Dentistry College Medical Physics

Physics of Eyes and Vision

Dr.muhannad sami

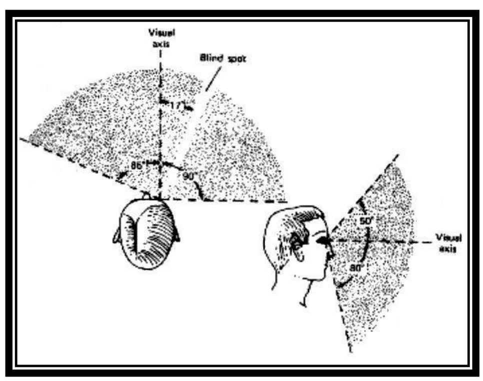
<u>The sense of vision consists of three major components: -</u>

1. The eyes that focus an image from the outside world on the light-sensitive retina.
2. The system of millions of nerves that carries the information deep into the brain.
3. The visual cortex-that part of the brain where "it is all put together".

Blindness results if any one of the parts does not function.

Our optical system has the following **special features**, most of which are not available on even the most expensive cameras: -

1. The eye can observe events over a very large angle while looking intently at an object directly ahead of it.



2. Blinking provides the front lens (cornea) with a built-in lens cleaner and lubricator.

3. A rapid automatic focusing system permits viewing objects as close as 20cm one second and distant objects the next. Under relaxed conditions the focus for normal eyes is set for "infinity" (distant viewing).

4. The eye can operate effectively over a range of light intensity of about 10 billion to one (10^{10}:1)-brilliant daylight to very dark night.

5. The eye has automatic aperture adjustment (the iris).

6. The cornea has a built-in scratch remover; even though it has no blood supply it is made of living cells and can repair local damage.

7. The eye has a self-regulating pressure system that maintains its internal pressure at about 20mmHg and thus keeps the eye in shape. If "dented", the eye rapidly returns to its original shape.

8. The eyes are mounted in a well-protected casing almost completely surrounded by bone, and each eye rests on a cushion of fat that reduces sharp shocks.

9. The image appears upside down on the light-sensitive retina at the back of the eyeball, but the brain automatically corrects for this.

10. The brain blends the images from both eyes, giving us good depth perception and true three-dimensional viewing. If vision from one eye is lost, the vision from the remaining eye is adequate for most needs.

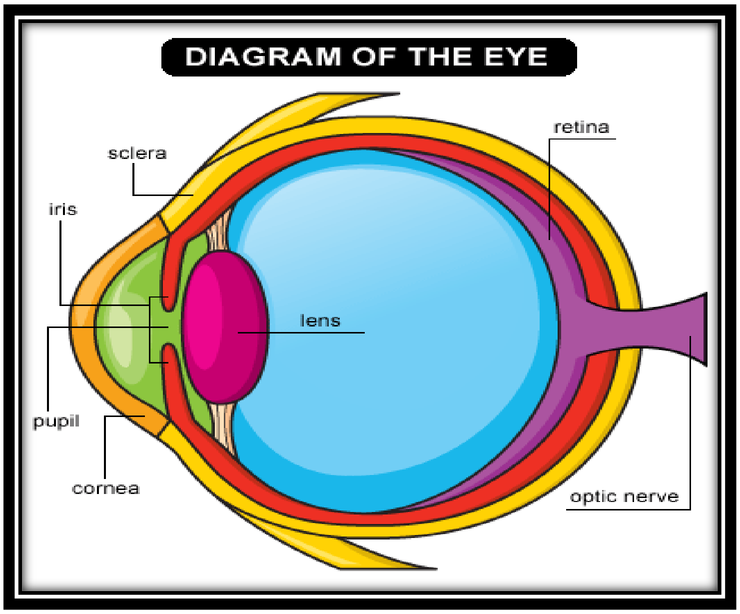
11. The muscles of the eye permit flexible movement up and down, sideways, and diagonally. After a little practice, the eyes can even be made to go in circles.

