SPECIAL SENSES

Introduction

There are four senses, viz., visual, auditory, gustatory and olfactory, which give special information about the environment; hence, these are named as special senses. For example, visual sensation not only gives us the sensation of light but we extract many information from the scenery, *e.g.*, soothing or repulsive, hostile or friendly and so on. The vestibular apparatus which gives the sense of movement and of gravity is also included in this group, but as related to posture and equilibrium, it is discussed in that chapter (p. 444).

1 CHAPTER — Vision

The sense organs for vision are the two eyeballs. These are situated in the orbits, i.e., the bony cavities to which the eyeballs are attached by some muscles (**extrinsic muscles of eye**). The eyeballs are highly mobile to enable us to get vision from a maximum possible portion of our environment even without moving our head.

STRUCTURE OF THE EYEBALL

Each eyeball is of 24 mm in diameter anteroposteriorly and has three coats (Fig. 12.1) from outside inwards. These are : sclera, choroid and retina.

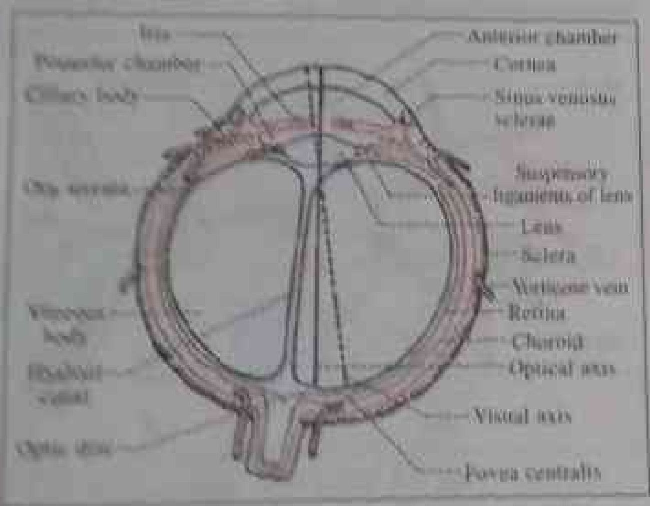

Fig. 12.1. *A horizontal section through the right eye ball.*

Sclera

It is an opaque, fibrous protective coat of the eyeball, which is anteriorly replaced by the transparent cornea.

The **cornea** is composed of five layers (Fig. 12.2) from outside inwards. These are : corneal epithelium, Bowman's membrane or anterior elastic lamina, substantia propria, Descemet's membrane or posterior elastic lamina and the corneal endothelium. This endothelial layer is believed to be responsible for maintaining the transparency of the cornea by pumping out water from the corneal substance and thereby maintaining adequate hydration. The epithelium in front can completely repair small damages very quickly, but if the injury involves the anterior elastic lamina, then healing becomes incomplete and scarring occurs. Scarring makes the cornea opaque and vision is hampered, which needs treatment by corneal grafting.

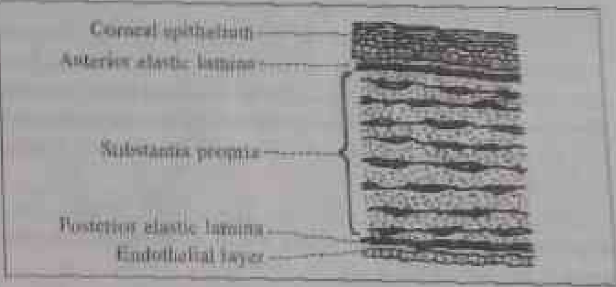

Fig. 12.2. *Structure of cornea.*

The cornea receives its nutrition from aqueous humour (see below) behind and tear in front. There are no blood vessels in cornea to maintain its transparency. Free nerve endings in cornea act as receptors for pain, touch, temperature (according to some, cornea has only pain sensation).

Donation of eye means donation of the cornea only and no other parts of eye from the donor can be used at present. The cornea from the donor is grafted on the recipient (with a damaged cornea). Partial thickness corneal graft is done in case of superficial opacities (lamellar keratoplasty) and whole thickness grafting (penetrating keratoplasty) can also be done in need. It should be remembered that due to avascular nature of the cornea, graft rejection is minimum.

Choroid

It is the pigmented vascular layer composed of blood vessels and provides nutrition to the eyeball. It is continuous anteriorly with the ciliary body, etc., containing smooth muscles in them (**intrinsic muscles of the eye**). The whole of the middle coat is called uveal tract.

The ciliary body forms a ring at the sclerocorneal junction (Fig. 12.3) to which the iris, the suspensably ligaments of the lens and the ciliary processes are attached :

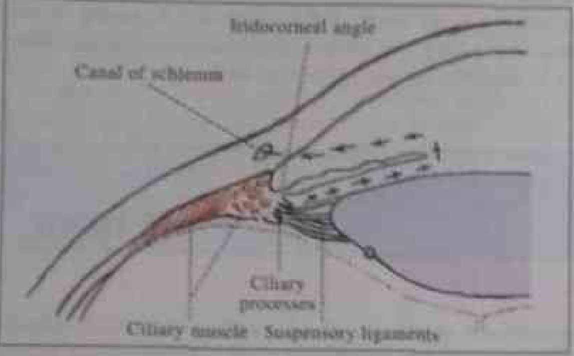

Fig. 12.3. *Sclerocorneal junction with the ciliary body. Arrows indicate the movement of aqueous humour.*

Iris

It is a circular muscular membrane attached peripherally to the ciliary body and is situated behind the cornea. It has a central hole called **pupil**, which allows light to enter in the eye for vision. The radial muscles of the iris (dilator pupillae) are supplied by sympathetic nerves; on contraction they increase the size of the pupils.

The concentric muscles of iris (constrictor pupillae) are supplied by parasympathetic nerves, their contraction decreases the size of the pupils. By the action of these muscles, the diameter of the pupil can be varied highly and light entry can be efficiently controlled. Normally, diameter of pupil varies from 2 to 8 mm.

The colour of one's eye, *i.e.*, blue, black, brown, etc., depends on the colour of the iris, which is determined by the amount of pigment in it.

Suspensory ligaments

These ligaments suspend the lens and are attached radially around the lens. The other name is zonule.

Ciliary processes

These are 60 to 70 finger like processes hanging radially from the whole of the cilliary body. These are situated behind the iris and are the sites of production of the aqueous humour (see below).

Retina

It is the innermost layer of the eyeball and contains the photoreceptors, the rods and the cones. It has ten layers (Fig. 12.4). From outside inwards these are :

Pigment epithelium → layer of rods and cones → outer limiting membrane → outer nuclear layer → outer plexiform layer → inner nuclear layer → inner plexiform layer → ganglion cell layer → layer of optic nerve fibres → inner limiting membrane.

The outer and inner limiting membranes are formed by the processes of the Muller cells (glial cells). There are also some other types of cells in retina. Anteriorly, the retina ends before the sclerocorneal junction in an irregular margin called ora serrata.

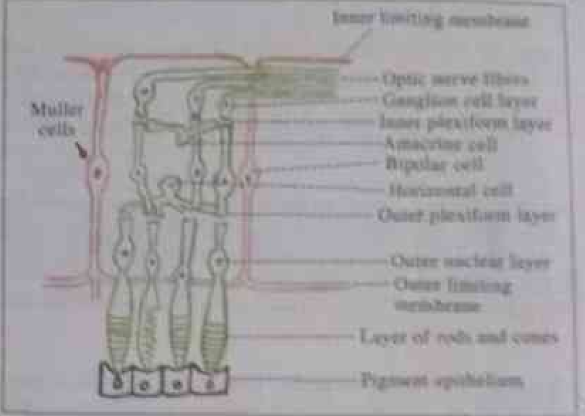

Fig. 12.4. *Layers of retina.*

Nutrition of the retina is maintained mainly by the choroid. Retinal detachment means separation of retinal layers from the pigment epithelium and then the retina is deprived of supply from the choroid. The retina then needs immediate fixing. The retinal vessels which pass through the optic nerve (Fig. 12.5) supply from the inner side of the retina. These retinal vessels are the only vessels of the body, which can be seen easily from outside by instruments like ophthalmoscope.

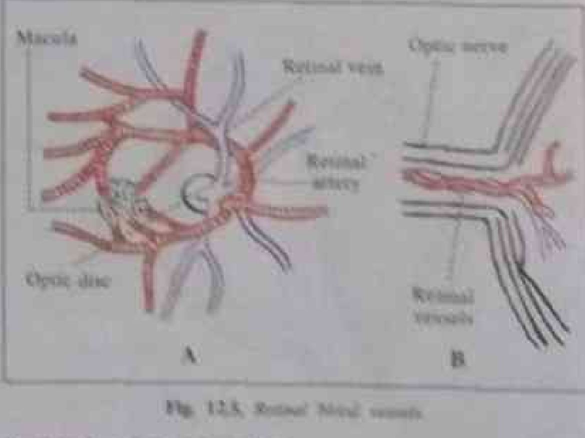

Fig. 12.5. *Retinal blood vessels.*

Regional variations in retina

Posterior part of the retina contains relatively more cones, while there are more rods anteriorly. Near the posterior pole is a yellowish portion on the retina, called **macula lutea** which is thinnest and has no blood vessels on it (Fig. 12.5). Its central part is called **fovea centralis,** a depressed area containing only cones. 3 mm on the nasal side of fovea, the **optic disc** is present which contains no receptor cells (also called **blind spot**). The nerve fibres of the retina (axons of the ganglion cells) converge to this disc to form the optic nerve which goes out and retinal vessels enter and leave the eyeball through this disc.

