visit our website **www.ejaypee.com,** for detailed information on physiology books, visit our website **www.ejaypee.com,** for detailed information on physiology books, visit our website **www.ejaypee.com,**

diginerve®
A Jaypee Initiative
• Video Lectures • Dr. Wise AI Chatbot
• Question Bank • Notes
Download App

3rd Edition

PHYSICON

The Reliable Icon in

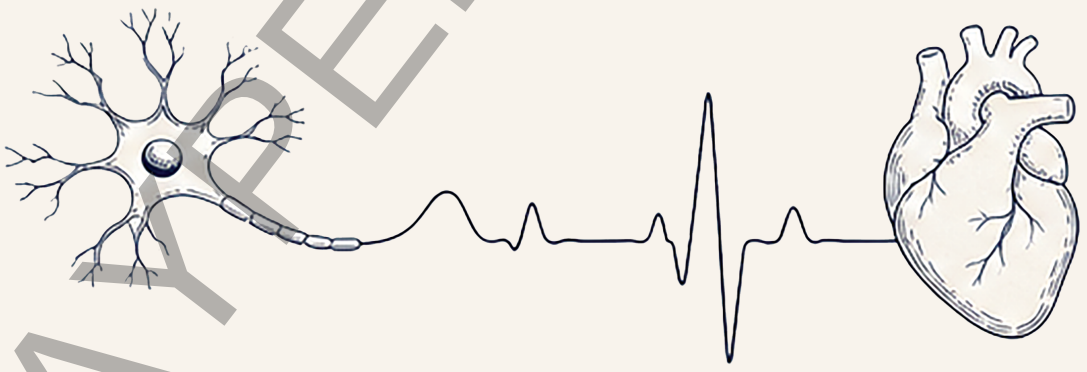
PHYSIOLOGY

EXAM PREPARATORY MANUAL

FOR UNDERGRADUATES

As per the Revised Competency-based Medical Education Curriculum (NMC)

THEORY SIMPLIFIED | **PRACTICALS & VIVA** | **CLINICAL CORRELATIONS** | **MCQs & REASONING QUESTIONS**



Revised by

Avi Sanjaykumar Borkhatariya

Sanoop KS • Mridul GS • Nishanth PS

Foreword
N Geetha

JAYPEE

JAYPEE BROTHERS

Contents

Section I: Theory

1. General Physiology 3

- Transport Across Cell Membrane *3*
- Body Fluid Compartments *7*
- Apoptosis *9*
- Intercellular Connections *10*
- Action Potential *11*
- Recording of Membrane Potential *14*
- Gibbs-Donnan Effect *15*
- Cell Structure *16*
- Homeostasis *21*

2. Circulating Body Fluids 23

- Blood *23*
- Plasma Proteins *24*
- Hemoglobin *25*
- Erythrocytes (RBC) *29*
- Hemopoiesis *30*
- Leukocytes *35*
- Platelets *38*
- Hemostasis *38*
- Blood Groups *42*
- Immunity *44*
- Lymphatic System *48*

3. Respiratory System 53

- Functional Anatomy of Respiratory Tract *53*
- Respiratory Membrane *54*
- Mechanism of Breathing/Ventilation *56*
- Transport of Gases *65*
- Regulation of Respiration *69*
- Applied Physiology *75*
- High Altitude Physiology *81*

4. Cardiovascular System 85

- Cardiovascular System *85*
- Organization of the Vascular System *86*
- Hemodynamics *87*
- Properties of Cardiac Muscle *89*
- Functional Anatomy of Heart *92*
- Cardiac Cycle *96*
- Arterial Pulse *103*
- Heart Sounds *104*
- ECG *104*
- Heart Block *110*
- Cardiac Output *113*
- Stroke Volume *114*
- Heart Rate *115*
- Blood Pressure *119*
- Local and Systemic Cardiovascular Regulatory Mechanism *124*
- Coronary Circulation *125*
- Cerebral Circulation *126*
- Cerebrospinal Fluid *127*
- Pulmonary Circulation *128*
- Fetal Circulation *130*
- Cutaneous Circulation and Triple Response *130*
- Circulatory Shock *132*
- Cardiac Arrhythmias *135*
- Cardiac Failure *137*

5. Gastrointestinal System 140

- Physiological and Functional Anatomy of GIT *140*
- Saliva *142*
- Stomach and its Secretion *143*
- Pancreatic Juice *149*
- Liver *150*
- Gallbladder *151*
- Small Intestine *154*
- Large Intestine *154*
- Movements of GIT *154*
- Gastric Movements *156*
- Movements of Small Intestine *158*
- Movements of Large Intestine/Colon *159*
- Digestion and Absorption *160*
- Gastrointestinal Hormones *165*

6. Renal Physiology 169

- Introduction and Functional Anatomy of Kidney *169*
- Nephron *170*
- Juxtaglomerular Apparatus *172*
- Renal Circulation *173*
- Mechanism of Urine Formation *176*
- Concentration of Urine *184*
- Acidification of Urine *186*
- Renal Clearance Tests *188*
- Micturition *189*
- Diuresis *192*
- Dialysis *193*

JAYPEE BROTHERS

7. Temperature Regulation 195
- Body Temperature Regulation *195*
- Central Regulation of Temperature *196*
- Fever *197*
- Conditions of Heat Stress *197*

8. Endocrinology 199
- Pituitary Gland *202*
- Thyroid Gland *210*
- Parathyroid Glands *215*
- Pineal Gland *221*
- Pancreas *221*
- Adrenal Cortex *226*
- Adrenal Medulla *230*

9. Reproductive System 235
- Sex Determination and Sex Differentiation *236*
- Abnormal Sexual Differentiation *236*
- Male Reproductive System *237*
- Female Reproductive System *241*
- Pregnancy *247*
- Contraception *254*
- Infertility and IVF *257*

10. Nerve and Muscle Physiology 259
- Neuron *259*
- Neuromuscular Junction *265*
- Skeletal Muscle *267*
- Energy Source and Muscle Metabolism *272*
- Smooth Muscle *273*
- Cardiac Muscle *275*

11. Central Nervous System 278
- Introduction and Organization of Nervous System *279*
- Synapse *279*
- Receptors *287*
- Reflexes *289*
- Sensory System *294*
- Pain Sensation *300*
- Motor System *302*
- Autonomic Nervous System *308*
- Spinal Cord Lesions *310*
- Regulation of Posture *314*
- Reticular Formation *318*
- Cerebellum *319*
- Thalamus *323*
- Electroencephalogram *324*
- Sleep *326*
- Basal Ganglia *328*
- Hypothalamus *332*
- Cortical Areas *335*
- Limbic System *338*
- Higher Functions of Nervous System *339*
- Learning and Memory *342*
- Gait *343*

12. Special Senses 347
- Vision *347*
- Audition *357*
- Vestibular Apparatus *361*
- Sensation of Taste *364*
- Olfaction *366*

13. Integrated Physiology 369
- Cardiovascular Changes in Exercise *369*
- Respiratory Changes in Exercise *370*
- Physiology of Ageing, Free Radicals, and Antioxidants *372*
- Physiology of Infancy *373*

Section II: Practicals

14. Hematology 379
- Determination of Erythrocyte Sedimentation Rate *379*
- Packed Cell Volume (Hematocrit) *381*
- Estimation of Hemoglobin (Sahli's Method) *382*
- RBC Count *384*
- WBC Count *385*
- DLC *387*
- Determination of Blood Group *388*
- Reticulocyte Count *388*
- Platelet Count *389*
- Bleeding Time and Clotting Time *390*
- Absolute Eosinophil Count *391*

15. Amphibian Experiments 392
- Gastrocnemius Muscle and Sciatic Nerve Preparation of Frog *392*
- Recording of a Simple Muscle Curve *392*
- Effect of Two Successive Stimuli on Skeletal Muscle *393*
- Effect of Temperature on Simple Muscle Twitch *394*
- Genesis of Fatigue *395*
- Effect of Afterload and Free-Load on Muscle Contraction *395*
- Genesis of Tetanus *396*

JAYPEE BROTHERS

- Velocity of Nerve Impulse *397*
- Amphibian Heart Experiments *397*

16. Clinical Examinations **402**

- Clinical Examination Proforma *402*
- Human Arterial *403*
- Examination of Respiratory System *405*
- Examination of Cardiovascular System *406*
- Examination of Higher Functions and Sensory System *408*
- Examination of Motor System *409*
- Examination of Cranial Nerve *410*
- Examination of Reflexes *415*

Section III: Extra Mile

17. Multiple Choice Questions **419**

- General Physiology *419*
- Circulating Body Fluids *420*
- Respiratory System *424*
- Cardiovascular System *429*
- Gastrointestinal System *433*
- Renal Physiology *437*
- Reproductive System *440*
- Endocrinology *443*
- Nerve Muscle Physiology *447*
- Central Nervous System *450*
- Special Senses *457*

18. Reasoning Type Questions **463**

- Circulating Body Fluids *463*
- Respiratory System *463*
- Cardiovascular System *464*
- Gastrointestinal System *465*
- Renal Physiology *465*
- Endocrinology *466*
- Reproductive System *467*
- Central Nervous System *467*
- Special Senses *468*

19. Calculations **469**

20. Common Laboratory Values **473**

- Circulating Body Fluids *473*
- Respiratory System *473*
- Cardiovascular System *474*
- Gastrointestinal System *474*
- Renal Physiology *474*
- Endocrinology *475*
- Reproductive System *475*
- Nerve and Muscle Physiology *475*
- Central Nervous System *475*
- Special Senses *475*
- General *475*

Appendix 477

Index 481

JAYPEE BROTHERS

Chapter

12 Special Senses

Competencies

PY11.1 Describe and discuss physiology of smell and its applied aspects.

PY11.2 Describe and discuss physiology of taste sensation and applied aspects.

PY11.3 Describe and discuss functional anatomy of ear and auditory pathways, vestibular apparatus and equilibrium.

PY11.4 Discuss physiology of hearing, pathophysiology of deafness and hearing tests.

PY11.5 Discuss functional anatomy of eye, visual pathway, light and pupillary reflex and clinical implication of lesions in visual pathway.

PY11.6 Discuss physiology of image formation, refractive errors and physiological principles of its management.

PY11.7 Discuss physiology of vision including color vision and color blindness.

JAYPEE BROTHERS

PY11.5: VISION

Structure of the Eye

The eye **(Fig. 12.1)** is a special organ of the sense of sight. In the adult human eyeball, the A-P diameter is about 24 mm. The human eyeball has three principal layers:

1. Outer protective layer, sclera
2. Middle vascular layer, choroid (uveal tract)
3. Inner neural retina (lines the posterior 2/3rd of the choroid).

The light rays enter through the transparent cornea (sclera is modified anteriorly to form transparent cornea). The crystalline lens is a transparent structure held in place by suspensory ligament (zonule). The zonule is attached to thickened rim of smooth muscle, the ciliary body. The functions of the ciliary body are:

- Formation of aqueous humor
- Keeps lens in position.

The ciliary body contains circular and longitudinal muscle fibers that attach near the corneoscleral junction. In front of the lens, lies the pigmented and opaque iris (colored portion of the eye). Iris has two sets of smooth muscles:

1. Sphincter pupillae (circular) constricts the pupil and is supplied by parasympathetic fibers through oculomotor nerve (nucleus is Edinger–Westphal).
2. Dilator pupillae (radial) is supplied by sympathetic fibers.

Retina

The retina extends from the margin of the optic disk to just behind the ciliary body where it ends abruptly as a

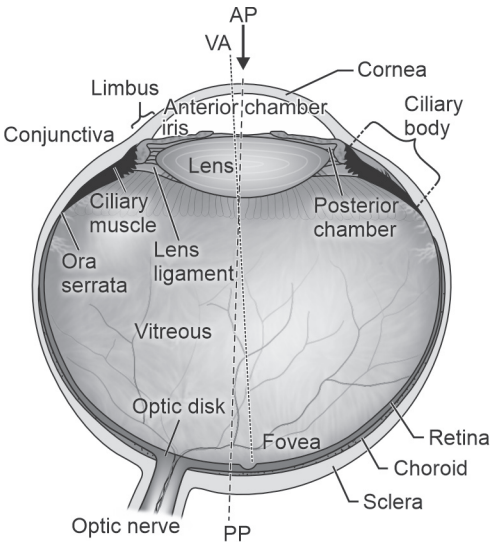


Fig. 12.1: Structure of eye.

