CBCS 3RD SEM (M) PAPER 3026

UNIT :3 NERVOUS SYSTEM

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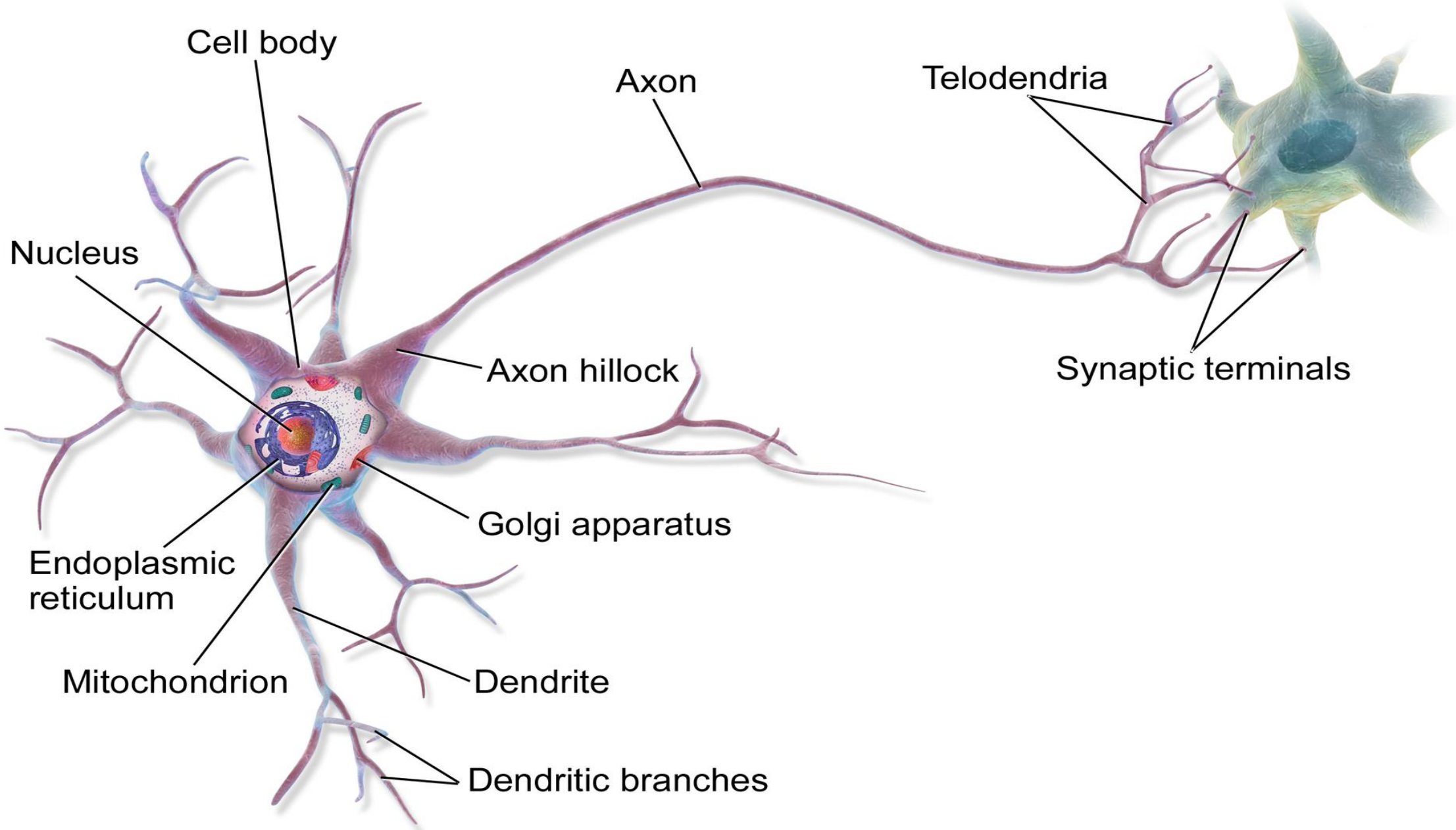
Unit 3: Nervous System

Structure of neuron, resting membrane potential, Origin of action potential and its propagation across the myelinated and unmyelinated nerve fibers; Types of synapse, Synaptic transmission and, Neuromuscular junction; Reflex action and its types - reflex arc; Physiology of hearing and vision.

STRUCTURE OF A NEURON

A neuron or nerve cell is an electrically excitable cell that communicates with other cells via specialized connections called synapses. It is the main component of nervous tissue in all animals except sponges and placozoa. Plants and fungi do not have nerve cells. The spelling neurone has become uncommon.


Cell body
Axon
Telodendria
Nucleus
Axon hillock
Synaptic terminals
Golgi apparatus
Endoplasmic reticulum
Mitochondrion
Dendrite
Dendritic branches

Neurons are typically classified into three types based on their function.

Sensory neurons respond to stimuli such as touch, sound, or light that affect the cells of the sensory organs, and they send signals to the spinal cord or brain.

Motor neurons receive signals from the brain and spinal cord to control everything from muscle contractions to glandular output.

Interneurons connect neurons to other neurons within the same region of the brain or spinal cord.

A group of connected neurons is called a neural circuit.

A typical neuron consists of a cell body (soma), dendrites, and a single axon. The soma is usually compact.

The axon and dendrites are filaments that extrude from it. Dendrites typically branch profusely and extend a few hundred micrometers from the soma.

The axon leaves the soma at a swelling called the axon hillock, and travels for as far as 1 meter in humans or more in other species.

It branches but usually maintains a constant diameter.

At the farthest tip of the axon's branches are axon terminals, where the neuron can transmit a signal across the synapse to another cell. Neurons may lack dendrites or have no axon.

The term neurite is used to describe either a dendrite or an axon, particularly when the cell is undifferentiated.

Most neurons receive signals via the dendrites and soma and send out signals down the axon. At the majority of synapses, signals cross from the axon of one neuron to a dendrite of another. However, synapses can connect an axon to another axon or a dendrite to another dendrite.

The signaling process is partly electrical and partly chemical. Neurons are electrically excitable, due to maintenance of voltage gradients across their membranes.

If the voltage changes by a large enough amount over a short interval, the neuron generates an all-or-nothing electrochemical pulse called an action potential.

This potential travels rapidly along the axon, and activates synaptic connections as it reaches them. Synaptic signals may be excitatory or inhibitory, increasing or reducing the net voltage that reaches the soma.

Anatomy and histology

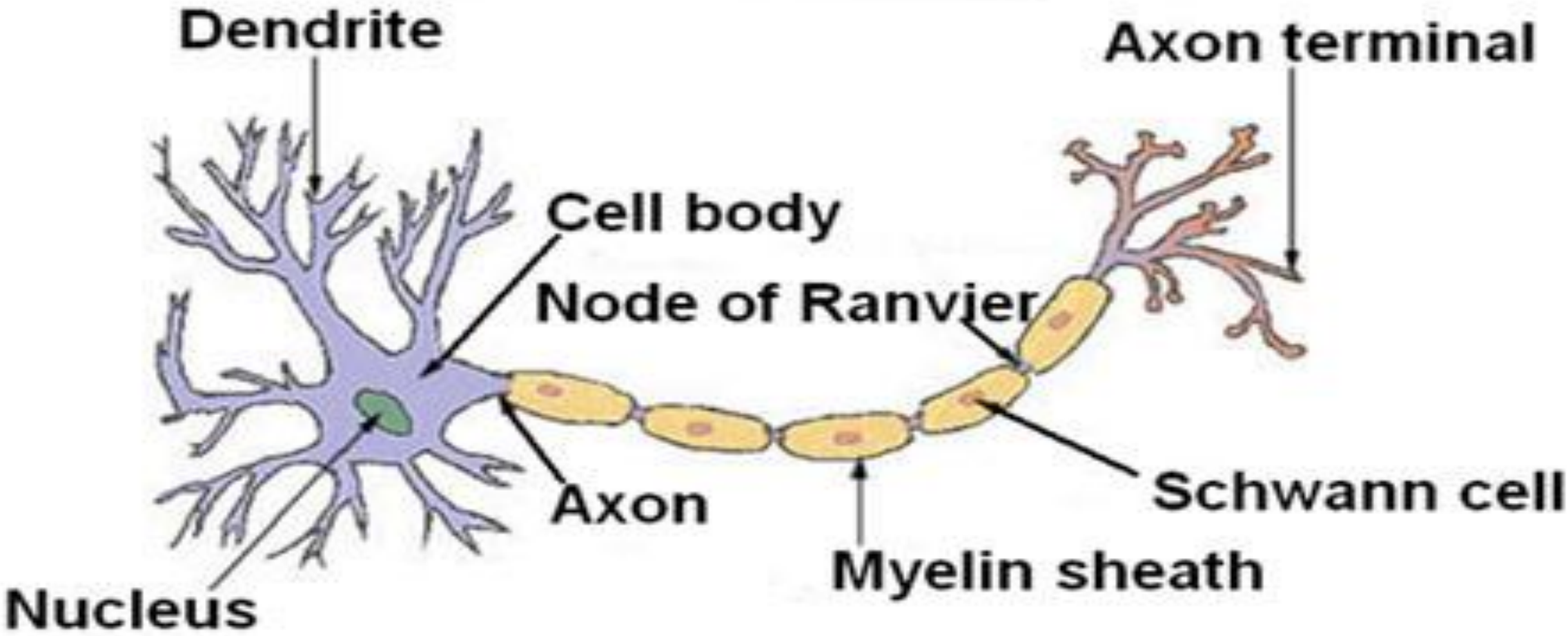
Neurons are highly specialized for the processing and transmission of cellular signals.

Given their diversity of functions performed in different parts of the nervous system, there is a wide variety in their shape, size, and electrochemical properties.

For instance, the soma of a neuron can vary from 4 to 100 micrometers in diameter.

The soma is the body of the neuron. As it contains the nucleus, most protein synthesis occurs here. The nucleus can range from 3 to 18 micrometers in diameter.

Structure of a Typical Neuron



The dendrites of a neuron are cellular extensions with many branches. This overall shape and structure is referred to metaphorically as a dendritic tree.

This is where the majority of input to the neuron occurs via the dendritic spine.

The axon is a finer, cable-like projection that can extend tens, hundreds, or even tens of thousands of times the diameter of the soma in length. The axon primarily carries nerve signals away from the soma, and carries some types of information back to it.

Many neurons have only one axon, but this axon may—and usually will—undergo extensive branching, enabling communication with many target cells.

The part of the axon where it emerges from the soma is called the axon hillock.

Besides being an anatomical structure, the axon hillock also has the greatest density of voltage-dependent sodium channels.

This makes it the most easily excited part of the neuron and the spike initiation zone for the axon. In electrophysiological terms, it has the most negative threshold potential.

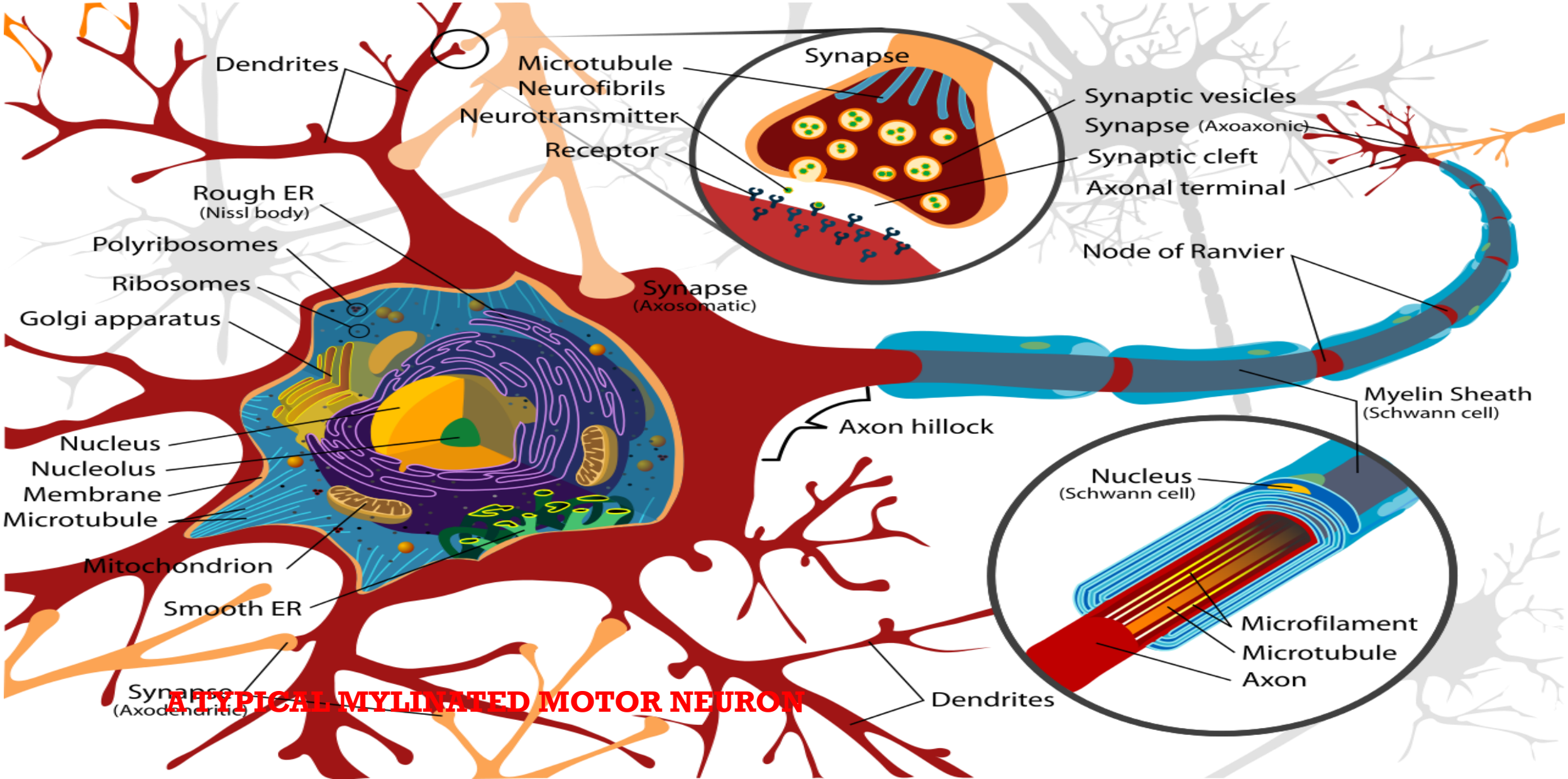
While the axon and axon hillock are generally involved in information outflow, this region can also receive input from other neurons.

The axon terminal is found at the end of the axon farthest from the soma and contains synapses.

Synaptic boutons are specialized structures where neurotransmitter chemicals are released to communicate with target neurons.

In addition to synaptic boutons at the axon terminal, a neuron may have en passant boutons, which are located along the length of the axon.

The accepted view of the neuron attributes dedicated functions to its various anatomical components; however, dendrites and axons often act in ways contrary to their so-called main function



A TYPICAL MYLINATED MOTOR NEURON

Axons and dendrites in the central nervous system are typically only about one micrometer thick, while some in the peripheral nervous system are much thicker.

The soma is usually about 10–25 micrometers in diameter and often is not much larger than the cell nucleus it contains. The longest axon of a human motor neuron can be over a meter long, reaching from the base of the spine to the toes.

Sensory neurons can have axons that run from the toes to the posterior column of the spinal cord, over 1.5 meters in adults. Giraffes have single axons several meters in length running along the entire length of their necks. Much of what is known about axonal function comes from studying the squid giant axon, an ideal experimental preparation because of its relatively immense size (0.5–1 millimeters thick, several centimeters long).

Fully differentiated neurons are permanently postmitotic however, stem cells present in the adult brain may regenerate functional neurons throughout the life of an organism (see neurogenesis).

Astrocytes are star-shaped glial cells. They have been observed to turn into neurons by virtue of their stem cell-like characteristic of pluripotency.

Classification

Neurons vary in shape and size and can be classified by their morphology and function.

The anatomist Camillo Golgi grouped neurons into two types;

type I with long axons used to move signals over long distances and type II with short axons, which can often be confused with dendrites.

Type I cells can be further classified by the location of the soma.

The basic morphology of type I neurons, represented by spinal motor neurons, consists of a cell body called the soma and a long thin axon covered by a myelin sheath.

The dendritic tree wraps around the cell body and receives signals from other neurons. The end of the axon has branching axon terminals that release neurotransmitters into a gap called the synaptic cleft between the terminals and the dendrites of the next neuron.

Structural classification
Polarity
Different kinds of neurons:

1 Unipolar neuron

2 Bipolar neuron

3 Multipolar neuron

4 Pseudounipolar neuron

Most neurons can be anatomically characterized as:

Unipolar: single process

Bipolar: 1 axon and 1 dendrite

Multipolar: 1 axon and 2 or more dendrites

Golgi I: neurons with projecting axonal processes; examples are pyramidal cells, Purkinje cells, and anterior horn cells

Golgi II: neurons whose axonal process projects locally; the best example is the granule cell

Anaxonic: where the axon cannot be distinguished from the dendrite(s)

Pseudounipolar: 1 process which then serves as both an axon and a dendrite

Other

Some unique neuronal types can be identified according to their location in the nervous system and distinct shape. Some examples are:

Basket cells, interneurons that form a dense plexus of terminals around the soma of target cells, found in the cortex and cerebellum

Betz cells, large motor neurons

Lugaro cells, interneurons of the cerebellum

Medium spiny neurons, most neurons in the corpus striatum

Purkinje cells, huge neurons in the cerebellum, a type of Golgi I multipolar neuron

Pyramidal cells, neurons with triangular soma, a type of Golgi I

Renshaw cells, neurons with both ends linked to alpha motor neurons

Unipolar brush cells, interneurons with unique dendrite ending in a brush-like tuft

Granule cells, a type of Golgi II neuron

Anterior horn cells, motoneurons located in the spinal cord

Spindle cells, interneurons that connect widely separated areas of the brain

Functional classification

Direction

Afferent neurons convey information from tissues and organs into the central nervous system and are also called sensory neurons.

Efferent neurons (motor neurons) transmit signals from the central nervous system to the effector cells.

Interneurons connect neurons within specific regions of the central nervous system.

Afferent and efferent also refer generally to neurons that, respectively, bring information to or send information from the brain.

Action on other neurons

A neuron affects other neurons by releasing a neurotransmitter that binds to chemical receptors. The effect upon the postsynaptic neuron is determined by the type of receptor that is activated, not by the presynaptic neuron or by the neurotransmitter.

A neurotransmitter can be thought of as a key, and a receptor as a lock: the same neurotransmitter can activate multiple types of receptors.

Receptors can be classified broadly as excitatory (causing an increase in firing rate), inhibitory (causing a decrease in firing rate), or modulatory (causing long-lasting effects not directly related to firing rate).

Discharge patterns

Neurons have intrinsic electroresponsive properties like intrinsic transmembrane voltage oscillatory patterns. So neurons can be classified according to their electrophysiological characteristics:

Tonic or regular spiking. Some neurons are typically constantly (tonically) active, typically firing at a constant frequency. Example: interneurons in neurostriatum.

Phasic or bursting. Neurons that fire in bursts are called phasic.
Fast spiking. Some neurons are notable for their high firing rates, for example some types of cortical inhibitory interneurons, cells in globus pallidus, retinal ganglion cells

Neurotransmitter

Cholinergic neurons—acetylcholine.

Acetylcholine is released from presynaptic neurons into the synaptic cleft. It acts as a ligand for both ligand-gated ion channels and metabotropic (GPCRs) muscarinic receptors.

Nicotinic receptors are pentameric ligand-gated ion channels composed of alpha and beta subunits that bind nicotine.

Ligand binding opens the channel causing influx of Na+ depolarization and increases the probability of presynaptic neurotransmitter release. Acetylcholine is synthesized from choline and acetyl coenzyme A

GABAergic neurons—gamma aminobutyric acid. GABA is one of two neuroinhibitors in the central nervous system (CNS), along with glycine.
GABA has a homologous function to ACh, gating anion channels that allow Cl^- ions to enter the post synaptic neuron. Cl^- causes hyperpolarization within the neuron, decreasing the probability of an action potential firing as the voltage becomes more negative (for an action potential to fire, a positive voltage threshold must be reached).

GABA is synthesized from glutamate neurotransmitters by the enzyme glutamate decarboxylase.

Glutamatergic neurons—glutamate. Glutamate is one of two primary excitatory amino acid neurotransmitters, along with aspartate.

Glutamate receptors are one of four categories, three of which are ligand-gated ion channels and one of which is a G-protein coupled receptor (often referred to as GPCR).

AMPA and Kainate receptors function as cation channels permeable to Na+ cation channels mediating fast excitatory synaptic transmission. NMDA receptors are another cation channel that is more permeable to Ca2+.

The function of NMDA receptors depend on glycine receptor binding as a co-agonist within the channel pore. NMDA receptors do not function without both ligands present.

Metabotropic receptors, GPCRs modulate synaptic transmission and postsynaptic excitability.
Glutamate can cause excitotoxicity when blood flow to the brain is interrupted, resulting in brain damage.

When blood flow is suppressed, glutamate is released from presynaptic neurons, causing greater NMDA and AMPA receptor activation than normal outside of stress conditions, leading to elevated Ca2+ and Na+ entering the post synaptic neuron and cell damage.

Glutamate is synthesized from the amino acid glutamine by the enzyme glutamate synthase.

Dopaminergic neurons—dopamine. Dopamine is a neurotransmitter that acts on D1 type (D1 and D5) Gs-coupled receptors, which increase cAMP and PKA, and D2 type (D2, D3, and D4) receptors, which activate Gi-coupled receptors that decrease cAMP and PKA.

Dopamine is connected to mood and behavior and modulates both pre- and post-synaptic neurotransmission.

Loss of dopamine neurons in the substantia nigra has been linked to Parkinson's disease.

Dopamine is synthesized from the amino acid tyrosine. Tyrosine is catalyzed into levadopa (or L-DOPA) by tyrosine hydroxlase, and levadopa is then converted into dopamine by the aromatic amino acid decarboxylase.

Serotonergic neurons—serotonin. Serotonin (5-Hydroxytryptamine, 5-HT) can act as excitatory or inhibitory. Of its four 5-HT receptor classes, 3 are GPCR and 1 is a ligand-gated cation channel.

Serotonin is synthesized from tryptophan by tryptophan hydroxylase, and then further by decarboxylase.

A lack of 5-HT at postsynaptic neurons has been linked to depression. Drugs that block the presynaptic serotonin transporter are used for treatment, such as Prozac and Zoloft

Histaminergic neurons—histamine. Histamine is a monoamine neurotransmitter and neuromodulator. Histamine-producing neurons are found in the tuberomammillary nucleus of hypothalamus. Histamine is involved in arousal and regulating sleep/wake behaviors.

RESTING MEMBRANE POTENTIAL

The human organism is composed of multiple cells, all of them with different components and therefore with differents resting membrane potentials.

Some of these cells are excitable (e. g.: cells; neurons; muscle fibers), generating an action potential when subjected to an external stimulus, causing its membrane depolarization.

The resting membrane potential (RMP) is due to changes in membrane permeability for potassium, sodium, calcium, and chloride, which results from the movement of these ions across it.

Once the membrane is polarized, it acquires a voltage, which is the difference of potentials between intra and extracellular spaces.

Contents

Resting membrane potential is:

the unequal distribution of ions on the both sides of the cell membrane;
the voltage difference of quiescent cells;

the membrane potential that would be maintained if there weren't any stimuli or conducting impulses across it;
determined by the concentrations of ions on both sides of the membrane;

a negative value, which means that there is an excess of negative charge inside of the cell, compared to the outside.
much depended on intracellular potassium level as the membrane permeability to potassium is about 100 times higher than that to sodium.

Producing and maintaining RMP

RMP is produced and maintained by:

Donnan effect

described as large impermeable negatively charged intracellular molecules attracting positively charged ions (e. g.: Na+ and K+) and repelling negative ones (e. g.: Cl–)

Membrane selectivity

is the difference of permeabilites between different ions

Active transport (Na+/K+ ATPase pump)

is the mediated process of moving particles across a biological membrane, against the concentration gradient.

Primary active transport – if it spends energy. This is how the Na+/K+ ATPase pump functions.

Secondary active transport – if it involves an electrochemical gradient. This is not involved in maintaining RMP.

Ion affection of resting membrane potential

RMP is created by the distribution of ions and its diffusion across the membrane.

Potassium ions are important for RMP because of its active transport, which increase more its concentration inside the cell.

However, the potassium-selective ion channels are always open, producing an accumulation of negative charge inside the cell.

Its outward movement is due to random molecular motion and continues until enough excess negative charge accumulates inside the cell to form a membrane potential.

Na+/K+ ATPase pump affection of the RMP

The Na+/K+ ATPase pump creates a concentration gradient by moving 3Na+ out of the cell and 2K+ into the cell. Na+ is being pumped out and K+ pumped in against their concentration gradients. Because this pump is moving ions against their concentration gradients, it requires energy.

Ion channels affection of resting membrane potential

The cell membrane contains protein channels that allow ions to diffuse passively without direct expenditure of metabolic energy. These channels allow Na + and K+ to move across the cell membrane from a higher concentration toward a lower. As these channels have selectivity for certain ions, there are potassium- and sodium- selective ion channels. All cell membranes are more permeable to K+ than to Na+ because they have more K+ channels than Na+.

The Nernst Equation

Ihhs a mathematical equation applied in physiology, to calculate equilibrium potentials for certain ions.

$$Ei=(R\cdot TF\cdot z)\cdot \ln[X]1[X]2$$

R = Gas Constant
T = Absolute temperature (K)
E = The potential difference across the membrane
F = Faradays Constant (96,500 coulombs/mole)
z = Valency of ion

The Goldman-Hodgkin-Katz Equation

Is a mathematical equation applied in Physiology, to determine the potential across a cell's membrane, taking in account all the ions that are permeable through it.

$$Em=58\log(PNa\cdot[Na]out+PK\cdot[K]outPNa\cdot[Na]in+PK\cdot[K]in)$$

E = The potential difference across the membrane

P = Permeability of the membrane to sodium or potassium

[ ] = Concentration of sodium or potassium inside or outside

Measuring resting potentials

In some cells, the RPM is always changing. For such, there is never any resting potential, which is only a theoretical concept. Other cells with membrane transport functions that change potential with time, have a resting potential.

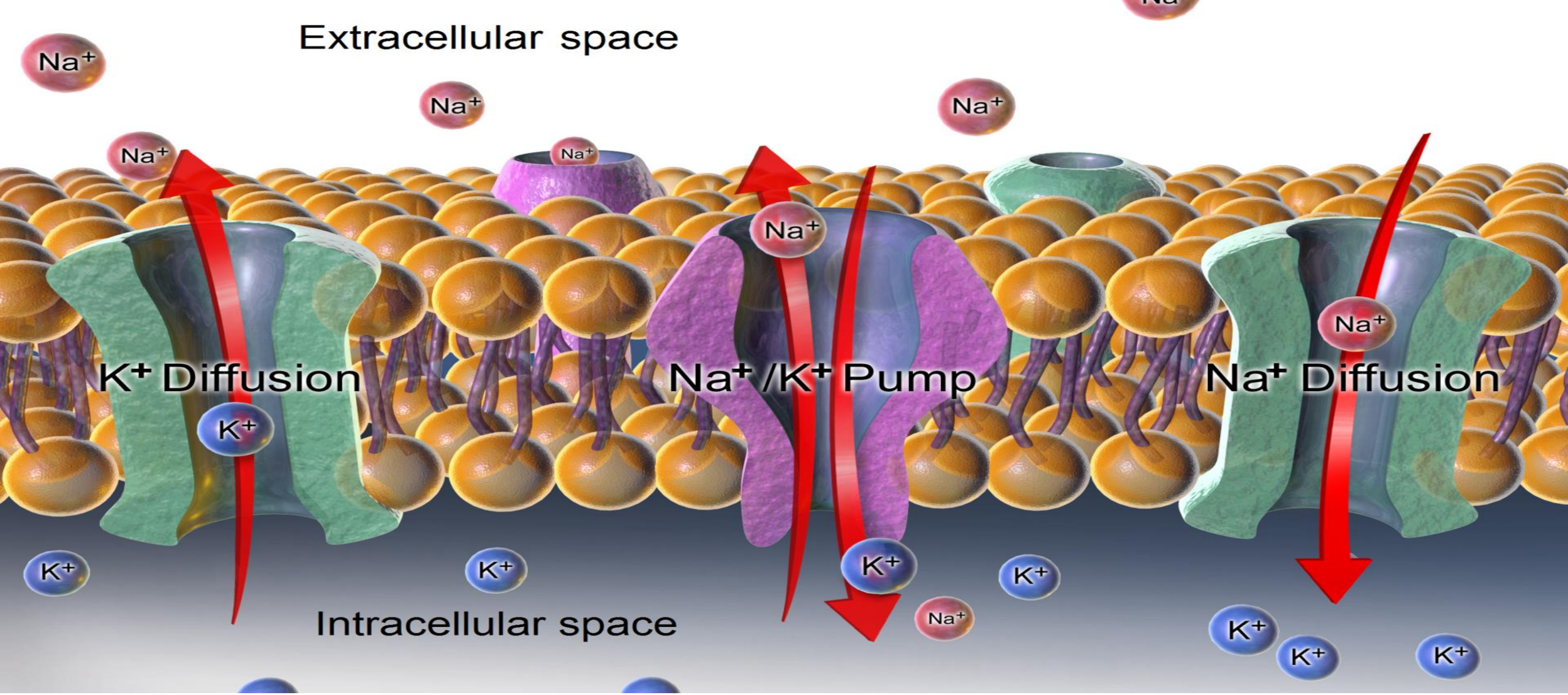
This can be measured by inserting an electrode into the cell. Transmembrane potentials can also be measured optically with dyes that change their optical properties according to the membrane potential.

Resting membrane potential varies according to types of cells
For example:
Skeletal muscle cells: −95 mV
Smooth muscle cells: −50 mV
Astrocytes: −80/−90 mV
Neurons: −70 mV
Erythrocytes: −12 mV

Resting Membrane Potential (RMP) is the voltage (charge) difference across the cell membrane when the cell is at rest. RMP is a product of the distribution of charged particles (ions).

The relatively static membrane potential of quiescent(HIDE) cells is called the resting membrane potential (or resting voltage).

as opposed to the specific dynamic electrochemical phenomena called action potential and graded membrane potential.



The Na+/K+-ATPase, as well as effects of diffusion of the involved ions, are major mechanisms to maintain the resting potential across the membranes of animal cell

Apart from the latter two, which occur in excitable cells (neurons, muscles, and some secretory cells in glands), membrane voltage in the majority of non-excitable cells can also undergo changes in response to environmental or intracellular stimuli.

The resting potential exists due to the differences in membrane permeabilities for potassium, sodium, calcium, and chloride ions, which in turn result from functional activity of various ion channels, ion transporters, and exchangers.

Conventionally, resting membrane potential can be defined as a relatively stable, ground value of transmembrane voltage in animal and plant cells.

The typical resting membrane potential of a cell arises from the separation of potassium ions from intracellular, relatively immobile anions across the membrane of the cell.

Because the membrane permeability for potassium is much higher than that for other ions, and because of the strong chemical gradient for potassium, potassium ions flow from the cytosol into the extracellular space carrying out positive charge, until their movement is balanced by build-up of negative charge on the inner surface of the membrane.

Again, because of the high relative permeability for potassium, the resulting membrane potential is almost always close to the potassium reversal potential. But in order for this process to occur, a concentration gradient of potassium ions must first be set up. This work is done by the ion pumps/transporters and/or exchangers and generally is powered by ATP.

In the case of the resting membrane potential across an animal cell's plasma membrane, potassium (and sodium) gradients are established by the Na+/K+-ATPase (sodium-potassium pump) which transports 2 potassium ions inside and 3 sodium ions outside at the cost of 1 ATP molecule.

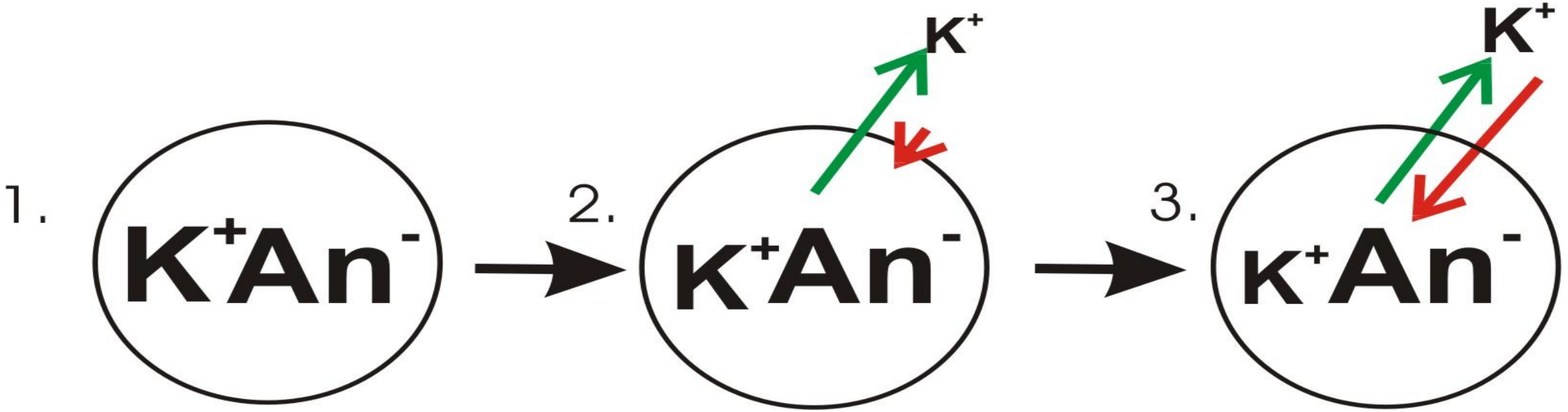
In other cases, for example, a membrane potential may be established by acidification of the inside of a membranous compartment (such as the proton pump that generates membrane potential across synaptic vesicle membranes).

Generation of the resting potential

Cell membranes are typically permeable to only a subset of ions. These usually include potassium ions, chloride ions, bicarbonate ions, and others.

To simplify the description of the ionic basis of the resting membrane potential, it is most useful to consider only one ionic species at first, and consider the others later.

Since trans-plasma-membrane potentials are almost always determined primarily by potassium permeability, that is where to start.



A diagram showing the progression in the development of a membrane potential from a concentration gradient (for potassium). Green arrows indicate net movement of K+ down a concentration gradient. Red arrows indicate net movement of K+ due to the membrane potential.

The diagram is misleading in that while the concentration of potassium ions outside of the cell increases, only a small amount of K+ needs to cross the membrane in order to produce a membrane potential with a magnitude large enough to counter the tendency of the potassium ions to move down the concentration gradient.

Panel 1 of the diagram shows a diagrammatic representation of a simple cell where a concentration gradient has already been established.

This panel is drawn as if the membrane has no permeability to any ion. There is no membrane potential because despite there being a concentration gradient for potassium, there is no net charge imbalance across the membrane.

If the membrane were to become permeable to a type of ion that is more concentrated on one side of the membrane, then that ion would contribute to membrane voltage because the permeant ions would move across the membrane with net movement of that ion type down the concentration gradient

.There would be net movement from the side of the membrane with a higher concentration of the ion to the side with lower concentration.

Such a movement of one ion across the membrane would result in a net imbalance of charge across the membrane and a membrane potential.

This is a common mechanism by which many cells establish a membrane potential

In panel 2 of the diagram, the cell membrane has been made permeable to potassium ions, but not the anions (An^-) inside the cell. These anions are mostly contributed by protein.

