SENSORY RECEPTORS

Qn. What is meant by the term receptor?

This is a cell or tissue, which can transform any of the various forms of energy [like electrical, chemical, mechanical or radiant energy] into action potential in neurones.

CLASSIFICATION OF RECEPTORS

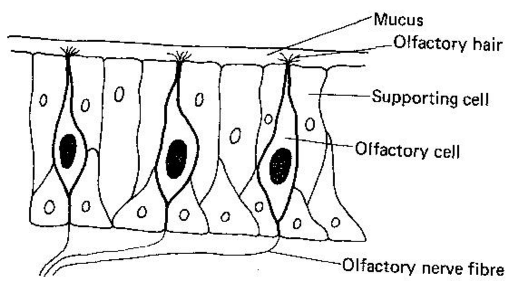
Sensory receptors may be categorized on the basis of their structure, the stimulus energy they transduce, their location or the nature of their response.

A. Basing on structure

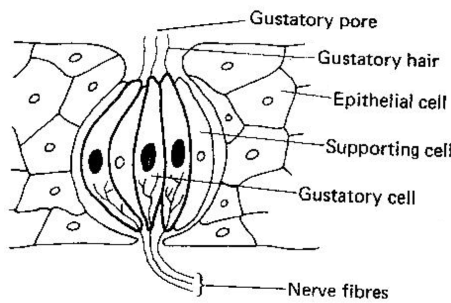
Primary receptor cells	Secondary receptor cells	Sensory organs
These are single sensory neurons whose dendrons are sensitive to a single type of stimulus, and which transmit an impulse to the CNS. ***Examples***: Pacinian corpuscle, Meisssner's corpuscle	These are epithelial cells that are adapted to detect a particular stimulus and communicate with a receptor neuron via a synapse. ***Examples***: olfactory cells, taste buds	Are complex receptors, consisting of many receptor cells, sensory neurons and supportive tissue. ***Examples***: eye, ear

Description of some primary and secondary receptors

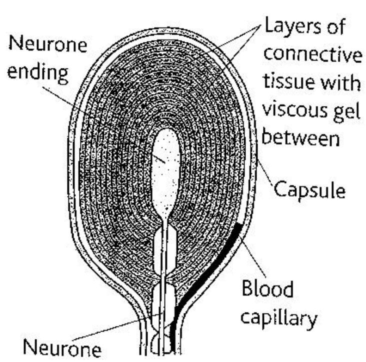
Olfactory epithelium of the nose



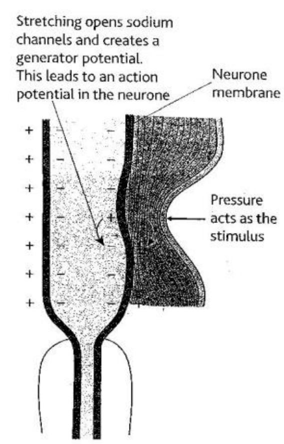
Taste cells of the tongue



Pacinian in the human skin



Creation of a generator potential in a Pacinian corpuscle



B. Basing on positioning in the body

Exteroceptors	Interoceptors	Proprioceptors
Respond to externally derived stimuli. ***Examples***: ear, eye	Respond to internally derived stimuli like homeostatic state. ***Examples***: carotid and aortic bodies	Respond to stimuli concerned with muscular and skeletal positions and movements. Proprioceptors include receptors in the muscles, tendons, and joints. ***Examples***: ear's vestibular apparatus

C. Basing on stimuli received

Type of receptor and example	Stimulus energy	Stimuli detected
Photoreceptor; *eye*	Electromagnetic	Visible light, UV light in insects
Chemoreceptor; *olfactory epithelium, taste buds*	Chemical	Smell, taste, blood PH, humidity
Mechanoreceptor; *ear, skin receptors*	Mechanical	Sound, touch, pressure, gravity
Thermoreceptor; *skin*	Thermal	Temperature

D. Basing the nature of their response

(i) Tonic receptors continue to fire as long as the stimulus is maintained. They monitor the presence and intensity of a stimulus.

(ii) Phasic receptors respond to stimulus changes; they do not respond to a sustained stimulus. Phasic receptors partly account for sensory adaptation to sustained stimuli.

PROPERTIES OF RECEPTORS

Qn. Describe the general features common to all receptors.

1. They transduce stimuli into nerve impulses in neurones. Transduction is the transformation of the various forms of energy [e.g. electrical, chemical, mechanical or radiant energy] into action potential.

2. Different receptors are excited at varying threshold levels of stimuli. The magnitude of stimulation of cells in receptors is proportional to the intensity of stimulation until saturation, and the threshold of different cells of the same receptor may vary. **Threshold value is the stimulus required just to induce an action potential**

3. They show adaptation, that is they gradually cease to create an action potential if repeatedly stimulated. E.g. the inability hear a clock's ticking in a room after prolonged exposure to its ticking. Receptors however vary in the speed with which they become adapted, thus **phasic receptors** are those which **adapt rapidly** while **tonic receptors** are those which adapt slowly

Qn. Of what advantage is receptor adaptation to organisms?

- It provides animals with precise information about changes in the environment. The nervous system ignores unchanging environmental conditions and concentrate on monitoring those of survival value.
- It prevents overloading of the nervous system with irrelevant information which reduces energy wastage.

4. Each is specialised to receive one type of energy only, although a few exceptions have been noted. According to the law of specific nerve energies, each sensory receptor responds with lowest threshold to only one modality of sensation. That stimulus modality is called the **adequate stimulus**. Stimulation of the sensory nerve from a receptor by any means is interpreted in the brain as the adequate stimulus modality of that receptor.

5. All receptors when stimulated create a generator potential, whose magnitude of potential change is directly proportional to the strength of the stimulus applied to the receptor. After the generator potential reaches a threshold value, increases in the magnitude of the depolarization result in increased frequency of action potential production in the sensory neuron. Thus a weak stimulus results in a small generator potential and slow impulse frequency discharge while a stronger stimulus produces larger generator potentials and faster impulse frequency discharge.

Qn. How does a generator potential differ from an action potential?

Generator potential	*Action potential*
● Depolarisation only results from a specific stimulus	● Depolarisation may also result from a neurotransmitter
● It is proportional to the size of stimulus	● It obeys the all-or-nothing law

6. Receptors are sensitive to low intensity stimulation. E.g. in some insects, tactile receptors can respond to airborne sounds when stimulated just 3.6 nm. In rod cells of human eyes, high sensitivity results from **retinal convergence.**

Qn. What is meant by retinal convergence?

A phenomenon in which many rod cells make synaptic contact with one bipolar neurone, which in turn connects with one optic nerve fibre which relays information to the brain.

Qn. Of what significance is retinal convergence?

It enables the eye to be more sensitive because action potential can be fired by **summation** of stimulation of several rod cells, in which stimulation of individual rod would be insufficient to ignite an impulse.

