CORDINATION IN ANIMALS

(Nervous Coordination)

Tr. BAGOOLE DANIEL

Educan

Values Beyond School

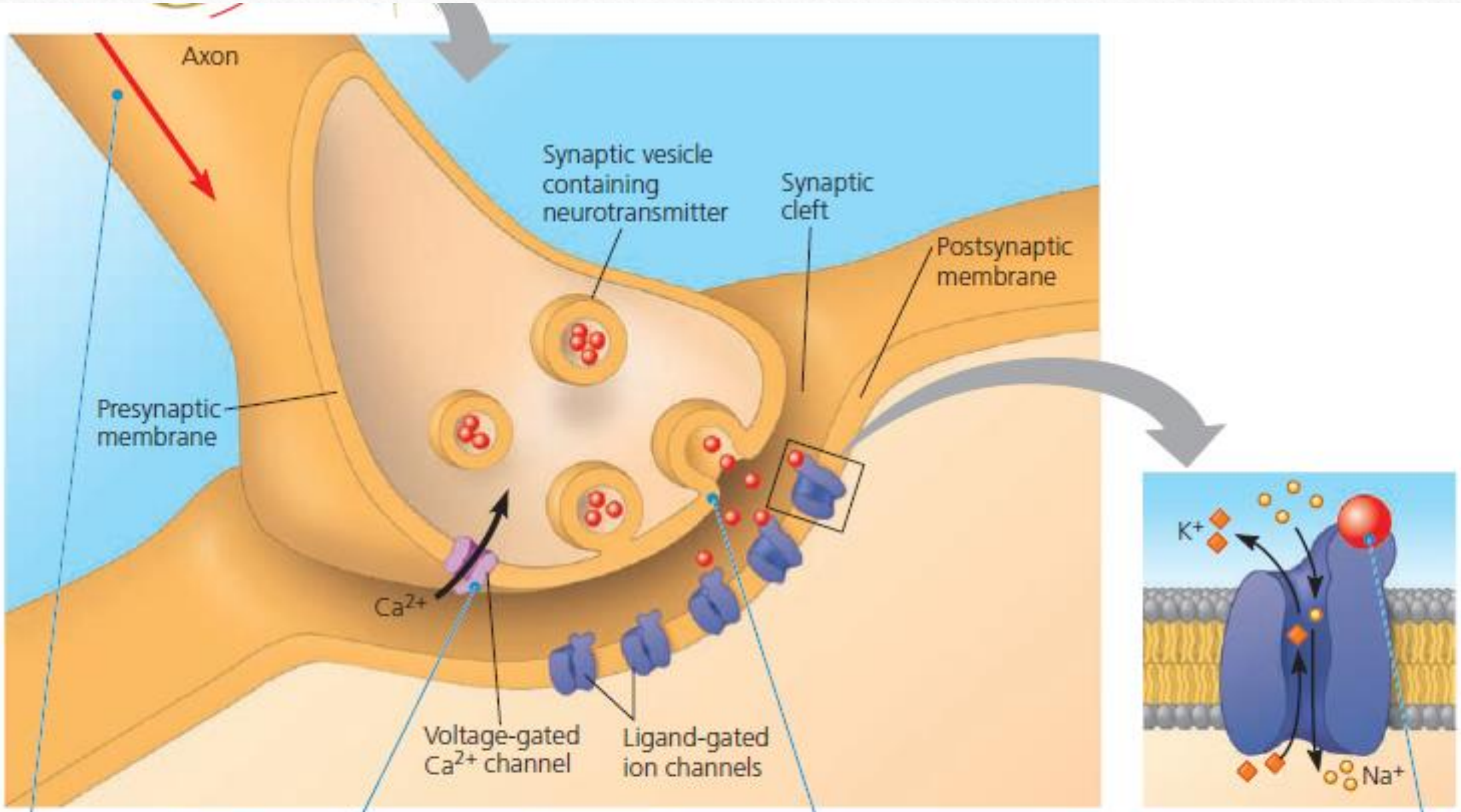
NERVOUS IMPULSE

- This is the point where the axon of one neuron meets and joins with the dendrite or cell body of another neuron.
- This allows information to cross from one neuron to another neuron.

- Where two neurones meet, they do not quite touch. There is a very small gap, about 20 nm wide, between them.
- This gap is called the **synaptic cleft.**
- The parts of the two neurones near to the cleft, plus the cleft itself, make up a synapse

Types of synapses

- Synapses can be:
- **Inhibitory** i.e. neurotransmitter opens Cl- ion or K+ ion-gated channels in the post-synaptic membrane, causing hyperpolarization which makes it difficult to generate an action potential
- **Excitatory** i.e. neurotransmitter opens Na+ channels to cause depolarization in the post-synaptic membrane.



1 An action potential arrives, depolarizing the presynaptic membrane.

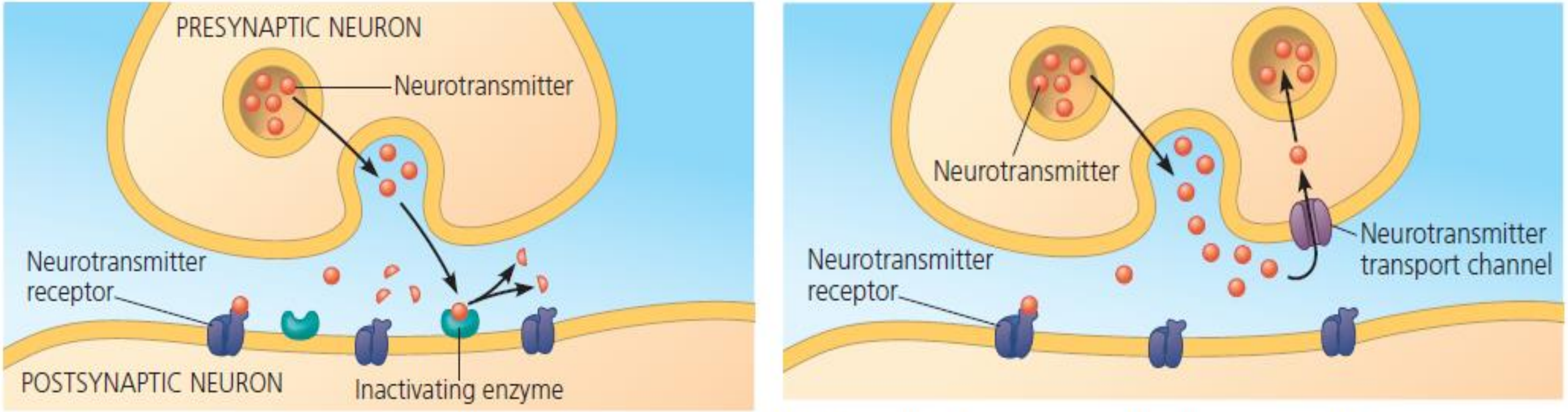
2 The depolarization opens voltage-gated channels, triggering an influx of Ca^{2+}.

3 The elevated Ca^{2+} concentration causes synaptic vesicles to fuse with the presynaptic membrane, releasing neurotransmitter into the synaptic cleft.

4 The neurotransmitter binds to ligand-gated ion channels in the postsynaptic membrane. In this example, binding triggers opening, allowing Na^+ and K^+ to diffuse through.

Note:

- After neurotransmitter substance has performed its function, it does not stay because if it was to stay it would continue to stimulate the post synaptic neuron.
- Acetyl choline is normally hydrolyzed by an enzyme**, acetyl cholinesterase** to choline and acetyl. These two products then diffuse back and re-enter the presynaptic knob and combine back to form the transmitter substance which is packed into vesicles ready for reuse.
- *Because this process is energy demanding, it explains why the synaptic knob has many mitochondria.*



(a) Enzymatic breakdown of neurotransmitter in the synaptic cleft

(b) Reuptake of neurotransmitter by presynaptic neuron

Brain checkpoint

(a). Name the process by which vesicles release their contents at the presynaptic membrane.

(b). Describe the role of acetylcholinesterase.

(c) Suggest why:

(i) a impulses travel in only one direction at synapses

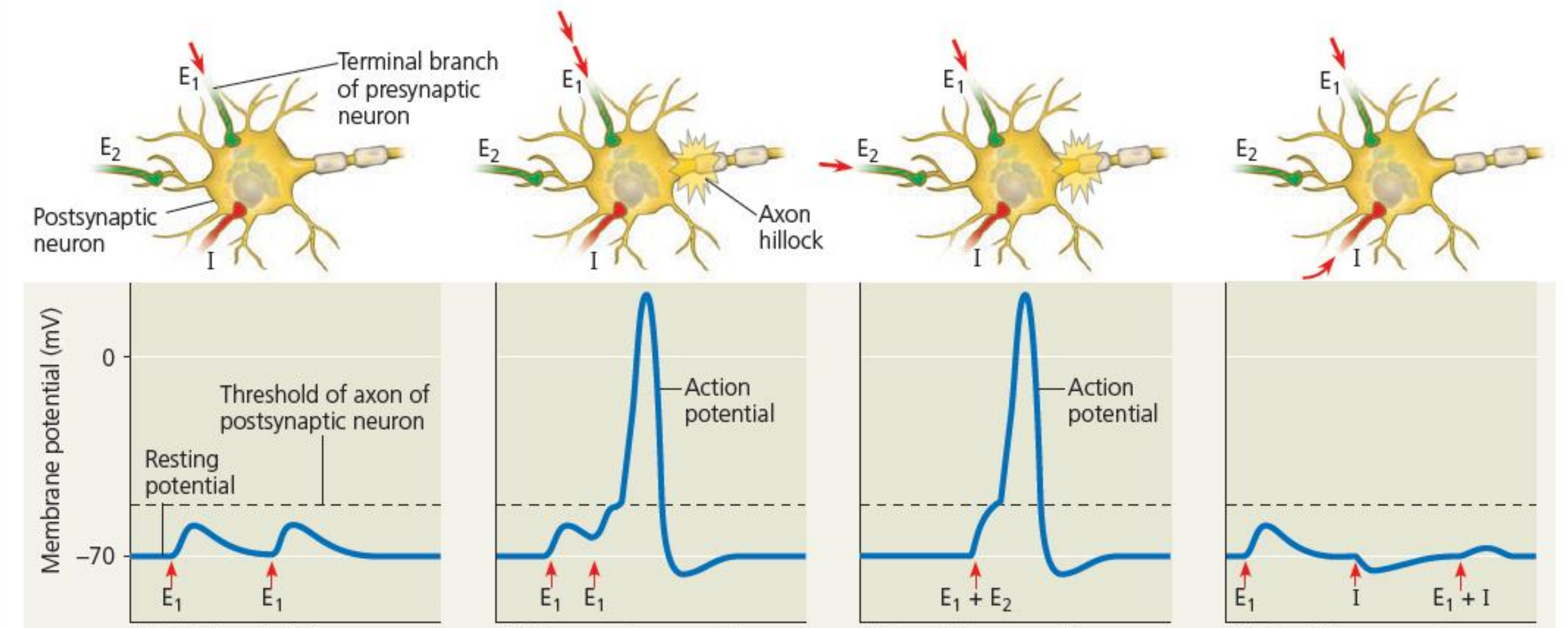
(ii) if action potentials arrive repeatedly at a synapse, the synapse eventually becomes unable to transmit the impulse to the next neurone.

Action of drugs on synapses

- The fact that transmission of impulse is as a result of chemicals, it provides explanations that drugs and poisons have an effect on the synapse:
- **Cocaine** blocks reuptake of neurotransmitter
- **Curare** blocks action of **acetylcholine** by binding to receptors on the post synaptic membrane.

- **Organophosphate** insecticides and nerve gases block **acetylcholinesterase**, thus acetylcholine remains active for longer periods.
- Being an antagonist of **acetylcholine-receptors** and **adrenaline-receptors** on membrane of muscle cells in heart, **curare** in small doses is used as a general muscle relaxant in patients undergoing major surgery.
- **Curare** is commonly applied on tips of hunting arrows to paralyze animals.

Summation



(a) Subthreshold, no summation
(b) Temporal summation
(c) Spatial summation
(d) Spatial summation of EPSP and IPSP

Teacher BAGOOLE DANIEL (0701706589 / 07846527120)

Summation

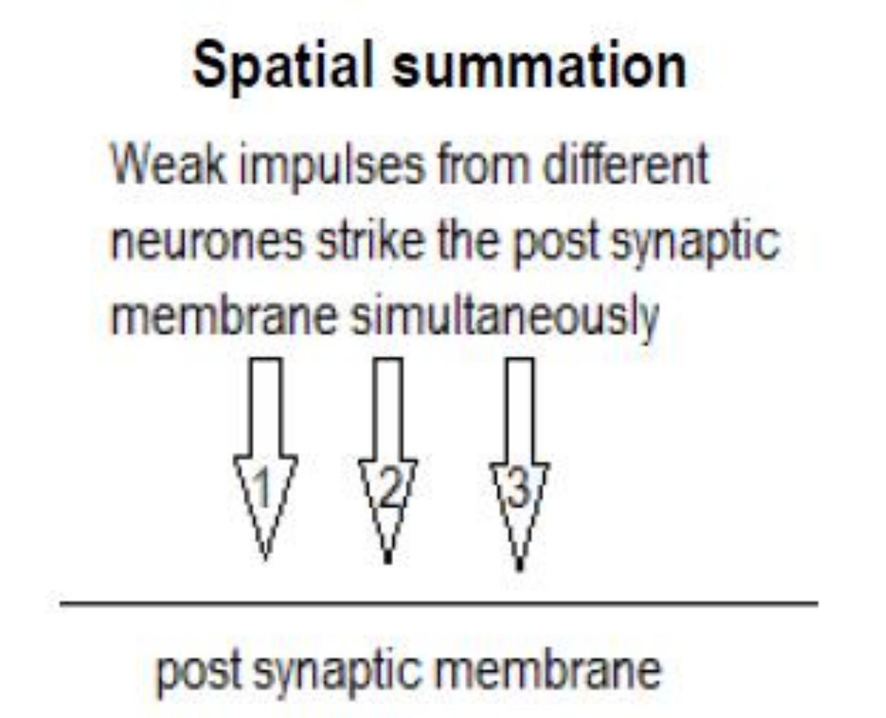
This is a phenomena used to describe how the depolarizing effect of several excitatory post synaptic potential is additive. There are two types.

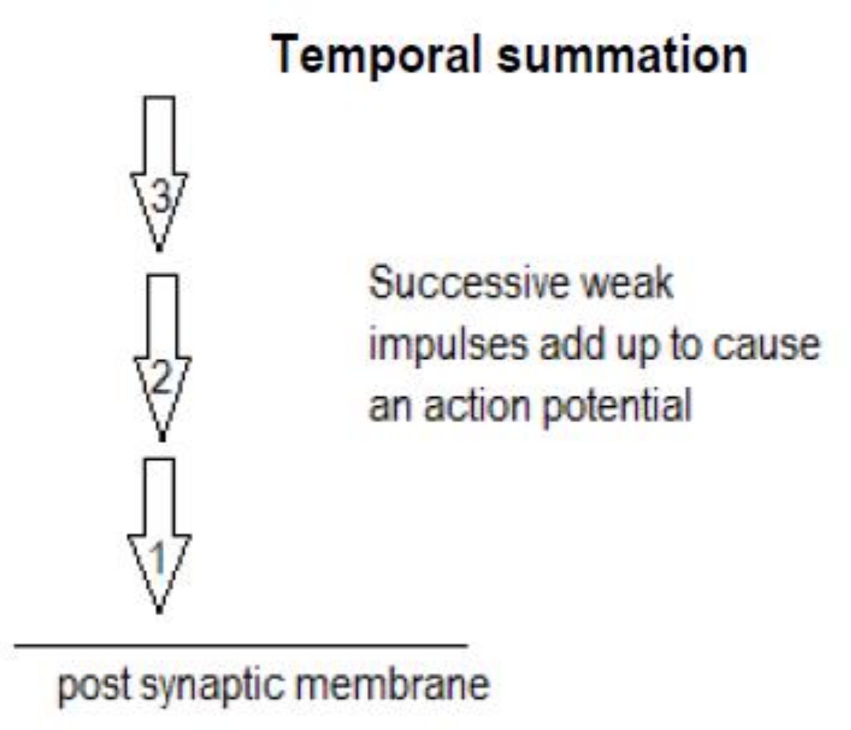
Spatial summation:

- This is the addition of transmitter substances from two synaptic knobs so that it can be enough to excite the post synaptic membrane.

Temporal summation:

- This involves the facilitation process i.e. the first impulse transmission is insufficient to trigger off an impulse in the post synaptic membrane but cause an effect, therefore the second faster stimulation will add to the former and generate an impulse at the post synaptic membrane


Spatial summation
Weak impulses from different neurones strike the post synaptic membrane simultaneously
1
2
3
post synaptic membrane


Temporal summation
3
2
1
Successive weak impulses add up to cause an action potential
post synaptic membrane

Functions of the synapse

- They transmit information between neurones.
- They filter out low frequency impulses.
- They act as valves to ensure that impulses pass across them in one direction only.

- They also act as junctions allowing impulses to be divided up along many neurones or merge into one.
- To protect effectors from damage by overstimulation.
- Synapses may be involved in memory and the learning process.
- Adaptation

Disadvantages of synapse

- Slows down the speed of transmission.
- Are highly prone to drugs and fatigue which may inhibit impulse transmission.

NEUROMUSCULAR JUNCTION

This is a single synapse or junction made between one motor neuron and one muscle fiber

Skeletal muscle contracts when it receives an impulse from a neurone.