There is energy stored in the potassium ion concentration gradient that can be converted into an electrical gradient when potassium (K^+) ions move out of the cell. Note that potassium ions can move across the membrane in both directions but by the purely statistical process that arises from the higher concentration of potassium ions inside the cell, there will be more potassium ions moving out of the cell.

Because there is a higher concentration of potassium ions inside the cells, their random molecular motion is more likely to encounter the permeability pore (ion channel) that is the case for the potassium ions that are outside and at a lower concentration.

An internal K+ is simply "more likely" to leave the cell than an extracellular K+ is to enter it. It is a matter of diffusion doing work by dissipating the concentration gradient.

As potassium leaves the cell, it is leaving behind the anions. Therefore, a charge separation is developing as K+ leaves the cell.

This charge separation creates a transmembrane voltage. This transmembrane voltage is the membrane potential

.As potassium continues to leave the cell, separating more charges, the membrane potential will continue to grow. The length of the arrows (green indicating concentration gradient, red indicating voltage), represents the magnitude of potassium ion movement due to each form of energy.

The direction of the arrow indicates the direction in which that particular force is applied. Thus, the building membrane voltage is an increasing force that acts counter to the tendency for net movement of potassium ions down the potassium concentration gradient.

In Panel 3, the membrane voltage has grown to the extent that its "strength" now matches the concentration gradients. Since these forces (which are applied to K+) are now the same strength and oriented in opposite directions, the system is now in equilibrium.

Put another way, the tendency of potassium to leave the cell by running down its concentration gradient is now matched by the tendency of the membrane voltage to pull potassium ions back into the cell.

K+ continues to move across the membrane, but the rate at which it enters and leaves the cell are the same, thus, there is no net potassium current. Because the K+ is at equilibrium, membrane potential is stable, or "resting" (EK).

The resting voltage is the result of several ion-translocating enzymes (uniporters, cotransporters, and pumps) in the plasma membrane, steadily operating in parallel, whereby each ion-translocator has its characteristic electromotive force (= reversal potential = 'equilibrium voltage'), depending on the particular substrate concentrations inside and outside (internal ATP included in case of some pumps).

H+ exporting ATPase render the membrane voltage in plants and fungi much more negative than in the more extensively investigated animal cells, where the resting voltage is mainly determined by selective ion channels.

Resting potential

- The electrical pot. of the i.c space is always negative compared to the e.c space because there is an excess of negative charge inside of the cell.

- Equilibrium potential → the net transmembrane flux of an ion (k^+) is zero.
  - Nernst eq:

$$E_{eq,K^+} = \frac{RT}{zF} \ln \frac{[K^+]_o}{[K^+]_i},$$

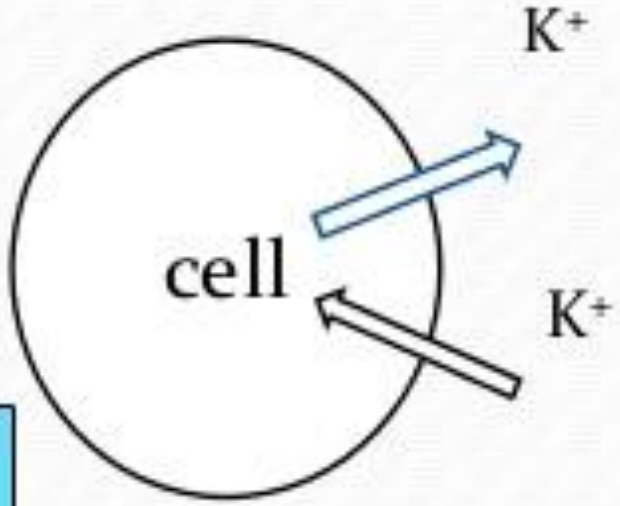
  - Eq. potential for k^+ is around -89mV. Na^+ is around +60mV

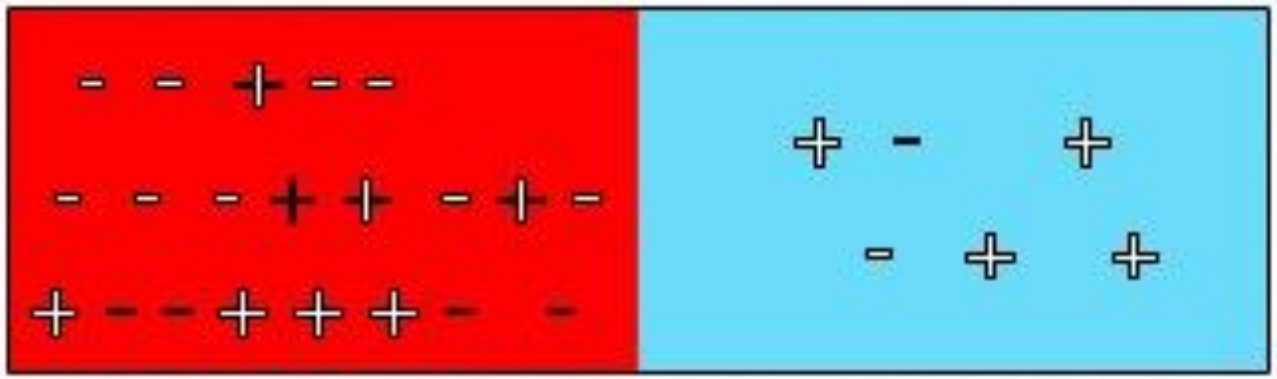
- Thermodynamic equilibrium (K^+)

  One k+ comes into the cell, at the same time one k+ goes out of the cell. Thus no net flux of K^+ and the MP does not change.

  - Energy is not expended

- Electrochemical equilibrium
  - No net transport of charge and no net flux of chemical gradient.





Factors determining the resting potential

- **Goldman-Hodgkin-Katz voltage equation/diffusion potential, GHK equation:**
  - Represents all ion species, most significant contribution.
  - concentrations of ions, permeability, conductance of each ion species.
  - Not a thermodynamic equilibrium.
  - When the permeability of a given ion increases dramatically, the RMP gets closer to the Eq. pot. of the given ion.

$$E_m = \frac{RT}{F} \ln \left(\frac{P_{Na+}[Na^+]_o + P_{K+}[K^+]_o + P_{Cl-}[Cl^-]_i}{P_{Na+}[Na^+]_i + P_{K+}[K^+]_i + P_{Cl-}[Cl^-]_o} \right)$$

Factors determining the resting potential

- **Pump Potential**
  - $3Na^+$ are being pumped out and $2K^+$ pumped in against their concentration gradients.
  - Requires energy.

- **Donnan Potential**
  - large impermeable negatively charged intracellular molecules (proteins) attracting positively charged ions (e. g.: Na^+ and K^+) and repelling negative ones (e. g.: Cl^-)

ORIGIN OF ACTION POTENTIAL AND ITS PROPAGATION ACROSS THE MYLINATED AND NON MYLINATED NERVE FIBERS

In physiology, an action potential (AP) occurs when the membrane potential of a specific cell location rapidly rises and falls: this depolarization then causes adjacent locations to similarly depolarize.

Action potentials occur in several types of animal cells, called excitable cells, which include neurons, muscle cells, endocrine cells, glomus cells, and in some plant cells.

In neurons, action potentials play a central role in cell-to-cell communication by providing for—or with regard to saltatory conduction, assisting—the propagation of signals along the neuron's axon toward synaptic boutons situated at the ends of an axon; these signals can then connect with other neurons at synapses, or to motor cells or glands. In other types of cells, their main function is to activate intracellular processes.

In muscle cells, for example, an action potential is the first step in the chain of events leading to contraction. In beta cells of the pancreas, they provoke release of insulin.

Action potentials in neurons are also known as "nerve impulses" or "spikes", and the temporal sequence of action potentials generated by a neuron is called its "spike train". A neuron that emits an action potential, or nerve impulse, is often said to "fire".

Origin of action potential and its propagation in myelinated and unmyelinated nerve fiber

- The human central nervous system (CNS) contains about 100 billion neurons.
- 40% of the human genes participate, at least to a degree, in its formation.

The Action Potential

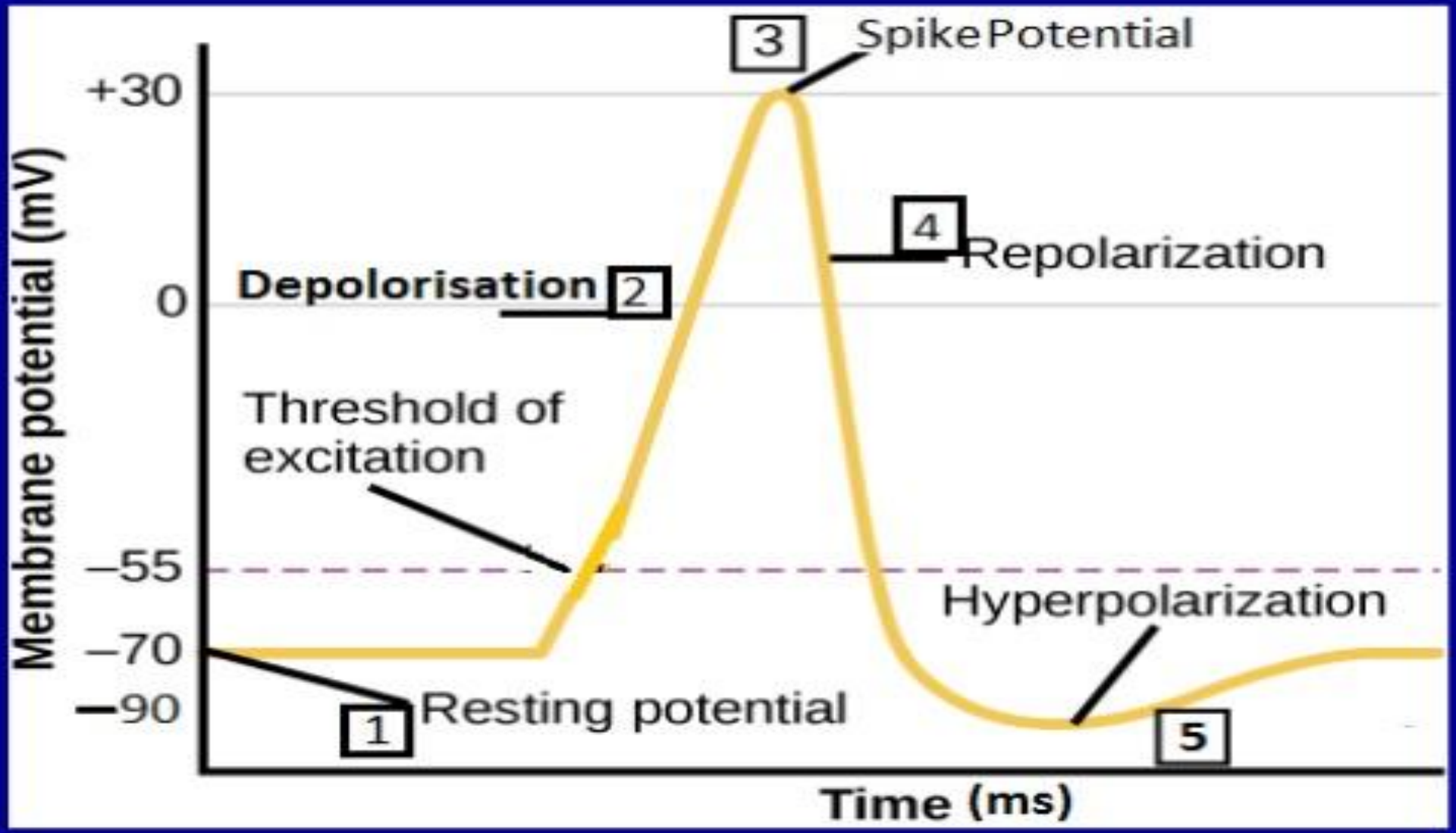
- Neurons communicate over long distances by generating and sending an electrical signal called a nerve impulse, or action potential.
- Action Potentials are required for the senses - Sight, hearing, and touch are all dependent on action potentials for transmission of information to the brain.
- The action potential is a large change in neuronal membrane potential from a resting value of about -70 mill volts to a peak of about +40 mill volts , and back to -70 mill volts again.

Action Potential Generation

Biophysical Basis:

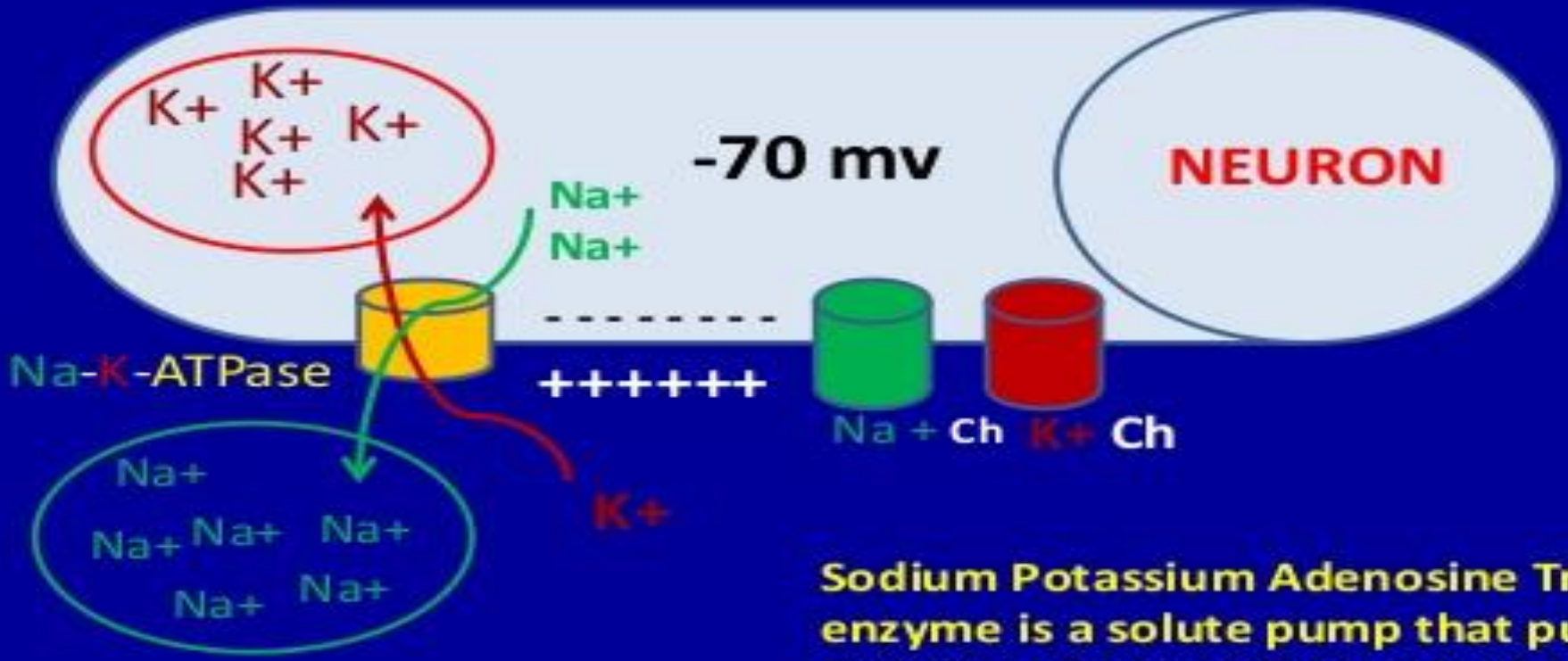
The action potential results from a rapid change in the permeability of the neuronal membrane to sodium - Na^+ and potassium - K^+. The permeability changes as voltage-gated ion channels open and close.

Stages of Generating Action Potential



1-Stage : Resting Membrane Potential

Voltage-gated sodium and potassium channels are closed & the neuron is at rest with – 70 mv membrane potential.



Sodium Potassium Adenosine Triphosphatase enzyme is a solute pump that pump Na+ out & K+ into the membrane , both against their concentration gradient.

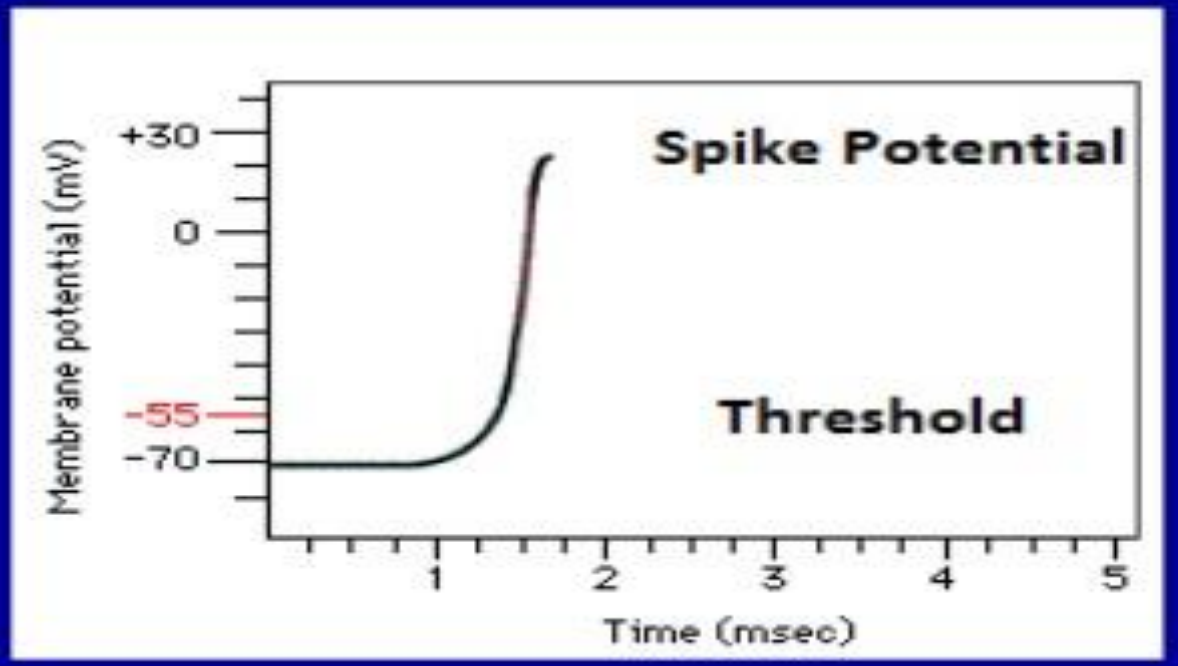
2-Stage : Depolarization

Voltage-gated sodium channels open rapidly, resulting in movement of sodium into the membrane & membrane potential start increasing .

Within 1 ms membrane potential becomes -55 mv ,this stage known as Threshold , a special membrane potential where the process of depolarization becomes regenerative.

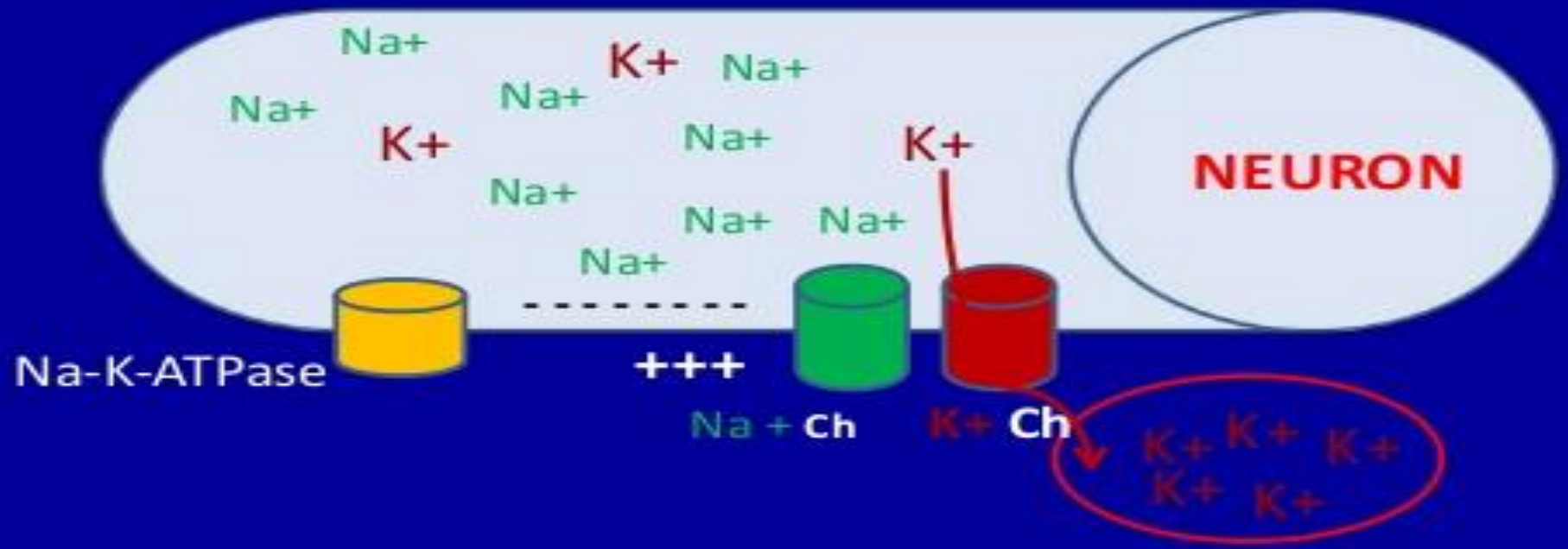
3-Stage : Spike Potential

The membrane potential rapidly rises to a peak potential of +40 mV within 2 ms of Resting Potential , this potential is known as **Spike Potential or Action Potential**, just after this the sodium channel start closing.



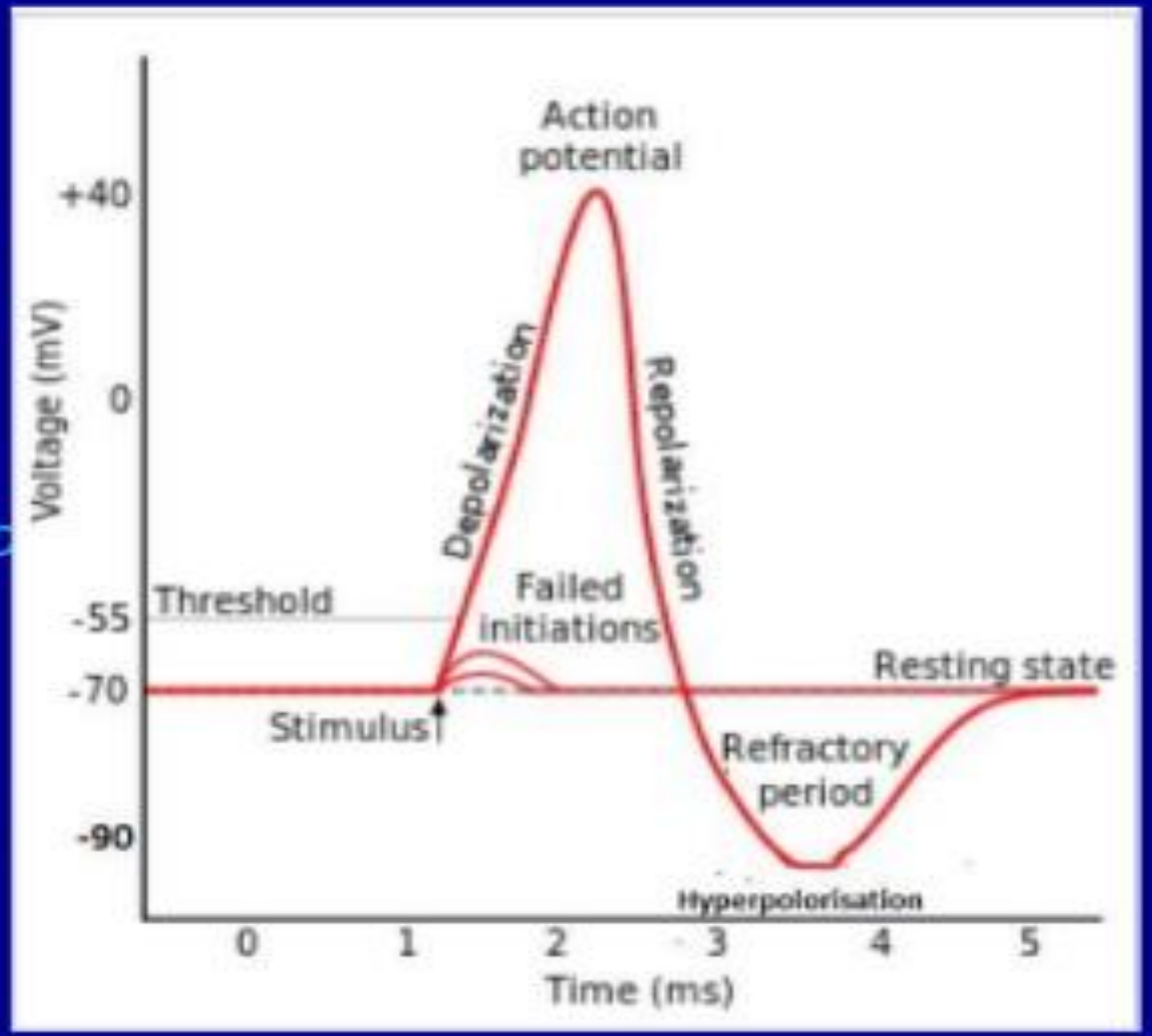
4-Stage : Repolarization

At this stage potassium leaving the membrane as voltage-gated potassium channels opened. With less sodium moving into the cell and more potassium moving out, the membrane potential becomes more negative, moving toward its resting value.



5-Stage : Hyper polarization

In many neurons, the slow voltage-gated potassium channels remain open after the membrane has repolarized. Potassium continues to move out of the cell, *causing the membrane potential to become more negative (-90 mv) than the resting membrane potential.* This process is called **hyperpolarization ,** by the end of the hyperpolarization, all the potassium channels are closed.

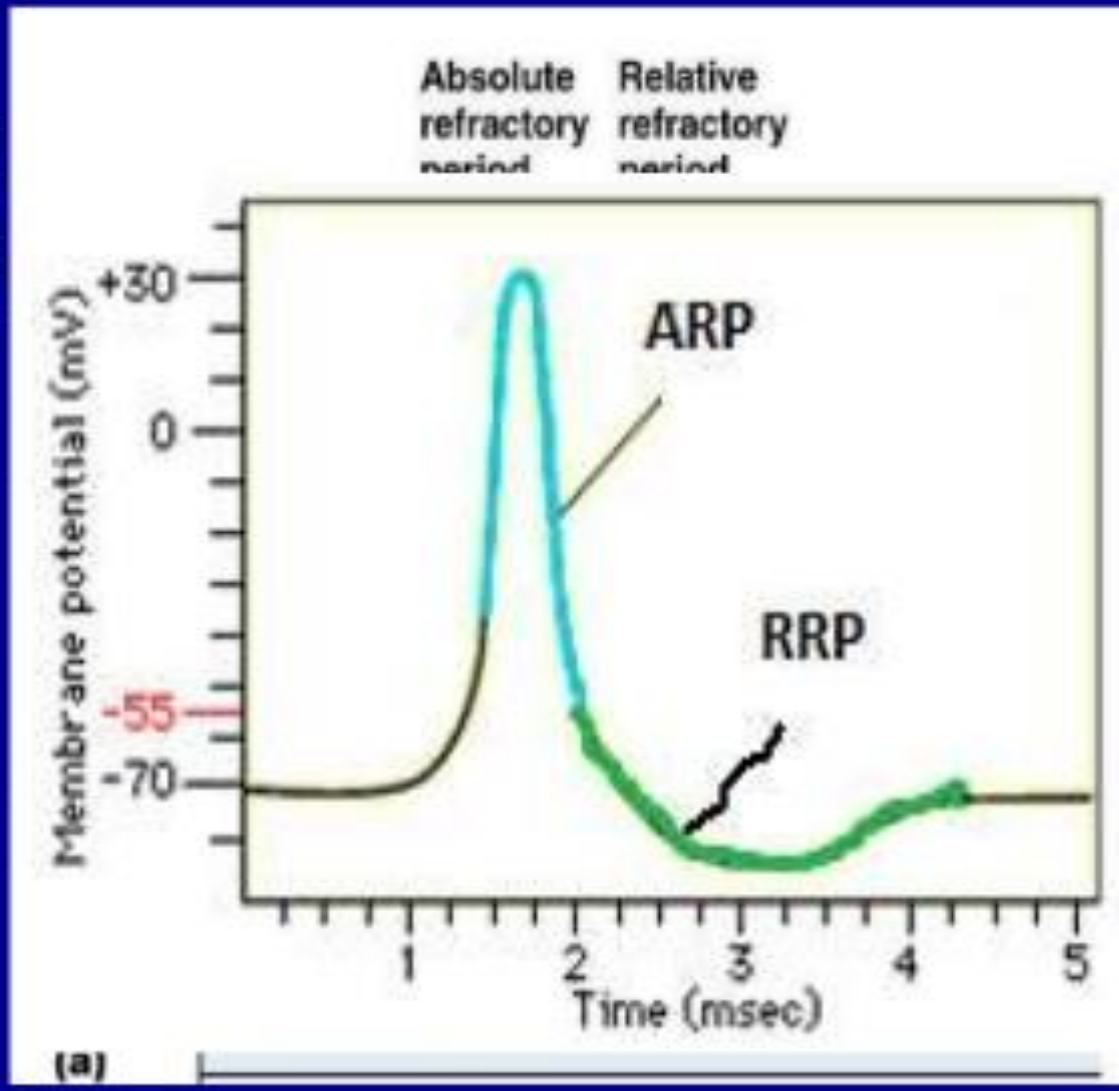


Absolute Refractory Period

From the time the threshold potential is reached until repolarization is about one-third complete.

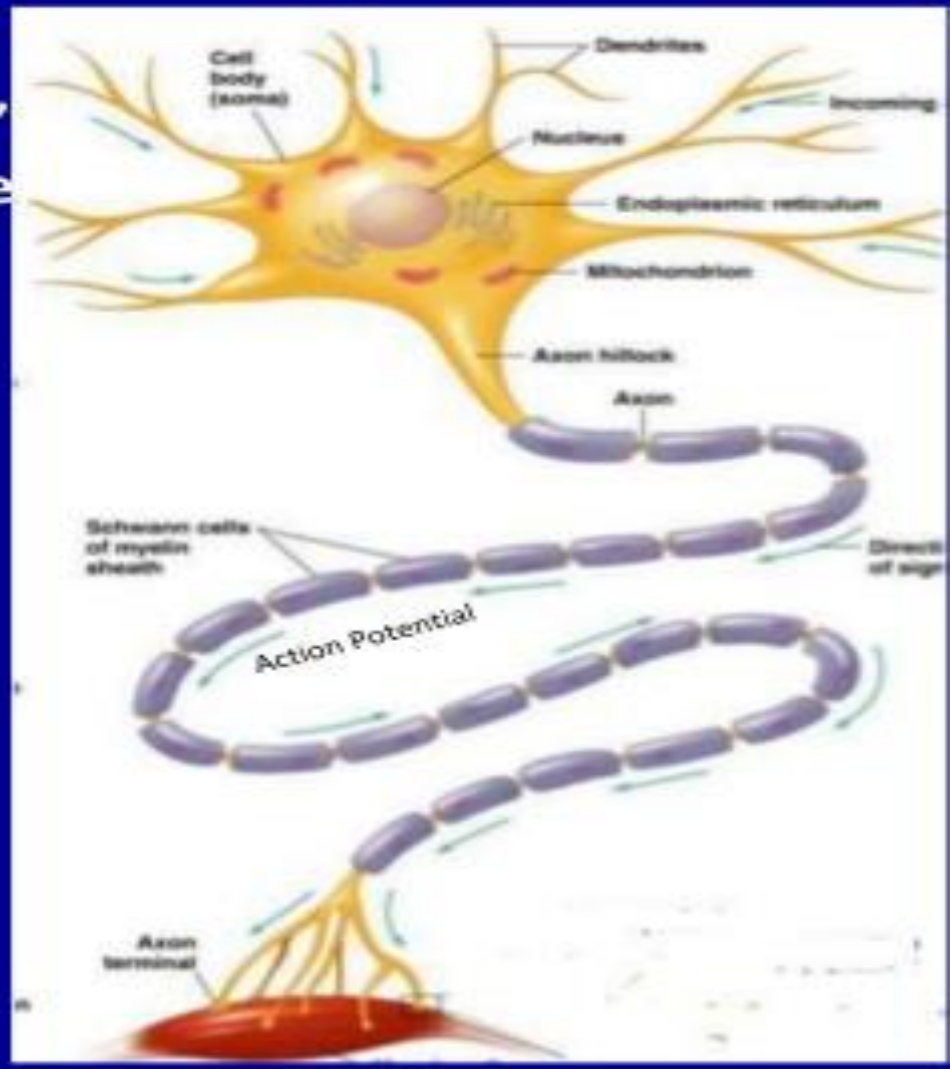
Relative Refractory Period

From the end of absolute refractory period to the start of after–depolarization.



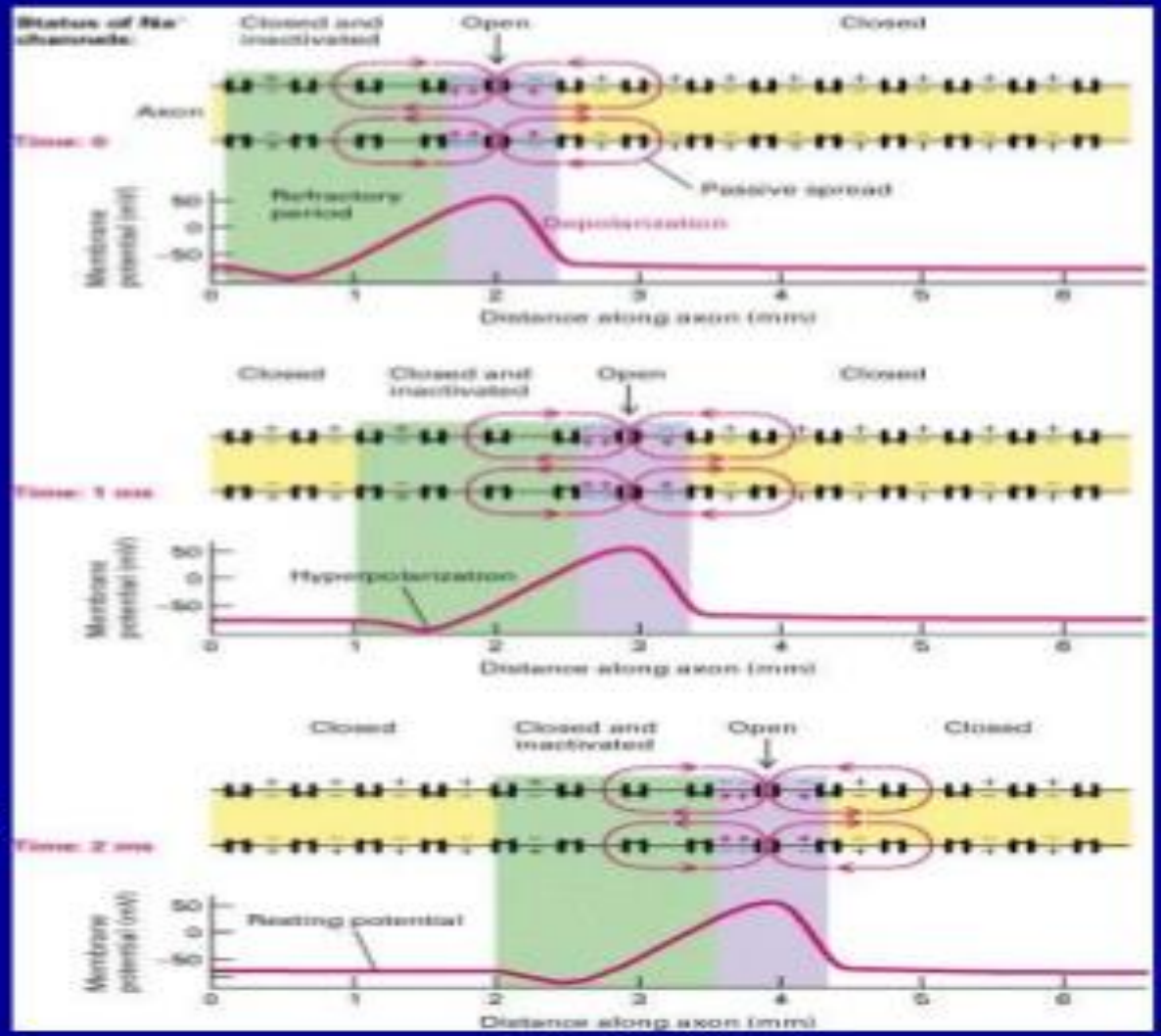
Conduction of Action Potential

- **All or Non Law**
  - AP Travel along axon in an "All-or-None" fashion. Reach threshold potential and fire or don't.
  - Axons conduct action potentials unidirectionally.
- AP is generated at the axon hillock, it is propagated down the axon.
- APs are conducted across long distances without decaying.
- AP not only have a specific size and shape but also exists within a specific time frame , ave. 1 to 5 msec.