Other feature common to receptors but not general to all

7. Some receptors show spontaneous activity i.e. they form nerve impulses in sensory neurones without stimulation. This is important because it increases the sensitivity of the receptor by enabling it to respond to a receptor that would normally be too small to produce a response in the sensory neurone. Any slight change in the intensity of the stimulus will now add to the existing potential in the receptor and produce a change in the frequency of impulses along the sensory neurone.

PROPRIOCEPTION

Proprioception is the determination of the position and movements of muscles, bones, and joints of the body by proprioceptors.

Pacinian corpuscles

Pacinian corpuscles detect deep pressure and are found in many areas of the body, including the skin, the mesenteries surrounding the gut, and joint capsules. The Pacinian corpuscles in joints provide the CNS with information on the limbs and portions of the body.

Proprioception in Pacinian corpuscles

Qn. (i) Describe the sequence of events by which a Pacinian corpuscle enables determination of position of limbs.

RELATEDLY: Explain how a Pacinian corpuscle produces a generator potential in response to a specific stimulus.

- During the resting potential, the pressure-sensitive sodium channels of the neurone membrane of a Pacinian corpuscle in the **capsule of a joint** prevent passage of sodium ions.
- When the corpuscle is deformed by pressure, the pressure-sensitive sodium channels of the neurone membrane open, allowing influx of sodium ions and ion exchange along electrochemical gradients.
- The neurone membrane in the Pacinian corpuscle depolarises, leading to a change in voltage called **generator potential** in the nerve ending.

●The greater the pressure the more sodium channels open and the larger the generator potential. If a threshold value is reached, an action potential occurs and nerve impulses travel along the sensory neurone, via other neurones to the central nervous system which interprets the information about limb position. The frequency of the impulse is related to the intensity of the stimulus.

(ii) What is stretch-mediated (pressure-sensitive) sodium channel?

A special type of trans-membrane channel protein that increases permeability to sodium ions when stretched.

Note:

Sensory receptors are not evenly distributed over the surface of the body. Some areas such as the fingertips are more sensitive to touch; which indicates higher densities of sensory receptors, i.e. there are more receptors per unit area

TASTE

The sense of taste is mediated by taste buds, in which a particular taste bud is most sensitive to one of four taste modalities: sweet, sour, bitter, and salty. Taste buds are located in characteristic regions of the tongue according to the modality to which they are most sensitive. Salty and sour taste are produced by movements of sodium and hydrogen ions, respectively, through membrane channels; sweet and bitter tastes are produced by binding of molecules to specific signal transmitting protein receptors.

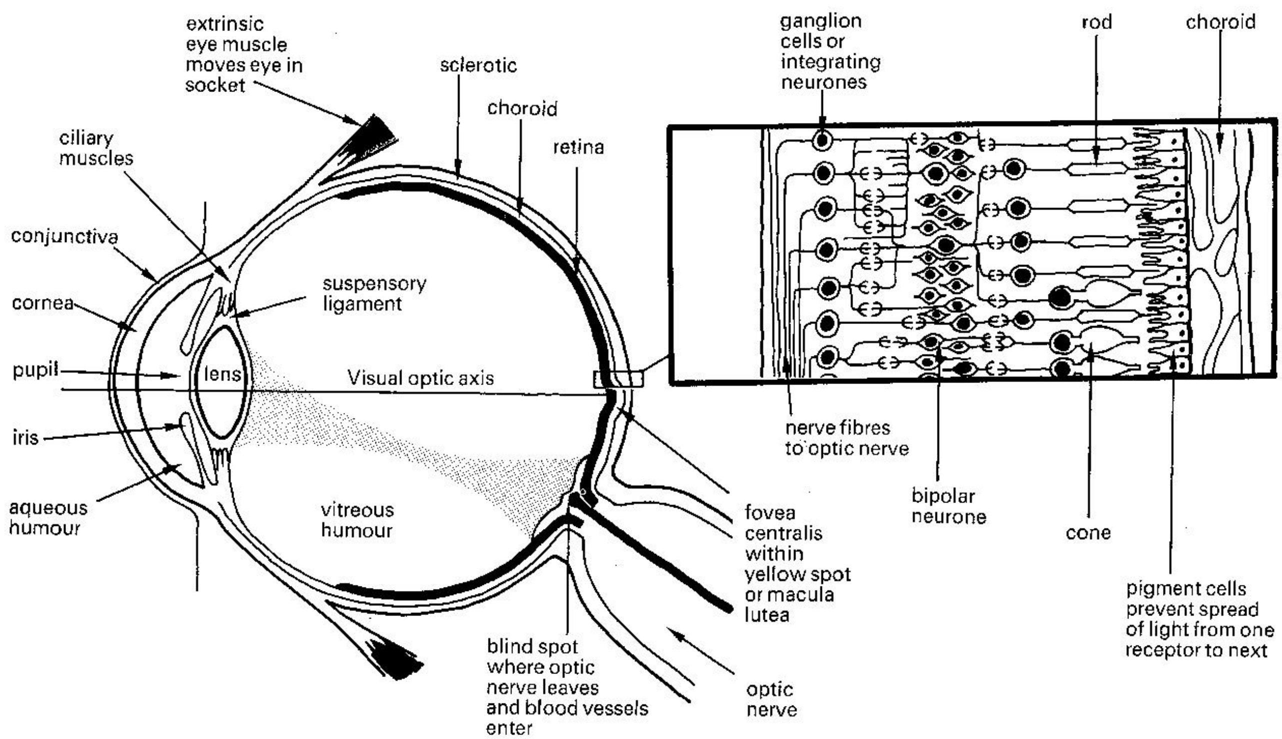
SMELL

The olfactory receptors are neurons that synapse within the olfactory bulb of the brain.

Odorant molecules bind to membrane protein receptors. There may be as many as a 1,000 different receptor proteins responsible for the ability to detect as many as 10,000 different odors.

Binding of an odorant molecule to its receptor causes the dissociation of large numbers of specific signal transmitting protein receptors subunits, the effect is thereby amplified, which may contribute to the extreme sensitivity of the sense of smell.

