Sense Organs in Fishes

Sense organs

Specialized organs, which receive physical and chemical stimuli from the environment called sense or sensory organ.

Fishes posses a number of sense organs for smell, sight, hearing, taste, touch, temperature etc.
The sense organs are associated with the nervous system and transmit the environmental stimuli to the central nervous system.

Sense organs:

1. Eye

2. Internal Ear

3. Chemo-sensory organs
a. Gustatory (taste buds)
b. Olfactory (olfactory rosette)

4. Lateral line system

5. Electro-receptor organs
a. Ampullary organ
b. Tuberous organ

Eye

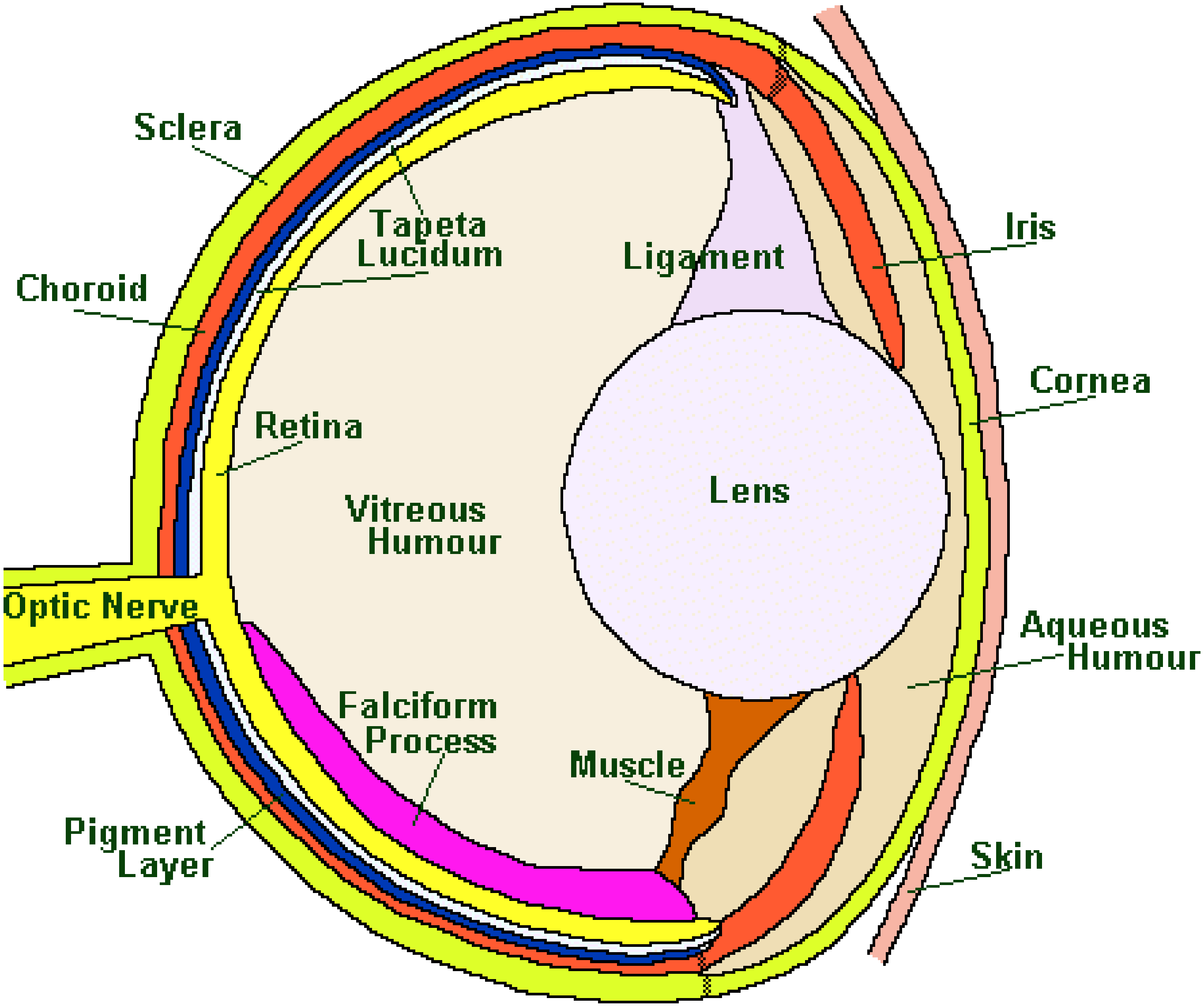
Eye are the photoreceptor organs in fishes and resembles in structure with the other vertebrate

The eye in most of fishes is lid less but some shark (Galeorhinus) possess lid like nictitating membrane. Fishes have monocular vision. The field of view of each eye is considerably enlarged and extended forward continues laterally to almost behind the fish

Structure:

i) Cornea
ii) Iris
iii) Lense
iv) Eye ball

A Diagrammatic Representation of a Teleost Eye



Cornea

It is the anterior part of the eye. It is composed of

- **corneal epithelium**
- **corneal stroma**
- **corneal endothelium**

Most of fishes the cornea is without pigment and hence it is transparent. Cornea help in retention of water and thus prevent drying of eye

Iris

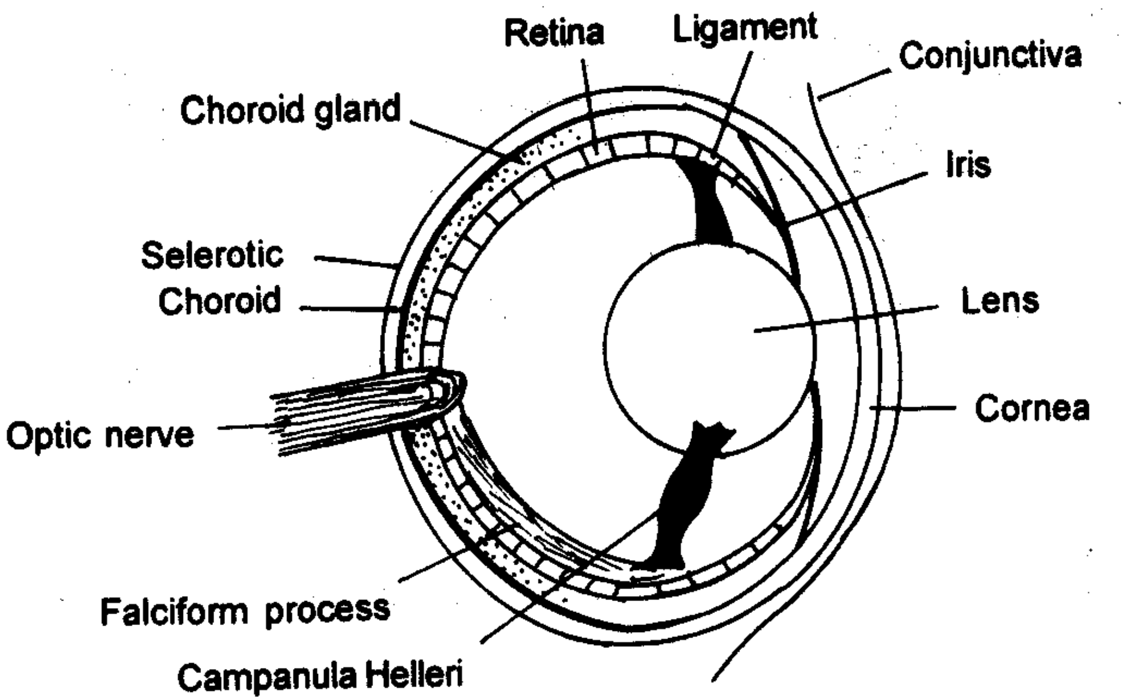
It is lies just in front of lens and composed of pupil to control the amount of light reaching to retina

Lens

Lens is transparent, ball like and composed of non collagenous protein. Lens is covered by lens capsule and filled with lens substances.

Accommodation of lens

It is the process in which fish adjust or accommodate the lens in accordance to the viewing object.
It usually achieved by altering the position of lens rather than the shape of the lens.
Fish altering the position of the lens with the help of lentis muscle or campaluna of helleri.



Eye ball

Eye ball has usually three layers- Outer Sclerotic capsules, middle choroid and inner retina

a) Sclerotic capsules: It is the outmost fibrous layer strengthened by cartilaginous element

b) Chroid layer: It is the middle higly vascular layer. Horse shoe shaped choriod gland is present in the posterior end. It consists a network of blood capillaries called rete mirabile . It has counter current oxygen multiplier which supply extra amount of oxygen to the retina.

c) Retina: It is the most sensitive part of the eye and closely resembles to the other vertebrates. It consists –
i) A layer of light sensitive visual cells (Rod and cone)
ii) a layer of bipolar cells and connected to the visual cells
iii) a layer of ganglion cells connecting the bipolar cells to the optic nerve.

Retina contains two types of light sensitive pigments- rhodopsin (purple colour) and porphyropsin (Rose colour)

Photo-pigment

Visual photo-pigment consists of two parts: Retinal (a vitamin A derivative) and Opsin (a glycoprotein).

Photopigments are broadly divided into two groups:

1) Purple colour rhodopsin

(opsin + aldehyde of Vitamin A) responsible for monochrome vision

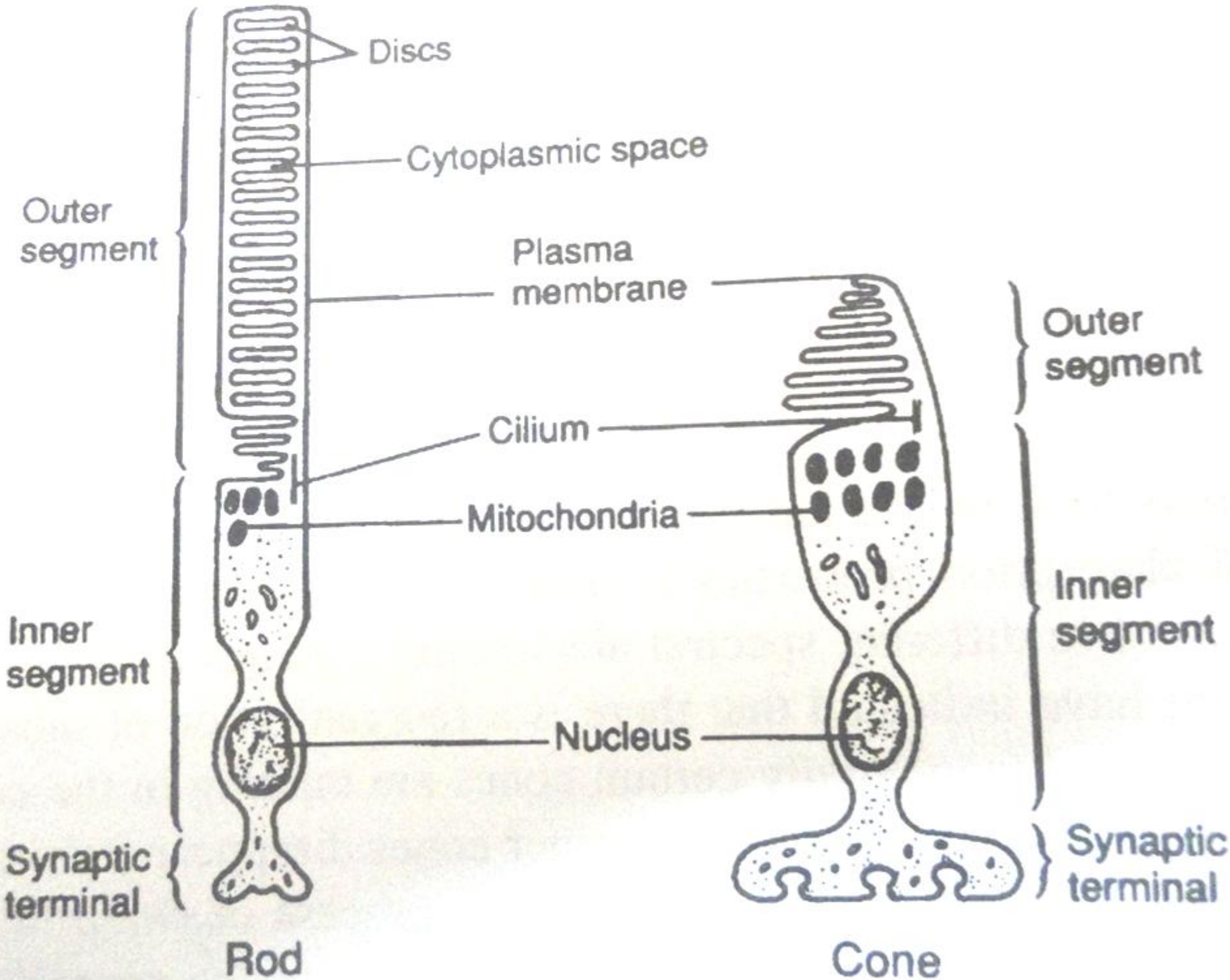
2) Rose colour Porphyropsin

(opsin + 3-dehydroretinal) responsible for colour vision

There are different kinds of photopigments in cones, in which opsin are same but retinal or vitamin A derivatives are slightly different in structure enabling each photopigment to absorb a different range of light wavelengths (different colors). A mixed stimulation of different cones (called red, green, and blue for their optimally absorbed wavelengths) provides for the perception of varied colors.