A: Conduction of AP in Unmyelinated Axon

- Positive charges from the membrane ahead and behind the action potential flow into the area of negativity.
- By drawing off (+) charges, this flow decreases the polarity of the membrane ahead of the action potential.
- This initiates a local response.
- When the threshold level is reached, a propagated response occurs that in turn electronically depolarizes the membrane in front of it.



A: Conduction of AP in Myelinated Axon

Myelin Sheath:

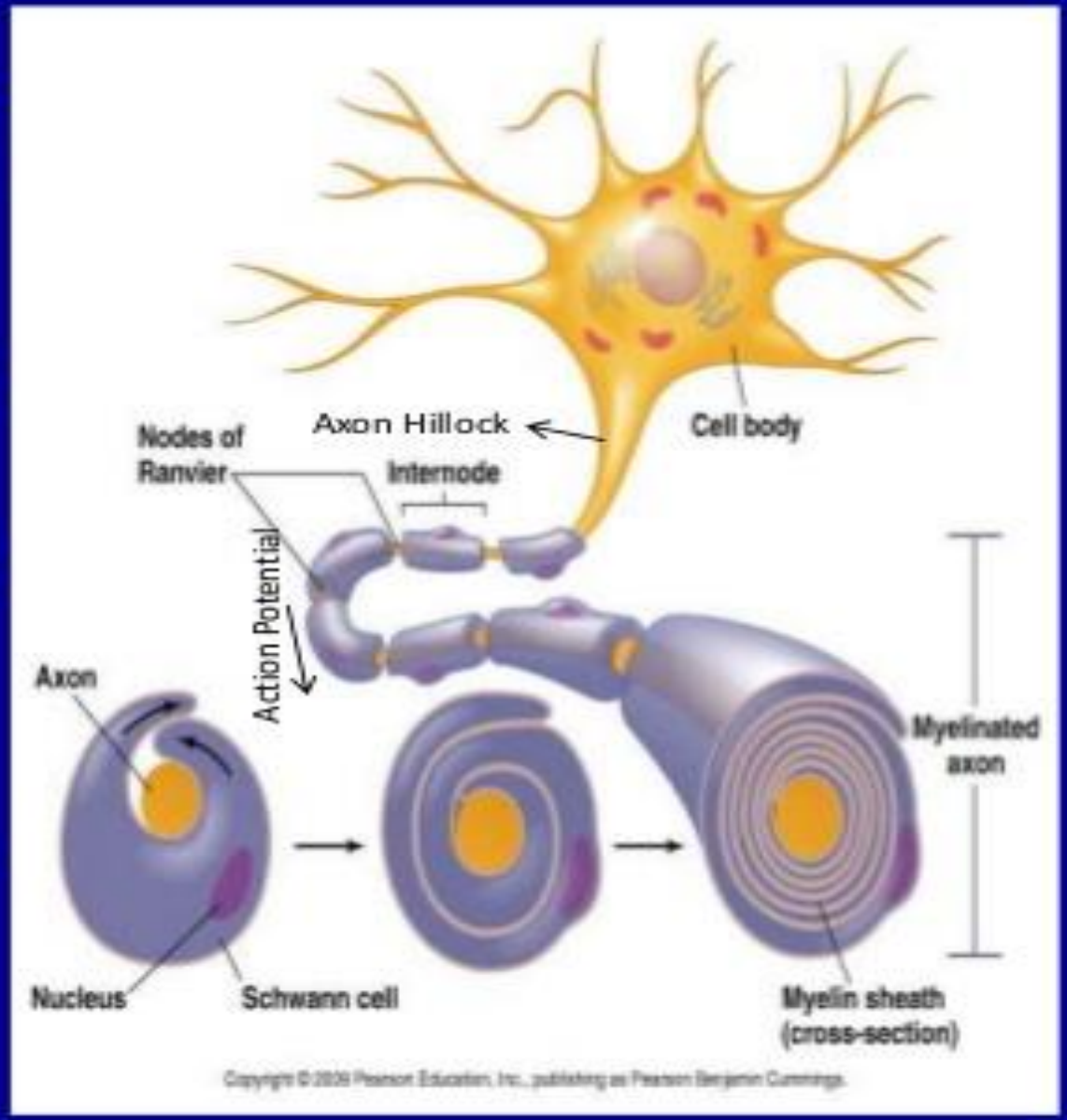
Wraps around vertebrate axons prevents current leak out of the cells, acts like an insulator.

Schwann cells:

- Specialized lipid-rich cells that form a myelin sheath by wrapping in a spiral pattern around a single axon.
- Several Schwann cells may wrap long axons.
- Myelinated regions = internodes.

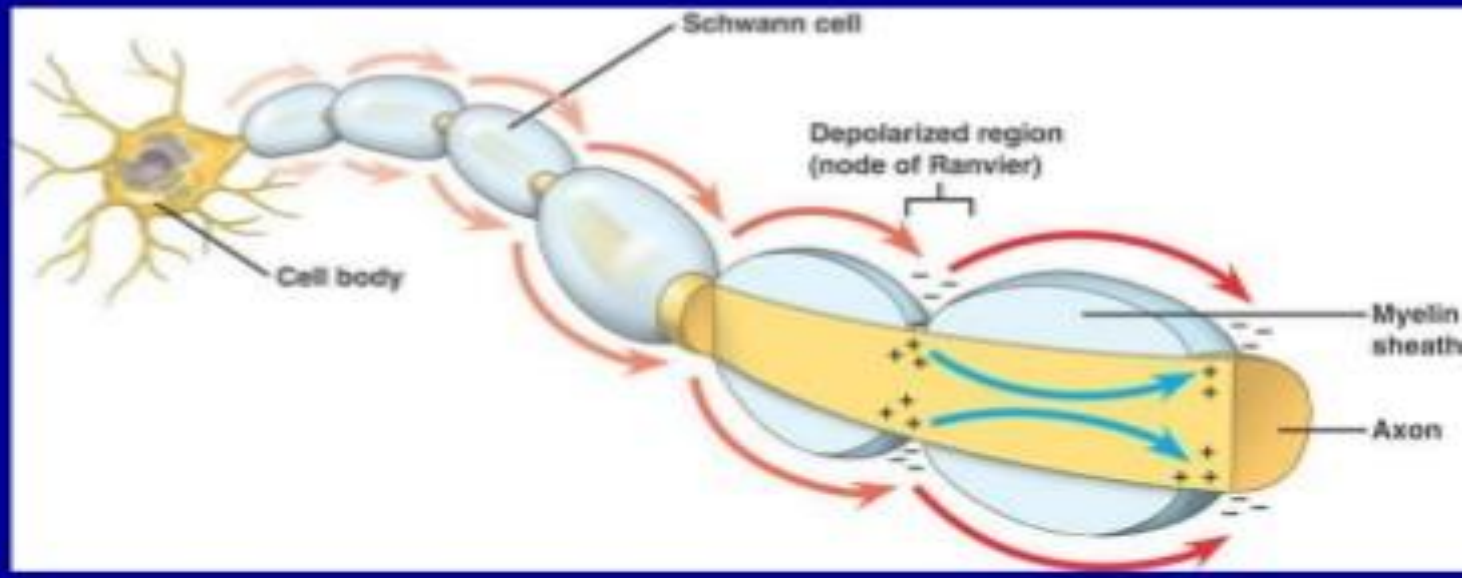
Nodes of Ranvier:

- Exposed sections o axonal membrane in between internodes. contain high densities of voltage-gated ion channels.



Saltatory Conduction:

- Action potentials only occur in nodes of Ranvier.
- Action potentials appear to "jump" from one node to another along the axon.



- Current spreads electrically through internodes.
- Conduction occurs faster and with less degradation along myelinated axons than along unmyelinated axons.

Orthodromic: From synaptic junctions or receptors along axons to their termination.

Antidromic: The opposite direction (towards the soma).

Summary

Action Potentials govern our lives These are the electrical signals that are transmitted along our nerve and muscle fibres. They are essential for the communication of information to, from, and within the brain. Your ability to read page and to understand this message, to laugh and cry, to think and feel, to see and hear, and to move your muscles, depends on **action potentials**.

Nerve impulses are extremely fast, with some myelinated neurons conducting at speeds up to 120 m/s (432 km/h) & unmyelinated axon conduction velocities range from about 0.5 to 10 m/s .

Thank You...!

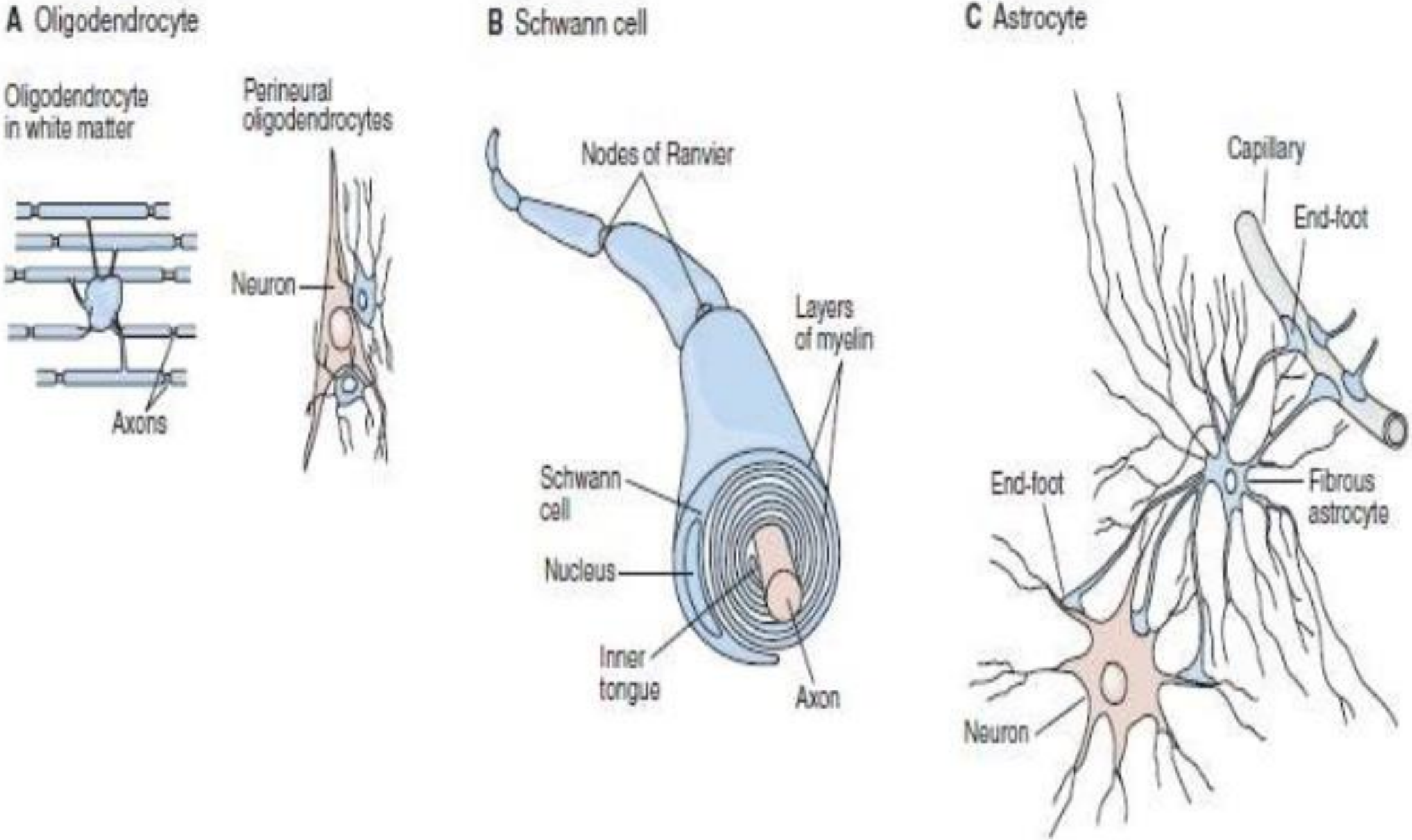
CELLULAR ELEMENTS IN THE CNS

- **GLIAL CELLS**
- the word *glia is* Greek for *glue.*
- *Theses cells are recognized for* their role in communication within the CNS in partnership with neurons.
- Unlike neurons, glial cells continue to undergo cell division in adulthood and their ability to proliferate is particularly noticeable after brain injury (eg, stroke).

- two major types of glial cells in the vertebrate nervous system:
- **microglia and macroglia**
- Microglia are scavenger cells that resemble tissue macrophages and remove debris resulting from injury, infection, and disease.

- three types of macroglia:
- **oligodendrocytes,**
- **Schwann cells,**
- **astrocytes .**
- **Oligodendrocytes** and **Schwann cells are involved in myelin formation around** axons in the CNS and peripheral nervous system, respectively.

- Astrocytes, which are found throughout the brain, are of two subtypes.
- **Fibrous astrocytes, which contain many** intermediate filaments, are found primarily in white matter.
- **Protoplasmic astrocytes are found in gray matter and have a** granular cytoplasm.
- Both types send processes to blood vessels, where they induce capillaries to form the tight junctions making up the **blood–brain barrier.**


A Oligodendrocyte
Oligodendrocyte in white matter
Axons
Perineural oligodendrocytes
Neuron
B Schwann cell
Nodes of Ranvier
Layers of myelin
Schwann cell
Nucleus
Inner tongue
Axon
C Astrocyte
Capillary
End-foot
End-foot
Fibrous astrocyte
Neuron

EXCITATION & CONDUCTION

- Nerve cells respond to electrical, chemical, or mechanical stimuli.
- Two types of physicochemical disturbances are produced:

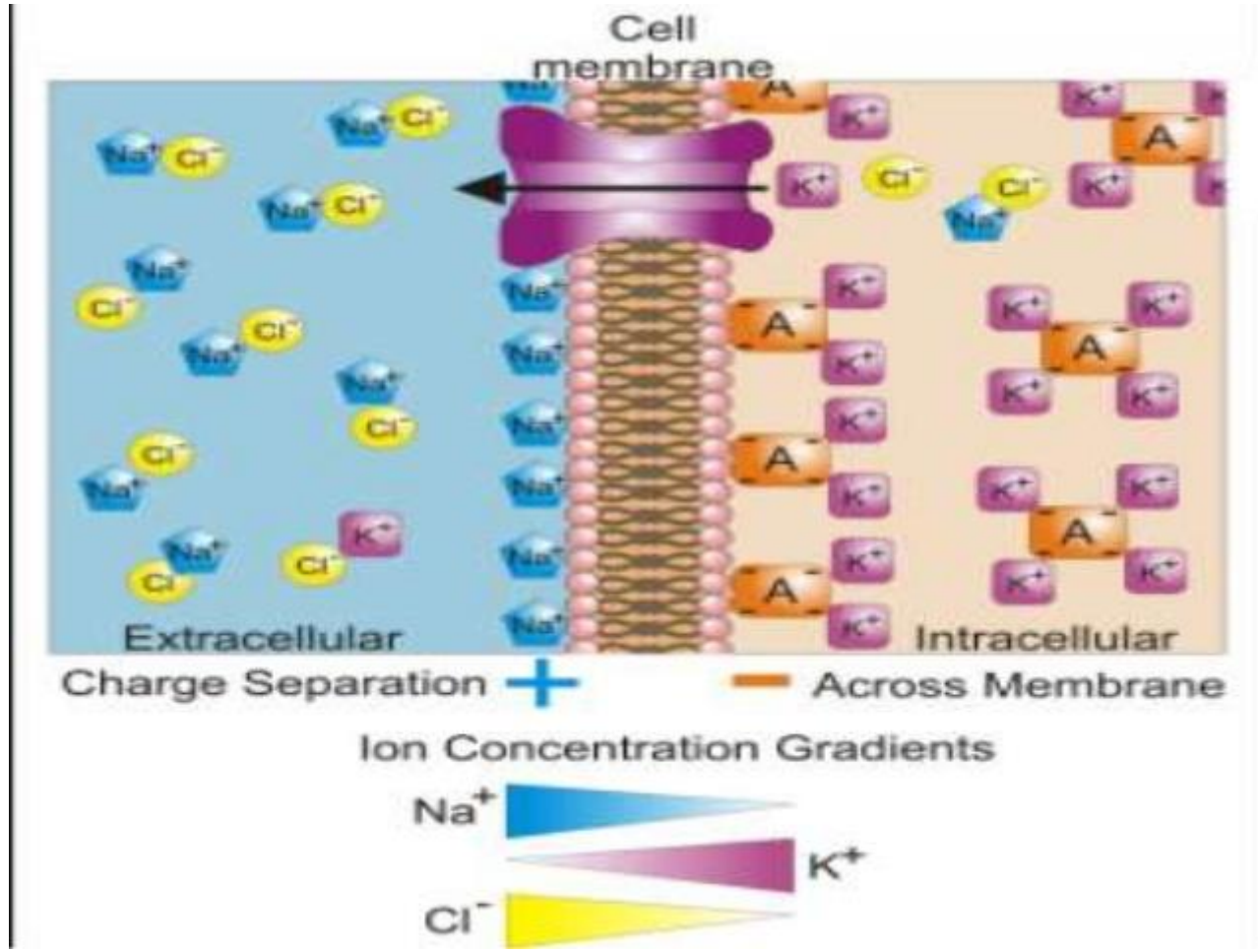
- local, nonpropagated potentials called, depending on their location, **synaptic, generator, or electrotonic potentials;**

- **Propagated** potentials, the **action potentials (or nerve impulses).**

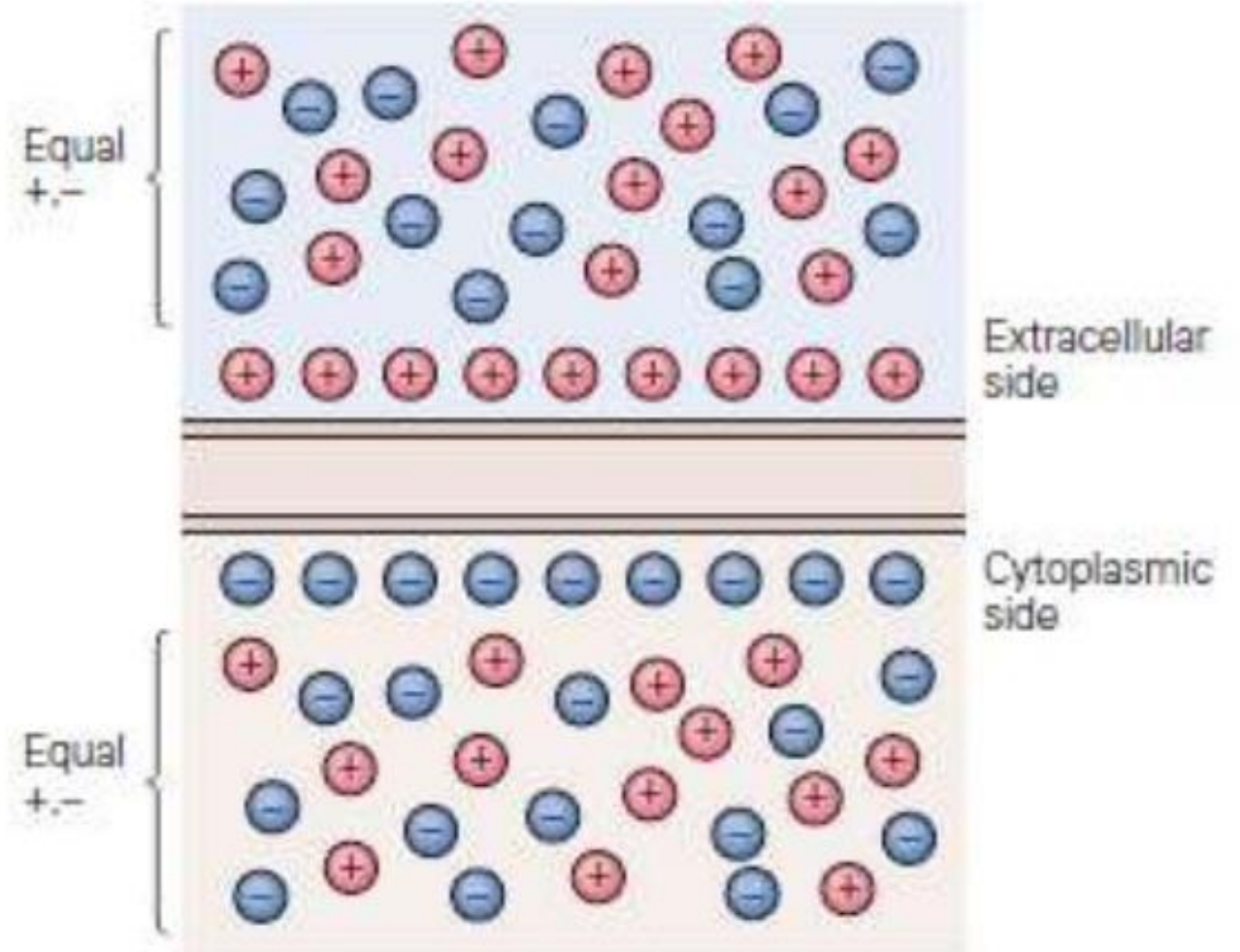
RESTING MEMBRANE POTENTIAL

- **Resting Membrane Potential** (RMP) is the voltage (charge) difference across the cell **membrane** when the cell is at **rest**.
- In neurons, the **resting membrane potential is usually** about –70 mV, which is close to the equilibrium potential for K+.
- **Because there are more open K+** channels than Na + channels at rest, the membrane permeability to K+ is greater.

- The resting membrane potential represents an equilibrium situation at which the driving force for the membrane-permeant ions down their concentration gradients across the membrane is equal and opposite to the driving force for these ions down their electrical gradients.


Cell membrane
Extracellular
Intracellular
Charge Separation
Across Membrane
Ion Concentration Gradients
Na+
K+
Cl-

A membrane potential results from separation of positive and negative charges across the cell membrane.



Action Potential

- A momentary change in electrical potential associated with the passage of an impulse along the membrane of a muscle cell or nerve cell.
- An **Action potential** is the neurons way of transporting electrical signals from one cell to the next.

- Action potentials are the primary electrical responses of neurons and other excitable tissues, and they are the main form of communication within the nervous system.
- They are due to changes in the conduction of ions across the cell membrane.
- The electrical events in neurons are rapid, being measured in **milliseconds (ms) ; and the potential changes are small, being** measured in **millivolts (mV).**

How an action potential is generated?

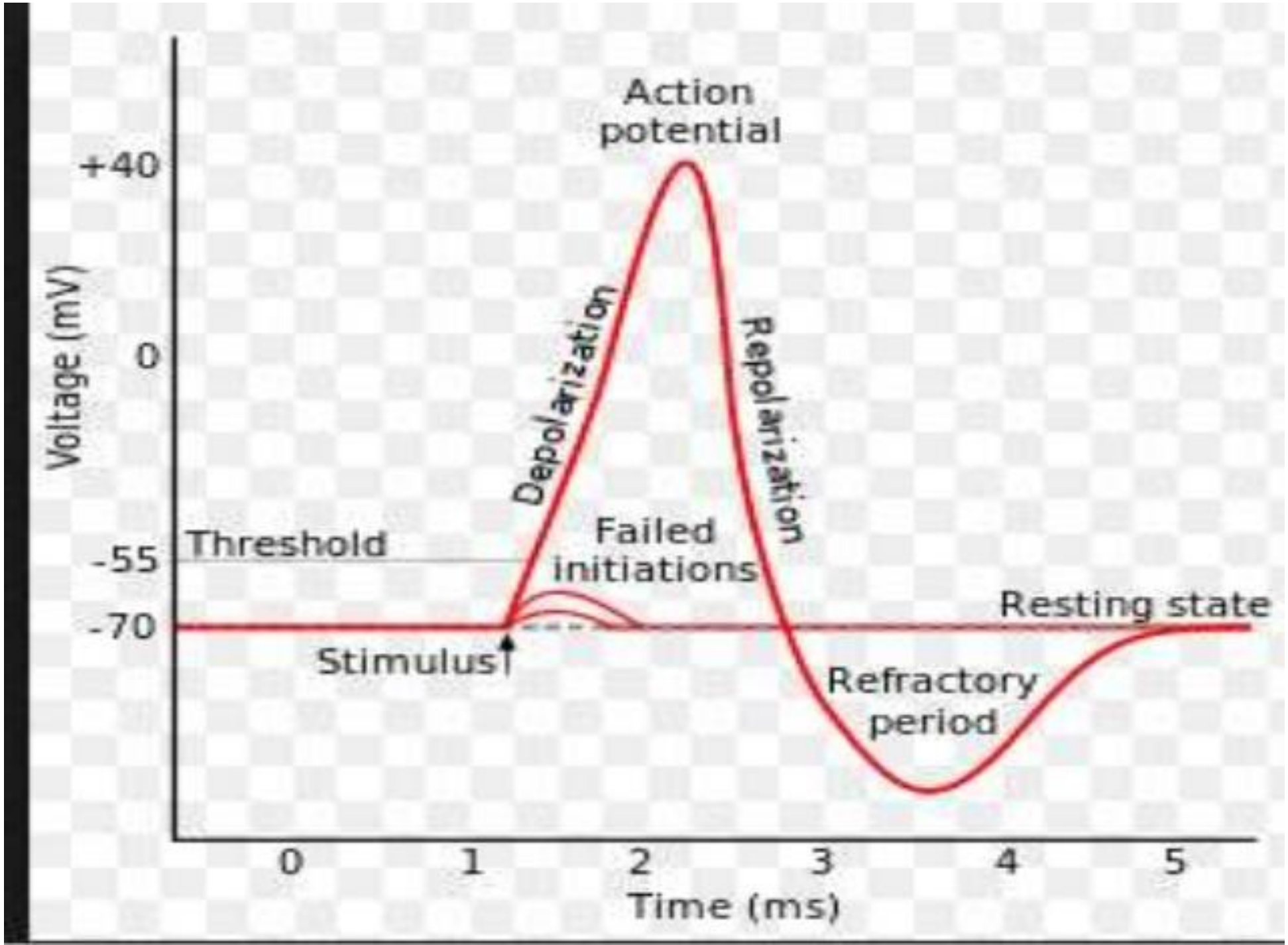
- A neuron that emits an **action potential** is often said to "fire".
- **Action** potentials are **generated** by special types of voltage-gated ion channels embedded in a cell's plasma membrane. ..
- The rapid influx of sodium ions causes the polarity of the plasma membrane to reverse, and the ion channels then rapidly inactivate.
- Thus, the sodium channel activation moves in a wave-like fashion: .

How an action potential is propagated?

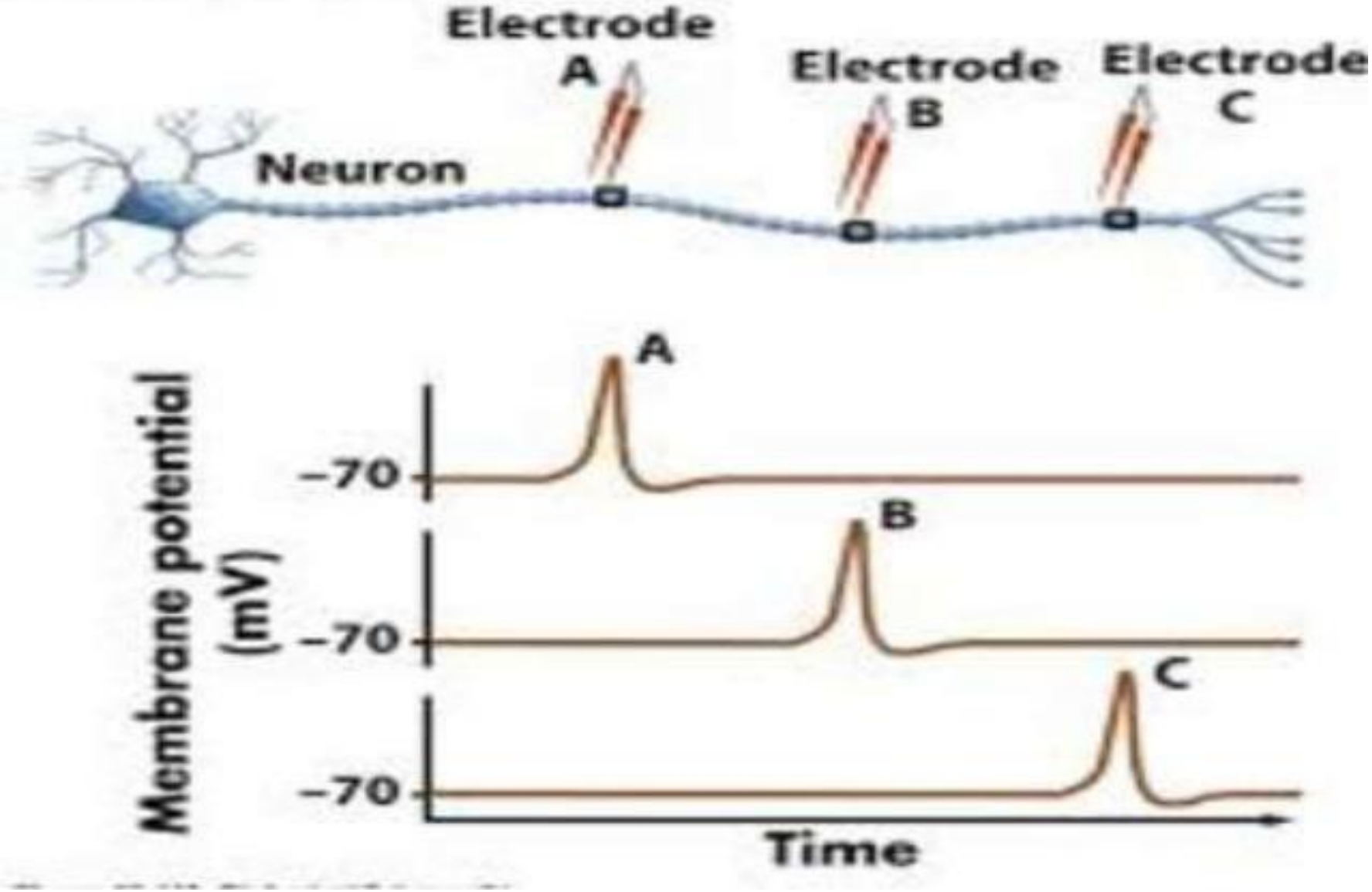
- The **action potential** is **propagated** down the length of the neuron, from its input source at the dendrites, to the cell body, and then down the axon to the synaptic terminals

How does a stimulus trigger an action potential?

- The **stimulus triggers an action potential** in the cell membrane of the nerve cell, and that **action potential** provides the **stimulus** for a neighboring segment of the cell membrane.


Action potential
+40
0
-55
-70
Voltage (mV)
Depolarization
Repolarization
Threshold
Failed initiations
Resting state
Stimulus
Refractory period
0
1
2
3
4
5
Time (ms)

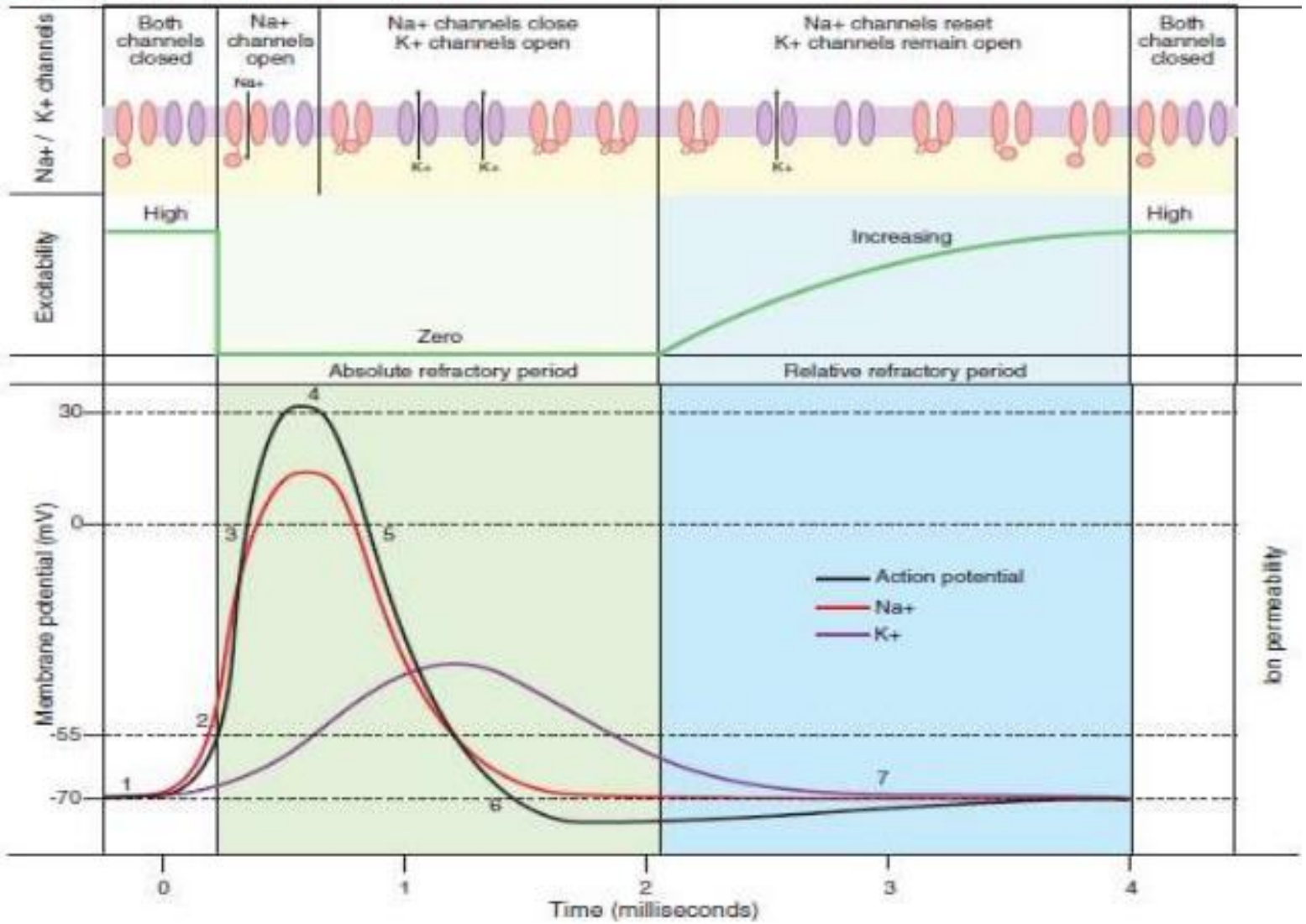
Action potential spreads as a wave of depolarization.