THE MAMMALIAN EYE



NOTE:

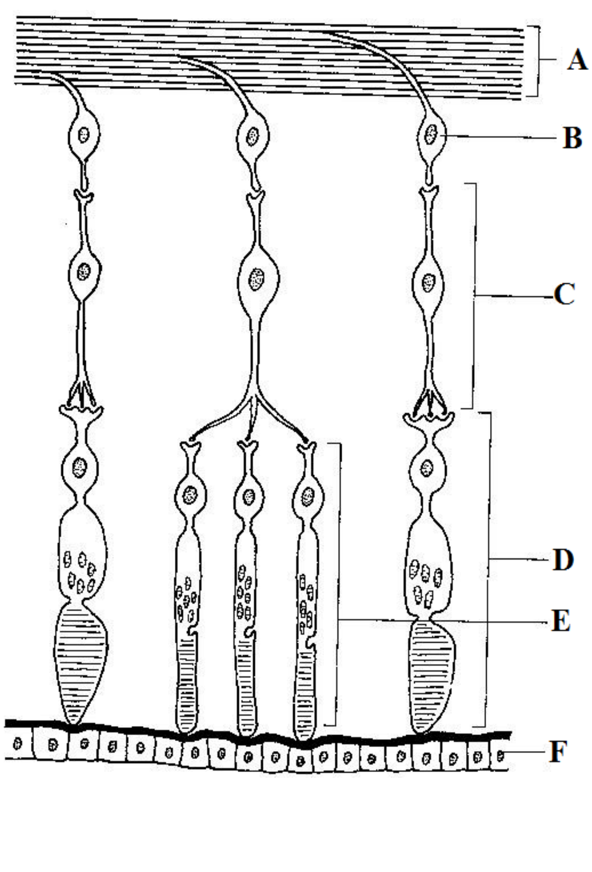
A surprising feature of the retina is that it is back-to-front (**inverted**). The photoreceptor cells are at the back of the retina, and the light has to pass through several layers of neurones to reach them. This is due to the evolutionary history of the ey e, and in fact doesn't matter very much as the neurones are small and transparent

Conjunctiva	Is a thin layer of epithelial cells which protects the cornea against damage by friction
Cornea	Is the transparent, curved front of the eye which converges (refracts) the light rays which enter the eye
Sclera	Is an opaque, fibrous, soft outer connective tissue which provides attachment surfaces for eye muscles
Choroid	Has a network of blood vessels to supply nutrients to the cells and remove waste products. Its pigment makes the retina appear black, thus preventing reflection of light within the eyeball.
Ciliary body	Has suspensory ligaments that hold the lens in place. It secretes the aqueous humour, and contains ciliary muscles that enable the lens to change shape, during accommodation
Iris	Is a pigmented muscular structure consisting of an inner ring of circular muscle and an outer layer of radial muscle. It controls the amount of light entering the eye so that **(1)** too much light does not enter the eye which would damage the retina **(2)** enough light enters to allow a person to see
Pupil	Is an aperture in the middle of the iris where light is allowed to continue its passage.
Lens	Is a **transparent**, flexible, curved structure which focuses incoming light rays onto the retina.
Retina	Is a layer of sensory neurones, the key structures being photoreceptors (rod and cone cells) which respond to light. Contains relay neurones and sensory neurones that pass impulses along the optic nerve to the part of the brain that controls vision
Fovea (yellow spot)	A part of the retina that is directly opposite the pupil and contains only cone cells. It is responsible for good visual acuity (good resolution)
Blind spot	Is where the bundle of sensory fibres form the optic nerve; it lacks light-sensitive receptors
Vitreous humour	Is a transparent, jelly-like mass located behind the lens. It acts as a 'suspension' for the lens so that the delicate lens is not damaged. It maintains the shape of the posterior chamber of the eyeball
Aqueous humour	It maintains the shape of the anterior chamber of the eyeball

The path followed light as it passes through the eye is as follows: through the conjunctiva then cornea, the pupil, aqueous humour, lens, vitreous humour and finally the retina.

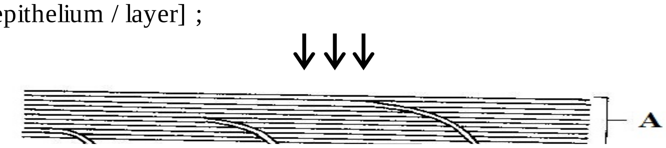
THE RETINA

The retina contains the photoreceptor cells and their associated interneurones (bipolar neurones) and sensory neurones (ganglion cells). They are arranged as shown below:



(a) (i) Name the structures labelled A to F

A – Optic nerve fibres; B - ganglion cell; C – bipolar neurone; D – cone cell; E – rod cell; F – choroid epithelium / layer [pigment epithelium / layer] ;



(b) What is the significance of the fact that:

(i) several cells of type labelled E connect to one cell in layer C?

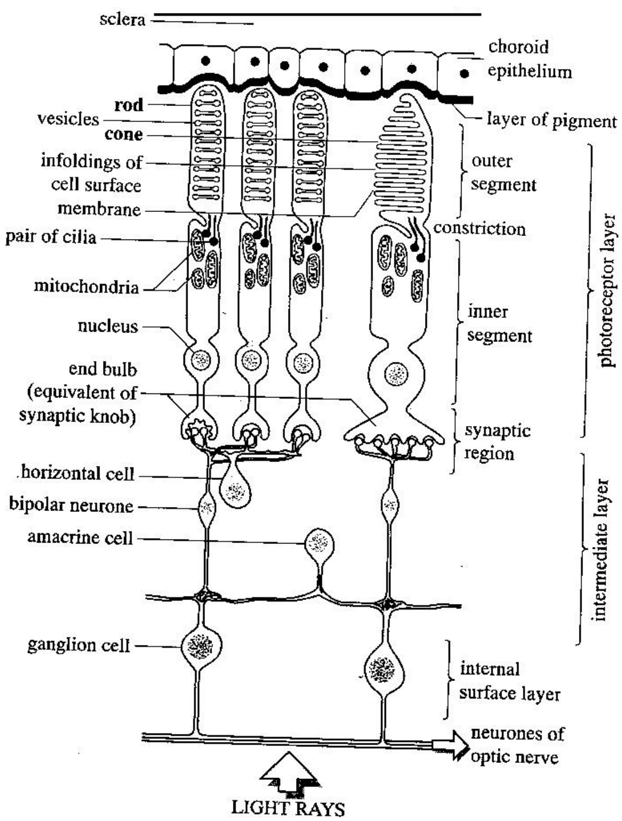
Retinal convergence increases the eye's sensitivity. Light which activates one rod cell (cell E) may be insufficient to generate an action potential in the bipolar neuron (cell C) connected to it yet several rods when hit by light simultaneously may activate action potential the bipolar neuron (cell C) due to summation of generator potentials. Impulse propagation to the CNS results in image formation.

(ii) one cell of type labeled D connects to one cell in layer C?

It improves visual acuity / precision / resolving power of the eye because light from two objects close together stimulate two cones (cell D), the brain receives two impulses and interprets this as two separate objects rather than when different impulses summate into a single message received by the brain]

COMPARISON OF RODS AND CONES

Rods	**Cones**
Outer segment is rod shaped	Outer segment is cone shaped
Greater numbers (about 10^9 cells per eye)	Fewer numbers (about 10^6 cells per eye).
Distributed more at the periphery of the retina (absent at fovea), so used for peripheral vision.	Concentrated in the fovea, so can only detect images in centre of retina.
Sensitive to low light intensity – can detect a single photon of light, so are used for night vision.	Not sensitive to low light intensity – need bright light, so only work in the day.
Only 1 type, so only give monochromatic vision.	3 types (red green and blue), so are responsible for colour vision.
Many rods usually connected to one bipolar cell, so poor acuity (i.e. rods are not good at resolving fine detail).	Each cone usually connected to one bipolar cell, so good acuity (i.e. cones are used for resolving fine detail such as reading).