How to examine the fundus

Clinically the fundus means the interior of the eyeball. It can be seen easily through the pupil by ophthalmoscope. It will be better if the pupils are made to dilate beforehand with a suitable anticholinergic preparation.

Conjunctiva

It is a thin membrane which covers the exposed portion of the sclera (**bulbar conjunctiva**) and the inner surfaces of the eyelids (**palpebral conjunctiva**). Both the conjunctivae are continuous above and below to form upper and lower conjunctival sacs (Fig. 12.6).

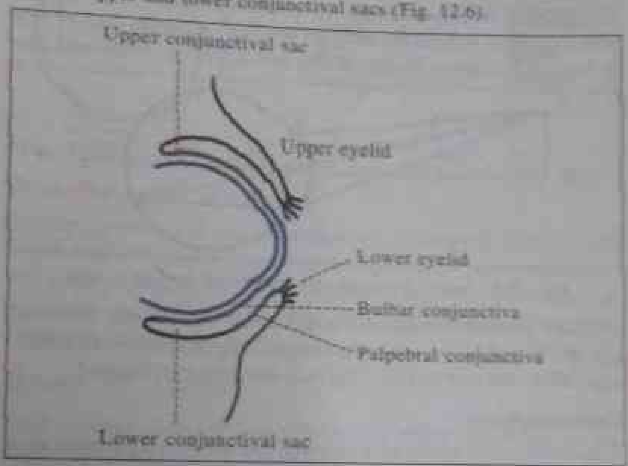

Fig. 12.6. *Conjunctiva*

Tear

It is the watery secretion of the lacrimal glands situated laterally on the roof of the orbit. Tear is poured into the upper conjunctival sac (Fig. 12.7) and then moved medially by the blinking actions of the eyelids to be drained through the lacrimal passages into the nasal cavity. Tear is essential to keep the anterior surface of the cornea moist, smooth and clean. It is antiseptic as it contains lysozyme and also supplies O_2 to the cornea. Excess tear is produced in grief, which then rolls down the cheek.

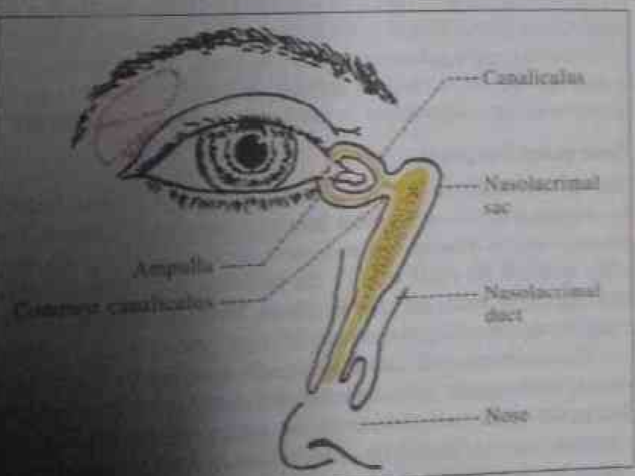

Fig. 12.7. *Schematic diagram of lacrimal passage*

CONTENTS OF THE EYEBALL

Inside the eyeball the most important structure is the lens which divides the interior of the eyeball into anterior and posterior compartments (see Fig. 12.1). Anterior compartment contains **aqueous humour** and is subdivided into anterior and posterior chambers by the iris. The posterior compartment contains a transparent gelatinous substance, called **vitreous humour**, covered by the hyaloid membrane.

Aqueous humour

It is the watery fluid which fills the anterior compartment of the eye. It is secreted from the ciliary processes in the posterior chamber. It is in part an ultrafiltrate of plasma.

From the posterior chamber, the aqueous humour passes through the pupil (see Fig. 12.3) into the anterior chamber. Then it enters into the **canal of Schlemm** in the sclerocorneal junction through the trabecular **spaces of Fontana** at the iridocorneal angle. From the canal of Schlemm it ultimately drains into the venous blood. Part of the aqueous humour also passes through the vitreous.

Functions of aqueous humour

(i) Maintains intra-ocular pressure (also called intra-ocular tension) and thus the shape of the eyeball. This way it helps to keep the intra-ocular structures in place and to maintain the corneal curvature.

(ii) Gives nutrition to the lens and cornea.

(iii) Removes metabolites from these parts of the eyeball.

Glaucoma

The pressure within the eyeball is called intra-ocular tension. The normal value of the intra-ocular tension is 17 to 22 mm of Hg. It shows diurnal variation. Though the aqueous humour is the main determinant, other factors also influence the intra-ocular tension.

When there is an increase of intra-ocular tension, the condition is called glaucoma. It develops mainly due to defect in the drainage of the aqueous humour and which may be due to the following reasons :

(i) When the spaces of Fontana, etc., are blocked due to some reasons or others. Here the iridocorneal angle remains wide; hence the name is **open angle glaucoma**.

(ii) When narrowing or closure of the iridocorneal angle prevents the aqueous humour to enter into the spaces of Fontana, the condition is called **closed angle glaucoma**. This type is aggravated by dilatation of the pupil by drugs like atropine.

(iii) Glaucoma is also produced due to other reasons.

Note : (a) Intra-ocular tension decreases in severe dehydration.

(b) It is also said that raised intra-ocular tension does not lead to glaucoma which is a degenerative disease and may be present with normal intra-ocular tension. But glaucoma worsens with the rise of intra-ocular tension.

Refractive media of the Eyeball

Most of the intra-ocular contents are transparent and act as media for the light rays which enter the eye. Light passes through these media to strike the retina.

The media are : cornea (refractive index 1.37), aqueous humour (refractive index 1.33), lens (refractive index 1.42), vitreous humour (refractive index 1.33) and their relative positions are such that a sharp image is produced on the retina. Light, while passing through, suffers refraction only at three [illegible] of one minute when the size of the retinal image is 4.5 μ (diameter of each foveal cone is 1.5 μ, so this image will stimulate at least two cones.) It should be kept in mind that the size of the object will have to be increased with the distance from the eye to subtend the same visual angle (Fig. 12.10). Thus [illegible], a larger object, placed at a greater distance, will subtend the same angle as a smaller object placed nearer the eye.

Fig. 12.10. Objects of different sizes and distance that subtend same visual angle.

Resolution power of the eye

Human eye can see smallest objects of diameter 200 μ (light microscope 0.2 μ; electron microscope 0.001 μ), which means two points separated by this distance will be identified as two separate points by the eye, *i.e.*, only when two adjacent cones are stimulated by these points.

Acuity of Vision

This means sharpness of vision, *i.e.* when the details of an object is seen.

Testing of visual acuity

It is performed both for distant and near vision. Test for **distant vision** is performed by asking the individual to see objects (charts) at a distance of 6 metres or 20 feet, where the finer details of the given objects subtend visual angle of one minute.

Charts used are as follows :

(1) **Snellen's Chart** consists of special letters whose individual segments subtend an angle of 1 minute and the angle subtended by the whole letter is of 5 minutes (Fig. 12.11).

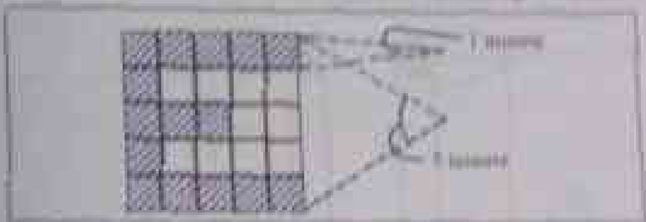

Fig. 12.12. Construction of letters used for eye testing for distance vision.

There are several lines of such letters on the chart with different sizes but each line at a specified distance will obey the above rule (Fig. 12.12) and a person with normal visual acuity should be able to read the top line from a distance of 60 metres, the second line from 36 metres and so on. As the chart is read in practice from a distance of 6 metres and a normal person can read upto the 7th line, the distant vision is then expressed as 6/6. There is another line below this which can be read at a distance of 5 metres but some normal people can read this from a distance of 6 metres.

Fig. 12.11. Charts for testing distant vision. A, Snellen's test types. B, 'E' test types for illiterate persons. [illegible]

(2) **Landolt C Chart** contains broken circles (like the alphabet C), each gap is of the size of one minute. Similar 'E' test types can also be used. These are used for individuals who cannot read (illiterate).

Near vision is tested by asking the subject to read **Jaeger's chart** containing printed letters of different sizes [illegible] (Fig. 12.13) held at a distance of 25 to 30 cm. The smallest type which the subject can read clearly is noted (*e.g.*, N_5 means subject can read up to 5 point type).

