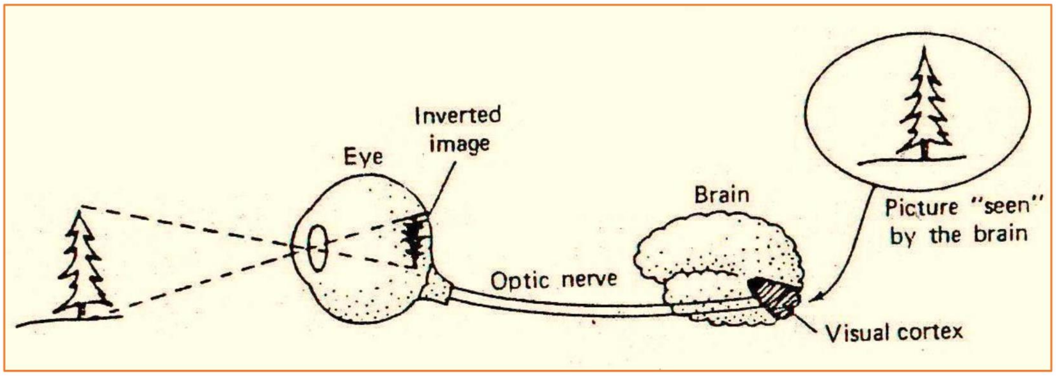
Physics of eye and vision

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 the parts does not function.

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

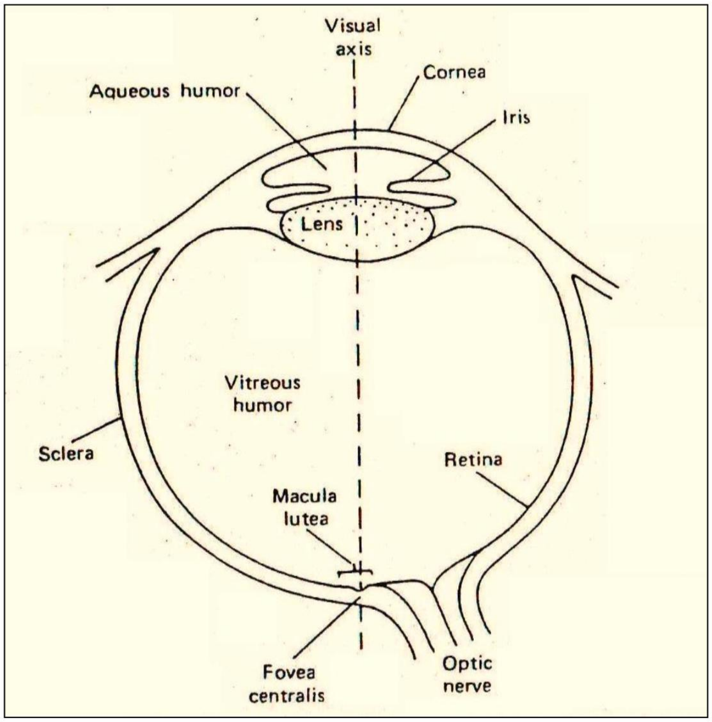
1- **The cornea (**which is the clear transparent bump on the front of the eye)
2- **The Lens**

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 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

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.



The lens 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.

-The pupil is the opening in the center of the iris where light enters the lens. 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.

-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 the entire eye except the cornea. The sclera is protected by a transparent coating called the conjunctiva.