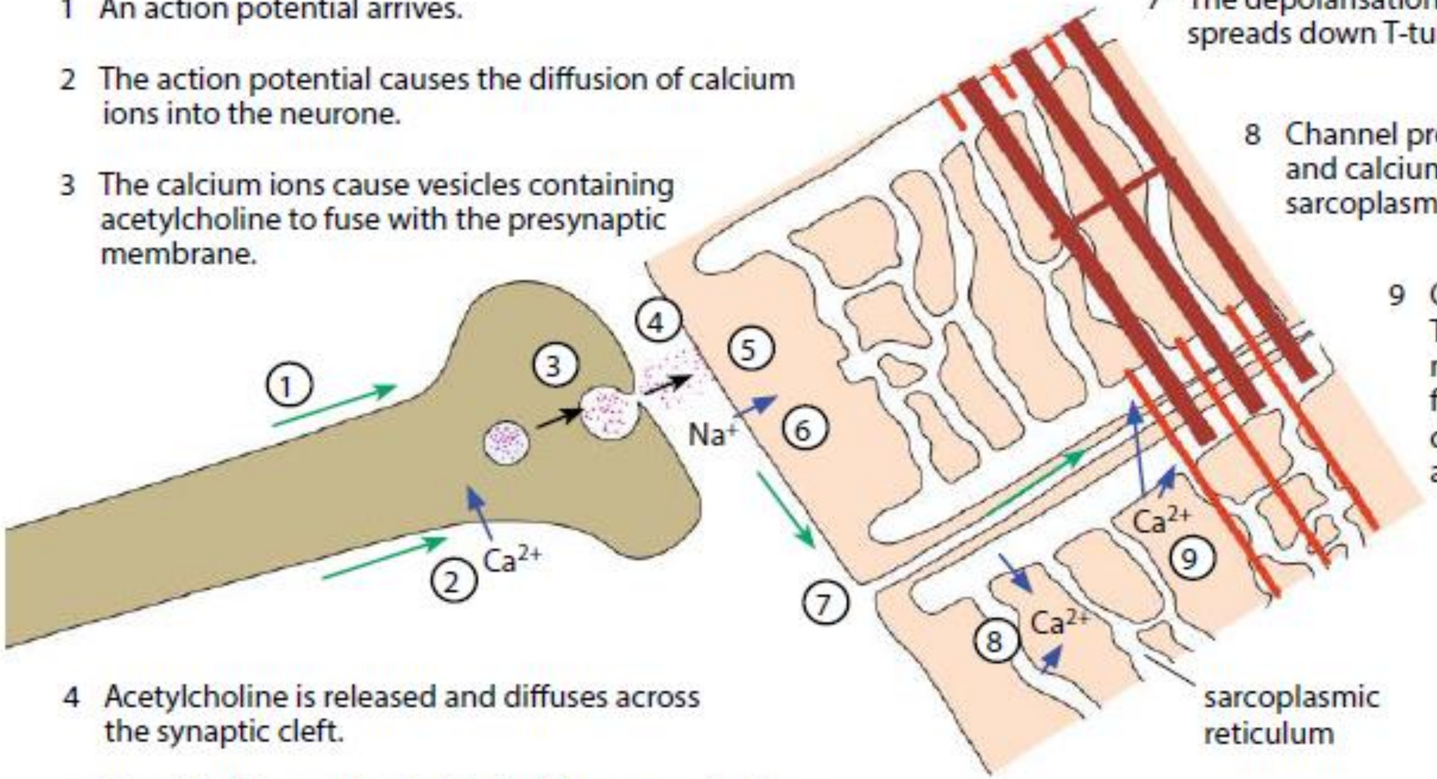
An impulse moves along the axon of a motor neurone and arrives at the presynaptic membrane

Events at the neuromuscular junction

1 An action potential arrives.

2 The action potential causes the diffusion of calcium ions into the neurone.

3 The calcium ions cause vesicles containing acetylcholine to fuse with the presynaptic membrane.



4 Acetylcholine is released and diffuses across the synaptic cleft.

5 Acetylcholine molecules bind with receptors in the sarcolemma, causing them to open channel proteins for sodium ions.

6 Sodium ions diffuse in through the open channels in the sarcolemma. This depolarises the membrane and initiates an action potential which spreads along the membrane.

Events in muscle fibre

7 The depolarisation of the sarcolemma spreads down T-tubules.

8 Channel proteins for calcium ions open and calcium ions diffuse out of the sarcoplasmic reticulum.

9 Calcium ions bind to troponin. Tropomyosin moves to expose myosin-binding sites on the acti filaments. Myosin heads form cross-bridges with thin filament and the sarcomere shortens.

Key

→ action potential

→ ion movements

→ acetylcholine movements

THE CENTRAL NERVOUS SYSTEM

- *What happens in your brain when you solve a math problem or listen to music?*

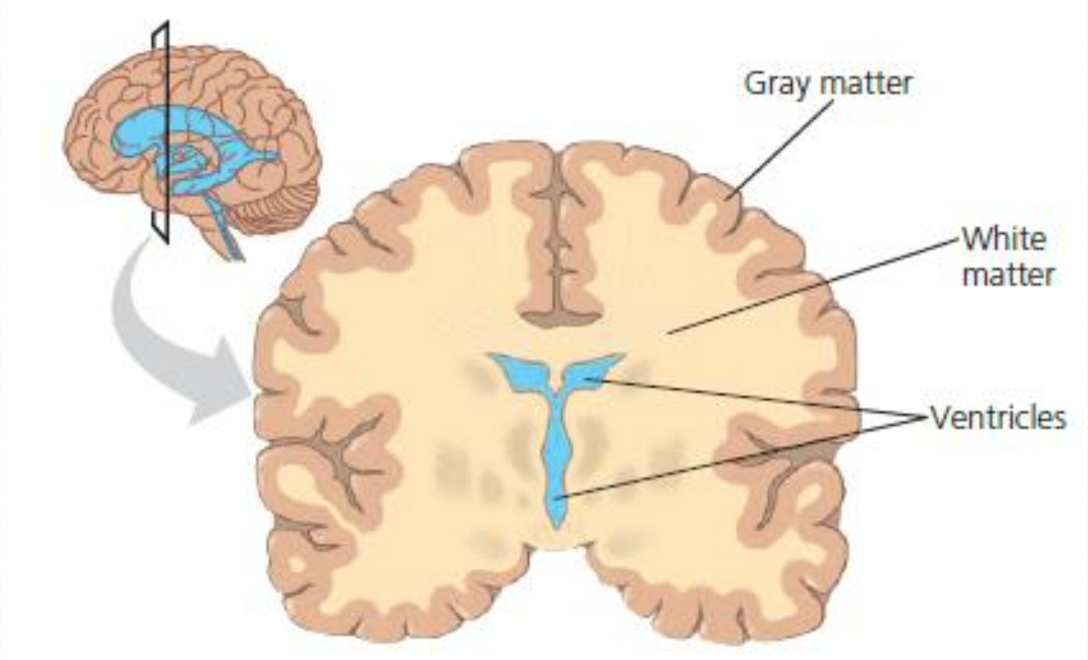
  Answering such a question was for a long time nearly unimaginable.

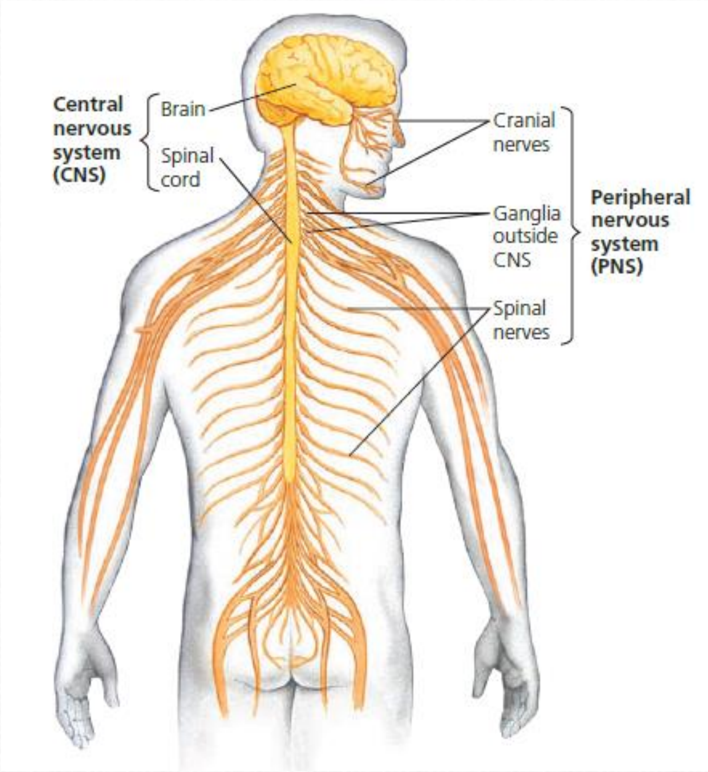
- The human brain contains an estimated **100 billion neurons**.

  Interconnecting these brain cells are circuits more complex than those of even the most powerful supercomputers

- However, thanks in part to several exciting new technologies, scientists have begun to explore the cellular mechanisms that underlie thought and emotion.
- One breakthrough came with the development of powerful imaging techniques that reveal activity in the working brain
- In this section, we'll focus on specialization in regions of the vertebrate brain. We'll then turn to the ways in which brain activity makes information storage and organization possible

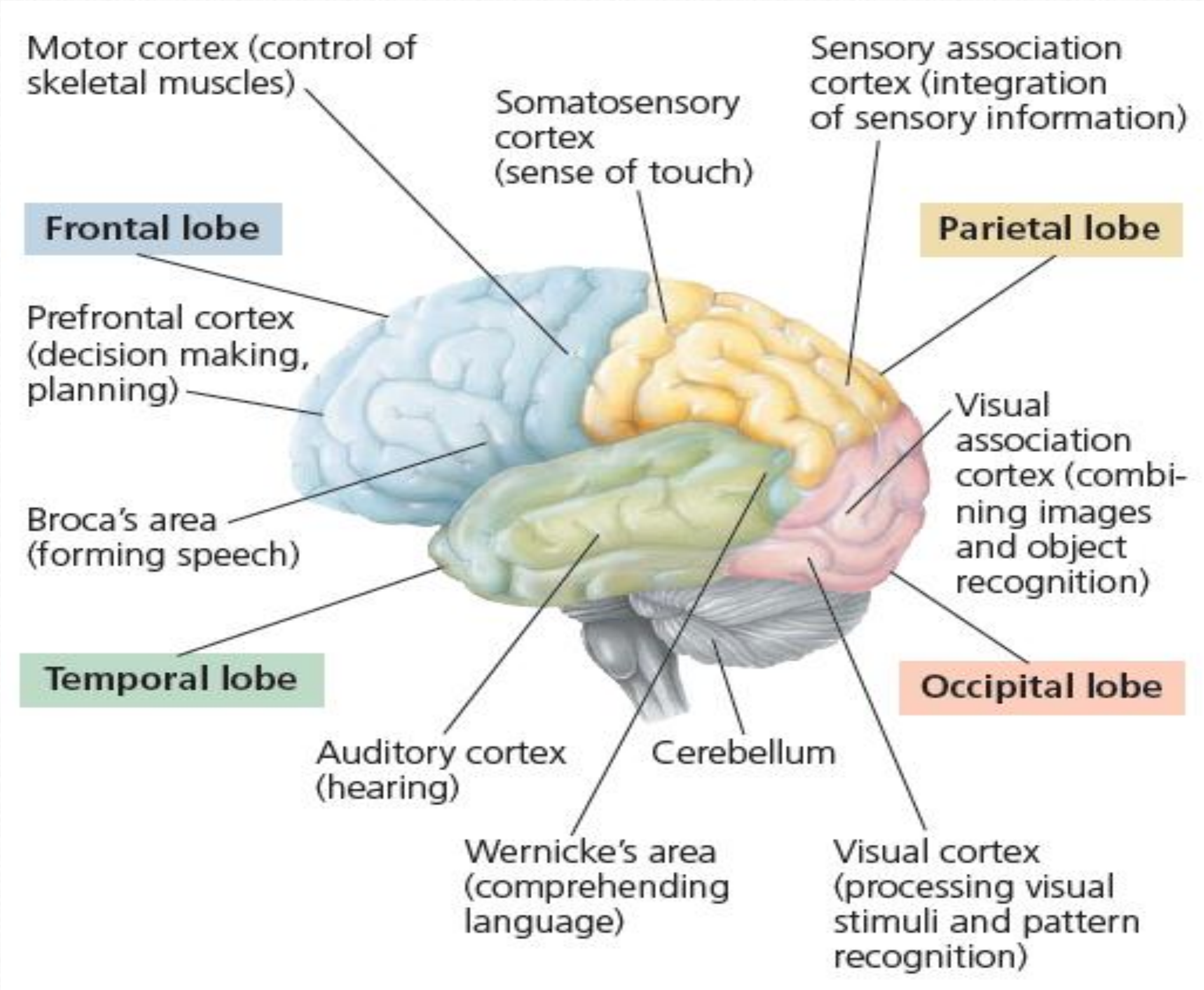
Organization of the Vertebrate Nervous System





THE BRAIN

- The brain is covered and protected externally by the skull (cranium) and internally by membranes called meninges.
- It is made up of three distinct areas namely the **forebrain, midbrain and hindbrain.**


Motor cortex (control of skeletal muscles)
Somatosensory cortex (sense of touch)
Sensory association cortex (integration of sensory information)
Frontal lobe
Parietal lobe
Prefrontal cortex (decision making, planning)
Visual association cortex (combi-ning images and object recognition)
Broca's area (forming speech)
Temporal lobe
Occipital lobe
Auditory cortex (hearing)
Cerebellum
Wernicke's area (comprehending language)
Visual cortex (processing visual stimuli and pattern recognition)

Functions of the parts of the brain

THE FORE BRAIN

It consists of:

(i) The cerebrum (cerebral hemisphere):

- It consists of right and left cerebral hemispheres which are interconnected by the corpus callosum. It is covered by a thin layer of cerebral cortex.

Cont..

- The *right hemisphere sends and receives impulses from the left side of the body while the left hemisphere receives impulses from the right side of the body.*
- It coordinates **learning, memory, reasoning, conscience and personality.**
- It is responsible for **intelligence.**

Cont..

(ii) Thalamus:

- It transmits impulses of sensations received from sense organs to the cerebral cortex.

(iii) Hypothalamus:

- It controls activities of the pituitary gland.
- It also coordinates and controls the autonomous nervous system.

THE MID BRAIN

- It relays audio and visual information.
- It is also responsible for movement of the head and the trunk.

HIND BRAIN

It is made up of:

(i) Cerebellum: It is responsible for balance and muscular coordination.

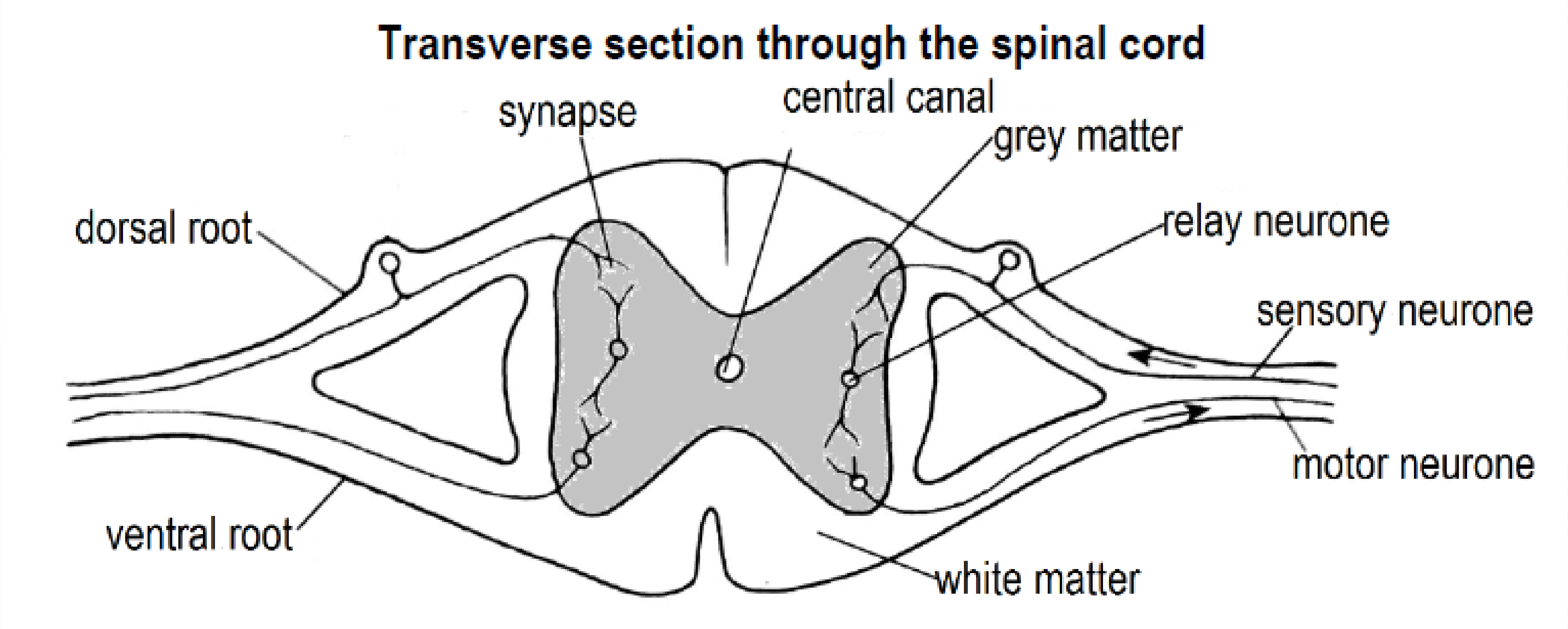
(ii) Medulla oblongata: It controls heartbeat, blood pressure, breathing rate, coughing and sneezing.

General Functions of the brain

- It receives impulses from all receptors and sends back impulses to the effectors.
- It integrates and coordinates all activities in the body such that the body works efficiently.
- It stores information.
- It is involved in cranial reflex actions but it does not initiate them.

THE SPINAL CORD

- This is part of the central nervous system that runs from the brain through to the tail and protected by the vertebral column



Transverse section through the spinal cord
synapse
central canal
grey matter
dorsal root
relay neurone
sensory neurone
motor neurone
ventral root
white matter

Functions of the spinal cord

- It connects the peripheral nervous system to the brain.
- It is a center for simple spinal reflex actions.
- Receives impulses from receptors.
- Interprets messages especially in reflex arc.
- Sends impulses to the effectors.

THE PERIPHERAL NERVOUS SYSTEM

- It is made up of neurones that link the brain and spinal cord to muscles and organs such as the eyes and ears.
- It is divided into autonomic nervous system and somatic nervous system. The autonomic nervous system is responsible for the ***involuntary*** control of internal organs, blood vessels, smooth muscles and cardiac muscles.
- The somatic nervous system is responsible for the ***voluntary*** control of skin, bones, joints and skeletal muscles.