IONIC FLUXES DURING THE ACTION POTENTIAL

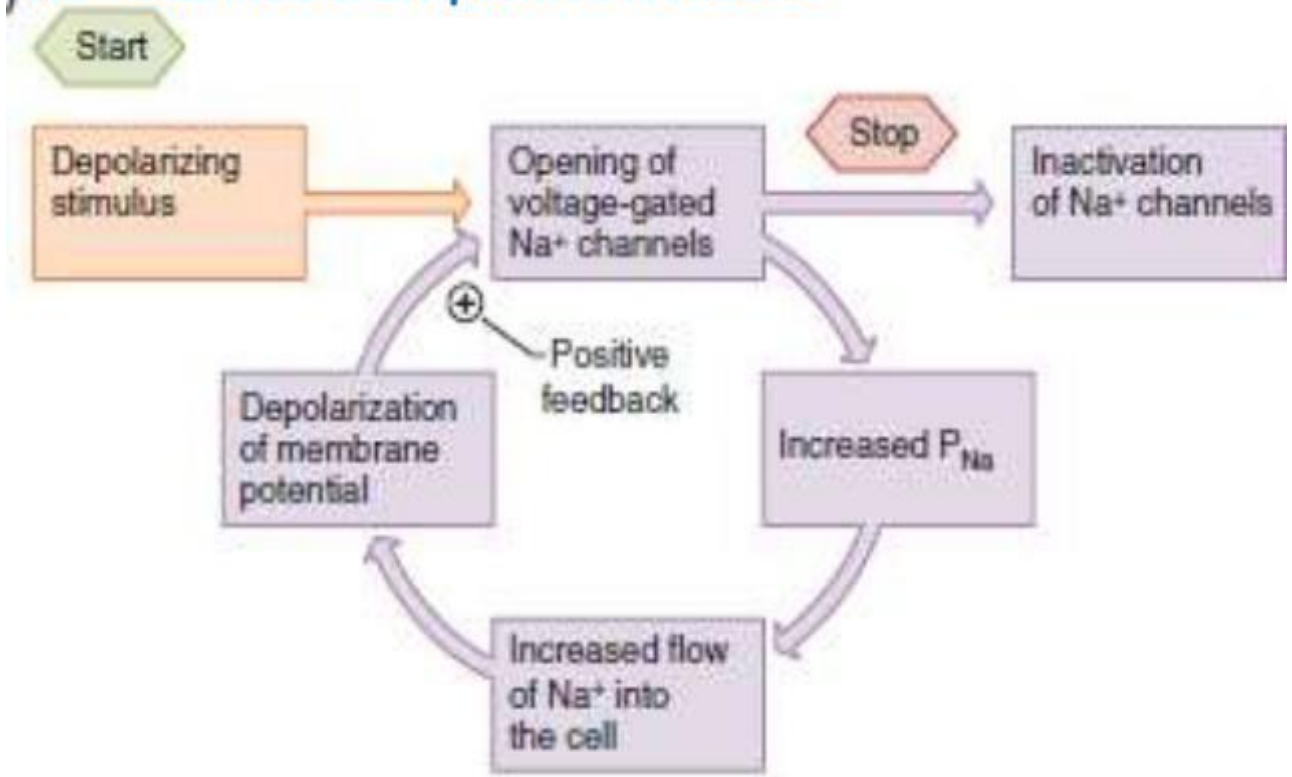
- The conductance of an ion is the reciprocal of its electrical resistance in the membrane and is a measure of the membrane permeability to that ion.
- In response to a depolarizing stimulus, some of the voltage-gated Na+ channels open and Na + enters the cell and the membrane is brought to its **threshold potential and the voltage-gated Na+** channels overwhelm the K + and other channels.

Changes in membrane potential and relative membrane permeability to Na + and K + during an action potential.

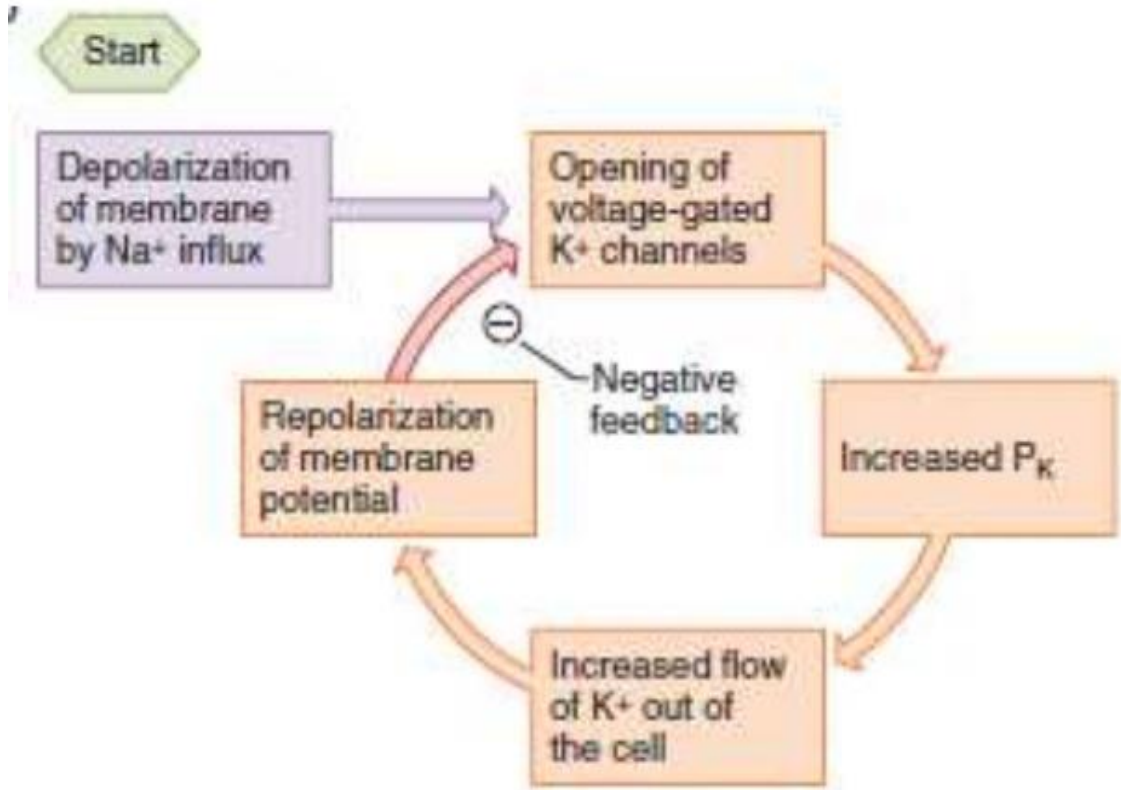


Feedback control in voltage-gated ion channels in the membrane.

Na + channels exert positive feedback.

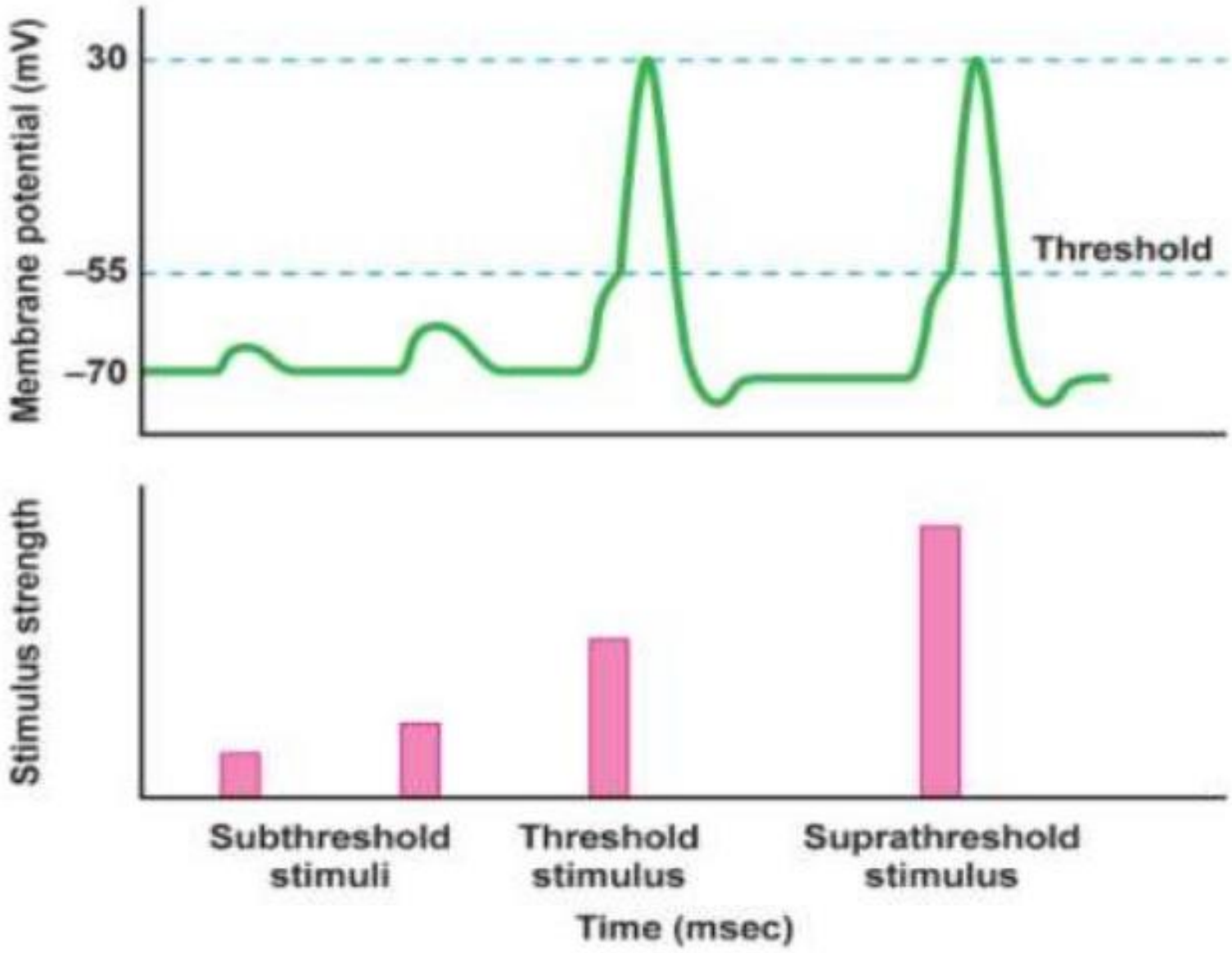


K + channels exert negative feedback



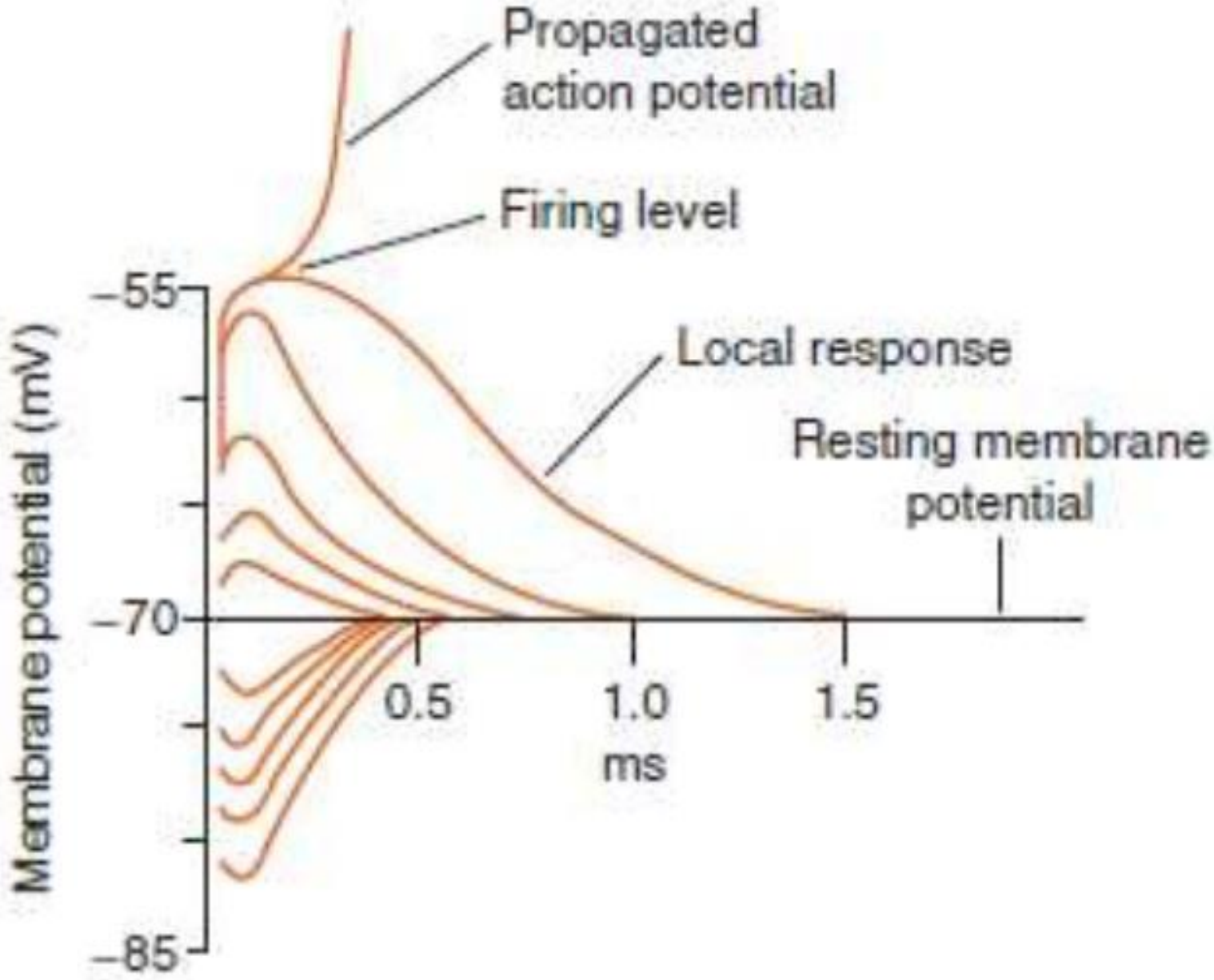
ALL-OR-NONE ACTION POTENTIALS

- The **all-or-none law** is the principle that the strength by which a nerve or muscle fiber responds to a stimulus is independent of the strength of the stimulus.
- If that stimulus exceeds the threshold **potential**, the nerve or muscle fiber will give a complete response; otherwise, there is no response.


Membrane potential (mV)
30
–55
–70
Threshold
Stimulus strength
Subthreshold stimuli
Threshold stimulus
Suprathreshold stimulus
Time (msec)

ELECTROTONIC POTENTIALS, LOCAL RESPONSE, & FIRING LEVEL

- A non-propagated local **potential**, resulting from a local change in ionic conductance.
- Although subthreshold stimuli do not produce an action potential, they do have an effect on the membrane potential.
- This can be demonstrated by placing recording electrodes within a few millimeters of a stimulating electrode and applying subthreshold stimuli of fixed duration.
- Application of such currents leads to a localized depolarizing potential change that rises sharply and decays exponentially with time.


Propagated
action potential
Firing level
Local response
Resting membrane
potential
Membrane potential (mV)
−55
−70
−85
0.5
1.0
1.5
ms

CHANGES IN EXCITABILITY DURING ELECTROTONIC POTENTIALS & THE ACTION POTENTIAL

- During the action potential, as well as during electrotonic potentials and the local response, the threshold of the neuron to stimulation changes.
- Hyperpolarizing responses elevate the threshold, and depolarizing potentials lower it as they move the membrane potential closer to the firing level.

CONDUCTION OF THE ACTION POTENTIAL

- The nerve cell membrane is polarized at rest, with positive charges lined up along the outside of the membrane and negative charges along the inside. During the action potential, this polarity is abolished and for a brief period is actually reversed.
- **Positive charges from the membrane ahead of** and behind the action potential flow into the area of negativity represented by the action potential ("current sink").

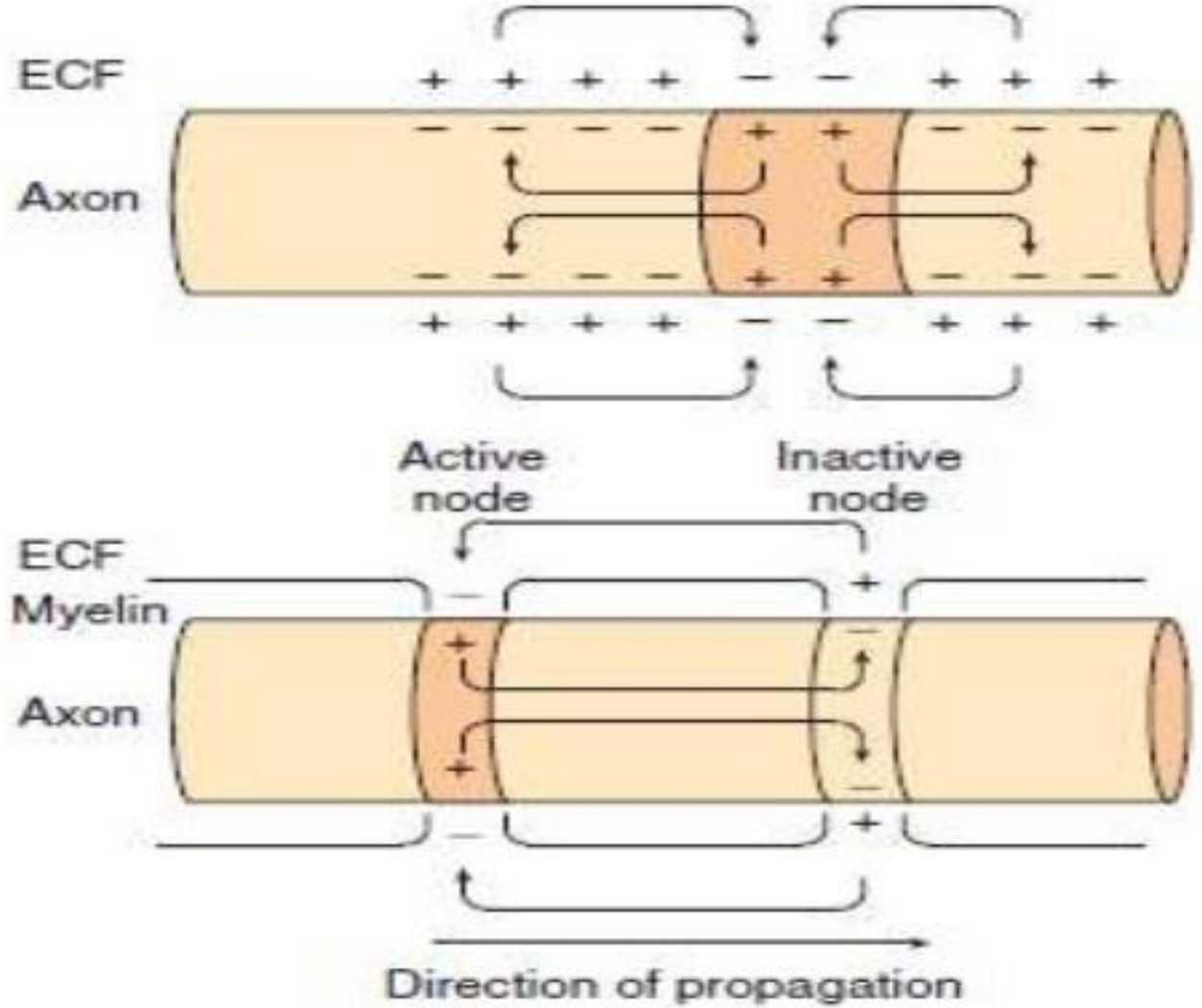
- By drawing off positive charges, this flow decreases the polarity of the membrane ahead of the action potential.

- Such electrotonic depolarization initiates a local response, and when the firing level is reached, a propagated response occurs that in turn electrotonically depolarizes the membrane in front of it.

- The spatial distribution of ion channels along the axon plays a key role in the initiation and regulation of the action potential.
- Voltage-gated Na + channels are highly concentrated in the nodes of Ranvier and the initial segment in myelinated neurons.

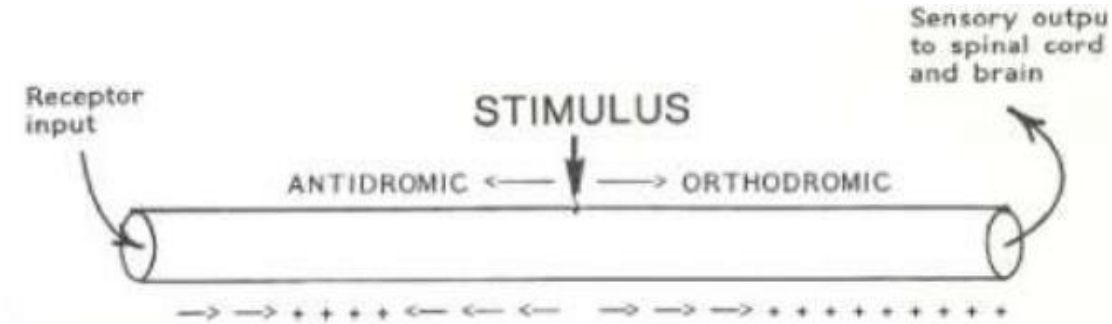
Local current flow (movement of positive charges) around an impulse in an axon. Top: Unmyelinated axon.

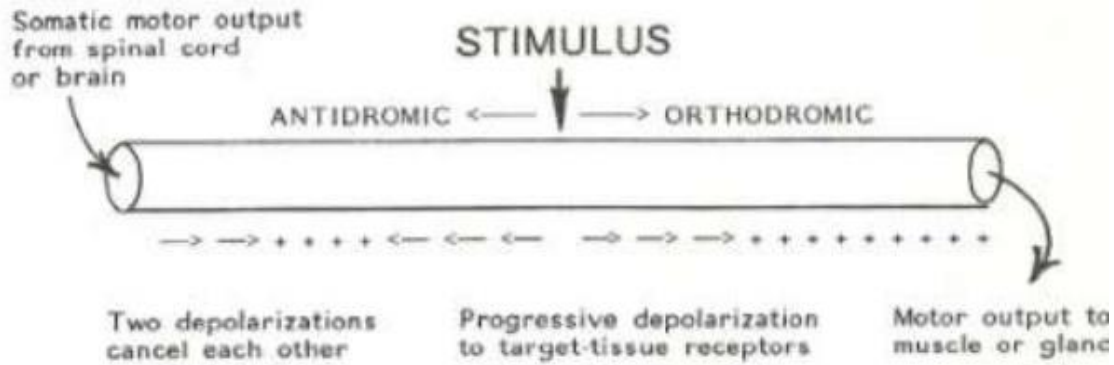
Bottom: Myelinated axon.



ORTHODROMIC & ANTIDROMIC CONDUCTION

- An axon can conduct in either direction.
- When an action potential is initiated in the middle of the axon, two impulses traveling in opposite directions are set up by electrotonic depolarization on either side of the initial current sink.
- In the natural situation, impulses pass in one direction only, ie, from synaptic junctions or receptors along axons to their termination.
- Such conduction is called **orthodromic. Conduction** in the opposite direction is called **antidromic.**

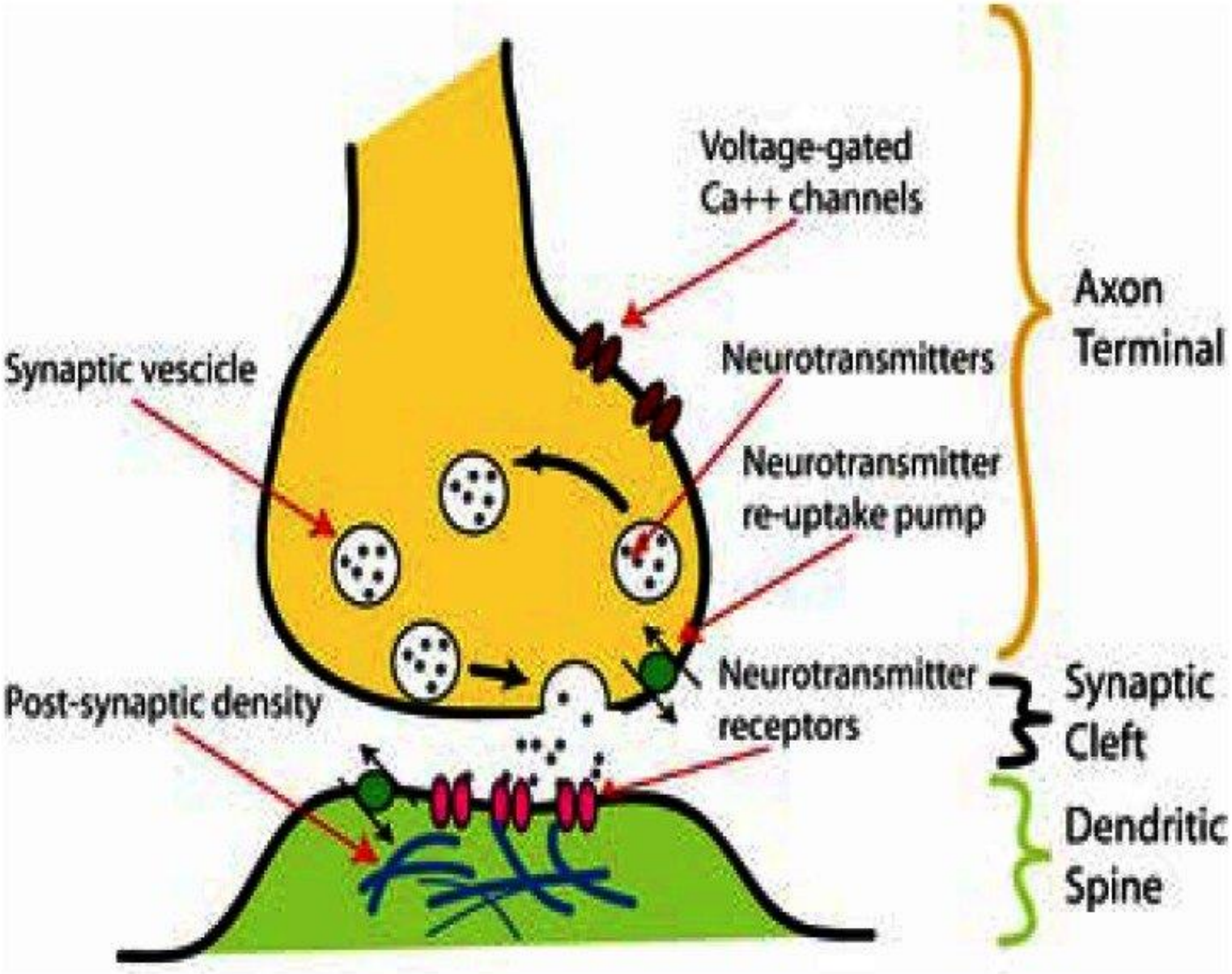

Sensory outpu
to spinal cord
and brain
Receptor
input
STIMULUS
ANTIDROMIC
ORTHODROMIC
Two depolarizations
cancel each other
Progressive depolarization
to CNS for perception


Somatic motor output
from spinal cord
or brain
STIMULUS
ANTIDROMIC
ORTHODROMIC
Two depolarizations
cancel each other
Progressive depolarization
to target-tissue receptors
Motor output to
muscle or gland

TYPES OF SYNAPSES :

Synapse, also called neuronal junction, the site of transmission of electric nerve impulses between two nerve cells (neurons) or between a neuron and a gland or muscle cell (effector).

A synaptic connection between a neuron and a muscle cell is called a neuromuscular junction.



Chemical and electrical synapses

In a chemical synapse, electrical activity in the presynaptic neuron is converted (via the activation of voltage-gated calcium channels) into the release of a chemical called a neurotransmitter that binds to receptors located in the plasma membrane of the postsynaptic cell.

The neurotransmitter may initiate an electrical response or a secondary messenger pathway that may either excite or inhibit the postsynaptic neuron.

. Chemical synapses can be classified according to the neurotransmitter released:

glutamatergic (often excitatory),

GABAergic (often inhibitory),

cholinergic (e.g. vertebrate neuromuscular junction),

and adrenergic (releasing norepinephrine).

Because of the complexity of receptor signal transduction, chemical synapses can have complex effects on the postsynaptic cell.

In an electrical synapse, the presynaptic and postsynaptic cell membranes are connected by special channels called gap junctions that are capable of passing an electric current, causing voltage changes in the presynaptic cell to induce voltage changes in the postsynaptic cell. The main advantage of an electrical synapse is the rapid transfer of signals from one cell to the next.

Synaptic communication is distinct from an ephaptic coupling, in which communication between neurons occurs via indirect electric fields.

An autapse is a chemical or electrical synapse that forms when the axon of one neuron synapses onto dendrites of the same neuron.

Types of interfaces

Synapses can be classified by the type of cellular structures serving as the pre- and post-synaptic components.

The vast majority of synapses in the mammalian nervous system are classical

axo-dendritic synapses (axon synapsing upon a dendrite),.

axo-axonic,

dendro-dendritic,

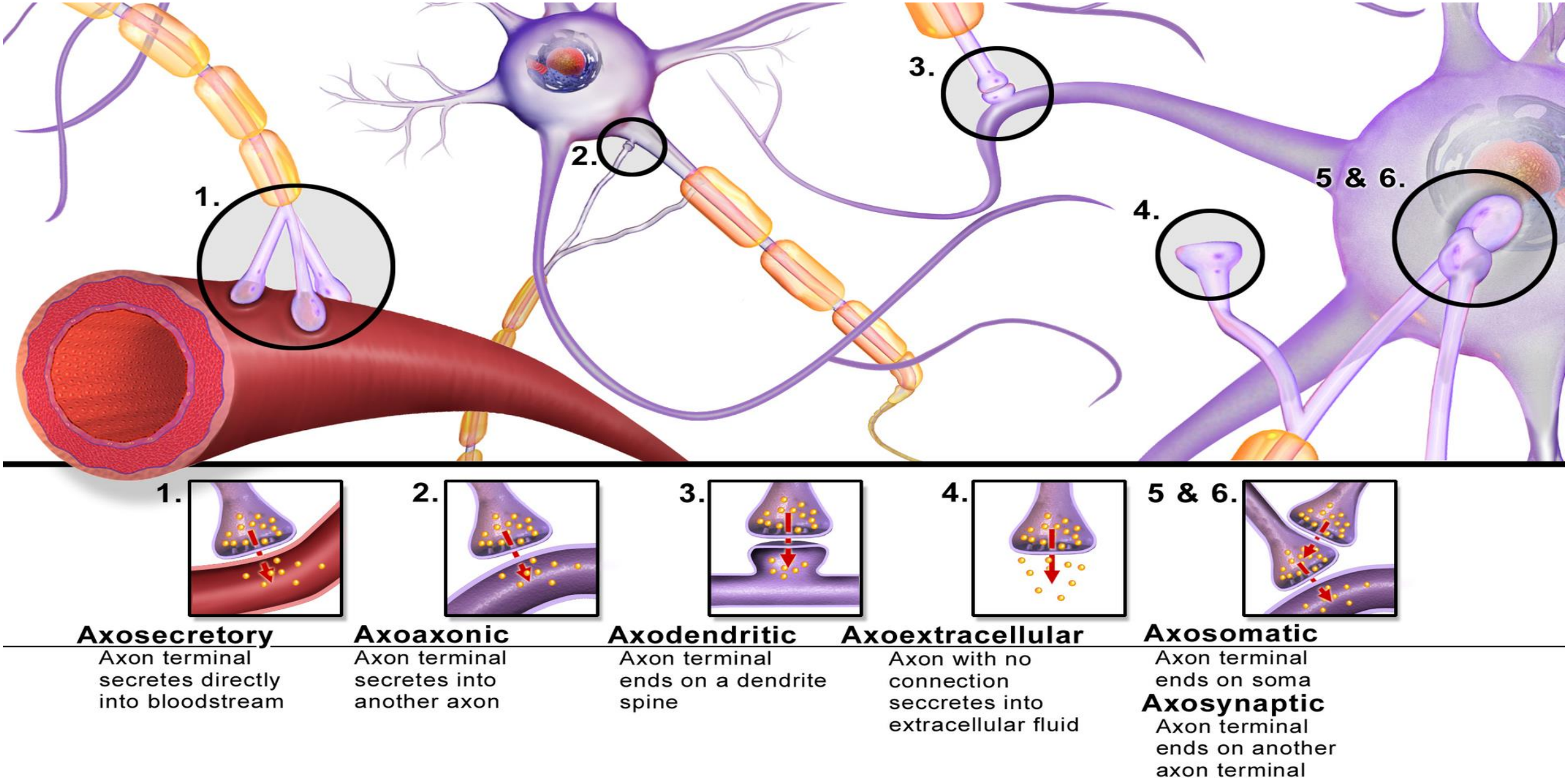
axo-secretory,

somato-dendritic,

dendro-somatic, and

somato-somatic synapses.

The axon can synapse onto a dendrite, onto a cell body, or onto another axon or axon terminal, as well as into the bloodstream or diffusely into the adjacent nervous tissue.



Fig; Different types of synapses

Synaptic transmission : Neuromuscular junction

Synaptic transmission is the biological process by which a neuron communicates with a target cell across a synapse.

Chemical synaptic transmission involves the release of a neurotransmitter from the pre-synaptic neuron, and neurotransmitter binding to specific post-synaptic receptors.

A synapse is a gap that is present between two neurons. Action potentials are communicated across this synapse by synaptic transmission (also known as neurotransmission).

Neurotransmission requires the release of a readily available neurotransmitter by exocytosis, binding at post-synaptic receptors, an appropriate response by the post-synaptic cell and removal or deactivation of the neurotransmitter.

In this article we shall look at the stages of synaptic transmission and clinical conditions that arise in its pathology.