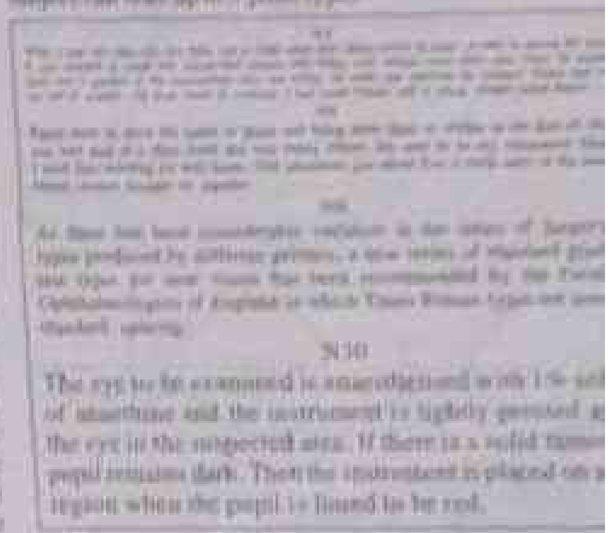

Fig. 12.13. Jaeger's chart.

Optical defects in Eye

Optical defects can occur both in emmetropic and ametropic eyes (see above). The defects which can occur in ametropic eyes are myopia, hypermetropia, astigmatism and those in both types are presbyopia and spherical aberrations.

Myopia

In an eye when the parallel rays are focussed at a plane in front (Fig. 12.14), but not on the retina, the defect is called myopia. This eye fails to see distant objects, but can see nearer objects clearly, hence the other name of this condition is **short-sightedness.** This defect is usually seen in elongated eyeballs (*i.e.*, where the distance between the cornea and the retina is increased).

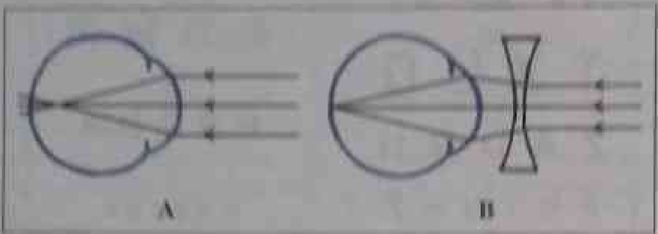

Fig. 12.14. *Myopia*
A. *Parallel rays are focussed in front of the retina*
B. *Correction of myopia with biconcave lens*

There is also possibility of myopia when the power of the lens system is high due to increased curvature of cornea, etc., which focusses the parallel rays in front of the retina.

Myopia is usually seen in young age and gradually the defect increases with age due to increase in the size of the eyeball along with the body and normally stops when body growth stops. (There is also a progressive type, called malignant myopia). Myopia is said to occur in children (below 2 yrs) sleeping in lighted room and in young adults involved in too much close work like reading.

Myopia is corrected by using biconcave lens (Fig. 12.14B). Biconcave lens diverges the parallel rays before entering in the eye, which are then focussed on the retina instead of in front of it. Because the same power in the eye which was focussing the parallel rays at an earlier point, cannot do so when the rays are made divergent by the biconcave lens.

Hypermetropia

If the parallel rays from an object are focussed at a plane behind the retina (Fig. 12.15A) in an eye, the defect is called hypermetropia. So the distant objects cannot be seen clearly by a relaxed eye but may be seen after accommodation. There will be more difficulty in focussing the nearer objects

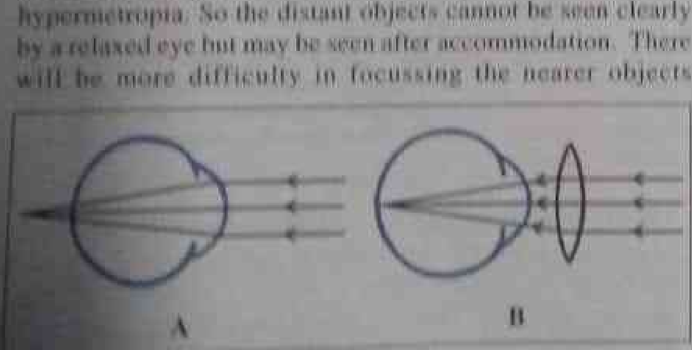

Fig. 12.15. *Hypermetropia*
A. *Parallel rays are focussed behind the retina*
B. *Correction of hypermetropia with convex lens*

(where from light rays are divergent). Hence, this conditi[on is] also named as long-sightedness. This condition results [due] to short eyeball. This defect is corrected by using bico[nvex] lens (Fig. 12.15B), which helps by converging the rays b[efore] they enter the eye. These rays now can be focussed by th[e lens] on the retina.

Presbyopia

With the advancement of age the near point (see a[bove]) recedes, as a result the parallel rays can be focussed o[n the] retina but not the divergent rays from a nearer object[. This] condition is called presbyopia. These individuals canno[t see] details of nearby objects (*e.g.*, letters of a book he or [she is] reading) due to failure of adjustment of visual apparatu[s for] near vision. It usually develops after the age of 40 year[s due] to decreased plasticity of the lens. The condition is corr[ected] by using biconvex lens during near vision, *e.g.*, reading [glass] (hence also called reading glass). Obviously the myope[s do] not need correction in the early stage and presbyopia [may] develop early in the hypermetropes.

Astigmatism

This condition results due to uneven anterior surface o[f the] cornea or due to different curvatures of cornea in diff[erent] meridians. It may also result due to same type of defe[ct in] the lens due to displacement or other reasons. This lea[ds to] failure to focus all the rays from an object on the retin[a in a] single plane. This is because the rays along the meridi[an with] increased curvature will be converged more than the o[thers.] Similarly, the rays along the meridian with less curvatur[e will] not be converged properly. Therefore, the object wi[ll be] blurred. This defect is corrected best by contact lens [or by] using cylindrical lens in the axis of the defect.

A convex cylindrical lens is a cut section of a glass cyl[inder] (Fig. 12.16B), *i.e.*, a planoconvex lens with convexity i[n one] meridian only. This lens is incorporated in the spectac[les in] such a way that its long axis is along the meridian o[f less] curvature (flatter) of the eye. On the other, a con[cave] cylindrical lens (Fig. 12.16C) is placed along the meridi[an of] increased curvature of the eye.

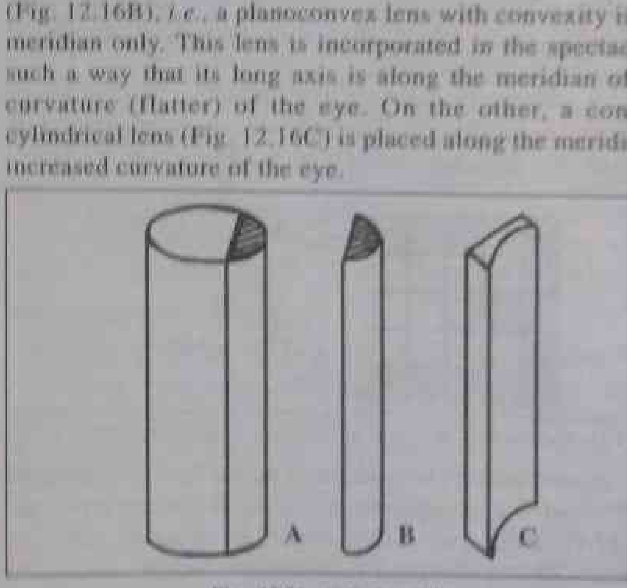

Fig. 12.16. *Cylindrical lens*
A. *Cylindrical lens is a cut section of a cylinder*
B. *Convex cylindrical lens* C. *Concave cylindrical lens*

Contact lenses are concavo-convex discs which ju[st fit] on the external surface of the cornea. Contact lenses are p[...]

position of the eyes on the head, *e.g.*, a fish has only monocular field. Binocular vision is essential for stereopsis (see later).

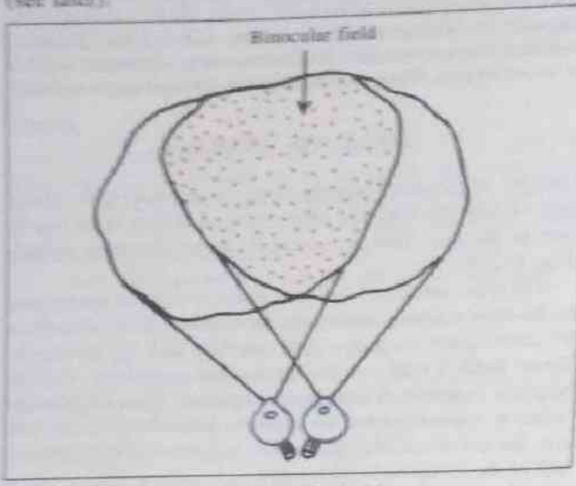

Fig. 12.21. *Field of vision.*

Corresponding retinal points

These are the points on each retina, images from where can be fused by the brain into a single image. Taking fovea as the centre, temporal retina of one side corresponds with the nasal retina of the opposite side and so on. Therefore, regarding fusion of image, for every point on one retina there are corresponding points on the other retina. If we want to see an object as a single one, then its images must form on the corresponding points of two retinae. Otherwise, one object will be seen as two objects, which is called **diplopia** or double vision. Diplopia may result due to various reasons. If it persists, the brain ignores the image from one eye and accepts the other. The eye whose image is ignored is called 'lazy eye' and the condition is called amblyopia. Amblyopia also occurs in the eye having higher refractive error than the other and not corrected properly.