Elements of the eye

1-Focusing elements of the eye: The eye has two major focusing components:

The cornea, which is the clear transparent bump on the front of the eye that does about two-thirds of the focusing, and **the lens**, which does the fine focusing. The cornea is a fixed focus element; the lens is variable in shape and has the ability to focus objects at various distances.

The cornea focuses by bending (refracting) the light rays. The amount of bending depends on the curvatures of its surfaces and the speed of light in the lens compared with that in the surrounding material (relative index of refraction).



Nearly all of the focusing by the cornea is done at the front surface since the aqueous humor in contact with the back surface has nearly the same index of refraction as the cornea.

Since the living cells in the cornea are not supplied with oxygen by the blood, they must get their oxygen from the air. Having blood vessels in the cornea would not help our vision! The nutrients for the cells in the cornea are supplied by the aqueous humor that is in contact with its back surface. The aqueous humor contains all of the blood components except blood cells.

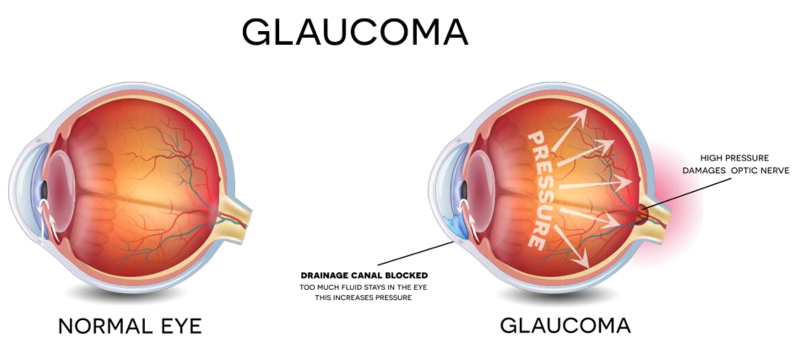
If the cornea is scratched it will heal itself, but some other types of damage are more permanent. Some types of radiation (ultraviolet, neutrons, X-rays, etc.) can cause opacities to develop in the cornea that will block out light.

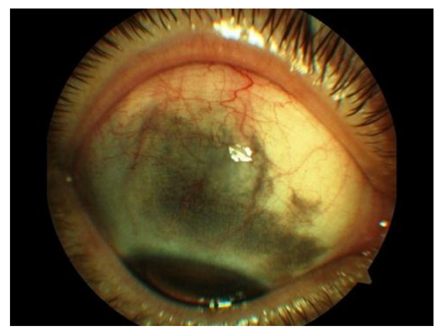
The lens has focusing properties at both its front surface and its back surface. The lens is more curved in the back than in the front. It changes its focal strength by changing its curvature. The focusing power of the lens is considerably less than that of the cornea because it is surrounded by substances that have indexes of refraction close to its own. The lens is made up of layers somewhat like an onion, and all layers do not have the same index of refraction.

The lens, like the cornea, can be damaged by ultraviolet and other forms of radiation. It can develop cataracts, which destroy its clarity.

2-other elements of the eye

- **The pupil** is the opening in the center of the iris where light enters the lens. It appears black because essentially all of the light that enters is absorbed inside the eye. Under average light conditions, the opening is about 4mm in diameter. It can change from about 3mm in diameter in bright light to about 8mm in diameter in dim light.
- **Iris** aids the eye by increasing or decreasing incident light on the retina until the retina has adapted to the new lighting conditions. In addition, under bright light conditions it plays an important role in reducing lens defects.
- **The aqueous humor** fills the space between the lens and the cornea. This fluid, mostly water, is continuously being produced, and the surplus escapes through a drain tube, the canal of Schlemm. Blockage of the drain tube results in increased pressure in the eye; this condition is called glaucoma.





The aqueous humor contains many of the components of blood and provides nutrients to the nonvascularized cornea and lens. It maintains the internal pressure of the eye at about 20mmHg. If you press on the eye, you find it is fairly stiff; you cannot indent it much. The reasons are that the fluids in the eye are incompressible at the pressure you use and that the covering of the eyeball does not stretch easily. When you rub your eyes, you greatly increase the internal pressure.