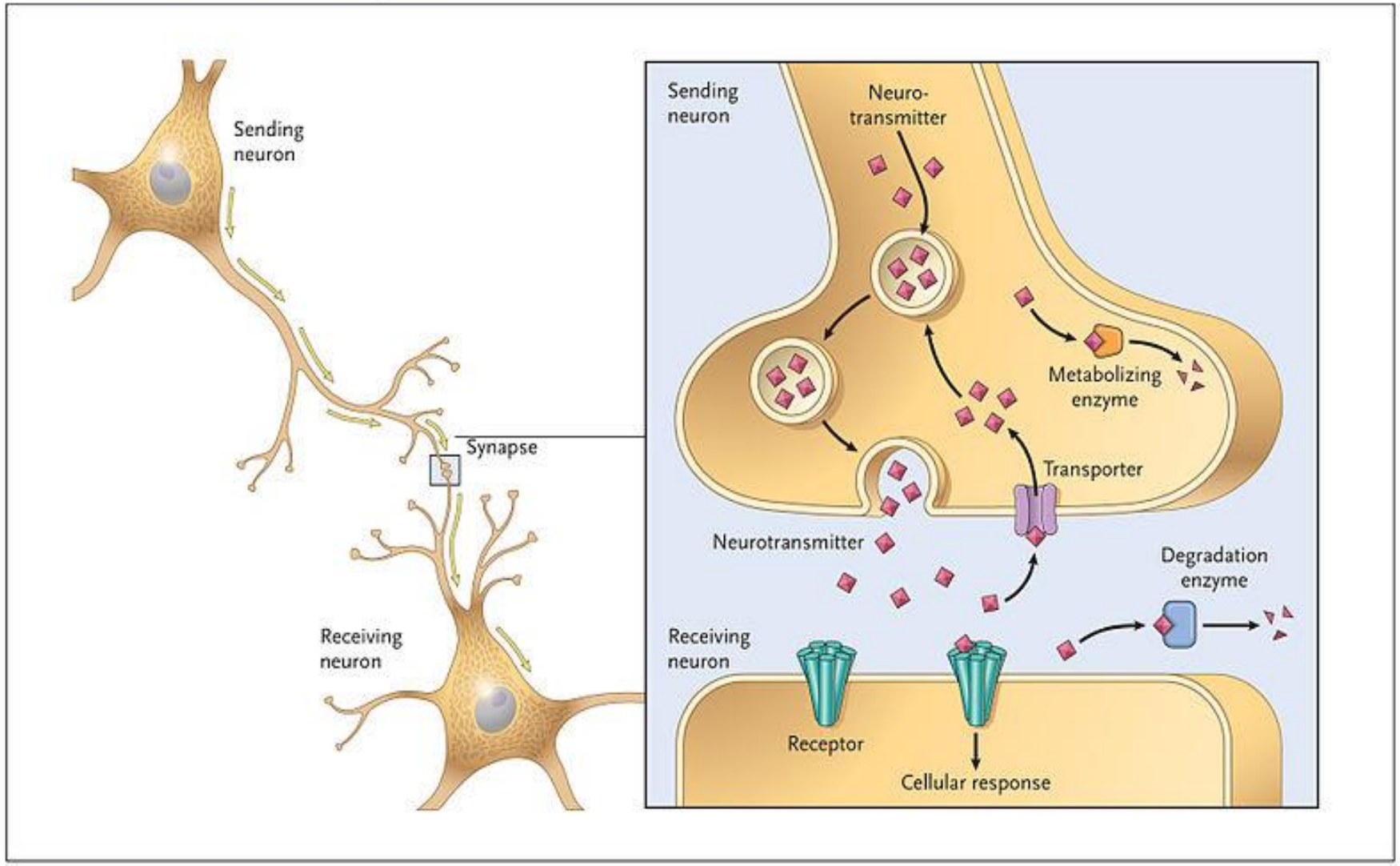


Fig 1 – Diagram showing the general process of synaptic transmission

Synthesis and Storage of Neurotransmitters

This is the first step of synaptic transmission. Some neurotransmitters (eg acetylcholine, ACh) are synthesised in the axon while others (eg neuropeptides) are made in the cell body.

Acetylcholine– synthesised within the axon. Precursors (choline, acetate) taken into the cell by membrane channels or created as byproducts of other processes. Precursors used to synthesise neurotransmitters via enzymes (choline acetyltransferase) transported from the cell body where it is made to the axon terminal.

Endogenous opioids – a neuropeptide (larger neurotransmitter) made within the cell body to allow formation of peptide bonds.

Made as any secretory protein via transcription in the nucleus and translation in the endoplasmic reticulum before being transported to the synaptic terminal ready for exocytosis.

Once synthesised, neurotransmitters are stored in vesicles within the synaptic terminal until an action potential arrives, causing their release.

Neurotransmitter Release

Action potentials arriving at the synaptic terminal leads to the opening of voltage gated calcium channels.

This allows an influx of calcium in the terminal resulting in the migration of neurotransmitter storage vesicles to the pre-synaptic membrane.

These vesicles fuse with the cell membrane (exocytosis) under the influence of calcium causing neurotransmitter release into the synaptic cleft.

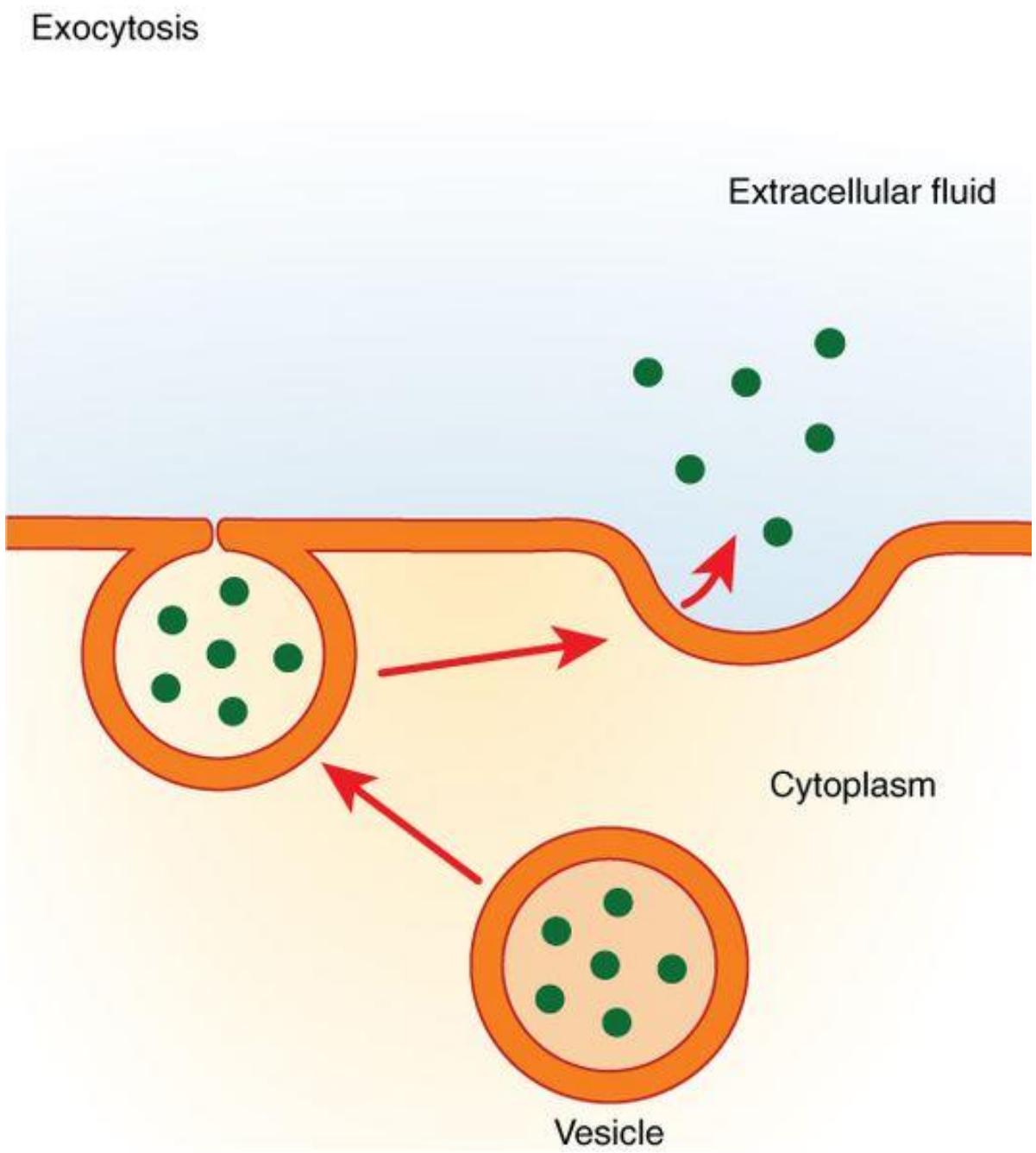


Fig 2 – Diagram showing exocytosis, the process by which neurotransmitters are released into the synaptic cleft.

Postsynaptic Receptors

Neurotransmitter in the synaptic cleft diffuses across the gap to the post-synaptic membrane. Here, they can bind to two types of post-synaptic receptors.

Name	**Inotropic** receptors	**Metabotropic** receptors
Type	Ligand gated ion channels	G protein coupled receptors
Response	Channel allows **ion flux** to change cell voltage	Receptor acts through **secondary messengers** to cause cellular effects
Speed of response	Rapid	Slow
Length of response	Short-acting	Prolonged response

This can cause either depolarisation to promote or hyperpolarisation to inhibit action potential generation in the post-synaptic neurone.

Inactivation/Removal of Neurotransmitters

Once the post-synaptic membrane has responded the neurotransmitter in the synaptic cleft is either inactivated or removed. This can be done in several ways:

Re-uptake – serotonin is taken back into the pre-synaptic neurone by transporter proteins in its membrane. These neurotransmitters are then either recycled by re-packaging into vesicles or broken down by enzymes

Breakdown – acetylcholine is broken down by acetylcholinesterase present in the synaptic cleft, inactivating the neurotransmitter
Diffusion into surrounding areas

Clinical Relevance - Acetylcholinesterase Inhibitors

Acetylcholinesterase inhibitors are a class of drug that inhibit the activity of **acetylcholinesterase** within the synaptic cleft. This increases cholinergic transmission as ACh is present within the synaptic cleft for a longer period of time.

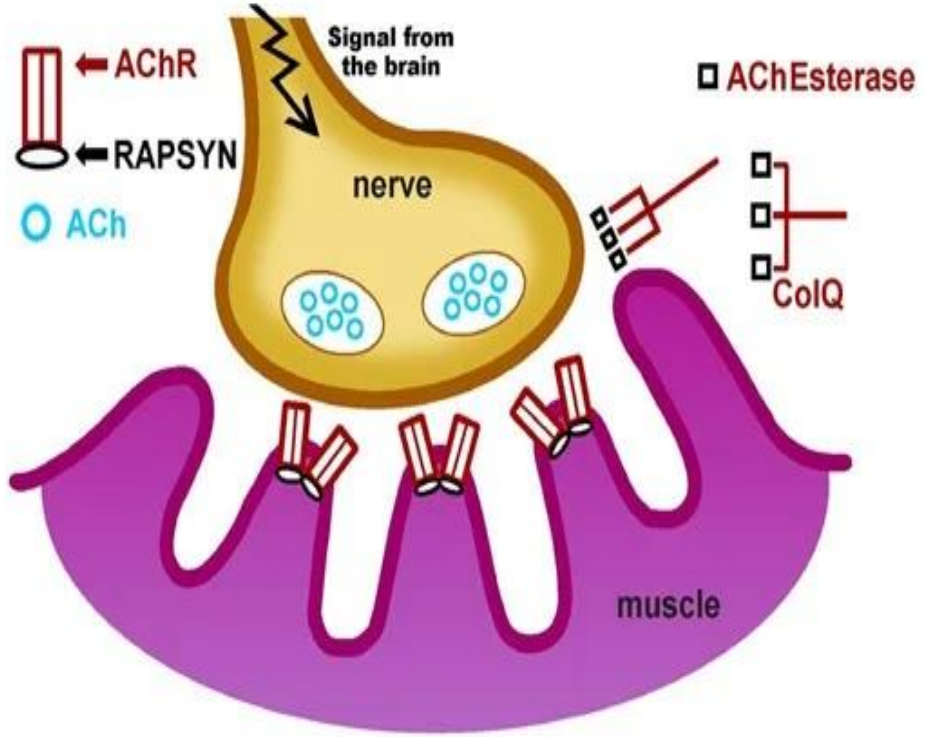
These drugs, such as **pyridostigmine**, rivastigmine and donepezil, can be used to treat various conditions:

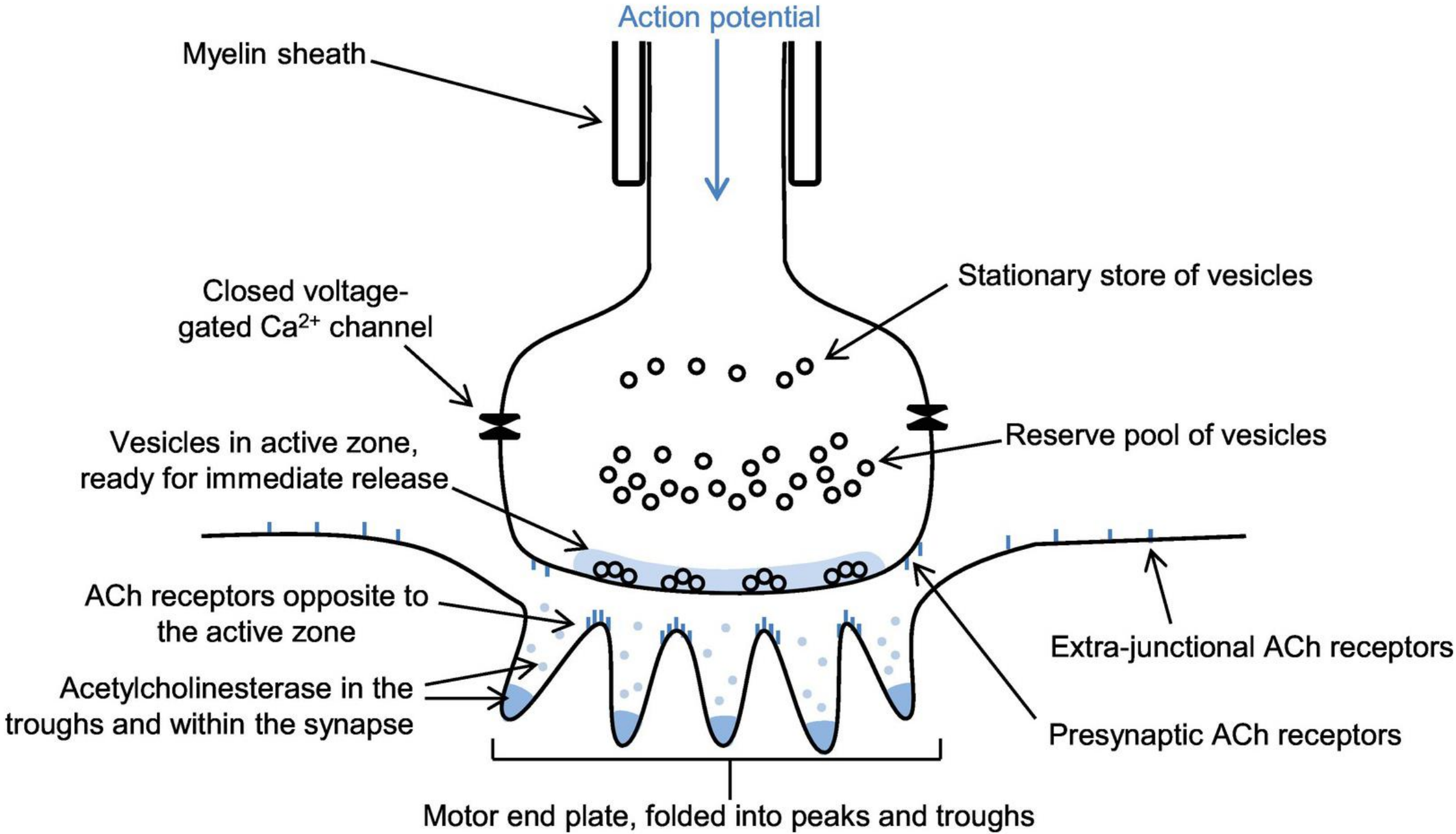
- **Myasthenia gravis** – the inhibition of acetylcholinesterase works at the neuromuscular junction rather than at the synaptic cleft in this disease
- **Alzheimer's** disease
- **Glaucoma**
- To reverse the effect of non-depolarising muscle relaxants, such as suxamethonium

As cholinergic transmission is widespread throughout the body these drugs can cause many side effects such as bradycardia, hypotension, diarrhoea, excessive salivation, **muscle spasm.**

Neuromuscular junction

A neuromuscular junction (or myoneural junction) is a chemical synapse between a motor neuron and a muscle fiber. It allows the motor neuron to transmit a signal to the muscle fiber, causing muscle contraction. Neuromuscular junction.




Action potential
Myelin sheath
Closed voltage-gated Ca^{2+} channel
Stationary store of vesicles
Vesicles in active zone, ready for immediate release
Reserve pool of vesicles
ACh receptors opposite to the active zone
Acetylcholinesterase in the troughs and within the synapse
Extra-junctional ACh receptors
Presynaptic ACh receptors
Motor end plate, folded into peaks and troughs

To understand myasthenia, it helps to understand how the neuromuscular junction should work.

1. To make any muscle move a signal has to be sent from the brain, down the nerve to the muscle. Mostly we are totally unaware that this is happening, especially in the muscles that help us to breathe and swallow.

2. When the signal reaches the end of the nerve it causes a special chemical called acetylcholine (ACh) to be released from the nerve.

The ACh travels across the gap between the nerve and the muscle and binds to the acetylcholine receptors (AChR) which are clustered by molecules called RAPSYN on the muscle.

3. The AChR is a channel that is normally closed but when the ACh binds to it following a signal, it opens for a short time to let in ions. It is this influx of ions that causes the muscle to work.

After the process, any ACh left over is broken down by the acetylcholine-esterase (AChE), which is held in the gap between the nerve and the muscle by a protein called COLQ. The ACh is then recycled by an enzyme called ChAT.

For all of this to happen, the AChRs need to be clustered in its correct position to receive the ACh. This is achieved by a number of different proteins (including DOK-7 and RAPSYN).

Interference in any of these processes can prevent the muscles from working properly and cause weakness.

Reflex action and its type: Reflex arc

What is reflex action? Write its types and two examples of each.

The process of responding to a peripheral nerve stimulation that occurs involuntarily i.e., without conscious effort or thought and requires the involvement of the spinal cord. These reflexes are very rapid, automatic, stereotyped behaviour in which the same kind of stimulus evokes for a short-lived response.

Reflex action is of two types:

1. Unconditioned reflexes: These are inborn. These include knee jerk, peristalsis, salivation on the tasting of food,e etc.
2. Conditioned reflexes: These are acquired and requires some sort of learning after birth. These include playing a musical instrument, knitting without looking, writing as well as reading, etc.

What is Reflex Action?

An involuntary or instantaneous action by the human body parts in response to a stimulus is called reflex action. It is because of numerous neural pathways that are known as reflex arcs that act on an impulse before it reaches the brain. Reflex action doesn't need any conscious thought or awareness about the automatic response.

What Happens in Reflex Action?

When a specialized tissue receives a stimulus, it may either directly/indirectly alter the relation of other tissue or also the whole individual to the environment from where stimuli arise. Let's understand by a few examples of the mechanism of the reflex action. The pupil of the eye changes its size when light acts as a stimulus; when a pin pricks our hands or legs or we touch something very hot, we suddenly withdraw them; we cough or sneeze when foreign irritants go to our nasal passages. In these situations, our reactions are instantaneous, involuntary, and quick. It doesn't require much of a thinking process and conscious brain control, therefore, the action is called the reflex action in scientific terms. And here, the major role is of the spinal cord and the nerve pathway which is involved in this action including a sensory nerve, a synapse in between, and a motor nerve is called a reflex arc. The pathway of reflex action (reflex arc) can be clearly understood below in the diagram.

(image will be uploaded soon)

Types of Reflex Action

To understand reflex action, we should understand all parts of the reflex arc responsible to cause a reflex action. Types of reflex action can be myotatic reflexes, tendon reflex, or reflexes observed only in human infants such as sucking reflex, and other reflexes such as abdominal reflexes or cough reflex.

The reflex arc is the neural pathway controlling the reflexes and acts on an impulse even before it reaches the brain. The two types of reflex arcs are:

1. **Autonomic Reflex Arc:** It affects the functioning of inner organs.
2. **Somatic Reflex Arc:** It affects the functioning of muscles.

The Various Parts of the Reflex arc are Described as Follows -

- **Receptor**

It is the part of the reflex arc responsible for detecting the stimulus. A specialized receptor cell or a particular dendrite has this receptor end in a sensory organ. It is highly sensitive to any kind of internal or external change resulting from the stimulus.

- **Sensory Neuron**

It conveys the sensory information to the brain or the spinal cord. Dendrite, cell body and axon of a sensory neuron are present to assist it in accomplishing its function. Its function is to transmit nerve impulses from the receptor into the spinal cord or brain.

- **Interneuron**

Also known as relay neurons, it serves as a processing center and conducts nerve impulses from the sensory neuron to a motor neuron. Interneurons are the central nodes of neural circuits, responsible for communicating between sensory or motor neurons and the central nervous system (CNS). It is the dendrite, cell body, and axon of a neuron within the brain or spinal cord.

- **Motor Neurons**

It conducts motor output to the periphery and it is a nerve cell forming part of the pathway along which impulses travel from the brain or spinal cord to a gland or muscle. It transmits nerve impulses from the brain or spinal cord out to an effector.

- **Effector**

Effector cells are muscle, organ, or gland that acts in response to a stimulus. It responds to stimulation by the motor neuron and produces a behavioral response called a reflex.

What is the Significance of Reflex Action

Reflex action is an involuntary response of effectors to the stimulus and it helps us in protecting us from any sudden stimulus which may harm us and thus takes care of the survival of an organism. It is the major point that explains the importance of reflex action.

The importance of reflex action is due to the fact that reflex arcs are composed of different components that are significant to create a reflex. The function of each component is explained below -

1. **Receptor -** It receives the information and assists in generating impulses.
2. **Sensory Nerve -** It carries information from the receptor to the interneurons in the spinal cord.
3. **Interneuron -** It processes the information and generates effective responses.
4. **Motor Nerve -** It carries the information from the spinal cord to the effector organ.
5. **Effector Organ -** It receives information from effector neurons and results in the appropriate response (reflex).

List Down 10 Examples of Reflex Action

Reflex Action Examples in Humans Include-

1. Closing of eyes when a bright light hits our eyes
2. Sudden withdrawing hands or legs when they touch something hot or pricking
3. Coughing or sneezing due to irritants in the nasal passage
4. Batting of eyelids frequently
5. Blinking eyes when insects come in contact
6. Rooting reflex in infants
7. Sucking reflex in infants
8. Grasp reflex in infants
9. The reflex of abdominal muscles to contract upon any force to the abdomen (Muscular defense)
10. Knee-jerk reflex is known as a patellar reflex: when the patellar tendon is stretched, the contraction of quadriceps takes place.

1. What do you Mean by Monosynaptic and Polysynaptic Reflex Action?

A monosynaptic reflex action is when a reflex arc consists of only one sensory neuron and one motor neuron where a single chemical synapse occurs. Example: Patellar reflex. Polysynaptic reflex action occurs when one or more sensory and motor signals are connected i,e, interneurons connect afferent and efferent signals.

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2. What is a Reflex Arc?

A reflex arc is a nerve pathway through which different components like receptor, sensory neuron, interneuron, motor neuron, and effector function altogether to produce a reflex action. These components act in a five-step process to generate a reflex action that is initiated by a stimulus. It can be diagrammatically represented to make it more comprehensible. A reflex arc governs all the operations of reflexes. The types of reflex actions are also based on their functionalities and types. A reflex arc makes it possible for reflexes through the neural pathways that act on an impulse prior to reaching the brain.

A reflex arc is a neural pathway that controls a reflex. In vertebrates, most sensory neurons do not pass directly into the brain, but synapse in the spinal cord. This allows for faster reflex actions to occur by activating spinal motor neurons without the delay of routing signals through the brain.

The brain will receive the sensory input while the reflex is being carried out and the analysis of the signal takes place after the reflex action.

There are two types: autonomic reflex arc (affecting inner organs) and somatic reflex arc (affecting muscles). Autonomic reflexes sometimes involve the spinal cord and some somatic reflexes are mediated more by the brain than the spinal cord.

During a somatic reflex, nerve signals travel along the following pathway:

Somatic receptors in the skin, muscles and tendons
Afferent nerve fibers carry signals from the somatic receptors to the posterior horn of the spinal cord or to the brainstem.

An integrating center, the point at which the neurons that compose the gray matter of the spinal cord or brainstem synapse
Efferent nerve fibers carry motor nerve signals from the anterior horn to the muscles.

Effector muscle innervated by the efferent nerve fiber carries out the response.
A reflex arc, then, is the pathway followed by nerves which (a.) carry sensory information from the receptor to the spinal cord, and then (b.) carry the response generated by the spinal cord to effector organs during a reflex action.
The pathway taken by the nerve impulse to accomplish a reflex action is called the reflex arc.

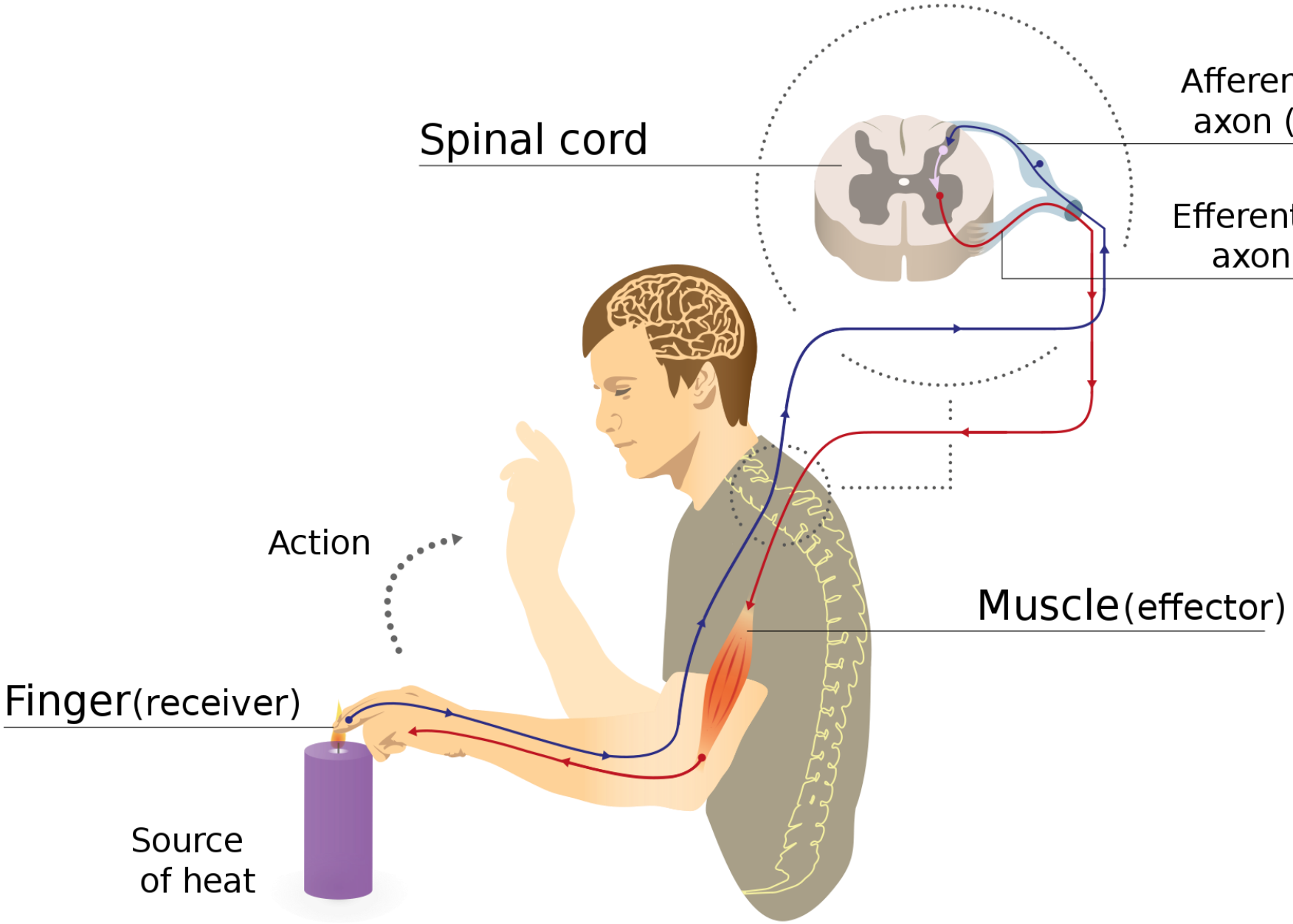
Monosynaptic vs. polysynaptic

When a reflex arc in an animal consists of only one sensory neuron and one motor neuron, it is defined as monosynaptic, referring to the presence of a single chemical synapse.

In the case of peripheral muscle reflexes (patellar reflex, achilles reflex), brief stimulation to the muscle spindle results in contraction of the agonist or effector muscle.

By contrast, in polysynaptic reflex pathways, one or more interneurons connect afferent (sensory) and efferent (motor) signals. All but the most simple reflexes are polysynaptic, allowing processing or inhibition of polysynaptic reflexes within the brain.

Reflex arc demon strated



PHYSIOLOGY OF VISION

Physiological events of vision consists of following;

- Refraction of light entering the eye
- Focusing of image on the retina by accommodation of lens
- Convergence of image
- Photo-chemical activity in retina and conversion into neural impulse
- Processing in brain and perception

Refraction of light entering the eye:

Light wave travels parallel to each other but they bend when passes from one medium to another.

This phenomenon is called refraction.

Before light reach retina it passes through cornea, aqueous humor, lens vitrous humor, so refraction takes place in every medium before it falls on retina.

In normal eye, light wave focused on retina.

However in myopic eye (short sightedness) light focused in front of retina.

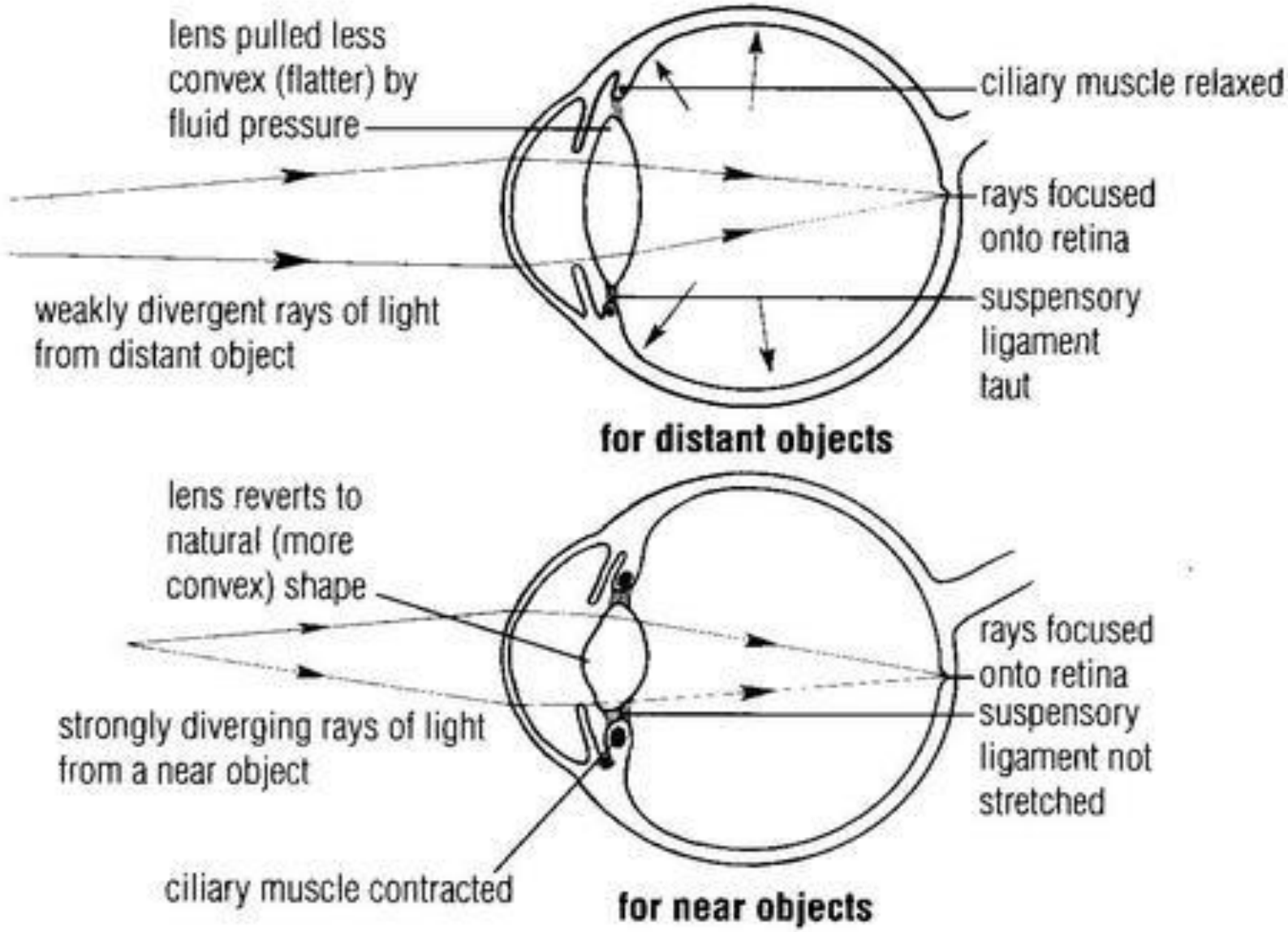
So this defect can be treated by using cancave lens.

In case of far sightedness light focused behind retina, so no image is formed. This defect can be treated by using convex lens.

Accommodation of lens to focus image:

Accommodation is a reflex process to bring light rays from object into perfect focus on retina by adjusting the lens.
When an object lying less than 6 meter away is viewed, image formed behind retina. But due to accommodation of lens image formed in retina and we can see the object.

For accommodation to view closer object, ciliary muscle contract and lens become thick which causes focus on closer object.
Similarly, when distant object is viewed, ciliary muscles relaxes, so the tension of ligament become greater which pull lens and lens become thinner, due to which image forms on retina.
The normal eye is able to accommodate light from object about 25 cm to infinity.


lens pulled less convex (flatter) by fluid pressure
ciliary muscle relaxed
rays focused onto retina
suspensory ligament taut
weakly divergent rays of light from distant object
for distant objects
lens reverts to natural (more convex) shape
rays focused onto retina
suspensory ligament not stretched
strongly diverging rays of light from a near object
ciliary muscle contracted
for near objects

Focus on nearer object:

Ciliary muscle contract———-ciliary body pull forward and inward ———tension on suspensory ligament of lens reduced ——lens become thicker and round due to its elasticity ——possible to focus near object

Focus on distant object:

Ciliary muscles relaxes——ciliary body return to its normal resting state—— tension on suspensory ligament of lens increases———-lens become thinner and flat———possible to focus distant object

Convergence of image:

Human eye have binocular vision, it means although we have two eye, we perceive single image

In binocular vision, two eye ball turns slightly inward to focus a close object so that both image falls on corresponding points on retina at same time. This phenomenon is called convergence.

Photo-chemical activity in retina and conversion into neural impulse

1. Photochemical activity in rods:

Each eye contains 125 million rods which are located in neuro-retina. Rods contains light sensitive pigment-rhodopsin.

Rhodopsin is a molecule formed by combination of a protein scotopsin and a light sensitive small molecule retinal (retinene).

Retinene (retinal) is a carotenoid molecule and is derivative of vitamin A (retinol).

Retinal exists in two isomeric form- cis and trans according to light condition.

The extra cellular fluids surrounding rod cells contains high

concentration of Na+ ion and low concentration of K+ ions while concentration of Na+ is low and K+ is high inside rod cells. The concentration is maintained by Na-K pump

In resting phase, K+ tends to move outside the rod cells creating slightly –ve charge inside.

When light is falls on rod cell, it is absorbed by rhodopsin and it breaks into scotopsin and 11 cis- retinal. The process is known as bleaching.

11 cis-retinal absorb photon of light and change into all trans-retinal which inturn activates scotopsin into enzyme.