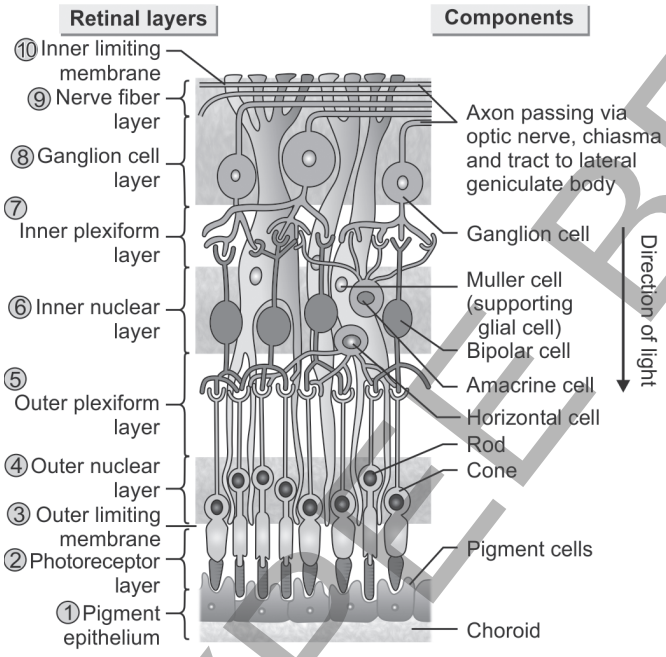


Fig. 12.2: Layers of retina.

dentated border known as ora serrata. It is organized in 10 layers and contains the rods and cones, which are the visual receptors **(Fig. 12.2)**.

Retina has four types of neurons; bipolar cells, ganglion cells, horizontal cells and amacrine cells. The rods and cones which are next to the choroids, synapse with bipolar cells, and the bipolar cells synapse ganglion cells. The axons of ganglion cells converge and leave the eye as the optic nerve. Horizontal cells connect receptor cells to other receptor cells in the outer plexiform layer. Amacrine cells connect ganglion cells to one another in the inner plexiform layer via processes of varying length and patterns. The neural elements of retina are bound together by glial cells called **Muller cells**. The processes of these cells form an internal limiting membrane on the inner surface of the retina and an external limiting membrane in the receptor layer. Optic nerve leaves retina from optic disk which lies 3 mm medial to and slightly above posterior pole.

Fundus Oculi/Fundus

The posterior part of interior of the eyeball is called fundus oculi or fundus. The fundus can be examined by ophthalmoscope. The fundus has two important structures:

1. **Optic disc/blind spot:** It is situated near the center of the posterior wall of eyeball. Optic disc (1.5 mm in diameter) is formed by the convergence of axons from ganglion cells. It contains all the layers of retina except rods and cones. Therefore, it is insensitive to light (object is not seen if image falls on this area). Because of this, the optic disc is known as **blind spot**.
2. **Macula lutea/yellow spot:** Near the posterior pole of the eye is a yellowish pigmented spot called macula lutea (5.5 mm in diameter). The central 1.5 mm of the macula is termed as fovea, which has a small, central depression called *foveola*. The fovea is region of greatest acuity of vision as it contains:
   a. Only cones
   b. Each cone directly relays to a single cone
   c. Wide presentation in occipital primary visual area
   d. All layers of retina are shifted aside leaving cones to be hit directly by the light.

Vitreous Humor

Space between lens and the retina is filled primarily with a clear gelatinous material called vitreous humor containing water, collagen fibrils, mucopolysaccharides and hyaluronic acid.

Functions

- Prevents collapse of the eyeball.
- Helps in maintaining normal intraocular pressure.
- Keeps intraocular structures in position and thus helps in normal positioning of image on retina.

Aqueous Humor

Aqueous humor is a thin clear liquid that fills the space between the lens and cornea. It is produced in the ciliary body by ultrafiltration and active transport from the plasma at the rate of 2 mm^3/min. It flows through the pupil and fills the anterior chamber of the eye. It is normally reabsorbed

JAYPEE BROTHERS

through a network of trabeculae into the canal of Schlemm and uveoscleral outflow (venous channel at the junction between iris and cornea). Refractive index of aqueous humor is 1.336 and pH is 7.1–7.3. The space between the lens and cornea is divided into anterior and posterior chamber by iris. Space between iris and cornea is anterior chamber, space between iris and lens is posterior chamber. Both the chambers are filled with aqueous humor and they communicate with each other through the pupil.

Functions

- Helps to maintain normal intraocular pressure.
- It is the 2nd medium of refraction.
- Provides nutrition to cornea and lens.
- Takes the place of lymph that is absent in eye.

Contents

Protein, electrolytes (Na^+, K^+, HCO_3^-, Cl^-), nonelectrolytes (glucose, urea and uric acid), organic acid (ascorbic acid, lactic acid and hyaluronic acid), dissolved O_2.

Mechanism of formation

Mainly ultrafiltration and some amount by active secretion.

Circulation of aqueous humor: Formed in posterior chamber by ciliary processes.

Posterior chamber → pupil → anterior chamber → canal of Schlemm (at the limbus) → episcleral venous plexus. Circulation is necessary for both metabolic process and to regulate the intraocular pressure.

Note: Any disturbance in this normal flow may increase the intraocular tension leading to glaucoma.

Glaucoma

It is a degenerative disease in which there is loss of retinal ganglia cells. Obstruction of canal of Schlemm leads to increased intraocular pressure. There are two types of glaucoma:

1. **Open angle glaucoma:** Here the cause of increased pressure is decreased permeability through the trabecular meshwork, through which aqueous humor is drained.
2. **Angle-closure glaucoma:** Here there is forward movement of iris, which obliterates the anterior chamber angle (angle between the iris and the cornea) thereby block the opening of trabecular meshwork at the angle.

Normal intraocular pressure is 10–21 mm Hg. Pressure in venous plexus is 10–15 mm Hg. This difference helps in continuous drainage of aqueous humor to venous plexus. The two important factors maintaining normal intraocular pressure are rate of formation and rate of reabsorption.

Visual Process

Receptors

The receptors (photoreceptors) of retina are rods and cones. Rods and cones communicate their message to bipolar cells. Bipolar cells, in turn, pass on the message to ganglion cells. The axon of ganglion cells forms the optic nerve which leaves the eye to reach the brain. Although there are approximately 100–120 million rods and cones, there are only about one million ganglion cells, indicating considerable convergence. That means there is no one-to-one relationship of photoreceptors with bipolar cells and ganglion cells (except at fovea).

The two photoreceptors differ from each other in several ways. Rods and cones differ in number, structure, retinal distribution, photochemical molecules, sensitivity, wavelength, color, synaptic connections and functions. There is total 100–120 million photoreceptors (rods and cones) in each eye, the ratio of rods to cones being 20:1. Number of rods is about 90–100 millions and of cones is approximately is 3–6 millions.

Although the total number of rods is much more than cones, there is small area in the central retina which has more cones than rods. This area is called the **macula lutea** (macula). At the center of macula, there is a small area called as fovea centralis (fovea). The center of fovea, i.e., foveola contains only cones and no rods. The extremely high density of cones in the fovea and the one-to-one relationship with bipolar and ganglion cells (i.e., no convergence), endows this region with the capacity to mediate high visual acuity. As the cone density declines with eccentricity (periphery) and the degree of convergence onto retinal ganglion cells increases, acuity is markedly reduced. Visual pathway starts from receptors that respond to electromagnetic stimulation. Each rod and cone **(Fig. 12.3)** is divided into an outer segment, an inner segment that includes a nuclear region and a synaptic zone. The outer segments are modified cilia and are made up of regular stacks of flattened saccules or disks composed of membrane. These saccules and disks contain the photosensitive compounds that react to light, initiating action potentials in the visual pathways. The inner segments are rich in mitochondria. The rods are named for the thin, rod like appearance of their outer segments. Cones generally have thick inner segments and conical outer segments **(Table 12.1)**.

Photoreceptor Mechanism

Visual or phototransduction is the process by which light energy is converted into receptor potential in visual receptors. The potential changes that initiate action potentials in the retina are generated by the action of light

JAYPEE BROTHERS

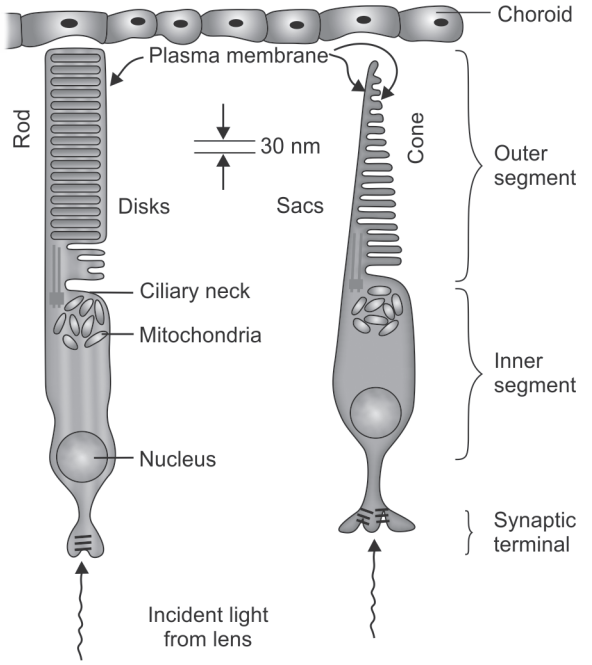


Fig. 12.3: Electron microscopic appearance of rods and cones.

Table 12.1: Difference between rods and cones.

Rods	***Cones***
Outer segment is rod shaped with regular stocks of membranes disks	Outer segment is cone shaped
Disks or saccules are separated from the cell membrane	Disks are infoldings of cell membrane
Has photo pigment called rhodopsin. It contains opsin (scotopsin) and vitamin C	Three types of cone pigments; erythrolabe (red), cyanolabe (blue), chlorolabe (green)
Except in fovea, rods predominate	Abundant in fovea
Helps in dim light vision	Helps in bright light vision, color vision, visual acuity
There are 120 million rods	There are 6 million cones

on photosensitive compounds in rods and cones. The conformational change which happens when light falls on these substances triggers a sequence of events that initiate generation of action potential.

Ionic basis

In the dark Na^+ channels in the outer segments of the photoreceptors are kept open by cGMP, so there is a steady current flow from the inner to the outer segments of the rods. The steady current also flows in the synaptic ending of the photoreceptors. Light leads to increased conversion of cGMP to 5´–GMP, resulting in the closing of Na^+ channels (due to decrease in concentration of cGMP). This decreases current flow and resulting hyperpolarization generates local graded potentials (generator potential) in the synaptic terminal of the photoreceptor. In the dark, retinine 1 in rhodopsin is present in 11 *cis* configuration **(Figs. 12.4 and 12.5)**.

*Development of receptor potential or phototransduction **(Fig. 12.6)***

It is a local graded potential generated in the ganglion cells only. The sequence of events involved in phototransduction of rods and cones are:

Light stimulus → structural changes in the retinine 1 of rhodopsin (11 *cis* retinene → all transretinine) → conformational change of opsin → activation of transducin (G protein; Gt 1 in rods and Gt 2 in cones) → α subunit separates from G protein → activation of phosphodiesterase converts cGMP → 5'GMP → decreased intracellular concentration of cGMP → closure of Na^+ channels → hyperpolarization of receptor → decreased release of synaptic transmitter (glutamate) cause disinhibition of bipolar cells and thus an action potential develops in ganglion cells.

Dark Adaptation

When a person enters a dark room from a brightly lit outdoor, at first, he sees nothing but gradually gets adapted to the dark.

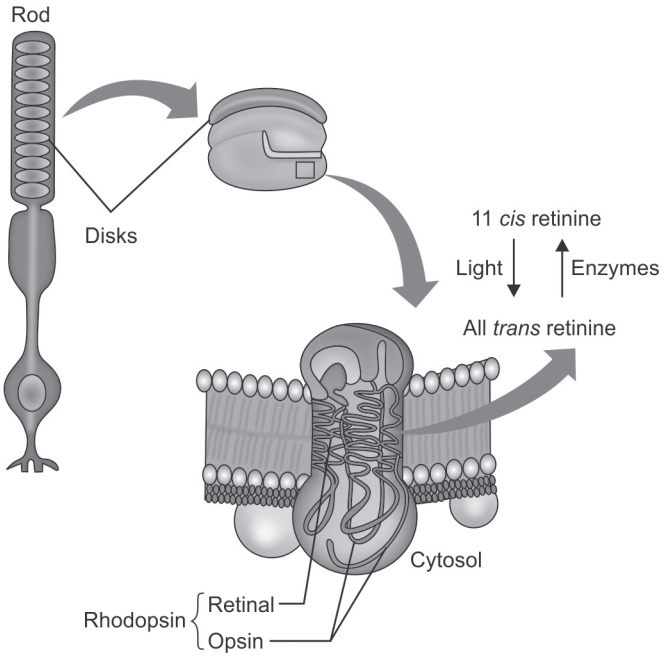


Fig. 12.4: Ionic basis of photoreceptor mechanism.