There is only one kind of photo-pigment in rod known as rhodopsin.

A


Discs
Cytoplasmic space
Outer segment
Plasma membrane
Outer segment
Cilium
Mitochondria
Inner segment
Inner segment
Nucleus
Synaptic terminal
Synaptic terminal
Rod
Cone

Difference between Rod and Cones

Rods	Cones
Photopigment: Rhodopsin (opsin + aldehyde of Vitamin A)	Photopigment: Porphyropsin (opsin + 3-dehydroretinal)
Highly sensitive, nocturnal	Lower sensitivity, diurnal
More photopigment, greater photon capture, high amplification	Less photo-pigment, less amplification
Saturation at low level of brightness	Saturation only in intense light
Low resolution	High resolution
Slow response kinetics and long integration time	Fast response kinetics and Short integration time
More sensitive to scattered light	More sensitive to direct rays emanating from target
Only one type of photoreceptor thus no colour vision (monochromatic)	Several type of photoreceptor with differential sensitivity and hence the capacity for colour vision

Conversion of light into sight

When a photo-pigment absorbs light, retinal unit of photo-pigment changes shape, causing it to separate from opsin. Because the product is colourless, the process is called bleaching.

When a photoreceptor is stimulated, the freed opsin becomes chemically active and initiates a series of chemical reactions Activated Opsin stimulates a G protein (transducin), which in turn activate cGMP phoshodiesterase enzyme. This enzyme catalyzes the breakdown of cGMP to 5’GMP.

As cGMP concentration lowered, Na^+ channels close, thereby causing the hyperpolarization of plasma membrane

Hyperpolarization stops the normal secretion of the neurotransmitter, which in turn stimulates a graded potential in the bipolar cells. This change in membrane potential send signals to the brain which convert light into sight or image.

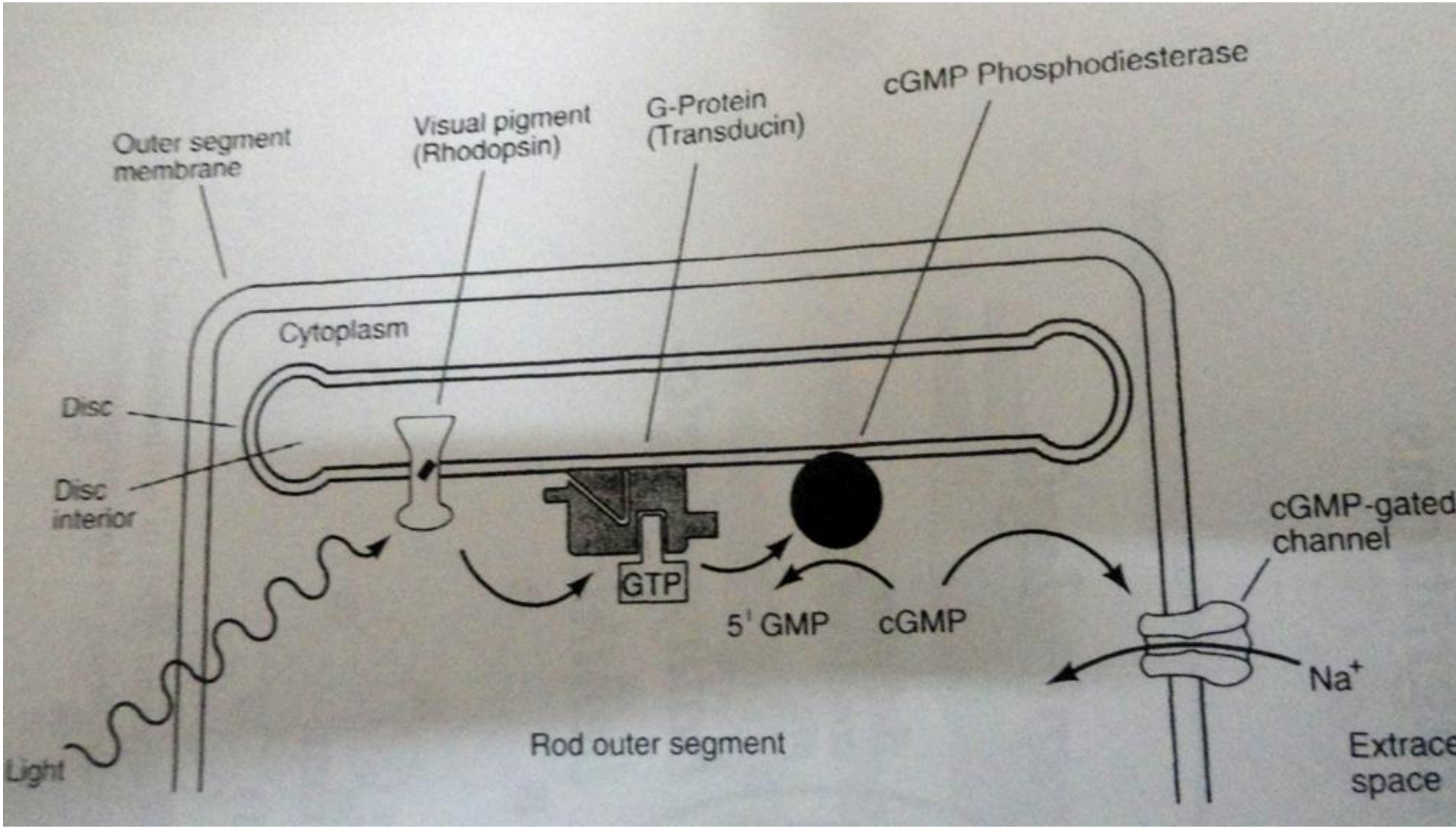


Photo-transduction in Rod Cell: Conversion of light into sight

Light sensitivity of retina

The membrane of retina contain melanin and border of choroid coat.

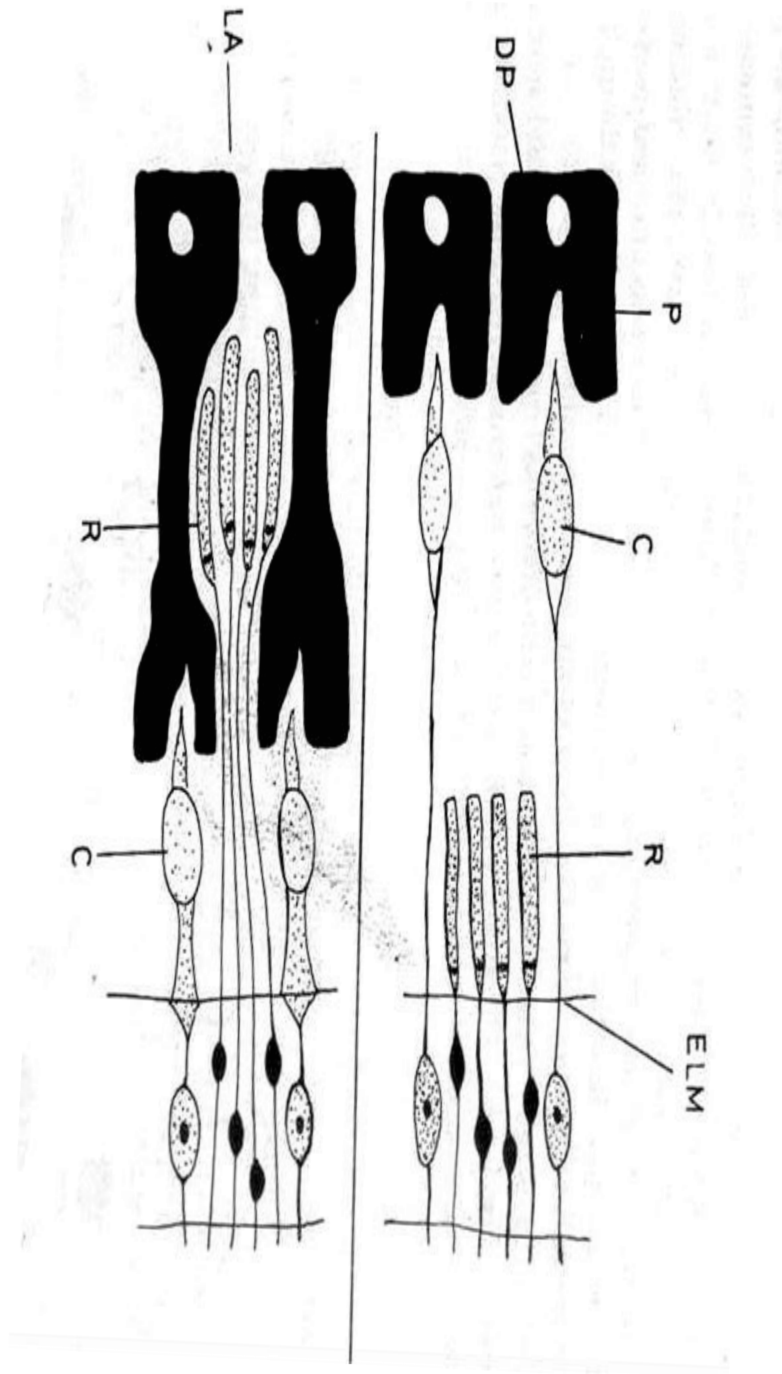
Melanin is photosensitive and in bright light it spreads and shades the sensitive rod .

In weak light it aggregates near the choroid border, so that the photosensitive cells are fully exposed to the amount of light available.

At the same time contractile muscle present at the base of the rods and cones moves in such a way that the rods are moved away from the lens in bright light, whereas, in dark brings near to the lens.

The cones move opposite to the rods. This mechanism is much developed in fishes than other vertebrates.

Light Adapted



Dark Adapted

Dark and light adaption of fish eye

In bright light, the very light-sensitive rhodopsin in rods cannot be regenerated as fast as it is broken down, so most of the rhodopsin remains inactive. As a result, the less light-sensitive pigments in cones are active in normal or bright light.

When fish move from bright conditions to dark conditions, the photo-pigments in cones are too insensitive to detect light, vision returns as rhodopsin is regenerated, a process called dark adaptation.

When fish again move from dark to bright conditions, very light-sensitive rods are suddenly overwhelmed with stimulation, producing the sensation of glare. Light adaptation occurs as the rhodopsin in rods is completely bleached and the less light-sensitive cones resume activity.

Internal Ear or Membranous Labyrinth

•The membranous labyrinth or the internal ear is the chief organ of hearing and equilibrium.

•Internal ear is a membranous sac partially divided into an upper chamber utriculus and a lower one called sacculus, having a small outgrowth, the lagena.