Voluntary Vs involuntary actions

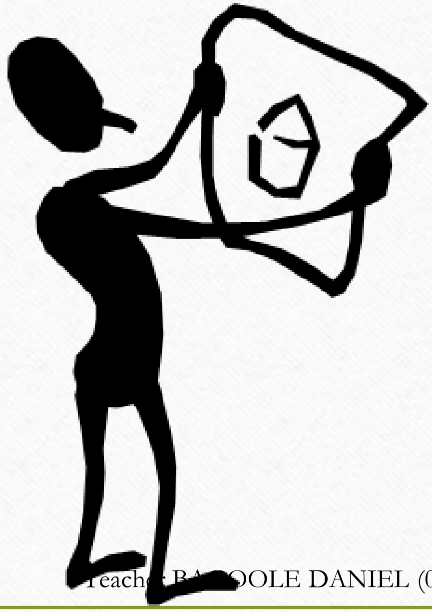
- *A voluntary action is one initiated consciously under the direct control of the brain i.e. they are actions one does at will e.g. dancing, laughing, stealing, etc.*
- These actions are performed consciously by an animal
- *Involuntary actions are the ones that occur without conscious thoughts e.g. breathing, etc.*

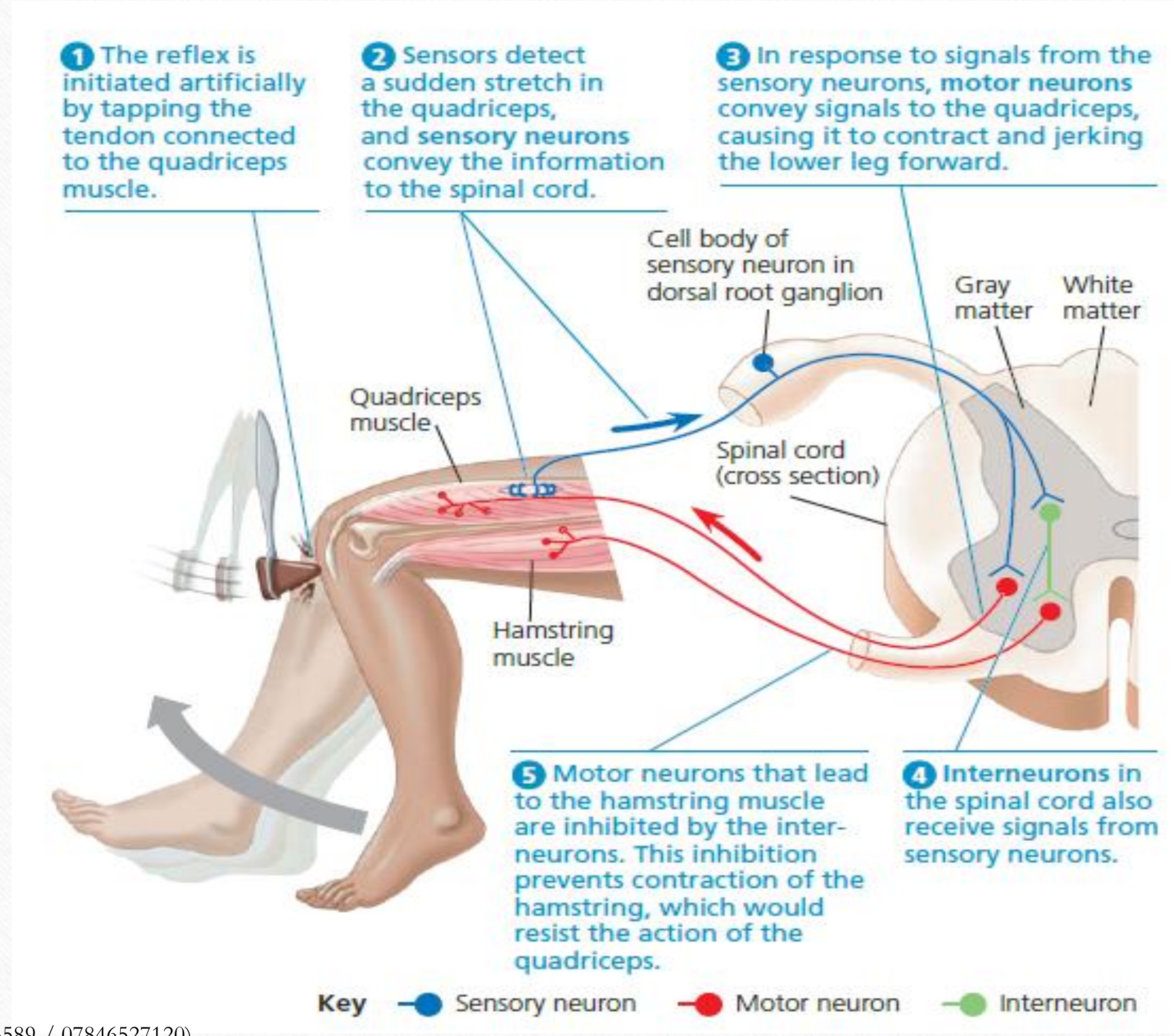
THE REFLEX ACTION

- A reflex action is an automatic (involuntary) response to a particular stimuli.
- Take place without the awareness of the individual.
- Occurs as a result of impulses travelling along neurons in a path called a ***reflex arc***. A reflex action can either be **simple** or **conditioned reflex**
- It is also known as an ***instinctive reflex*** which does not have to be learnt

A CASE STUDY

(Knee jerk)





SENSORY RECEPTORS

A receptor is a cell or tissue which can transform an impulse into action potential in neurones. It informs the CNS of external and internal changes.

- All sensory processes begin with stimuli, and all stimuli represent forms of energy.
- A sensory receptor converts stimulus energy to a change in membrane potential, thereby regulating the output of action potentials to the central nervous system (CNS).
- Decoding of this information within the CNS results in sensation.

- When a stimulus is received and processed by the nervous system, a motor response may be generated.
- One of the simplest stimulus-response circuits is a reflex, such as the kneejerk reflex

Characteristics (properties) of receptor cells

- **(1) Transduction**: Receptor cells are capable of changing physical stimuli into an electrical impulse.

- **(2) Sensitivity**: Receptor cells are able to detect the slightest change in their environment (stimulus).

(3) Adaptation

- If a stimulus is maintained, receptor cells are able to adapt to it so that the stimulus no longer causes an impulse, however strong it is. For example, the inability to 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

Significance of adaptation

- It provides animals with precise information about changes in the environment.
- It enables the nervous system ignore 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.

- **5) Precision:** Receptors are able to transmit the information precisely without alteration.
- **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.
- 7) They are specialized in structure and position.

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 receptors

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

Secondary receptors

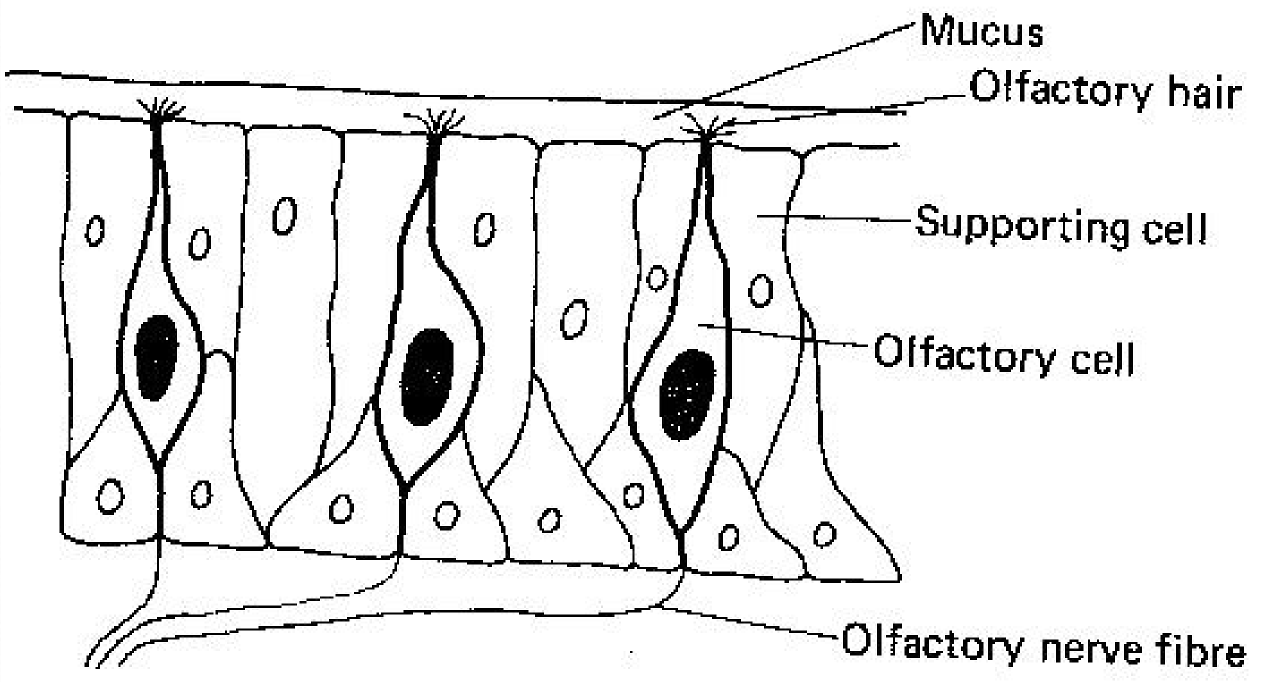
These are epithelial cells that are adapted to detect a particular stimulus and communicate with a receptor neuron via a synapse. ***Examples***: olfactory cells, taste buds

Sensory receptors

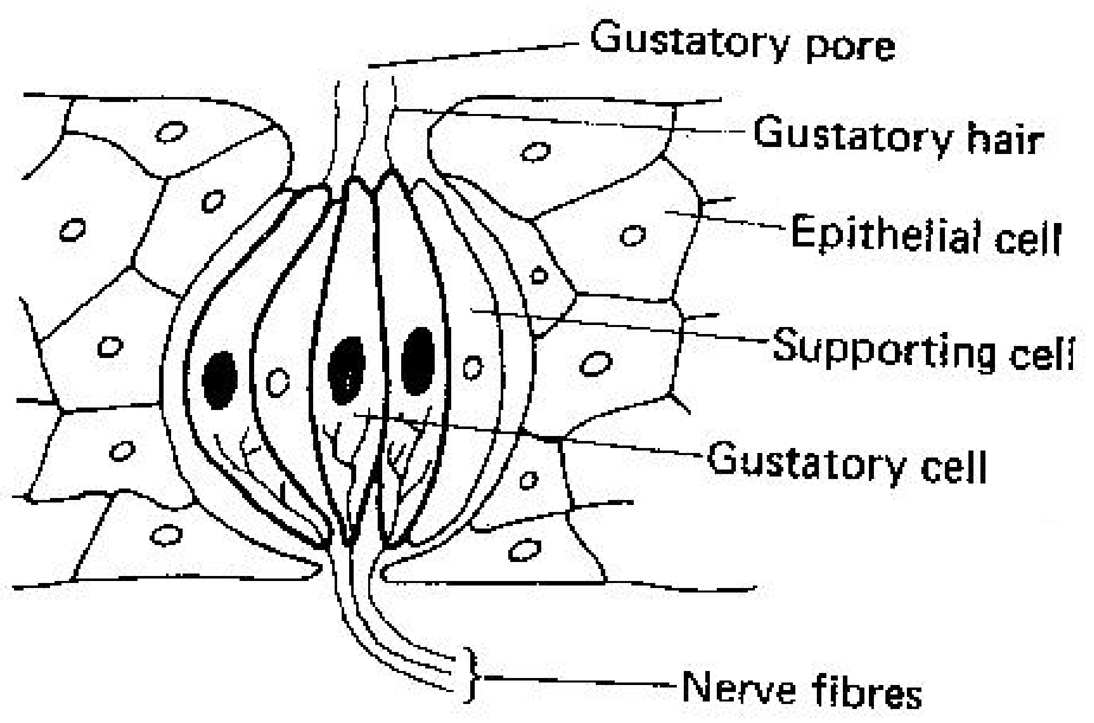
Are complex receptors, consisting of many receptor cells, sensory neurons and supportive tissue. ***Examples***: eye, ear

Description of some primary and secondary receptors

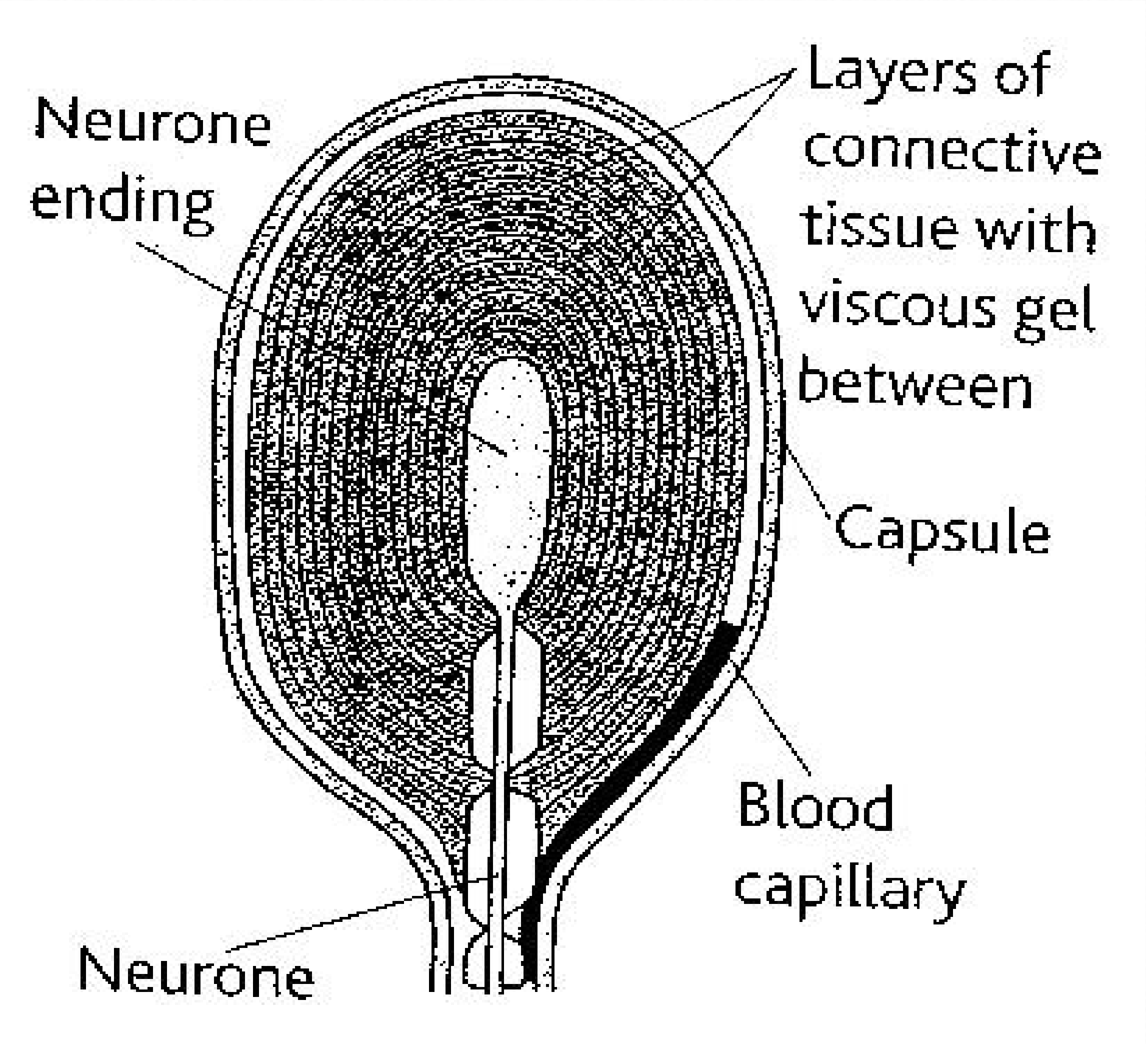
Olfactory epithelium of the nose (Secondary)



Taste cells of the tongue (Secondary)



Pacinian corpuscle in the human skin



Basing on positioning in the body

1. Exteroceptors

Respond to externally derived stimuli.

Examples: ear, eye

2. Interoceptors

Respond to internally derived stimuli like homeostatic state.

