Physics of Eyes and Vision

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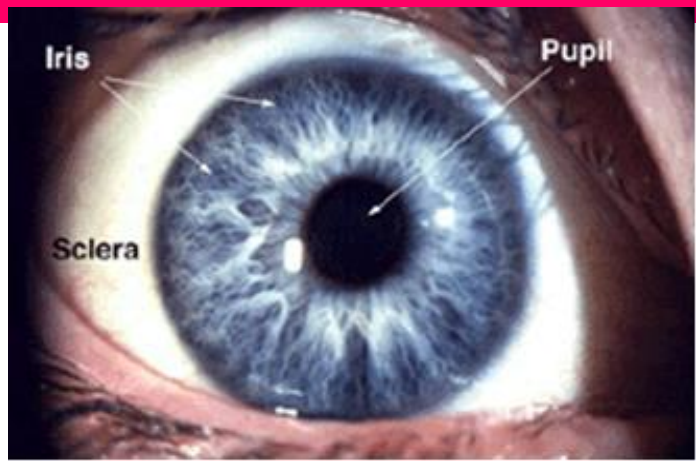
Physics of Eyes and Vision



❖Sense of vision

- Most of our knowledge of the world around us comes to us through our eyes.
- The sense of vision consists of three major components:

(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,

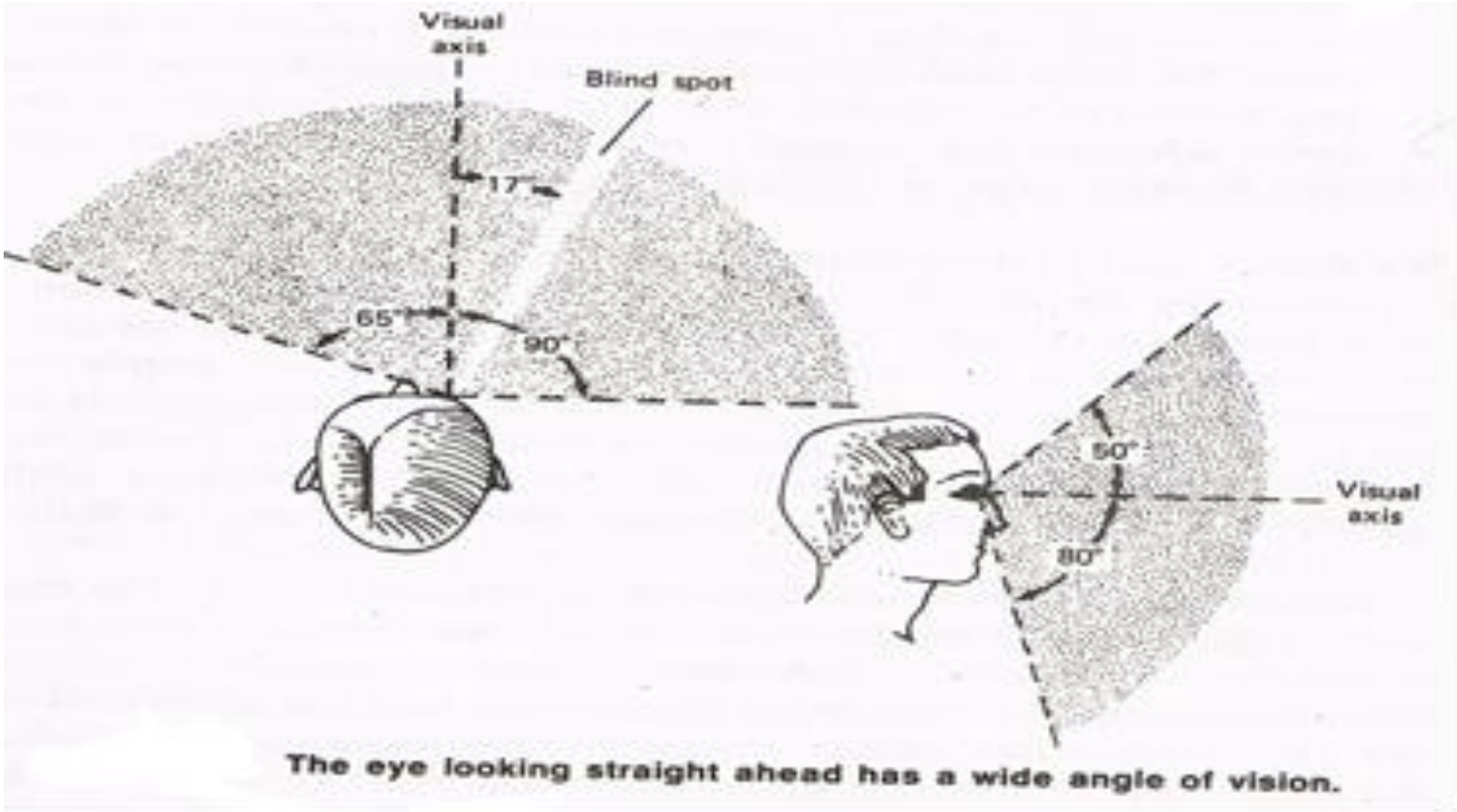
(3) The visual cortex-that part of the brain where "it is all put together"

- Blindness results if any one of these parts does not function.

Sense of vision

- **Our optical system has the following special features.**

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



The eye looking straight ahead has a wide angle of vision.

Sense of vision

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 20 cm one second and distant objects the next.

4. The eye has an automatic aperture adjustment (the iris).

5. 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.

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

Sense of vision

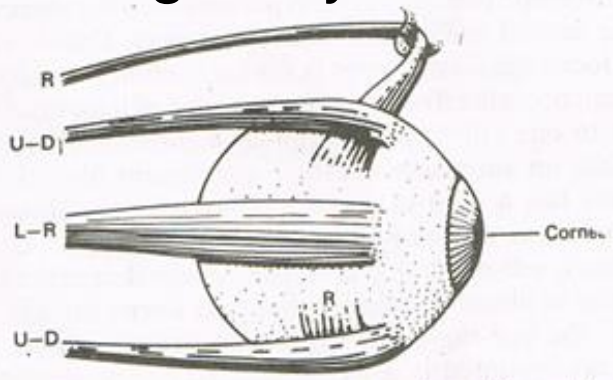
7.The eyes are mounted in a well-protected casing almost completely surrounded by bone, and each eye rests on a cushion of fat that reduces sharp shocks.

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

9.The brain blends the images from both eyes. Giving us good depth perception and true three- dimensional viewing.

10.The muscles of the eye (see bellow Fig.) permit flexible movement up and down, sideways, and diagonally.

A surprisingly large percentage of people have good eyesight. These people are called emmetropes, The rest of us have noticeable vision imperfections and are called ametropes.