JAYPEE BROTHERS

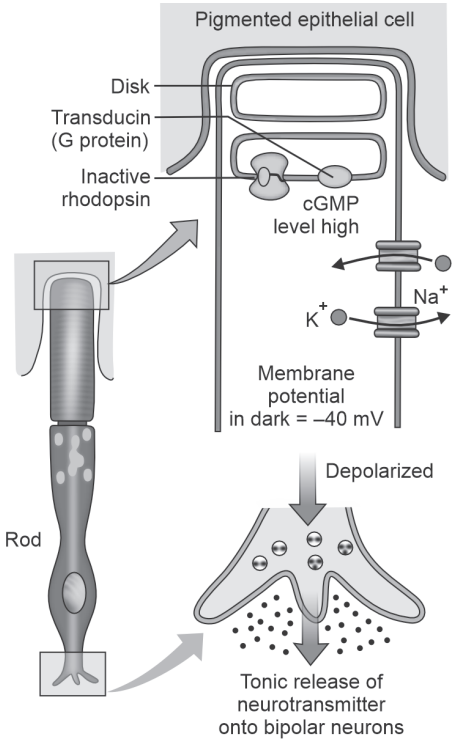


Fig. 12.5: Events involved in the depolarization step (in dark) of phototransduction in rods and cones.

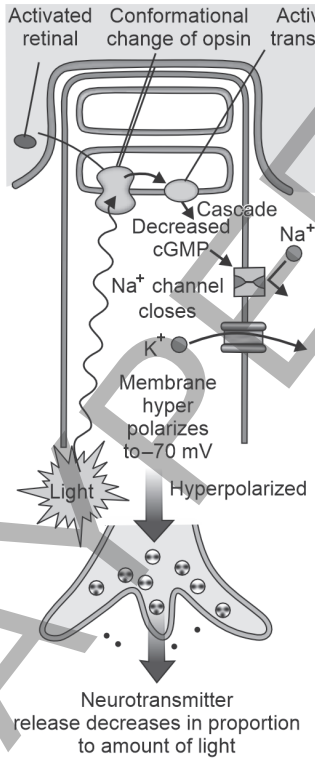


Fig. 12.6: Events involved in the hyperpolarization (activation) step of phototransduction in rods and cones.

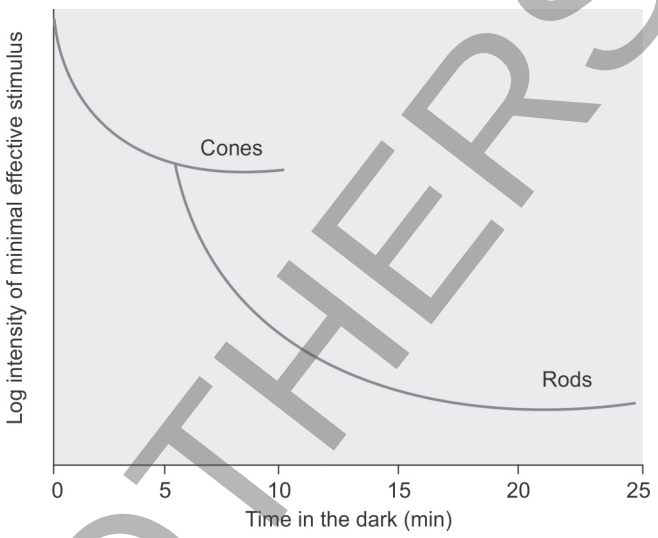


Fig. 12.7: The curve shows the change in the intensity of a stimulus necessary to just excite the retina in dim light as a function of the time the observer has been in the dark.

Reason

In bright light, vision was only due to cones. Cones have high threshold for stimulation. So, when the person enters a darkroom, the low intensity light that is available in the dark is unable to stimulate cones, but visual perception improves quickly at first and more slowly thereafter. This decrease in visual threshold and increase in sensitivity of eye to light is dark adaptation **(Fig. 12.7)**

There are two components for this:

1. **Fast response:** This is first drop in visual threshold and is rapid due to dark adaptation of cones. This is called paradoxical adaptation of cones. Its duration is 4–5 minutes.
2. **Slow response:** Further drop in visual threshold occurs over a period of 20–25 minutes due to dark adaptation of rods. Time for dark adaptation depends on time taken for resynthesis of rhodopsin.

Important Changes

- Dilatation of pupil (mydriasis).
- Change of photoreceptors from cones to rods.
- Resynthesis of rhodopsin (occurs when the activated rhodopsin is inactivated by the enzyme rhodopsin kinase thereby a reversal of all reactions occurs).

Light Adaptation

When one passes suddenly from a dim to a brightly lit environment, the light seems intense until the eyes adapt to the increased illumination. This adaptation occurs over a period of about 5 minutes and is called

JAYPEE BROTHERS

light adaptation. Photoreceptors signal light by decreasing their neurotransmitter output. Intense light reduces their neurotransmitter output to zero so that no further decrease is possible. This renders rods useless for signaling bright light, but the neurotransmitter output of cones gradually increases again even in the continued presence of bright light. Ca^{2+} plays an important role in this recovery of conal sensitivity to bright light. When light falls on the cone, there is closure of Na^{+} channels resulting in membrane hyperpolarization. The hyperpolarization causes closure of Ca^{2+} channels, resulting in a reduction in intracellular Ca^{2+}. Intracellular Ca^{2+} normally inhibits guanylyl cyclase; the enzyme that converts GTP into cGMP. A low intracellular Ca^{2+} therefore elevates intracellular cGMP levels. The cGMP keeps the Na^{+} channels open, leading to the depolarization of the outer segment and the resumption of neurotransmitter output.

Visual Acuity

It is the degree to which the details and contours of objects are perceived. It is usually defined in terms of the minimum separable, i.e., the shortest distance by which two lines can be separated and still be perceived as two lines. It is tested using Snellen letter charts. Normally, Snellen's letter charts are viewed at a distance of 20 ft (6 m). It is 20/20 normally.

Visual Fields

Visual field of each eye is the portion of the external world visible out of that eye. It can be mapped using perimeter. The extent of normal visual field with a 5 mm white color object is superiorly 50°, nasally 60°, inferiorly 70°, temporally 90°.

Duplicity Theory

The rods are extremely sensitive to light and they are receptors for night vision (scotopic vision). Cones have high threshold for stimulation (photopic vision), i.e., there are two types of inputs from rods and cones to central nervous system. The existence of these two types of inputs working maximally under different degrees of stimulation is known as duplicity theory.

Optics of Eye

When a ray of light passing from one media to another having different refractive index, it refracts or bends; greater the difference in refractive index greater will be the refraction. Light passes through the following refractive medias: Cornea → Aqueous humor → Lens → Vitreous humor.

Power of lens (in diopter) = 1/f (in meter)

All parallel rays that strike on biconvex lens get refracted and converge to a point; this point is called focus. Difference between optical center of lens and focus is called focal length.

Reduced Eye

Due to the differences in the refractive indices of the eye structures, the refraction of light is complex. Therefore, compound eye refraction can be simplified as reduced or schematic eye as proposed by listing. The reduced eye of listing is 24 mm long in AP diameter **(Fig. 12.8)**. It consists of a single refracting plane (resultant of all refractive media in the eye) situated 1.5 mm behind the anterior surface of cornea and a single nodal point N (nodal point-center of optical system). A ray passing through nodal point suffers no refraction. In Listing's reduced eye, the nodal point is 17 mm anterior to retina (focal length of the optical system). Hence, power of the single lens of Listing's eye (equivalent to combined powers of all lenses of natural eye) is about 59 D (1000/17).

Visual Pathway

It is a three-order neuronal pathway. The visual fibers arise in the layer of nerve cells (bipolar and ganglion cells) in the retina.

1. **1st order neuron:** These are bipolar cells with which receptors synapse. It is of 3 types: rod bipolar cell with rods, flat bipolar cell with cones, midget bipolar cell. Bipolar cell synapse with ganglion cell.
2. **2nd order neuron:** These are ganglion cells. Ganglion cells are of two types: Large Magno and small parvo. Axons of ganglion cells emerge out of the eyeball as optic nerve. Optic nerve consists of two groups of fibers:
   a. Fibers from the nasal half of retina which carry light sensation from temporal half of field of vision.

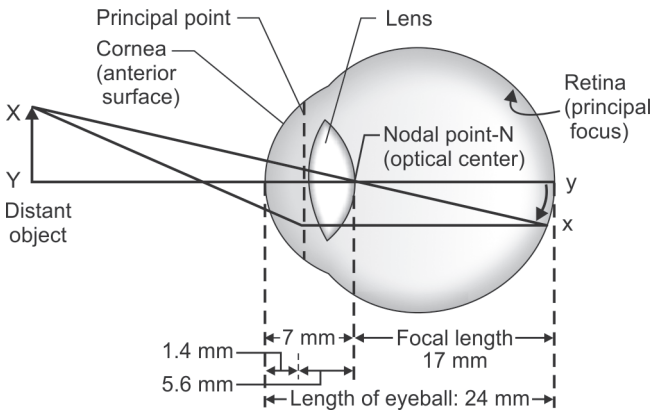


Fig. 12.8: Reduced/schematic eye.

JAYPEE BROTHERS

b. Fibers from temporal half of retina which carry light sensation from nasal half of field of vision.

Partial crossing of optic nerve fibers occurs at optic chiasma and two optic tracts are thus formed. The optic tract ends in lateral geniculate body (LGB).

3. **3rd order neurons:** These arise from LGB and ends in visual cortex. LGB has six layers, the layer 1 and 2 of LGB form magnocellular pathway and from layers 3–6 parvocellular pathway projects to visual cortex **(Fig. 12.9)**.

Magnocellular pathway is concerned with detection of movement, depth, flicker. Parvocellular pathway is concerned with color of object, texture, shape and other fine details of object. Some fibers in intralaminar region of LGB ends in blobs in visual cortex and is concerned with color vision only.

Pathways end in 1° visual area 17, visual association area 18 (concerned with depth perception, visual orientation, relay of information), area 19 (occipital eye field for conjugate movement of eye to opposite side) and area 8 (frontal eye field for visual reflexes).

Some fibers from optic tract deviate from main tract and end in:

a. Midbrain (which mediate visual reflexes).
b. Suprachiasmatic nucleus (which mediate light and dark cycles).

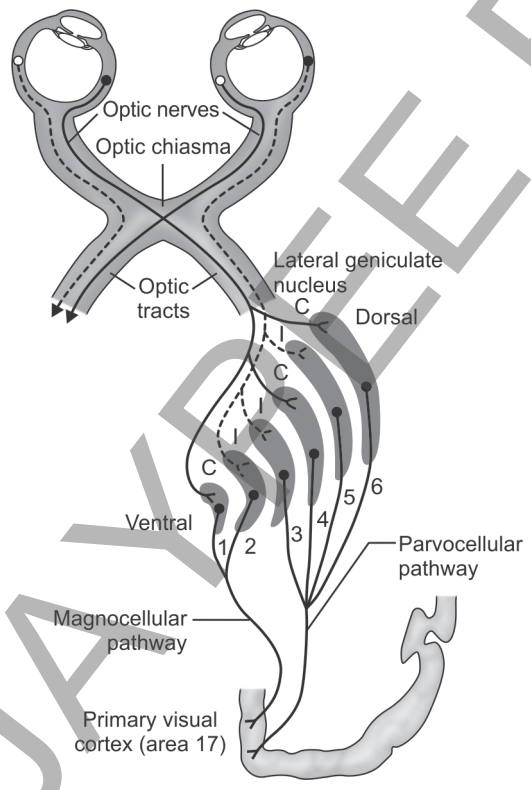


Fig. 12.9: Visual pathway.