-The retina-the light detector of the eye

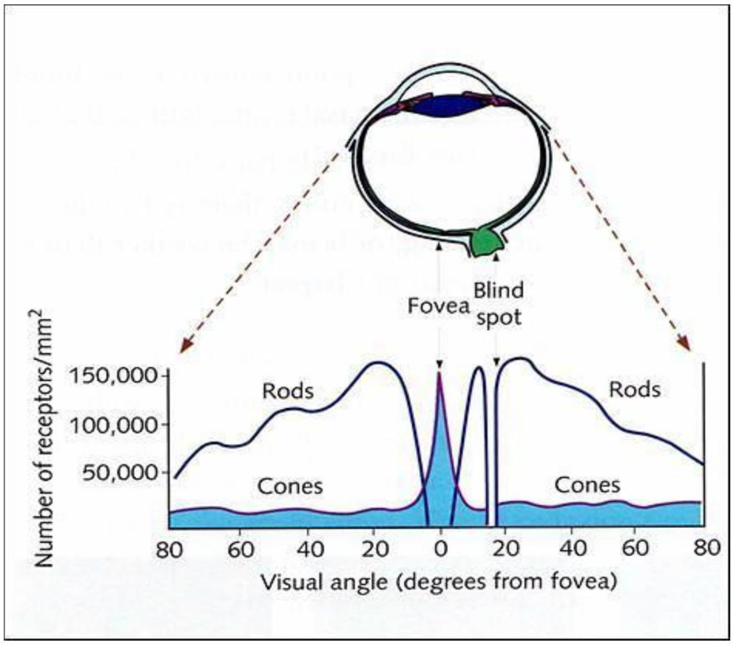
The retina, the light-sensitive part of the eye, converts the light images into electrical nerve impulses that are sent to the brain. The absorption of a light photon in a photoreceptor causes a photochemical reaction in it, which in some way initiates the action potential then produce electrical nerve impulses that are sent to the brain.

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.

Eye photoreceptors

There are two general types of photoreceptors in the retina: **the cones** and **the rods**.

The rods and cones are distributed symmetrically in all directions from the visual axis except in one region-the blind spot.



The cones	The rods
6.5 million in each eye	120 million in each eye
They are used for daylight, where we see fine details and recognize different colors.	They are used for night vision and for peripheral vision.
They primarily found in the fovea centralis	They cover most of the retina but their aximum density at an angle of about 20^o from the vision axis.
Each of them has its nervous link to the brain.	Hundreds of rods send their information to the same nerve fiber.
Their density determines the amount of details we can resolve in the eye.	Their ability to resolve two close sources of light is poor.
They have a maximum sensitivity at about 550 nm in the yellow-green region. (The maximum solar spectrum of the earth surface).	Most sensitive to the blue-green light (~510nm).
They are most rapid in dark adaptation (5min).	They continue to dark adapt for 30 to 60 min.

There is a region from about 13 ° to 18° 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.

Diopter strength of the Eye

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 1 m has strength of 10 D. 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 F1 and F2 is given by: -

$$\frac{1}{F}=\frac{1}{F_1}+\frac{1}{F_2}+\cdots.+\frac{1}{F_n}$$

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

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

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 (near point) P = 0.25m

$$\frac{1}{F_{near}}=\frac{1}{P_{near}}+\frac{1}{Q}=\frac{1}{0.25}+\frac{1}{0.02}=54\ D$$

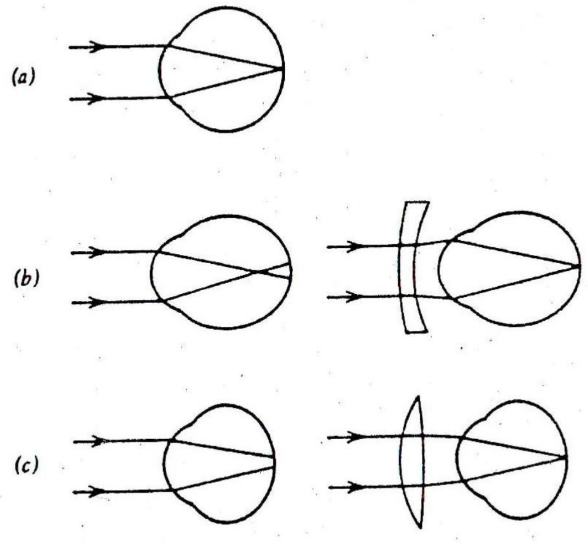
- If the eye focuses on an object at (far point) *P* = infinity

$$\frac{1}{F_{far}}=\frac{1}{P_{far}}+\frac{1}{Q}=\frac{1}{\infty}+\frac{1}{0.02}=50\ D$$

The range of accommodation of the eye= P_{near} -P_{far} = 54 - 50 = 4D.

Types of defective eyesight due to focusing:

1. Myopia (near-sightedness).
2. Hyperopia (far-sightedness).
3. Astigmatism (asymmetrical focusing).
4. Presbyopia (old sight) or lack of accommodation.



This Figure shows (a) The normal, or emmetropic, eye focuses the image on the retina. (b) The near-sighted, or myopic, eye focuses the image in front of the retina. This problem is corrected with a negative lens, (c) The far-sighted, or hyperopic, eye focuses the image behind the retina. This problem is corrected with a positive lens.