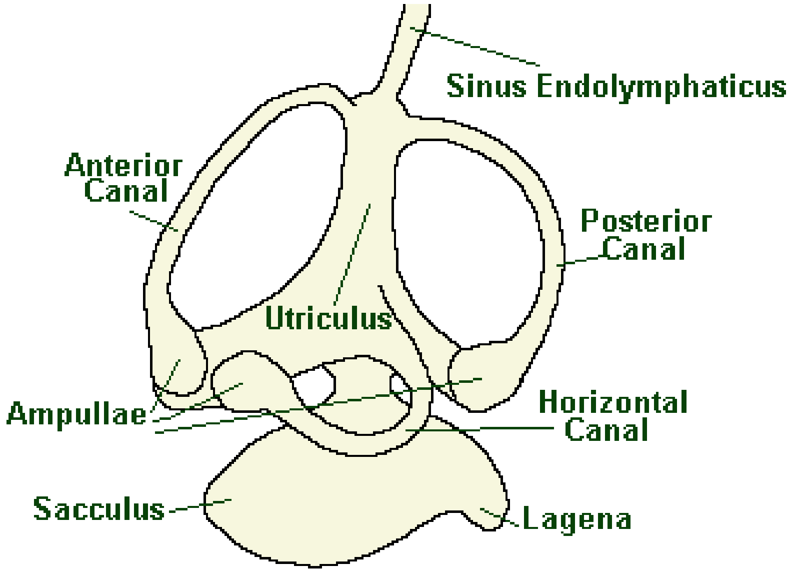
•Three semi circular canals open into the utriculus.

•Each canal has a small swelling at the end called ampulla.

The cavity of utriculus, sacculus and lagena contain a fluid called endolymph and group of highly sensitive cells (Sensory Hair Cells) are present in their wall.

In the cavity of ear, solid concretions called otolith are present. Three otholiths are present in three sac and called lapillus, sagitta and asteriscus.

Diagramatic Representation of a Teleost Ear

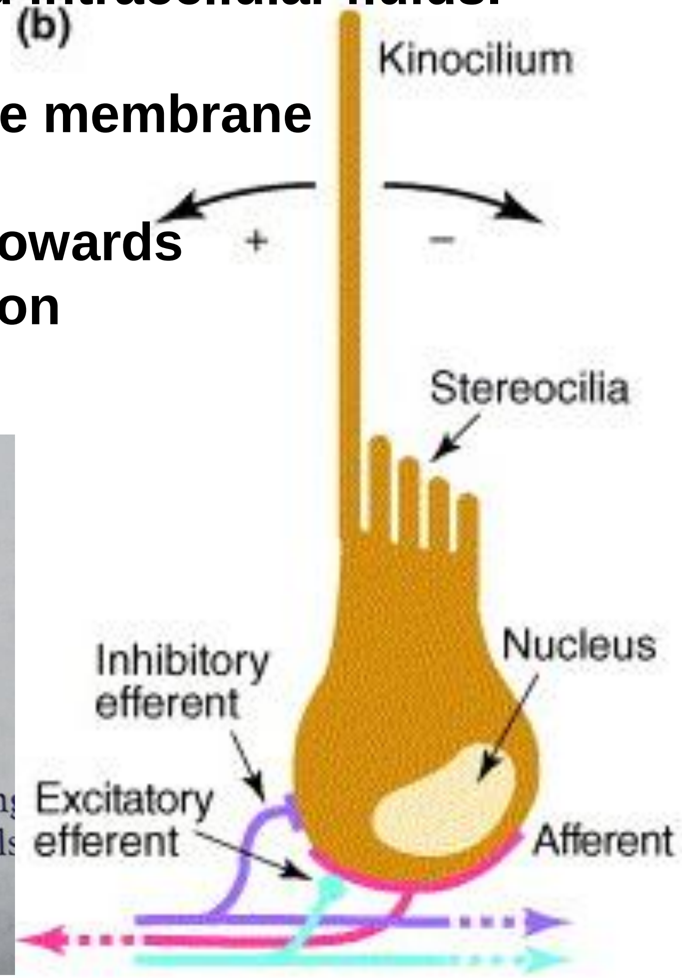


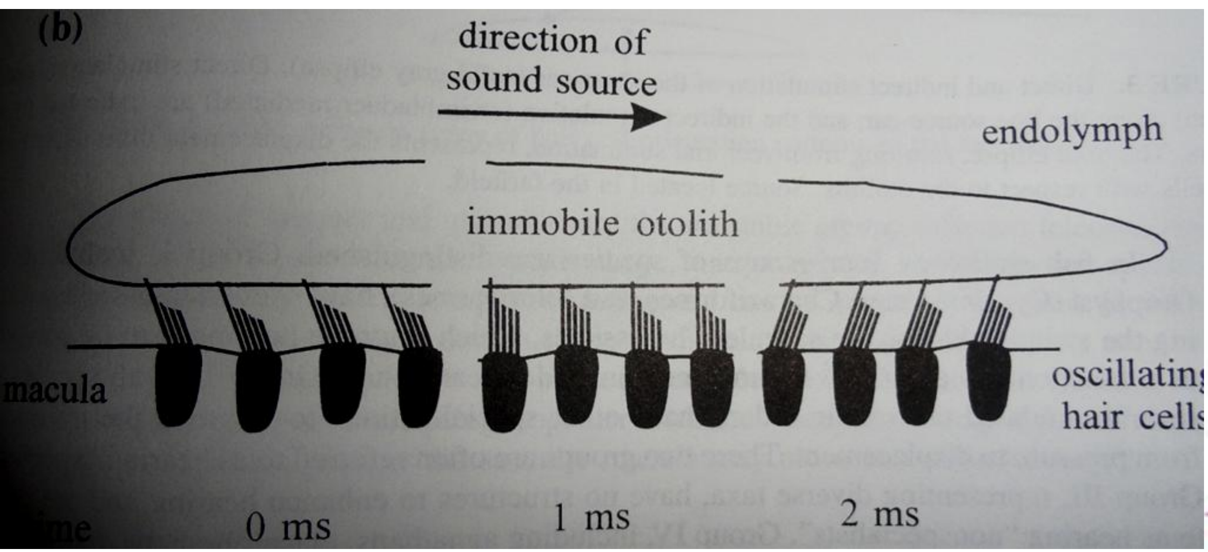
Semi circular canals and utriculus ars mainly responsible for the maintenance of equilibrium while the sacculus and lagena are site for the sense of hearing

The hair cells are sensitive to mechanical deflection of hairy processes. electrical potential exist at the apical and baso-lateral ends of the cells, due to difference in ionic contents of extra and intracellular fluids.

Deflection of cilia cause flow of ions across the membrane

Afferent fibers exicted when stereocilia bend towards kinocilium, while deflection in opposite direction inhibit the afferent fibers.





Auditory mechanism in inner ear

The density of fish body and water are similar. In response to sound, fish’s body follows the motion of the water molecules. However, the otolith lag behind the rest of the body because of their higher density and weak suspension.

Above 50 to 100 Hz, an otolith, behaving like a damped harmonic oscillator, can be considered to be immobile.

The result is that hair cells oscillate with respect to otolith and hair bundles are deflected. This mechanism is referred to as direct stimulation of the ear.

Deflection of cilia cause flow of ions across the membrane and depolarization of hair cells. The depolarization is followed by an increase in the firing rate of the nerve fibers transmitting the sensory information to the brain.

Chemosensory Organs

Fish have two well defined chemical-sensing system

1. **Gustatory System (Taste)**

2. **Olfactory System (Smell)**

Chemosensory Behavior

Feeding → Gustation

Detecting Danger

Non sexual Social interaction

Orientation

Reproductive synchrony

} Olfactory

Gustatory System

The sense of taste is generally defined as that portion of the nervous system associated with sensory cells of taste buds.

Although, fishes have dense concentration of taste buds in their mouth, the distribution of these structure may frequently include the gills and exterior surface of the animal.

The gustatory sense of fishes is associated with distinct cranial nerves (VII, IX, X), all of which are projected to different areas of brain.

Taste Buds

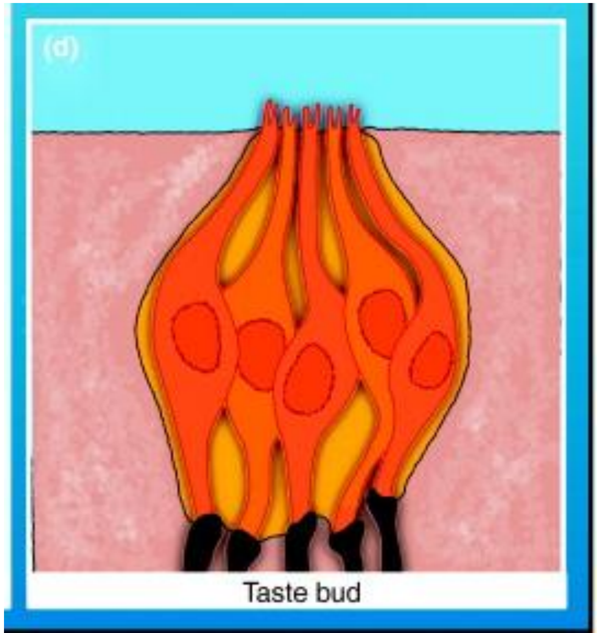
✓Sensory cells of taste buds present on the external body, lips and rostral palate form synapse with facial (cranial nerve VII) neurons

✓Sensory cells of taste buds present along the floor of the oral cavity and gill rakers of first gill arch form synapse with glossopharyngeal (cranial nerve IX) neurons

✓Sensory cells of taste buds present more posterior in pharynx synapse with vagal (cranial nerve X) neurons

❖Taste buds that synapse with cranial nerve VII are important in appetitive (food search) feeding activity

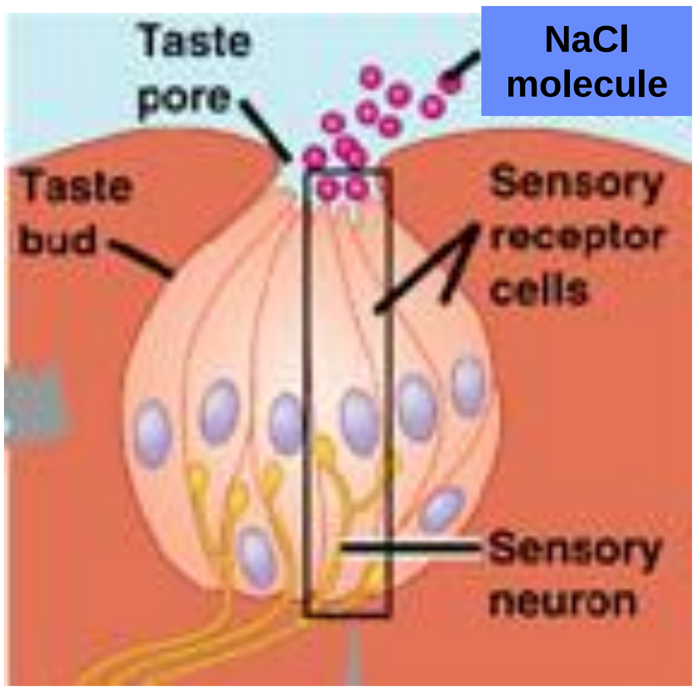
❖Taste buds that synapse with IX and X cranial nerves are important in consummatory (ingestive and swallowing) feeding behavior.