Qn. Suggest why convergence of rod cells in the retina of human eyes reduces the ability to read small print in dim light

Light falling on groups of rods is transduced into an impulse in only one receptor neurone so the power of resolution is low

Qn. Suggest a chemical explanation of convergence

Only when many synaptic knobs release their neural transmitter simultaneously does its concentration reach a threshold at which depolarisation of the post-synaptic membrane occurs.

Qn. Why should pilots waiting to fly at night not be exposed to bright lights?

Even a short exposure to bright light would cause the rhodopsin in the rods to break down so destroying the pilot's night vision.

Qn. Many nocturnal mammals like cats have a reflective layer – the tapetum lining the back of the eye rather than a pigmented layer. Suggest the value of this arrangement

Light will be reflected back off the tapetum so that it passes twice through the light-sensitive cells, thereby increasing the size of the generator potential developed in the cells

The retina of most mammals contains only rod cells. Discuss the significance of this observation.

Most mammals do not have colour vision; they are sensitive to dim light but not to colour; their visual acuity is low.

(a) When sitting in a dimly lit room, objects often appear slightly fuzzy and colours are more difficult to distinguish. Explain.

Seeing objects using rod cells leads to lower visual acuity; rod cells are insensitive to colour

(b)Explain why brightly coloured objects often appear grey in dim light

Only rods are stimulated by low-intensity (dim) light. Rods cannot distinguish between wavelelngths / colours of light, therefore the object is perceived only in a mixture of black and white i.e. grey.

(c) At night, it is easier to see a star in the sky by looking slightly to the side of it rather than directly at it. Suggest why this is so.

Light reaching the earth from a star is of low intensity. Looking directly at a star focuses light on to the fovea, where there are only cone cells. Cone cells respond only to bright light, so they are not stimulated by dim light from the star and it cannot be seen. Looking to one side of the star ensures that light from the star is focused to the periphery of the retina, where there are mostly rod cells. These are stimulated by low light intensity and therefore the star is seen.

(d) What is the role of:

(i) Horizontal cells? They cause lateral inhibition which increases sensitivity and visual acuity i.e. they inhibit (cancel out) equal intensity stimuli if received from two adjacent rods thereby increasing contrast between weakly stimulated and strongly stimulated areas. E.g. edges of objects stand out stand out more clearly.

(ii) Amacrine cells? After partial processing, they transmit information about changes in the level of illumination

Qn. Explain the following phenomena:

(i) when a person moves from bright sunlight into a dimly-lit room; objects in the room cannot at first be seen but they gradually become visible.

In bright light, the circular muscles contract to narrow the pupil**;** and reduce on over-stimulation of the retinal cells by entry of light into the eye**.** In dim light, radial muscles contract to dilate the pupil slowly to allow entry of light**;** whose threshold at first is low to stimulate the rods for objects to be seen**;** but later improves to enable vision as the pupil dilates fully**;**

(ii) in the dimly-lit room, objects are only visible in black and white.

Rods which are sensitive to light of low intensity do not respond to light of various wavelengths**;** causing images to appear black and white**;**

(iii) some nocturnal animals like cats close their pupils to a vertical slit and also squint in bright light

The retina of nocturnal animals is almost entirely composed of rods**;** with rhodopsin which is particularly sensitive to low levels of light and breaks down so rapidly in bright light**;** The slit pupil and squinted eyes reduce the amount of light entering the eye to enable rhodopsin form faster than it breaks down for vision to occur**;**

(iv) when trying to see a faint star in the sky, it is better to look slightly to one side of it rather than directly at it.

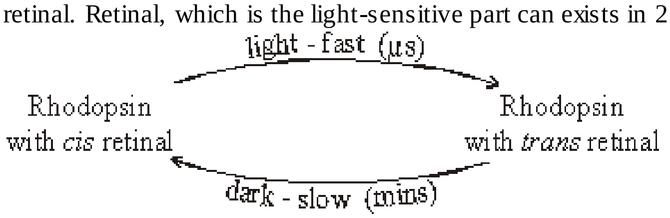
When you look directly at an object, its image forms on the retina's *Fovea centralis* (yellow spot) which is packed with cone cells yet these are only activated by bright light, hence cant see in dim light. Looking slightly away from a faint star moves the image off the fovea and onto parts of the retina that have more rod cells, which are more light-sensitive than the cones.

(v) if both your eyes are open and you press the side of one of your eyeballs, you see double.

Pressing of eye ball distorts the eye position such that the two eyes are unable to look directly at an object in the same direction, hence the brain fails to blend together the images from the two eyes, causing double vision to be perceived

PHOTORECEPTION IN RODS

The detection of light occurs at the vesicles (membrane disks) in the outer segment. The vesicles are filled with the photoreceptor molecule called rhodopsin, which consists of a lipoprotein called opsin and a derivative of vitamin A called retinal. Retinal, which is the light-sensitive part can exists in 2 forms: a *cis* form and a *trans* form:



[Note: a dietary deficiency in vitamin A causes night-blindness (poor vision in dim light)].