- **The vitreous humor** is a clear jelly-like substance that fills the large space between the lens and the retina. It helps keep the shape of the eye fixed and is essentially permanent. It is sometimes called the vitreous body.
- **The sclera** is the tough, white, light-tight covering over all of the eye except the cornea. The sclera is protected by a transparent coating called the conjunctiva.

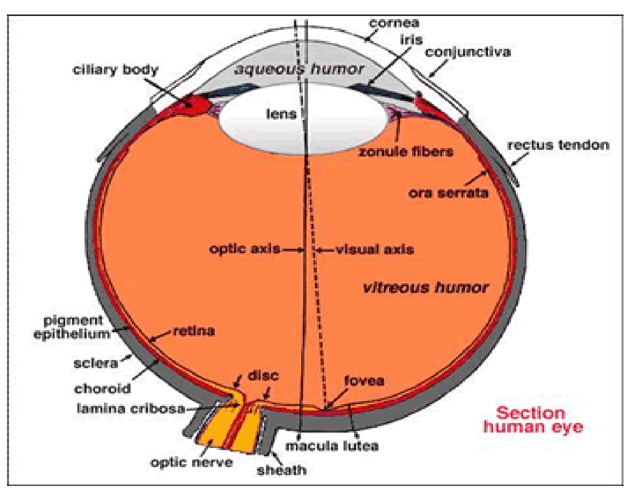
3-The retina-the light detector of the eye

The retina, the light-sensitive part of the eye, converts the light images into electrical nerve impulses that are sent to the brain.

The absorption of a light photon in a photoreceptor causes a photochemical reaction in it, which in some way initiates the action potential then produce electrical nerve impulses that are sent to the brain.

The retina covers the back half of the eyeball. While this large expanse permits useful "warning" vision over a large angle, most vision is restricted to a small area called the macula lutea, or yellow spot. All detailed vision takes place in a very small area in the yellow spot (~0.3mm in diameter) called the fovea centralis.

There are two general types of photoreceptors in the retina: **the cones** and **the rods**. Throughout most of the retina the cones and rods are not at the surface of the retina but lie behind several layers of nerve tissue through which the light must pass. However, in the fovea centralis most of this nerve tissue is pushed to the side and there is a slight dip. The rods and cones are distributed symmetrically in all directions from the visual axis except in one region-the blind spot.



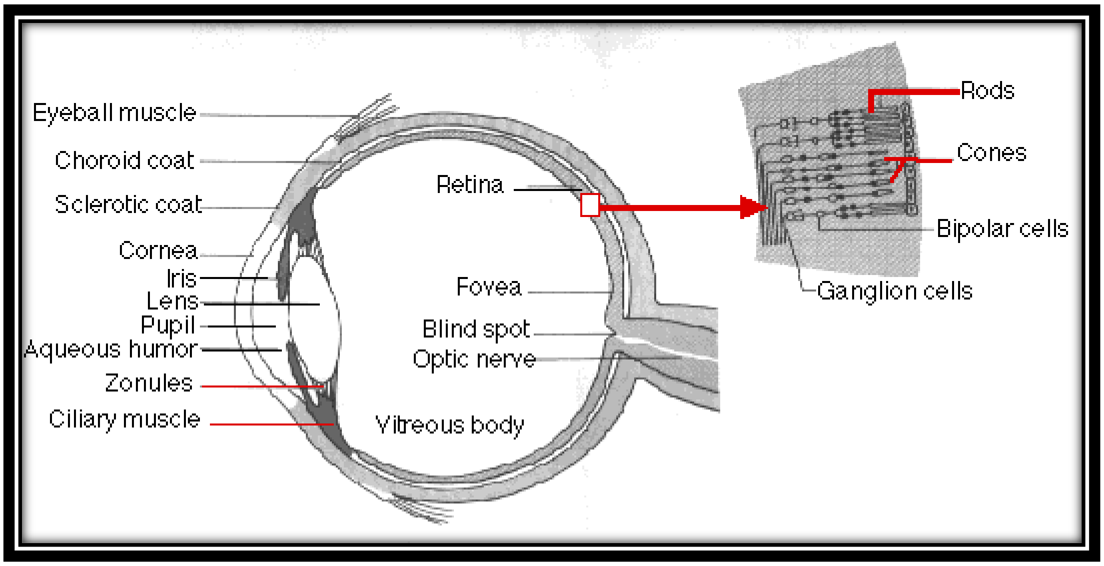
The cones: (~6.5 million in each eye) are primarily used for daylight, or photopic, vision. With the cones, we can see fine detail and recognize different colors. The cones are primarily found in the fovea centralis, although some are scattered throughout the retina. We see later that the density of the cones in the fovea centralis determines the amount of detail we can resolve in an image. Each of the cones in the fovea has its own "telephone line" to the brain. In the rest of the retina several cones share one nerve fiber. The cones are not uniformly sensitive to all colors but have a maximum sensitivity at about (550nm) in the yellow-green region.