Examples: carotid and aortic bodies

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

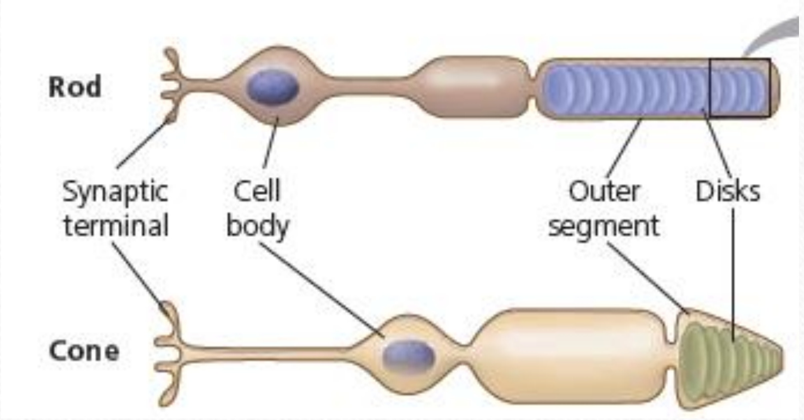
Basing the nature of their response

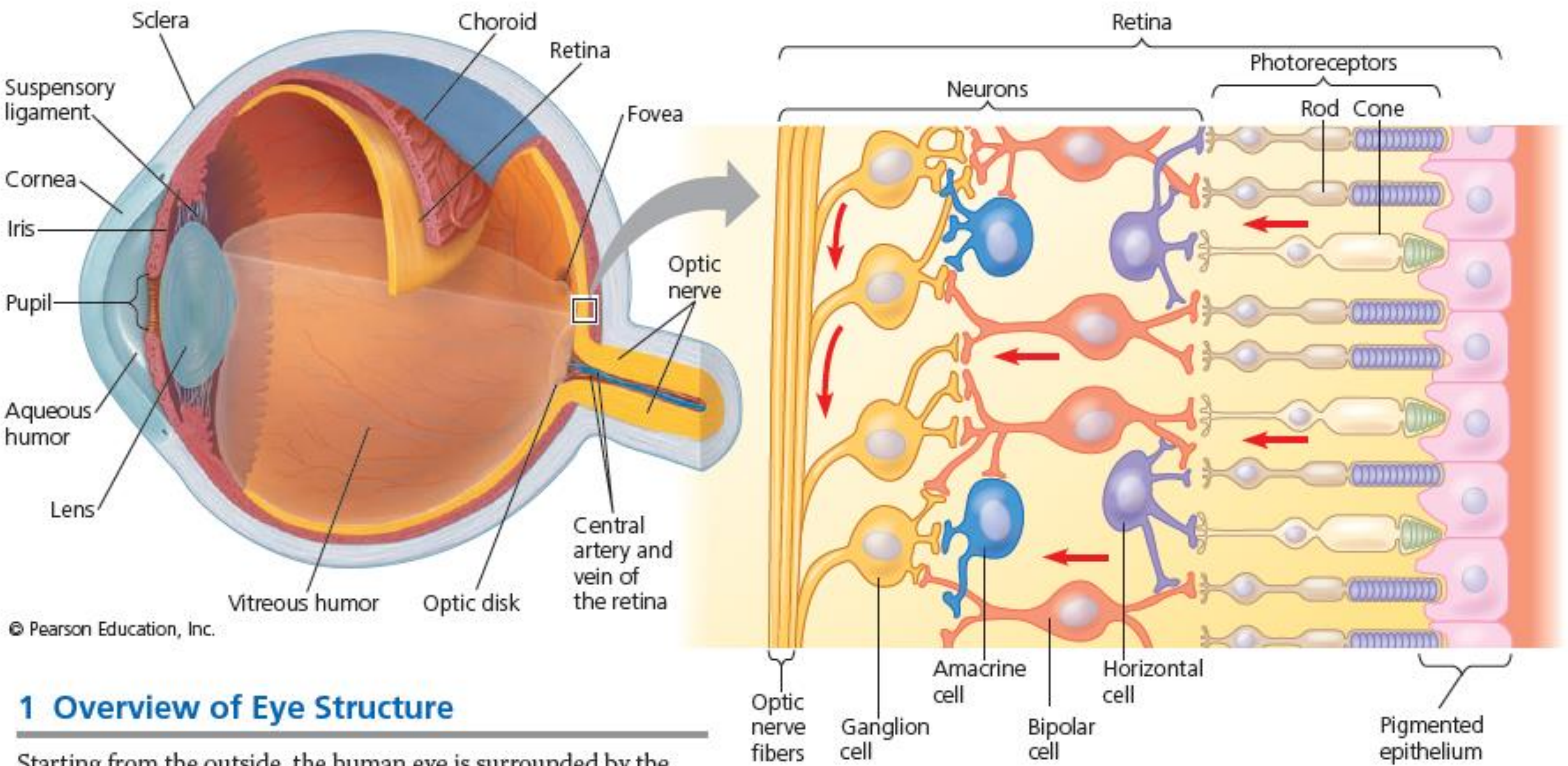
(i) Tonic receptors continue to fire as long as the stimulus is maintained. They monitor the presence and intensity of a stimulus.

(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.

THE MAMMALIAN EYE

- Receptor organ for the stimulus of light.
- Contains light sensitive cells (Photoreceptors); RODS and CONES





1 Overview of Eye Structure

Starting from the outside, the human eye is surrounded by the

- 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 eye, 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

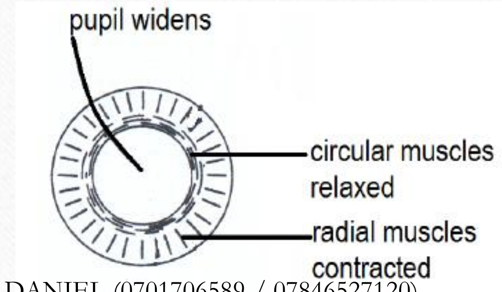
Control of light amount entering the eye

- The iris controls the amount of light entering the eye. It is made up of circular and radial muscles.
- This is done to protect the retina from damage by bright light and the wide size of the pupil during dim light allows in enough light of low intensity.

Control of light amount entering the eye

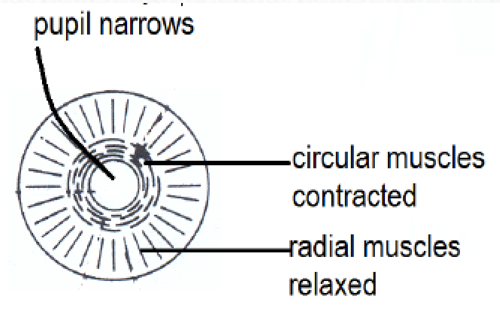
Control of amount of light entering the eye in dim light

- In dim light, radial muscles contract,
- Circular muscles relax,
- Pupil widens and more light is admitted into the eye.



Control of amount of light entering the eye in bright light

- Circular muscles of the iris contract,
- Radial muscles relax,
- Pupil becomes smaller and narrower hence less light is admitted into the eye.

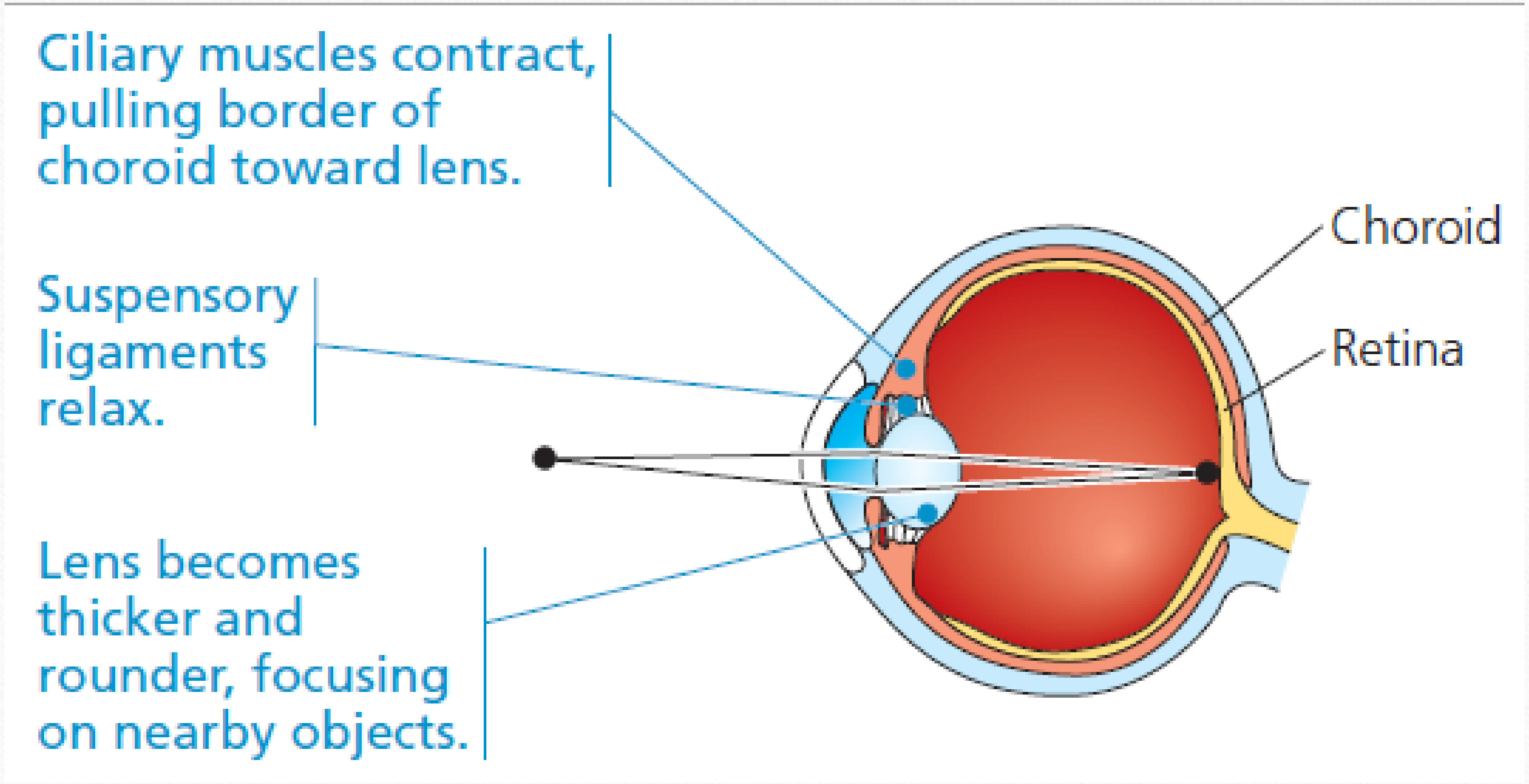


Accommodation of the eye

- ability of the eye to change the focal length of the lens when viewing distant or nearby objects.

Accommodation for a nearby object:

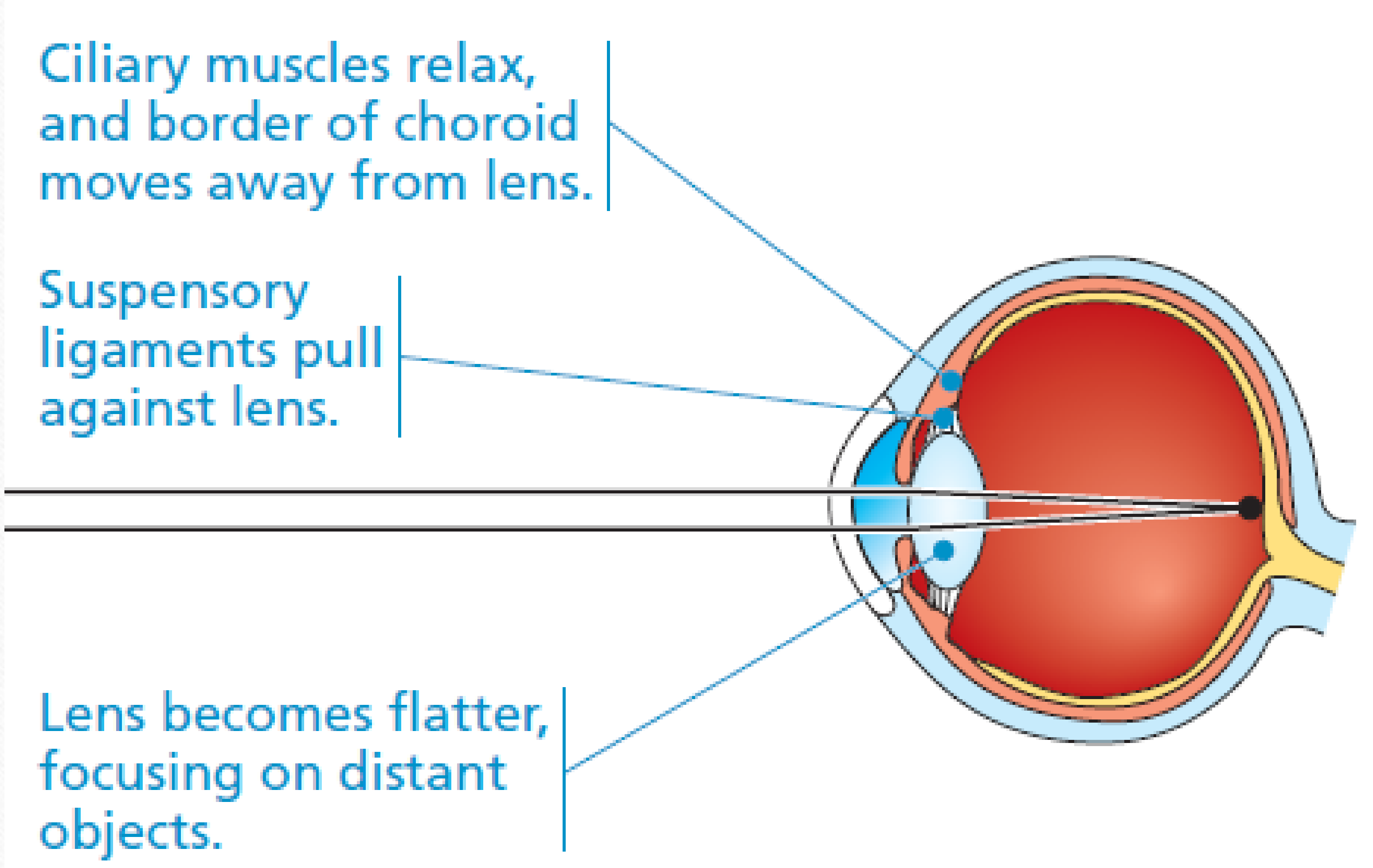
- When looking at a nearby object, the ciliary muscles in the ciliary body contract, the suspensory ligaments slacken. This makes the lens short and thick. This increases the ability of the lens to refract light and reduces the focal length of the lens for the nearby object to be seen clearly.



Ciliary muscles contract, pulling border of choroid toward lens.
Suspensory ligaments relax.
Lens becomes thicker and rounder, focusing on nearby objects.
Choroid
Retina

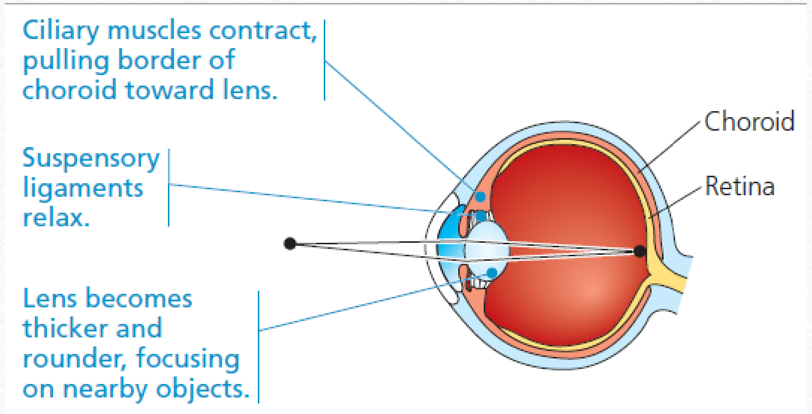
Accommodation for a distant object:

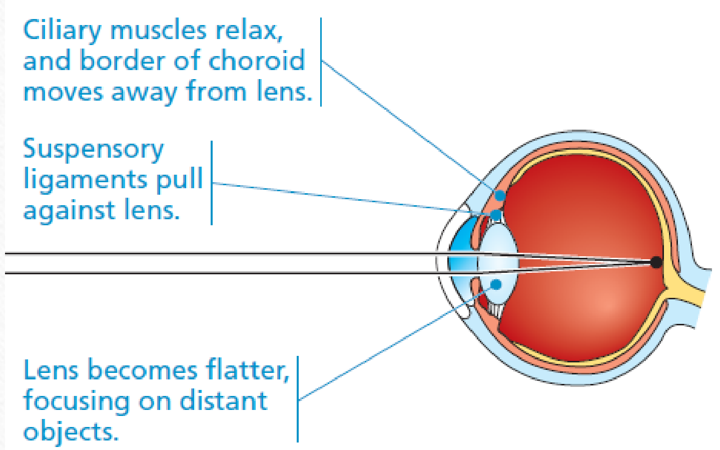
- When viewing a distant object, the ciliary muscles in the ciliary body relax. This causes tension in the suspensory ligaments.
- The suspensory ligaments pull the lens apart making the lens thin and long. This makes the lens to refract less and increase the focal length of the lens.


Ciliary muscles relax, and border of choroid moves away from lens.
Suspensory ligaments pull against lens.
Lens becomes flatter, focusing on distant objects.

Summary of accommodation

Nearby object	Distant object
Diverging light rays from a nearby object are refracted by cornea.	Parallel light rays from a distant object are refracted by the cornea.
Ciliary muscles in the ciliary body contract.	Ciliary muscles in the ciliary body relax.
Suspensory ligament slacken.	Suspensory ligaments develop tension.
The lens become short and thick.	The lens becomes thin and long.
The focal length of the lens decreases	The focal length of the lens increases.
Light rays are refracted to the retina.	Light rays are refracted to the retina.