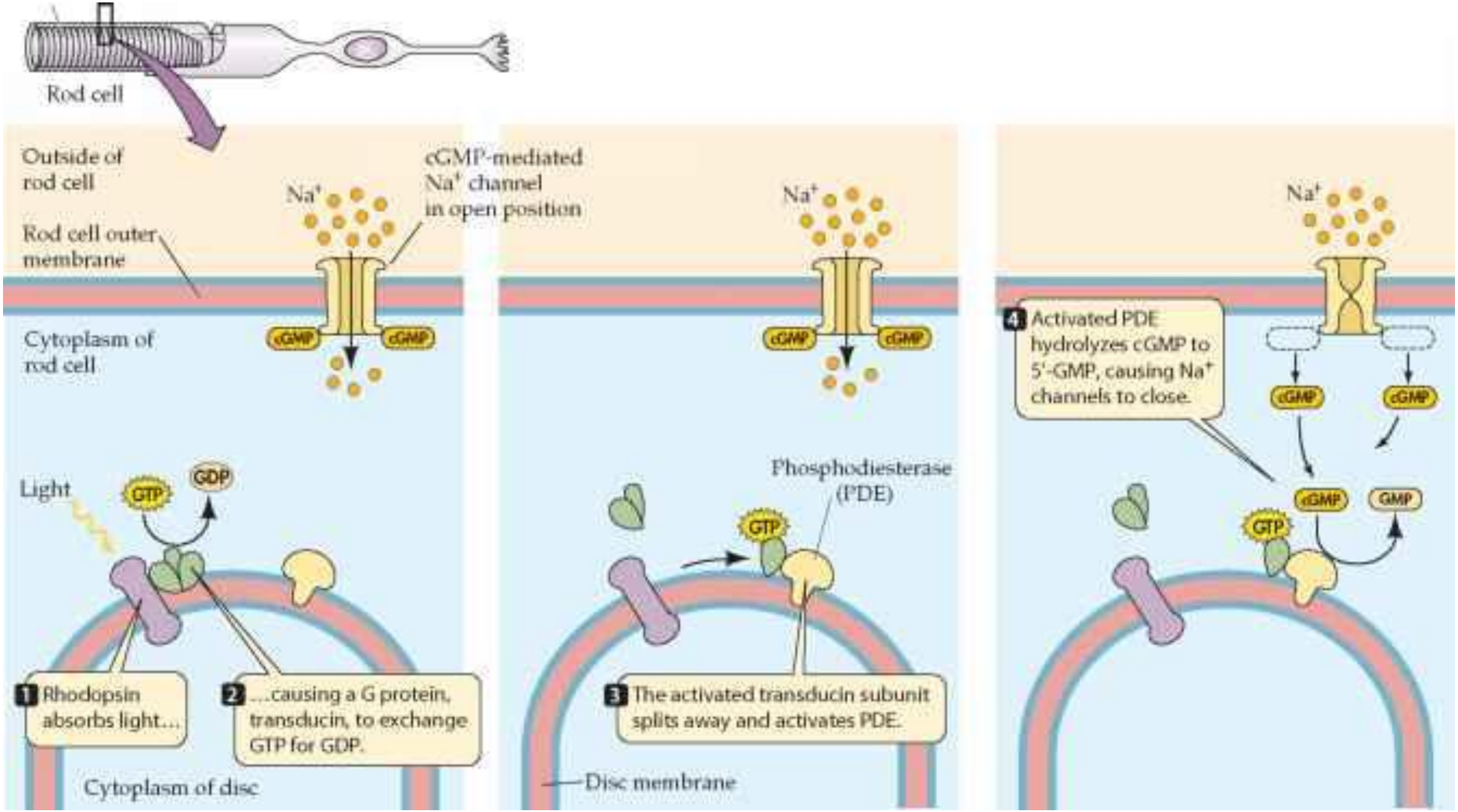
This reaction produces large amount of transducin which activates another enzyme phosphodiesterase

This reaction produces large amount of transducin which activates another enzyme phosphodiesterase.

Phosphodiesterase hydrolyses cGMP which causes to cease the flow of Na+ ion inside rod cell. This causes increased negative charge inside cell creating hyperpolarized state.

Hyperpolarized rod cells transmit the neural signal to bipolar cell.

Bipolar cell, amacrine cell and ganglion cell process the neural signal and generate action potential to transmit to brain via optic nerve.


Rod cell
Outside of rod cell
Rod cell outer membrane
Cytoplasm of rod cell
cGMP-mediated Na+ channel in open position
Na+
cGMP
cGMP
Light
GTP
GDP
1 Rhodopsin absorbs light...
2 ...causing a G protein, transducin, to exchange GTP for GDP.
Cytoplasm of disc
Phosphodiesterase (PDE)
3 The activated transducin subunit splits away and activates PDE.
Disc membrane
4 Activated PDE hydrolyzes cGMP to 5'-GMP, causing Na+ channels to close.
GMP

2. Photochemical activity in cones:

Each eye contains 7 million cone cells.

The neural activity in cone cell is similar to that of rod cell but there are three different types of cone cells and each cone cell contains different photo-pigment and are sensitive to red, green and blue.

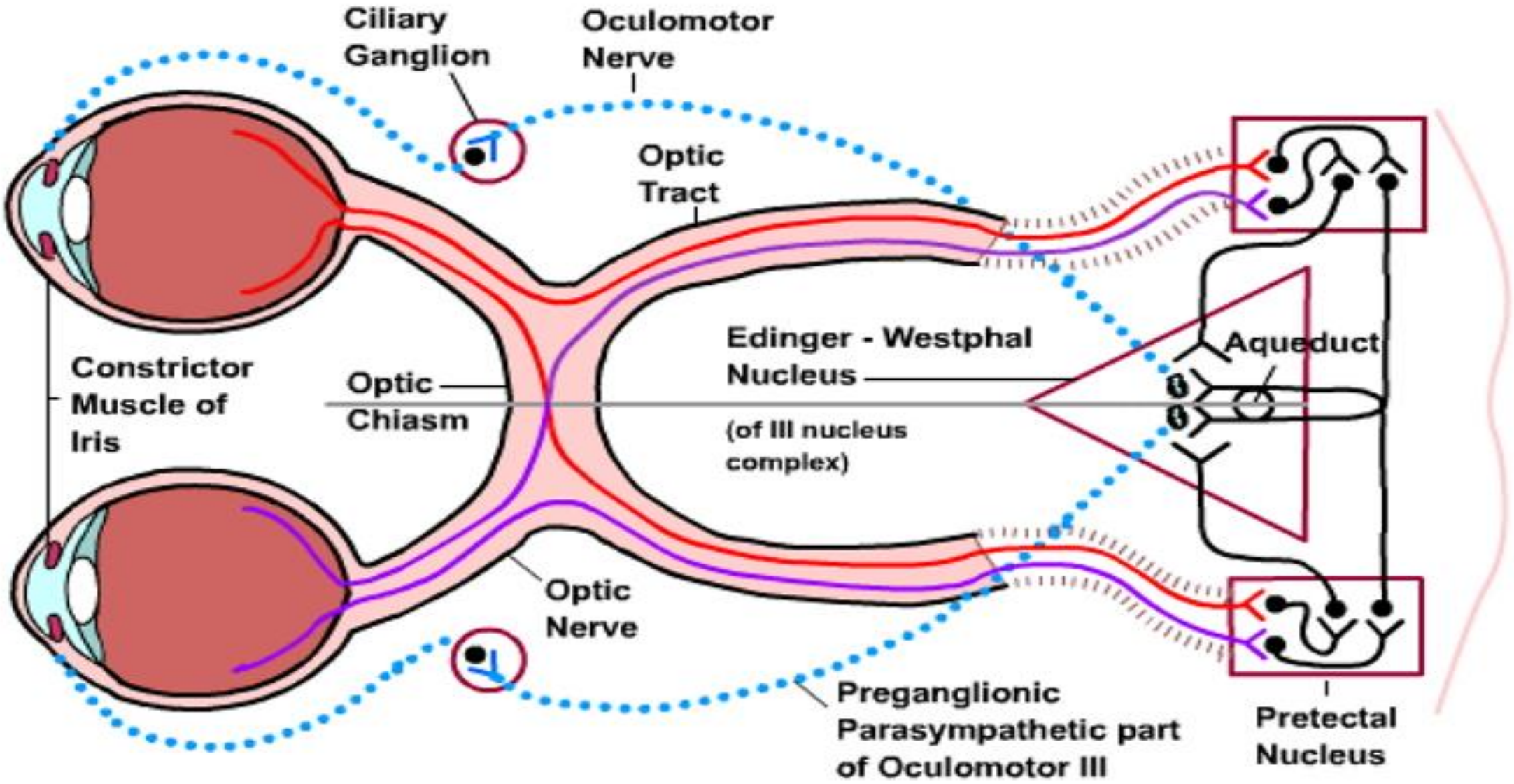
Like rod, cone cell contains iodopsin as photo-pigment which is composed of 11 cis-retinal and photopsin.

The perception of color depends upon which cone are stimulated.

The final perceived color is combination of all three types of cone cell stimulated depending upon the level of stimulation.

The proper mix of all three color produce the perception of white and absence of all color produce perception of black.

Processing of image in brain and perception:



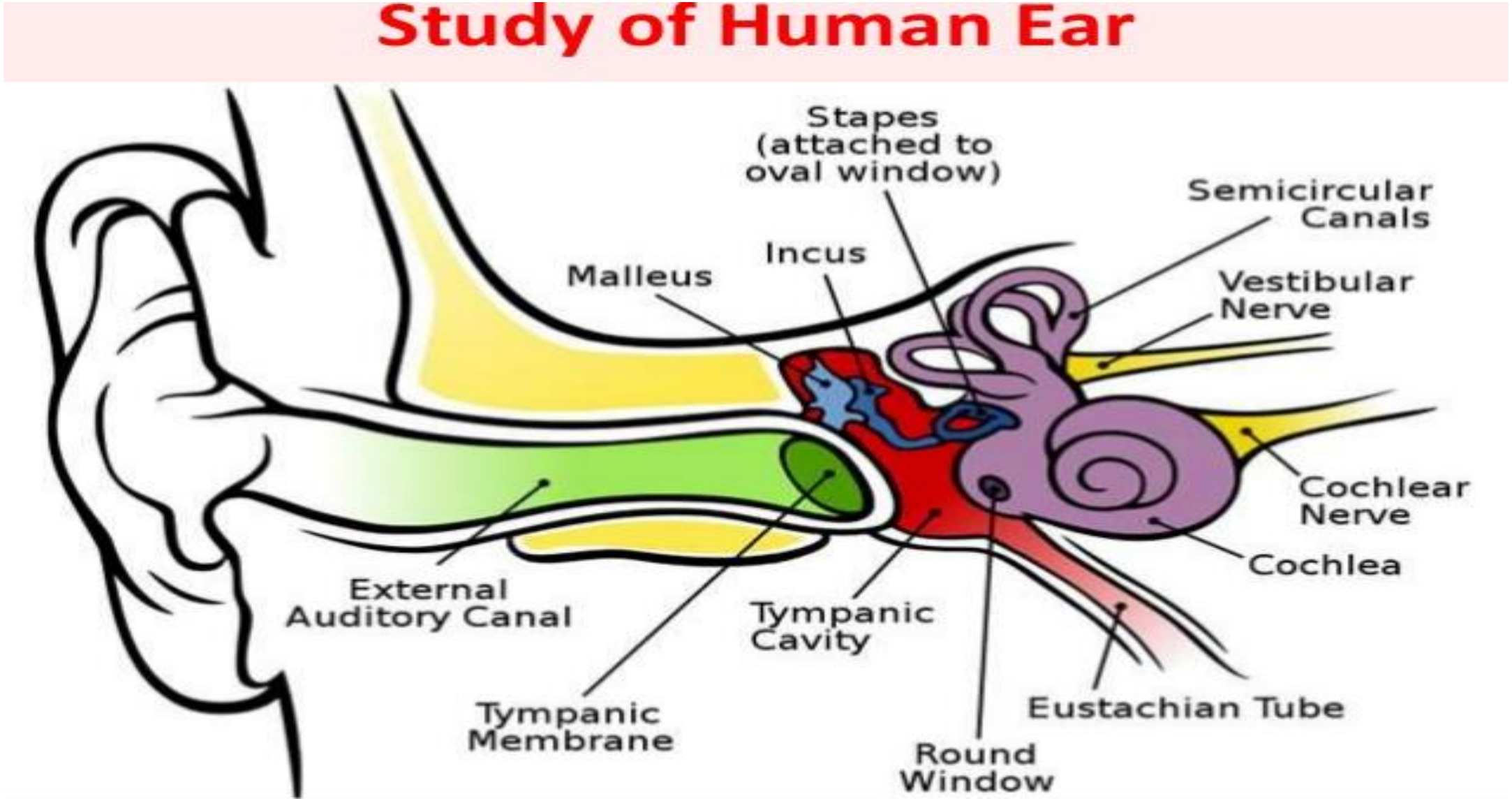
All visual information originates in retina due to stimulation of rods and cones are conveyed to brain.
Retina contains 5 types of cells and they are interconnected by synapse. These cells are photoreceptor cells (rod and cone), bipolar cell, ganglion cell, horizontal cell and amacrine cell.

Photoreceptor cells, bipolar cells and ganglion cells transmit impulse directly from retina to brain.
The nerve fiber of ganglion cells from both eyes carries impulse along two optic nerve.

The optic nerves meets at optic chiasma where fibers from nasal half of each retina cross-over but fibers from temporal half of each retina do not cross-over.
The optic nerve after crossing the chiasma is called as optic tract.

Each optic tract continues posteriorly until it synapse with neuron in thalamus called lateral geniculate body which project to primary visual cortex in occipital lobe of cerebrum and image is perceived.

Physiology of Hearing



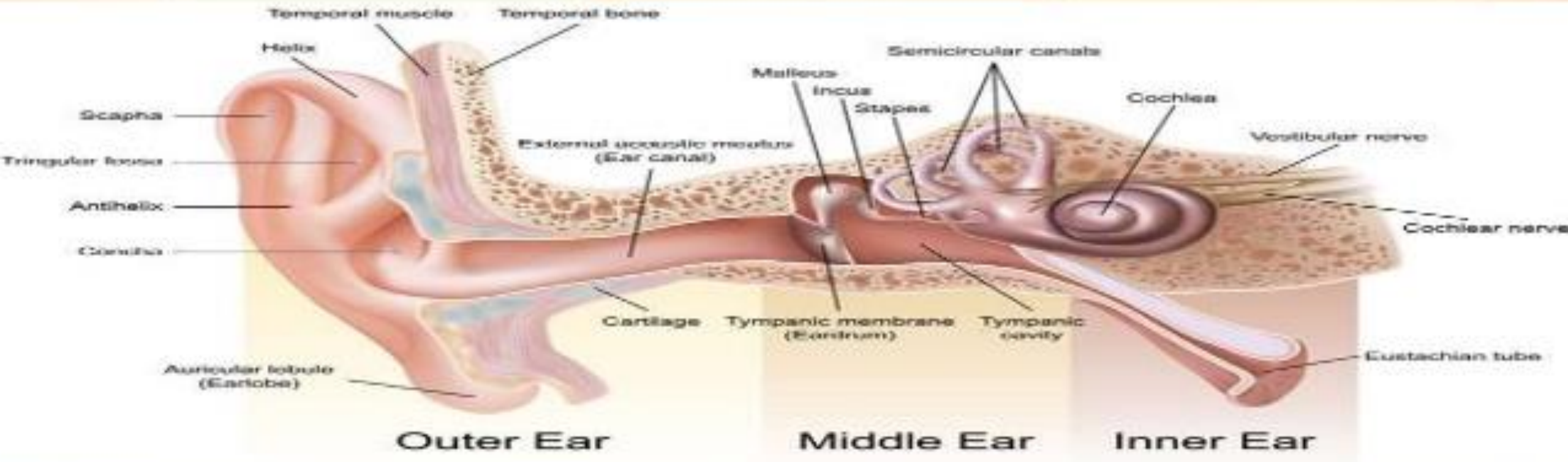
INTRODUCTION

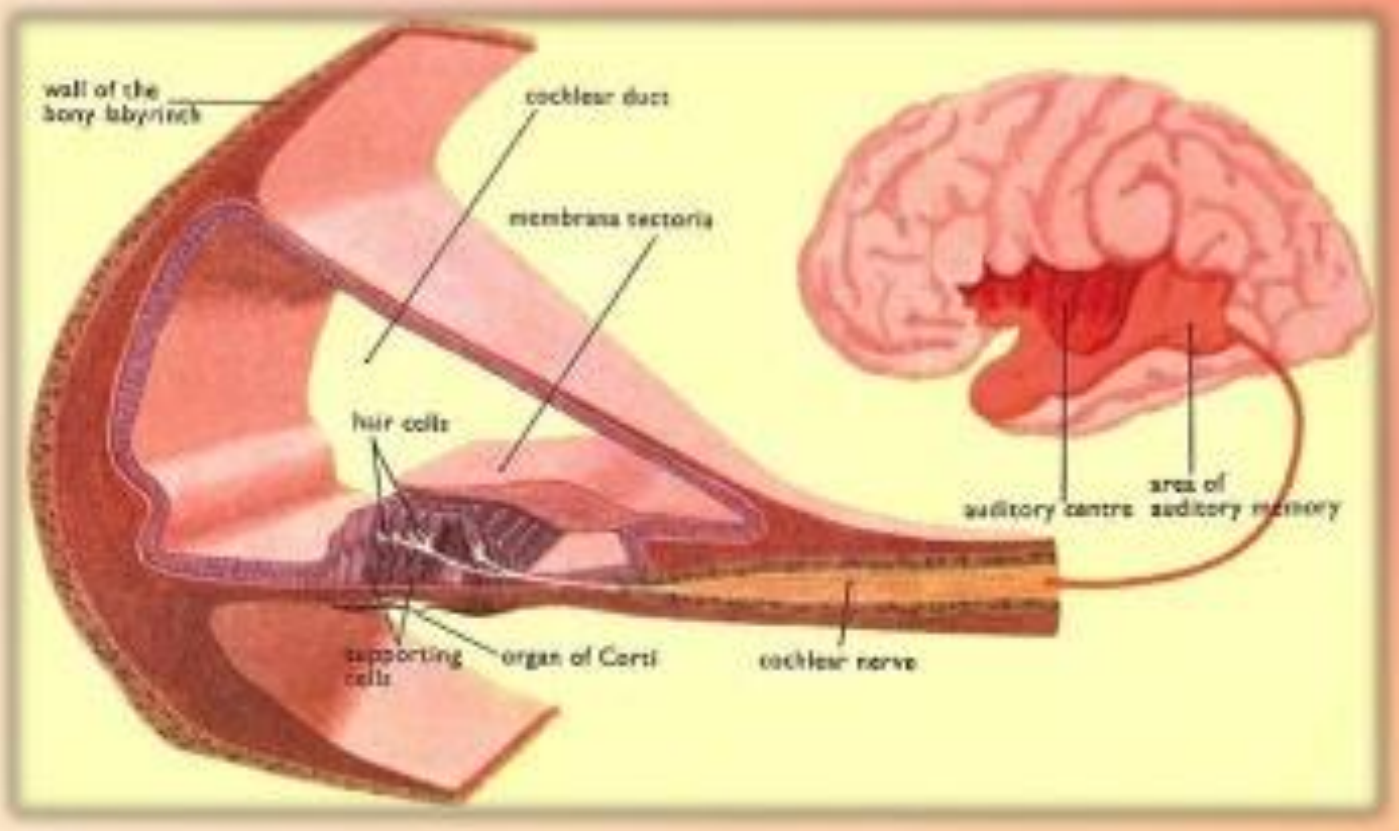
- The auditory system is comprised of three components; the outer, middle, and inner ear, all of which work together to transfer sounds from the environment to the brain.

The outer ear includes the portion of the ear that we see—the pinna/auricle and the ear canal.

The middle ear is composed of the tympanic membrane and the cavity, which houses the ossicular chain.

The inner ear is composed of the sensory organ for hearing—the cochlea, as well as for balance—the vestibular system.

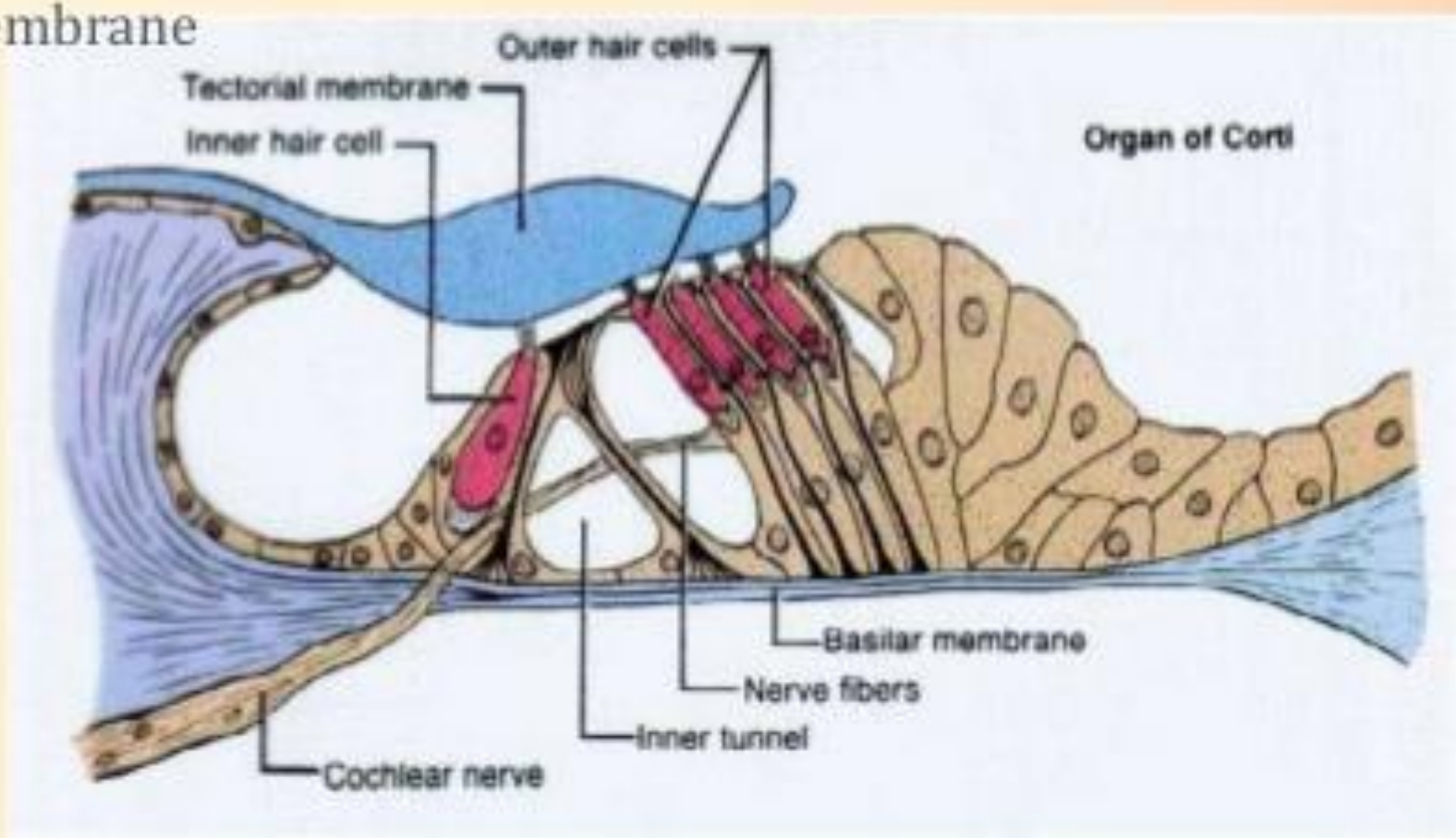




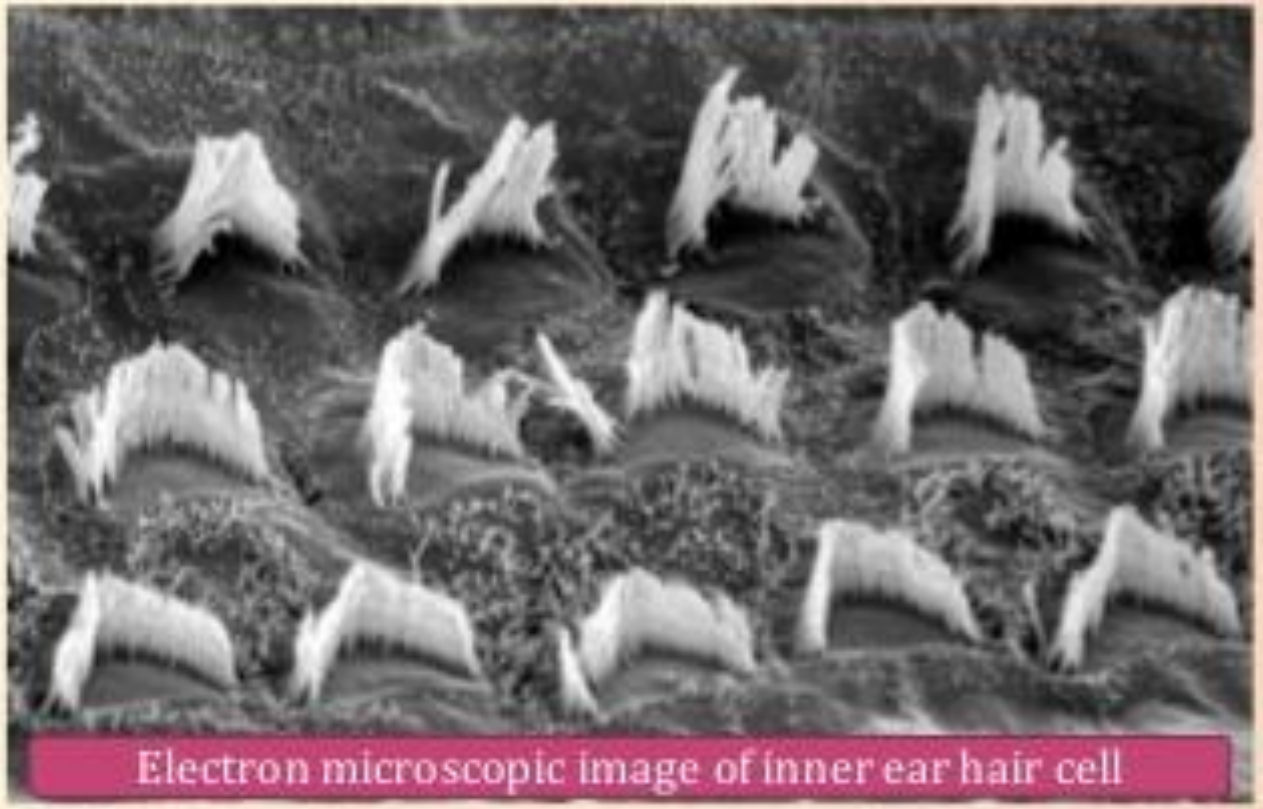
Auditory System

ORGAN OF CORTI

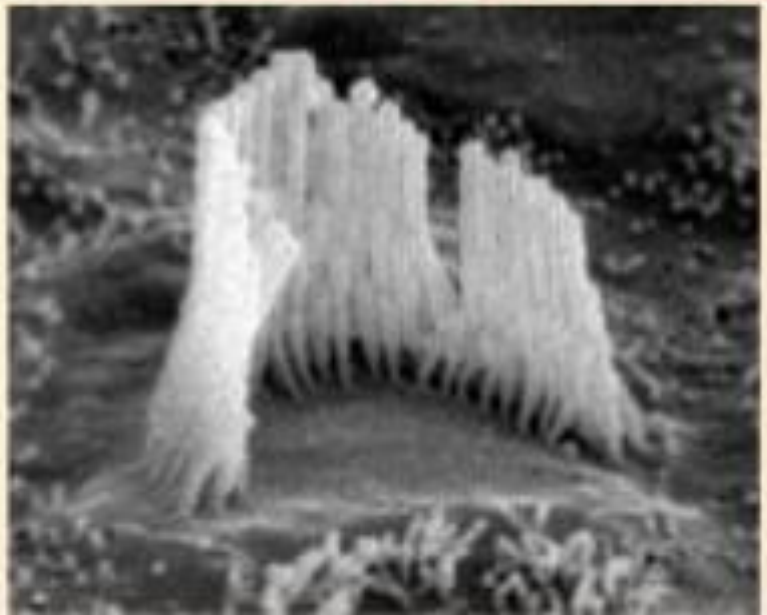
- Sense organ of hearing
- Situated in the basilar membrane
- Components are:
  - Tunnel of corti
  - Hair cells
  - Supporting cells
  - Tectorial membrane



- ***Tunnel of corti*** is formed by inner and outer rods. Contains a fluid called CORTILYMPH. → exact function is unknown
- ***Hair cells*** are important receptors of hearing and convert sound energy to electrical energy. Inner hair cells are supplied with afferent cochlear fibres. Outer hair cells mainly receive efferent innervation from olivary complex.
- ***Supporting cell.*** Deiter's cell are situated between outer hair cells and provide support. Cells of Hensen lie outside Deiters cell.
- ***Tectorial membrane*** consist of gelatinous matrix with delicate fibres. Overlies the organ of corti.



Electron microscopic image of inner ear hair cell

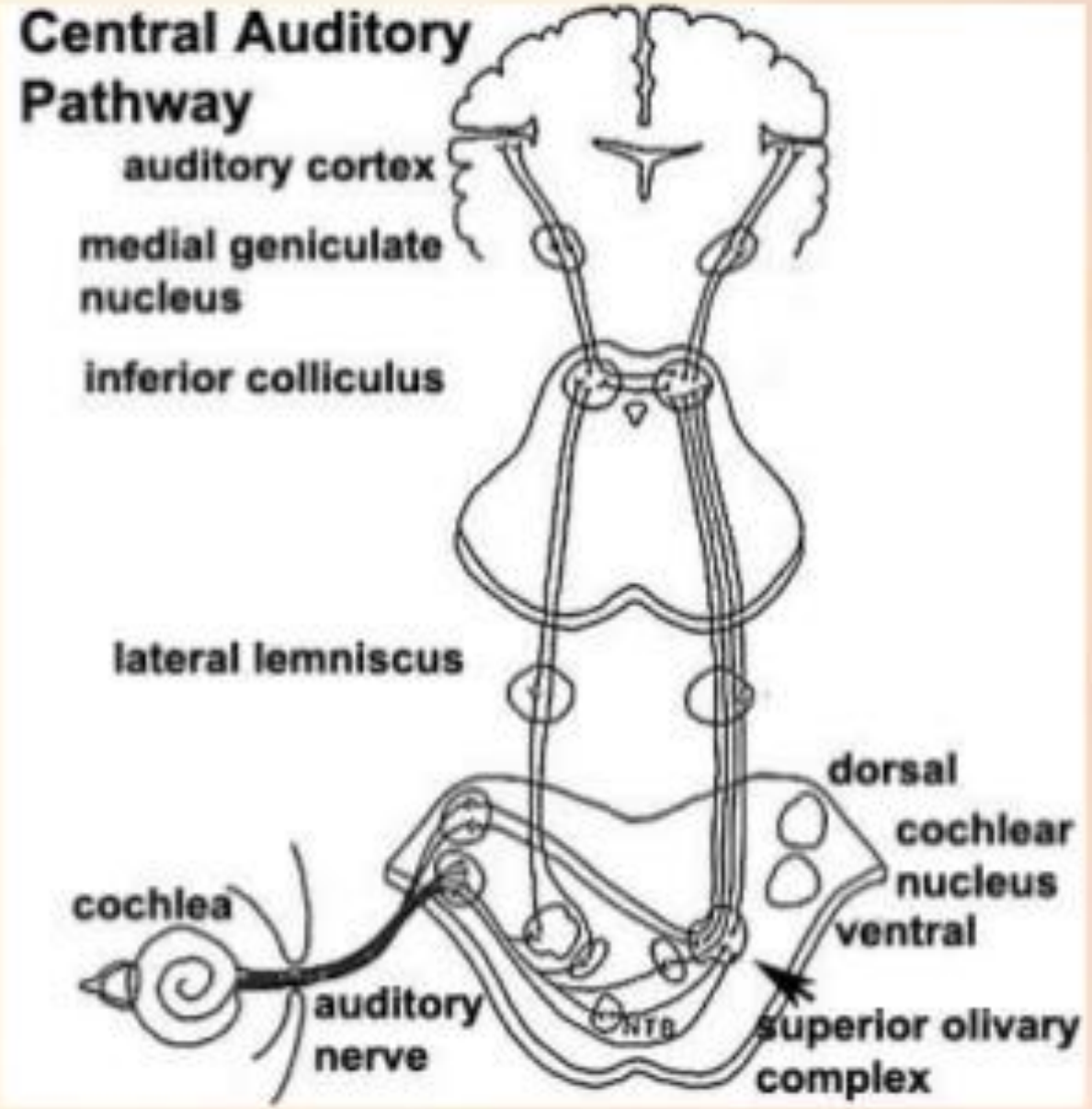


Higher magnification of one of these cells

Nerve supply of Hair cells

- 95% of Afferent fibres of spiral ganglion supply the inner hair cells, while 5% supply the outer hair cells.
- Efferent fibres to the hair cells come from olivocochlear bundle whose cell bodies are situated in superior olivary complex.