Colour vision

It is tested to see whether or not the person is able to identify different colours properly (discussed later).

VISUAL PATHWAY

It is the pathway through which the visual impulse produced in the retina passes towards the central nervous system. When the light, from an object we see, strikes the retinal receptors, action potential is produced in the afferent nerves (axons of the ganglion cells). These afferent nerves from one retina form the optic nerve of that side.

The rods are more in number (20 times) than the cones and the total number of the receptors is about 126 million. The number of the ganglion cells or the optic nerve fibres is about one million. This indicates that a good amount of convergence occurs in the retina. There is no convergence from the foveal cones and each cone here has a personal line' upto the higher level.

The optic nerves thus formed, proceed medially and join together to form the optic chiasma (Fig. 12.22). In the optic chiasma the fibres from the nasal half of one retina cross to the opposite side to form optic tracts with the fibres from the temporal retina of that side.

Therefore one optic tract contains the temporal fibres from the retina of that side and the nasal fibres of the opposite retina. This makes one optic tract (or one side of the brain) responsible for one side of the field of vision. (In other words the right side of the visual field goes to the left hemisphere and the left side to the right hemisphere).

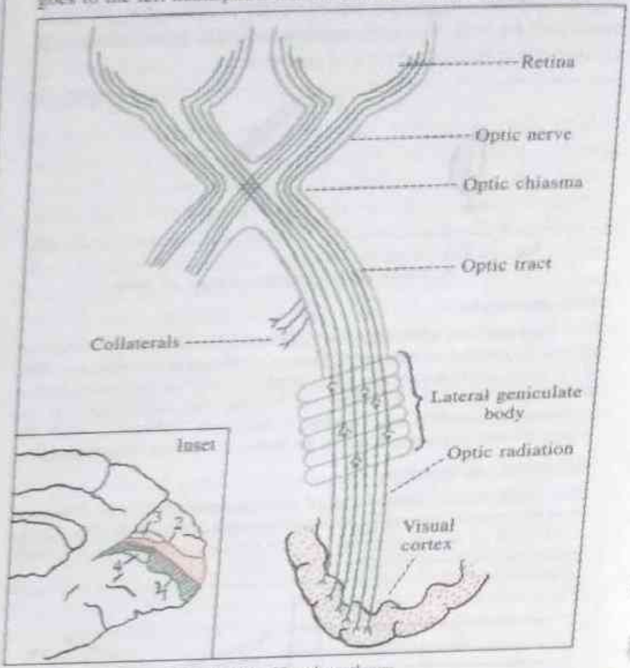

Fig. 12.22. *Visual pathway.*
Inset shows termination of the fibres from lower macula (1), upper macula (2), upper peripheral retina (3) and from lower peripheral retina (4) in the occipital cortex.

The optic tracts then proceed medially and end in the respective lateral geniculate body (LGB). Each LGB has its cells arranged in six layers, of them the layers 1, 4 and 6 receive fibres from the opposite eye and the layers 2, 3 and 5 receive fibres from the same eye. Each layer of LGB has point to point representation of the retina and one retina is superimposed on the other. This sort of arrangement probably helps in fusion of images seen by the two eyes and also may help in depth perception. LGBs are part of the thalamus and act as relay centre for visual sense.

The 1st and 2nd layers of LGB are related to black and white, whereas, the 3rd, 4th, 5th and 6th layers are related to colour vision.

From the LGB, the fibres proceed to the visual cortex via the optic radiation. The fibres representing the upper half of the visual field pass through the temporal lobe and those representing the lower half pass through the parietal lobe. The visual cortex is situated in the medial surface of the occipital lobe, in and around the calcarine sulcus (areas 17, 18, 19). Area 17 is the visuosensory area, area 18 is the visual association area and the area 19 is the occipital eye field which has role in movements of the eye. There is point to point representation of the retina on the visual cortex. The macula has a wide area (Fig. 12.22, inset) and the peripheral retina is represented in the cortex in a smaller area. Upper part of retina is represented above, while lower part is represented below the area of the macula. (If the visual fields are considered it will be reverse).

Collaterals given out from the visual path at different levels are as follows :

(1) To the suprachiasmatic nucleus of hypothalamus. This connection probably supplies information about the night and day cycle to the hypothalamus for circadian rhythm.

(2) To the pretectal region for the Edinger-Westphal nucleus for light reflex. The pretectal region also gets fibres from superior colliculus, visual cortex and the frontal lobe.

(3) To the accessory optical system for integration of visuovestibular reflex and for many other functions.

(4) To the superior colliculus for reflex connections, *i.e.*, visuospinal. This is for movement of the head in the direction of the object of interest in the visual field.

(5) To the pulvinar part of the thalamus.

(6) To the brain stem for saccadic eye movements (p. 491).

Lesions in the Visual path and

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cone shaped and that of the rods are rod shaped, that is why these are named as cones and rods respectively (Fig. 12.24A), but in the foveal cones the outer part is rod shaped. The part of the receptors outside the outer limiting membrane is divided into outer segment and inner segment. The inner segment contains along with other organelles, plenty of mitochondria which provide the energy for synthesis of visual pigments (see below). The outer segment contains the visual pigments impregnated in the membrane of the flat membranous discs. These discs, as many as thousands, are stacked one after another, made from the plasma membrane of the receptor cells. The discs are separate in case of the rods (Fig. 12.24B) but are produced by infolding of the plasma membrane in case of the cones. These discs are under continuous renewal.

The parts of the rods and the cones inside the outer limiting membrane have two important structures : the nucleus forming the outer nuclear layer and the synaptic ends which form synapses (Fig. 12.4) with the bipolar cells and horizontal cells in the outer plexiform layer.

Visual pigments

These are substances responsible for linking light energy to the receptor activity. These pigments are primarily of two types : the rod pigments (rhodopsin) and the cone pigments. Each of the pigments is formed of an aldehyde form of retinol (vitamin A), called retinene (Fig. 12.25A & B) and a protein, called opsin. The protein differs in different pigments. The protein in the cone pigments are of three types resulting in three different types of cone pigments : **cyanolabe, chlorolabe, erythrolabe** showing highest sensitivites to the wavelength of 430, 535 and 575 nm respectively. The protein

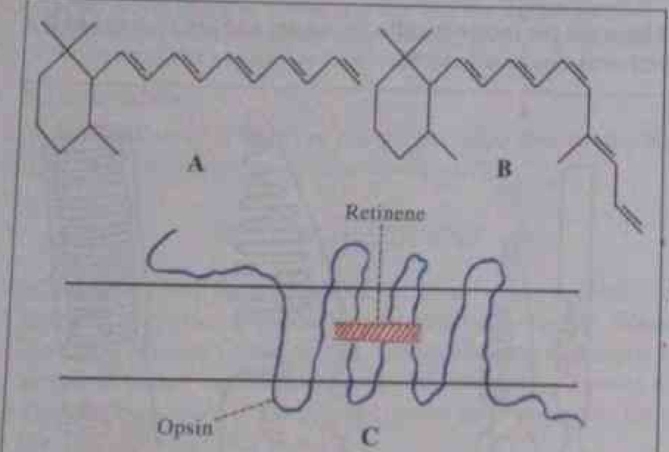

Fig. 12.25A. *Retinene (all trans.).* **B.** *Retinene (11 cis.).* **C.** *Rhodopsin molecule in the disc membrane.*

of rhodopsin is called scotopsin. The opsin in each case is a sarpentine protein, which spans the disc membrane seven times (Fig. 12.25C) and the retinene is attached to it.

Photochemical changes

Light enters in the eye as follows :

the object → cornea → aqueous humour → lens → vitreous humour → retina.

When light strikes the retina, it is taken ultimately by the receptors on the inner side of the discs (see above) and chemical changes those occur in the visual pigments are as follows :

Rhodopsin —Light→ Prelumirhodopsin → Lumirhodopsin → Metarhodopsin → Metarhodopsin II → Retinal (all trans retinene) + Opsin.

The metarhodopsin II is instrumental for the production of receptor potential. The excess light rays which are not used in the receptors are absorbed in the pigment layer. Due to this, scattering of light is prevented and a sharp retinal image is produced.

Complete separation of opsin and retinene is called **bleaching,** this exhausts the pigments, so a continuous supply of the pigments is necessary. It is achieved by two processes :

(i) Resynthesis from the bleached pigments :

Retinene (all-trans) —*Isomerase*→ 11-cis retinene ⇌ Rhodopsin (+ Opsin)

(ii) Synthesis from vitamin A :

Retinol (all-trans) —*Retinol Isomerase*→ 11-cis retinol —*Retinol dehydrogenase*→

11-cis retinal (Retinene) ⇌ Rhodopsin (+ Opsin)

Both of these processes take place in the pigment epithelia as well as in the rods.