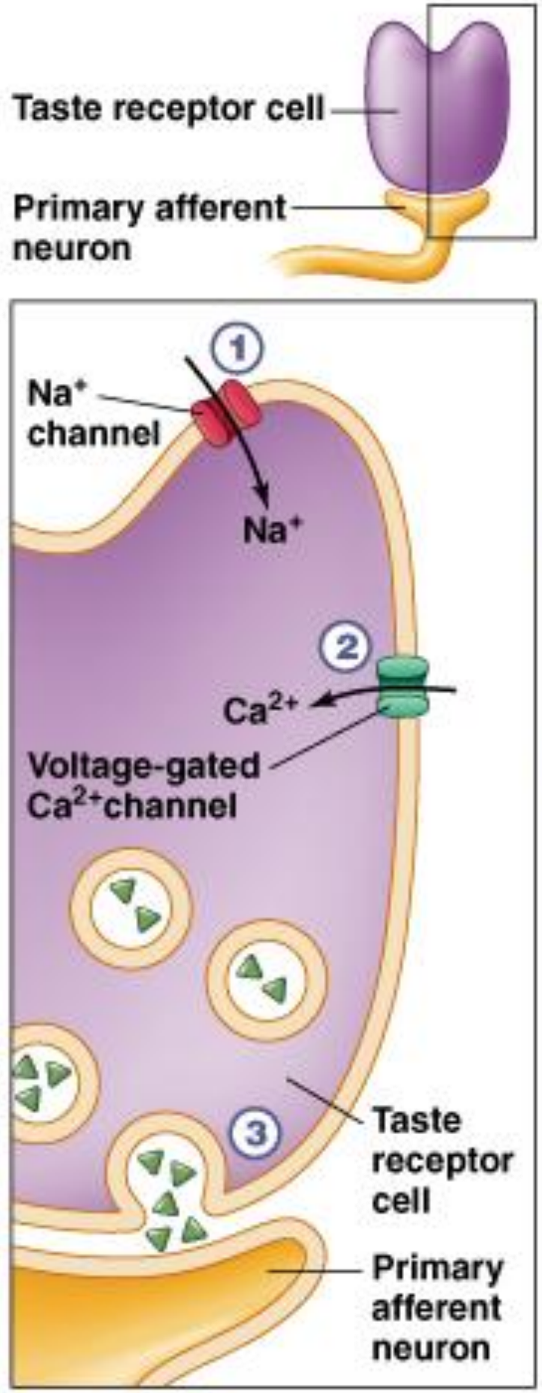


Taste Physiology

Chemical stimuli dissolved in the water enter the mucous layer at the apical portion of the taste bud and bind to taste receptor molecules located within the membrane of the apical microvilli of sensory cells.

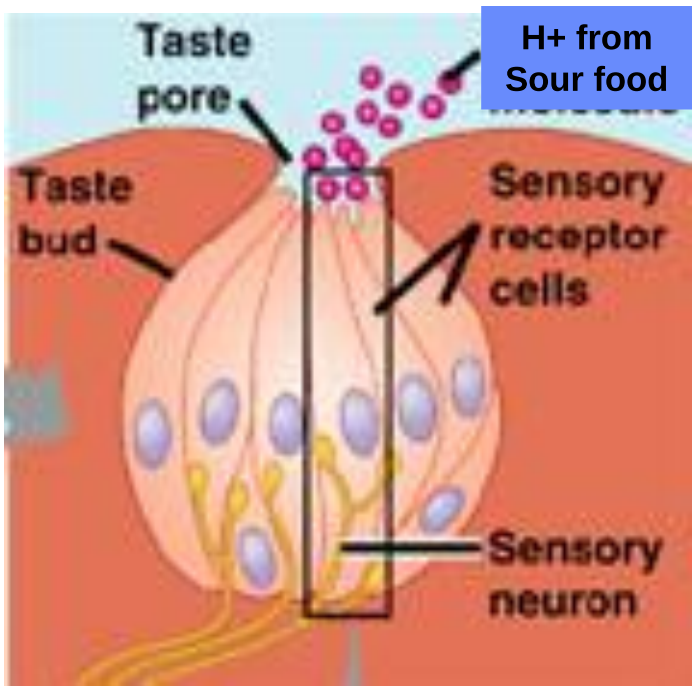
These interaction leads to a membrane conductance change, depolarization of the cell and release of a neuro-transmitter that results in either the production or modulation of action potential activity in the taste fibers. This series of events, termed as **“taste transduction”.**



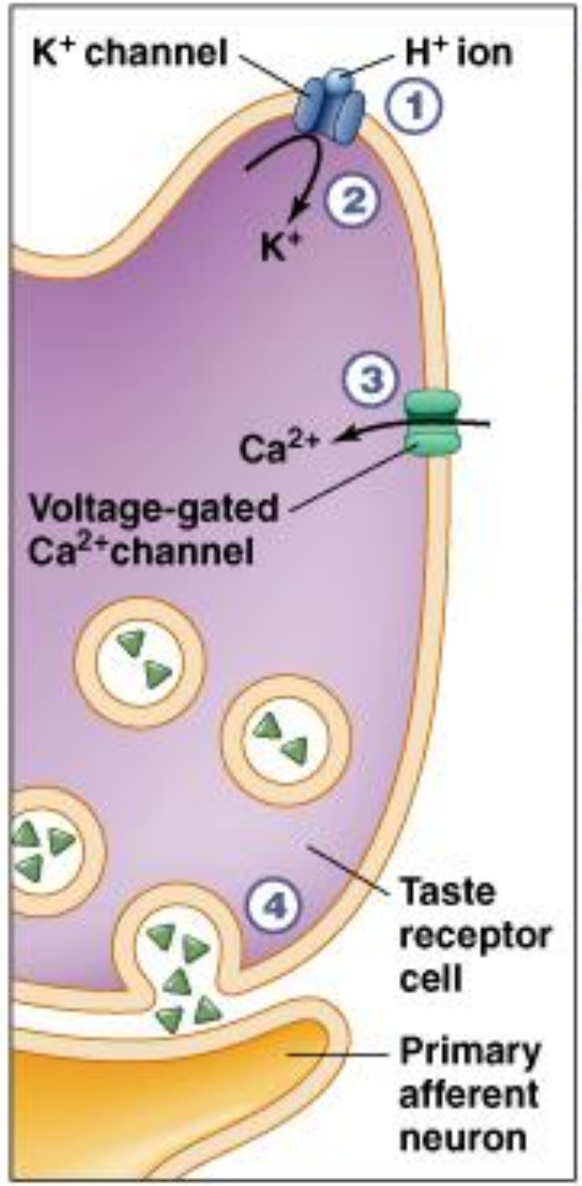


1. Na$^+$ from salty food enters through a Na$^+$ channel.
2. The resulting depolarization opens voltage-gated Ca^{2+} channels.
3. The influx of Ca^{2+} causes neurotransmitter release.

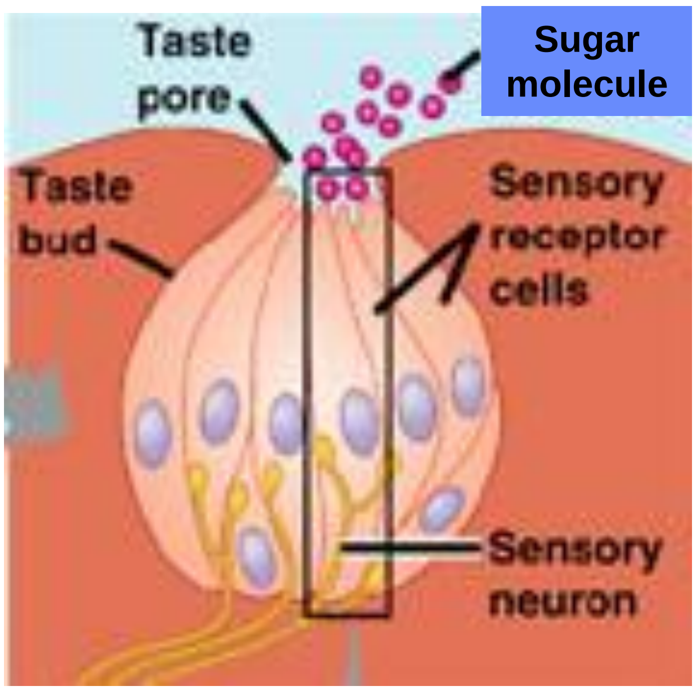
Salty Taste Transduction



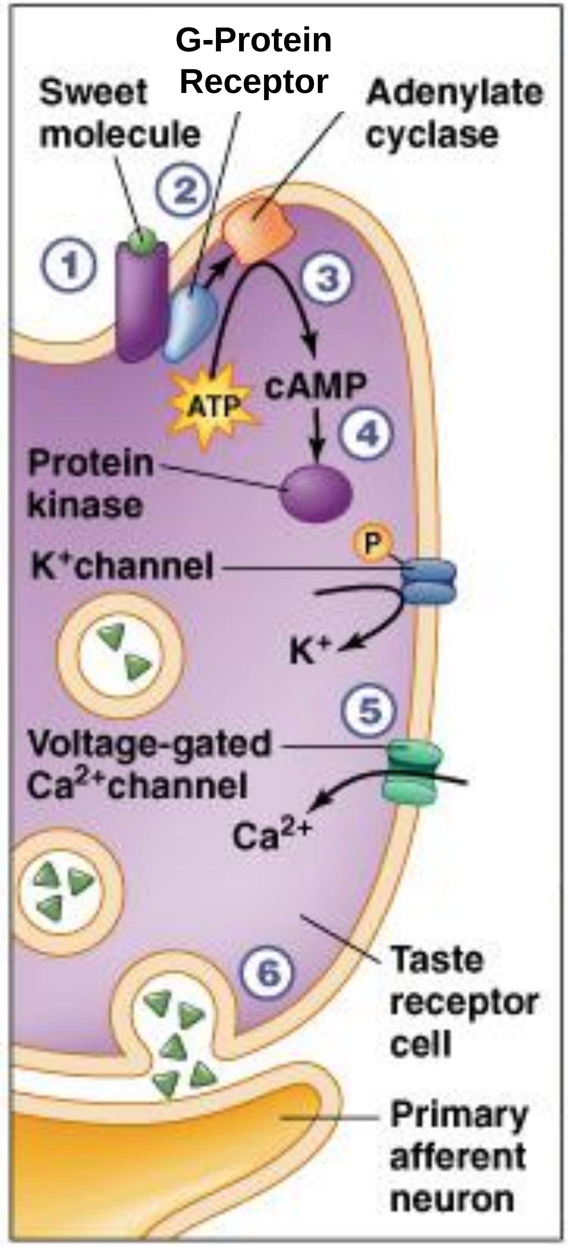
Sour Taste Transduction



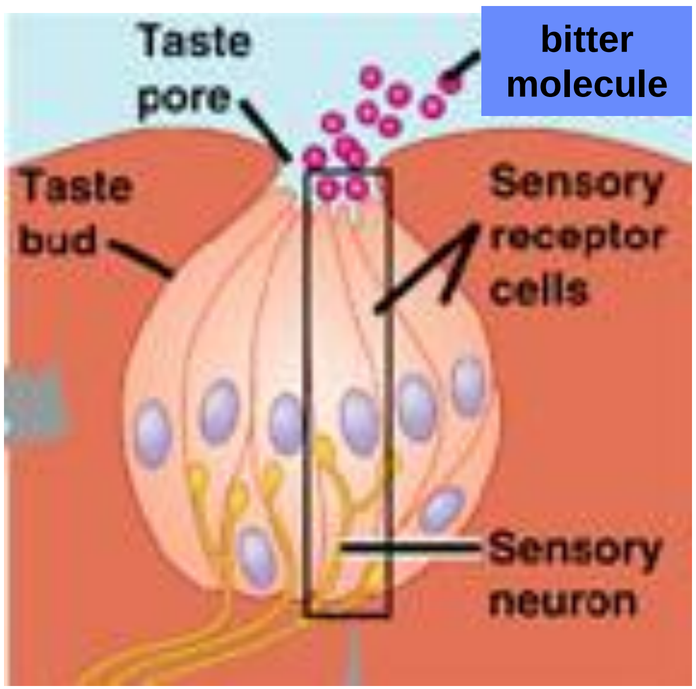
1. H^+ ions from sour foods block the K^+ channel.
2. This blockage prevents K^+ from leaving the cell.
3. The resulting depolarization opens voltage-gated Ca^{2+} channels.
4. The influx of Ca^{2+} causes neurotransmitter release.