PY11.5: Effects of Lesion of Optic Pathway

The effect of lesion of the visual pathways is described in term of field of vision. The following definitions will help to understand these defects:

- **Anopia:** Complete loss of visual field in an eye.
- **Hemianopia:** Blindness of ½ of visual field.
- **Quadrant anopia:** Loss of ¼ of visual field.
- **Homonymous hemianopia:** When same side (right/left) of visual field of both eyes are lost.
- **Heteronymous hemianopia:** When different sides of field of vision of both eyes are lost.
- **Scotoma:** Loss of vision in eye which is confined to center of visual field.
  - *Lesion of optic nerve (at A in* **Fig. 12.10***):* Anopia of affected side.
  - *Lesion of optic chiasma (at B in* **Fig. 12.10***):* Heteronymous hemianopia.
  - *Lesion of optic tract (at C in* **Fig. 12.10***):* Homonymous hemianopia.
  - *Lesion of LGB:* Homonymous hemianopia.
  - *Lesion of optic radiation/geniculocalcarine tract:* Homonymous hemianopia with macular sparing.
  - *Lesion of occipital cortex:* Scotoma/quadrant anopia

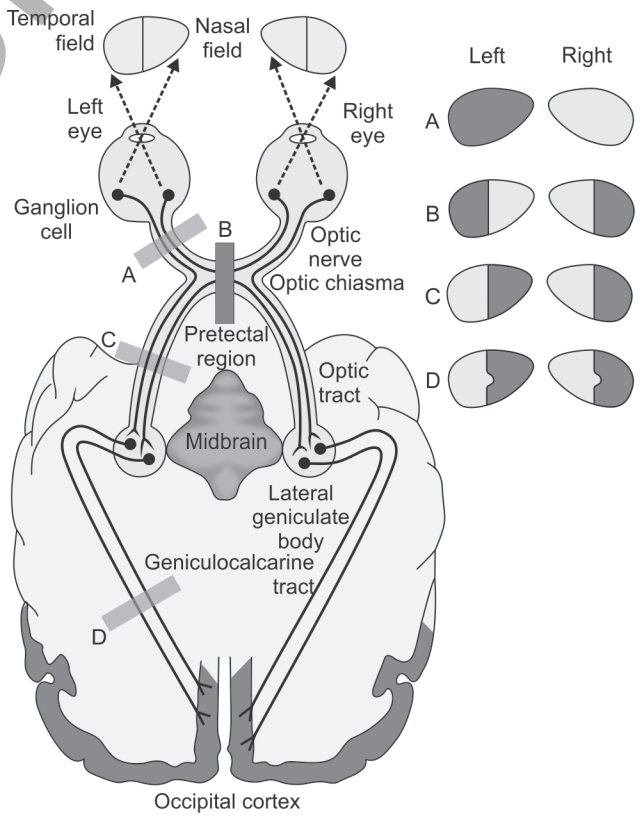


Fig. 12.10: Effect of lesion on optic pathway.

JAYPEE BROTHERS

Macula Sparing (at D in Fig. 12.10)

Loss of peripheral vision with intact macular vision. This is because the macula has large area of representation in the occipital lobe and it is greater than that of peripheral part of the retina.

Binocular Vision

The central parts of the visual fields of the two eyes coincide, therefore, anything in this portion of the field is viewed with both eyes and is fused at the cortical level into a single image and is important in-depth perception.

Visual Reflexes

Light Reflex (Direct, Indirect)

When light is directed to one of the eye, pupil of that eye constricts, it is called direct/pupillary light reflex. In addition, it also results in the constriction of pupil of the opposite eye, called as indirect/consensual light reflex both sides it forms the basis of indirect light reflex.

Pathway of Light reflex (Fig. 12.11)

Light sensation → optic nerve → optic chiasma → optic tract → enter midbrain via superior colliculus → pretectal nucleus of both sides → Edinger–Westphal nucleus of 3rd cranial nerve (parasympathetic) → ciliary ganglion → short ciliary nerve → sphincter pupillae of iris.

Effect is constriction of pupil of both sides.

Accommodation Reflex (Fig. 12.12)

Accommodation is defined as the ability of the eye to focus an object at varying distances. It is a reflex action. When a person changes his gaze from distant object to a near object, three adjustments are made in the eyeballs **(Flowchart 12.1)**.

1. Convergence of eyeball due to the contraction of medial recti.
2. Constriction of the pupil due to contraction of constrictor pupillae of iris.
3. Increase in anterior curvature of lens due to contraction of ciliary muscle.
   This is also called near response.

Afferent pathway

Visual impulse from retina pass through the optic nerve, optic chiasma, optic tract, LGB and optic radiation to visual cortex. From here, the association fibers carry the impulses to the frontal lobe.

Center: Center for accommodation lies in the frontal eye field, situated in the frontal lobe area 8.

Efferent pathway

- **Efferent fibers to ciliary muscle and sphincter pupillae:** From area 8, the corticonuclear fibers pass via internal capsule to the Edinger–Westphal nucleus of 3rd cranial nerve on both sides. From here, the preganglionic fibers pass through the 3rd cranial nerve to ciliary ganglion. The postganglionic fibers from ciliary

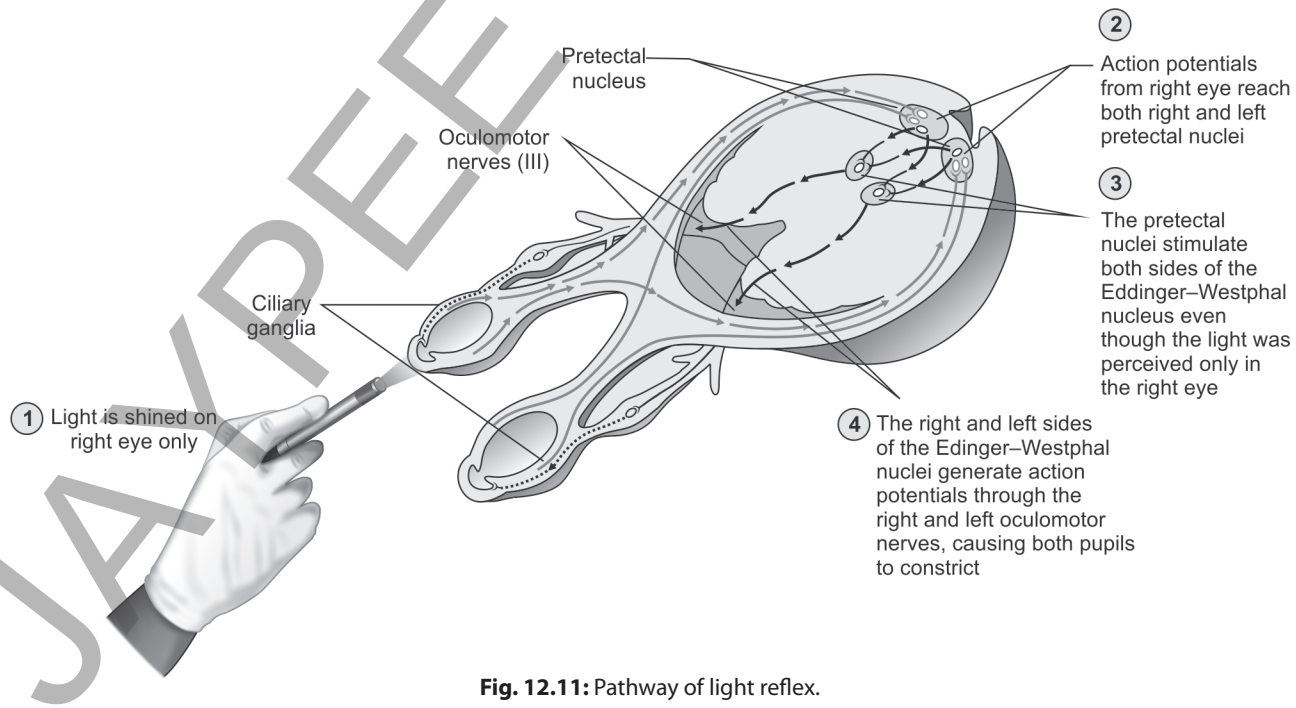


Fig. 12.11: Pathway of light reflex.

JAYPEE BROTHERS

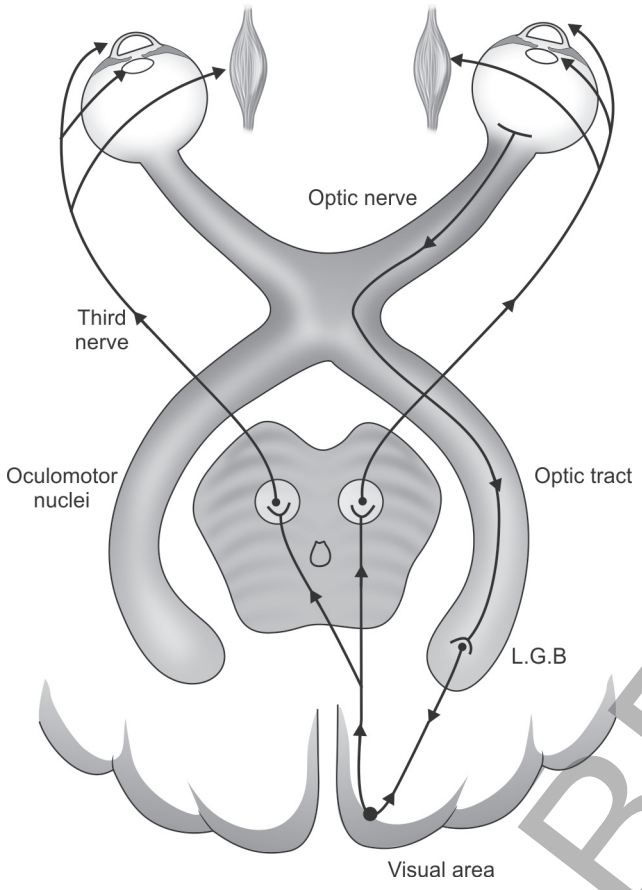
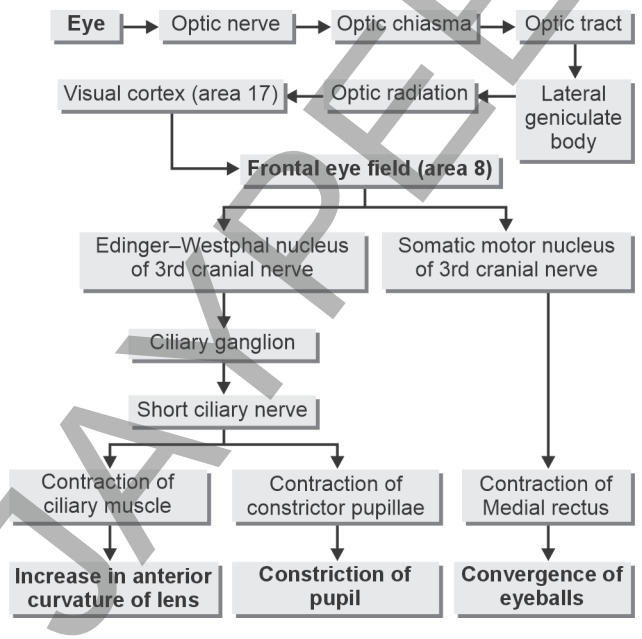


Fig. 12.12: Pathway of accommodation reflex.

Flowchart 12.1: Schematic diagram of accommodation reflex.



ganglion pass via the short ciliary nerves and supply the ciliary muscle and sphincter pupillae.

- **Efferent fibers to medial rectus:** Some of the fibers from frontal eye field terminate in the somatic motor nucleus of 3rd nerve. The fibers from motor nucleus supply the medial rectus.

Applied Aspects

Argyll Robertson Pupil

In this condition pupillary constriction in response to a light stimulus is absent or decreased while the response to accommodation is present. Pupillary reflex pathway is dorsal to the pathway for near response. Consequently, even if the light response is lost the response to accommodation still remains intact. Usually seen in midbrain lesion. The effects can be remembered like this accommodation reflex present (ARP), pupillary reflex absent (PRA).

Strabismus or Squint

Normally visual axis of the two eyes is parallel to each other and this alignment is maintained in all positions of gaze. A misalignment of the visual axis of the two eyes is called squint or strabismus.

Near Point of Vision

Nearest point to the eye at which an object can be clearly seen with maximal accommodation.

Far Point

Under resting condition, eye is adapted for distant vision, there is complete relaxations of lens. So parallel rays are focused in retina. At this point power is 59 D. This is taken as zero position of object.

PY11.6: Common Errors of Refraction

The errors of refraction **(Fig. 12.13)** can be studied under two groups. Normal eye is emmetropic (emmetropia is defined as the normal refractive condition of the eye in which the accommodation is relaxed and all the parallel rays of light are brought accurately to a focus upon the retina).

Pathological Errors

Myopia /shortsightedness

Parallel rays are focused in front of retina. Person fails to see distant objects but near vision is normal.

JAYPEE BROTHERS

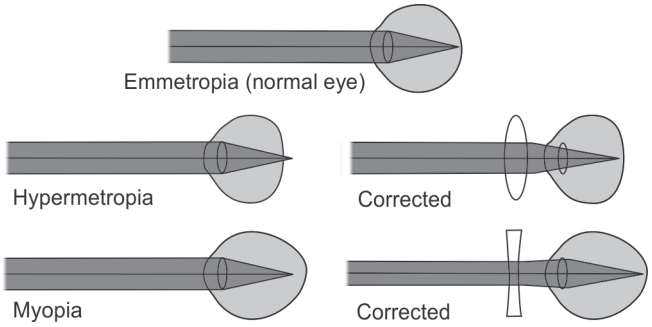


Fig. 12.13: Common errors of refraction.