(The chemical changes in the cones are presumed to be same as in rods.)

Role of vitamin A

It is clear from the above discussion that vitamin A plays the central role, therefore a continuous supply of vitamin A is highly essential. Deficiency of vitamin A leads to a spectrum of eye diseases (see vitamins). **Night blindness** (nyctalopia) means inability to see in the dark. This is the first symptom of vitamin A deficiency and results due to less availability of visual pigments. Further deficiency leads to structural changes like Bitot's spot, keratomalacia, conrneal ulcer and ultimately blindness. It is the major cause of blindness in India, which can be easily prevented simply by supplying vitamin A to the victims at proper time.

Scotopic vision/Photopic vision

Vision in dim light is called **scotopic vision** and is the function of the rods. This is because the rhodopsin is more sensitive and can react in presence of very small amount of light. But scotopic vision gives only a vague idea about the objects seen. Vision in bright light is called **photopic vision** where cones are the receptors. Cone pigments have high threshold and help to analyse the details of the object seen. This is because, the details including colours can only be seen in bright light when the cone pigments operate. Hence, the cones are responsible for acuity of vision.

Dark adaptation

Adjustment of visual mechanism from bright light vision to dim light vision is called dark adaptation (*i.e.*, switching the eye from cone vision to rod vision).

The eye operates on a sliding scale of sensitivity which is very very high in dark and remarkably low in broad day light. When one is seeing in bright light, the sensitivity of the visual mechanism is very low which must be increased if one wants to see in dark afterwards, where intensity of light is very low and that is what occurs in dark adaptation.

To change the sensitivity some time is required (Fig. 12.26) and before this, one fails to see in dark. This typically poses a problem in finding seats inside a theatre after entering from day light and also by the radiologists*. The early part of the rise of sensitiviy as shown in Fig. 12.26 is due to the cones and the later part is due to the rods. Sensitivity increases 10 times within one minute, 6000 times by 20 minutes and to 25,000 times by 40 minutes, when adaptation becomes almost complete. This gives a fair idea about the range of sensitivity of the eye.

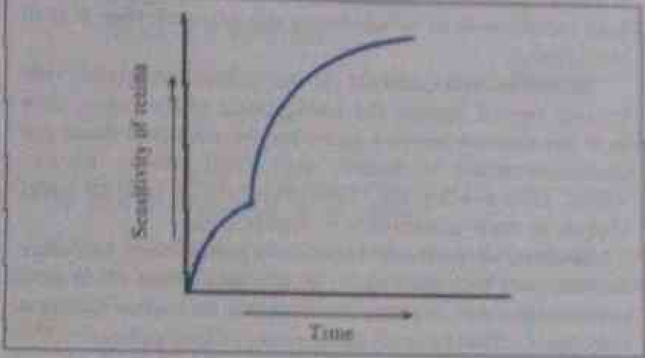

Fig. 12.26. *Dark adaptation*

During dark adaptation, following changes occur :

(i) Resynthesis of the visual pigments which were exhausted (bleached) during exposure to bright light. This is the key step and is seriously hampered in vitamin A deficiency when dark adaptation takes longer time or may fail to occur. (ii) There is increased gain of the retinal components due to spatial and temporal summation (p. 179) occurring in dark. (iii) Pupils dilate to allow more light into the eyes. (iv) **Purkinje shift** : It means shifting of vision from the yellow-green part of the spectrum, where the eye operates at bright light to the blue-green part of the spectrum in the dark, *i.e.*, the eye is more sensitive to shorter wave lengths in dark and to longer wave lengths in bright light. This explains why the red flowers first lose their glow (*i.e.*, appear black) when dusk sets in but a blue flower still appears to glow.

***Note :** Wearing red goggles prevents breakdown of the rhodopsin pigments and radiologist use red goggles while in bright light. Therefore, during their work involving frequent change between bright and dark environment they do not need to wait for dard adaptation.

Light adaptation

This is opposite to dark adaptation. When a person comes suddenly to bright light after a long stay in the dark, he or she cannot see properly. This is because the eye requires some time to shift from high sensitivity to the lowest. During this, the rods are stimulated at their maximum and the cones sufficiently. Maximally stimulated rods cannot differentiate the variations of the stimuli but the cones can do and help to see the details in bright light.

COLOUR VISION

This is the most important part of vision, without this the colourful world would become grey. The eyes have the ability to respond to all the wave lengths of the visible part of the spectrum (i.e. the light rays with wave length from 400 to 700 nm) and enable us to enjoy all the possible colours. The visible part of the spectrum has seven colours but we have only three types of cone pigments : cyanolabe, chlorolabe and erythrolabe showing higher response to specific parts of the spectrum (Fig. 12.27).

It is seen from the figure that one wave length may stimulate more than one type of cone. Due to differential stimulation of these three types of cones we can perceive all the colours. For example, the wave length, 580 nm stimulates the red cones maximally but the green cones to some extent and we see orange. Or, the wave length 700 nm will stimulate the red cones only to give sensation of red.

This way we can see more than 150 colours by these three types of cones. This is the trichromatic theory of colour vision and is also called **Young-Helmholtz theory**. When all the three types are stimulated maximally, the sensation of white is obtained; on the other hand, black means absence of colour.

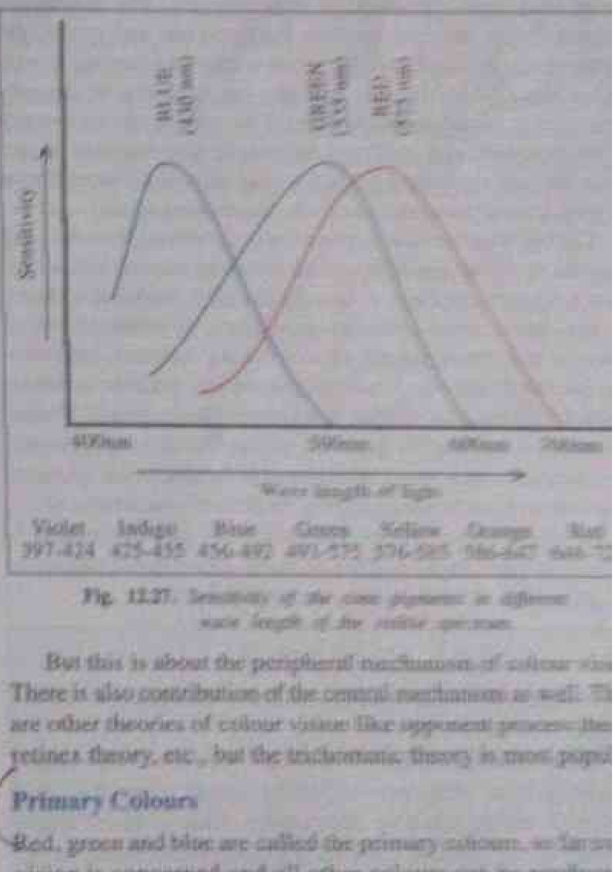

Fig. 12.27. *Sensitivity of the cone pigments to different wave length of the visible spectrum.*

But this is about the peripheral mechanism of colour vision. There is also contribution of the central mechanism as well. There are other theories of colour vision like opponent process theory, retinex theory, etc., but the trichromatic theory is most popular.

Primary Colours

Red, green and blue are called the primary colours, so far as vision is concerned and all other colours can be produced by proper mixture of these three colours.

Complementary colours

If two colours mixed in proper proportion, give a sensation of grey or white, then the colours are said to be complementary

Hearing

The sensory organs for hearing are the ears. Each ear is divided into three parts : external, middle and internal ear (Fig. 12.37). Though the mankind of today's civilised world is not dependent on this faculty like their ancestors for existence, but can derive a huge amount of information from the sounds around them. All the sound systems (man made or natural) are not meaningless because of this faculty.

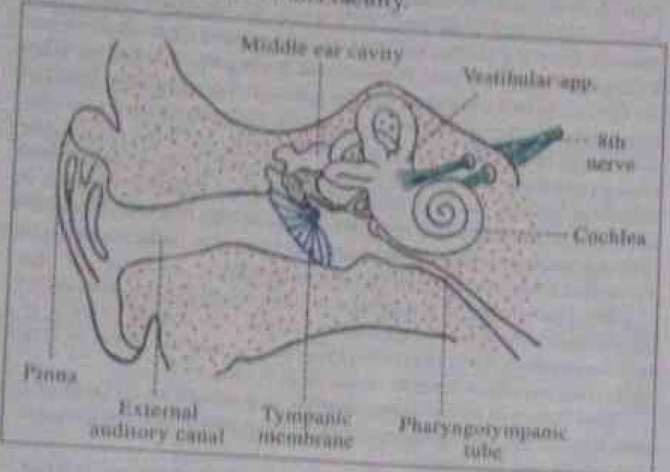

Fig. 12.37. *Ear.*

External ear is formed of the **pinna** and the **external auditory canal**. The pinna or the auricle, which adds to the facial beauty along with some role in collection of sound is formed of cartilage covered with skin excepting the lobule where cartilage is absent. The external auditory canal transmits the sound waves to the middle ear. It is a 24 mm long tube partly cartilaginous and partly bony. The outer part of the external auditory canal is directed medially, upwards and backwards. The inner part is directed medially, downward and forward. This direction is to be remembered when the external ear is to be inspected. The inner end of the canal is shut off by the tympanic membrane (TM) and the outer end is open (Fig. 12.37) to the exterior. Another function of the external ear is collection of **ear wax** which leads to a lot of trouble parti-cularly in young age. Ear wax is the secretion of ceruminous and sebaceous glands present here. The external ear receives sensory supply from 5th, 7th and 10th cranial nerves and also from the C_2 and C_3 segments of the spinal cord.