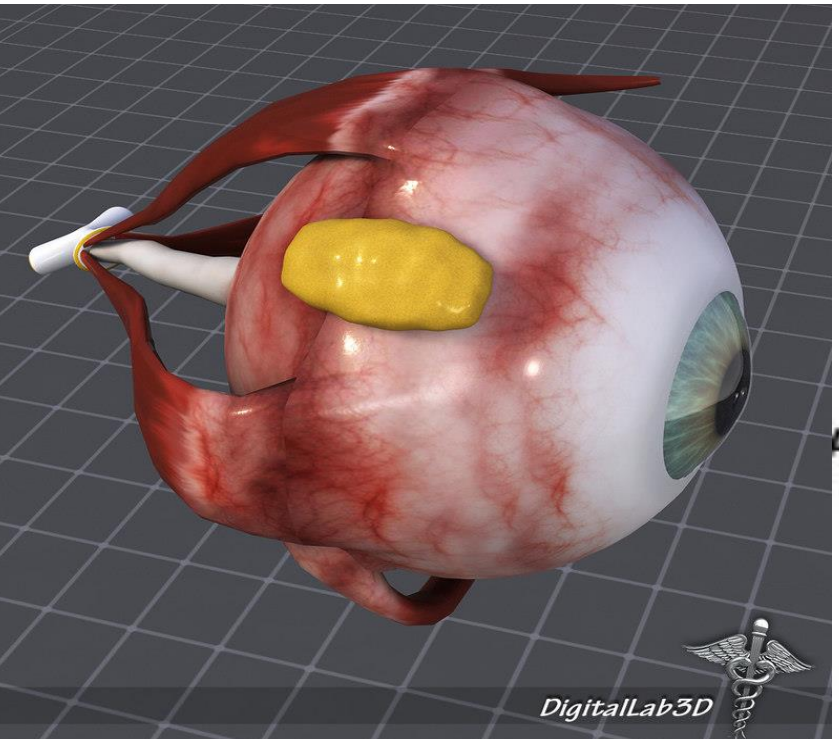


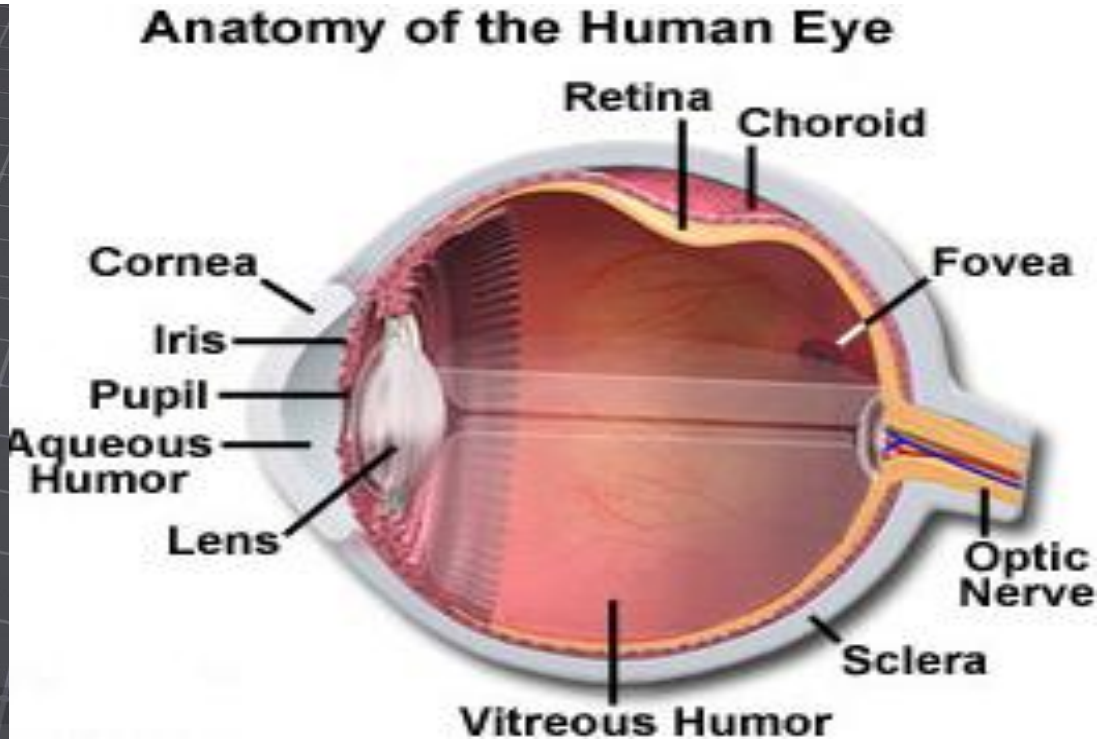
The six muscles of the right eye permit a wide variety of motion. The muscles work in pairs: one pair controls up and down movement (U-D), one pair controls left and right movement (L-R), and one pair controls rotation (R). The rotation muscles pass through bony loops. All six muscles are attached to the skull behind the eye.

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,**
- **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.



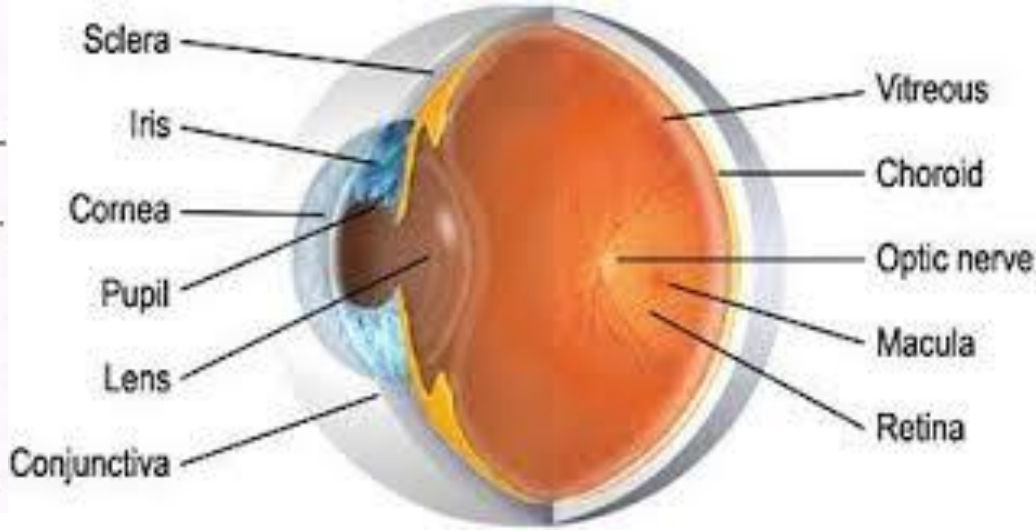


Focusing Elements of the Eye

- 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) .
- The indexes of refraction of the cornea and other transparent parts of the eye are given in Table bellow.

Table 1 The Indexes of Refraction of the Cornea and Other Optical Parts of the Eye

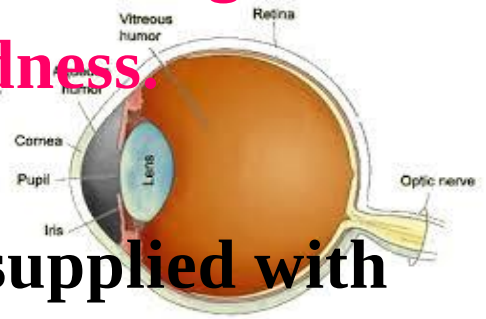
Part of the Eye	Index of Refraction
Cornea	1.37
Aqueous humor	1.33
Lens cover	1.38
Lens center	1.41
Vitreous humor	1.33



- When the cornea is underwater, it loses most of its focusing power because the index of refraction (n) of the water (1.33) is close to that of the cornea (1.37) .

Focusing Elements of the Eye

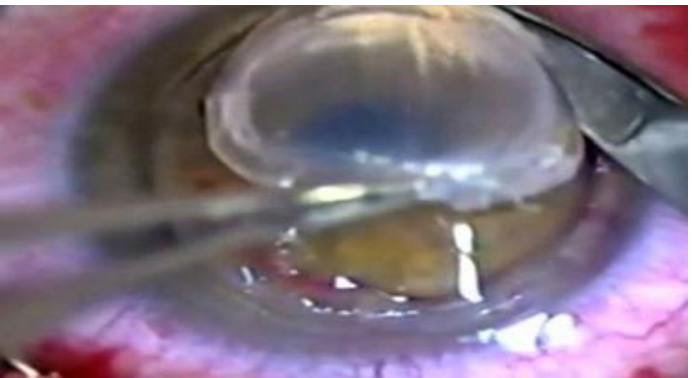
- The index of refraction is nearly constant for all corneas, but the curvature varies considerably from one person to another and is responsible for most of our defective vision.
- If the cornea is curved too much the eye is near-sighted.
- Not enough curvature results in far-sightedness.
- Uneven curvature produces astigmatism.
- Since the living cells in the cornea are not supplied with oxygen by the blood, they must get their oxygen from the air.

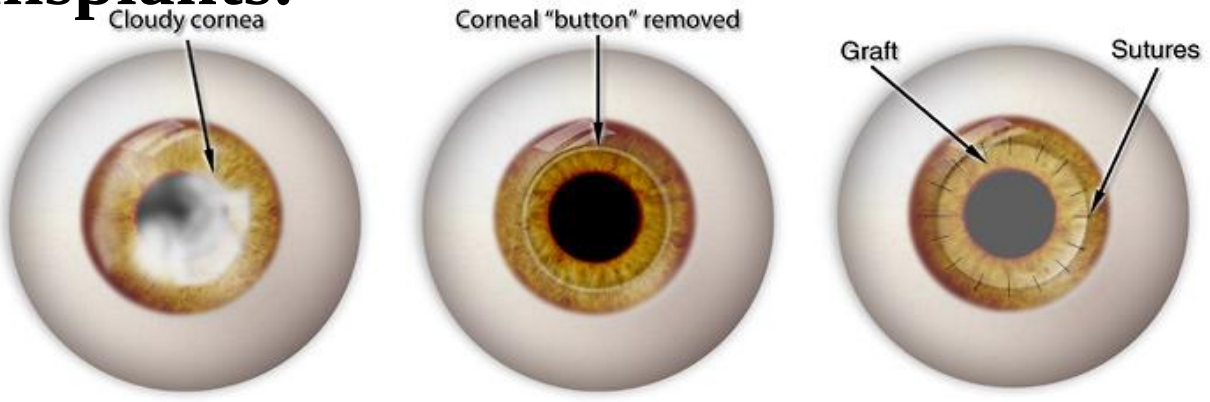


- Having blood vessels in the cornea would not help our vision!
- The nutrients for the cells in the cornea are supplied by the aqueous humor that is in contact with its back surface.
- The aqueous humor contains all of the blood components except blood cells.

Focusing Elements of the Eye

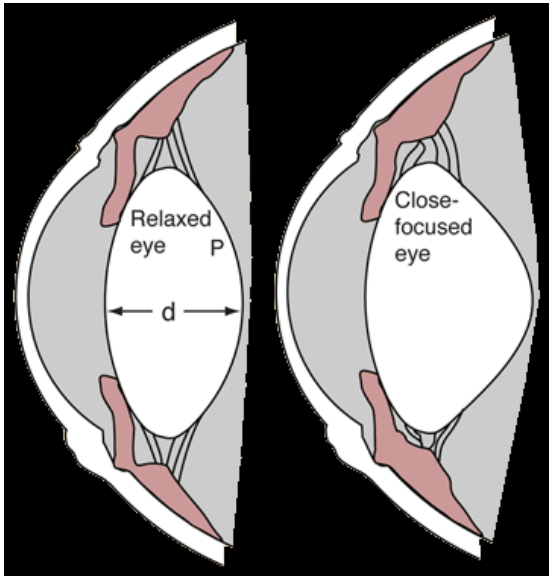
- If the cornea is scratched it will heal itself, but some other types of damage are more permanent.
- Some types of radiation (Ultraviolet, Neutrons, X-rays, etc.) can cause opacities to develop in the cornea that will block out light.
- It is now possible to perform cornea transplant using corneas removed from donors shortly after death
- Since the cells of the cornea have a low metabolism rate, rejection is not usually as much of a problem as in most organ transplants.





