THE EYE

The eye performs three functions: it makes adjustment to admit appropriate amount of light, it bends the rays of light to form a sharp image, and it collects and sends information about the image to the brain for further 'processing'. Different parts of the eye perform these functions. Figure shows the basic components of the human eye.

The different parts of the eye are contained within the spherical eyeball, which is about 2.5 cm in diameter. An opaque, white, protective membrane called the sclera covers most of the outer part of the eyeball. This is what we call the 'white of the eye'. A small portion at the front of the eyeball bulges out. A transparent protective membrane called the cornea covers this portion. Behind the cornea the major structures of the eye are the iris, which controls the amount of light entering the eye, the crystalline lens, which helps in bending light, and the retina, on which the image is formed. The lens divides the eye into two chambers. The smaller of these two is between the cornea and the lens. It is filled with a watery fluid called the aqueous humour. The larger chamber, between the lens and the retina, is filled with jellylike fluid called the vitreous humour. This fluid helps in maintaining the shape of the eyeball.

Light control Between the cornea and the lens lies a muscular diaphragm called the iris. The round, coloured part that we see in the eye is the iris. It has a small opening called the pupil, through which light enters the eye. The iris controls the diameter of the pupil automatically. In dim light, the iris widens (or *dilates)* the pupil to admit more light into the eye. In bright light, it contracts the pupil so that less light goes in. In this way, the iris—pupil combination controls the amount of light into the eye to ensure that the best-possible image is formed under different light conditions.

Formation of **image** Light is bent by refractions at the cornea and the lens such that a sharp image is formed on the retina. The crystalline lens is made up of jellylike, fibrous substances that make it elastic. The ciliary muscles, to which the lens is attached, can alter the curvature and thickness of the lens. The average of the refractive indices of the materials of the lens is about 1.396. The liquids in front of and behind the lens have a refractive index of about 1.336. When light enters the eye from air, most of the bending occurs at the cornea itself because of the sharp change in refractive index. The difference in the refractive indices of the lens and the liquids surrounding it being smaller, light bends less at the lens. So, the lens just provides a kind of fine tuning. The cornea—lens—fluid system is equivalent to a single converging lens, which we shall call the eye-lens. Since the ciliary muscles can change the curvature of the crystalline lens, it in effect can change the focal length of the eye-lens. **Sensing and passing on image information** The image formed by the eye-lens on the retina is real, inverted and much smaller than the actual size of the object. The eye passes on image information to the brain. The brain processes this information to show us an erect image, which is much larger than that formed on the retina.

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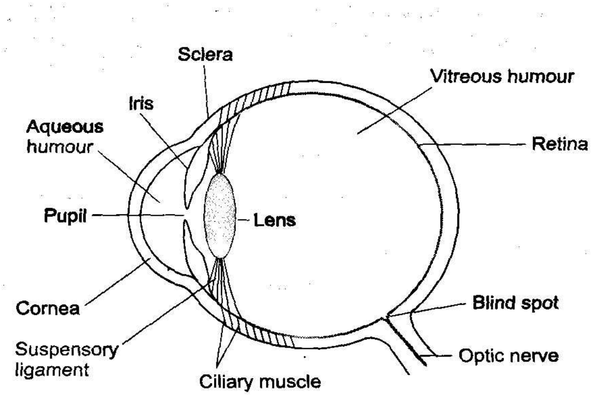
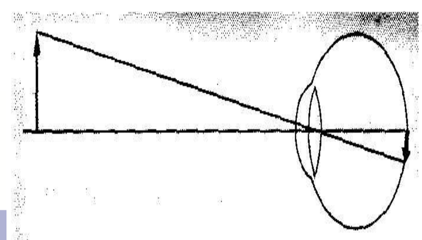
To sense image information, the retina has two types of *sense receptors*. They are called rods and cones (named so because that is how they look under high magnification). There are about 10 million cones and 100 million rods on the retina. The rods can sense very small amounts of light, while the cones need more light to perform their task of sensing colours and details. That is why in dim light we are able to see shapes but not colours and details.



The rods and cones are actually the ends of special light-sensitive nerve cells. The long fibres (or axons) of these nerve cells come together at a point on the retina to form an optic nerve, which is connected to the brain. When light falls on the rods and cones, electrical signals are generated. There are no rods or cones at the spot where the optic nerve leaves the eyeball.



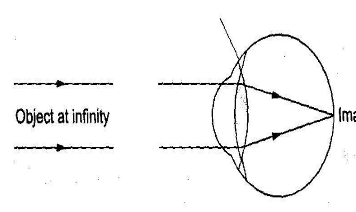
If an image is formed on this region of the retina, it is not sense and is not sensed, and hence, the object cannot be seen. This region is, therefore, called the blind spot of the eye.