The rods: used for night, or scotopic, vision and for peripheral vision. They are much more abundant than cones (~120 million in each eye) and cover most of the retina. They are not uniformly distributed over the retina but have a maximum density at an angle of about 20^o.

Histological studies have indicated that hundreds of rods send their information to the same nerve fiber. The rods are most sensitive to blue-green light (~51 0nm), which has a wavelength shorter than the optimum for the cones (~550nm). The rods and cones are equally sensitive to red light (650 to 700 nm).

The eyes do not have their greatest sensitivity to light under photopic conditions. If the light level suddenly decreases by a factor of 1000 we are momentarily "in the dark", but after a few minutes we are able to see many of the details that were not visible when it first became dark. This dark adaptation is apparently the time needed for the body to increase the supply of photosensitive chemicals to the rods and cones. The cones adapt most rapidly; after about 5min the fovea centralis has reached its best sensitivity. The rods continue to dark adapt for 30 to 60 min, although most of their adaptation occurs in the first 15min.

There is a region from about 13^o to 18^o that has neither rods nor cones-the blind spot. This is the point at which the optic nerve enters the eye. The blind spot is on the side toward the nose.

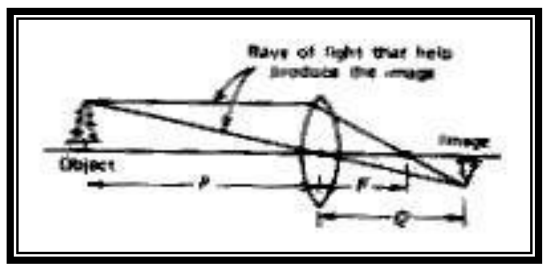


Defective vision and its correction

Glasses (corrective lenses) to help defective vision were among the first prosthetic devices invented.

In order to discuss the strength of a corrective lens for a detective eye we need to review the basic equations of simple lenses. There is a simple relationship between the focal length *F*, the object distance *P*, and the image distance *Q* of a thin lens.

$$\frac{1}{F}=\frac{1}{P}+\frac{1}{Q}$$



If *F* is measured in meters, then *1/F* is the lens strength in diopters (D). That is, a positive (converging) lens with a focal length of 0.1m has strength of 10D. The focal length *F* of a negative (diverging) lens is considered to be negative. A negative lens with a focal length of -0.5m has strength of -2D.

The focal length *F* of a combination of two lenses with focal lengths F_1 and F_2 is given by: -

$$\frac{1}{F}=\frac{1}{F_1}+\frac{1}{F_2}$$

Example: Assume lens *A* with focal length F_A=0.33m is combined with lens *B* with focal length F_B=0.25m. What is the focal length of the combination? What is the dioptric strength of the combination?

$$\frac{1}{F}=\frac{1}{F_A}+\frac{1}{F_B}=\frac{1}{0.33}+\frac{1}{0.25}=\frac{0.25+0.33}{0.0825}=\frac{0.58}{0.0825}=\frac{1}{0.143} ===> F=0.143\text{m}$$

$$\frac{1}{F}=\frac{1}{F_A}+\frac{1}{F_B}=\frac{1}{0.33}+\frac{1}{0.25}=3+4=7D$$

Let us consider the image distance *Q* of the cornea and lens of the eye to be **2cm, or 0.02m**