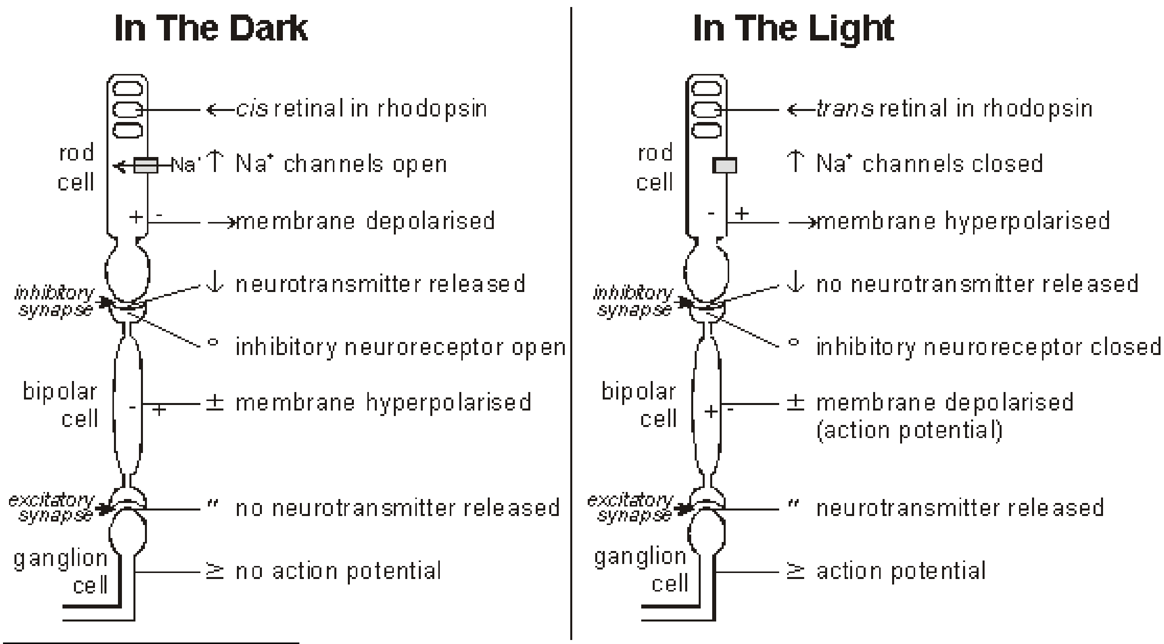
The mechanism of photoreception

In the dark retinal is in the *cis* form, but when it absorbs a photon of light it quickly switches to the *trans* form, its shape and therefore the shape of the opsin protein change in a process is called **bleaching**. The *trans* to *cis* retinal conversion is a slow enzyme catalysed reaction. This explains why a person is initially blind after walking from sunlight to a dark room: in the light almost all your retinal was in the *trans* form, and it takes some time to form enough *cis* retinal to respond to the light indoors.

Rhodopsin with *cis* retinal opens the sodium mediated protein channels and rhodopsin with *trans* retinal closes them. This means in the dark the channel is open, allowing influx of sodium ions causing the rod cell to be depolarised. This in turn means that rod cells release neurotransmitter in the dark. However the synapse with the bipolar cell is an inhibitory synapse, so the neurotransmitter stops the bipolar cell making a nerve impulse. In the light everything is reversed, and the bipolar cell is depolarised and forms a nerve impulse, which is passed to the ganglion cell and to the brain.

Qn. How is a rod cell suited for photoreception? (consider the following: mitochondria, lamellae, sensitivity of rhodopsin to light, rate of regeneration of rhodopsin, etc)

Qn. How are rod cells suited for photoreception? (consider all the above plus number of rods)



Visual Acuity (Resolution)

Visual acuity is the amount of detail that can be seen (image sharpness). Although there are far more rods than cones, we use cones most of the time because they have fine discrimination and can resolve colours. This is because one cone cell synapses to one bipolar cell which in turn synapses onto one ganglion cell as the information is relayed to the visual cortex. The more densely-packed the cone cells, the better the visual acuity. In the fovea of human eyes there are 160 000 cones per mm^2, while hawks have 1 million cones per mm^2, so they really do have far better acuity.

Defects in visual acuity

Myopia results from eyeball being too long, so that the image is brought to a focus in front of the retina; this is corrected by a concave lens.

Hyperopia results from eyeball being too short, so that the image is brought to a focus behind the retina; this is corrected by a convex lens.

Astigmatism is the condition in which asymmetry of the cornea and or lens causes uneven refraction of light around 360 degrees of a circle, resulting in an image that is not sharply focused on the retina.

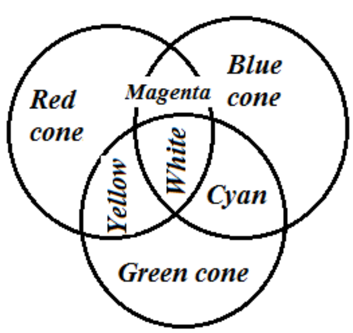
Colour vision in Cones

There are three different kinds of cone cell, each with a different form of opsin (they have the same retinal). These three forms of iodopsin are sensitive to different parts of the spectrum, so there are red cones (10%), green cones (45%) and blue cones (45%).

Trichromatic theory of colour vision

It suggests that different colours are produced by the degree of stimulation of the different types of cone.

When viewing an object, the three types of cone are stimulated to various degrees depending on the wavelength of light the object reflects. By comparing the nerve impulses from the three kinds of cone, the brain can interpret any colour. For example, when the red/blue/green receptors are stimulated in the ratio of 10:86:15, the color of an object is interpreted by the brain to be blue. When the ratio is 13:14:86, the color is interpreted as green, and when it is 100:20:99 the color is yellow.



- Red light stimulates red cones mainly
- Yellow light stimulates red + green cones roughly equally
- Cyan (peacock blue) light stimulates blue + green cones roughly equally
- In white light the cones are all stimulated equally.
- If no cones are stimulated, an object would be perceived as black.
- Grays are perceived when cones are stimulated in low levels in various combinations.
- Absence of any cone type fails to cause a response and colors will be perceived accordingly.

Note: Color receptors fatigue and cease to respond when they are stimulated continuously for a long period of time.

Colourblindness

It is the inability to distinguish between colours. Red-green colour blindness is the commonest, although other forms of colour blindness are also possible, but are much rarer.

The red, green and blue opsin proteins are made by three different genes. The green and red genes are on the X chromosome, which means that males have only one copy of these genes (i.e. they're haploid for these genes). About 8% of males have a defect in one or other of these genes, leading to red-green colour blindness.

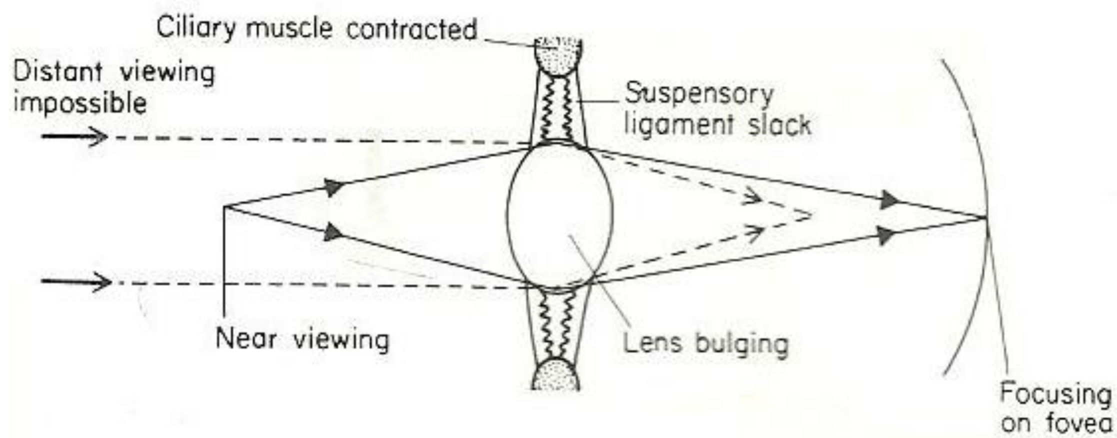
Accommodation of the eye

Accommodation refers to the ability of the eye to alter its focus so that clear images of both close and distant objects can be formed on the retina.