Focusing Elements of the Eye

- The lens (Table 1) 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 .



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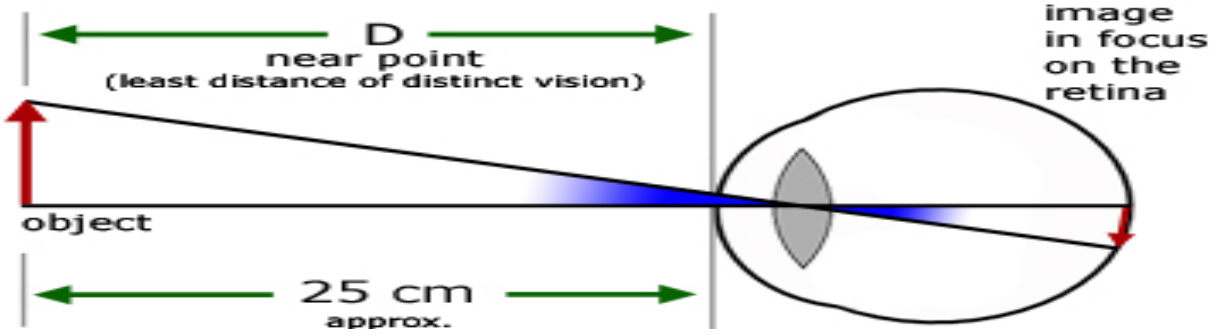
Focusing Elements of the Eye

- The lens is made up of layers somewhat like an onion, and all layers do not have the same index of refraction. The indexes of refraction in (Table 1) are average values.
- The lens has a flexible cover that is supported under tension by suspension fibers.
- When the focusing muscle of the eye is relaxed this tension keeps the lens somewhat flattened and adjusted to its lowest power, and the eye is focused on distant objects.
- The point at which distant objects are focused when the focusing muscle is relaxed is called the far point.

Focusing Elements of the Eye

- To focus on closer objects, the circular muscle around the lens contracts into a smaller circle and takes some or all of the tension off the lens.
- The lens oozes into a more spherical shape, primarily by becoming more curved in front, the lens then has a greater focusing power.
- The closest point at which objects can be focused when the lens is its thickest is called the near point, For a normal eye, the near point is located 25cm from the eye.

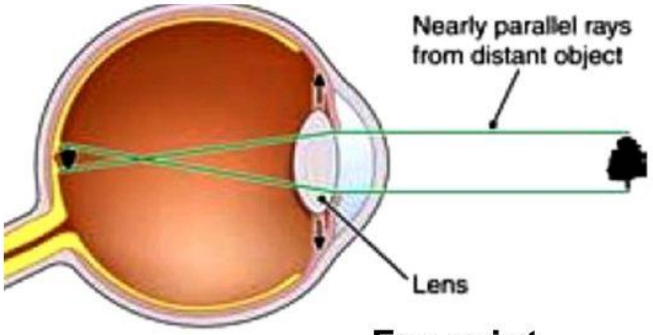


Focusing Elements of the Eye

- As people get older, their lenses lose some accommodation.
- Presbyopia (old sight) results when the lens has lost nearly all of its accommodation.

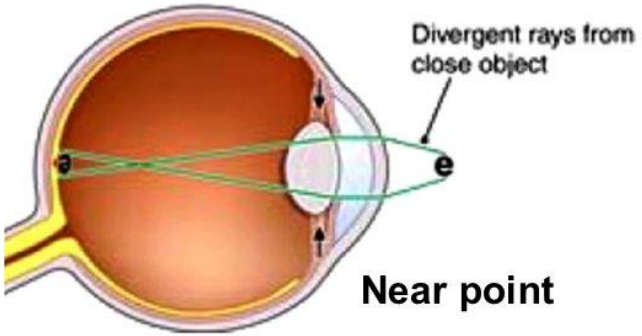
Range of accommodation

Def
It is the **distance** between the **far point** of distinct vision (normally infinity) and the **near point** of distinct vision



Far point

The **near point recedes** by **aging** due to the **decrease** of the **lens elasticity** and **ciliary muscle power**



Near point

Focusing Elements of the Eye

- The lens, like the cornea, can be damaged by ultraviolet and other forms of radiation. It can develop cataracts (see bellow Fig.), which destroy its clarity.
- It is possible to remove a damaged lens surgically and add extra correction to glasses. Of course no accommodation is then possible.

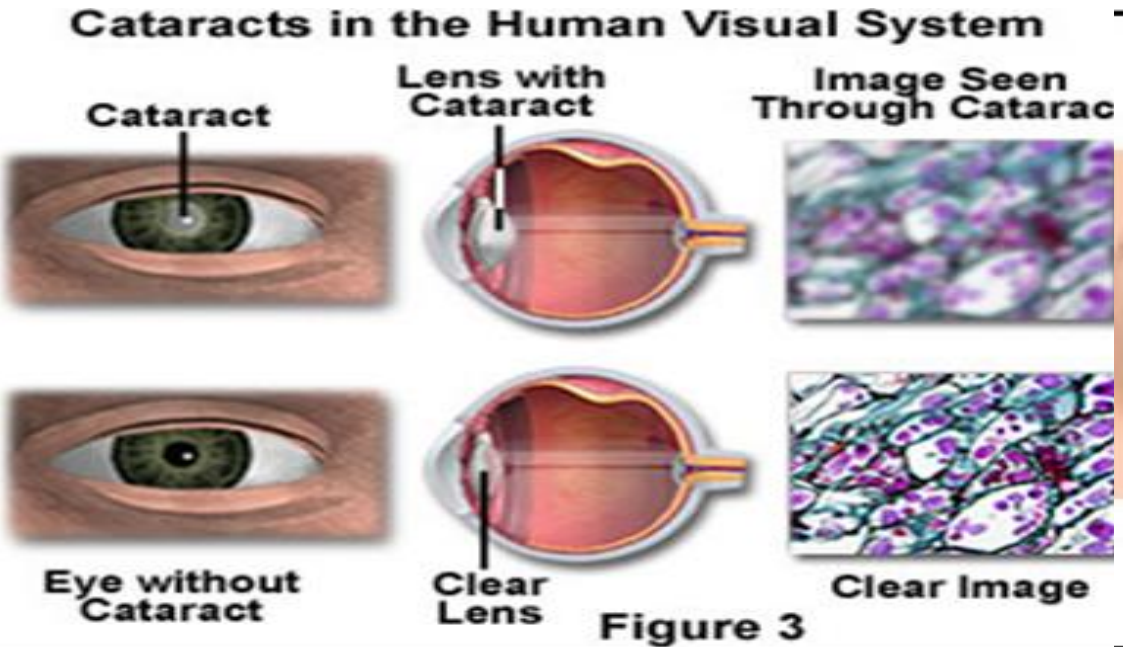
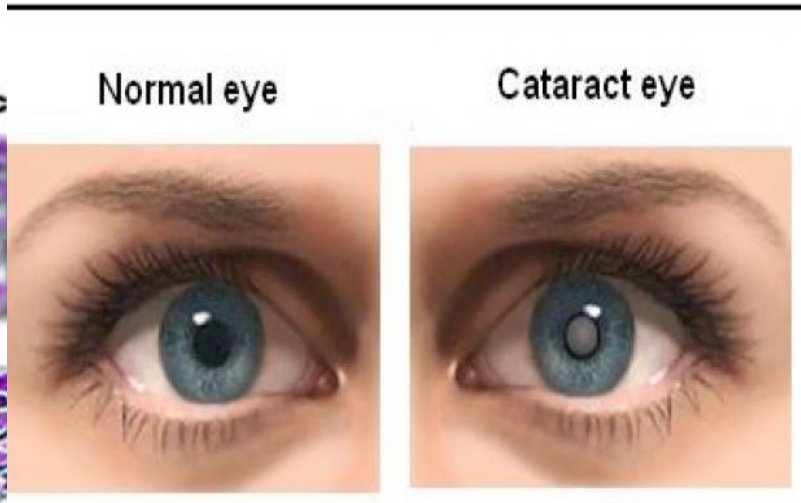