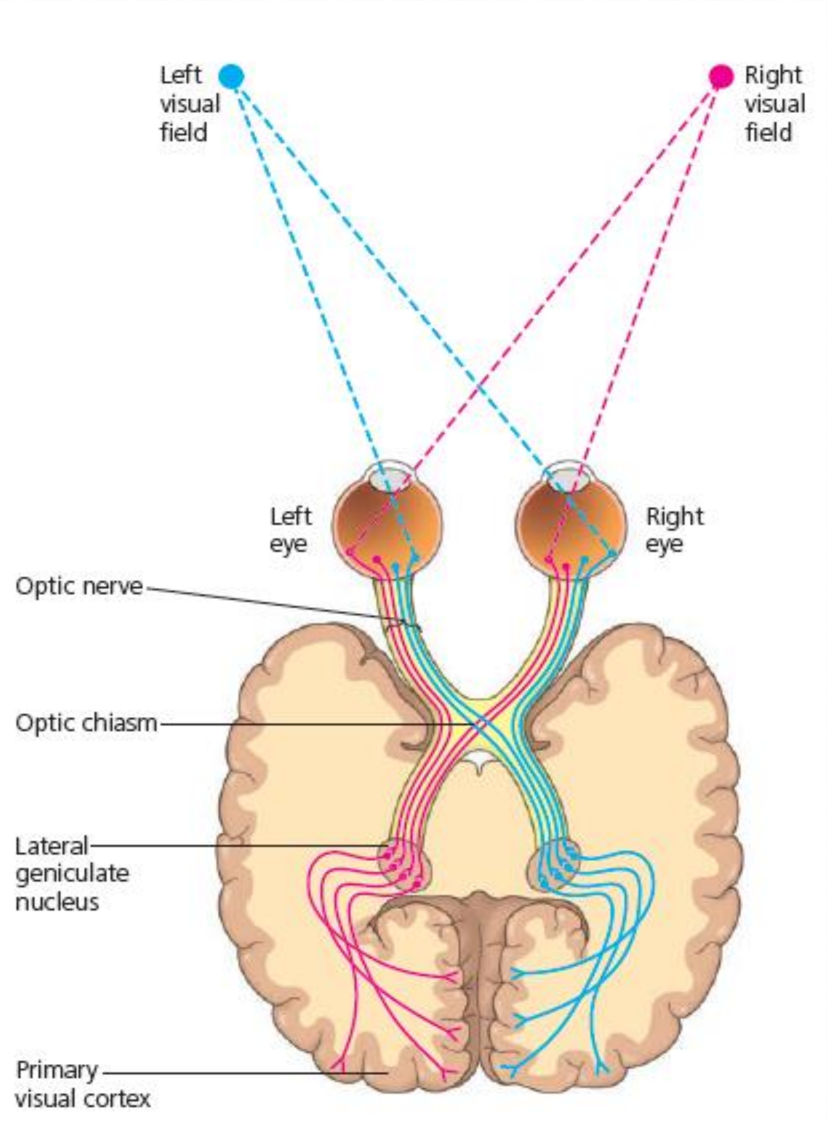




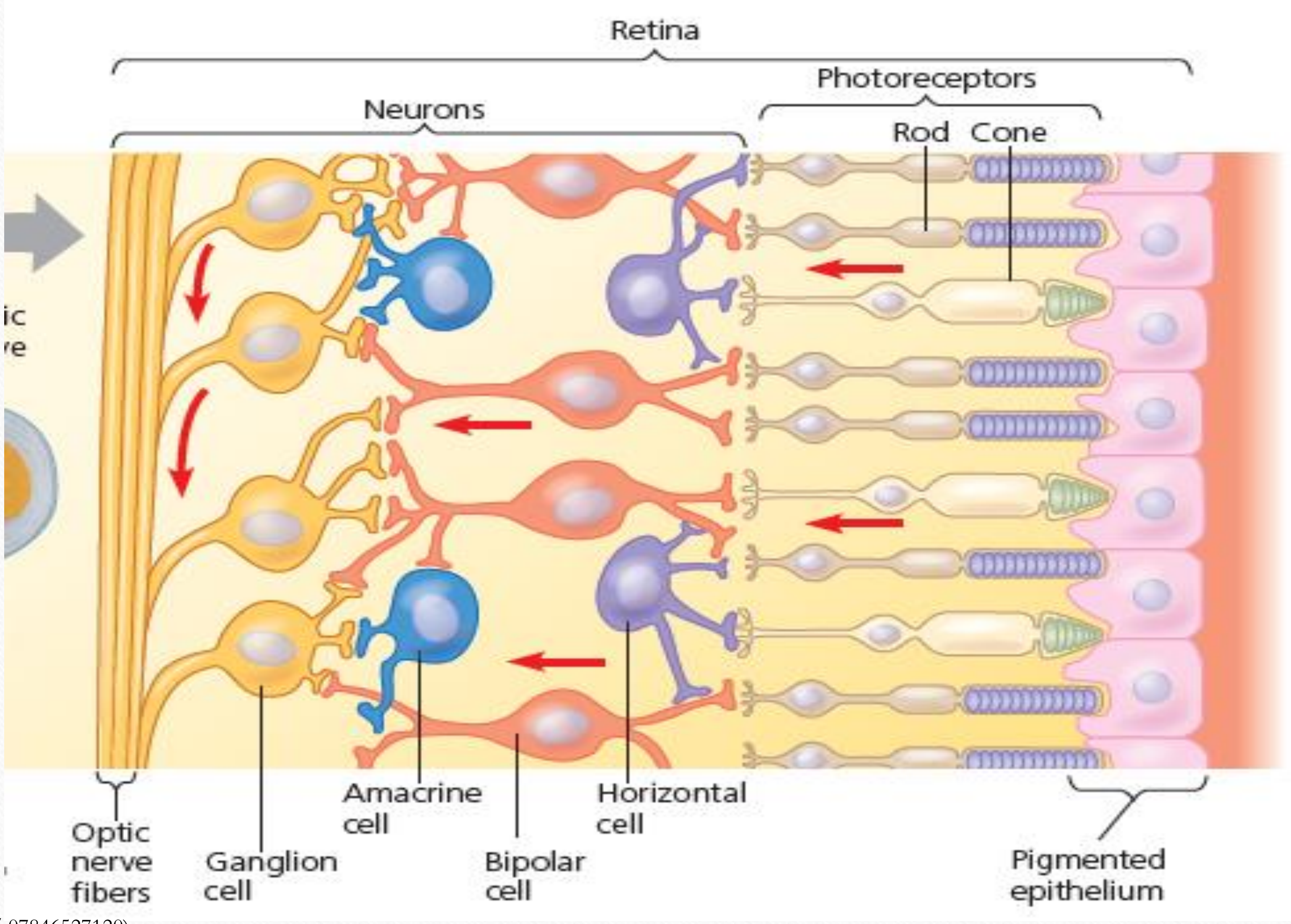
Neural pathways for vision

Each optic nerve contains about a million axons that synapse with interneurons in the lateral geniculate nuclei.

The nuclei relay sensations to the primary visual cortex, one of many brain centers that cooperate in constructing our visual perceptions.



THE RETINA



Retina
Photoreceptors
Neurons
Rod
Cone
Optic
nerve
fibers
Ganglion
cell
Amacrine
cell
Bipolar
cell
Horizontal
cell
Pigmented
epithelium

RETINA

- The human retina contains rods and cones, two types of photoreceptors that differ in shape and in function.
- Rods are more sensitive to light but do not distinguish colours; they enable us to see at night, but only in black and white.
- Cones provide colour vision, but, being less sensitive, contribute very little to night vision

RETINA

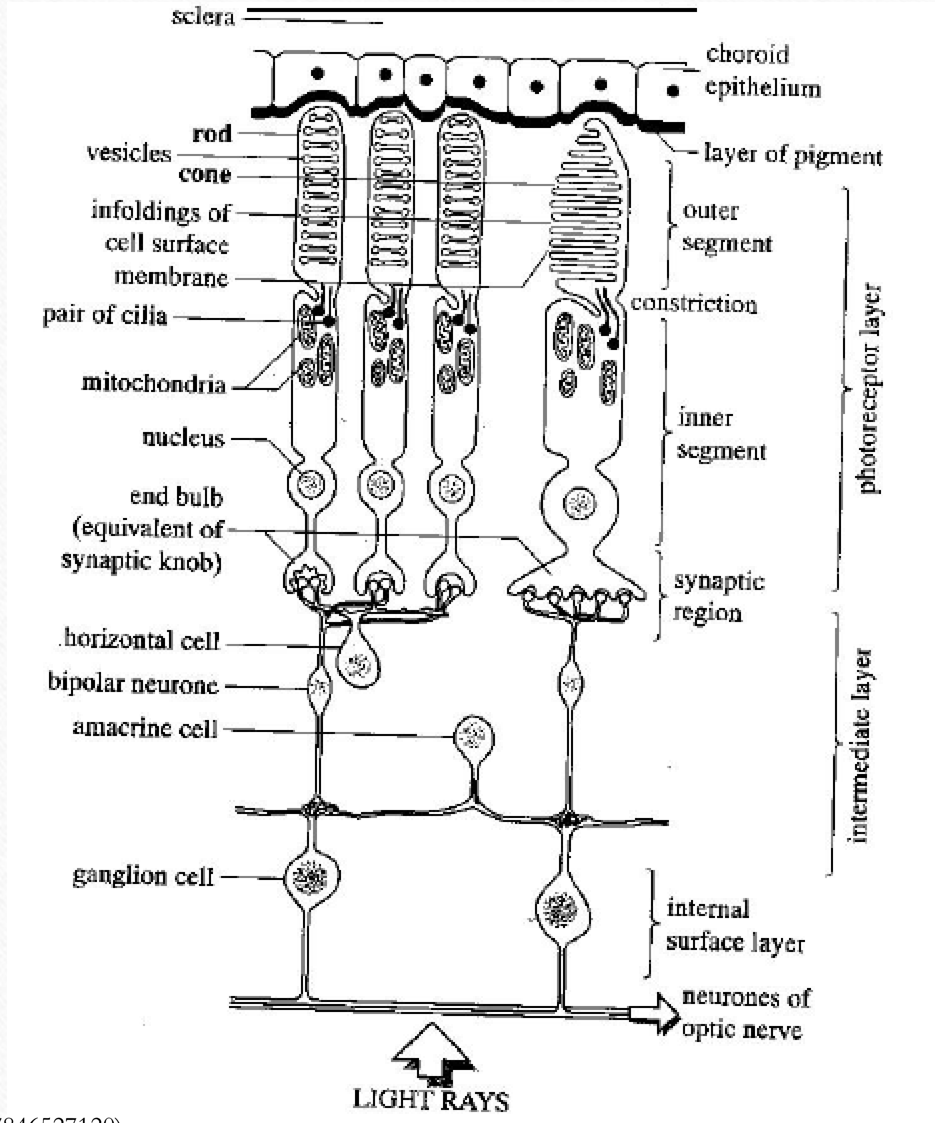
- There are 3 types of cones. Each has a different sensitivity across the visible spectrum, proving an optimal response to red, green, or blue light.
- The relative numbers of rods and cones in the retina varies among different animals, correlating to some degree with the extent to which an animal is active at night.
- The distribution of rods and cones varies across the human retina. Overall, the human retina contains about 125 million rods and about 6 million cones.

RETINA

- The fovea, the centre of the visual field, has no rods, but has a very high density of cones – about 150,000 cones per square millimeter.
- The ratio of rods to cones increases with distance from the fovea, with the peripheral regions having only rods.

RETINA

- In day light, you achieve your sharpest vision by looking directly at an object, such light shines on the tightly packed cones in your fovea.
- At night, looking directly at a dimly lit object is ineffective, since the rods-the more sensitive light receptors are found outside the fovea.
- Thus, for example, you see a dim star best by focusing on a point just to one side of it.


sclera
choroid
epithelium
rod
vesicles
cone
layer of pigment
infoldings of
cell surface
membrane
outer
segment
pair of cilia
constriction
mitochondria
nucleus
inner
segment
photoreceptor layer
end bulb
(equivalent of
synaptic knob)
synaptic
region
horizontal cell
bipolar neurone
amacrine cell
intermediate layer
ganglion cell
internal
surface layer
neurones of
optic nerve
LIGHT RAYS

The structure and composition of cones and rods

- Rods and cones have an essentially similar structure and their photosensitive pigments are attached to the outer surface of the membrane in the outer segment.
- They have four similar regions where structure and function are shown below;

Outer segment:

- This is the photosensitive region where light energy is converted into a generator potential. The entire outer segment is composed of flattened membranous vesicles containing the photosensitive pigments.

Constriction:

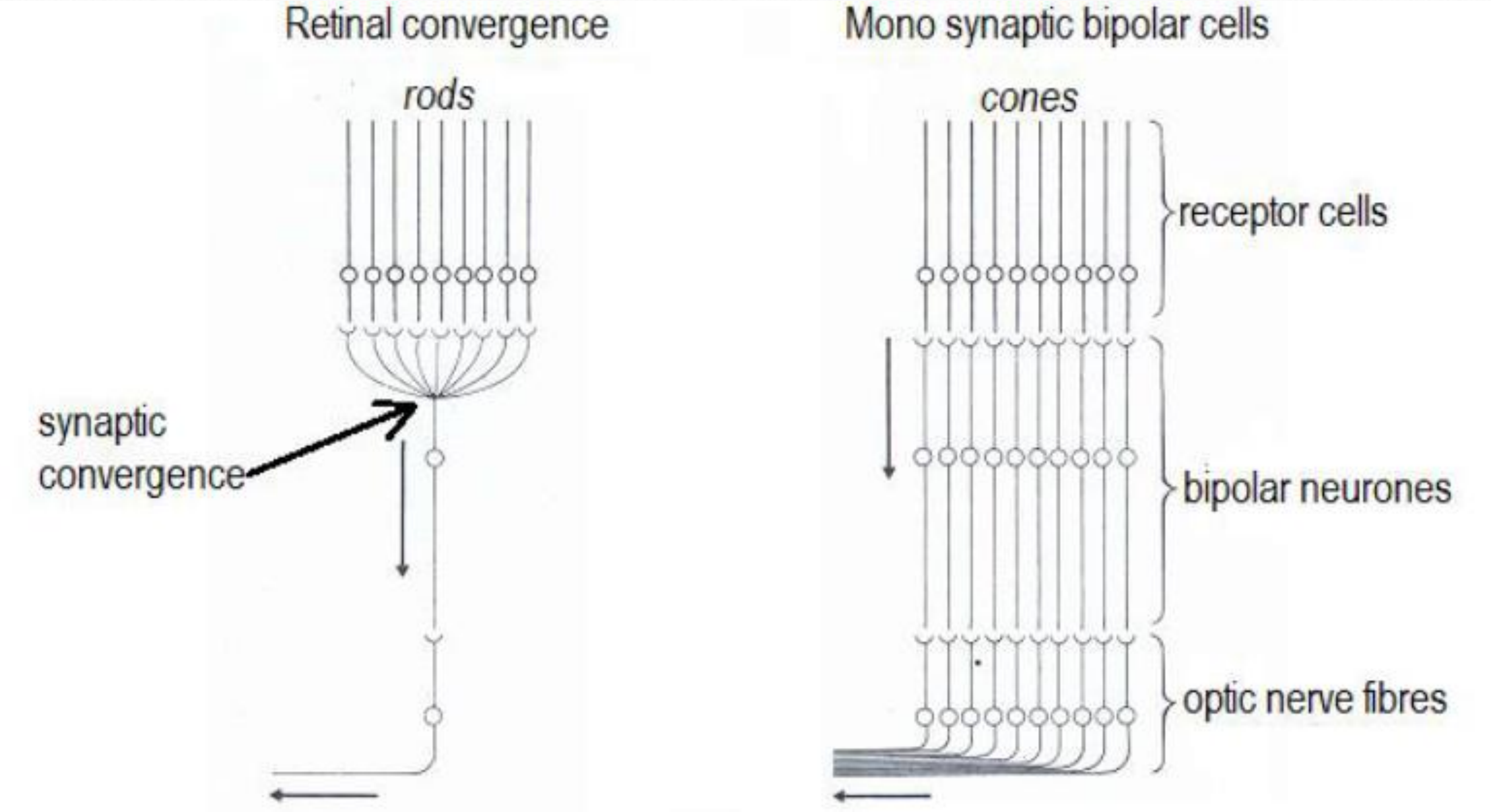
- The outer segment is almost separated from the inner segment by an in folding of the outer membrane. The two regions remain in contact by cytoplasm and pair of cilia which pass between the two.

Internal/inner segment:

- This is an actively metabolic region. It's packed with mitochondria producing energy for visual processes and polysomes for synthesis of proteins involved in the production of membranous vesicles and visual pigments. The nucleus is located in this region.

Synaptic region:

- Here the cells form synapses with bipolar cells.
- Different bipolar cells may have synapses with several rods; this is called synaptic convergence and it increases visual sensitivity


Retinal convergence
rods
synaptic convergence
Mono synaptic bipolar cells
cones
receptor cells
bipolar neurones
optic nerve fibres

- The high **visual acuity** in the cones is also because they are highly packed at fovea with direct connection to the optical nerves.
- ***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.

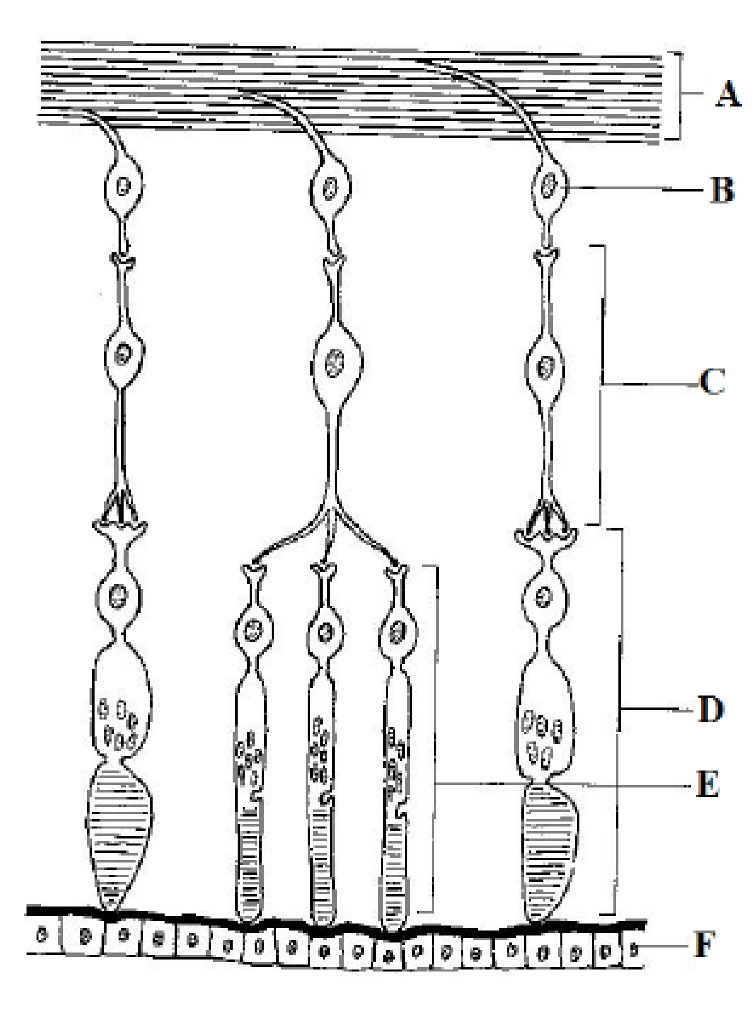
- The more densely-packed the cone cells, the better the visual acuity.

- In the fovea of human eyes there are **160 000 cones per mm2** , while hawks have **1 million cones per mm2**, so they really do have far better acuity.

Differences between rods and cones

Rods	Cones
Photochemical pigment is readily regenerated when bleached.	Pigment take long to be regenerated once bleached.
Poor colour vision	High ability of recognizing colours.
Have retinal convergence.	Lack retinal convergence.
The photosensitive pigment is rhodopsin.	The photosensitive pigment is iodopsin.
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).

Take home ice-cream !!