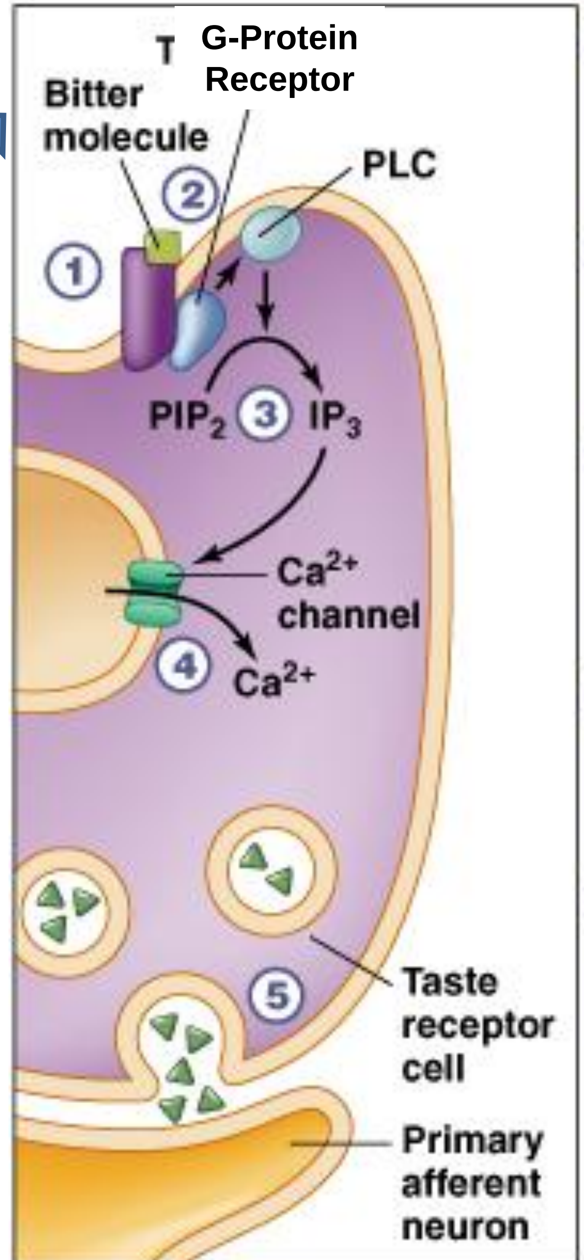


Sweet Taste Transduction



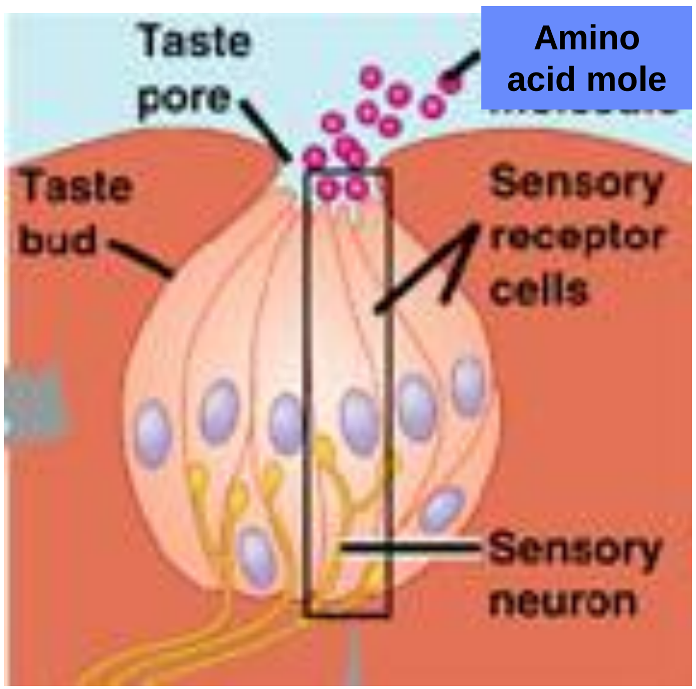
1. A sweet substance binds to its receptor, causing a conformational change.
2. The activated G protein, gustducin, activates adenylate cyclase.
3. Adenylate cyclase catalyzes the conversion of ATP to cAMP.
4. The cAMP activates a protein kinase that phosphorylates and closes a K^+ channel.
5. The resulting depolarization opens voltage-gated Ca^{2+} channels.
6. The influx of Ca^{2+} causes neurotransmitter release.



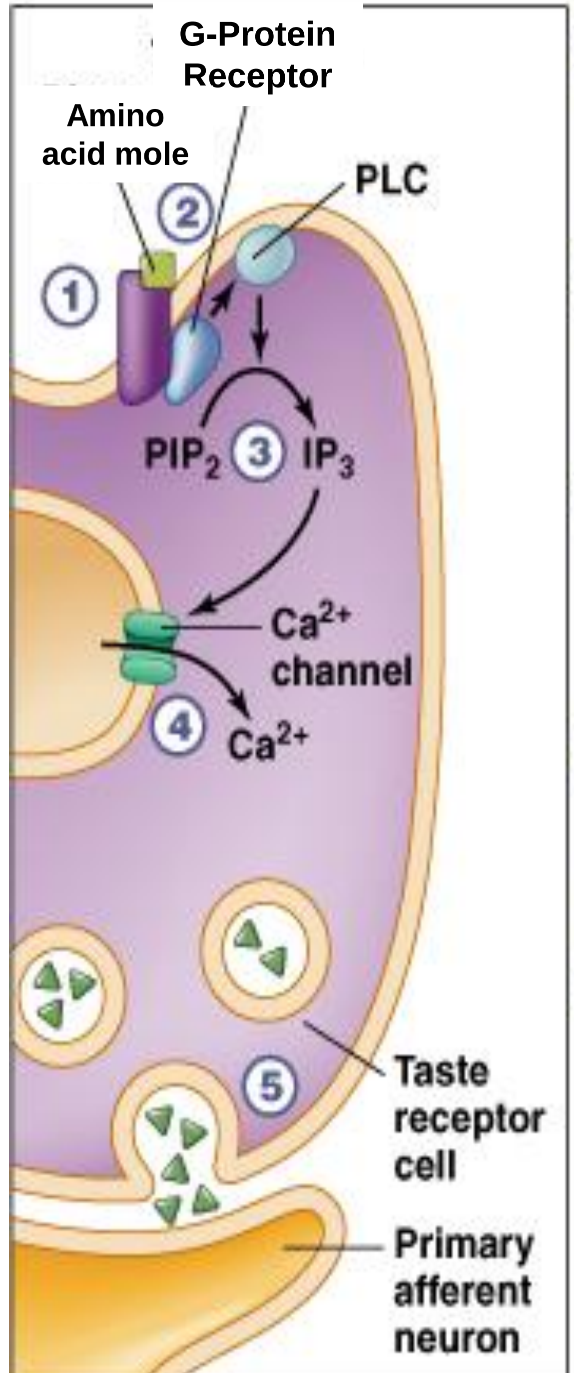


1. A bitter substance binds to its receptor, causing a conformational change.
2. The activated G protein, transducin, activates phospholipase C (PLC).
3. PLC catalyzes the conversion of PIP$_2$ into the second messenger IP$_3$.
4. IP$_3$ causes the release of Ca^{2+} from intracellular stores.
5. The influx of Ca^{2+} causes neurotransmitter release.

Bitter Taste Transduction



Amino acid taste Transduction



1. Amino acid molecule binds to its receptor, causing a conformational change.
2. The activated G protein, transducin, activates phospholipase C (PLC).
3. PLC catalyzes the conversion of PIP_2 into the second messenger IP_3.
4. IP_3 causes the release of Ca^{2+} from intracellular stores.
5. The influx of Ca^{2+} causes neurotransmitter release.

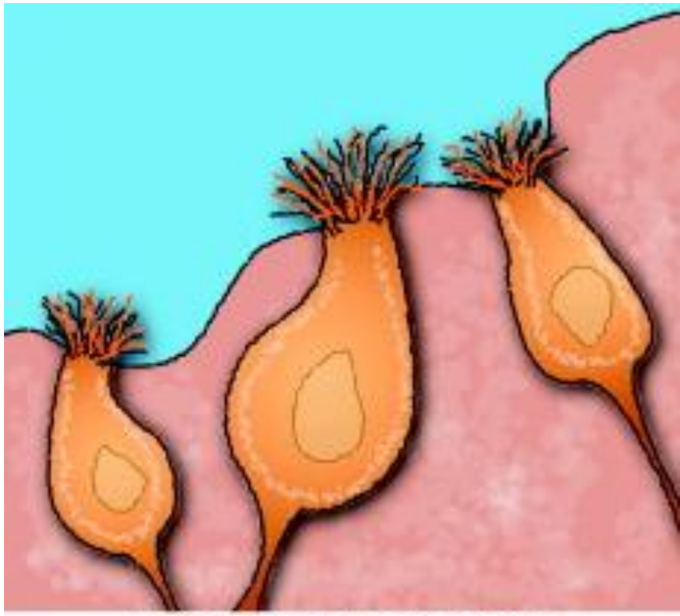
Olfactory System

Olfactory system mediates responsiveness to a much broader range of stimuli, including learned food odors, geographic locations and pheromones.

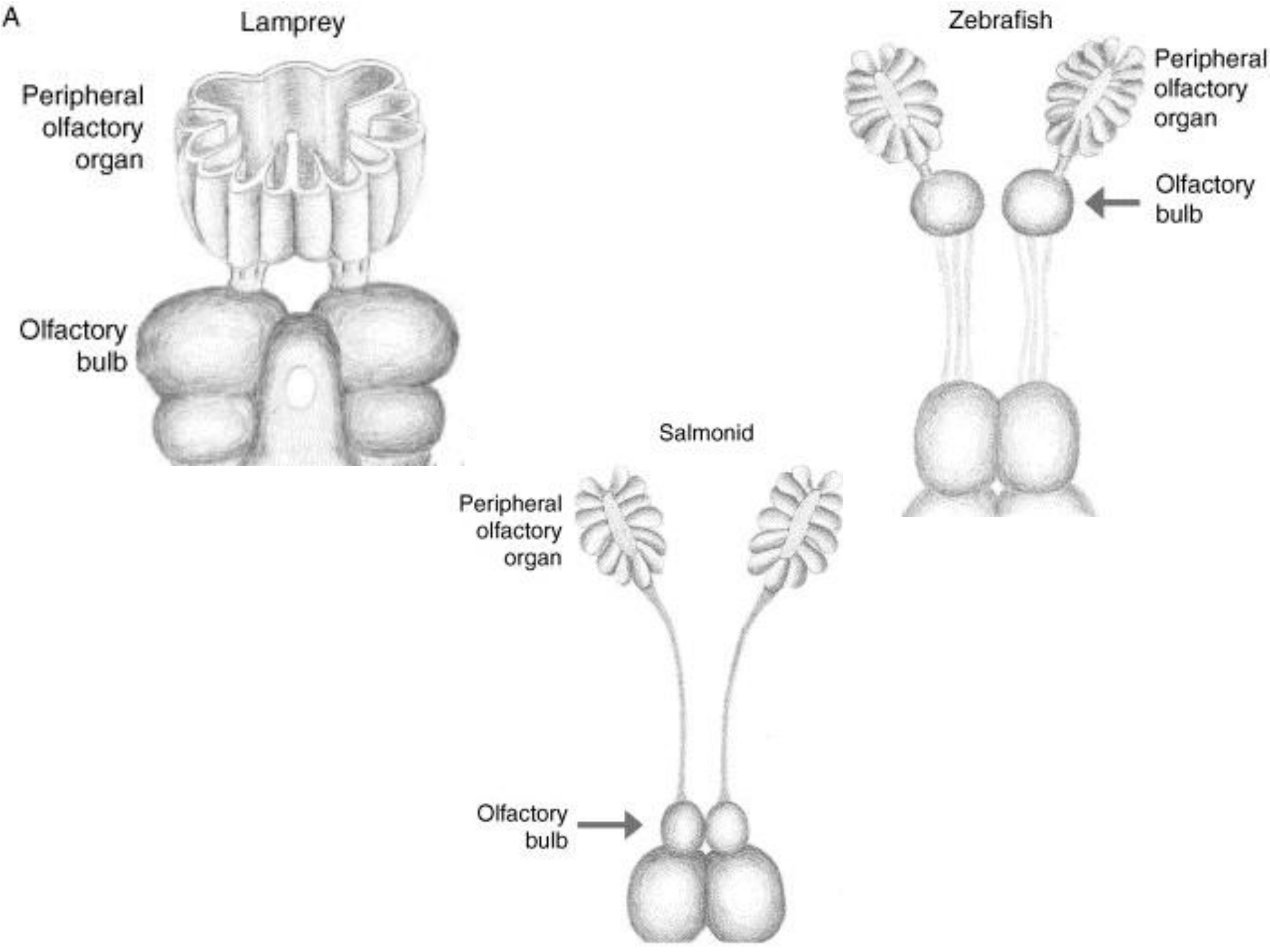
The variety of stimuli detected by the olfactory sense are much greater than gustatory system.