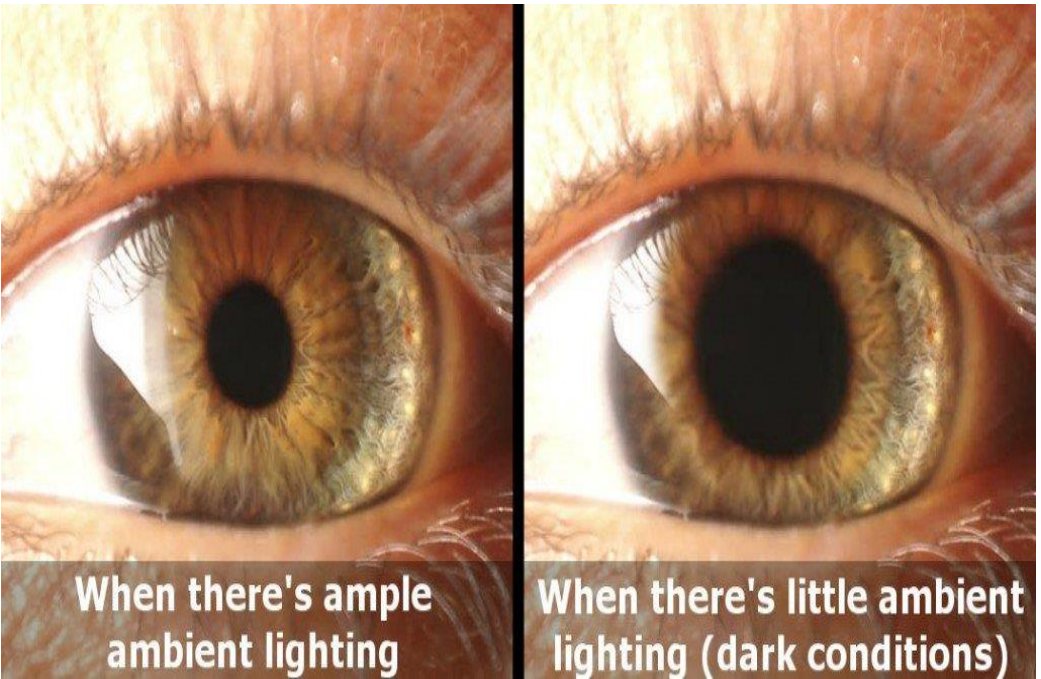
Figure 3

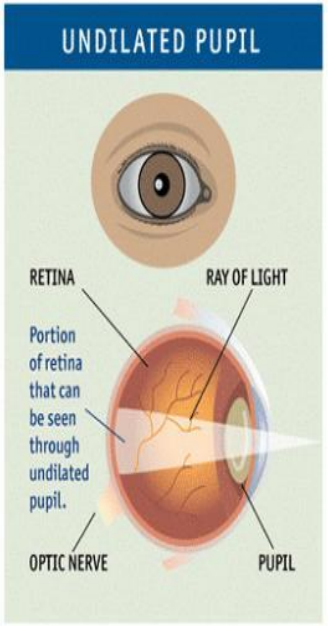


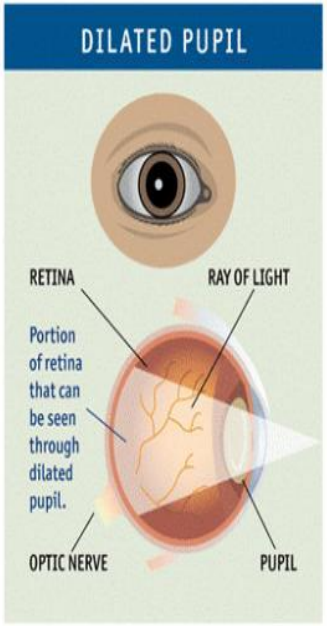
Cataract is an opacity (cloud formation) of the eye lens, develops due to aging.

Focusing Elements of the Eye

- **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 **4 mm** in diameter. It can change from about **3 mm** in diameter in **bright light** to about **8 mm** in diameter in **dim light**.







Focusing Elements of the Eye

- **The iris dose not respond instantly to a change of light levels;**
- **about 300 sec are needed for it to fully open, and about 5 sec are required for it to close as much as possible (see bellow Fig.).**
- **It is believed that the iris aids the eye by increasing or decreasing incident light on the retina until the retina has adapted to the new lighting** conditions**.**

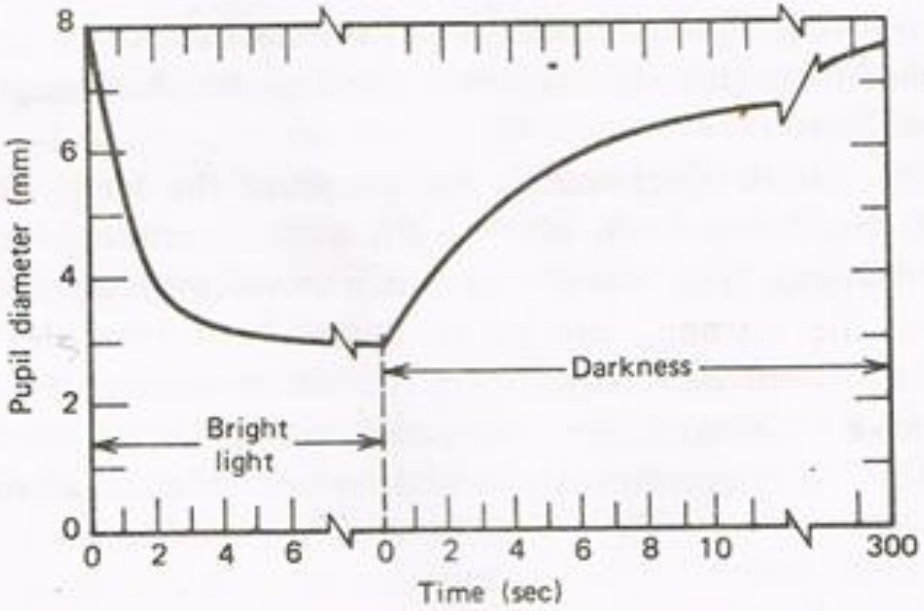
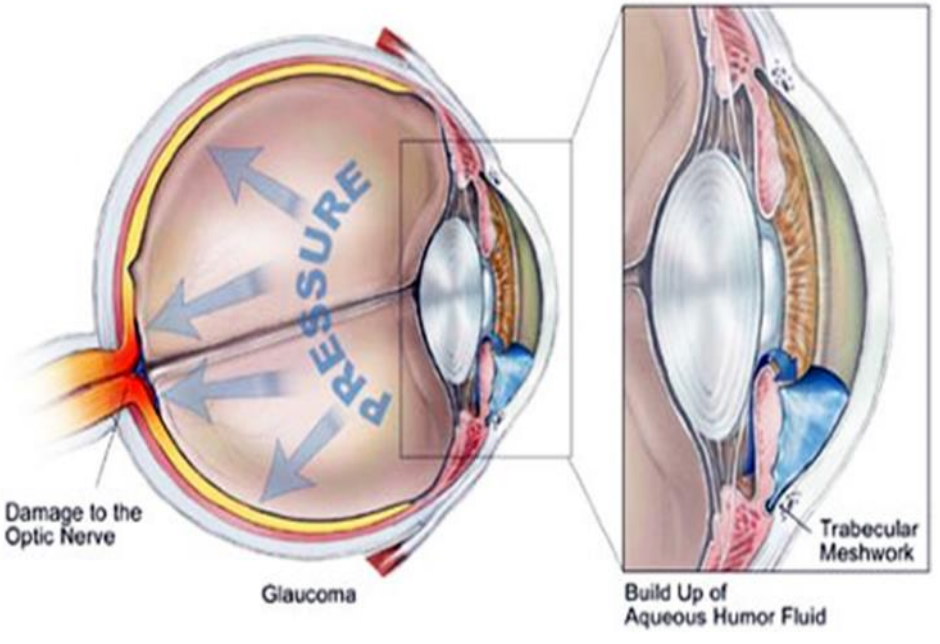


Figure The pupil does not open and close rapidly. Note that the maximum opening is not attained until the eye has been in the dark 5 min.