- Hair cells are innervated by dendrites of bipolar cells of spiral ganglion which is situated in Rosenthal's canal.
- Axons of these cells form cochlear division of auditory nerve (CN VIII)
- The area of cortex concerned with hearing is situated in the Superior Temporal Gyrus (Brodmann's area 81)



Outer vs. Inner Hair Cells

OHC	IHC
Shape: "flask"	Shape: "goblet"
~12,000	~3500
5-10% Afferent	90-95% Afferent
Vulnerable to trauma	Less Vulnerable
Free to move	Surrounded by cells
Active-help IHCs	Passive
Allow us to hear low intensities	Respond to mid-high intensities
Can test them: OAEs	Any true hearing test

Physiology of hearing

INTRODUCTION

- Any vibrating object causes waves of compression and rarefaction and is capable of producing sound.
- Sound travels faster in liquids and solids than in air (roughly 344 m per second)
- When sound energy has to pass from air to liquid, most of it is reflected because of the impedance offered by the liquid

Mechanism of hearing can be broadly classified into :

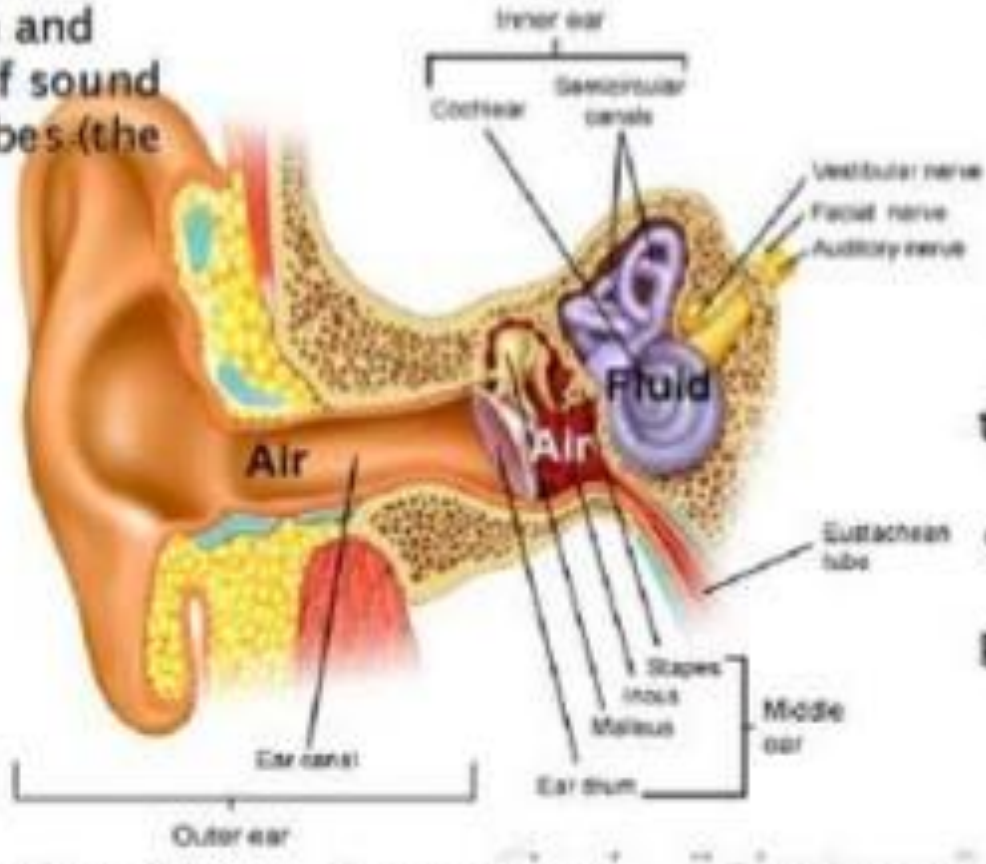
Mechanical conduction of sound

Transduction of mechanical energy into electrical impulses

Conduction of electrical impulses to brain

The Hearing mechanism

1. Collection and concentration of sound waves by ear lobes (the pinna)



4. In and out movement of the footplate of stapes at the oval window of cochlea – pressing on the fluid in the cochlear

2. Vibration of tympanic membrane (ear drum) in harmony with the frequency of sound source

3. Movement of three ossicles as lever system

- Pressure changes in the labyrinthine fluids move the basilar membrane.
- This stimulates the hair cells on the Organ of Corti

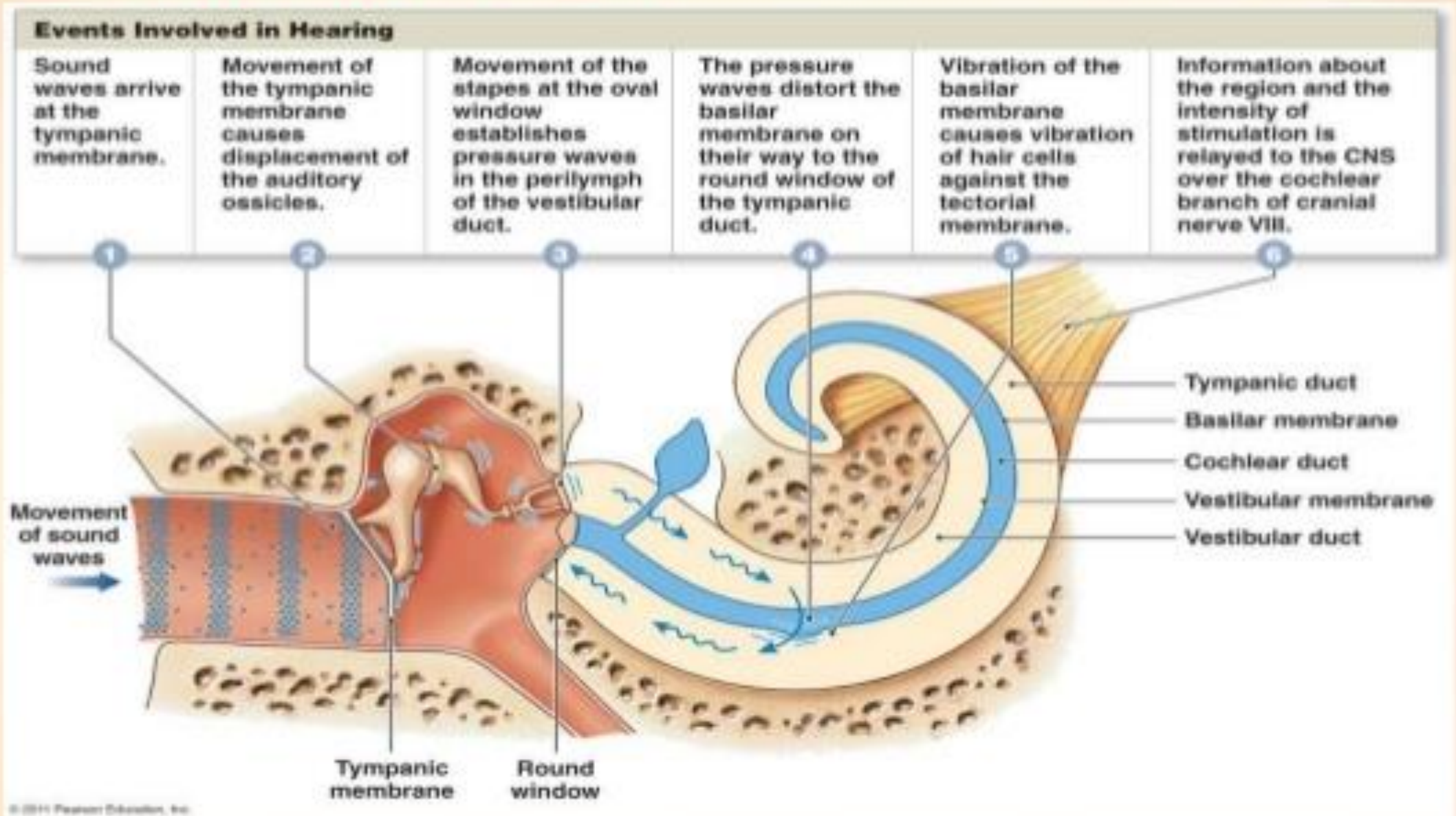
You might get a doubt right now – if sound is reflected when transferred from air to water then how do we hear clearly through the labyrinthine fluids?

- Nature has compensated for this loss of energy by having the middle ear in between which converts sound of **greater amplitude but lesser force to that of lesser amplitude and greater force.**
- This function of the middle ear is called impedance matching mechanism or transformer action.

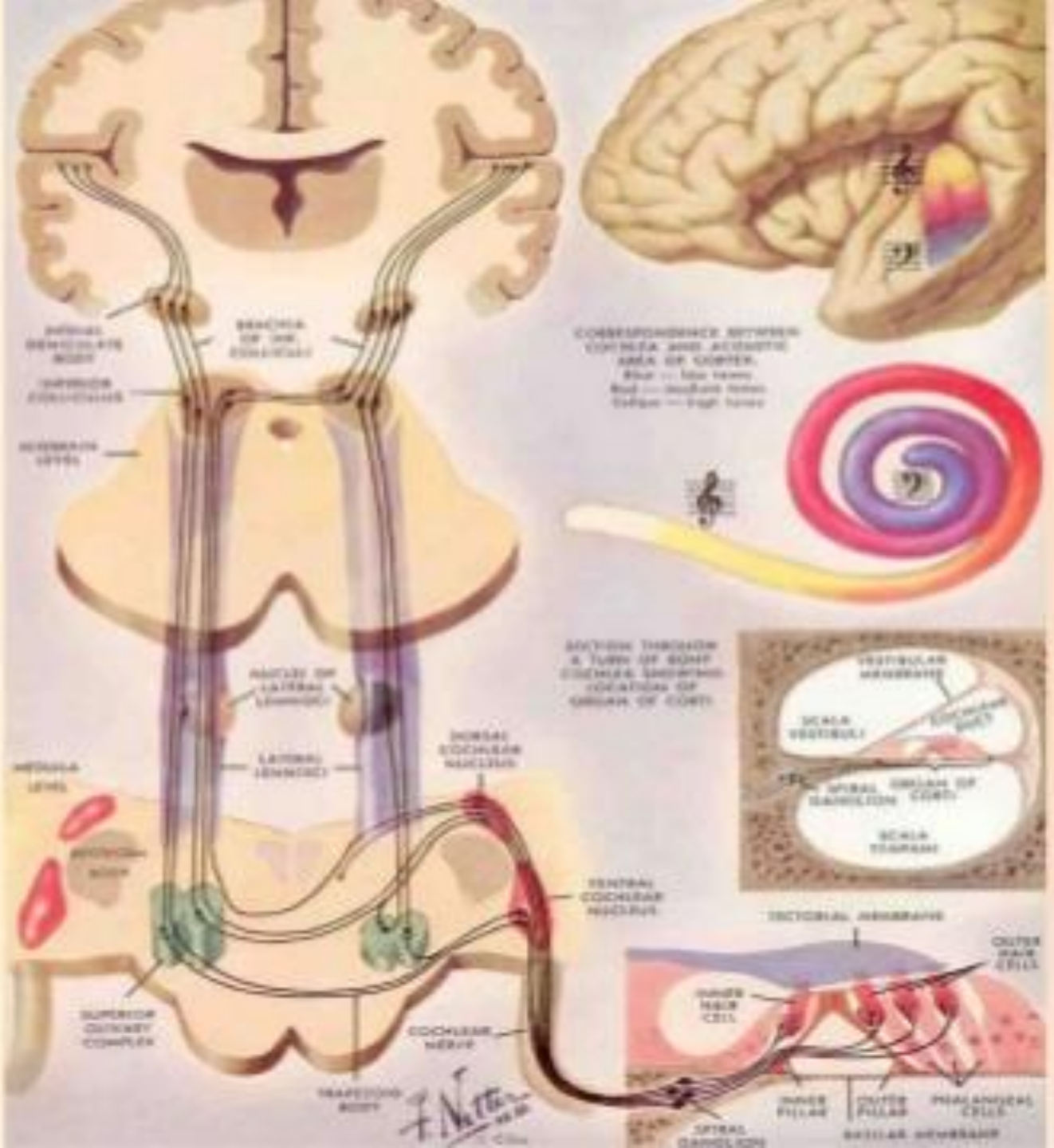
TRANSFORMER ACTION

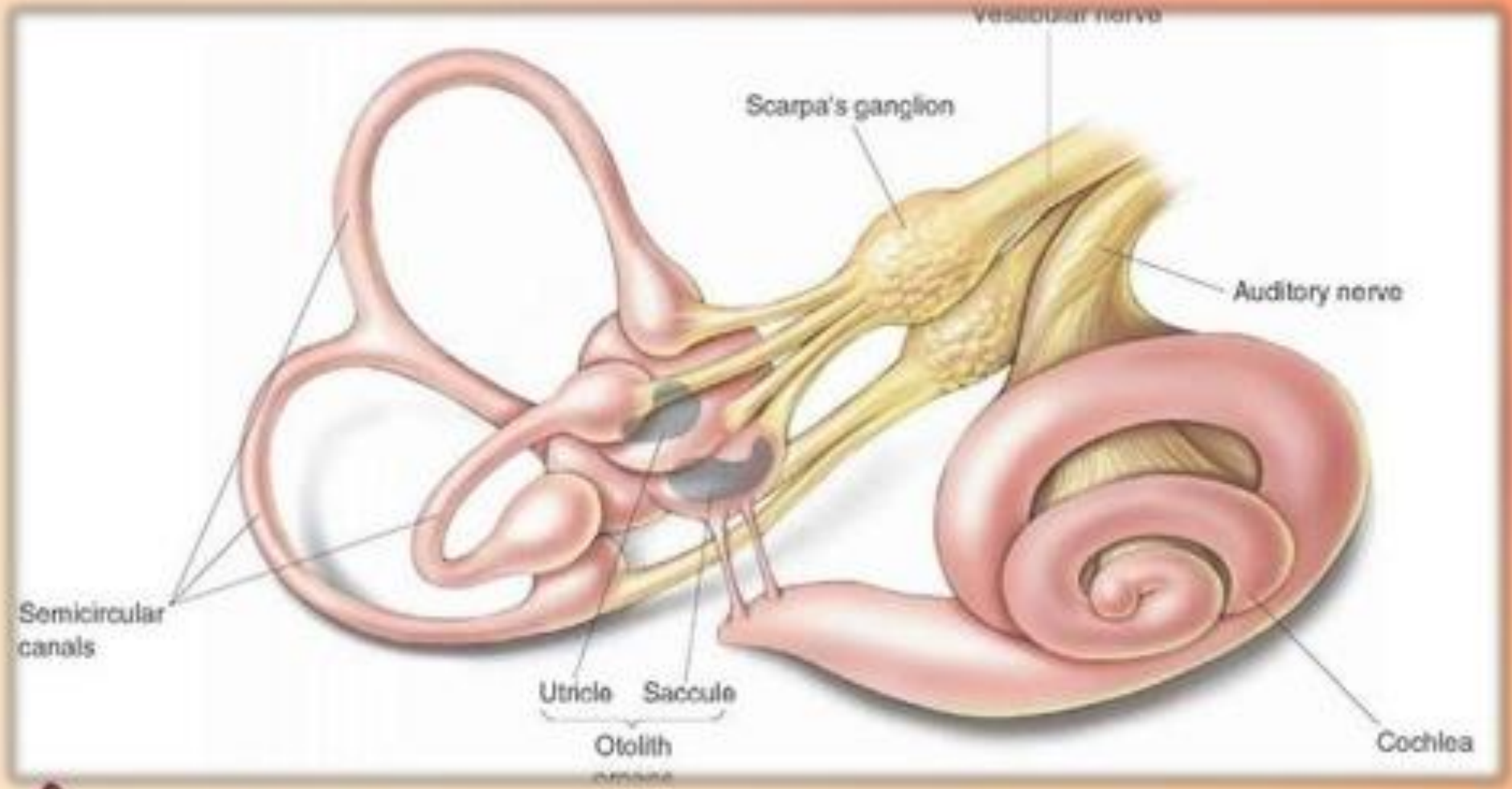
- It is accomplished by:
  - *Lever action of the ossicles :* handle of malleus is 1.3 times longer than long process of incus.
  - *Hydraulic action of tympanic membrane:* the area of tympanic membrane is much larger than the area of stapes footplate. The average ratio is 21:1. The effective vibratory area of tympanic membrane is only 2/3rd , so the effective areal ratio is reduced to 14:1. This is the mechanical advantage provided by the tympanic membrane.
  - *Curved membrane effect:* movements of the tympanic membrane are more at the periphery than at the centre.

TRANSDUCTION OF MECHANICAL ENERGY TO ELECTRICAL IMPULSES



NEURAL PATHWAYS





Vestibular System

PERIPHERAL RECEPTORS

- **CRISTAE:**
- Located in the ampullated ends of 3 semicircular ducts.
- It is a crest like mound of connective tissue which lies on sensory epithelial cells.
- Cilia of sensory hair cells project into the cupula.
- Hair cells are 2 types:
  - Type 1 – flask shaped with single large nerve terminal.
  - Type 2 – cylindrical with multiple nerve terminals

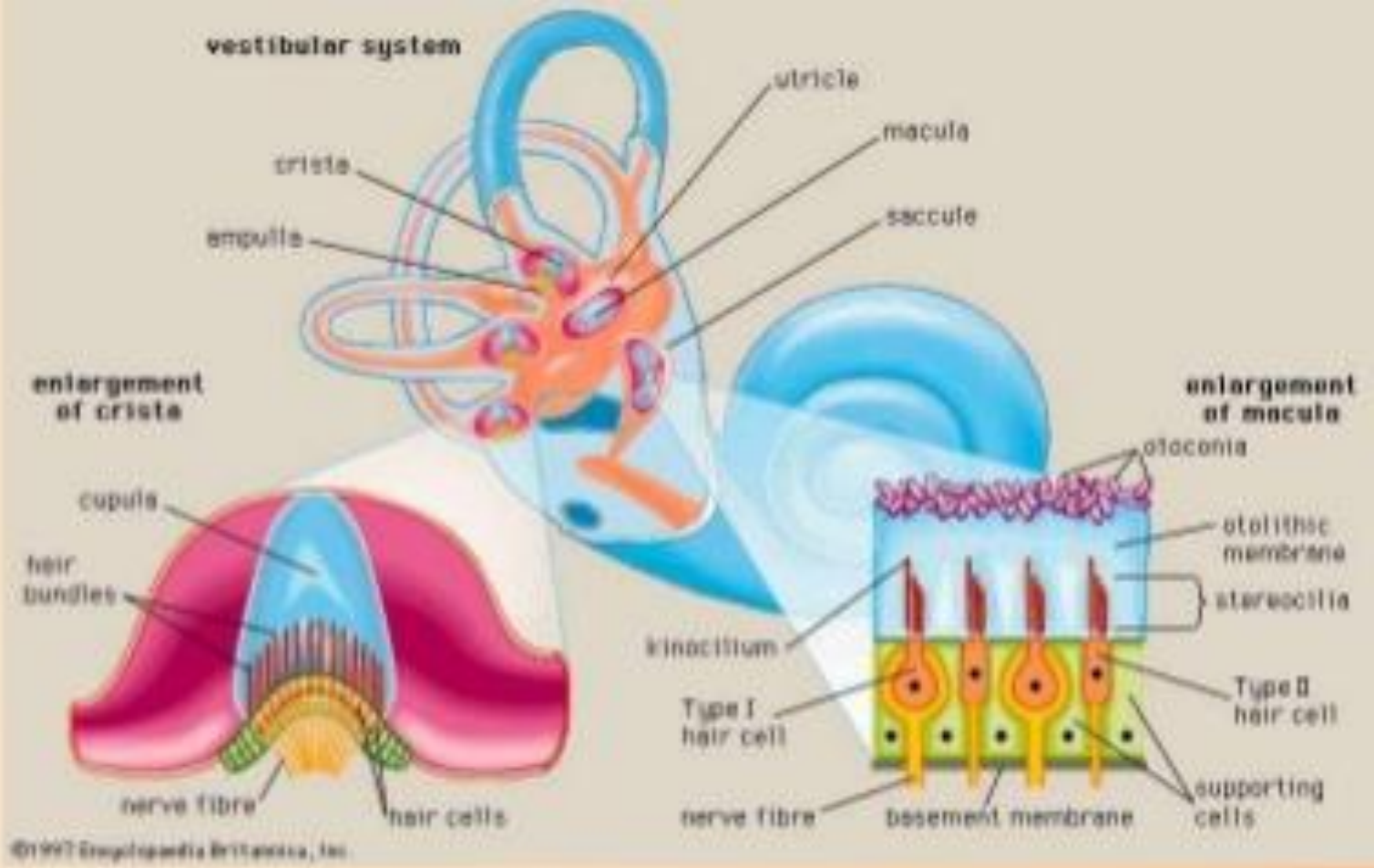
- **MACULAE:**
- Located in the otolith organs (utricle and saccule)
- Macula of utricle lies in its floor in a horizontal plane
- Macula of saccule lies in its medial wall in a vertical plane.
- Macula consists of 2 parts:
  - Sensory neuroepithelium
  - Otolithic membrane

VESTIBULAR NERVE / SCARPA'S GANGLION

- Located in the lateral part of the internal acoustic meatus
- Contains bipolar cells
- Distal processes of bipolar cells innervate sensory epithelium
- Central processes aggregate to form the vestibular nerve

CENTRAL VESTIBULAR CONNECTIONS

- AFFERENTS come from:
  - Peripheral vestibular receptors
  - Cerebellum
  - Reticular formation
  - Spinal cord
  - Contralateral vestibular nuclei
- EFFERENTS go ito:
  - Nuclei of CN III(optic nerve), IV (trochlear nerve)and VI (abduscent nerve)
  - Motor part of spinal cord
  - Cerebellum
  - ANS
  - Vestibular nuclei of opposite side
  - Cerebral cortex



Physiology of Vestibular System

Vestibular system

- The vestibular system, which contributes to balance and to the sense of spatial orientation, is the sensory system that provides the leading contribution about movement and sense of balance.
- Together with the cochlea it constitutes the labyrinth of the inner ear in most mammals, situated in the vestibulum in the inner ear
- Vestibular system is divided into:
  - ✓ ***Peripheral*** - made of membranous labyrinth and vestibular nerve
  - ✓ ***Central*** – made of nuclei and fibre tracts in CNS to integrate vestibular impulses

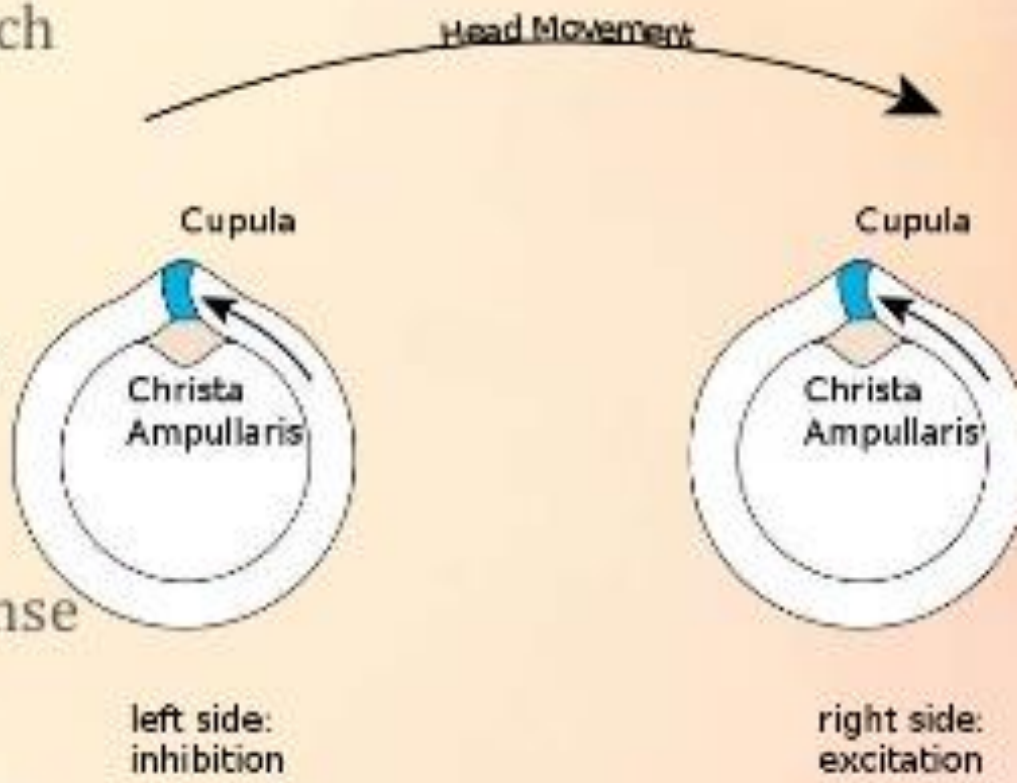
SEMICIRCULAR CANALS

- The semicircular canal system detects rotational movements.
- The vestibular system contains three semicircular canals in each labyrinth.
- They are approximately orthogonal (right angles) to each other, and are called
  - the horizontal (or lateral),
  - the anterior semicircular canal (or superior) and
  - the posterior (or inferior) semicircular canal.

Anterior and posterior canals may be collectively called vertical semicircular canals.

PUSH – PULL SYSTEM

- The canals are arranged in such a way that each canal on the left side has an almost parallel counterpart on the right side.
- Each of these three pairs works in a *push-pull* fashion: when one canal is stimulated, its corresponding partner on the other side is inhibited, and vice versa.
- This push-pull system makes it possible to sense all directions of rotation
- Vertical canals are coupled in a crossed fashion, i.e. stimulations that are excitatory for an anterior canal are inhibitory for the posterior, and vice versa.

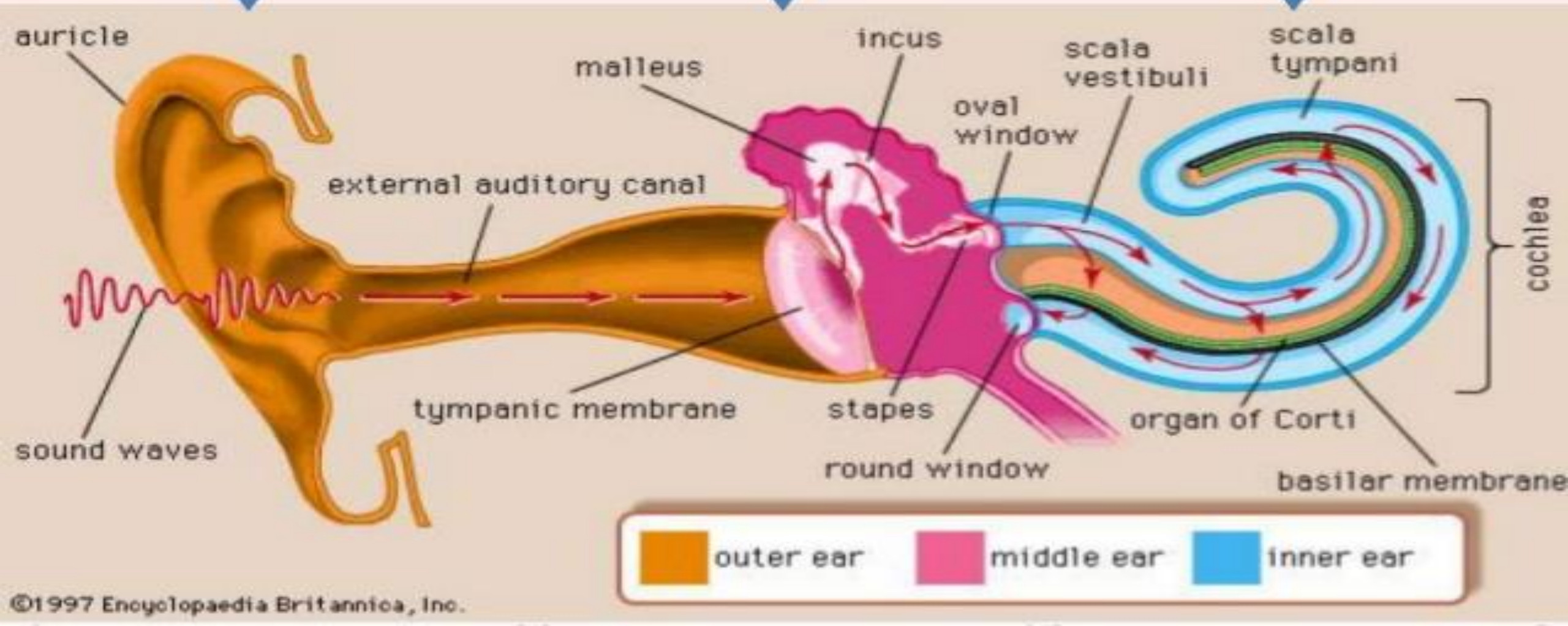


OTOLITHIC ORGANS

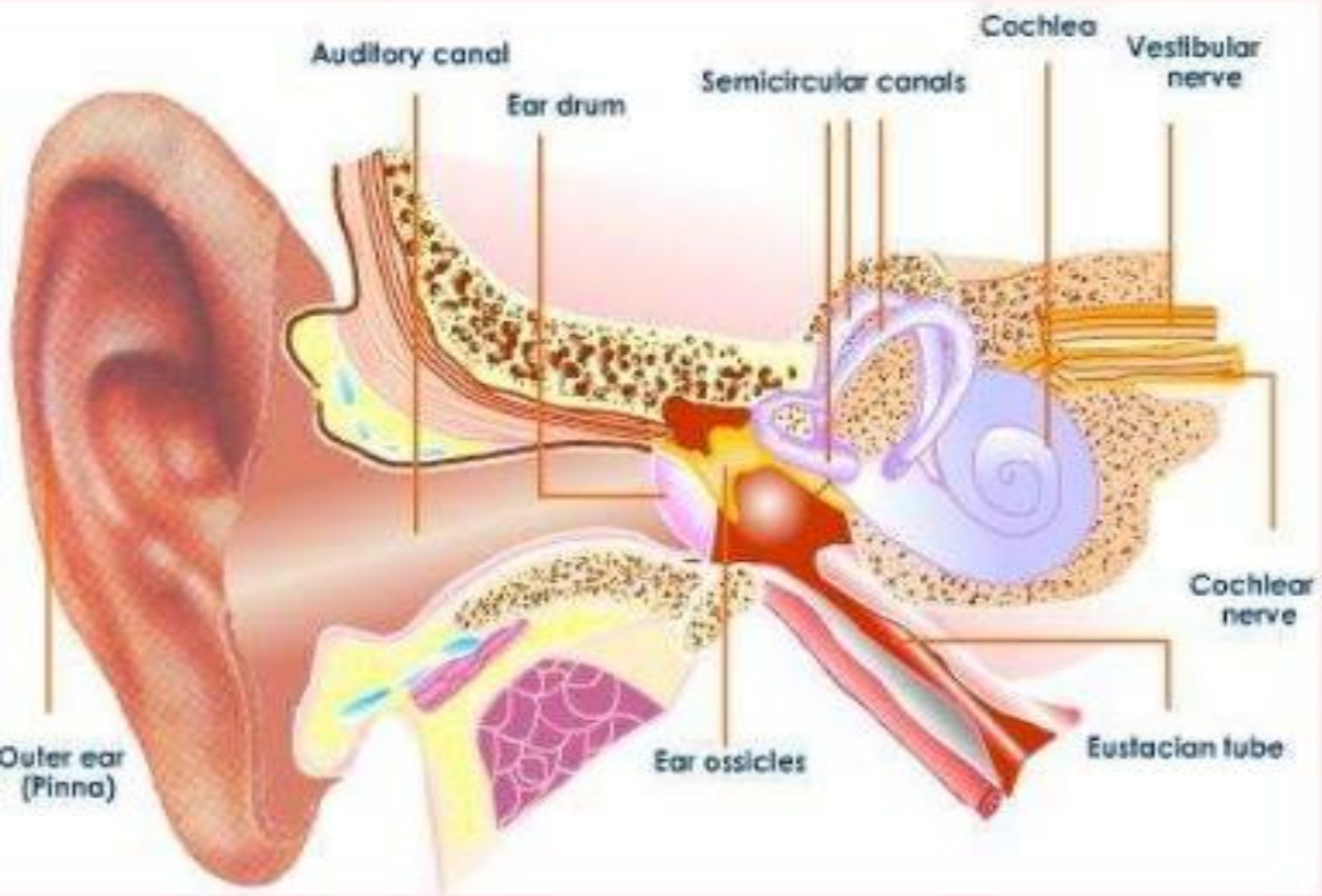
- The otolithic organs sense linear accelerations.
- There are two on each side, one called utricle, the other saccule.
- These organs each contain a patch of hair cells and supporting cells called a macula.
- Each hair cell of a macula has 40-70 stereocilia and one true cilium called a kinocilium. The tips of these cilia are embedded in a otolithic membrane.
- Any orientation of the head causes a combination of stimulation to the utricles and saccules of the two ears.
- The brain interprets head orientation by comparing these inputs to each other and to other input from the eyes and stretch receptors in the neck, thereby detecting whether the head is tilted or the entire body is tipping.

Option first end and option second start; you may choose any one

Three main parts of the Ear



Outer Ear

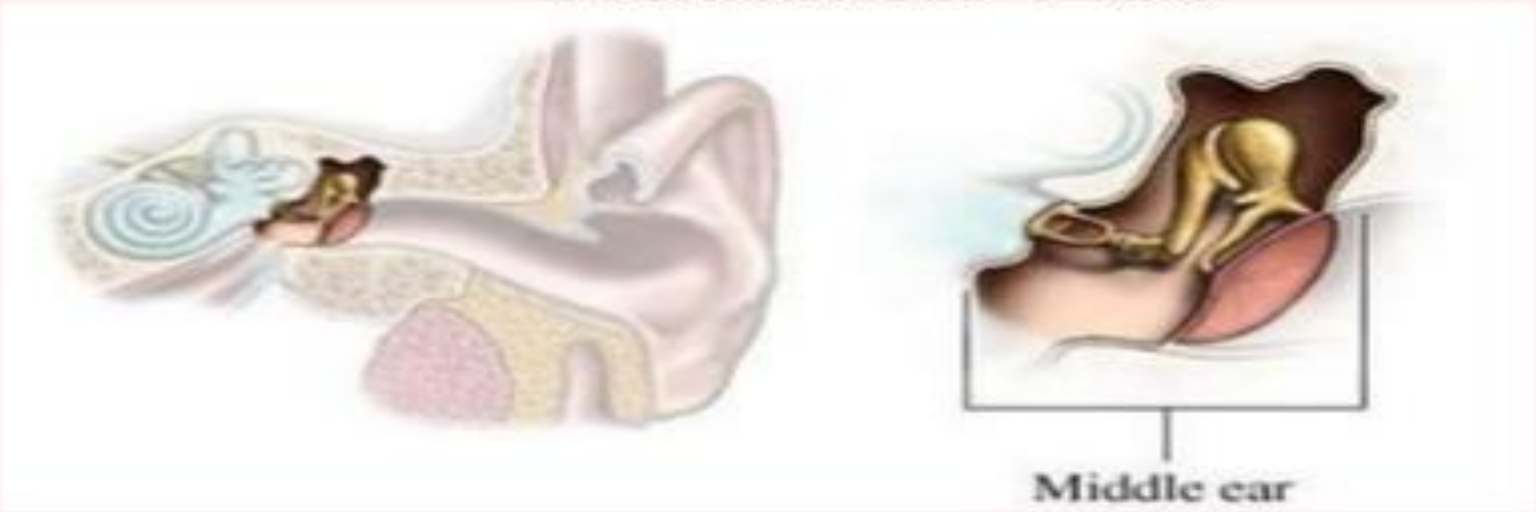

Auditory canal
Ear drum
Semicircular canals
Cochlea
Vestibular nerve
Cochlear nerve
Outer ear (Pinna)
Ear ossicles
Eustacian tube

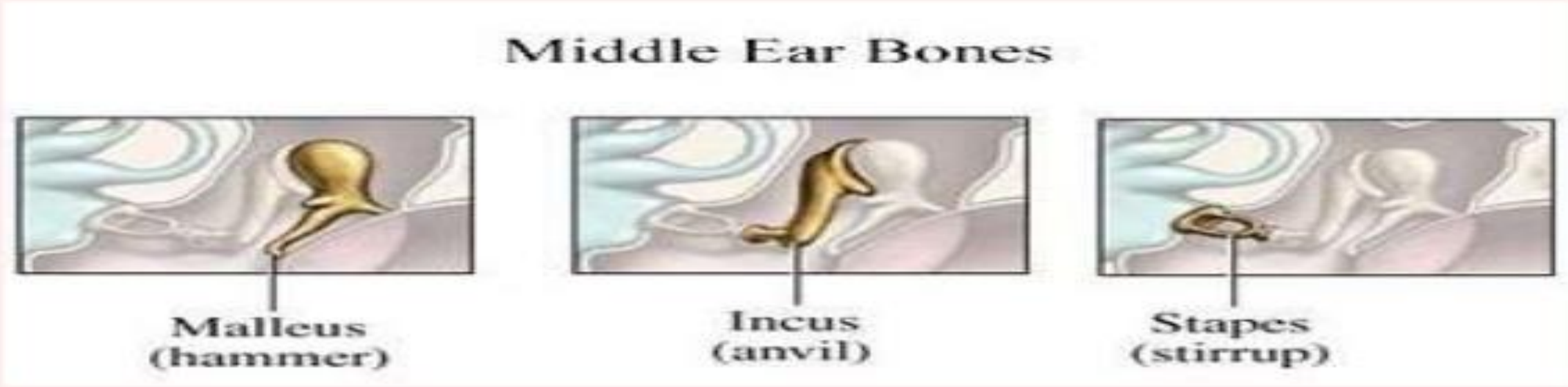

Outer Ear
pinna
auditory canal

Outer Ear

Structure	Function/Explanation
Pinna	Pinna is also called auricle or external ear, the flap like organ on either side of the head. Made of cartilage and skin and shaped like a funnel. It collects and directs sounds into the ear canal.
Auditory canal	Auditory canal is a tunnel or passageway that begins at the external ear and extends inward toward the eardrum. A long tube lined with hairs. It directs sounds to the eardrum.