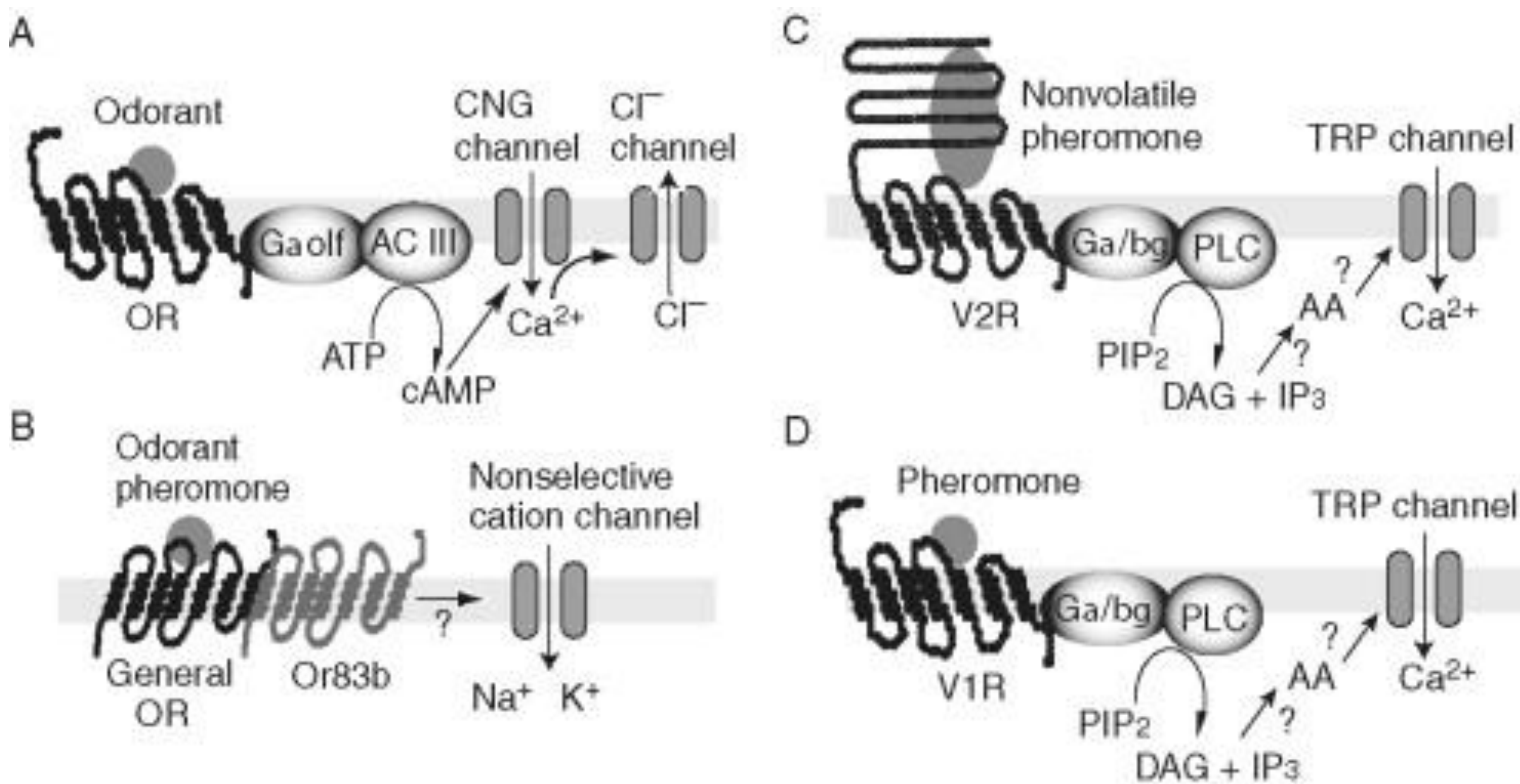
Olfactory sensitivity is mediated by a single cranial nerve (**the olfactory nerve**) projected directly to the brain and regenerate throughout the life of animal.

In fishes, olfactory receptor cells are located in olfactory epithelium which covers much of the surface of olfactory rossette, a structure found within the olfactory chamber of fish rostrum



Olfactory sensory neurons


A
Lamprey
Peripheral olfactory organ
Olfactory bulb
Zebrafish
Peripheral olfactory organ
Olfactory bulb
Salmonid
Peripheral olfactory organ
Olfactory bulb


A
Odorant
CNG channel
Cl⁻ channel
Ga olf
AC III
OR
ATP
cAMP
Ca2+
Cl⁻
B
Odorant pheromone
Nonselective cation channel
?
General OR
Or83b
Na+ K+
C
Nonvolatile pheromone
TRP channel
Ga/bg
PLC
V2R
?
AA
Ca2+
PIP2
?
DAG + IP3
D
Pheromone
TRP channel
Ga/bg
PLC
V1R
?
AA
Ca2+
PIP2
?
DAG + IP3

Olfactory Stimuli

❖ **Amino acids**

❖ **Bile acids**

❖ **Gonadal steroids and derivatives**

❖ **Prostaglandins**

❖ **Various alcohol, amines, carboxylic acids, nucleotides, aromatic hydrocarbons**

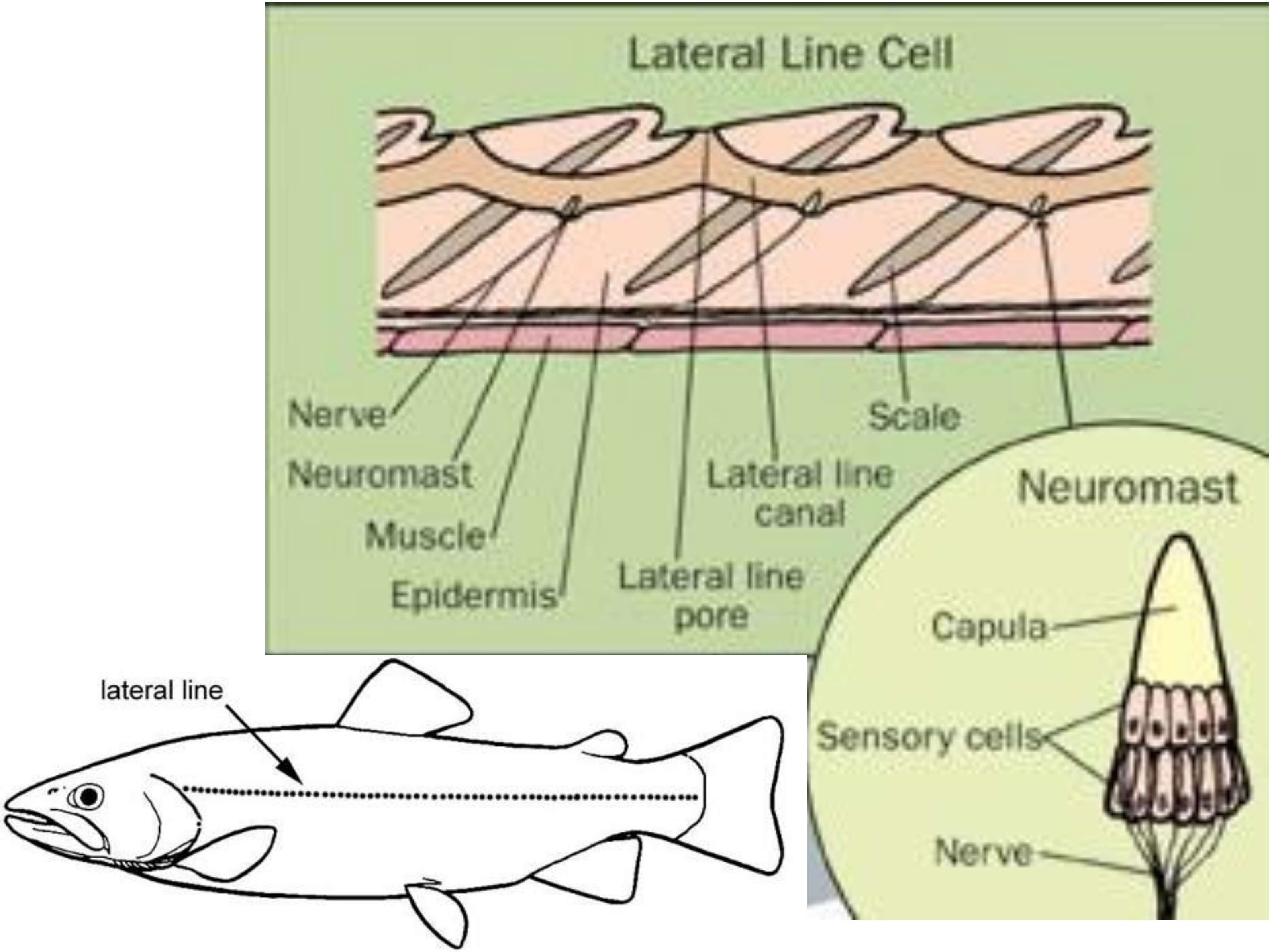
Lateral Line System

Lateral line system comprises specialized sense organs work as a mechano-sensory organ

The lateral line canals are arranged in a definite pattern in cephalic region. A prominent lateral line canal extend along each side of the body from head to tail and several branches are present in the head region.

In primitive fishes, canals are in the form of grooves while in chondricthyes and teleost they are closed tubes full of mucus which are open to exterior by means of tubules or pore at different intervals.