Causes

- Increased A–P diameter of eyeball.
- Changes in curvature of lens and cornea.

Correction: Using biconcave lens.

Hypermetropia/longsightedness

Parallel rays are focused behind the retina.

Causes

- Smaller A–P diameter of eye.
- Abnormalities in curvature of lens and cornea.

Correction: Using biconvex lens.

Astigmatism

In some cornea, curvature varies from meridian to meridian. Refractive index of astigmatic cornea is different in different meridians, all the rays are not focused in retina and the image is blurred.

Correction: Using cylindrical lens.

Presbyopia

Clinical condition seen after 40 years due to the loss of accommodation.

Causes

Loss of elasticity of crystalline lens due to changes in lens protein. So, lens become rigid and during accommodation, though the ciliary muscles are contracting, curvature of lens is not changed and person cannot see near objects when held at normal distance.

Correction: Use convex lens.

Physiological Errors of Refraction

Spherical aberration

When pupil is fully dilated, rays passing through peripheral portion of lens are not focused on the retina as the power of lens at extreme periphery is not identical to that at the center due to difference in curvature at the center and periphery. Thus, vision is blurred.

Chromatic aberration

At the periphery of lens, rays of different wavelengths are refracted differently.

Cataract

As age advances lens or its capsule become opaque and fails to transmit light due to the denaturation of lens fiber protein; elevated by exposure to strong sunlight and UV rays.

Correction: Surgical removal and artificial insertion of lens.

Aphakia

Condition where lens is absent. It may congenital or surgical.

Amplitude of accommodation: This is the difference in refractive power of the eye between the two states, complete relaxation and maximal accommodation.

PY11.7: Color Vision

The Young–Helmholtz Theory

The Trichromatic theory states that color vision is possible due to three types of cones: 1. Long (L) or red cones, 2. Medium (M) or green cones and 3. Short (S) or blue cones. It assumes that the signals generated in the three cone types, which are independent and have different spectral sensitivities (L for long wavelength sensitivity, M for medium wavelength sensitivity, and S for short wavelength sensitivity), are transmitted directly to the brain where '*color sensations*' are experienced that correlate in a simple and direct way to the three cone signals. The underlying premise of the theory is that it is possible to create all colors of the spectrum by mixing two primary colors.

Color Blindness

It is a clinical condition when people are unable to distinguish certain colors or have color weakness. It is an X-linked recessive disorder.

Types

There are following type of color blindness. Color blindness is tested using Ishihara charts. When green cones are absent, the person is green blind. The condition is called deuteranope and the person is called deuteranope. When red cones are absent, the person is red blind. The condition is called protanopia and the person is called protanope.

These two are the two most common types of color blindness. Six percent of all men are green color blind

JAYPEE BROTHERS

(deuteranopes) and two percent of all men are red color blind (protanopes) making a total of about 8% who are red-green blind. These two types are grouped together and called red-green color blindness because these are the most common type of color blindness and as both are unable to differentiate between red and green colors. When blue cones are absent, the person is blue blind. The condition is called tritanopia and the person is called tritanope. This is a very rare condition. As all these patients can appreciate only two primary colors, this defect is called dichromatic color blindness.

Sometimes person does not have color blindness, but has color weakness for a particular color because color cones are not missing but they are underrepresented. The person can appreciate all three primary color but is defective for one or two of them, therefore called trichromatic color blindness. Three types of such anomalies are there: red color defective–protanomaly, green color defective—deuteranomaly, blue color defective—protanomaly.

Achromatopsia

Color blindness due to lesion of V8 (projection area for color vision).

Nyctalopia/night blindness

Prolonged deficiency of vitamin A leads to anatomic changes in the rods and cones followed by degeneration of neural layers of the retina causing visual abnormalities leading to nyctalopia.

An individual taking sildenafil (Viagra), used for treating erectile dysfunction cause transient color blindness as it inhibits the enzyme phosphodiesterase.

PY11.3, 11.4: AUDITION

Structure of Ear

The ear consists of three parts namely external ear, middle ear and internal ear. The external ear is formed of two parts: auricle/pinna and the external auditory meatus **(Fig. 12.14)**.

External Ear (24 mm Length)

External ear funnels sound waves to the external auditory meatus. From the meatus, the external auditory canal passes inward to the tympanic membrane.

Middle Ear

The middle ear is an air-filled cavity in the temporal bone that opens via the auditory (Eustachian) tube into the nasopharynx and through it to the exterior. The three auditory ossicles, the malleus, incus, and stapes are

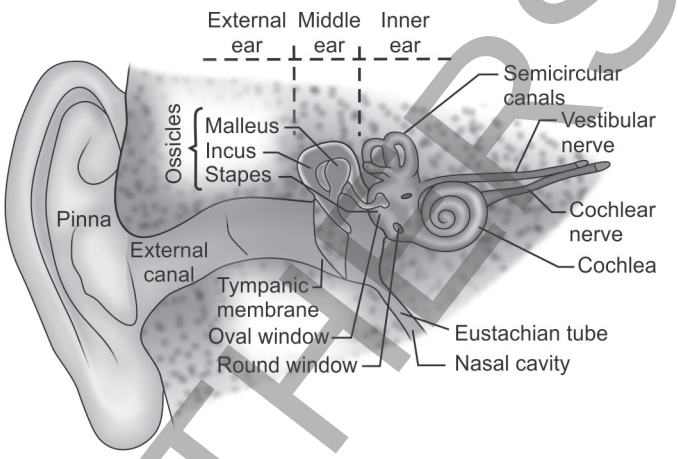


Fig. 12.14: Structure of ear.

located in the middle ear. The ear ossicles are arranged in the form of a chain extending across the middle ear from the tympanic membrane to oval window. Function of ear ossicles is to magnify the intensity of sound waves to about 1.2–1.3 times.

Functions of middle ear

Tympanic membrane as resonator

It acts as a resonator, i.e., it starts vibrating (in and out movements) freely when the sound waves strike.

Impedance matching

The sound waves have to pass from the air to the liquid medium in the internal ear. So, there will be resistance to the transmission of sound waves. This is overcome by increasing the pressure of sound waves at the level of oval window. The mechanisms are:

- Ear ossicles move as a single unit. The size of handle of malleus is less than the size of incus, while size of stapes is less than the incus; moreover, handle of malleus is longer than the long processes of the incus. The auditory ossicles thus function as a lever system that converts the resonant vibrations of the tympanic membrane into movements of the stapes against the perilymph-filled scala vestibuli of the cochlea. The lever action of the malleus and incus multiplies the intensity of sound waves to about 1.3 times.
- Effective surface area of tympanic membrane is 50–54 mm sq and that of oval window is 3–4 mm sq, i.e., there is a reduction in surface area by 17 times at the level of oval window.

Both these mechanisms lead to corresponding increase in sound pressure at the oval window. So total increase in sound pressure is about 22 times (17 × 1.3).

JAYPEE BROTHERS

Tympanic/acoustic/attenuation reflex

It is a protective reflex against the loud sound. Loud sound initiates a reflex contraction of the middle ear muscles.

- Contraction of tensor tympani pulls the handle of malleus medially which makes tympanic membrane more taut and decreases the vibration of tympanic membrane. Tensor tympani are the muscle attached to neck of malleus. It is supplied by 5th CN.
- Stapedius is attached to neck of stapes which is supplied by the 7th CN. Its contraction pulls footplate of stapes away from the oval window, thus, preventing transmission of sound waves to internal ear.

Both of these muscles contract reflexively in response to loud sound and thus excessive sound is prevented from going to oval window. This is known as tympanic/acoustic/attenuation reflex.

Equalization of pressure on either side of tympanic membrane: It equalizes the pressure on both sides of tympanic membrane with the help of eustachian tube. The eustachian tube is usually closed, but during swallowing, chewing and yawning it opens and equalizes the pressure on both sides of tympanic membrane.

Inner Ear

The inner ear (labyrinth) is made up of two parts; the bony labyrinth and the membranous labyrinth. The bony labyrinth is a series of channels in the petrous portion of temporal bone. The membranous labyrinth is present inside these channels and it is surrounded by a fluid called perilymph. This membranous labyrinth more or less duplicates the shape of bony channels and is filled with a fluid called endolymph. There is no communication between the spaces filled with endolymph and those filled with perilymph.

Internal ear is divided into 3 chambers; scala vestibuli, scala media and scala tympani by 2 membranes: Reissner's and Basilar membrane **(Figs. 12.15 and 12.16)**. Scala vestibuli and tympani are filled with perilymph and are continuous at the apex (helicotrema). Scala media is continuous with membranous labyrinth and is filled with endolymph.

Organ of Corti

It is located on the basilar membrane and it contains the hair cells. Hair cells are receptor cells that transduce sound energy into electrical energy. It extends from the apex to the base of the cochlea and has a spiral shape. There is one organ of Corti in each ear. The processes of hair cells

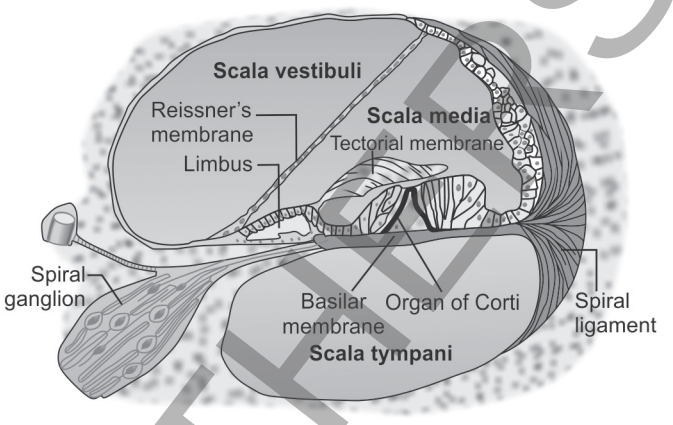


Fig. 12.15: Vertical section through cochlea.

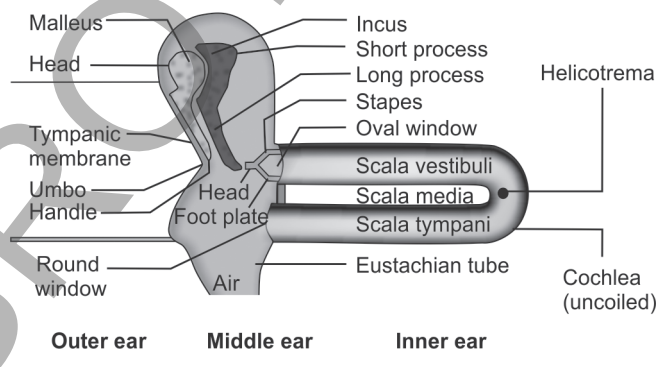


Fig. 12.16: Schematic diagram showing outer, middle and inner ear.

pierce the tough, membrane-like reticular lamina that is supported by rods of Corti. The hair cells are arranged in four rows; three rows of outer hair cells lateral to the tunnel formed by rods of Corti and one row of inner hair cell medial to the tunnel **(Fig. 12.17)**. There are 3,500 inner hair cells which are important for fine sensory transduction. There are about 20,000 outer hair cells which is responsible for detecting the presence of sound.

Outer hair cells are capped with gelatinous material called tectorial membrane. Cell bodies of afferent neuron that surround the bases of hair cells are located in the spiral ganglion. About 90–95% fibers innervate inner hair cells and only 5–10% innervates outer hair cells. In each hair cell, there are about 30–50 hairs called stereocilia. It has actin and myosin. Very fine processes called tip links tie the tip of each stereocilia to the side of its higher neighbor. At the junction, there are cation channels which are mechanically sensitive. When hair cells move in one direction towards longer stereocilia, channels open and there is Ca^{2+} and K^{+} influx. If hair cells move in opposite direction the ion channel closes.

JAYPEE BROTHERS

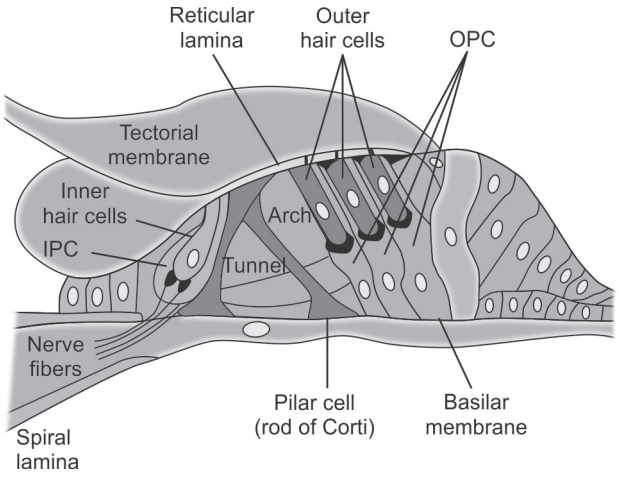


Fig. 12.17: Organ of Corti.