The ***myopic*** individual usually has too long eyeball or too much curvature of cornea, distant object comes to focus in the front of the retina, and rays diverge to cause a blurred image at the retina, this condition is easily corrected with a negative lens.

Example1: Determine the strength of a lens needed to correct a myopic eye with a far point 1.0m? This person has an eye lens with strength:

$$\frac{1}{F_{far}} = \frac{1}{P_{far}} + \frac{1}{Q} = \frac{1}{1} + \frac{1}{0.02} = 1 + 50 = 51\,D$$

The normal eye lens has strength:

$$\frac{1}{F_{far}} = \frac{1}{P_{far}} + \frac{1}{Q} = \frac{1}{\infty} + \frac{1}{0.02} = 0 + 50 = 50\,D$$

The strength of the lens needed = 50D – 51D = -1D. → **(A negative lens is needed).**

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.

Example2: A far-sighted eye with a near point of 2.0m. What power lens will let this person read comfortably at 0.25m?
The strength of a good eye focused at 0.25 is given by:

$$\frac{1}{F_{near}} = \frac{1}{P_{near}} + \frac{1}{Q} = \frac{1}{0.25} + \frac{1}{0.02} = 4 + 50 = 54\,D$$

For the person in the question;

$$\frac{1}{F_{near}} = \frac{1}{P_{near}} + \frac{1}{Q} = \frac{1}{2} + \frac{1}{0.02} = 0.5 + 50 = 5.5\,D$$

A correction lens of 54 – 50.5 = +3.5D would be prescribed for this person.

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.

Example3: The optometrist find that a patient who had good vision now has a near point of 0.5m and that he likes to read at a distance of 0.25m. What is his accommodation, and what strength reading glasses should he have?

An eye focused at 0.5m has strength of;

$$\frac{1}{F_{near}} = \frac{1}{P_{near}} + \frac{1}{Q} = \frac{1}{0.5} + \frac{1}{0.02} = 2 + 50 = 54\ D$$

A normal eye can focus at 0.25m has strength of;

$$\frac{1}{F_{near}} = \frac{1}{P_{near}} + \frac{1}{Q} = \frac{1}{0.25} + \frac{1}{0.02} = 4 + 50 = 54\ D$$

Therefore his reading glasses should have a strength of 54 – 52 = +2D.

Example4: If a patient has a near point of 15cm without glasses and wears a correction lens of -1.0D, what his near point when wearing glasses?

$$\frac{1}{F_{near}} = \frac{1}{P_{near}} + \frac{1}{Q} = \frac{1}{0.15} + \frac{1}{0.02} = 6.66 + 50 = 56.66\ D$$

$P_{\text{with glasses}} = P_{\text{n(without)}} + P_{\text{glasses}} = 56.66 + (-1.0) = 55.66\text{D}$

$$55.66 = \frac{1}{F_{near}} = \frac{1}{P_{near}} + \frac{1}{Q} = \frac{1}{x} + \frac{1}{0.02} \longrightarrow \frac{1}{x} = 5.66\ D$$

⇨ x = 0.1764 m OR (17.64 cm)

Example5: A patient has an accommodation of 3D, what is her near point?

Power of accommodation = $P_{near} - P_{far}$

3D = P_n – 50D ⇨ P_n = 53D

$$\frac{1}{F_{near}} = 53\ D = \frac{1}{P_{near}} + \frac{1}{Q}$$

$$53\ D = \frac{1}{x} + \frac{1}{0.02} \quad \longrightarrow \frac{1}{x} + 50 = 53\ D \quad \longrightarrow \frac{1}{x} = 3D$$

X=0.333 m ⇨ *x*=33.33 cm

Example 6: What is the power of accommodation of an eye that views objects between 20 and 500 cm from it?

Near point:

$$\frac{1}{F_{near}} = \frac{1}{P_{near}} + \frac{1}{Q} = \frac{1}{0.2} + \frac{1}{0.02} = 5 + 50 = 55\ D$$

Far point:

$$\frac{1}{F_{far}} = \frac{1}{P_{far}} + \frac{1}{Q} = \frac{1}{5} + \frac{1}{0.02} = 0.2 + 50 = 50.2\ D$$

Power of accommodation:

$= P_{near} - P_{far} = 55 - 50.2 = 4.8\text{D}$