Focusing Elements of the Eye

- **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.**



Focusing Elements of the Eye

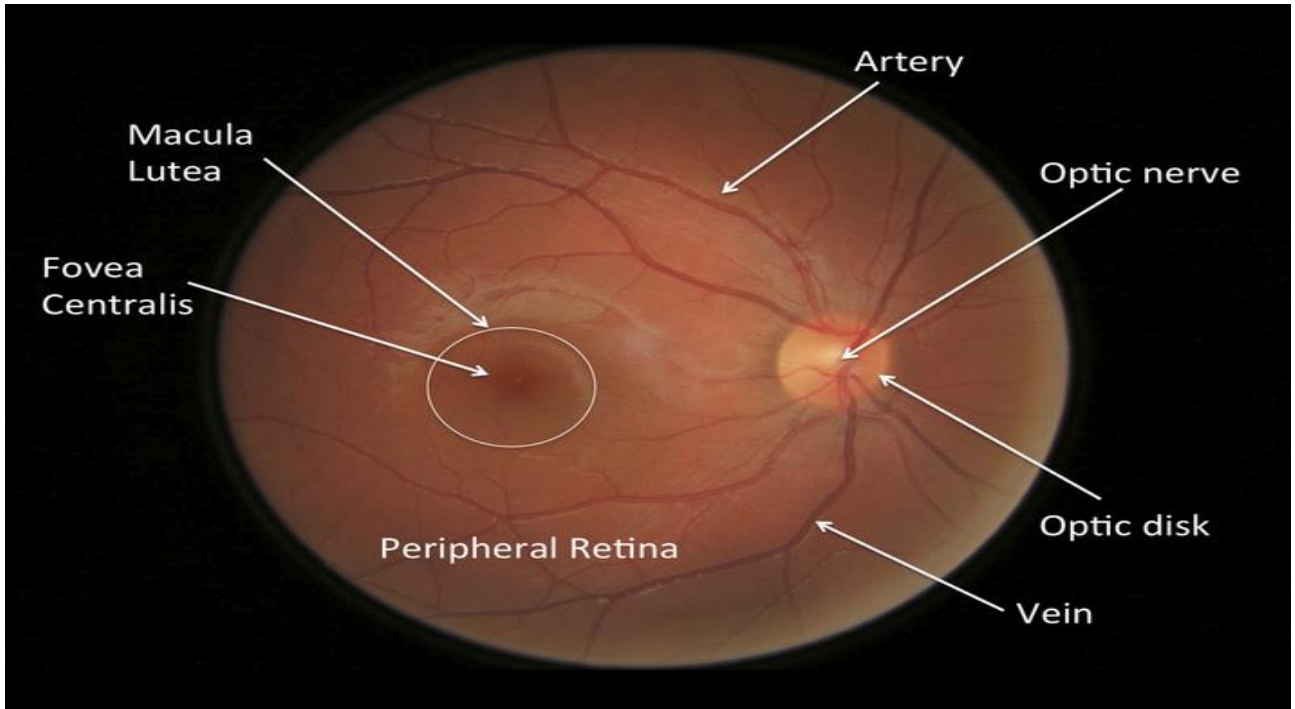
- The aqueous humor contains many of the components of blood and provides nutrients to the nonvascularized cornea and lens.
- It maintains the internal pressure of the eye at about **20 mm Hg**.
- When you rub your eyes , you greatly increase the internal pressure.

Focusing Elements of the Eye

- 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.

The retina-The light detector of the eye.

- The retina covers the back half of the eyeball.
- While this large expanse permits useful 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 (~0.3 mm in diameter) called the fovea centralis .



The retina-The light detector of the eye.

- **The image on the retina is very small.**
- **A convenient equation for determining the size of the image on the retina comes from the ratios of the lengths of the sides of similar triangles. In (next Fig.) O is the object size, I the image size, P the object distance, and Q the image distance, usually about 2 cm (0.02m).**

Thus we can write O/P = I/Q

Or **I=(Q/P)*O**

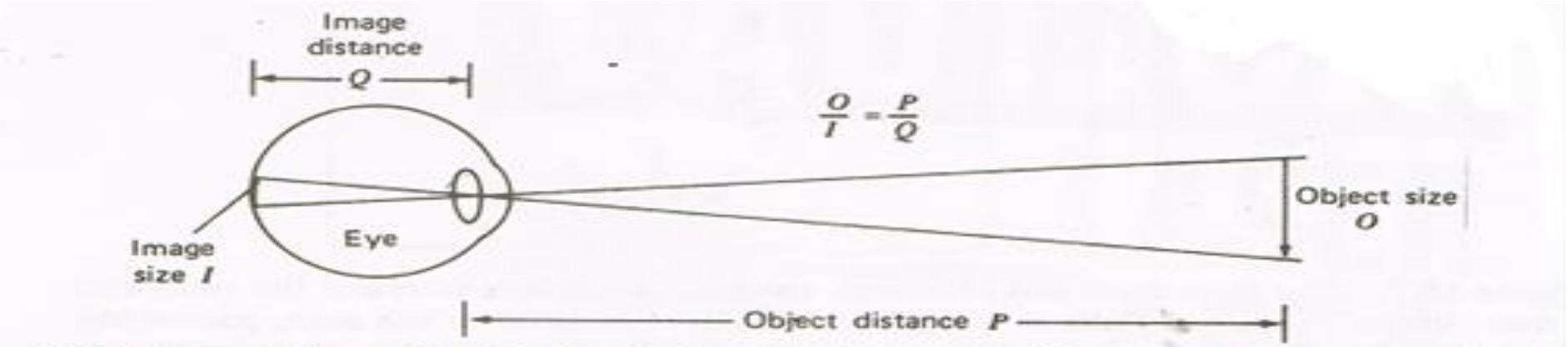


Figure There is a simple relationship between the object and image sizes and the object and image distances. The image on the retina is small because of the short image distance of about 2 cm.

The retina-The light detector of the eye.

- **Example 1:**

- **How big is the image on the retina of a fly on a wall 3.0 m away? Assume the fly is 3 mm (0.003m) in diameter and Q = 2cm=0.02m.**

$$I = (0.02/3) * 0.003 = 2 * 10^{-5} m = 20\ \mu m$$

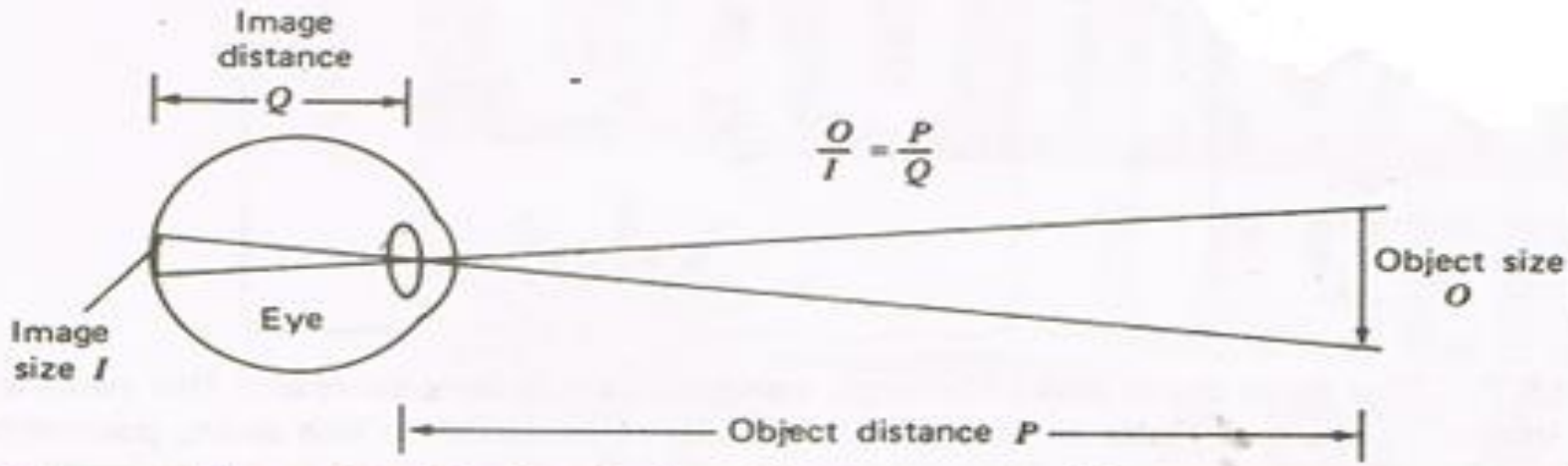


Figure There is a simple relationship between the object and image sizes and the object and image distances. The image on the retina is small because of the short image distance of about 2 cm.

Photoreceptors In Retina

- 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.