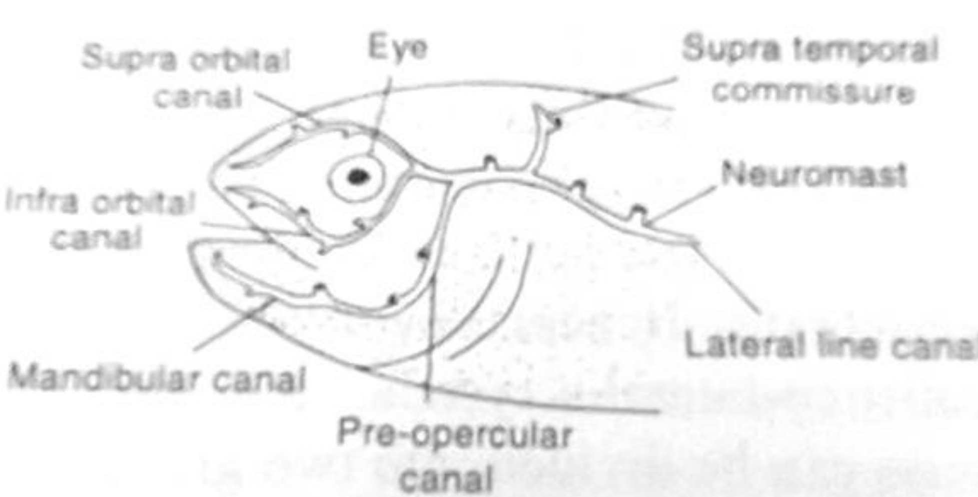
Lateral Line System in Teleost



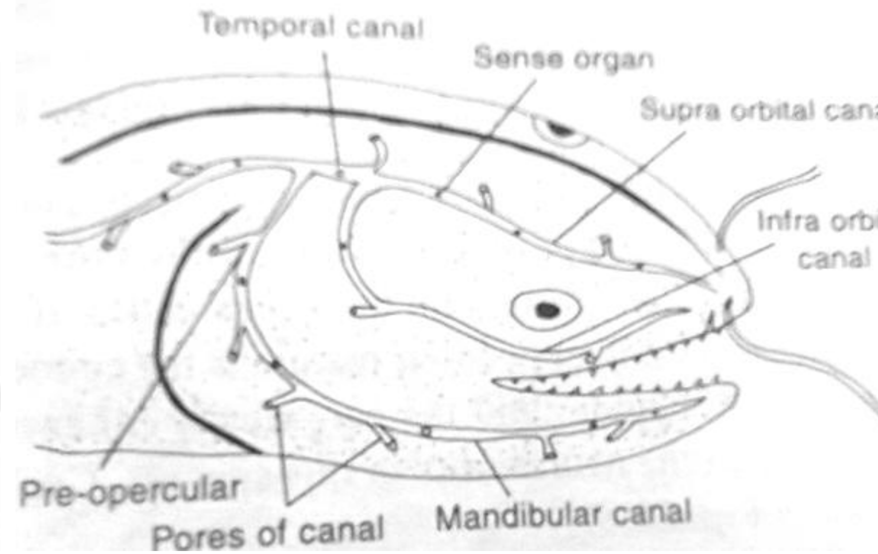
Cephalic Lateral Line canals

Cephalic lateral line canals generally divided into three branches

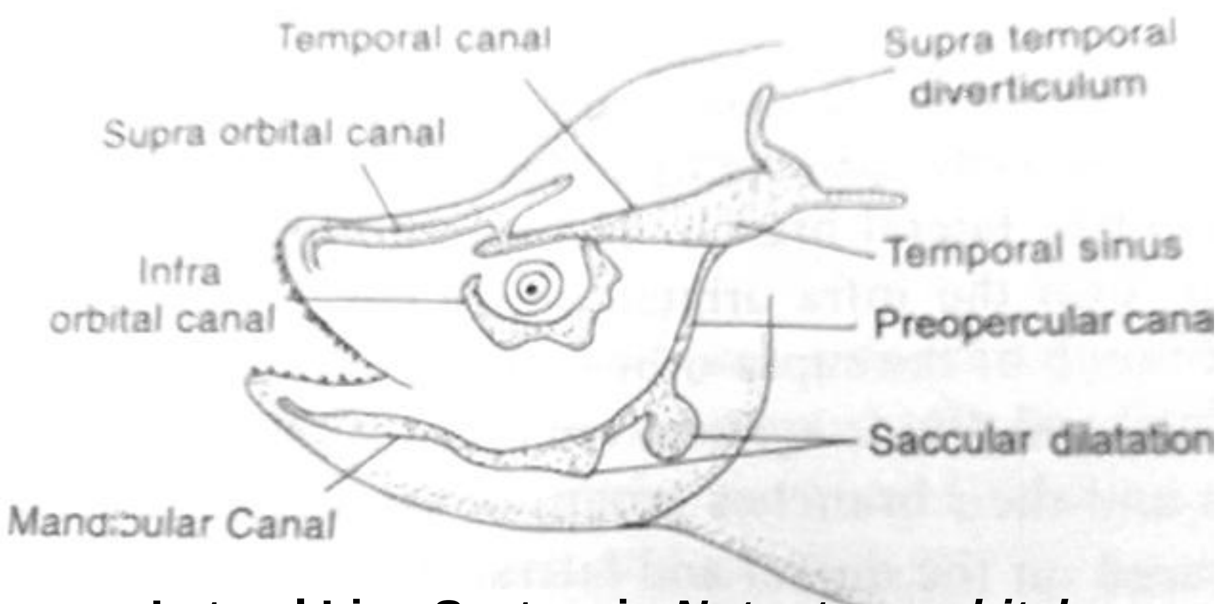
1. Supra-orbital (above eye, going to snout)
2. Infra-orbital (below eye, reaching upto snout)
3. Hymandibular (behind the eye, going upto lower jaw)



Lateral Line System in *Amia*



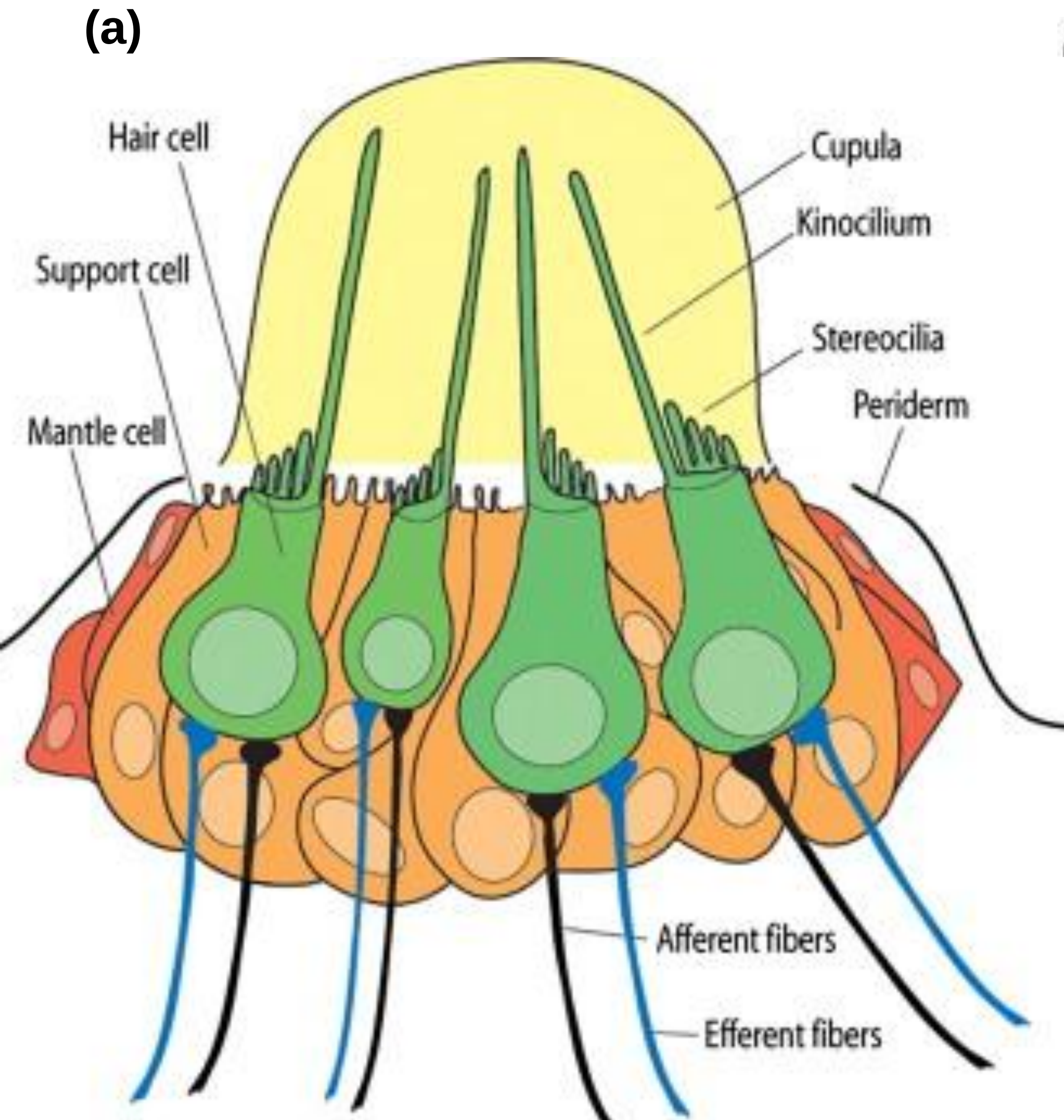
Lateral Line System in *Wallago attu*



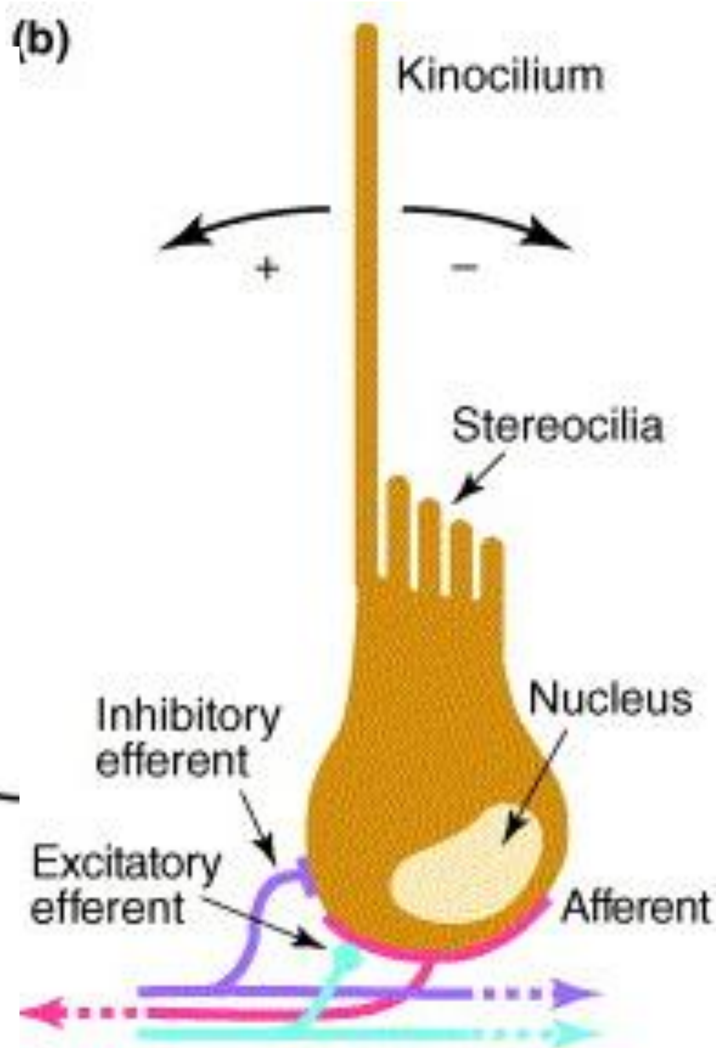
Lateral Line System in *Notopterus chitala*

Structure of Neuromast

- **Each neuromast is a group of cell consisting of sensory cells, supporting cells and basal cells.**
- **The sensory cells possess a bundle of cilia (stereocilia and kinocilium) on the apical surface and called hair cells.**
- **The stereocilia are full of microfilaments and become longer from one end of the bundle to the other.**
- **The Kinocilium is situated ecentrically at the margin of the bundle and has 9+2 arrangement of microtubules.**
- **The hair project above the surface of the epithelium and the cells are enclosed in a gelatinous tube called cupula. The cupula lies free and can be moved by the water or by mucus.**
- **Sensory cell is connected to the central nervous system by an afferent and an efferent nerve fibers.**
- **The cell is sensitive to deflection and is a mechano-receptor.**



Neuromast



Sensory Hair Cell

Sensory Mechanism in Neuromast

Cupula surrounding the hair cells of neuromast move freely when water surrounding it is set in motion.

Due to the movement of fish, pressure gradient or wave generated which results into oscillation and hair bundles of sensory cells are deflected.