The **middle ear** is a box-like cavity filled with air, whose ateral wall is formed by the tympanic membrane and the edial wall, which separates it from the internal ear, has the val and the round window. The **tympanic membrane** (TM) shiny and pearl-grey in colour and shows various landmarks ig. 12.38). It makes an angle of 40 to 45° with the floor of e external auditory canal. It is formed of outer epidermal, ner mucosal layers and the lamina propria in between. The cosal layer is supplied by the 9th nerve.

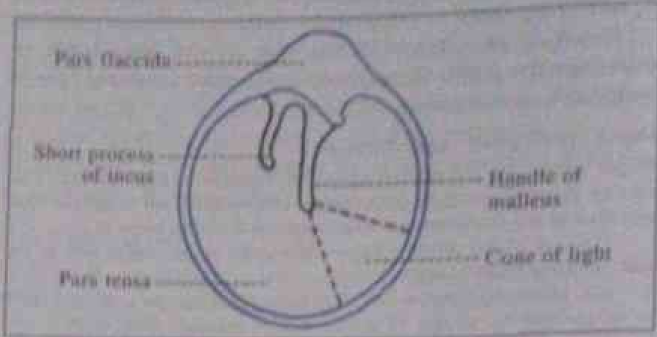

Fig. 12.38. *Tympanic membrane.*

The middle ear contains three ossicles in a chain : **malleus**, **incus** and **stapes** (Fig. 12.39) The handle of malleus is attached to the tympanic membrane (TM) and the foot plate of stapes to the oval window (Fig. 12.37). If the TM vibrates, the vibration is transmitted by these ossicles to the oval window with some magnification. There are two muscles in the middle ear:

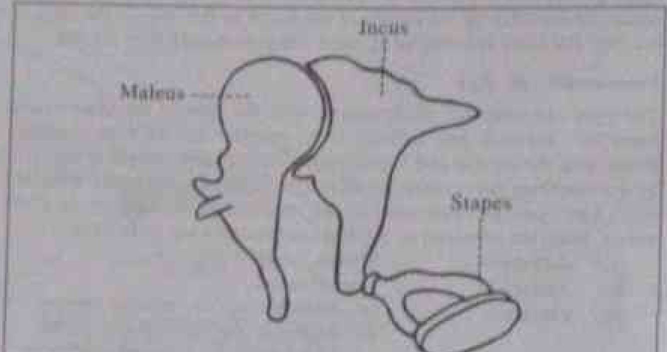

Fig. 12.39. *Middle ear ossicles.*

(i) the **tensor tympani** (supplied by the 5th cranial nerve) is attached to the handle of malleus, and

(ii) the **stapedius** supplied by the 7th cranial nerve is attached to the footplate of the stapes.

These muscles are protective in function (see below). The **eustachian tube** (pharyngotympanic or PT tube) connects the middle ear cavity with the pharynx and thus to the atmosphere; this keeps the middle ear air pressure equal to that of atmosphere. Therefore, the air pressure on the either side of the TM remains same and it can vibrate freely. It plays important role in aviation, mountaineering and space travel when the almospheric pressure varies.

The **internal ear** situated within the petrous part of the temporal bone is composed of the **vestibular apparatus** (see, section 11, chapter 10) and the **cochlea**. It is formed of a **membranous labyrinth** situated inside a bony labyrinth (Fig. 12.40A & B).

The membranous labyrinth contains a fluid, called endolymph and the space in between is filled by another fluid, called perilymph. The perilymph resembles ECF, whereas the endolymph has high K^+ and low Na^+ as in ICF.

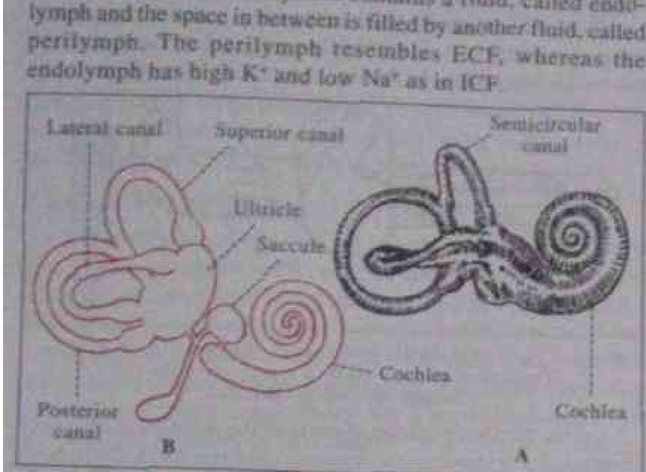

Fig. 12.40A. *Bony labyrinth.*
B. *Membranous labyrinth.*

The cochlea is a coiled tube made up of two and three-fourths turn of a three-tier system (Fig. 12.41). These three

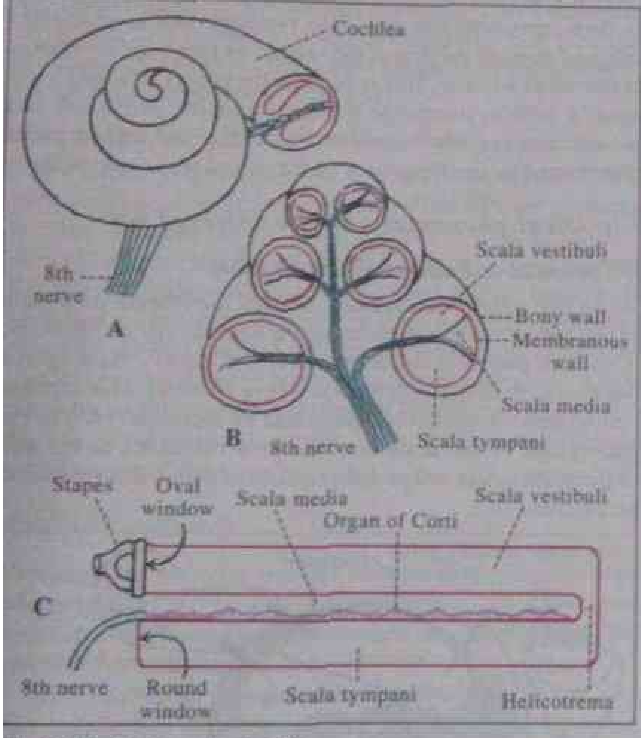

Fig. 12.41A. *Cochlea : A coiled tube.*
B. *Cochlea : Longitudinal section.* **C.** *Three tiers of the cochlea.*

rs, from above downwards are the **scala vestibuli**, **scala edia** and **scala tympani** (Fig. 12.42). The partitions forming se tiers are **Reissner's membrane** above and **basilar membane** below, *i.e.*, in between them is the scala media (the mbranous labyrinth of cochlea), which contains endolymph. e scala vestibuli and the scala tympani contain perilymph d are interconnected at the tip of the cochlea through an ning, called **helicotrema** (Fig. 12.41C). The basal end of the scala vestibuli is closed by the foot plate of stapes at the oval window and that of scala tympani is closed by the secondary TM at the round window. The bony labyrinth, with the membranous labyrinth inside, winds 2¾th turn around a bony axis, called **modiolus**. There is a bony spiral lamina around the modiolus which provides attachment to the Reissner's membrane and the basilar membrane and helps to form the three-tier system.

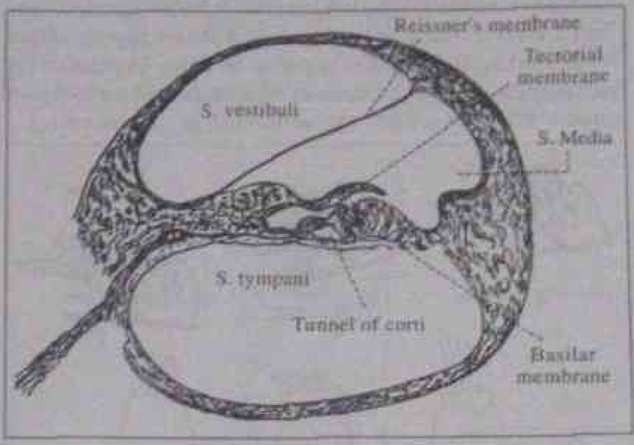

Fig. 12.42. *Showing the three tiers of cochlea.*

Organ of Corti

It is the sensory organ for hearing which receives sound energy and converts the same into nerve impulse. It is situated in the scala media over the basilar membrane and extends along the whole length of the cochlea (so, it is also called the **spiral organ of Corti**). The basilar membrane is wider (0·4 mm) at the apex and narrower (0·15 mm) towards the base of the cochlea and its length is 32 mm. It is taut at the basal part but is lax at the apical part.