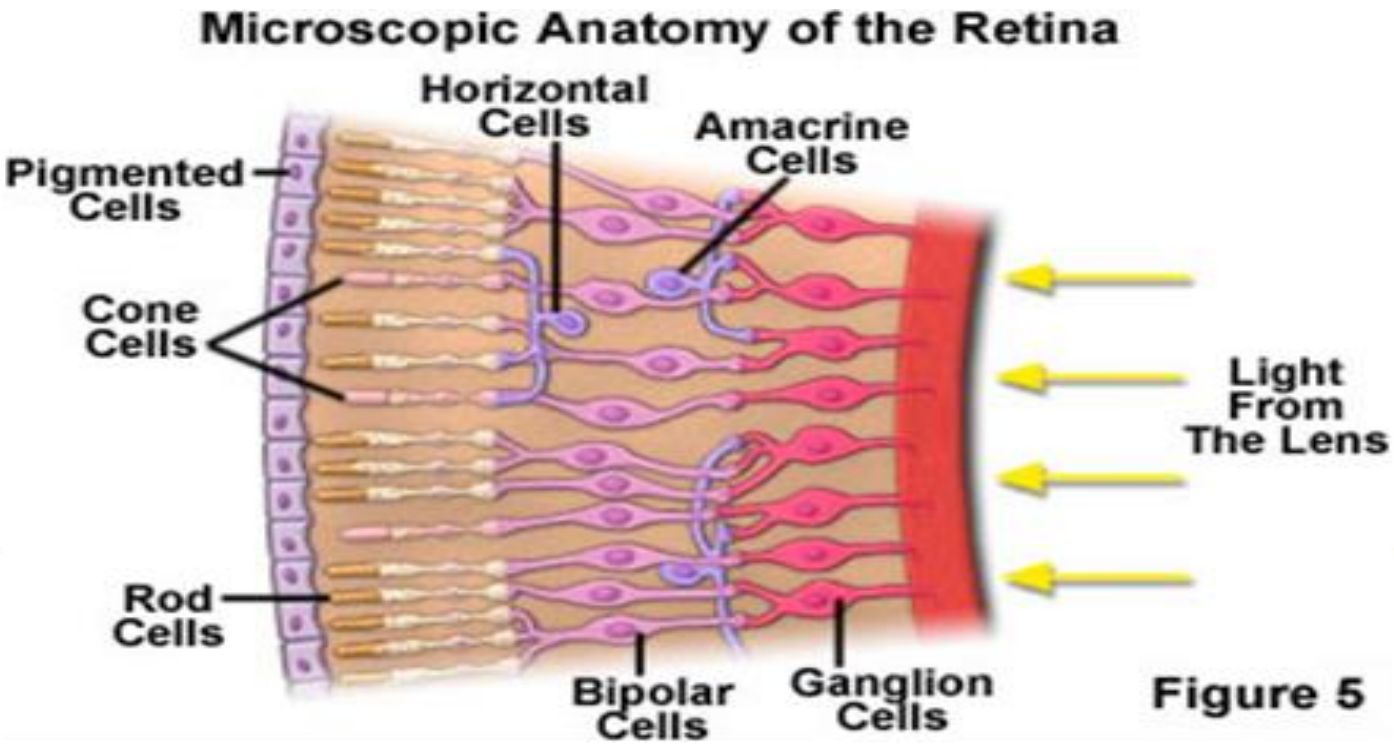


Figure 5

Photoreceptors In Retina

- 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.

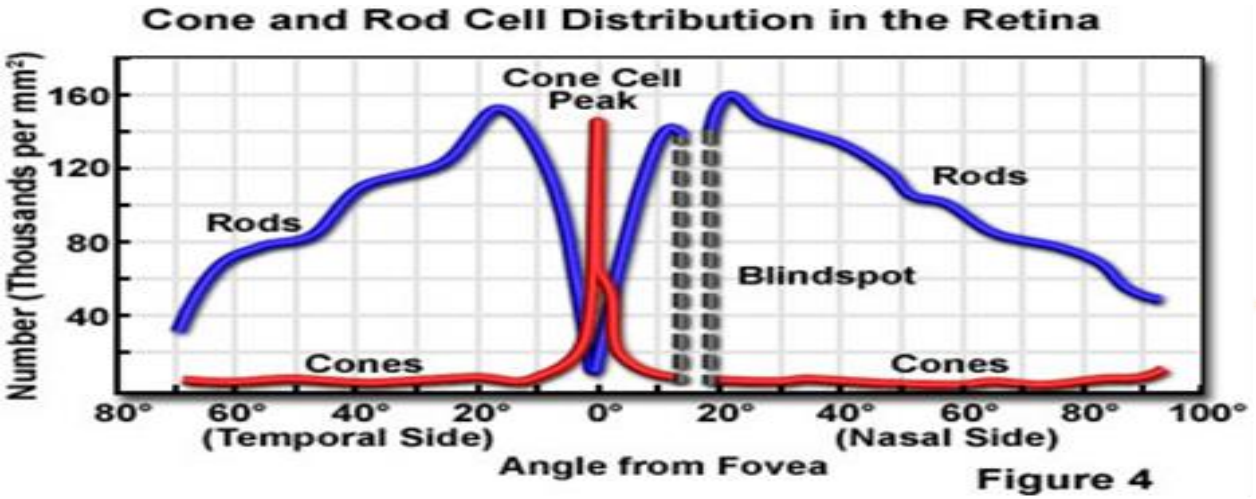


Figure 4

Photoreceptors In Retina

- The rods are used for night, or scotopic vision and for peripheral vision. They are much more abundant than the 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.
- Notice in (Fig.) that 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.

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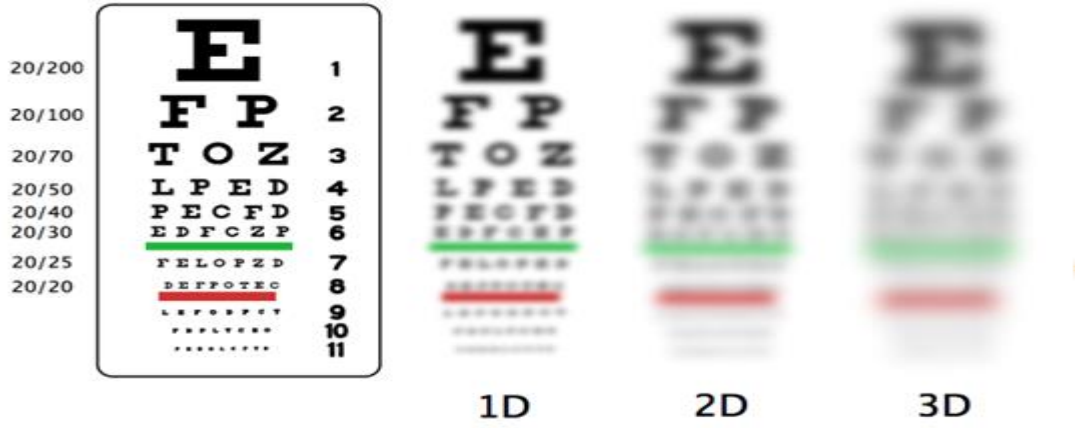
How sharp are your eyes?

- The familiar eye charts used to determine whether we need corrective lenses, test the property of our eyes called visual acuity. There are several tests for visual acuity, but the optometrist usually uses a Snellen chart.
- To test visual acuity. If he tells you that your eyes test normal at 20/20, he means that you can read detail from 20 ft that a person with good vision can read from 20 ft.
- If your eyes test at 20/40, you can just read from 20 ft the line that a person with good vision can read from 40 ft.
- The Snellen chart is a highly useful tool and will probably continue to be used because of its simplicity.



Defective vision and its correction

- In order to discuss the strength of the corrective lens for a defective eye we need to review the basic equation 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.
- 1/ F= 1/P + 1/Q

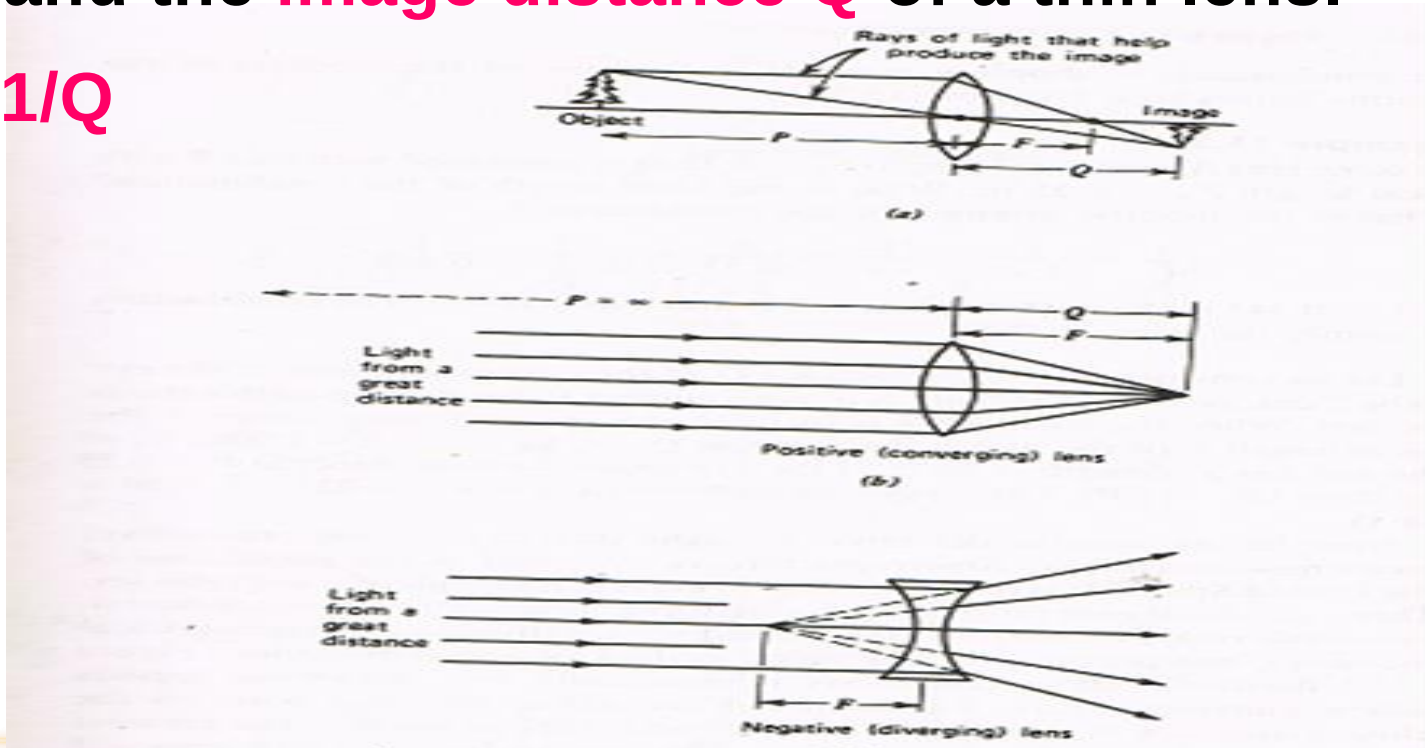
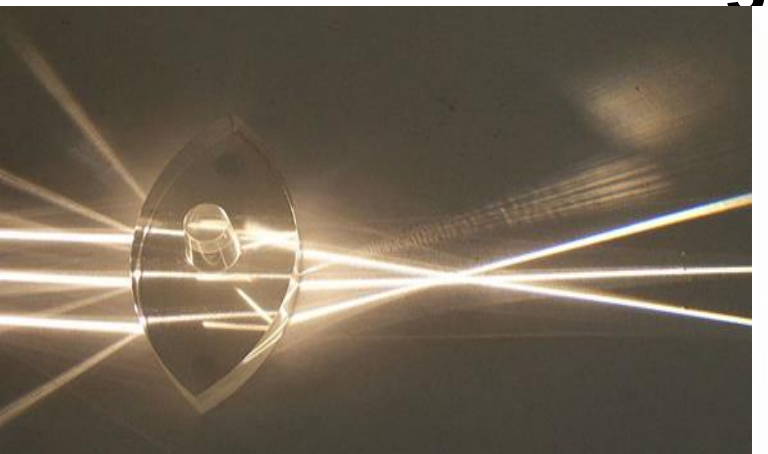
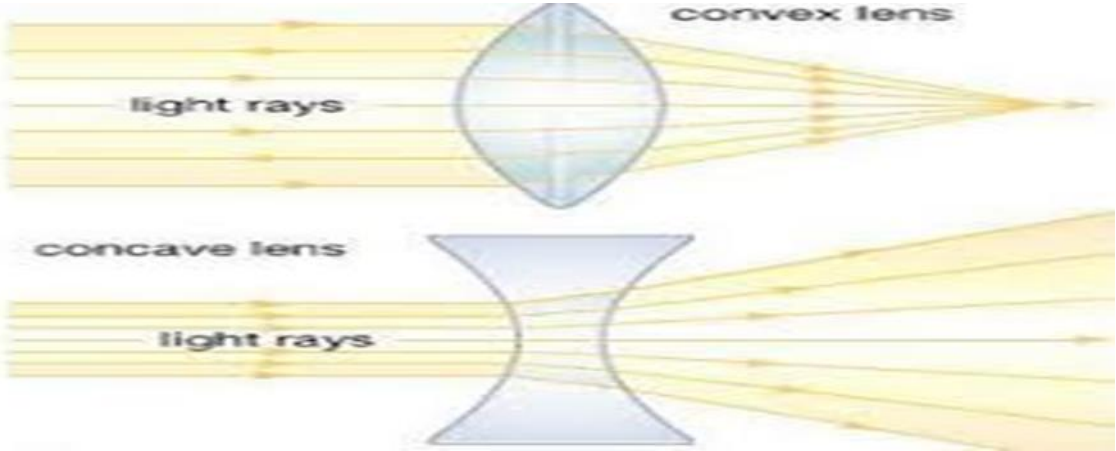