* If the eye focuses on an object at ***P* = 0.25m ===> (near point).**

$$\frac{1}{\text{F}}=\frac{1}{\text{P}}+\frac{1}{\text{Q}}=\frac{1}{0.25}+\frac{1}{0.02}=4+50=54\text{D}$$

* If the eye focuses on an object at ***P* = infinity ===> (far point).**

$$\frac{1}{\text{F}}=\frac{1}{\text{P}}+\frac{1}{\text{Q}}=\frac{1}{\infty}+\frac{1}{0.02}=0+50=50\text{D}$$

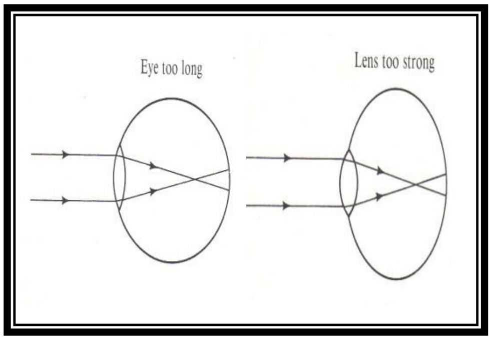
* The range of accommodation of the eye = $P_{\text{near}} - P_{\text{far}}$ = 54 – 50 = 4D.

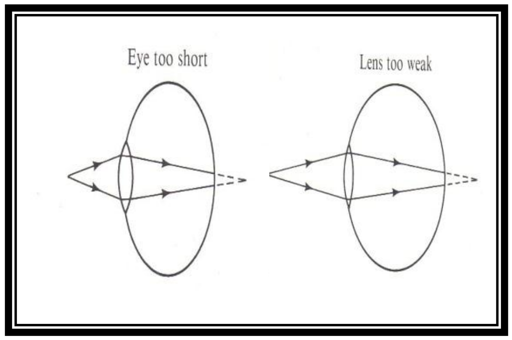
For each eye we define the near point as the closest distance at which it can see clearly; the far point is the greatest distance at which it has good vision.

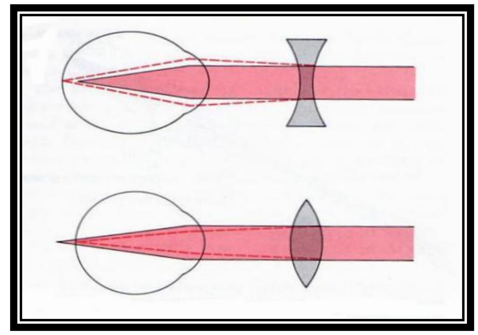
Type of vision Defective and its correction

1-*The myopia*: The myopic individual usually has too long an eyeball or too much curvature of the cornea; distant objects come to a focus in front of the retina, and the rays diverge to cause a blurred image at the retina. This condition is easily corrected with a negative lens.

2- *A hyperopia*: A hyperopic eye has a near point further away than normal and uses some of its accommodation to see distant objects clearly. The usual cause of hyperopia is too short an eyeball. A positive lens is used to correct this condition.





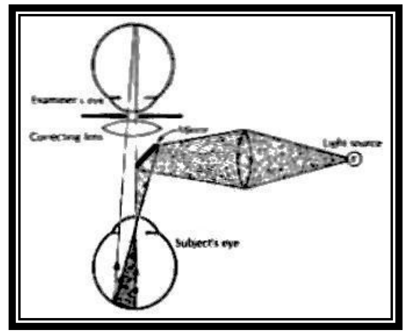


3- Astigmatism, the curvature of the cornea is uneven. Astigmatism cannot be corrected by a simple positive or negative lens. A simple test for astigmatism is to look at a pattern of radial lines. An astigmatic eye will see lines going in one direction more clearly than lines going in other directions. Astigmatism is corrected with an asymmetric lens in which the strength is greater in one direction than in the perpendicular direction.