Changes that occur in the human eye when viewing:

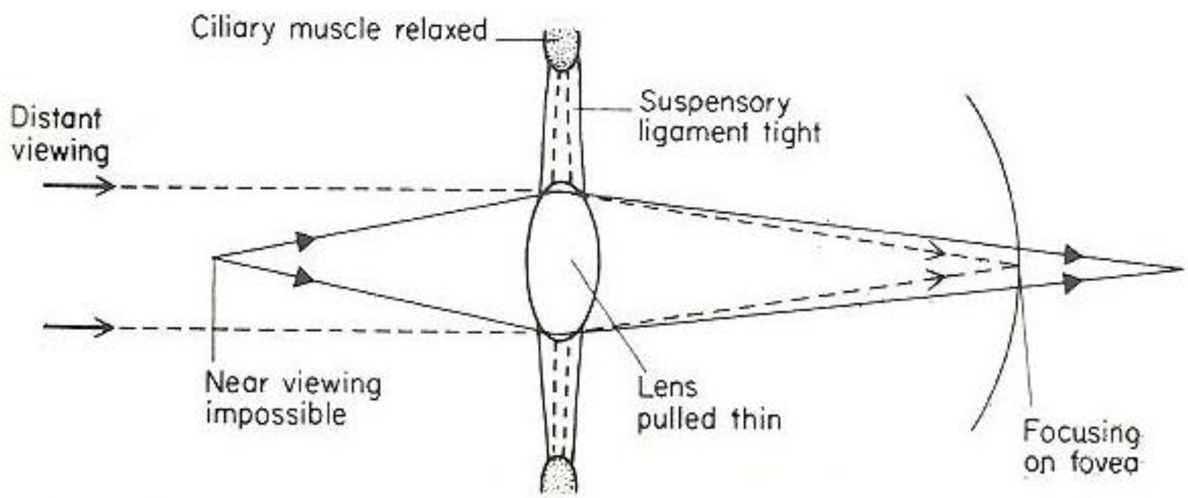
(i) near objects

- The diverging light rays reflected off the nearby object enter the eye through the cornea which refracts the rays through the pupil into the lens.
- The ciliary muscles contract, as the suspensory ligaments relax and slacken allowing the lens to become thicker and shorter, and become more convex.
- A thicker lens has a shorter focal length, which enables focusing the clear image onto the retina/fovea/yellow spot.



(ii) distant objects

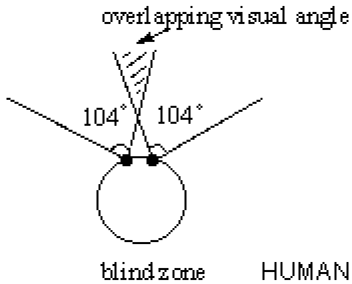
- The light rays reflected off the distant object which are almost parallel to each other enter the eye through the cornea which refracts the rays through the pupil into the lens.
- The ciliary muscles relax, as the suspensory ligaments tauten pulling on the edge of the lens, which thins and becomes less convex.
- A thinner lens has a longer focal length, which enables focusing the clear image onto the retina/fovea/yellow spot.



PERCEPTION OF DISTANCE AND SIZE

Binocular vision

This is vision in which both eyes aim simultaneously at the same visual target, equally and accurately as a coordinated team.



Each human eye has a fixed visual angle of 104°. Since the two eyes are placed close together, overlapping of visual angles allows more accurate judgment of distance of the object in front.

Stereopsis or stereoscopic vision

This is vision in which two separate images from two eyes are successfully fused into one image in the **visual cortex** of the **brain**. First, both eyes must have binocular vision; then, because the two eyes are located in different positions, each takes in a unique view from its own perspective sending two separate images to the brain simultaneously for processing, from where the images are fused into one three dimensional (3-D) image.

- Binocular and stereoscopic vision enables predator animals e.g. hawks and lions to accurately judge the distance to catch prey. Their eyes are set in front.
- The animals with eyes on the sides of their head e.g. a rabbit (a common prey) rely on **(1)** the relative size of an object, **(2)** the shadow it creates, **(3)** the movement of it relative to distant non-moving objects, to judge distance because they have poor stereoscopic vision due to little overlapping of visual field results. However, they have wide overall visual field, which is good for detecting movements.

Qn. Figure I below shows the number of receptor cells (types A and B) in the human retina along a horizontal line from the nasal side of the eye to the outer side. Distances are expressed in arbitrary units.

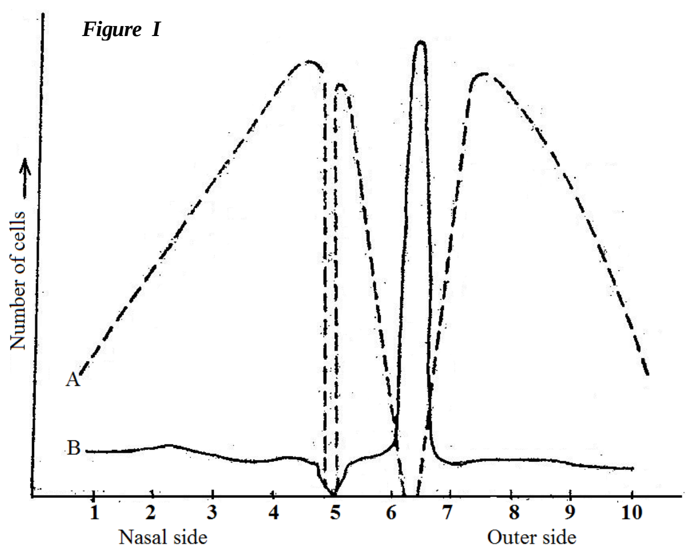


Figure II shows the absorption of different wavelengths of light by three varieties of the light sensitive pigment **iodopsin** as suggested by the trichromatic theory of colour vision in man.

Figure II

Light wavelength (nm)	**Amount of light absorbed as a percentage of maximum**		
	Red iodopsin	*Green iodopsin*	*Blue iodopsin*
660	5	0	0
600	75	15	0
570	100	15	0
550	85	85	0
530	60	100	10
500	35	75	30
460	0	20	75
430	0	0	100
400	0	0	30

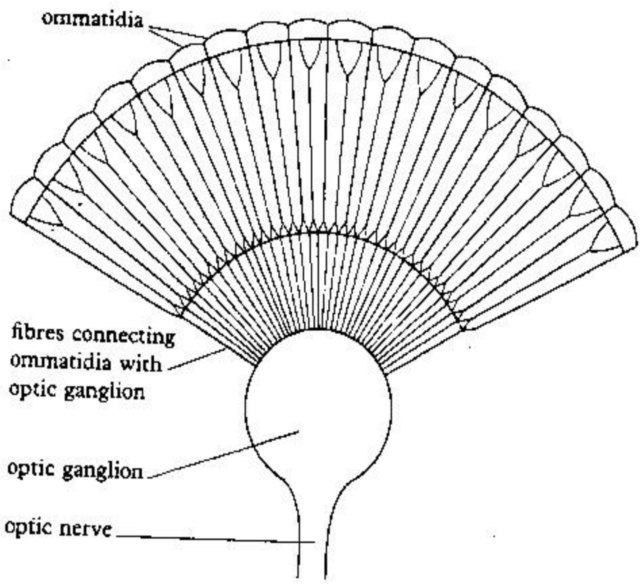
From figure I,
(a) (i) With a reason in each case, identify the types of receptor cells represented by letters A and B
(ii) Explain why there are no receptor cells at position 5
(iii) What is the name of the region of the retina at position 6?
(iv) Explain how position 6 is suited for functioning
From figure II,
(b) Plot a suitable graph to represent the data.
(c) Using the data in figure II, comment on perception of the wavelength of light as colour