Supporting cells are:

- Inner phalangeal cells (for supporting inner hair cells).
- Outer phalangeal cells/dieter's cell (support outer hair cells).

The outer phalangeal cells are supported by Hansen's cells which is again supported by Claudius cells. The junctions between hair cells and other supporting cells are tight junctions to prevent mixing of endolymph and perilymph.

Sound Transduction

Sound waves which enter the cochlea gets transmitted along the scala vestibuli and spreads towards helicotrema. At the same time sound waves are also transmitted to fluid in other chambers. This will lead to vertical up and down movement of basilar membrane. This results in up and down and side to side movement of hair cells. The processes of hair cells project into the endolymph whereas the bases are bathed in perilymph.

Mechanism

When tip links pull stereocilia the ion channels open, there is K^+ influx → receptor potential in hair cells → Ca^{2+} influx causes depolarization → release of neurotransmitter (glutamate) into synaptic cleft between receptor cell and afferent sensory nerve → neurotransmitter binds with specific receptor on the sensory nerve → ligand gated ion channels open → action potential in cochlear division of 8th cranial nerve → auditory pathway.

Auditory Pathway

The afferent fibers in the auditory division of the 8th cranial nerve are the 1st order neuron and it ends in dorsal and ventral cochlear nucleus **(Fig. 12.18)**. There are three sets of fibers from this level:

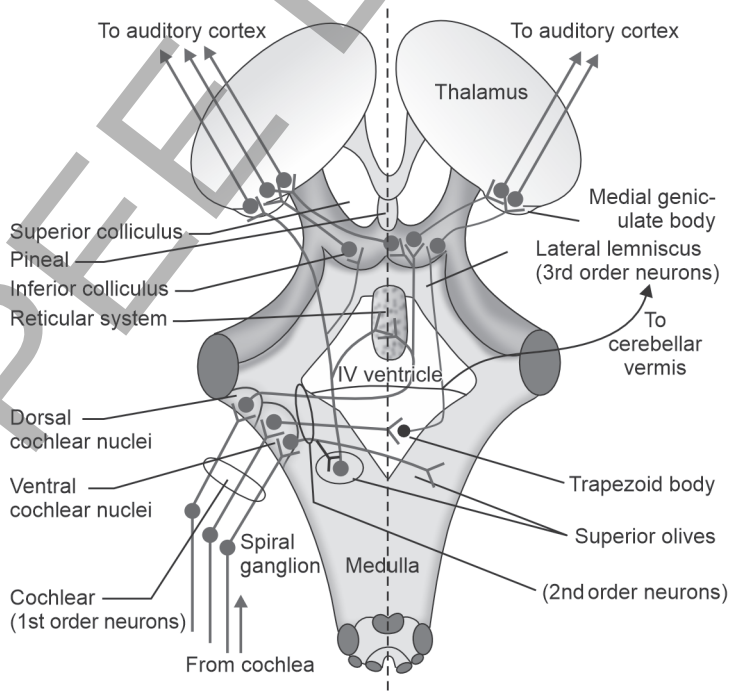


Fig. 12.18: Auditory pathway.

JAYPEE BROTHERS

1. Dorsal cochlear nucleus → 2nd order fibers cross to opposite side → ascend and end in inferior colliculus (many collaterals given to reticular formation) → 3rd order neurons arise → end in medial geniculate body of same and opposite → 4th order neurons arise → end in auditory cortex (primary auditory area 41, association area 20, 21, 22).
2. Ventral cochlear nucleus → 2nd order fibers cross to opposite side → end in trapezoid body → 3rd order neuron arises → end in inferior colliculus → 4th order neuron arises → medial geniculate body (no relay) → end in auditory cortex.
3. Ventral cochlear nucleus → 2nd order fibers end in superior olive → 3rd order fibers arise → ends in medial geniculate body (collaterals to inferior colliculus and reticular formation → 4th order neurons arise → ends in auditory cortex.

Efferent Pathway

Some fibers from cortex descend and ends in outer hair cells. Neurotransmitter released is ACh, although these inhibitory fibers end in outer hair cells, they actually modify the activity of inner hair cells.

Salient features of the pathway

- Bilateral representation due to extensive crossing of fibers.
- There is a descending pathway.
- Integration of visual and auditory impulse occurs due to connection between superior and inferior colliculus.
- General arousal as it gives collaterals to reticular formation.

Traveling Wave Theory/Place Theory

The movement of foot plate of stapes set up a series of traveling waves in the perilymph of scala vestibule **(Fig. 12.19)**. Basilar membrane is the mechanical analyzer of sound frequency. The basic pattern of movement of basilar membrane is like a traveling wave. High frequency sound waves produce maximum height at the oval window. Low frequency sound has maximum height near the apex. Correspondingly basilar membrane near the oval window vibrates in response to high frequency sound and basilar membrane near the apex vibrates in response to low frequency. That is different hair cells respond to different frequencies of sound depending upon their location on the basilar membrane. This is applicable to frequencies of 2,000–20,000 Hz. Human ear can discriminate sound of frequency between 20–20,000 Hz **(Fig. 12.20)**.

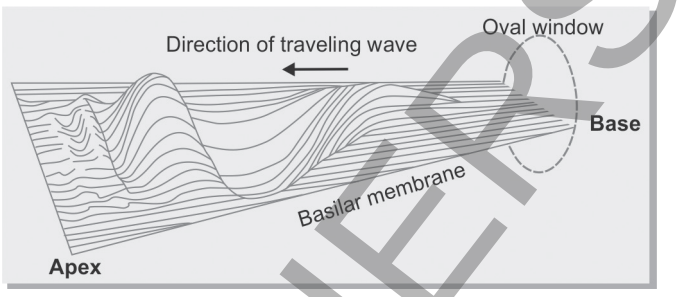


Fig. 12.19: Traveling wave theory.

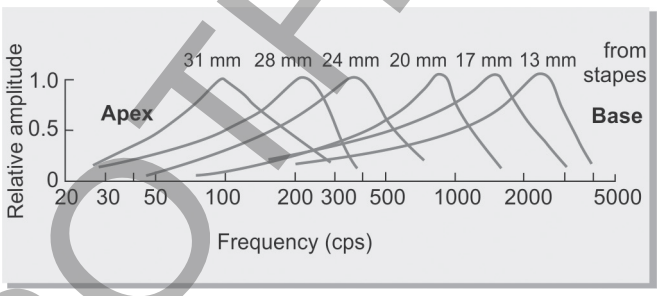


Fig. 12.20: Graphical representation of frequency of sound with the amplitude of vibrations in relation to distance from the stapes.

Volley's Principle/Frequency Theory

Volley's principle is applicable for low frequency of sound (less than 2,000 Hz). There is a relation between frequency of sound and action potential developed in sensory nerve endings. For low frequency sound, frequency of action potential is less. If greater frequency, a volley of action potential is produced.

Masking

It is a phenomenon to produce inaudibility of one sound by the presentation of another. In audiometry one ear is kept busy while the other being tested by a sound.

PY11.4: Deafness

Inability of an individual to hear either wholly or partially. Deafness is of two types:

1. **Conductive deafness:** Here, the defect is in conduction of sound due to impaired sound transmission.
   Causes: (a) Ear wax, (b) defect in vibration of tympanic membrane, (c) infection of middle ear (otitis media), (d) auto-sclerosis, (e) eustachian tube blocked due to common cold.
2. **Nerve deafness:** Due to damage to the hair cells or in the neural pathway.
   Causes: (a) Hereditary, (b) injury to 8th CN, (c) drugs like streptomycin, (d) vascular cause, (e) industrial noise pollution.

JAYPEE BROTHERS

Table 12.2: Tests of hearing.

Text	*Method*	*Normal*	*Conductive deafness*	*Nerve deafness*
Rinne test	Base of the vibrating tuning fork is placed on the mastoid process until subject no longer hears it (bone conduction), then it is held in the air, next to ear (air conduction)	Subject hears vibrations in air after bone conduction is over. Air conduction is better than bone conduction (Rinne's test positive)	Vibration in air not heard after bone conduction is over, that is bone conduction is better than air conduction (Rinne's test negative)	If partial nerve deafness. Rinne's test is positive. If complete nerve deafness, both air conducted and bone conducted sounds are not perceived
Weber test	Base of the vibrating tuning fork is placed on the vertex of skull in midline or over the mandible	Both the ears 'hear' the sound equally well	Sound is better heard in the affected ear	The 'deaf' ear remains deaf to bone conducted sound and sound is thus better heard and perceived by the normal ear, i.e., 'lateralized' to healthy ear
Schwabach test	Bone conduction of the subject is compared with that of the examiner's assuming that the latter is normal	Both the subject and examiner 'hear' the sound equally well	Subject's bone conduction is better than the examiner's	Subject's bone conduction is worse than the examiner's

Tests for Hearing

- Watch test
- Tuning fork tests **(Table 12.2)**
- Audiometry test

Auditory acuity (sharpness of hearing) can be measured with the help of an audiometer. This test helps to assess the degree of deafness and the frequency range in which deafness is most affected. The device consists of the following parts:

- Electronic oscillator
- Intensity dial
- Head phone

Vestibulo-ocular reflex: It is actually a reflex that maintains visual fixation on stationary points while the body rotates. When rotation starts, the eyes move slowly in a direction opposite to the direction of rotation, maintaining visual fixation.

Nystagmus: The regular and rhythmic to and fro involuntary oscillatory movements of the eyes. Meniere's disease/endolymphatic hydrops. It is a disorder of the inner ear where the endolymphatic system is distended with endolymph.

Endo cochlear/endolymphatic potential: A potential difference of about +80 millivolts exists all the time between endolymph and perilymph, with positivity inside the scala media and negativity outside. It is generated by continual secretion of K^+ ions into the scala media by the stria vascularis.

PY11.3: VESTIBULAR APPARATUS

Vestibular apparatus is the sensory organ for detecting sensation of equilibrium. It is encased in a system of bony tubes and chambers located in the petrous portion of the temporal bone, called the bony labyrinth. Within this system are membranous tubes and chambers called membranous labyrinth. The membranous labyrinth is the functional part of the vestibular apparatus. It consists of:

- Three semicircular canal
- The otolith organ—saccule and utricle (the two sac like organ) **(Fig. 12.21)**.

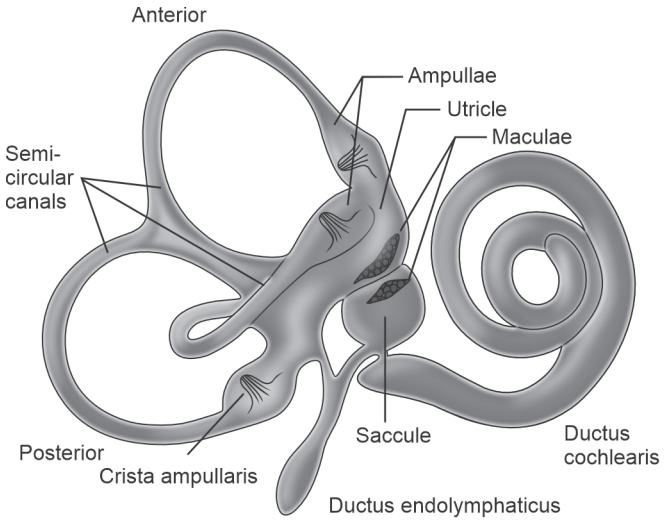


Fig. 12.21: Membranous labyrinth showing semicircular canals.

JAYPEE BROTHERS

Semicircular Canal

Semicircular canals are the tubular structures placed at right angles to each other. Because of this type of arrangement, the semicircular canals represent the three axis of rotation: vertical, anteroposterior and transverse axis. The three membranous canals are: horizontal (lateral), superior (anterior) and inferior (posterior). They contain endolymph and are separated from bony canal by the perilymph. Each canal begins as a dilation (or ampulla), containing a projecting ridge (on its inner aspect), called crista ampullaris **(Fig. 12.22)**. Cristae are the receptors in the semicircular canals.

Each crista consists of hair cells and sustentacular cells (supporting cell) surmounted by a gelatinous partition (cupula) that closes off the ampulla. The processes of the hair cells are embedded in the cupula, and the bases of the hair cells are in close contact with the afferent fibers of the vestibular division of the vestibulocochlear nerve.