Figure (a) The distance from the lens to the object P and the distance from the lens to the place where the image is formed Q are related to the focal length F of a positive lens by the equation 1/P + 1/Q = 1/F. (b) Light coming from a great distance to a positive lens converges at the focus of the lens; the image distance Q is equal to the focal length F. (c) Light from a great distance striking a negative lens diverges. The light appears to diverge from the focal point on the left side of the lens. No image is formed.

Defective vision and its correction

- 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 (F) of 0.1 m ,has a strength(1/F) of 10 D.
- The focal length F of a (diverging) lens is considered to be negative.
- A negative lens with a focal length(F) of -0.5 m has a lens strength of -2 D.



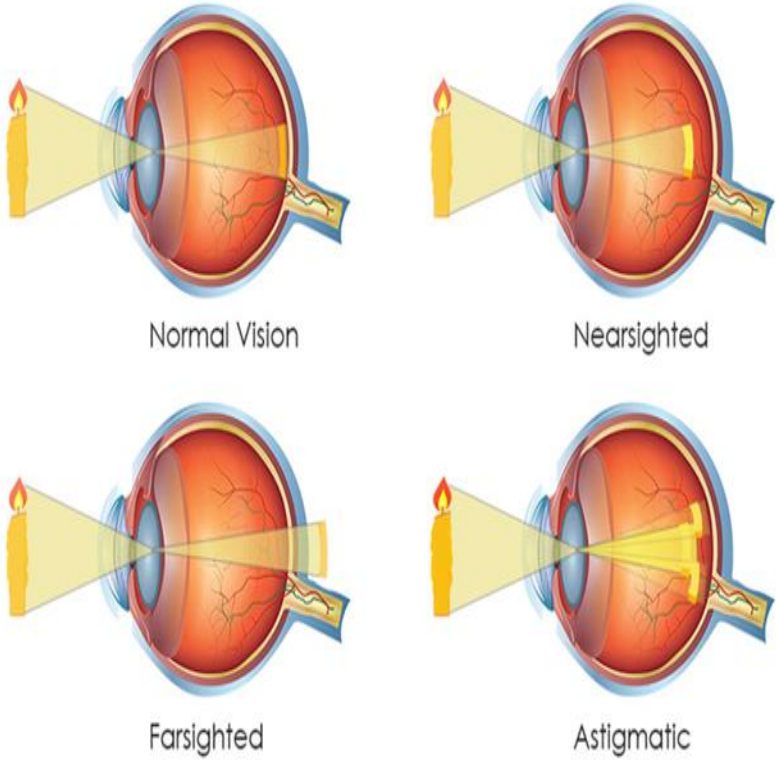


Defective vision and its correction

- Now let us discuss defective eyesight due to focusing (refractive) problems-ametropia.
- Ametropia affects over half of the population of the world. It is often possible to correct it completely with glasses.

Defective vision and its correction

- There are four general types of ametropia: myopia (near sightedness), hyperopia (far-sightedness), astigmatism (asymmetrical focusing), objects will appear to tilt if you have astigmatism . And presbyopia (old sight) or lack of accommodation..