COMPOUND EYE

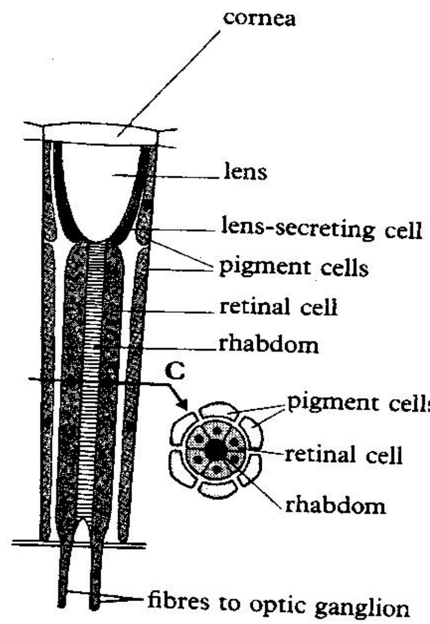
The eye of most arthropods which is composed of many light-sensitive elements, each having its own refractive system and each forming a portion of an image.

Structure of compound eye

Vertical section through compound eye and optic nerve



Ls and Ts through one Ommatidium



External structure

A compound eye has a mesh-like appearance because it consists of hundreds or thousands of tiny lens-capped optical units called **ommatidia**.

Internal structure

Each ommatidium has elongated retinal cells surrounding the centrally placed light-sensitive **rhabdom**. The cone-shaped lens is capped by a flattened cornea while the lower part borders retinal cells and the sides are surrounded by the lens secreting cells. The rhabdom and retinal cells are connected to optical nerve cells. The rhabdom is formed from concentration of microvilli from retinal cells. The ommatidia are separated from each other by varying degrees of pigmentation. Photo-active reactions in the rhabdom cause depolarisation in retinal cells.

Note: As each ommatidium is orientated in a slightly different direction, the honeycombed eye creates a **mosaic** image which, although poor at picking out detail, is excellent at detecting movement.

Types of compound eyes

(i) Apposition eye

This is a compound eye in which each ommatidium focuses only rays that are almost parallel to its long axis, so that each forms an image of only a very small part of the visual field. The image of the whole results from a combination of these part images e.g. in Diurnal insects.

(ii) Superposition eye

This is a compound eye in which the sensory cells of an ommatidium can pick up light from a large part of the visual field so that the image received may overlap those received by as many as 30 neighboring ommatidia. The superposition image has much brightness but low in sharpness compared with the apposition image e.g. in nocturnal insects.

Comparison of STRUCTURAL features of mammalian and compound eyes

Similarities	*Compound eye*	*Mammalian eye*
Both: (1) have convex lens (2) pigment cells (3) cornea (4) retinal cells (5) optic nerves	● Lens is crystalline hence inelastic ● Photosensitive part of retinal cells is rhabdom ● Photosensitive cells are not pigmented ● Has many units (ommatidia) capable of functioning independently ● Photosensitive cells are not differentiated ● Lacks extrinsic muscle attachment and is immovable ● Has rhabdom ● Lacks eye lids ● Ommatidia are relatively large, so few can pack per unit area	● Lens is membranous and elastic ● Photosensitive part of retinal cells is outer segment ● Photosensitive cells are pigmented ● The whole eye functions as a unit. ● Photosensitive cells are differentiated into rods and cones ● Has extrinsic muscle attachment for movement ● Lacks rhabdom ● Has eye lids ● Rods and cones are very tiny, so very many can pack per unit area.

Comparison of FUNCTIONAL properties of mammalian and compound eyes

Similarities	*Compound eye*	*Mammalian eye*
Both: (1) can perceive colour (2) function in bright and dim light (3) have photosensitive cells (4) have image overlap (5) optic nerves which propagate impulses (6) Experience lateral inhibition (mutual inhibition)	● Image overlap is greater hence blurred images are formed ● Focus is fixed, no accommodation ● Less power of colour vision ● Has quicker detection of movement ● Has poor resolution and visual acuity ● Has poor dark adaptation and hence poor night vision ● Ommatidia take shorter to generate impulse and recover ● Flicker fusion occurs at faster frequency	● Image overlap is smaller hence clear images are formed ● Focus is adjustable, hence can accommodate ● Greater power of colour vision ● Has slower detection of movement ● Has good resolution and visual acuity ● Has better dark adaptation and hence better night vision ● Rods take longer to generate impulse and recover ● Flicker fusion occurs at faster frequency

Lateral inhibition (mutual inhibition)

A phenomenon in which simultaneous stimulation of adjacent sensory units results in inhibition of impulse propagation in each of them. Lateral inhibition increases sensitivity and visual acuity

Qn. Using the mammalian ear as an example, show how a receptor organ functions. (09 Marks)

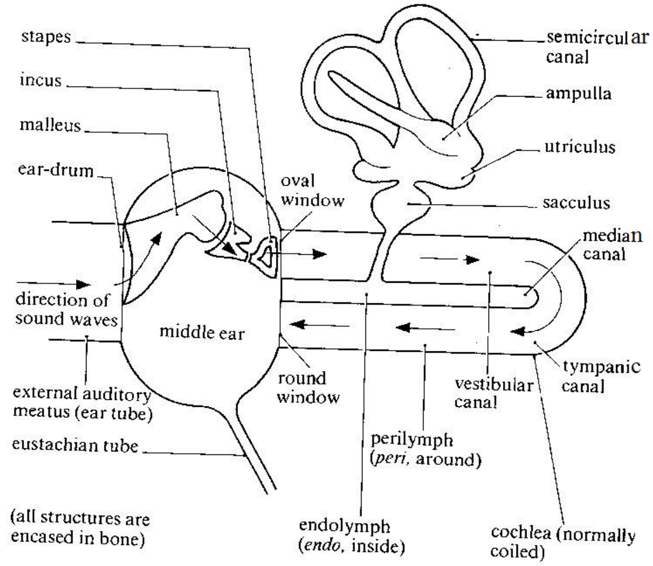
The ear functions both as an organ of hearing and of balance;✓01