Otolith Organ—Utricle and Saccule

The otolith organ is formed by utricle and saccule. The utricle communicates with the saccule by means of the ductus endolymphaticus. Both utricle and saccule contain a projecting ridge called the macula (like cristae, they are the receptors in otolith organ). Like crista, macula is also formed by hair cells and supporting cells which project into a firm gelatinous material, the cupula.

A large nonmotile hair called kinocilium **(Fig. 12.23)** is located at one end of hair cells. In the remaining hair cells, small cilia with progressive increase in height are present, called stereocilia. Between the hair cells lie the fibers of origin of vestibular division of VIII nerve. In the saccule and utricle, the cupula contains many chalky ($CaCO_3$) particles called otoliths (or otoconia) hence the name otolith organ.

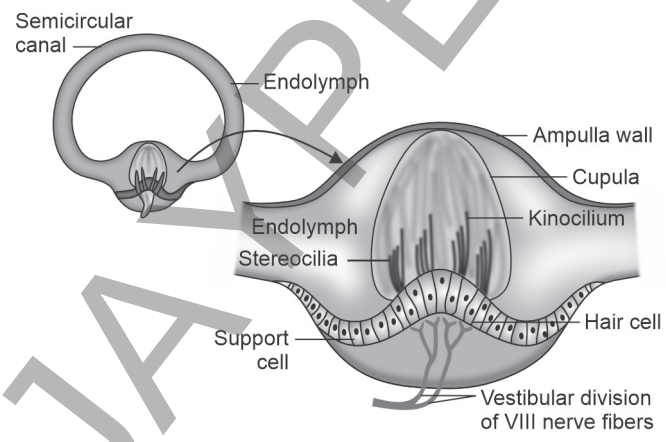


Fig. 12.22: Structure of crista (of semicircular canals) and macula (of Otolith organ).

The hairs plus gelatinous materials containing $CaCO_3$ is called otolith membrane.

When head is in the normal erect position:
- The macula of each utricle is in horizontal plane
- The macula in each saccule is in vertical plane **(Fig. 12.24)**.

Functions

The vestibular apparatus plays an important role in postural activity. The otolith organ (saccule and utricle) is stimulated by gravity and the semicircular canals activated by rotational movements. It plays an important role in postural activity.
- It gives rise to afferent impulses which reflexively adapt the position of the trunk and limbs to that of the head. Thus enable the erect position of the head and thus the normal posture of the head to be maintained.
- Information from the vestibular apparatus also reaches cranial nerve nuclei (which supply eye muscles) and the cerebral cortex. This helps in the recognition of the position and the movements of the head. As a result,

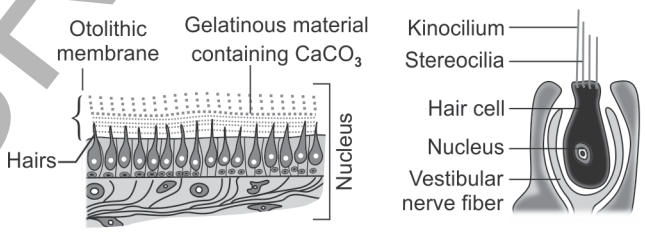


Fig. 12.23: Hair cell showing kinocilium and stereocilia.

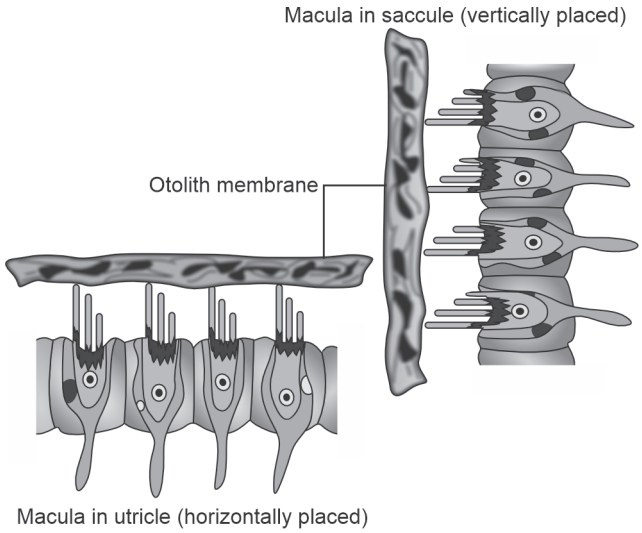


Fig. 12.24: Otolith organ (utricle and saccule with position of macula).

JAYPEE BROTHERS

the position of the eyes is held approximately constant allowing visual fixation on moving objects.

Vestibular Pathways

Nerve fibers arise from the cristae and maculae to form vestibular division of VIII nerve. The nerve cell bodies are situated at the vestibular ganglion (Scarpa's ganglion). The central axons of the Scarpa's ganglion proceed towards the brainstem and end in ipsilateral vestibular nucleus and flocculonodular lobe of cerebellum **(Fig. 12.25)**. Each vestibular nuclei have four subparts: lateral (Deiters), superior, medial and inferior (spinal) vestibular nuclei. Efferent fibers from vestibular nucleus terminate in the following regions:

- 3rd, 4th and 6th cranial nuclei, via median longitudinal fasciculus. Therefore, stimulation of vestibular nuclei leads to movement of the eyes.
- In the anterior horn of spinal cord cells via anterior and lateral vestibulospinal tract.
- In the cerebellum.
- In the nuclei of reticular formation.
- In the primary somatosensory cortex via the opposite thalamus.

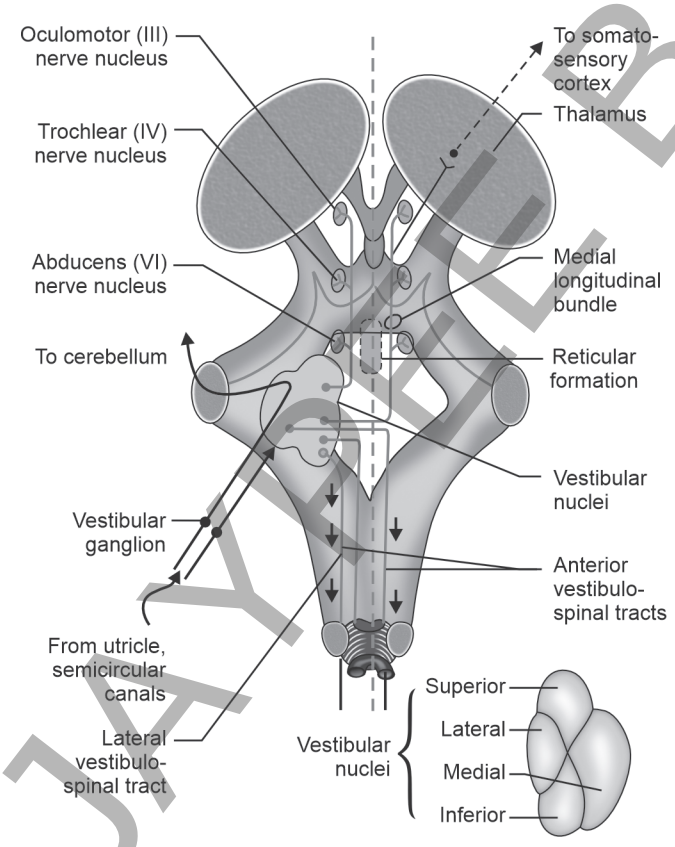


Fig. 12.25: Vestibular pathway.

Functioning of Vestibular Apparatus

Mode of Action of Otolith Organ

The saccule and utricle provide information about linear acceleration and change in head position relative to the force of gravity. Saccule respond to vertical acceleration and utricle to horizontal acceleration. The maculae of the saccule and utricle are stretch receptors. When in erect posture, the otolith membranes are so placed that the hair cells are least disturbed. Based on bending the head (e.g., sideways/ventro or dorsiflexion) gravity acts. The hair cells are thus deformed with resulting stimulation of the nerve fibers which lie between them **(Fig. 12.26)**.

- Saccule is stimulated when there is sideways flexion of neck. If head is tilted to right:
  - Cupula of right saccule hangs downwards and pulls on its macula; thus, maximally stimulated.
  - In left saccule there is upward movement of cupula to produce minimal stimulation.
- The utricular macula are stimulated when there is ventro- or dorsiflexion of neck.
  - Head erect (upright)-minimal stimulus.
  - Head is bend forward or backward-maximal stimulation.

For this reason, the maculae of saccule and utricle are called gravity receptors. The receptors of vestibular apparatus show little or no adaptation.

Mode of Action of Semicircular Canals

The semicircular canal detects angular action during rotation of head along three perpendicular axis. When a person rotates in clockwise direction, i.e., in vertical axis, horizontal canal moves in clockwise direction. But there is no corresponding movement of endolymph inside the canal at the beginning of rotation due to inertia. This phenomenon causes relative displacement of endolymph in the direction opposite to that of the rotation of head. That is, fluid is pushed in anticlockwise direction.

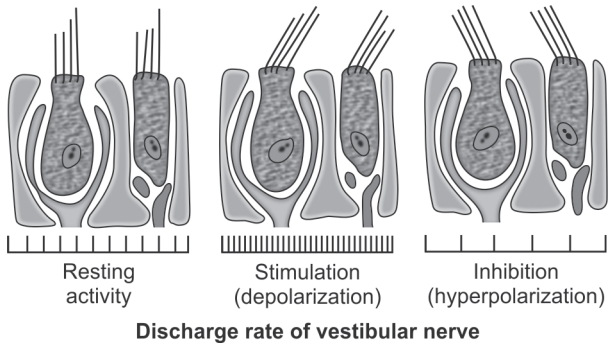


Fig. 12.26: Mode of action of Otolith organ.

JAYPEE BROTHERS

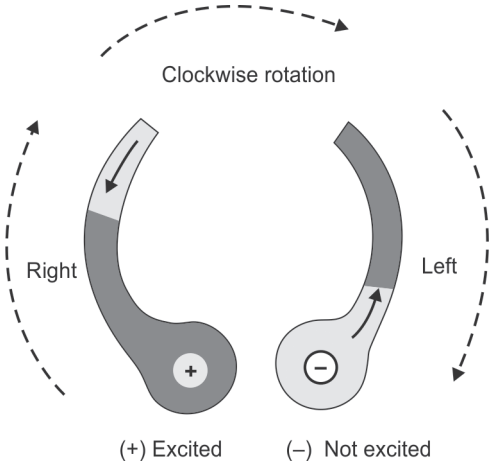


Fig. 12.27: Mode of stimulation of semicircular canals.

Thus, in the right semicircular canal, the endolymph flows towards the ampulla (stimulation) and in left canal fluid moves away from the ampulla (decreased impulse discharge). The combination of increased discharge from one ampulla and decreased discharge from other form the basis of detection of direction of movement **(Fig. 12.27)**.

The movement of endolymph in semicircular canal, in turn causes corresponding movement of gelatinous cupula causing cilia of hair cell to bent leading to stimulation of hair cells. Thus, at the beginning of rotation in clockwise direction around vertical axis, the hair cells at ampulla of horizontal canal in right ear are stimulated. But, the hair cells in horizontal canal of left ear are not stimulated. Because of stimulation, the hair cells in right horizontal canal send information (impulses) through sensory nerve fibers to vestibular, cerebellar and reticular centers. Now, these centers send proper instructions to various muscles of the body to maintain equilibrium of the body during angular acceleration (rotation). On the other hand, rotation in anticlockwise direction causes stimulation of hair cells in ampulla of horizontal canal in left ear only.

Adaption of Receptors in Semicircular Canal During Rotation

The hair cells of crista ampullaris generate impulse (50–100 impulse/min) at rest. At the beginning of rotation discharge increases to 600–800 impulse/min. However, rapid discharge of impulses lasts only for first 20–25 seconds of rotation. Afterwards during continuous rotation, the frequency of impulses falls back to resting level as endolymph starts moving along with semicircular canal at the same speed. This causes adaption of the hair cells.

Role in Regulation of Posture

- The tract that descends from the vestibular nuclei into the spinal cord maintains tone in antigravity muscle and coordinates the adjustments made by the limbs and eyes in response to the change in body position. The vestibular apparatus thus plays a role in the support of the head during movement, orientation of the head in space and in reflexes (tonic labyrinthine and righting reflexes) accompanying locomotion. That is why the vestibular apparatus is sometimes called the sense organ of balance (equilibrium).
- It controls eye movements via its ascending connections to the cranial nerve nuclei. Therefore, in spite of changes in head position the eye can remain fixed on the same point **(*vestibulo-ocular reflex*)**. For example, if the head is rotated to the left, the eyes move towards right in order to prevent an image from moving off the fovea.
- **Orientation in space:** Orientation, i.e., relative position of various body parts in space depends on four inputs:
  1. From vestibular receptors.
  2. From visual information.
  3. By impulses from proprioceptors in joint capsule.
  4. By impulses from cutaneous exteroceptors.