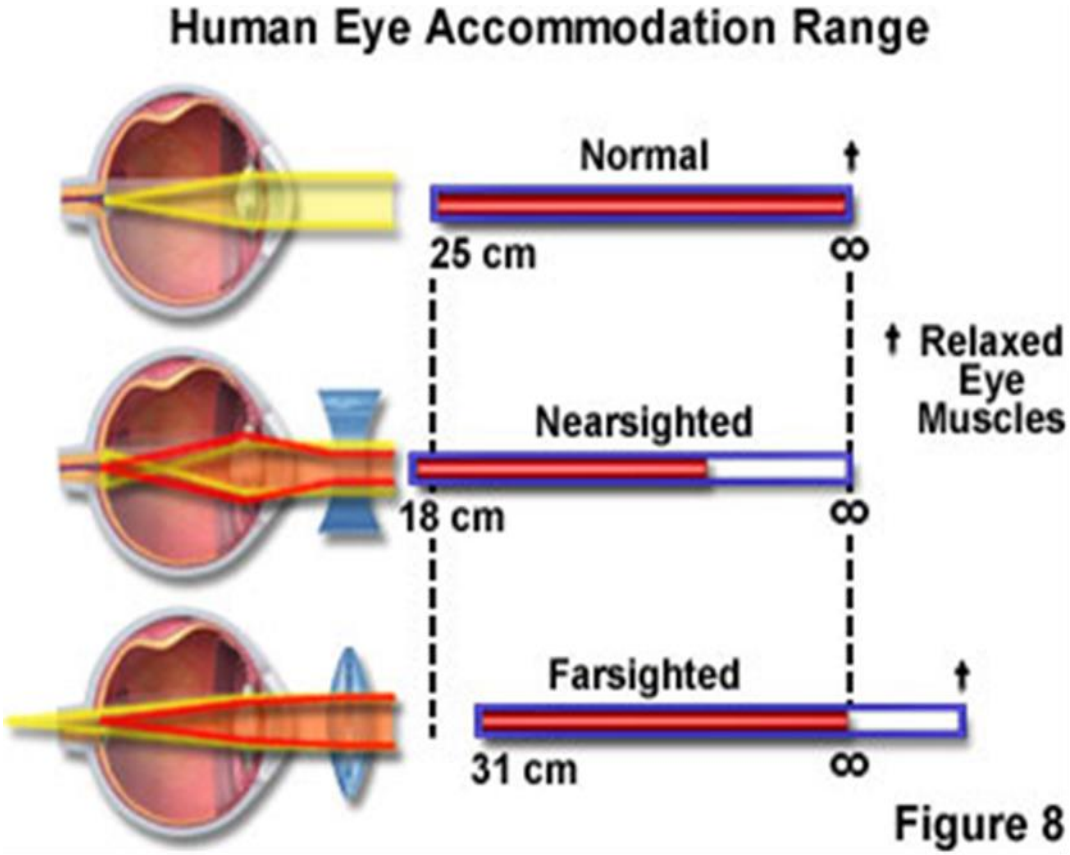


Figure 8

Defective vision and its correction

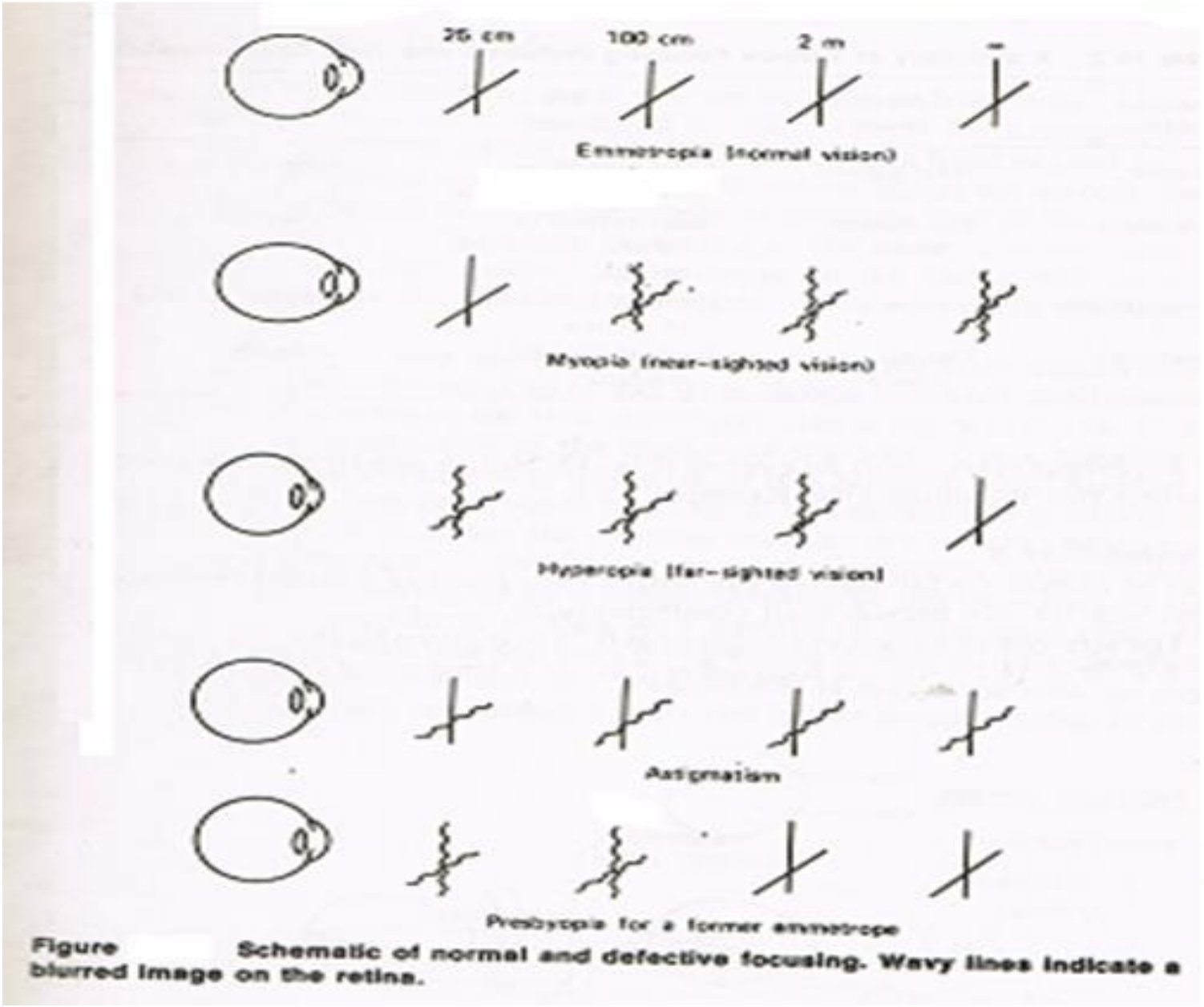


Figure Schematic of normal and defective focusing. Wavy lines indicate a blurred image on the retina.

Defective vision and its correction

- The myopic individual usually has too long an eyeball or too much curvatures 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.

Example 2:

Let us determine the strength of a lens needed to correct a myopic eye (near-sighted eye) with a far point of 1.0 m. We consider the image distance (lens to retina) to be 2cm (Q=0.02 m).

An eye able to focus at infinity (∞) has a lens strength of

$1/F = 1/P + 1/Q \Rightarrow 1/F = (1/\infty) + (1/0.02) = 50\ D.$

A person who is focusing an object at 1.0 m has a lens strength of:
$1/F = (1/1.0) + (1/0.02) = 51\ D.$

Thus a myopic person with a far point at 1.0 m has: 50 - 51 = -1 D,

and this negative (diverging) lens of -1.0 D will correct his vision.

Defective vision and its correction

- 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

Example 3:

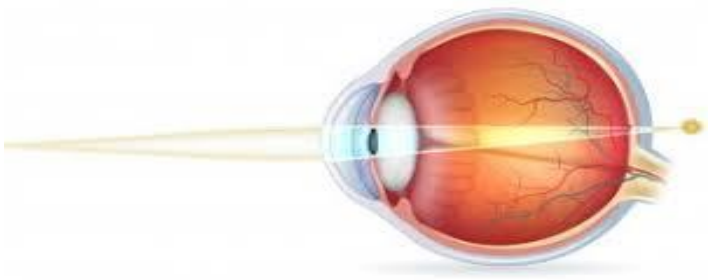
Let us consider a far-sighted eye with a near point of 2.0 m.

What power lens will let this person read comfortably at 0.25 m?

The strength of a good eye focused at 0.25 m is given by:

$1/F = 1/P + 1/Q$

$(1/0.25) + (1/0.02) = 4 + 50 = 54$ D.



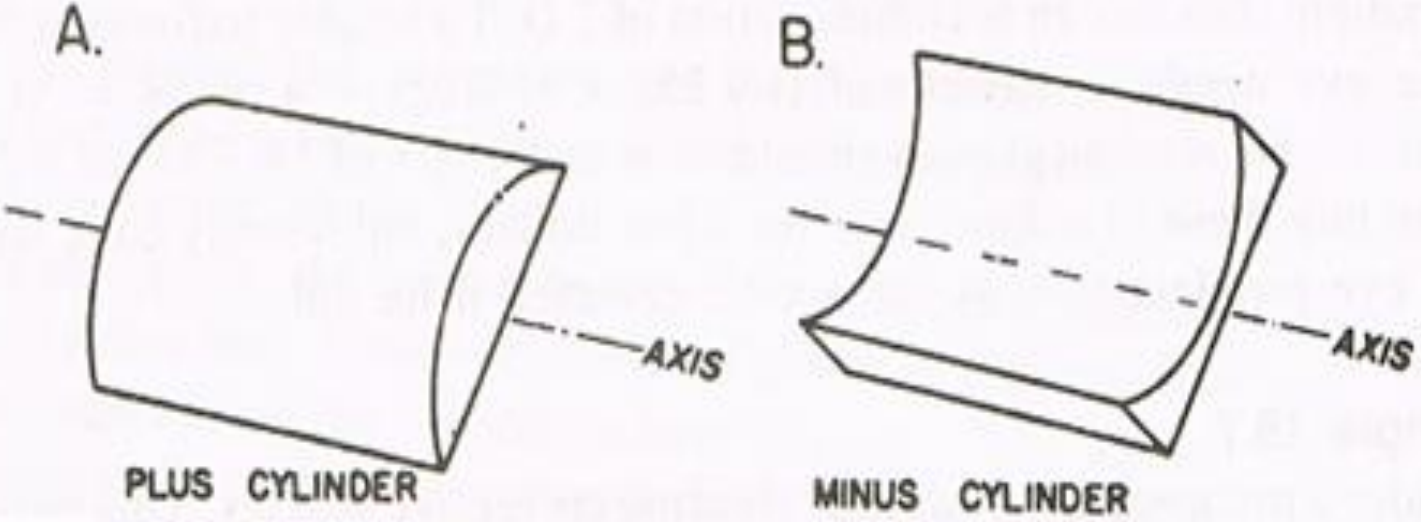
An eye focused at 2 m has a strength of

$(1/2.0) + (1/0.02) = 0.5 + 50 = 50.5$ D.

A positive (converging) lens of 54 - 50.5 = + 3.5 D would be prescribed for this eye.

Defective vision and its correction

In astigmatism, the curvature of the cornea is uneven. Astigmatism cannot be correct by a simple positive or negative lens.
Astigmatism is corrected with an asymmetric lens in which the strength is greater in one direction than in the perpendicular direction .



Astigmatism is corrected by adding a cylindrical lens to a spherical lens. The cylinder may be either (A) converging (plus cylinder) or (B) diverging (minus cylinder).

Defective vision and its correction

Example 4:

- **One prescription for glasses reads as follows:**

	Sphere	Cylinder		Axis
O.D.	-1.25	-1.25	*	180
O.S.	-1.75	-1.75	*	163

This means that this patient has a myopic eyes and he needs a negative (diverging) lens to correct a myopia, the right eye (O.D.) needs a spherical lens of – 1.25 D added to a cylindrical lens of -1.25 D in the horizontal plane (180º) to correct the astigmatism. The prescription for the left eye (O.S.) is interpreted in the same way.