4- *Presbyopia* : Often a person older than 50 notices that he has trouble reading fine print; when he holds the book far enough away to focus clearly, the print is too small for him to distinguish the letters. Although reading in a bright light helps because it narrows the pupil and gives him a better depth of focus, he will need reading glasses. If he already wears glasses to correct a vision defect, he will need bifocals. This problem is due to the loss of accommodation with age.

A summary of various focusing problems and their characteristics: -

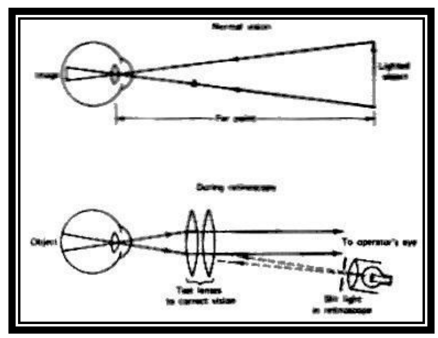
Focusing Problem	Common Name	Usual Cause	Corrected With
Myopia	Near-sighted vision	Long eyeball or cornea too curved	Negative Lens
Hyperopia	Far-sighted vision	Short eyeball or cornea not curved enough	Positive Lens
Astigmatism	-	Unequal curvature of cornea	Cylindrical Lens
Presbyopia	Old-age vision	Leak of accommodation	Bifocals



Instruments used in ophthalmology

1-Ophthalmoscope: -The ophthalmoscope, which permits the physician to examine the interior of the eye.

Bright light is projected into the subject's eye, and the returning light from the subject's retina is positioned so that it can be focused by the examiner.



2-Retinoscopy: -

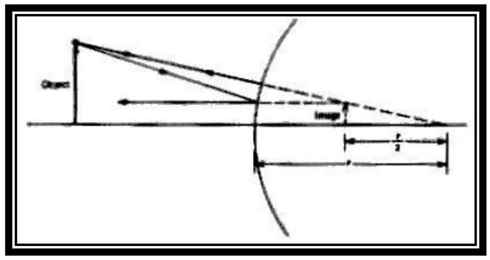
The retinoscope, is used to determine the prescription of a corrective lens without the patient's active participation, this technique is also can be used for example on an anesthetized infant.

A streak of light from the retinoscope is projected into the patient's unaccommodated dilated eye. This streak of light is reflected from the retina and acts as a light source for the operator. The retina's function in retinoscopy is the reverse of its normal function. Since an object at the eye's far point would be focused at the retina of a relaxed eye,

A light from the retina of a relaxed eye will produce a focused image at the far point. The operator views the patient's eye through the retinoscope and adds lenses in front of the patient's eye (positive or negative, as needed) to cause the image from the patient's retina to be focused at the operator's own eye.

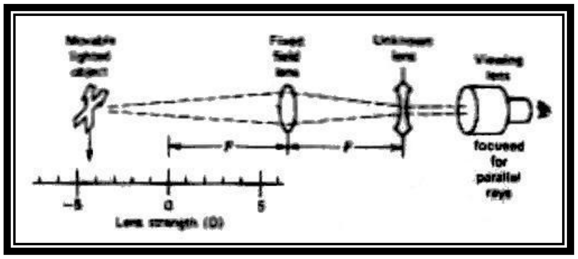
3-Keratometer: -

Is an instrument that measures the curvature of the cornea. This measurement is needed to fit contact lenses.



4-Lensometer: -

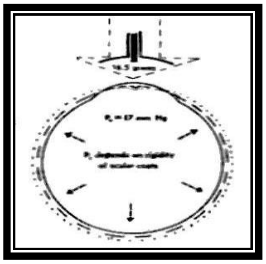
The **lensometer** is not used to study the eye; it determines the prescription of an unknown lens.



5- Tonometer: The tonometer, measures the pressure in the eye.

a-Schiotz tonometer: -

An instrument used for measuring the intraocular pressure.



The pressure measured by the tonometer is the original pressure plus the increase due to the instrument.

b-Goldmann tonometer: -To remove the effect of the rigidity of the eye, another measurement is taken with a heavier weight or with the Goldmann tonometer.