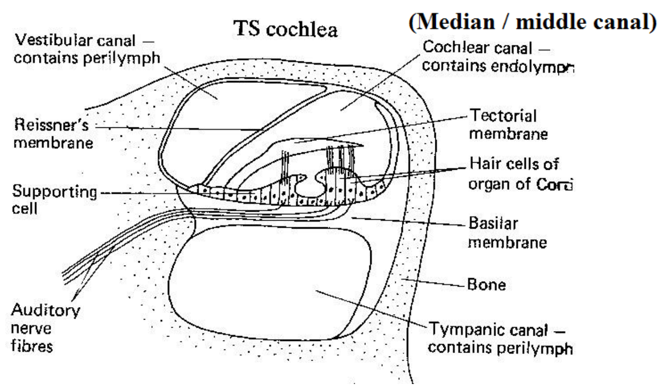
WHEN MARKING IGNORE THE DIAGRAM IF DRAWN

EITHER

How the mammalian ear functions as a sound receptor organ

- The outer ear funnels sounds waves of a given pitch / frequency (measured in hertz) and intensity (measured in decibels) to the tympanic membrane, causing it to vibrate;
- Vibrations of the tympanic membrane cause movement of the middle-ear ossicles, malleus, incus, and stapes, which in turn produces vibrations of the oval window of the cochlea;
- Vibrations of the oval window set up a traveling wave of perilymph in the scala vestibuli.
- Sounds of high frequency (high pitch / high tone) cause maximum displacement of the basilar membrane closer to its base near the stapes; sounds of lower frequency (low pitch) e.g. the rumbling sounds of distant thunder produce maximum displacement of the basilar membrane closer to its apex.
- Loud sounds / large amplitude sounds / high intensity sounds impinge greatly on the basilar membrane hence displacing it greatly and causing rapid firing of impulses in the auditory nerves than soft sounds.
- Displacement of basilar membrane causes sensory hairs to press against the tectorial membrane above them;
- The sensory hair cells are depolarized to produce generator potentials and initiation of action potential; in the axons of the auditory nerve;



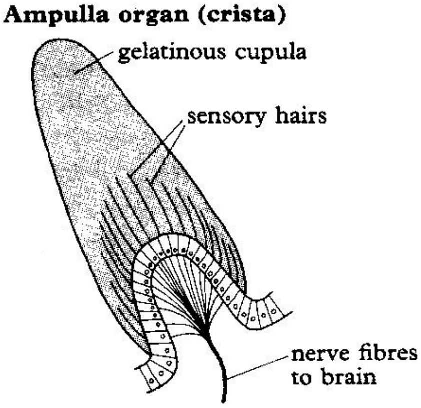


ALTERNATIVELY

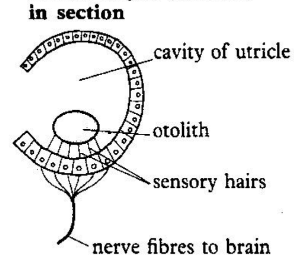
How the mammalian ear functions as an organ of balance

- The structure involved in equilibrium, known as the **vestibular apparatus**, consists of the utricle, saccule and the semicircular canals.
- The **<u>semicircular canals</u>** respond to **<u>rotational</u> movements (<u>angular acceleration</u>)** while the **<u>utricle</u> and <u>saccule</u>** respond to changes in the **position of the head** with respect to **gravity (linear acceleration) ;**
- When the head begins to <u>rotate</u> in any direction, the inertia of the endolymph causes it to lag behind and exerting pressure that deflects the <u>cupula</u> in the opposite direction; which bends the cilia atop hair cells;
- The sensory cells create generator potentials leading to propagation of action potentials in the vestibular neurons;
- When a person is upright, the sensory cells of the utricle are oriented vertically; those of the saccule are oriented horizontally.
- Linear acceleration produces a shearing force between the hairs and the otolithic membrane, thus bending and electrically stimulating the sensory cells
- The vertical and lateral displacement of the head causes the sensory cells produce generator potentials; leading to propagation of action potentials in the vestibular neurons;

Ampulla organ (crista)



Utricle organ (macula) in section



ECHOLOCATION (ACTIVE SONAR) IN BATS

- This is the use of sounds made by the animal itself to avoid obstacles during flight and locate food in total darkness.
- Bats generate ultrasound via the larynx and emit the sound through the open mouth or nose.
- Ranging is done by measuring the time delay between the animal's own sound emission and any echoes that return from the environment.
- The relative intensity of sound received at each ear and the time delay between arrival at the two ears provide information about the horizontal angle from which the reflected sound waves arrive.
- The echoes returning to the two ears arrive at different times and at different loudness levels, depending on the position of the object generating the echoes.
- The time and loudness differences are used by the animals to perceive distance and direction
- Echolocation enables the bat to locate direction, judge the size and nature of obstacles during flight.

Questions for thorough revision

1. (a) Describe how the ear is able to detect sounds of different pitch

By detecting vibrations in different parts of the cochlea

(b) Suggest how very loud noises might permanently damage a person's hearing.

Destroying sensitive hair cells

2. Explain the following observations:

(a) (i) Most people feel pain in their ears when they skin dive at a depth of 5 metres

(ii) Experienced skin divers overcome this pain by pinching their nose and blowing air into their closed nostrils

Water's pressure presses the eardrum inwards causing pain; therefore blowing the nose in this way forces air up the Eustachian tube thus increasing the pressure in the middle ear.

(b) (i) After spinning around for a short time, people feel dizzy when they stop

(ii) During this dizziness, they seem to be spinning in the opposite direction to the way they were actually spinning before.

Just as the inertia of the endolymph causes a deflection of the moving cupula when we start to spin, its inertia causes it to continue moving when we stop spinning. This deflects the cupula making us think we are still moving; it deflects it in the same direction as we are spinning which would normally happen when we start to move in the opposite direction and the cupula is deflected by stationary endolymph

3. With three examples, explain what is meant by *lateral inhibition* and give examples of its effects in three sensory systems.

Answer.

Lateral inhibition — the central nervous systemphenomenon by which sensory information is "sharpened" by inhibition of incoming neighboring (lateral) field information from the periphery of that region which is maximally stimulated.

Three sensory systems utilizing lateral inhibition are the senses of touch (cutaneous), hearing, and vision.

In the skin, a single touch is felt when a blunt object touches the skin because the surrounding fields have been "laterally inhibited" at the level of the central nervous system.

Similarly, in the discrimination of different pitches of sounds with similar frequencies, neural activity is "laterally inhibited" so that the hair cells along the basilar membrane which are maximally displaced by sound waves are selected for interpretation by the auditory cortex of the brain while hair cells with neural activity from the surrounding regions are suppressed.

Lateral inhibition is also at work in the processing of visual information at the level of the ganglion cells in the retina. Here, the receptive fields of each ganglion cell resembles a "bull's eye" with a central core area and an outer surround area that oppose one another, that is, are antagonistic. Those ganglion cells that have **on-center fields** are excited by light at the center of their visual fields while the surround is suppressed (or inhibited laterally). Those ganglion cells that have **off-center fields** are inhibited by light in the center and stimulated by light in the surround. Due to the distribution of these two types of ganglion cell fields along the retinal surface, incoming light excites some and inhibits some of these fields — which translates later at the occipital (striate) cortex as sharper visual acuity.