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

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

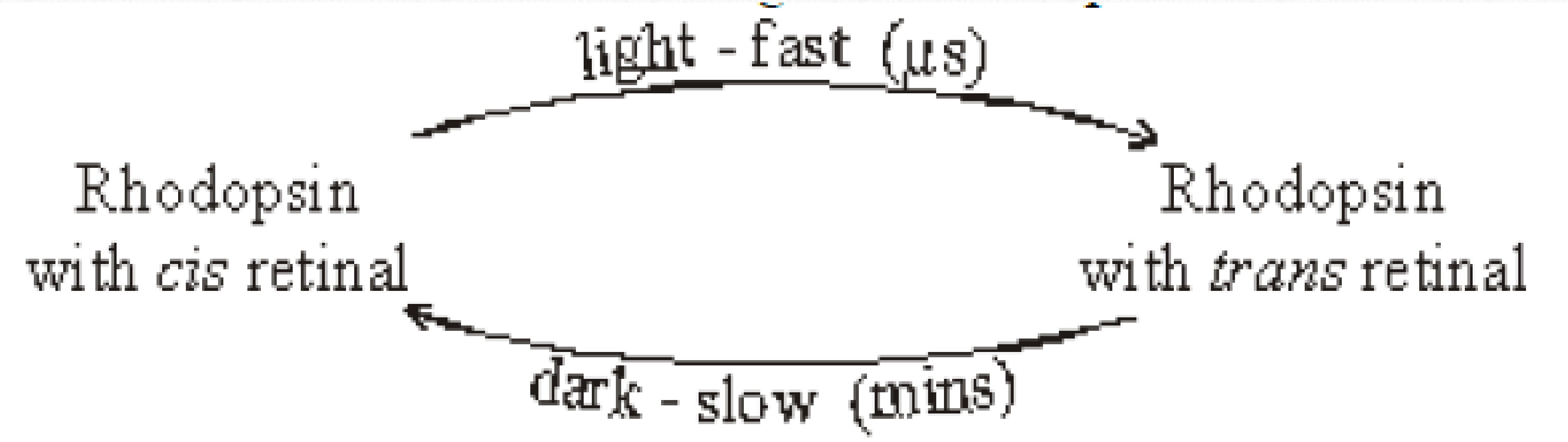
(i) Several cells of type labelled E connect to one cell in layer C?

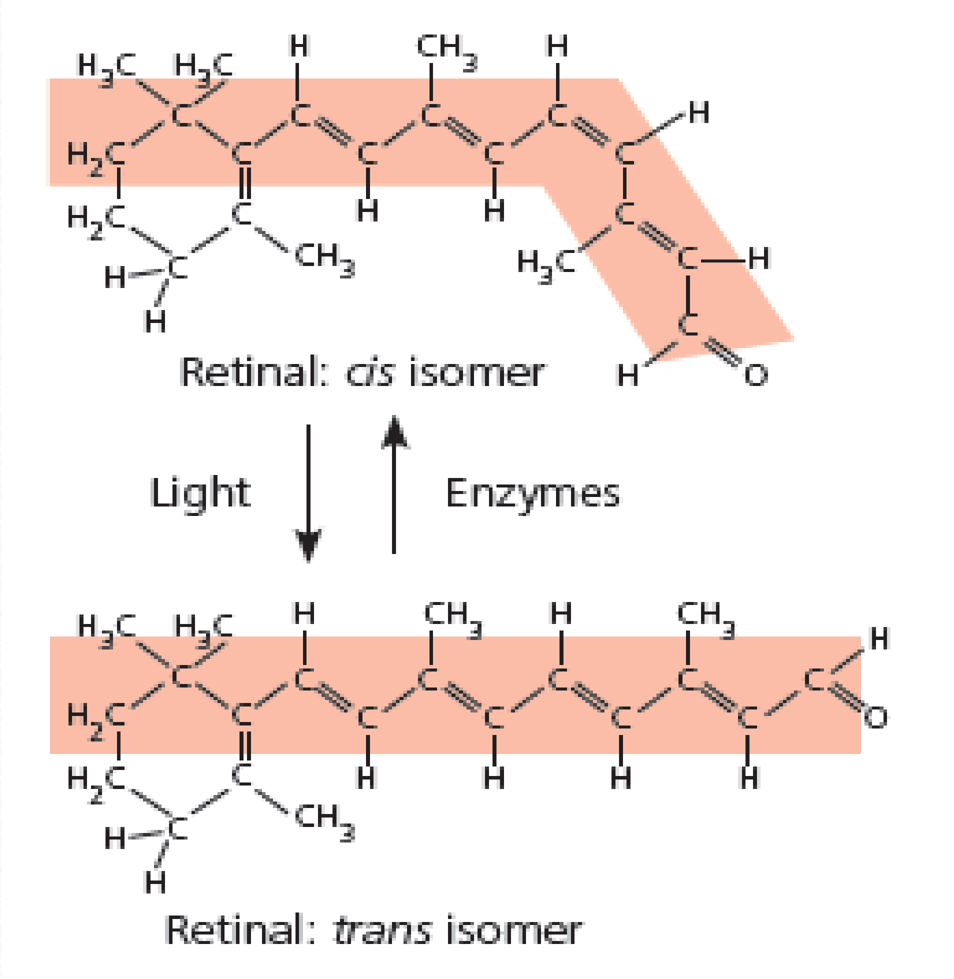
(ii) One cell of type labeled D connects to one cell in layer C?

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:**

Interconversion



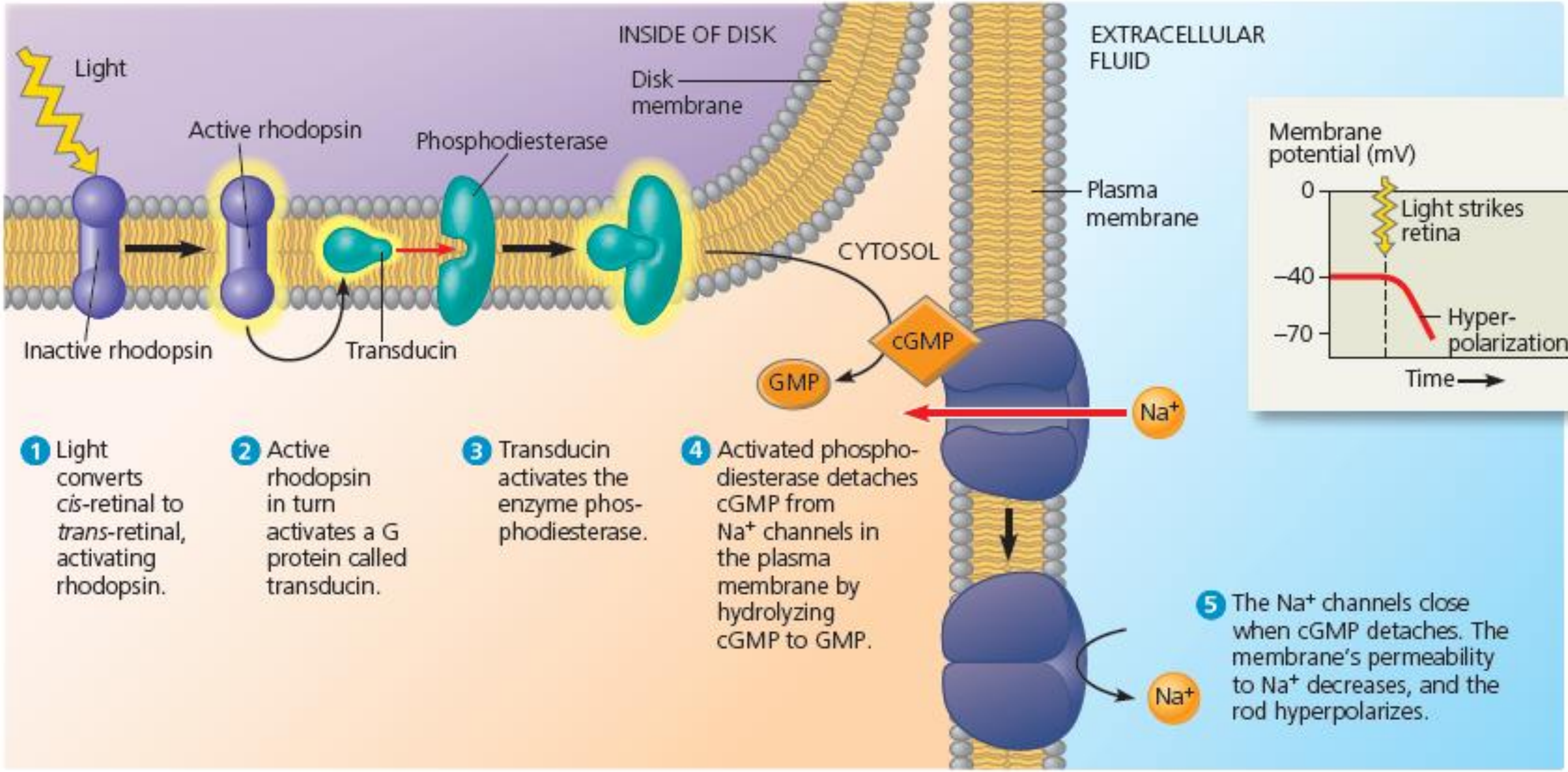

Retinal: cis isomer
Light
Enzymes
Retinal: trans isomer

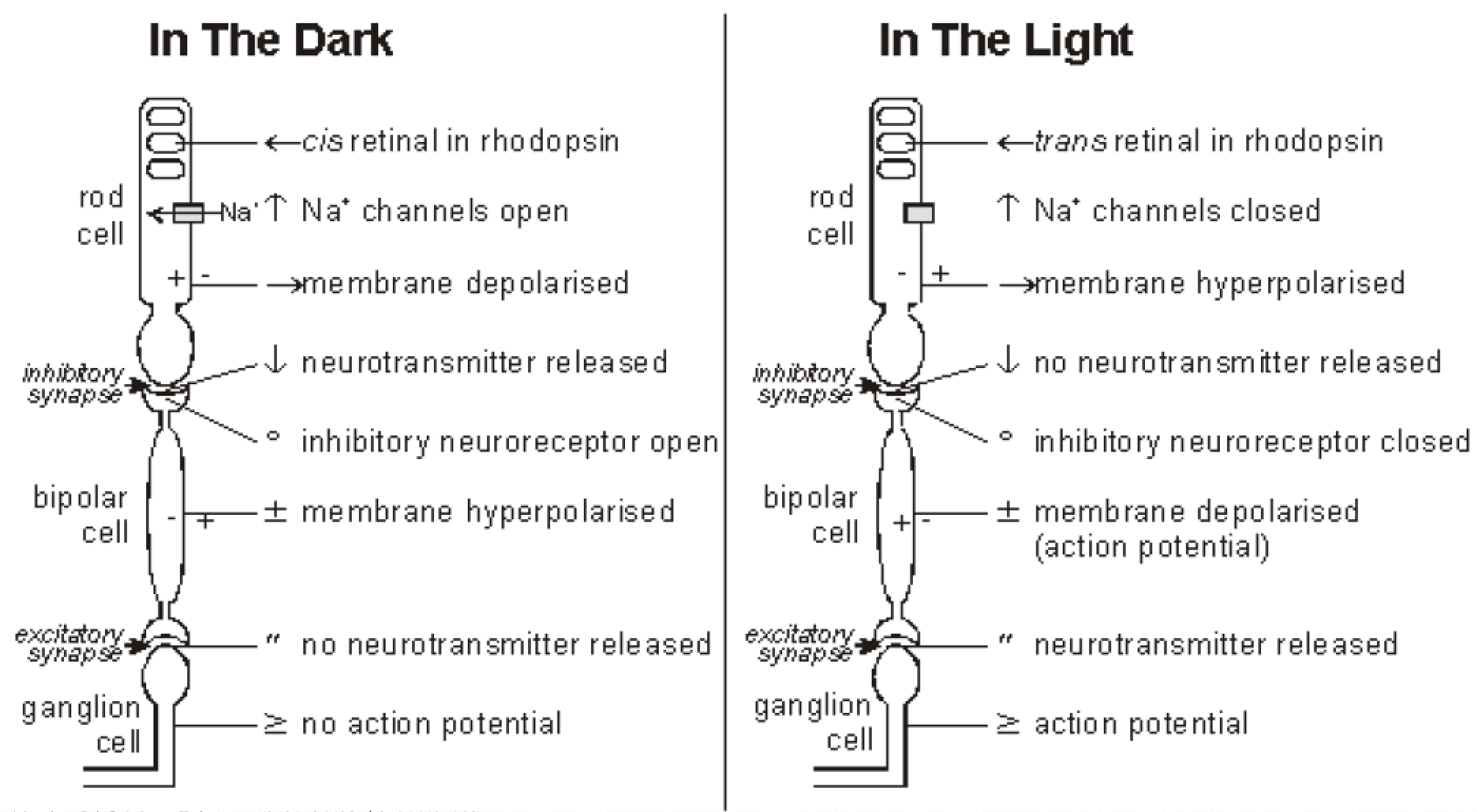
Mechanism

- 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.


INSIDE OF DISK
Light
Disk membrane
Active rhodopsin
Phosphodiesterase
EXTRACELLULAR FLUID
Membrane potential (mV)
0
Light strikes retina
−40
−70
Hyper-polarization
Time
Plasma membrane
CYTOSOL
cGMP
GMP
Na+
Inactive rhodopsin
Transducin
1 Light converts *cis*-retinal to *trans*-retinal, activating rhodopsin.
2 Active rhodopsin in turn activates a G protein called transducin.
3 Transducin activates the enzyme phos-phodiesterase.
4 Activated phospho-diesterase detaches cGMP from Na+ channels in the plasma membrane by hydrolyzing cGMP to GMP.
5 The Na+ channels close when cGMP detaches. The membrane's permeability to Na+ decreases, and the rod hyperpolarizes.


In The Dark
rod cell
cis retinal in rhodopsin
Na^+
Na^+ channels open
membrane depolarised
inhibitory synapse
neurotransmitter released
inhibitory neuroreceptor open
bipolar cell
membrane hyperpolarised
excitatory synapse
no neurotransmitter released
ganglion cell
no action potential
In The Light
rod cell
trans retinal in rhodopsin
Na^+ channels closed
membrane hyperpolarised
inhibitory synapse
no neurotransmitter released
inhibitory neuroreceptor closed
bipolar cell
membrane depolarised (action potential)
excitatory synapse
neurotransmitter released
ganglion cell
action potential

Rods are more sensitive than the cones because:

- i) Their pigment is readily broken down and regenerate faster than that of the cones. That's why they are mostly used for vision during conditions of low illumination or darkness.
- ii) They show retinal convergence where separate rods add up or summate to build a generator potential upto a threshold

Colour perception in the cones

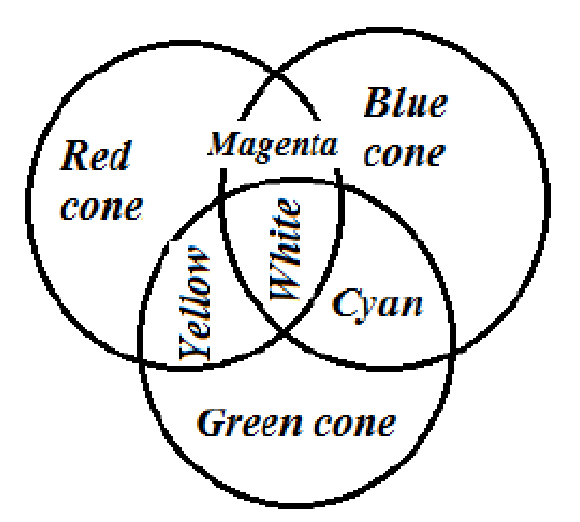
- There are three different kinds of cone cell, each with a different form of opsin (they have the same retinal).
- These three forms of iodopsin are sensitive to different parts of the spectrum, so there are red cones (10%), green cones (45%) and blue cones (45%).

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.

Trichromatic theory



- 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.

Explain the following;

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;

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

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;

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 can't 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.

If both your eyes are open and you press the side of one of your eyeballs, you see double.

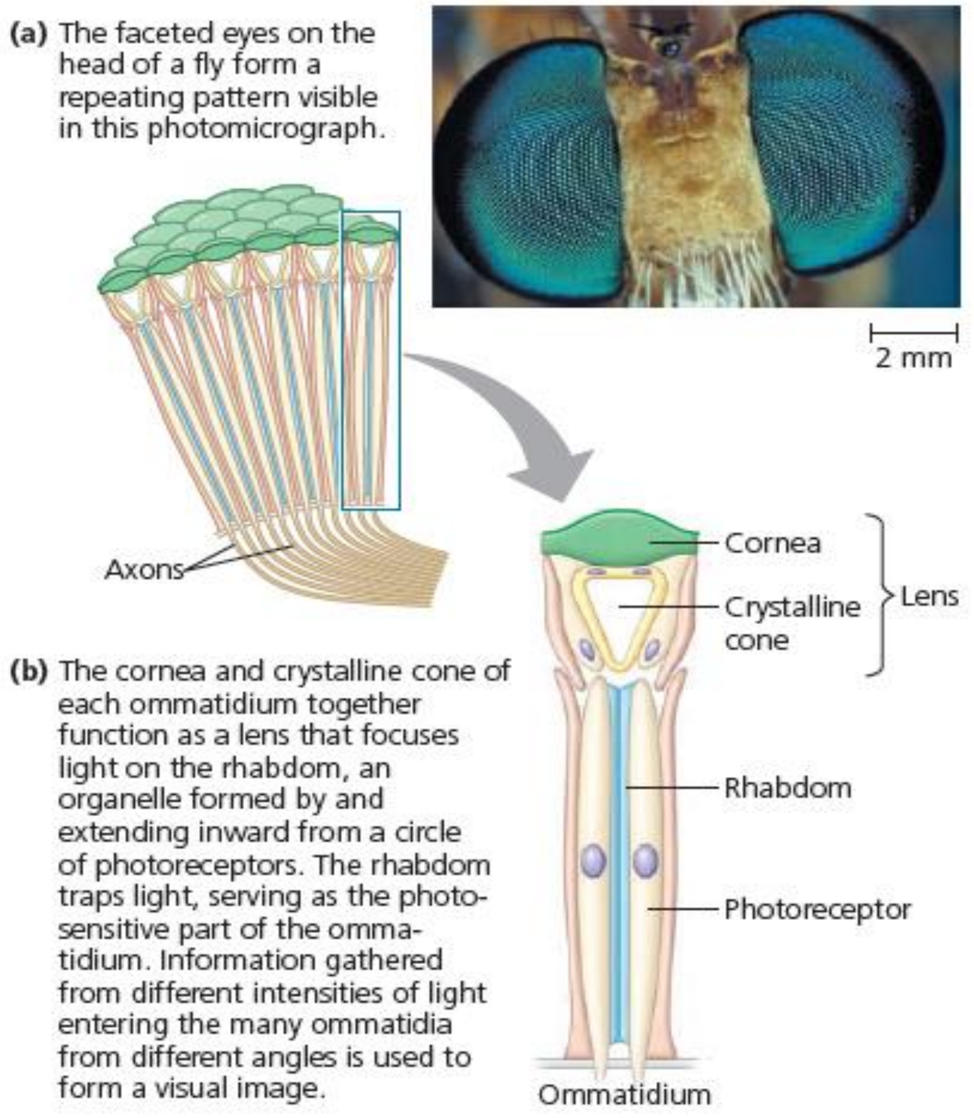
- Pressing of eye ball distorts the eye position such that the two eyes are unable to look directly at an object in the same direction, hence the brain fails to blend together the images from the two eyes, causing double vision to be perceived

Colour blindness

- 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.