How the Eye Adjusts for Objects at Different Distances: Accommodation

For clear vision, sharp images of objects have to form on the retina. Since the distance of the retina from the eye-lens is fixed, the image-distance v is fixed. However, we need to see objects that are at different distances from the eye. To form clear and sharp images of both at the same distance from the lens, the focal length of the eye-lens has to change. The cilliary muscles can change the focal length of the eye-lens. The ciliary muscles adjust the focal length in such a manner that a sharp image is formed on the retina. This process of adjustment of the focal length of the eye-lens is called accommodation.

Accommodation is the process by which the eye changes the focal length of the eye-lens such that a sharp image is always formed on the retina.

Far point and near point : The focal length of the eye cannot adjust enough to form sharp images of objects kept beyond a certain point and closer than a certain point. The farthest point up to which the eve can see properly is called the **far point of the eye**. For the normal eye, the far point is at infinity. When viewing an object at the far point, the ciliary muscles are in their most relaxed state, and the crystalline lens is at its thinnest. Thus, the eye-lens is at its maximum focal length when looking at an object at the far point. As an object is brought closer to the eye, the ciliary muscles contract. This



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increases the thickness of the crystalline lens and decreases the focal length of the eye-lens. This helps to form a sharp image on the retina. At a certain point near the eye, the ciliary muscles reach the limit of their contraction. If an object is brought closer still, the ciliary muscles cannot contract further. Th closest point object can be placed and seen clearly is called the near point of the eye. The near point of the eye varies from person to person and with age. At a very young age (below 10 years), the ciliary muscles are strong and flexible, and therefore, they can contract to a great extent. At this age, the near point may be as close as 7 to 8 cm from the eye. In old age, the ciliary muscles lose flexibility, and hence, the ability to contract to the required extent is lost. As a result, the near point recedes to 1 to 2 m, or even more. However, the standard value of the least distance of distinct vision for the normal human eye is taken as 25 centimeters.

Q. Calculate the power of the eye-lens of the normal eye when it is focused at its (a) far point (infinity) and (b) near point (25 cm from the eye). Assume the distance of the retina from the eye-lens to be 2.5 cm.

DEFECTS OF VISION

As with any organ of the body, the eye can also develop problems. The inability to see nearby objects clearly and the inability to see faraway objects clearly are among the most common defects of vision.

Near-sightedness (Myopia)

Near-sightedness is a defect of vision due to which a person is not able to see distant objects clearly. This defect is also called short-sightedness or myopia. It arises mainly due to two reasons:

(a) In certain people, the eyeball becomes elongated, i.e., longer than the normal eye. As a result, the distance of the retina from the crystalline lens increases. Then, parallel rays of light from faraway objects get focused at a point before the retina.

(b) In some cases, the curvatures of the cornea or the lens are such that the eye-lens has a shorter focal length (more power) than usual. In such cases also, the image forms short of the retina.

In both cases, faraway objects cannot be seen clearly.

Correcting near-sightedness

To correct near-sightedness, a parallel beam is made divergent before it enters the eye, by putting a concave lens in front of the eye. The focal length of the concave lens is so chosen that divergent rays entering the eye focus on the retina, and they appear to come from the far point of the unaided myopic eye.

Q. A person suffering from myopia cannot see clearly beyond 1 m What should be the focal length of the concave lens that will correct his vision?

Far-sightedness (Hypermetropia)

Some people cannot see nearby objects clearly, although they can see distant objects clearly. This defect is called far-sightedness, long sightedness, hypermetropia or hyperopia. **It** arises mainly due to two reasons.

(a) In some people, the eyeball becomes shorter than the normal. As a result, the distance of the retina from the crystalline lens decreases. Then, even for the minimum focal length of the eye-lens, i.e., when the ciliary muscles are most contracted, the image of a nearby object is formed *behind* the retina. Thus, nearby objects cannot be seen clearly.

(b) This defect can also occur if the eye-lens has a focal length that is larger than the normal due to abnormal curvatures of the cornea or the crystalline lens.

People suffering from far-sightedness have difficulty in reading a book or a newspaper, or viewing a small object placed close to the normal near point(at 25 cm).

Far-sightedness is a defect of vision due to which a person is not able to clearly see objects placed at the normal near point.

Correcting far-sightedness

To see an object placed at the normal near point, its sharp image should be formed on the retina. For this, the rays should seem to be coming from the near point of the defective eye. To do this, the rays are made less divergent by placing a convex lens in front of the eye. Rays of light coming from normal near point pass through the convex lens. When produced backwards, the emergent rays meet at the new near point. Thus, a sharp image is formed on the retina.

Q. A man cannot see objects closer than 1 metre from the eye clearly. What is the power of the corrective lens he should use?

Presbyopia

In old age, the ciliary muscles become weak and are not able to contract enough to decrease the focal length adequately. In this case also, objects at the normal near point are not focused on the retina. When far-sightedness occurs due to this reason, it is called presbyopia.