Vestibular Dysfunctions

Motion sickness: When a person, traveling by ship, rides a rough sea, he is expected to develop sea sickness; similar symptoms can develop when traveling by air or in a rough bus journey. All such sickness is called motion sickness. It is due to excessive and repeated stimulation of vestibular apparatus.

Symptoms

Nausea, vomiting, sweating, diarrhea, pallor, salivation, discomfort, headache, disorientation and lack of emotion.

Prevention

- Avoiding greasy and bulky food before travel.
- Taking antiemetic drugs (drug preventing nausea and vomiting).

PY11.2: SENSATION OF TASTE

Taste buds are the sense organs for taste. Size of taste bud is about 50–70 μm and they are ovoid in shape with 40 mm diameter. Each taste bud is made of three types of cells **(Fig. 12.28)**:

1. Taste/gustatory cells-type 3 cells.
2. Supporting/sustentacular cells-type 1 and 2 cells.
3. **Basal cells:** They differentiate into new receptor cells.

JAYPEE BROTHERS

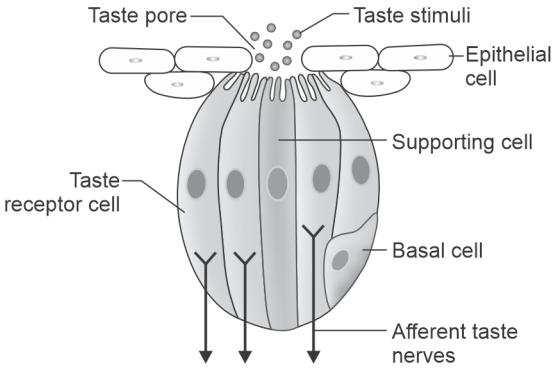


Fig. 12.28: Taste receptor (or taste bud).

Chemoreceptors are present in taste buds on walls of papilla. There are four types of papillae.

1. **Fungiform:** They are rounded structures most numerous near the tip of the tongue. It contains five taste buds located on the tip of the papillae.
2. **Filiform:** Small conical structures that cover the dorsum of the tongue. No taste buds are present on filiform papillae.
3. **Foliate:** These are found occasionally upon the posterolateral surfaces of tongue.
4. **Circumvallate:** They are prominent structures arranged in a V on the back of the tongue. They are 10–12 in number. Larger vallate papillae contains up to 100 taste buds located along the sides of the papillae.

Total number of taste buds is 10,000 and its number decreases with age. Taste bud is stimulated only at the tip as the necks of taste cells and sustentacular cells are connected to each other and to the surrounding epithelial cells by tight junctions so that only tip is exposed to oral fluids. At the base of taste bud, afferent nerve fibers are attached. Each taste bud is innervated by 50 nerve fibers.

All taste sensations result from various combinations of four basic tastes (primary taste sensations in **Figure 12.29**):

1. **Sour taste:** The sour taste is caused by acids, i.e., hydrogen ions. More acidic the food, more sour is the taste. The edges of tongue are more sensitive to sour.
2. **Salty taste:** The salty taste is elicited by ionized salts mainly by sodium ion concentration. The cation of the salt (Na^+) is mainly responsible, but anions can also contribute, to a lesser extent. Anterior half of the tongue is more sensitive to salty taste.
3. **Sweet taste:** The sweet taste is not caused by any single class of chemicals. It is produced by various classes of organic molecules. The tip of the tongue is most sensitive to sweet.

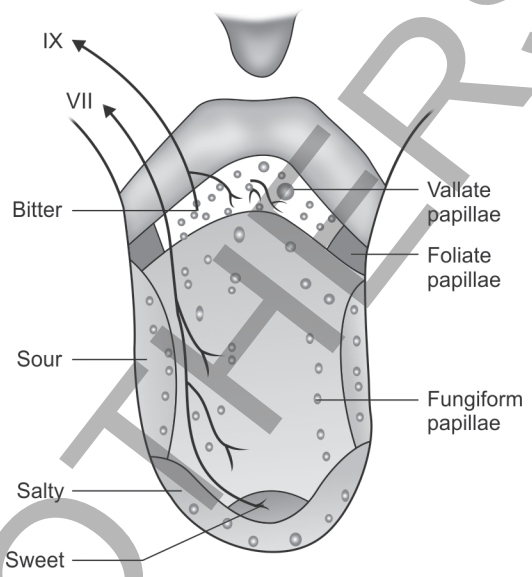


Fig. 12.29: Primary taste sensations.

4. **Bitter taste:** Bitter taste is produced by long-chain organic substances containing nitrogen and by alkaloids such as quinine and caffeine. The back of the tongue is particularly sensitive to bitter.

Taste Pathway

It is a three orders uncrossed pathway **(Fig. 12.30)**. 1st order neurons are:

- Chorda tympani branch of 7th CN, which carries sensation from anterior 2/3rd of tongue.
- 9th CN, which carries sensation from posterior 1/3rd of tongue.
- 10th CN, which carries sensation from areas other than tongue, i.e., epiglottis, pharynx and palate.

From taste cells in taste bud, 1st order neurons arise → reach nucleus tractus solitarius of medulla → 2nd order neurons ascend ipsilaterally in medial lemniscus → end in thalamus (ventral posteromedial nucleus) → 3rd order neurons arise → end in face area of somatosensory cortex in postcentral gyrus. Some fibers end on anterior part of insula.

The basic taste modalities are:

a. **Sweet:** Receptor is G protein activated gustducin.
b. **Bitter:** Receptor same as sweet.
c. **Salt:** Receptors are ENaCs (i.e., epithelium Na^+ channels).
d. **Sour:** Receptors are ENaCs HCN (hyperpolarization activated cyclic nucleotide gated cation channels).
e. **Umami (sweet pleasant taste evoked by monosodium glutamate):** Receptor is mGluR4 receptor.

JAYPEE BROTHERS

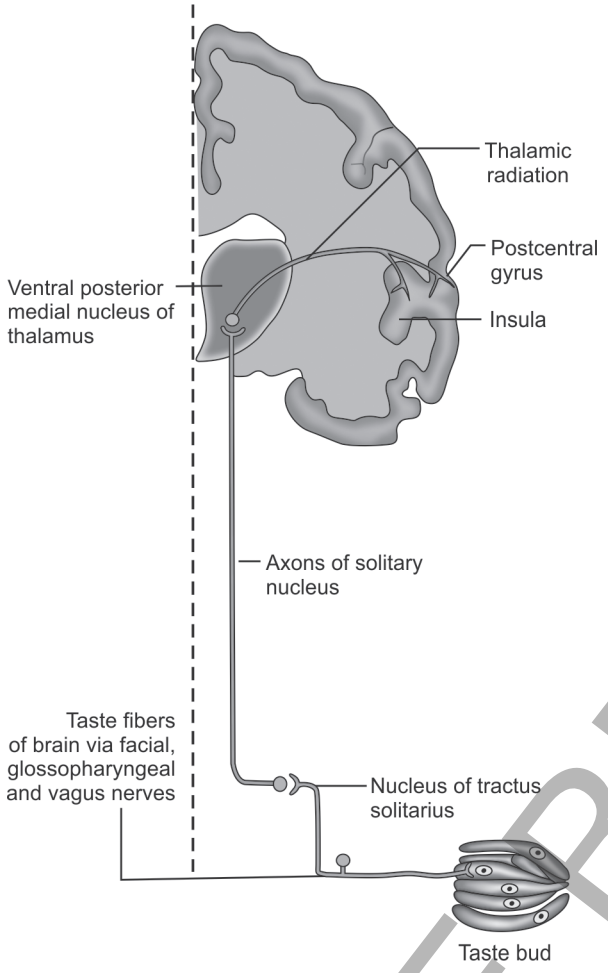


Fig. 12.30: Taste pathway.

Note: Miraculin-taste modifier protein which when applied to tongue makes acid taste sweet.

Abnormalities

1. **Ageusia:** Absence of taste and it is commonly drug induced
2. **Hypogeusia:** Diminished taste sensitivity
3. **Dysgeusia:** Disturbed sense of taste.

PY11.1: OLFACTION

The olfactory receptor cells are located in a specialized portion of the nasal mucosa, the yellowish pigmented olfactory mucous membrane. The olfactory mucous membrane is constantly covered by mucous which is produced by Bowman's cells, present under the basal lamina of the membrane. Receptors are bipolar neurons with lifespan of 60 days. The olfactory receptors are unique in that the receptor cell itself is a neuron. In between the receptor cells, there are supporting cells and basal cells. Each neuron has a short and thick dendrite with expanded end called as olfactory rod, from these rods 10–20 cilia (unmyelinated process) project to the surface of the mucosa.

Odoriferous substances combine with receptors on surface of cilia. This will initiate G protein coupled reaction, finally leading to opening of Ca^{2+} channels. Ca^{2+} influx initiates receptor potential, then action potential develops which gets transmitted along olfactory nerve.

Olfactory Bulb

Olfactory bulb is the part of cerebral hemisphere located at the base of cerebral cortex, just below the frontal lobe.

In the olfactory bulb, the axons of the receptors enter olfactory bulb via cribriform plate and synapse with primary dendrites of the mitral cells and tufted cells to form the olfactory glomeruli. In addition to mitral and tufted cells, it also contains inhibitory interneurons, i.e., granular and periglomerular cells. Each glomerulus receives information from 26,000 receptors but there are only 24 mitral cells and 68 tufted cells **(Figs. 12.31A and B)**. So olfactory glomeruli is a special synaptic unit in olfactory bulb.

Olfactory Pathway

Olfactory nerve → pierce cribriform plate of ethmoid → reach olfactory bulb → synapse with mitral and tufted cell → axons of mitral and tufted cells form olfactory stria. The olfactory striae are three in number **(Fig. 12.32)** They are:

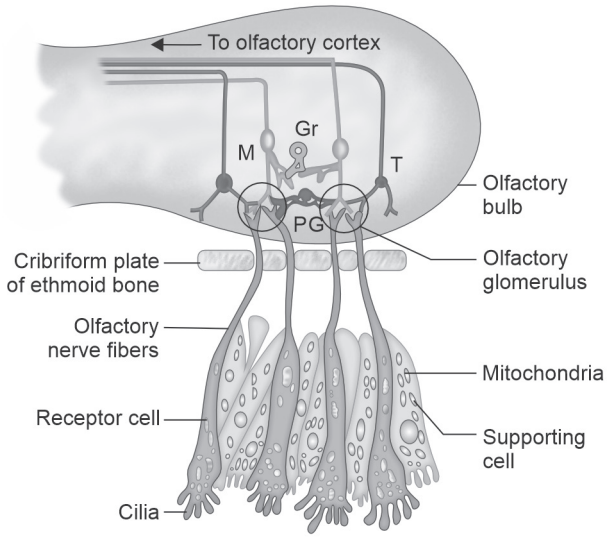


Fig. 12.31A: Olfactory receptor cells.

JAYPEE BROTHERS

for detailed information on physiology books, visit our website **www.ejaypee.com,** for detailed information on physiology books, visit our website **www.ejaypee.com,** for detailed information on physiolog

PHYSICON

The Reliable Icon in

PHYSIOLOGY

Salient Features

- Thoroughly updated as per the NMC competencies
- Presented in brief but comprehensive and easy-to-study format
- References from standard textbooks
- Numerous tables, flowcharts, and diagrams for more information in simple form and enhance study experience
- Clinical boxes highlighting the applied aspects and clinical integration with physiology
- Easy to remember and easy to recall and reproduce format.

This book is arranged in three sections:

- ♦ Section 1 (Theory): Covers all topics usually asked in the examination and can master the subject within a short period of time
- ♦ Section 2 (Practicals): Covers hematology, amphibian experiments, and clinical examinations with viva questions
- ♦ Section 3 (Extra Mile): A high-yielding collection of short notes, long essays, multiple choice questions, reasoning-type questions, calculations, and common laboratory values.

Avi Sanjaykumar Borkhatariya has completed his MBBS from Grant Medical College and Sir JJ Group of Hospitals, Mumbai, Maharashtra. He holds an MD and DNB in Physiology from Seth GS Medical College and KEM Hospital, Mumbai, where he currently serves as an Assistant Professor. His active involvement in undergraduate teaching and expertise in physiology has been instrumental in refining, reviewing, and updating the content to align with the current NMC competencies for this new version.

JAYPEE BROTHERS

Buy from ejaypee

JAYPEE BROTHERS

Shelving Recommendation
PHYSIOLOGY

ISBN 978-81-6799-993-1

9 788167 999931

3
Edi

Exam Preparatory Manual for Undergraduates

Avi Sanjaykumar Borkhatariya