THE COMPOUND EYE

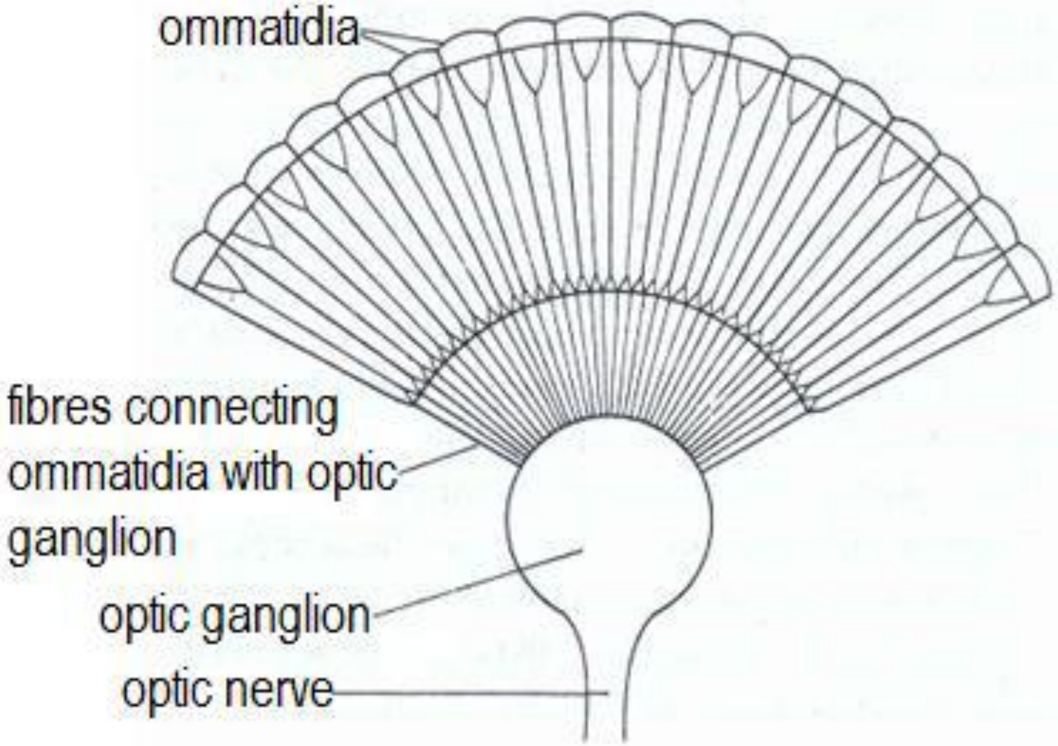
A compound eye consists of up to thousand light detectors called ommatidia, each with its own light focusing lens. Each ommatidium detects light from a tiny portion of the visual field.



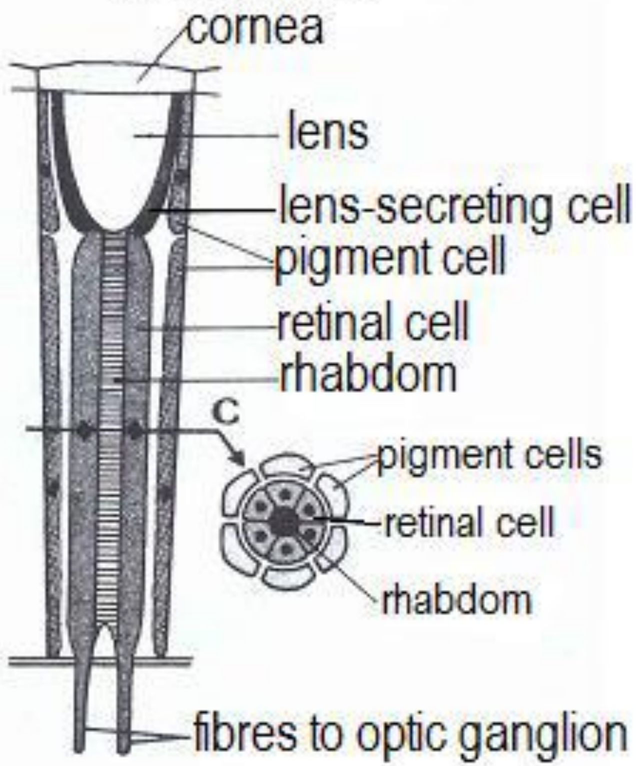
(a) The faceted eyes on the head of a fly form a repeating pattern visible in this photomicrograph.

(b) The cornea and crystalline cone of each ommatidium together function as a lens that focuses light on the rhabdom, an organelle formed by and extending inward from a circle of photoreceptors. The rhabdom traps light, serving as the photosensitive part of the ommatidium. Information gathered from different intensities of light entering the many ommatidia from different angles is used to form a visual image.

Structure of the compound eye



Longitudinal section through an ommatidium



***Note:* C** *- shows the cross section through ommatidium*

Functions of the parts

- The ***lens*** converges light rays onto the tip of the rhabdom.
- The ***pigment cells*** regulates the amount of light reaching the retinal cells. They also separate the ommatidium from its neighbor.
- The ***rhabdom*** is the light sensitive part of the ommatidium where photochemical stimulation occurs leading to depolarization of the membrane of the retinal cells.
- The ommatidia would serve the same function as the rods and cones of the vertebrate eye but they are much larger and this brings about the reduced visual acuity in arthropods.

- A compound eye is very effective at detecting movement, an important adaptation for flying insects and small animals constantly threatened with predation.
- Whereas the human eye can only distinguish about 50 flashes of light per second, the compound eyes of some insects can detect flickering at a rate six times faster. If they slipped into a movie theatre, these insects could easily resolve each frame of the film being projected as a separate still image- this is termed as flicker fusion.

- Insects have an excellent colour vision, and some (including bees) can see into the ultra-violet (UV) range of the electromagnetic spectrum. Because UV light is invisible to us, we miss seeing differences in the environment that bees and other insects detect

Comparison of Human and compound eye

THE HUMAN EAR

The ear has **mechanoreceptors** (receptors that detect physical transformation) associated with sound, gravity and displacement.

The ear performs three basic functions i.e. detection of:

1) Sound (hearing)

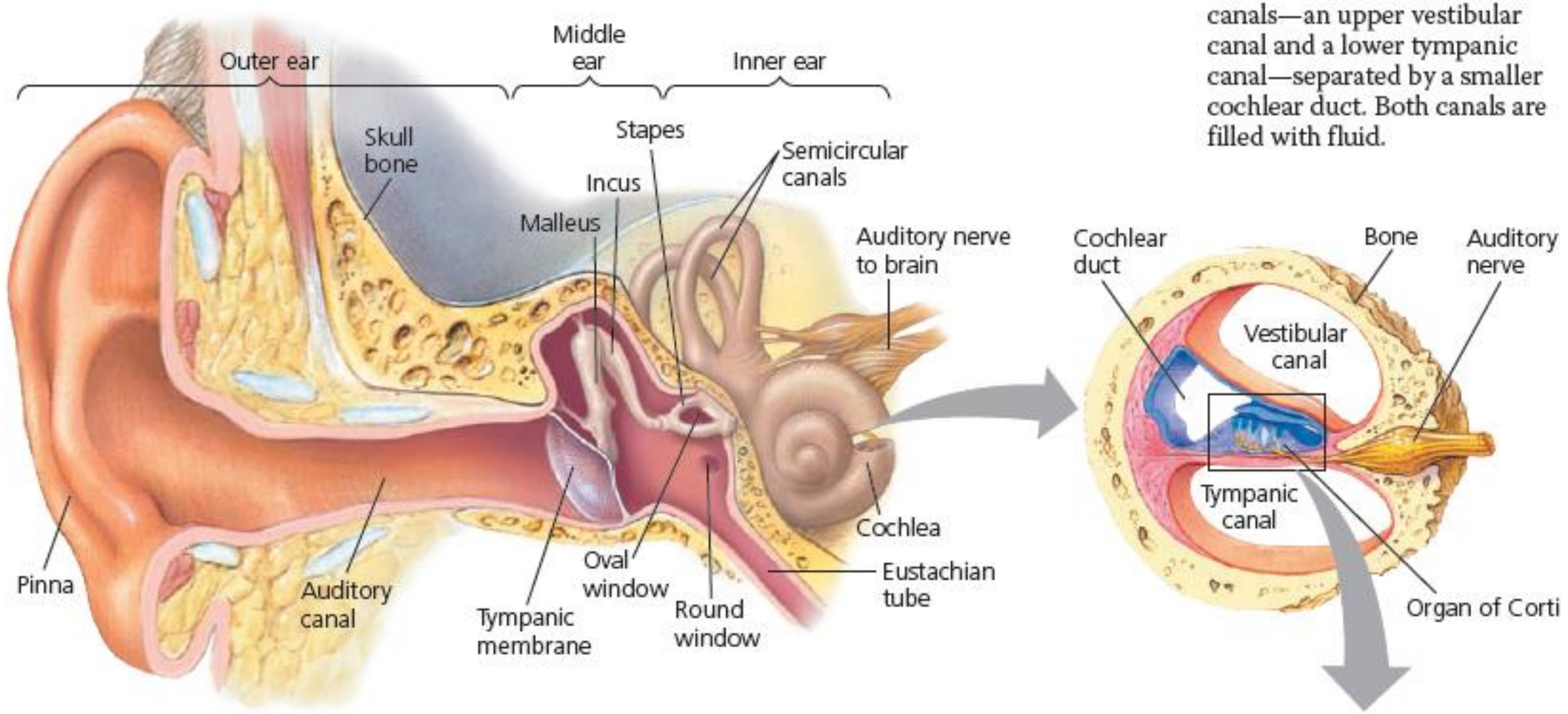
2) Head movements

3) Changes in gravity (balance or posture)

Overview of Ear Structure

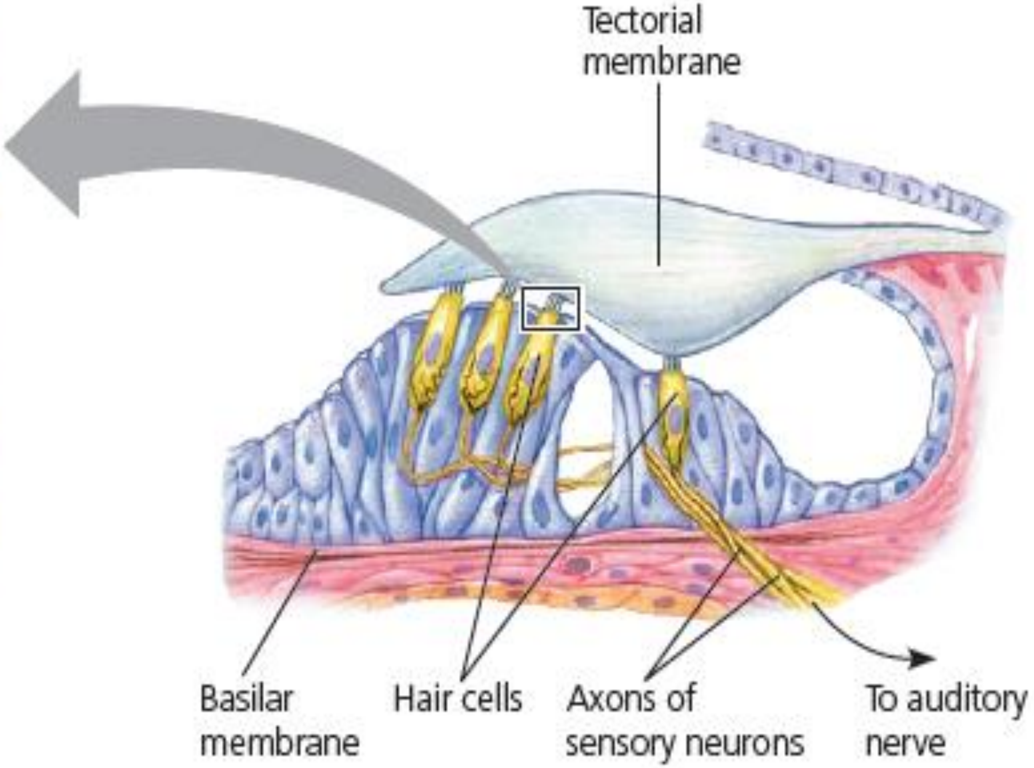
- and channel them to the **tympanic membrane** (eardrum), which separates the outer ear from the
- middle ear. In the **middle ear**, three small bones—the malleus (hammer), incus (anvil), and stapes
- (stirrup)—transmit vibrations to the **oval window**, which is a membrane beneath the stapes.

- The middle ear also opens into the **Eustachian tube**, which connects to the pharynx and equalizes pressure between the middle ear and the atmosphere.
- The **inner ear** consists of fluid-filled chambers, including the **semicircular canals**, which function in equilibrium, and the coiled **cochlea** (from the Latin meaning "snail"), a bony chamber that is involved in hearing.

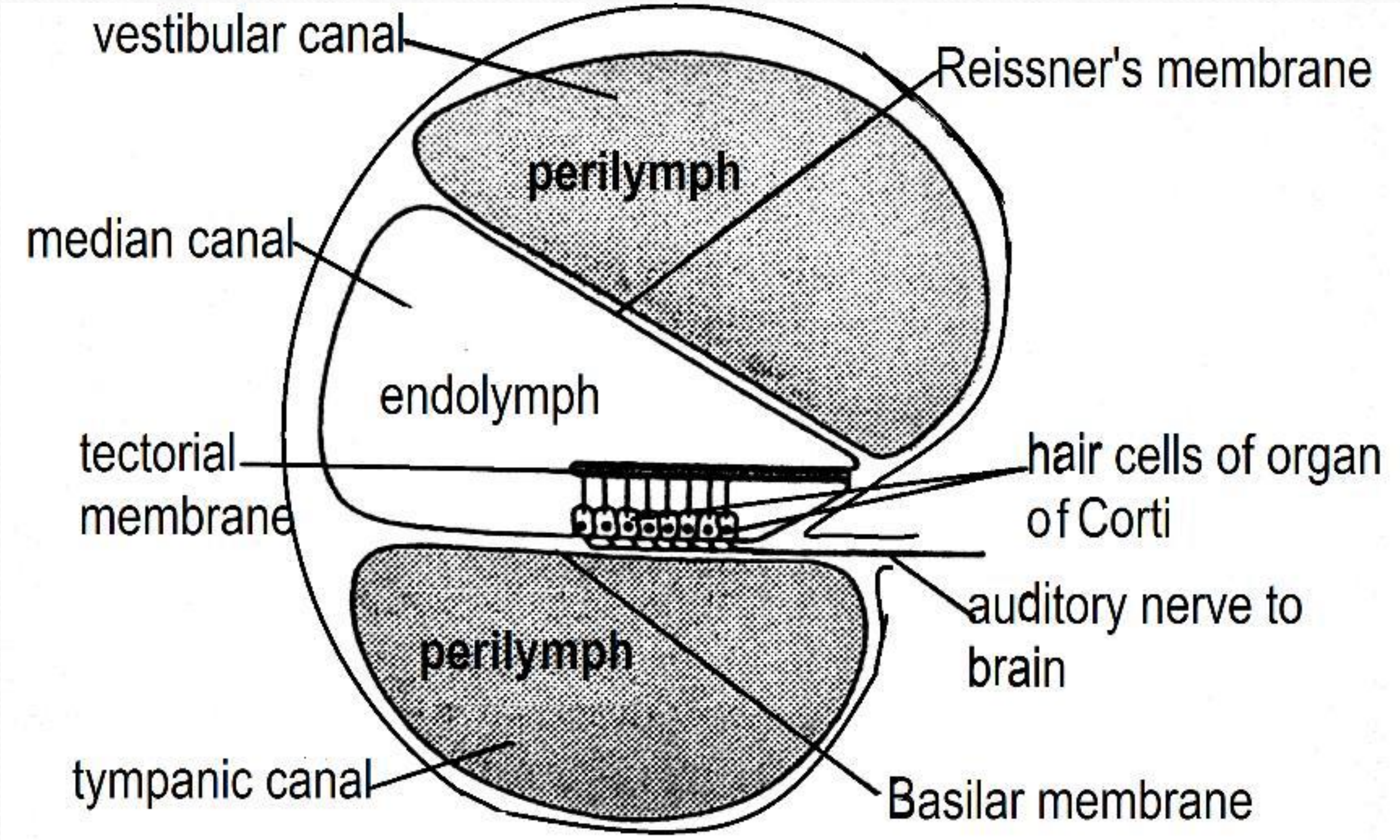


The cochlea has two large canals—an upper vestibular canal and a lower tympanic canal—separated by a smaller cochlear duct. Both canals are filled with fluid.

▲ Bundled hairs projecting from a single mammalian hair cell (SEM). Two shorter rows of hairs lie behind the tall hairs in the foreground.