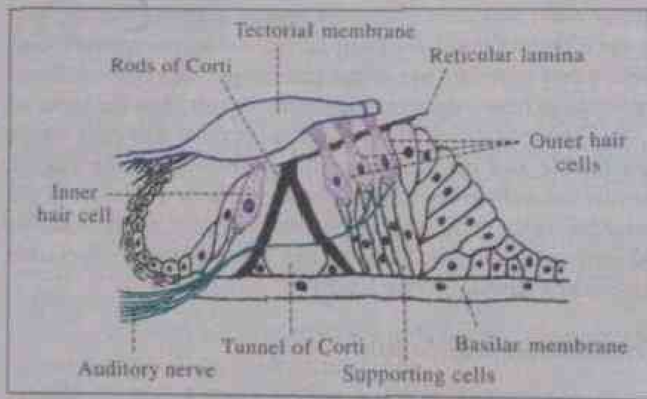

Fig. 12.43. *Organ of Corti.*

The organ of Corti is formed of hair cells (= receptors for sound) arranged on either side of the tunnel of Corti (Fig.12.43). The tunnel of Corti is formed by the rods of Corti and is filled by perilymph from below, *i.e.*, continuous with the perilymph of scala tympani. There are 3 to 4 rows of hair cells on the outer side and a single row on the inner side. There are about 3500 inner and about 20,000 outer hair cells. The hairs of those cells are directed upwards through a reticular lamina situated on the rods of corti. On the top of the hairs is the tectorial membrane; when there is movement of the basilar membrane along with the organ of Corti on it, due to passage of a sound, a shear force is produced due to relative lateral displacement of the basilar membrane against the tectorial membrane (Fig. 12.44). So, the hair cells move against the direction of movement of the tectorial membrane and it leads to bending of the cilia. If the cilia are moved towards the longest cilia on the basilar membrane (Fig 12.44D) the hair cells are depolarised and are hyperpolarised due to bending of the cilia in opposite direction. Depolarisation leads to release of neurotransmitter from the hair cells, which then initiates AP in the sensory nerves attached to the hair cells.

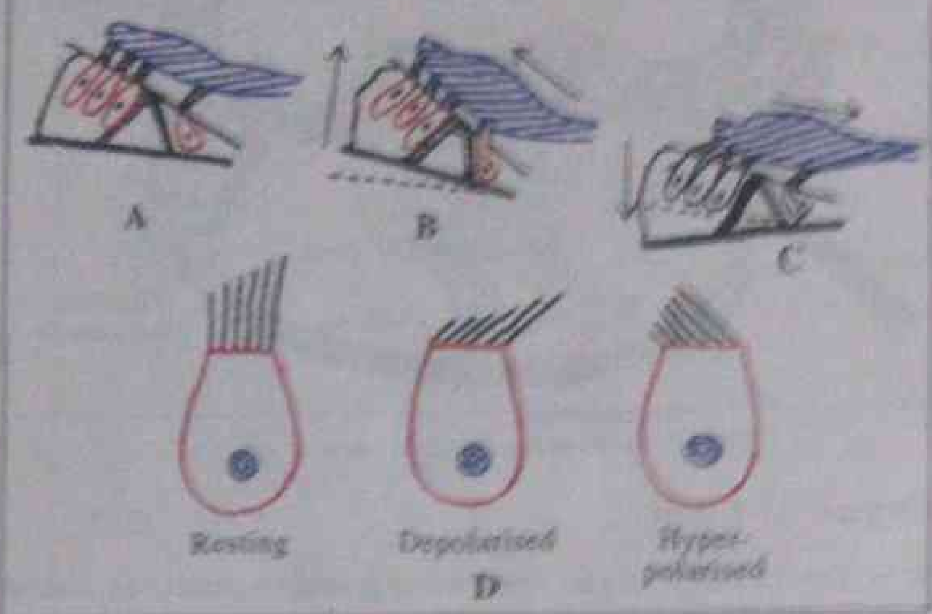

Fig. 12.44. *Showing movement of cochlear partition and bending of cilia of the hair cells.*
A. *Stationary.* **B.** *Upward movement.*
C. *Downward movement.* **D.** *Hair cells*

The hair cells are innervated by the afferent nerves of the cochlear division of the vestibulocochlear nerve. Each of the inner hair cells gets many nerve fibres but one nerve fibre supplies many outer hair cells (*i.e.,* convergence occurs). There is also some efferent fibres (olivocochlear bundle) to the organ of Corti, which end near the base of the hair cells. These efferent fibres believed to have role in regulating the signals from the organ of Corti. These fibres probably regulate the outer hair cells which are motile and can influence the movement of the basilar membrane and thereby improve hearing. Further the hairs of the outer hair cells, unlike that of the inner hair cells, are embedded in the tectorial membrane. The inner hair cells are mostly responsible for sending message to the brain.

3
CHAPTER

Gustation (Taste)

It is a chemical sense and gives taste of food or non-food materials placed in the mouth. It also helps to supply different grades of taste, *i.e.*, more sweet, less sweet, different qualities, *i.e.*, highly delicious, horrible, etc. Through this sensation, it is possible to detect an injurious food, which is of immense importance in case of lower animals, as it provides guards against harmful foods.

There are four basic or **primary taste sesations** : sweet, sour, salt and bitter. These are tasted in different parts of the tongue (Fig. 12.51) as follows :

(i) Sweet at the tip.
(ii) Sour along the sides.
(iii) Salt at the side of the dorsum on the anterior part.
(iv) Bitter at the back.

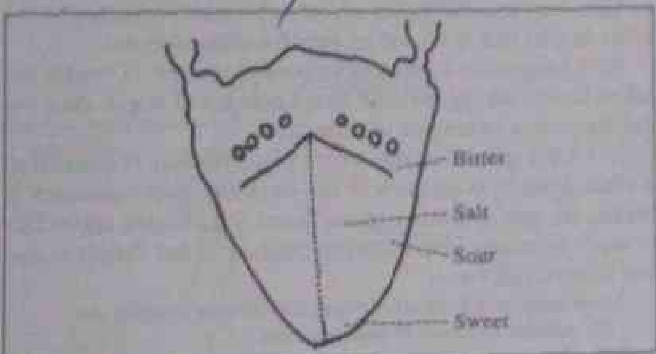

Fig. 12.51. *Dorsum of tongue showing the areas for primary taste sensations.*

Many other tastes, like spicy, crisp, etc., are produced with the help of the senses like temperature, pain, etc. Therefore, the trigeminal nerve has important role in taste sensation. Smell also adds to the sensation of taste. It means, in majority of cases the sensation of taste is a synthetic one. There seems to be a separate taste sensation for monosodium glutamate (umami).

Taste bud

The sense organ for gustation is the taste bud which contains the receptor cells. These taste buds are situated on the dorsum of the tongue everywhere except in the filiform papillae and are also present in palate, epiglottis, and in pharynx and larynx to some extent.

Taste buds are flask-shaped structures composed of many cells, and have openings at the tip, called taste pores. Each taste bud has two types of cells : the receptor cells and the supporting cells. Each receptor cell lives for about 10 days and is then replaced by new cell formed from the basal cells at the base of the taste buds. Each of these receptor cells have 6 to 18 hair like projections towards the taste pores (Fig. 12.52). These projections are called microvilli. The receptors mediating taste sensation, are situated on the membrane of these microvilli. The base of the receptor cells are in contact with the afferent nerve endings. These nerve fibres are myelinated and are supplied by the facial nerve to the anterior 2/3rd and by the glossopharyngeal to the posterior 1/3rd of the tongue. The vagus nerve supplies the taste buds present in the larynx, etc.