Deflection of cilia cause flow of ions across the membrane and depolarization of hair cells. The depolarization is followed by an increase in the firing rate of the nerve fibers transmitting the sensory information to the brain.

Function of Lateral Line system

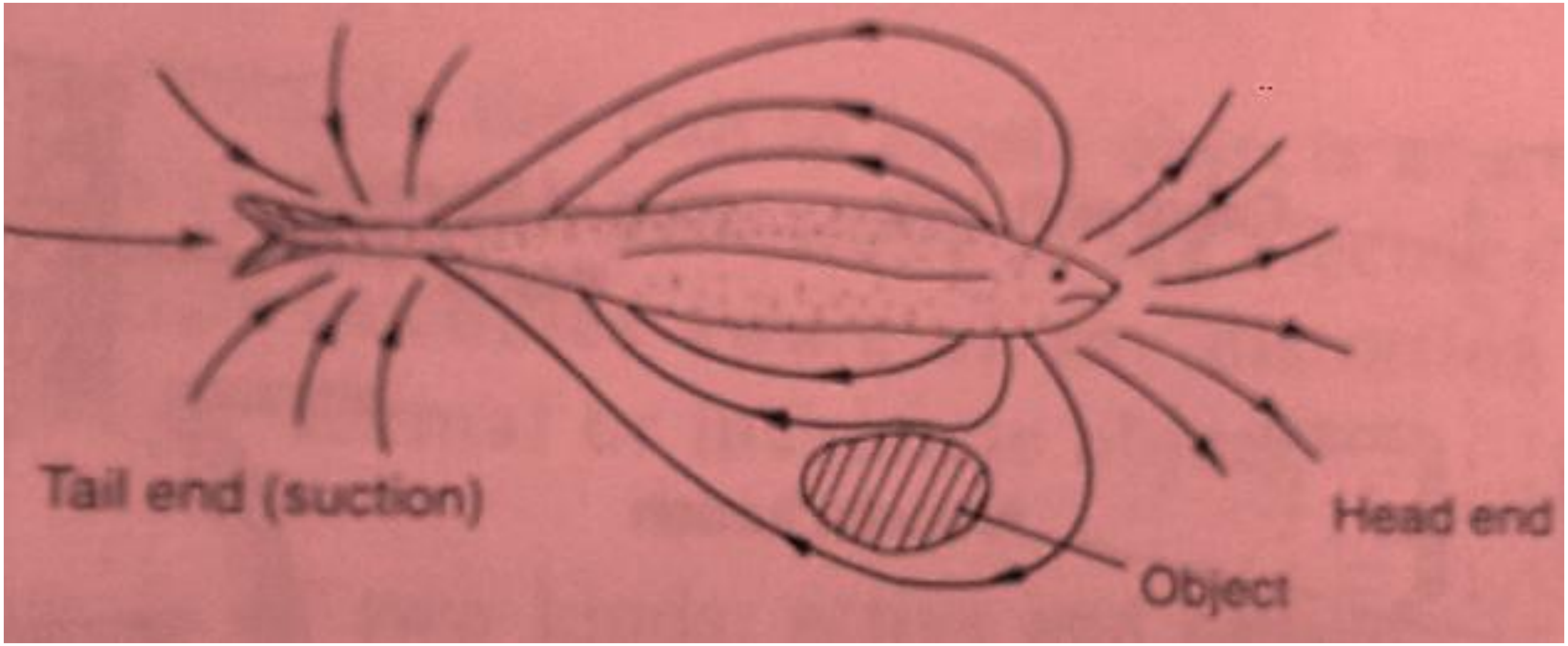
Neuromast of lateral line system are scattered all over the body and perform the function of mechano-receptors

The fish is able to detect and locate animal or inanimate mobile or immobile objects with the help of neuromast.

These organs are of considerable help in detecting the prey or food, avoiding predator, for schooling and for intraspecific communication.

Neuromast function as hydrodynamic detector, being sensitive to pressure gradient or waves generated in water due to the movements of fish or prey.

Thus, these organs function as “distant touch receptor” and fish can sense an object at a distance in dark, muddy water



Distortion of line of pressure by a solid object

Mauthner cell

The Mauthner cell was first identified by the Viennese ophthalmologist Ludwig Mauthner in the teleost fish for its associated neural circuit which mediates an escape response called the C-start or C-startle to direct the fish away from a predator.

The **Mauthner Cells** are a pair of big and easily identifiable neurons (one for each half of the body) located in the rhombomere 4 of the hindbrain in fish that are responsible for a very fast escape reflex (in the majority of animals - a so-called C-start response). The cells are also notable for their unusual use of both chemical and electrical synapses

Electro-receptor Organs

They are highly sensitive to the electric field and are used for electro communication, electro location and social signaling.

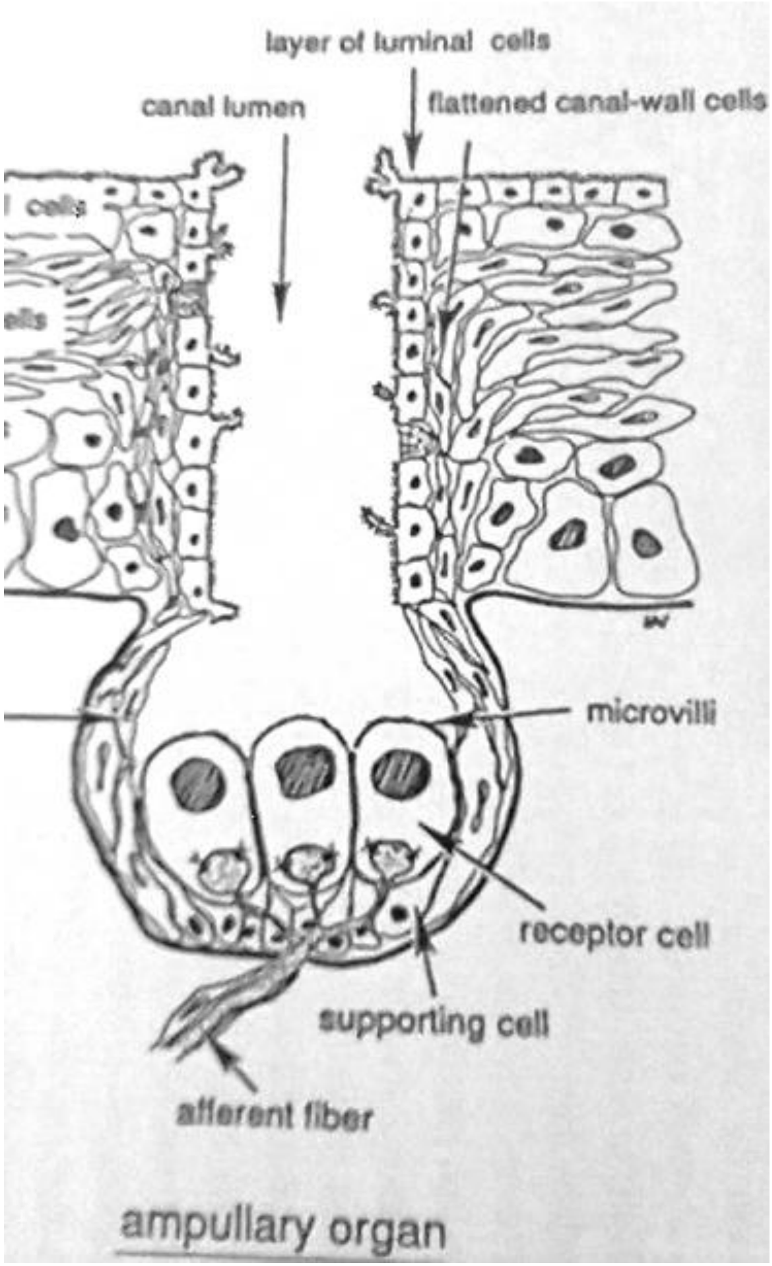
The electroreceptor show considerable variation in their morphology in different species and are distributed all over the skin of the fish.

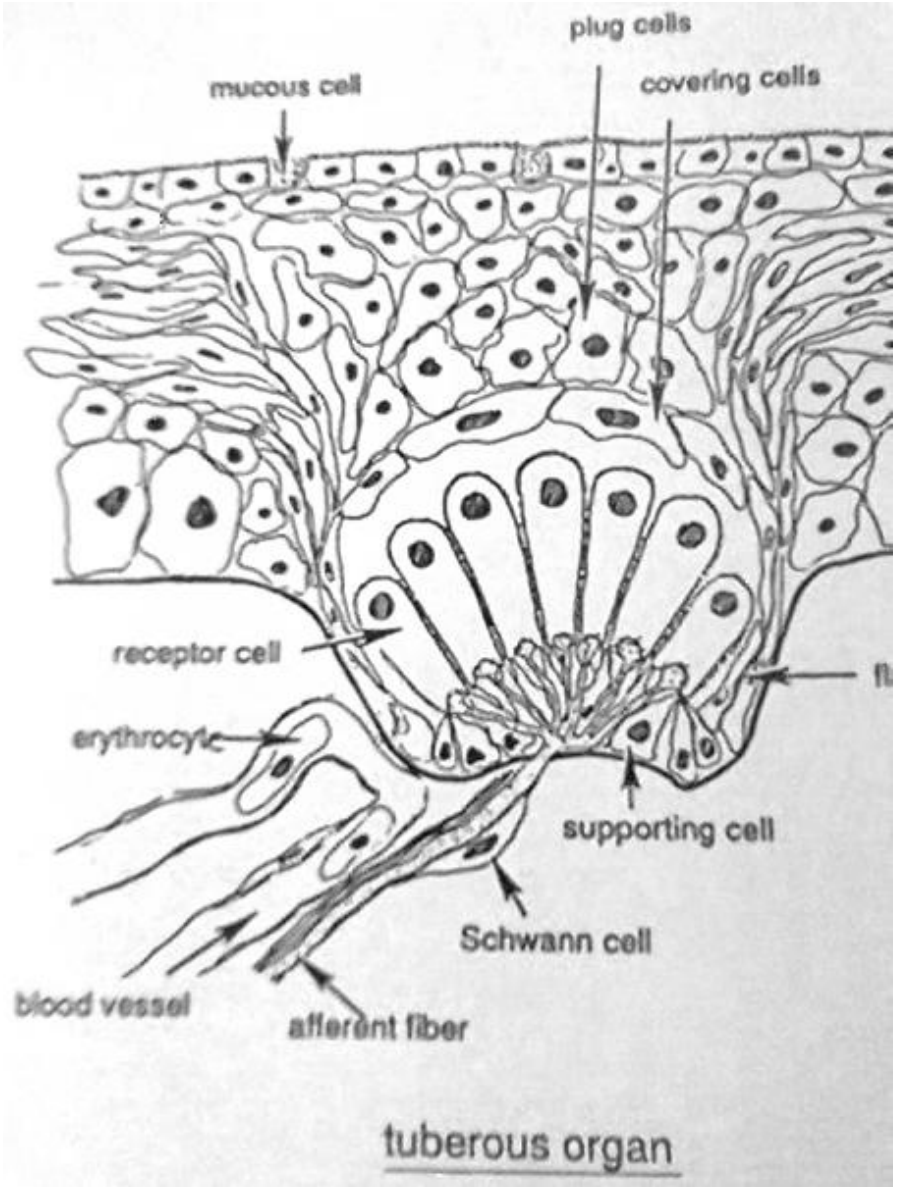
In fishes, electroreception is found among all non teleost taxa except Myxiniformes and Holostei. Two kinds of electroreceptors are found in fishes.

a. **The ampullary organs:** They respond to signals of low frequencies upto 50 Hz

b. **The Tuberous organs:** they are high frequency receptors and are restricted to electric fishes that produce their own high frequency electric signals.

Structure of Electro-receptors





Function of Electroreceptor

The electro-receptors enable the fish to locate objects at a distance, as the fish possessing them is far more sensitive to the electric field than those without them. The fish become aware of any distortion in the electric field caused by another animal or inanimate object.