearly closer than 50 cm (her near point). If she has no astigmatism and contact lenses are prescribed for her, what power and type of lens are required to correct her vision?

6. A myopic person (without astigmatism) has a far point of 100 cm and a near point of 15 cm. (a) What correction should an optometrist prescribe to move the myopic far point out to infinity? (b) With this correction, can the myopic person also read a book held at the normal near point, 25 cm from the eye? (Ans: (a) -1.00 D, (b) 17.6 cm) [Petrotti Int. To Optics.]

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