Other Problems of the Eye

Looking at the sun with naked eyes during a solar eclipse can damage the retina. A common problem in old age is cataract, which gradually reduces the amount of light reaching the retina. The crystalline lens of the eye is made of proteins that are arranged in a regular pattern, which makes the lens transparent. When a group of these protein molecules get lumped in a region, it becomes opaque, and we say that a cataract has developed in the region. Gradually the cataract grows, and finally, the whole lens becomes opaque. And as the cataract grows, the ability of the person to see diminishes. To restore vision, the affected lens is surgically removed, and an artificial lens is placed in its place.

Contact Lens

A contact lens is a small lens which is worn directly on the cornea. It has one clear advantage over spectacles. When a person wearing spectacles looks through the corner of the eye, the cornea and the centre of the lens are not in line. As a result, the peripheral view gets distorted. Since a contact lens moves with the cornea, this problem does not arise.

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ATMOSPHERIC REFRACTION

You know that the earth is surrounded by a layer of air called the atmosphere. The density of air in the atmosphere is not the same everywhere. In general, it is greatest at the earth's surface and goes on decreasing as we move higher. The refractive index of air depends on its density—higher the density of air, greater its refractive index. Under standard conditions of temperature, humidity, etc., near the earth's surface, the refractive index of air is slightly greater than 1. It decreases with height, and is very close to 1 in the outermost region of the atmosphere.

The changes in refractive index of air give rise to many phenomena. For example, a rising current of hot air makes the objects viewed through it seem to flicker. You might have seen this happen as hot air rises above the heated surface of roads on hot summer days or above a large burning stove or *chulha*.

Hot air has less density, and hence, less refractive index than normal or cold air. At a point in the area above a hot surface, the refractive index keeps on changing as currents of hot air passes through it. So, the amount by which light passing through it is bent keeps on changing. This makes the objects viewed through this area seem to sway or flicker.

Early Sunrise and Late Sunset

Consider an oblique ray from a heavenly body such as the sun or a star. While travelling through the atmosphere, it continuously moves into regions of higher refractive index. So, it continuously bends towards the normal, resulting in a path similar to that shown in Figure. Since we see an object in the direction of the ray incident on the eye, the heavenly body appears higher than its actual position.

Consider the situation when the sun just below the horizon. Rays of light coming from it get bent such that to an observer they seem to be coming from above the horizon. Thus, even when the sun's position is just below the horizon, the sun is visible to us. So, at sunrise we see the sun before it actually comes to the horizon. And at sunset we see it even after it has just dipped below the horizon. This increases daylight by about four minutes every day (two minutes at sunrise and two minutes at sunset).

You might have noted that the sun looks oval at sunrise and sunset. As you can see from the figure, the rays from the lower regions of the sun travel a greater distance through the atmosphere than those from the upper regions. So, they bend more. As a result, the image of the lower region gets shifted upwards more than that of the upper region. This makes the sun appear like a flattened circle, or an oval.

Twinkling of Stars

'Twinkle, twinkle little star' may have been the first rhyme you learnt, but maybe you are still wondering what makes stars twinkle. When we look at stars, quite often they do not appear to shine steadily. They disappear for a fraction of a second before reappearing (the intensity of light from them fluctuates), or their positions seem to shift slightly in random directions. We call this the twinkling of stars. Let us see why this happens.

Since the temperature of air and its humidity are not the same everywhere in the atmosphere, the refractive index of air varies between different masses (or pockets) of air, even at the same altitude. Thus, there exist air pockets whose

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refractive index is different from that of the air surrounding it. When a ray of light passes through such a pocket of air, it bends due to refraction. Light from a star may pass through one or more air pockets before reaching the eye. But the air pockets keep moving. So, the direction of the ray reaching the eye keeps changing, causing the image of the star to shift in random directions or even disappear for an instant. The amount of starlight reaching the eye also keeps changing due to the shift in the direction of the light. So, the brightness of the star seems to change.

The stars near the horizon twinkle more than those that are overhead. This is because light from a star near the horizon has to cover much more distance in the atmosphere than that from stars which are overhead. Therefore, it has greater chances of encountering air pockets whose density is different from the surrounding air.

Why planets do not twinkle Planets do not seem to twinkle like stars, although light coming from them also passes through the air pockets in the atmosphere. This is because stars appear as point objects to us due to their enormous distance from the earth. On the other hand, planets are comparatively nearer, and therefore, for us they are more like extended objects. Light from different parts of the planet form an extended image at the eye, and we are unable to detect the random shifts in the smaller portions of this image.

Q. A ray of light travelling in air is incident on the plane surface of a transparent medium. The angle of incidence is 45° and **the angle of refraction is 300. Find the refractive index of the medium.**

Q. A ray of light travelling in air **falls on the surface of a rectangular slab of a plastic material whose refractive index is 1.6. If the incident ray makes an angle of 53^0 with the normal, find the angle made by the refracted ray with the normal (sin 53° = 4/5).**

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