Transverse section of the cochlea



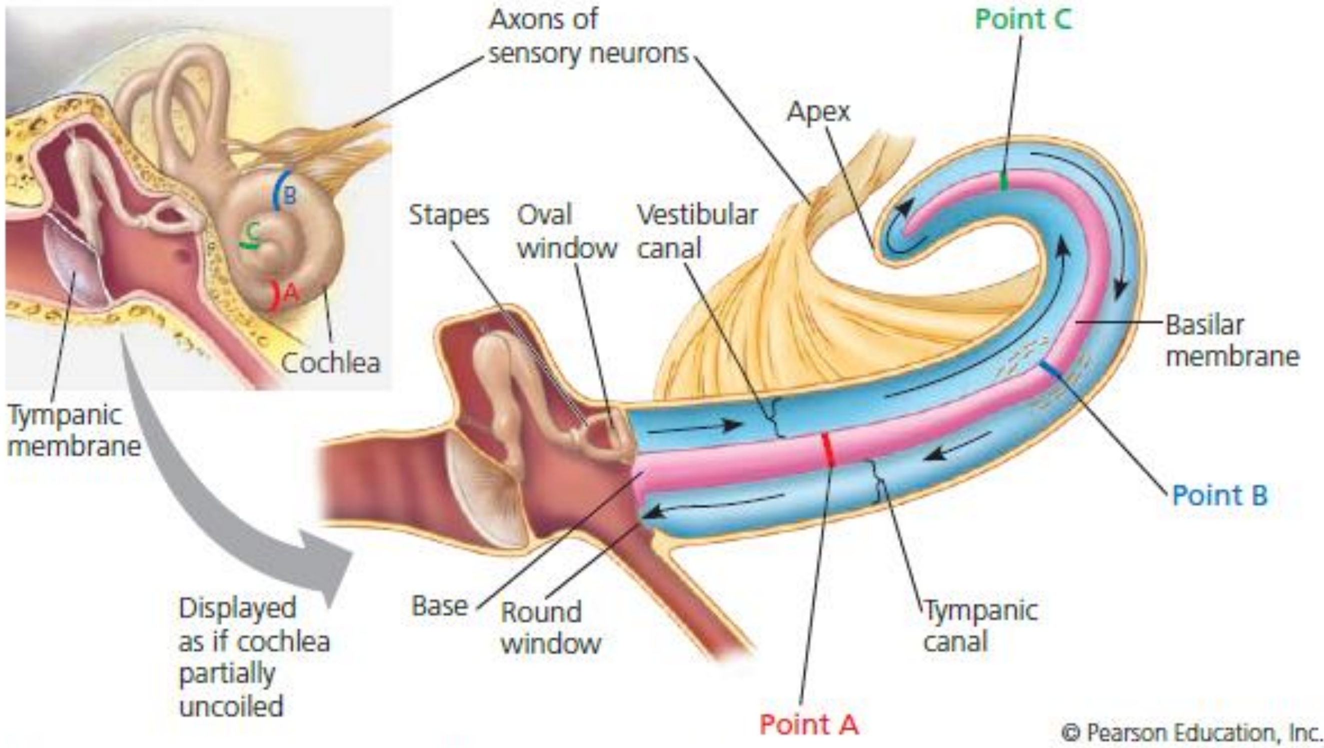
PROCESS OF HEARING

- The pinna receives and concentrates the sound waves.
- They are transmitted to the eardrum, which vibrates.
- The vibrations of the eardrum are transmitted to the ossicles that vibrate and transmit the vibrations to the oval window at the entrance of the **vestibular canal** of the cochlea.
- The **perilymph** (fluid in the vestibular canal) vibrates and causes **Reissner's membrane** to be displaced.

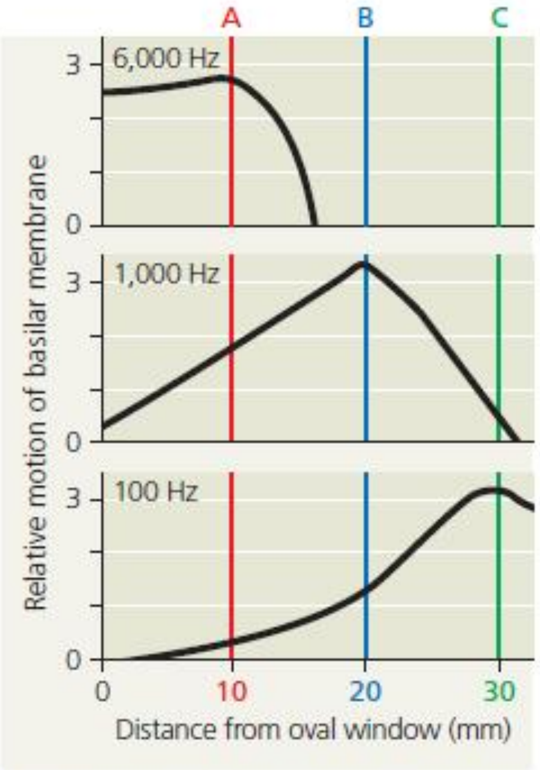
Cont…

- The displacement of Reissner's membrane causes the **endolymph** in the **median canal** to vibrate, which in turn causes the **basilar membrane** to vibrate.
- The vibration of the basilar membrane stimulates sensory cells (in the **organ of Corti**), which generate impulses.
- The impulses are transmitted by the auditory nerve to the brain, which interprets them into sounds.

DISCRIMINATION OF SOUND INTENSITY



© Pearson Education, Inc.



(a) Vibrations of the stapes against the oval window produce pressure waves (black arrows) in the fluid (perilymph; blue) of the cochlea. (For purposes of illustration, the cochlea on the right is drawn partially uncoiled.) The waves travel to the apex via the vestibular canal and back towards the base via the tympanic canal. The energy in the waves causes the basilar membrane (pink) to vibrate, stimulating hair cells (not shown). Because the basilar membrane varies in stiffness along its length, each point along the membrane vibrates maximally in response to waves of a particular frequency.

(b) These graphs show the patterns of vibration along the basilar membrane for three different frequencies, high (top), medium (middle), and low (bottom). The higher the frequency, the closer the vibration to the oval window.

- The human brain is able to discriminate the sound quality in terms of pitch and intensity.
- The pitch of sound (frequency) depends on its wave length.
- High tones are as a result of sound of high frequency (short wave length) while low tones are as a result of sound of low frequency (long wave length).
- The basilar membrane is about 2-5 times wider at the apex than at its base between the oval and round window. Sound of short wave length (high frequency) vibrates relatively a short portion of basilar membrane.
- Only the hair cells nearest the oval window will be stimulated. The impulses fired from these few cells and arriving at the brain are interpreted as a high pitched sound.

- On the other hand, sound of a longer wave length (low frequency) causes a larger portion of the basilar membrane to vibrate, therefore the sensory hair cells that are stimulated further along this membrane are stimulated.
- The impulses fired from these cells when they reach the brain are interpreted as sound of low pitch.
- In this way, the brain is therefore able to determine the pitch of each sound according to the source of impulse from the cochlea.

Deafness

the inability to hear. It may be brought about by a defect in the nerves or the conduction of waves.

Causes of deafness

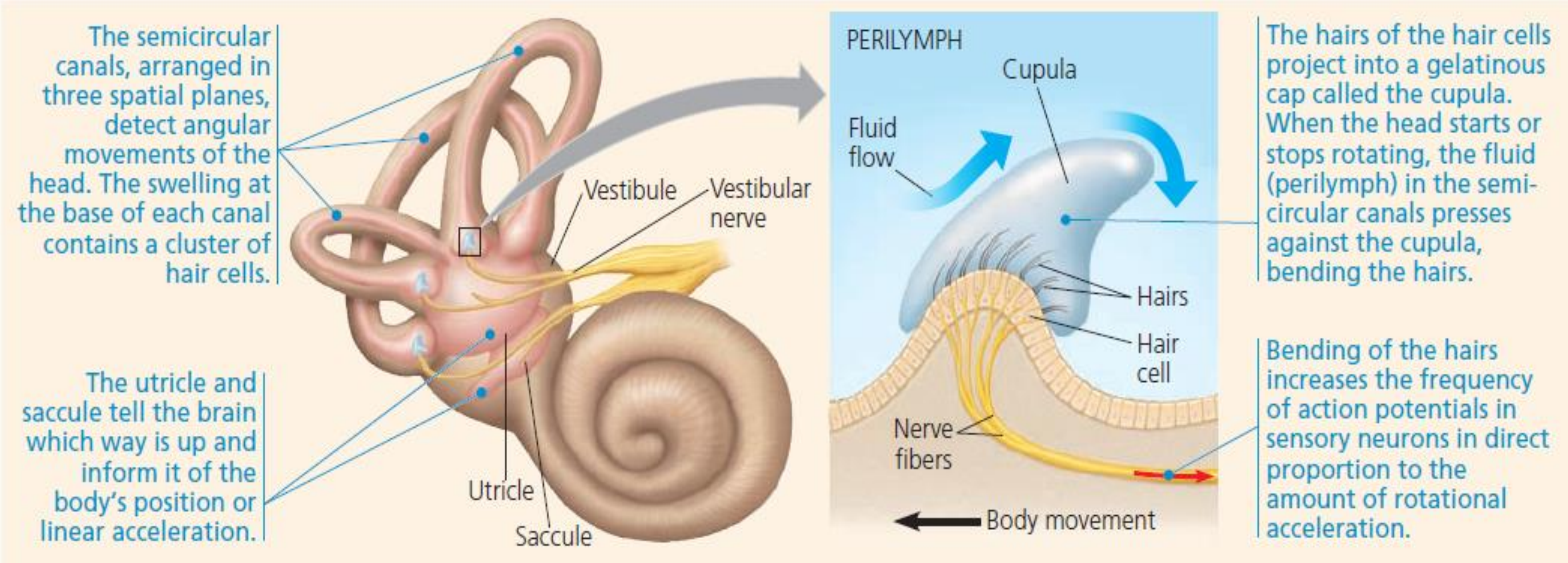
- **Accumulation and hardening of wax in the outer auditory canal** that presses against the eardrum. This can be controlled by use of cotton buds to remove excess wax after the wax has been softened using warm water.
- **Blocking of the Eustachian tube** as a result of accidents and certain infections such as the common cold, etc. This can be treated by use of antibiotics to kill the bacteria that caused the infection.

Cont…

- Some individuals are born with **thick eardrums** that do not easily vibrate. This can be solved by use of hearing aids.
- **Ruptured eardrum** due to accidents and infections. Sometimes the eardrums heal on their own or a hearing aid can also be used.

The Ear as an organ of Balance (Equilibrium)

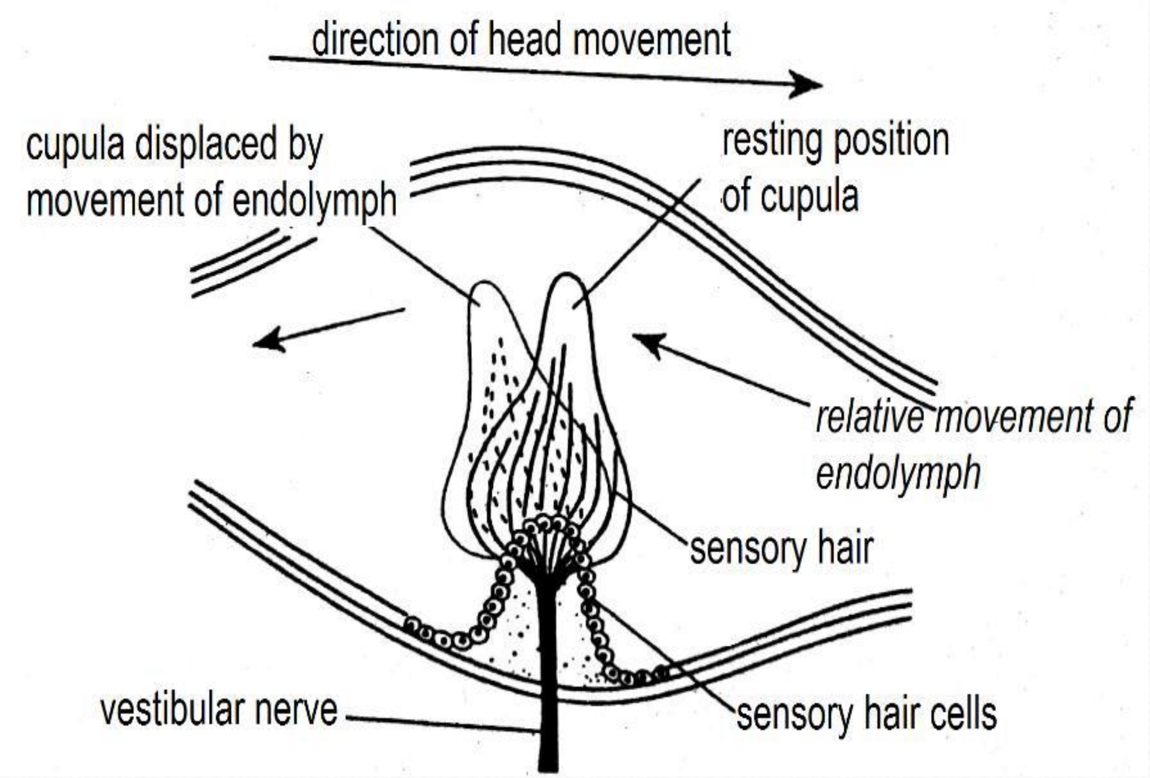
- The structure involved in equilibrium, known as the **vestibular apparatus**, consists of the utricle, saccule and the semicircular canals.
- The **semicircular canals** respond to **rotational movements (angular acceleration) while the utricle and saccule** respond to changes in the **position of the head** with respect to **gravity (linear acceleration) ;**

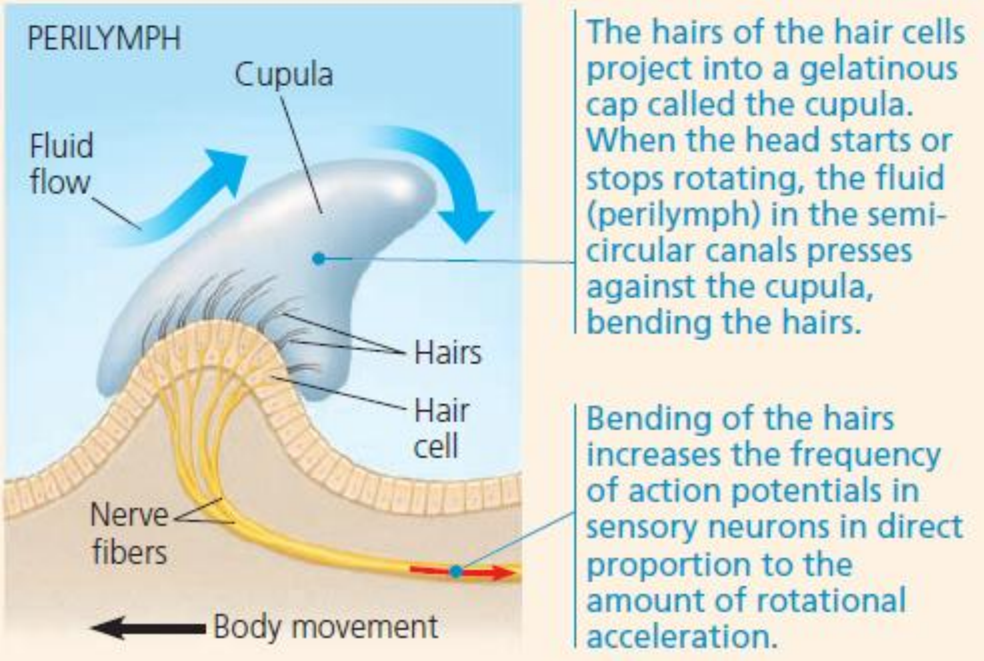

The semicircular canals, arranged in three spatial planes, detect angular movements of the head. The swelling at the base of each canal contains a cluster of hair cells.
The utricle and saccule tell the brain which way is up and inform it of the body's position or linear acceleration.
Vestibule
Vestibular nerve
Utricle
Saccule
PERILYMPH
Cupula
Fluid flow
Hairs
Hair cell
Nerve fibers
Body movement
The hairs of the hair cells project into a gelatinous cap called the cupula. When the head starts or stops rotating, the fluid (perilymph) in the semi-circular canals presses against the cupula, bending the hairs.
Bending of the hairs increases the frequency of action potentials in sensory neurons in direct proportion to the amount of rotational acceleration.

Role of semi-circular canals

The semi-circular canals are important in in dynamic equilibrium.

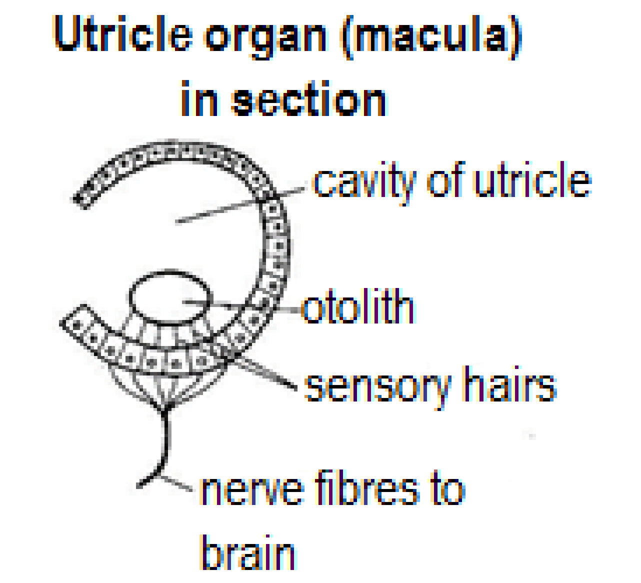
Each semi-circular canal terminates in a swelling known as the **ampulla**, which contains the **cupula** (dome-shaped, gelatinous structure). The cupula is in contact with sensory hairs.





- The canals are filled with fluid and are three in number, arranged in three planes; vertical canals detect movement in upward direction, horizontal canals detect backward and forward motion while lateral canals detect sidewise movements of the head.
- **When the head moves, the endolymph in the ampulla of one of the canals moves in the opposite direction and deflects the cupula**. This stimulates the **cristae** (sensory cells), which generate impulses. The impulses are transmitted by the **vestibular neurones** to the brain.
- The pattern of impulses is interpreted by the brain which detects the direction and speed of movement and sends instructions to relevant organs that maintain dynamic balance.

Utriculus and sacculus



- The utriculus and sacculus contain structures called **maculae** which maintain body posture (static equilibrium). Each macula consists of a patch of sensory cells with the free ends embedded in the **otolith** (gelatinous granule of calcium carbonate). The otolith detects the position of the head with respect to the force of gravity. By varying the position of the head, the pull of gravity over the hairs on the otolith tilts them accordingly.
- The different influences of the pull of gravity result in a pattern of impulses to the brain.
- The impulses are interpreted thus providing information about the position of the head and accordingly sends instructions to relevant muscles to restore balance.
- When the head is upright, the otolith is positioned on top of the sensory cells and no stimulation occurs.

Revision questions

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

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

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

.

(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.