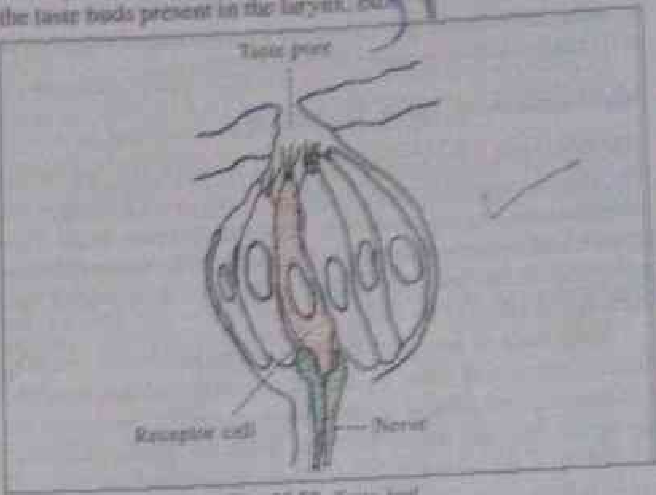

Fig. 12.52. *Taste bud.*

Pathway

The primary sensory neurones are situated in the geniculate ganglion (7th nerve) petrous ganglion (9th nerve) nodose

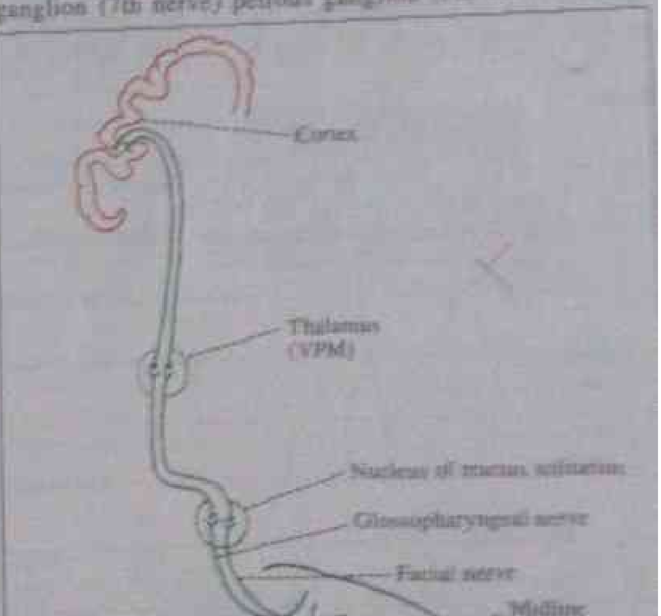

Fig. 12.53. *Taste pathway.*

Olfaction (Smell)

Olfaction is also a chemical sense like gustation. Here the substances which are smelled are volatile. These substances are called odorous substances. The sense of olfaction shows high degree of adaptation.

Area for receiving this sensation is situated at the roof of the nasal cavity (Fig. 12.54). Odorous substances reach here through air, but not by the normal respiratory movements of air, as it is well known that sneefing is necessary for optimum smell. Normally, this part of the mucous membrane is highly vascular and hence warm. This warmth produces convection current in the air and thus eddy, which helps to bring the odorous substance to the proper site.

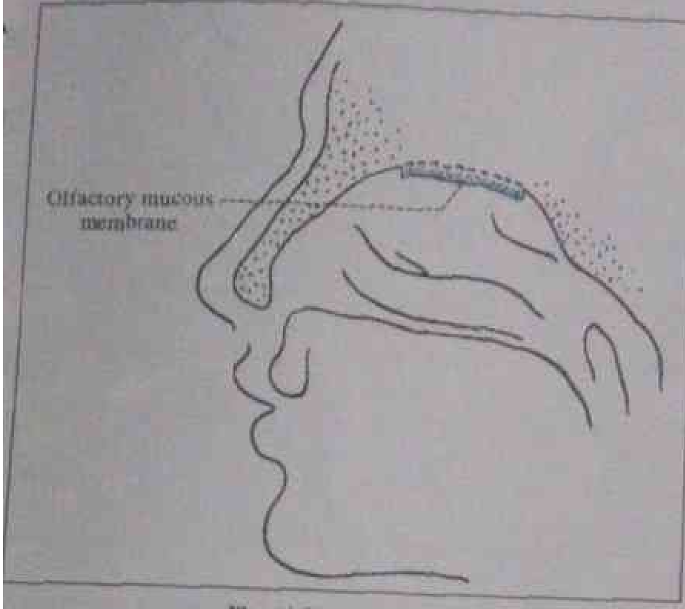

Fig. 12.54. *Nasal cavity.*

The area for olfaction is the olfactory mucous membrane. t is an area of about 5 cm^2 (including both sides) and is yellow n colour. The lining epithelium here is of pseudostratified iliated columnar variety and in between these cells are the lfactory receptor cells (10 to 20 million in number). These are e primary sensory neurones of olfaction.

These neurones have their enlarged dendritic ends ojected to the surface of the mucous membrane, called factory rods. From these rods project olfactory cilia ich have on their surface the receptors for the odorous lecules.

The substances to be smelled are dissolved at first in the retion on the surface of the mucous membrance. This retion comes from the **Bowman s glands** situated deep in mucous membrane. The dissolved odorous molecules then d to a carrier protein and are transported to the receptor ecules. The odorous molecules after binding to their ptors on the cilla, probably lead to opening of large number a$^+$ channels (via cAMP) and Na$^+$ entry (some authors state that it is due to Ca^{2+} *entry*). This creates the recept potential and leads to AP formation in the olfactory nerve But the problem is how the different odours are analysed a perceived.

Various theories are there though none is satisfactory, *e.g.*,

(1) **Receptacle theory** : The receptors have receptacle li structures and only a specific odorous molecule can attach to a speci receptacle.

(2) **Vibration theory** : Different odorant molecules have differe frequency of vibration. These molecular vibrations are detected by t sensory system through the identically tuned receptors.

Presently it is beleived that there are hundreds of different odora receptors. A receptor can be stimulated by many odours. Particul olfactory quality needs stimulation of many receptors and final analy is done at higher levels of CNS. There are various primary smells li taste e.g., floral aroused by the smell of rose, pungent aroused by rott egg. There are other primary sensations like ethereal, musk, campho vinegar, etc. But it is realy difficult to explain how the human bei can identify 10000 different odours.

Olfactory pathway

The olfactory neurones, *i.e.*, the receptor cells are the prima sensory neurones. The axons of these neurones, called olfacto nerves, directly enter into the brain. Unlike all other senso system this sensation bypasses the thalamus. The olfactory nerv pass through the holes in the cribriform plate of the ethmoid bo (Fig. 12.55). These axons form glomeruli in the olfactory bulb The glomerulus is a type of synapse found in other parts of CN also. In the glomeruli about 26000 receptor cells converge to mitral cells. These glomeruli are formed by the axons of t

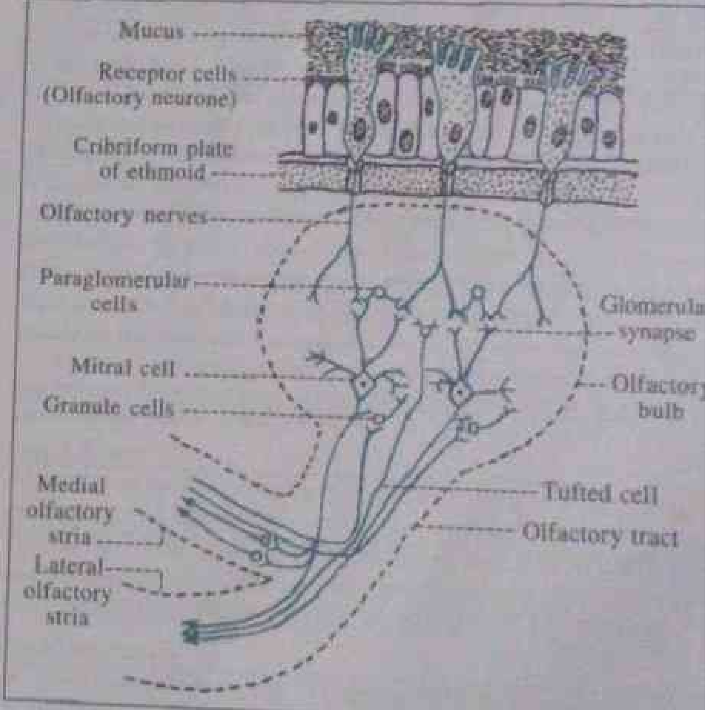

Fig. 12.55. *Olfactory pathway.*

olfactory neurones, dendrites of the mitral cells, tufted cells, paraglomerular cells, etc. In the olfactory bulb there are granule cells which synapse reciprocally with the mitral cell dentrites. The granule cells also receive centrifugal fibres.

The axons of the mitral cells and tufted cells form the olfactory tract, which proceed backwards and divide into medial and lateral olfactory striae which terminate as follows. (It should be remembered that this sensation reach the cerebral cortex without relaying in the thalamus).

(a) The medial olfactory stria cross to the opposite side via anterior olfactory nucleus for co-ordination of sensation between the two sides.

(b) The lateral olfactory stria distributes fibres to the different parts of the brain as follows :

(*i*) To the olfactory tubercle.

(*ii*) *To amygdala* for emotional responses. From the amygdala information travels via the medial forebrain bundle to the reticular formation *for* arousal and *to* hypothalamus *for* autonomic and endocrine effects.

(*iii*) To periamygdaloid and prepyriform cortices for olfactory discrimination and conscious perception.

(*iv*) To hippocampus, etc. for olfactory memory.

This means, it is extensively connected to the limbic system and the sense of olfaction is related to the activities of this system.

The parts of the brain, which receive olfactory connections, were called together as the nosebrain or rhinencephalon. This nosebrain is comparatively larger in animals who depend more on smell sensation for their survival, *e.g.*, fox. The olfactory bulb is also larger in them. In human, the size of this part of brain is quite small in comparison to the size of the whole brain. Further, this is now called limbic system (p. 464) and olfaction is only one of its many functions.

Some terms used to describe the abnormality in the sense of smell are :

Anosmia = Absence of the sensation of smell
Hyposmia = Decreased olfactory sensitivity
Dysosmia = Distorted sense of smell.

Notes