Middle Ear


Middle ear

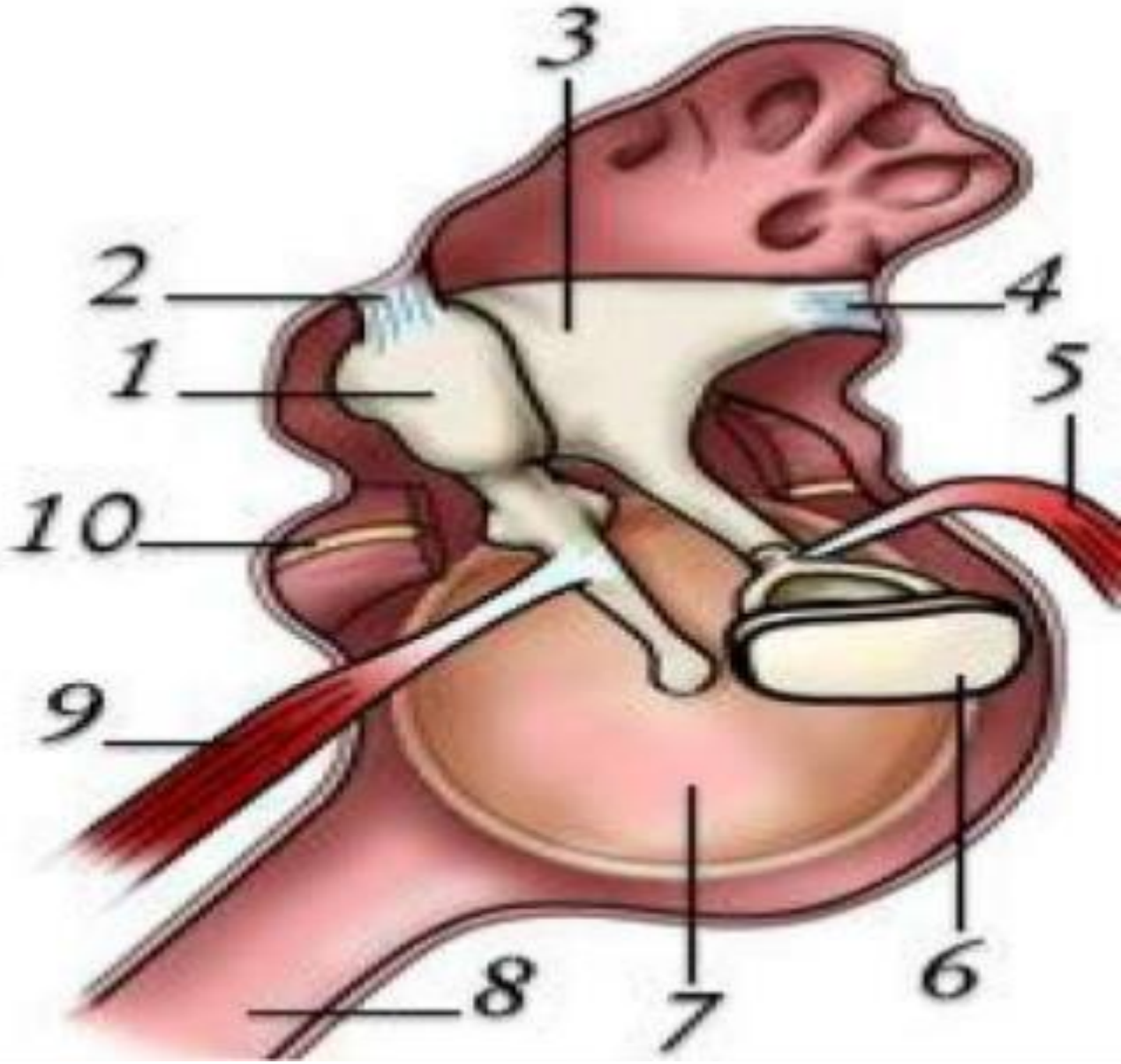

Middle Ear Bones
Malleus
(hammer)
Incus
(anvil)
Stapes
(stirrup)

Middle Ear

Structure	Function/Explanation
Eardrum	Eardrum also known as the tympanic membrane. semitransparent thin fibroelastic connective tissue membrane, covered by epidermis (external side) and a cuboidal mucous epithielium (inner side) .It vibrates and transmits sound waves to the ossicles.
Ossicles	Made up of three small bones which is the hammer *(Malleus)*, the anvil *(Incus)* and the stirrup *(stapes)*. It intensifies the vibrations of the sound waves by 22 times before transmitting to the oval window.
Eustachian tube	A narrow tube that joins the middle ear to the throat that balances the air pressure at both sides of the eardrum.
Oval window	An oval-shaped, thin membrane between the middle ear and the inner ear. It transmits sound vibrations from the middle ear to the inner ear.

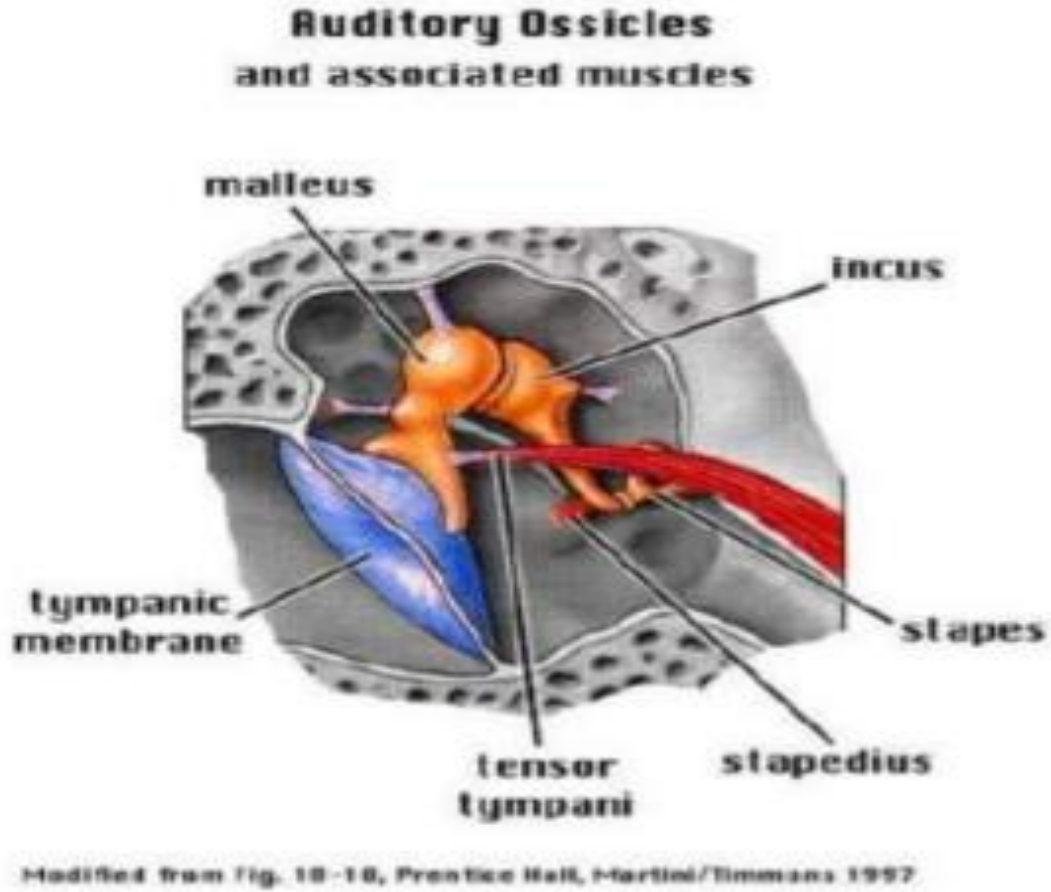
Bones & Muscles of Middle ear

- (1) Malleus ;
- (2) Malleus ligament ;
- (3) Incus ;
- (4) Incus ligament;
- (5) Stapes muscle (stapedius);
- (6) Stapes footplate;
- (7) Eardrum;
- (8) Eustachian tube;
- (9) Malleus muscle (tensor tympani);
- (10) Nerve (chorda tympani) sectioned.



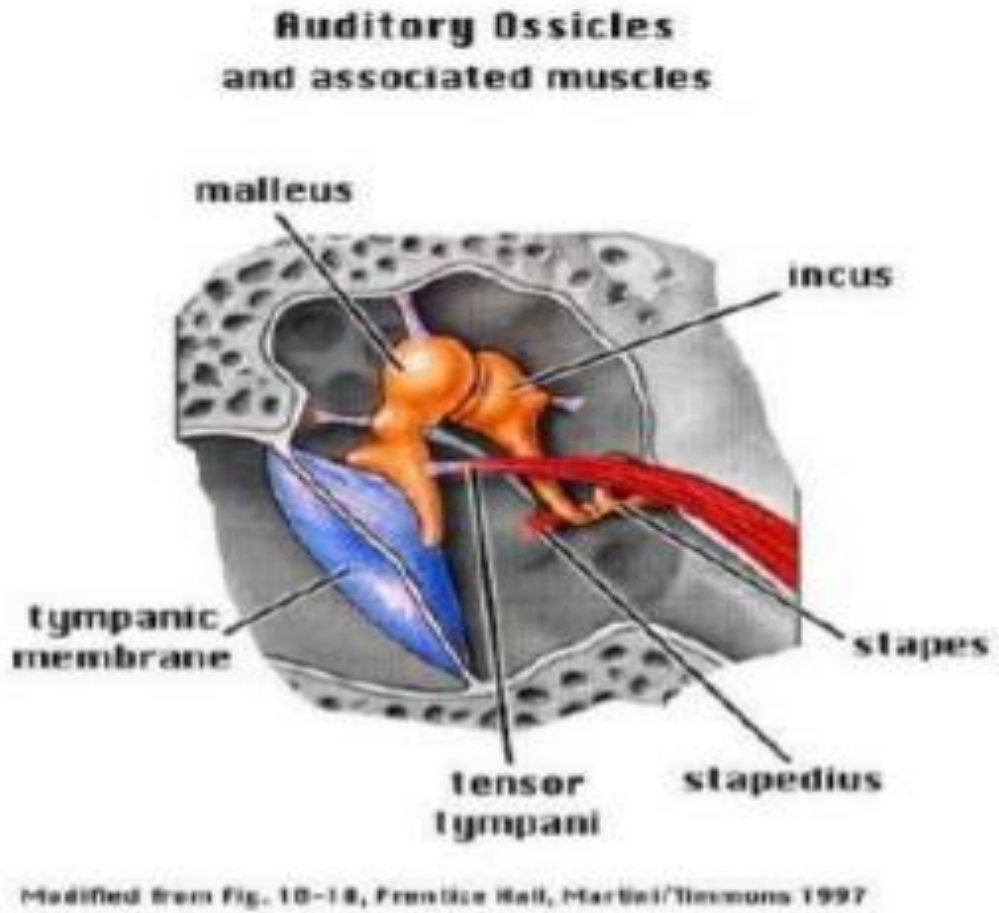
Muscles of the Middle Ear

- **Stapedius**
  - the **smallest skeletal muscle** in the human body.
  - **connects to the stapes** (the stirrup)
  - when it contracts, **it reduces the action of the stapes** (i.e., it reduces amplification)
  - **contracts just before speaking and chewing** because our own speaking and chewing actually could be loud enough to damage the sensitive mechanisms of the inner ear if the sounds were further amplified.
  - innervated by a branch of the Facial Nerve (CN VII).

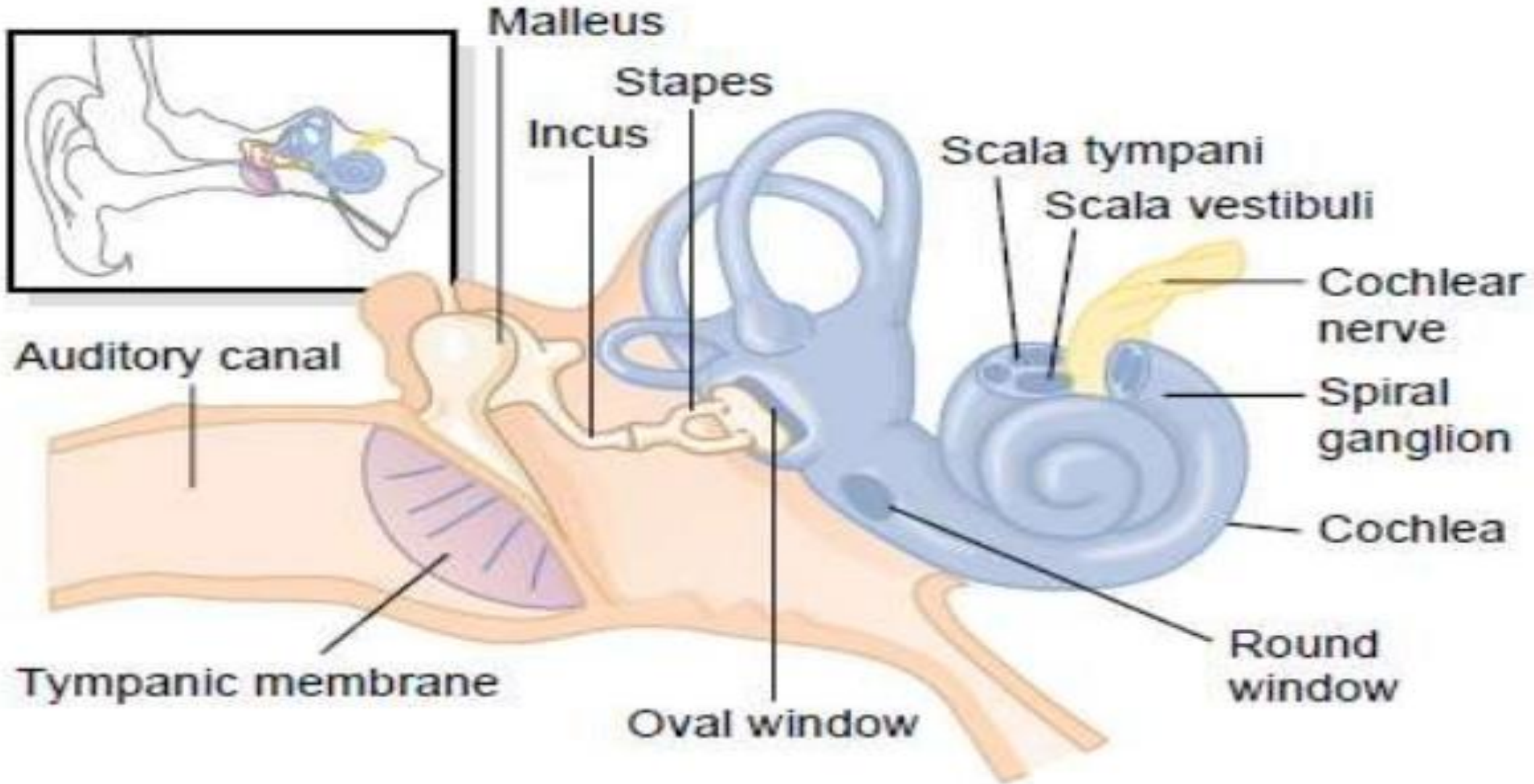


Muscles of the Middle Ear

- **Tensor tympani**
  - **inserts on the malleus** and **acts to <u>tense</u> the tympanic membrane** reducing the effectiveness of sound transmission, protecting the inner ear during loud sounds.
  - innervation from a branch of the mandibular nerve (V3 of CN V).



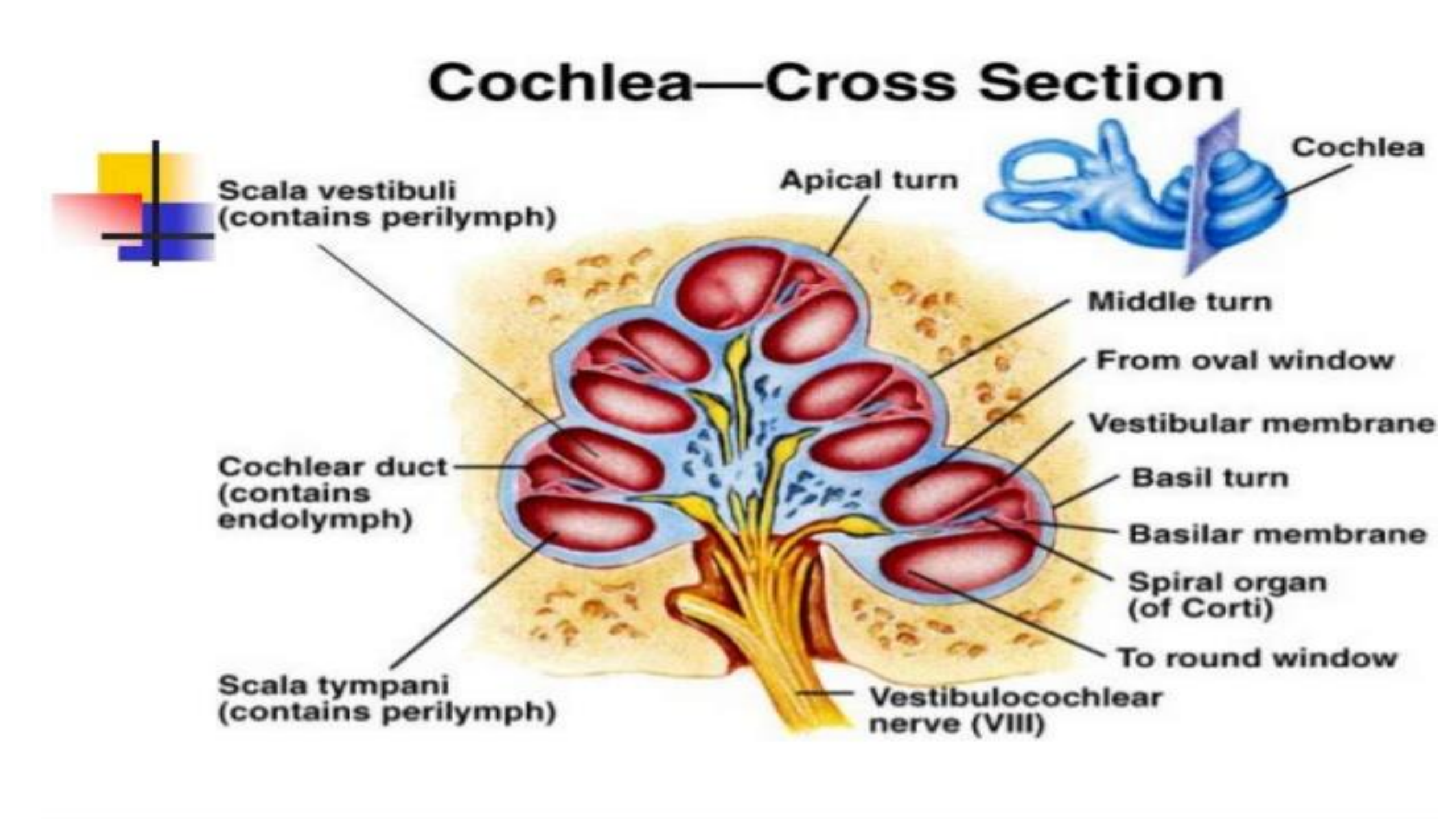
Inner ear


Malleus
Stapes
Incus
Scala tympani
Scala vestibuli
Cochlear nerve
Auditory canal
Spiral ganglion
Cochlea
Round window
Tympanic membrane
Oval window

Inner Ear or Bony Labyrinth

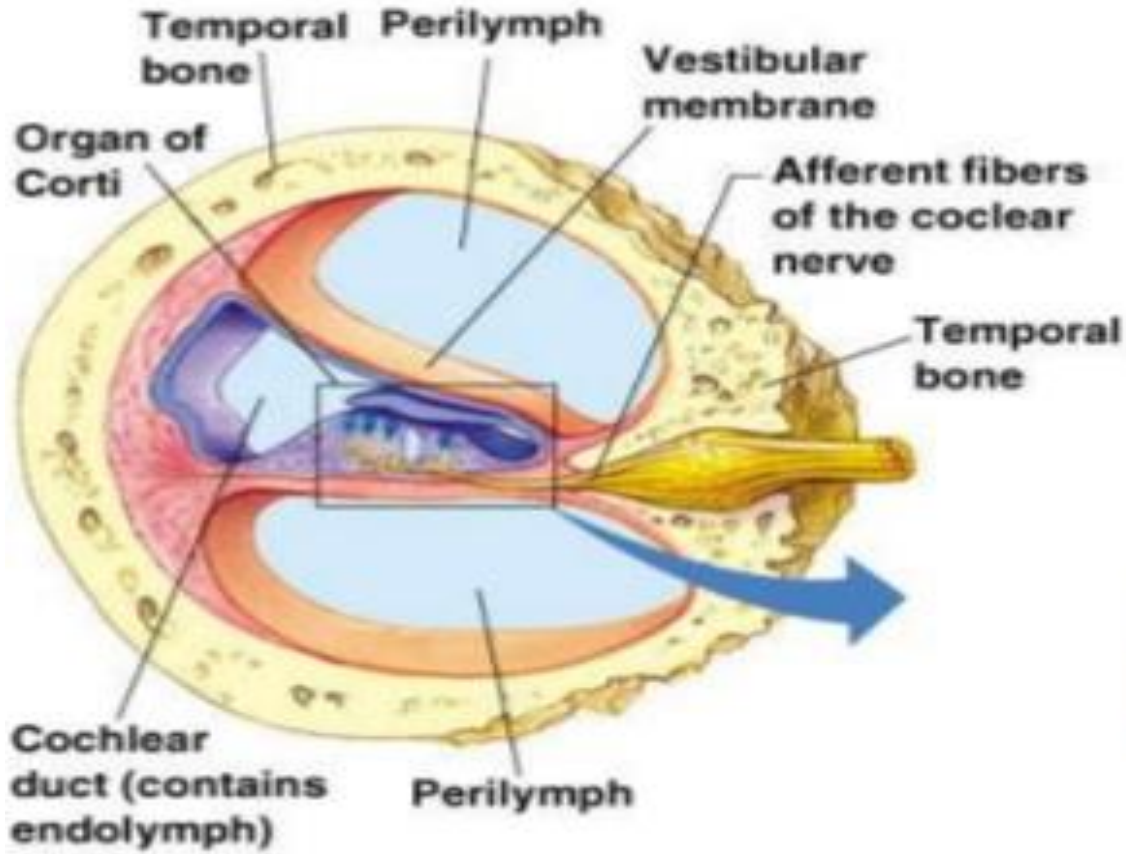
Structure	Function/Explanation
Cochlea	**Cochlea (bony labrynth) is a system of coiled tubes snail-like structure in the inner ear filled with fluid called *perilymph &endolymph.* It consists of three tubes (canals)** 1. Scala Vestibuli (Vestibular canal) 2. Scala media (cochlear canal) 3. Scala tympani (tympanic canal) **And ORGAN OF CORTI (electromechanically sensitive hair cells)**
Auditory nerve	**It carries the impulses to the brain which then interprets the impulses as sound.**
Semicircular Canals & Vestible	**For body balance.**

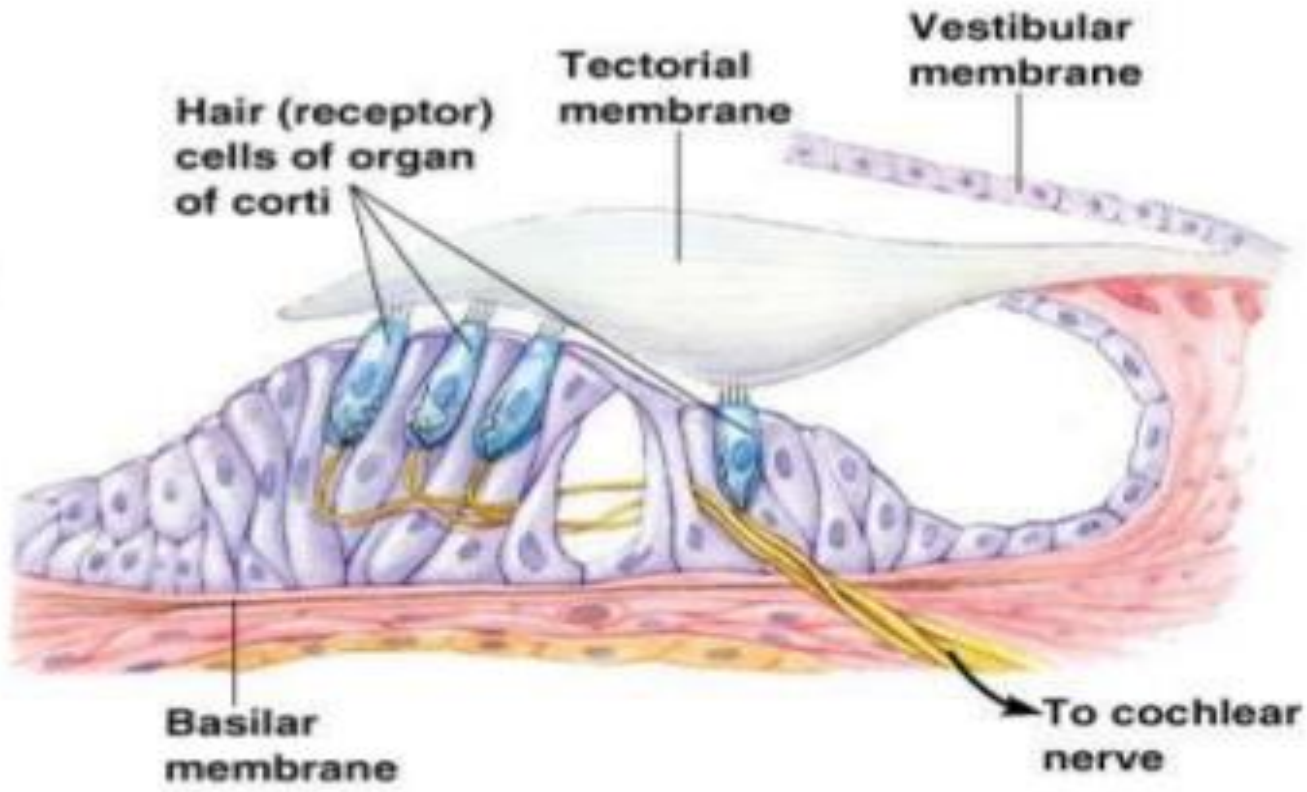
Cochlea—Cross Section

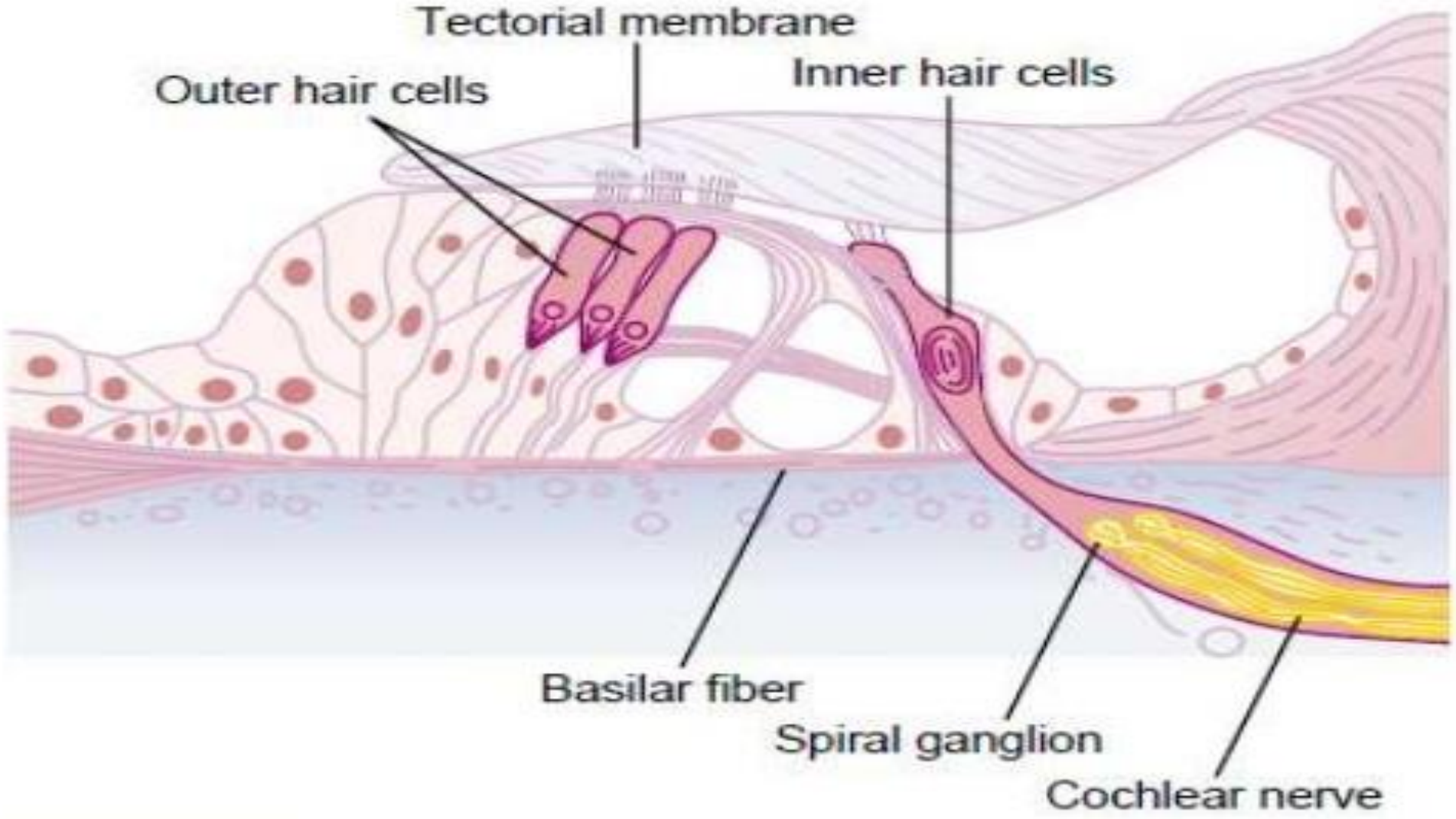


SENSORY CELLS FOR HEARING

- Contains Glutamate (transmitter)
- Connected with Auditory nerve fibers






Tectorial membrane
Outer hair cells
Inner hair cells
Basilar fiber
Spiral ganglion
Cochlear nerve

- **Reissner's membrane (Vestibular membrane)**
  - Soft thin membrane seperates scala vestibuli and scala media which does not obstruct the passage of sound
- **Basilar Membrane**
  - Fibrous membrane that separates the scala media from the scala tympani
- **Tectorial membrane**
  - Gel-like membrane is capable of bending hair cells
- **Organ of Corti**
  - Receptor organ that generates nerve impulses in response to vibration of the basilar membrane
  - Nerve cells:
    - Single row of internal hair cells (3500 nos, 12 μm dia)
    - three or four rows of external hair cells (12,000 nos , 8 μm dia)

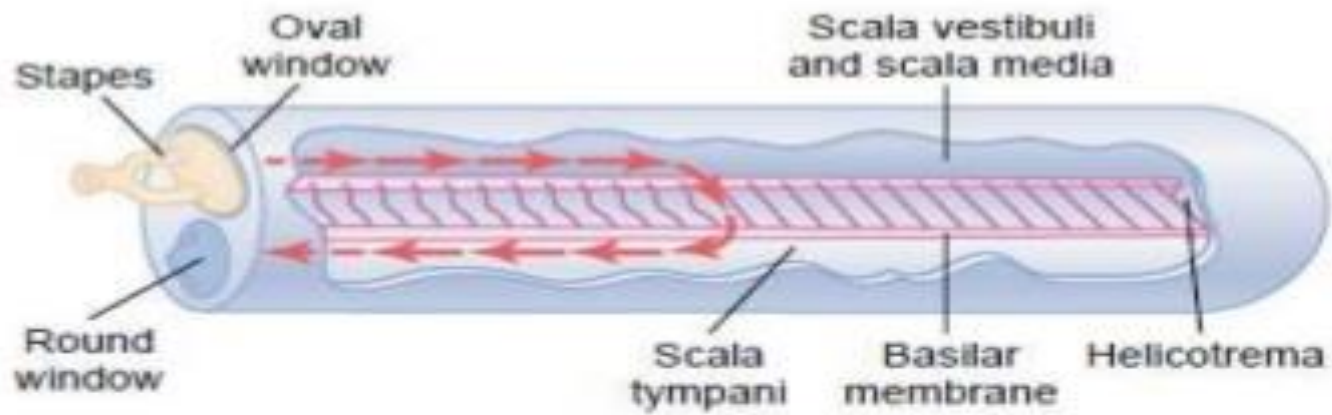
SOUND

- Results from the motion of air molecules which oscillate.
- Sound waves travel in all directions from their source.
- Waves are characterized by frequency and intensity
  - Frequency
    - Measured in hertz (cycles per second).
    - Greater the frequency the higher the pitch.
  - Intensity:
    - Directly related to amplitude of sound waves.
    - Measured in decibels (db).

AUDITORY PATHWAY

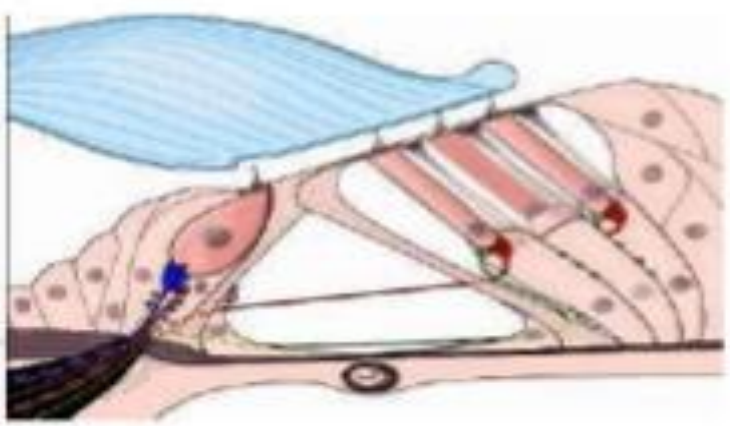
When sound waves travels through the auditory tunnel,

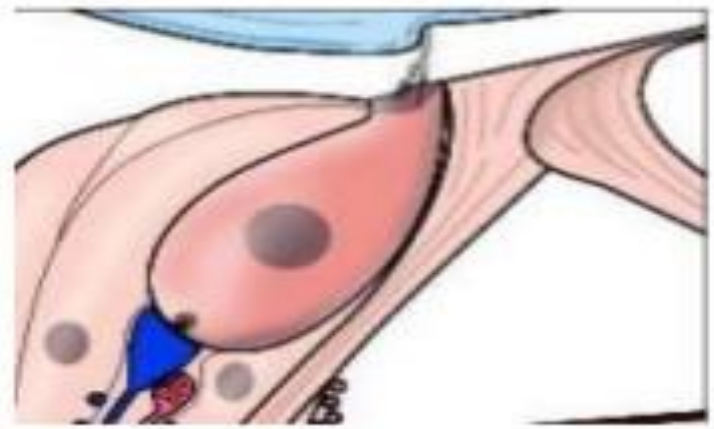
- Channels sound waves to the tympanic membrane and Increases sound wave intensity .
- The ossicles amplify the sound 22 X
- Tensor tymphani muscles initiates the vibrations depends upon frequency.
- When the foot of the stapes moves inward against the oval window, the round window must bulge outward because the cochlea is bounded on all sides by bony walls.
- Vibrations of stapes and oval window displace perilymph fluid within scala vestibuli



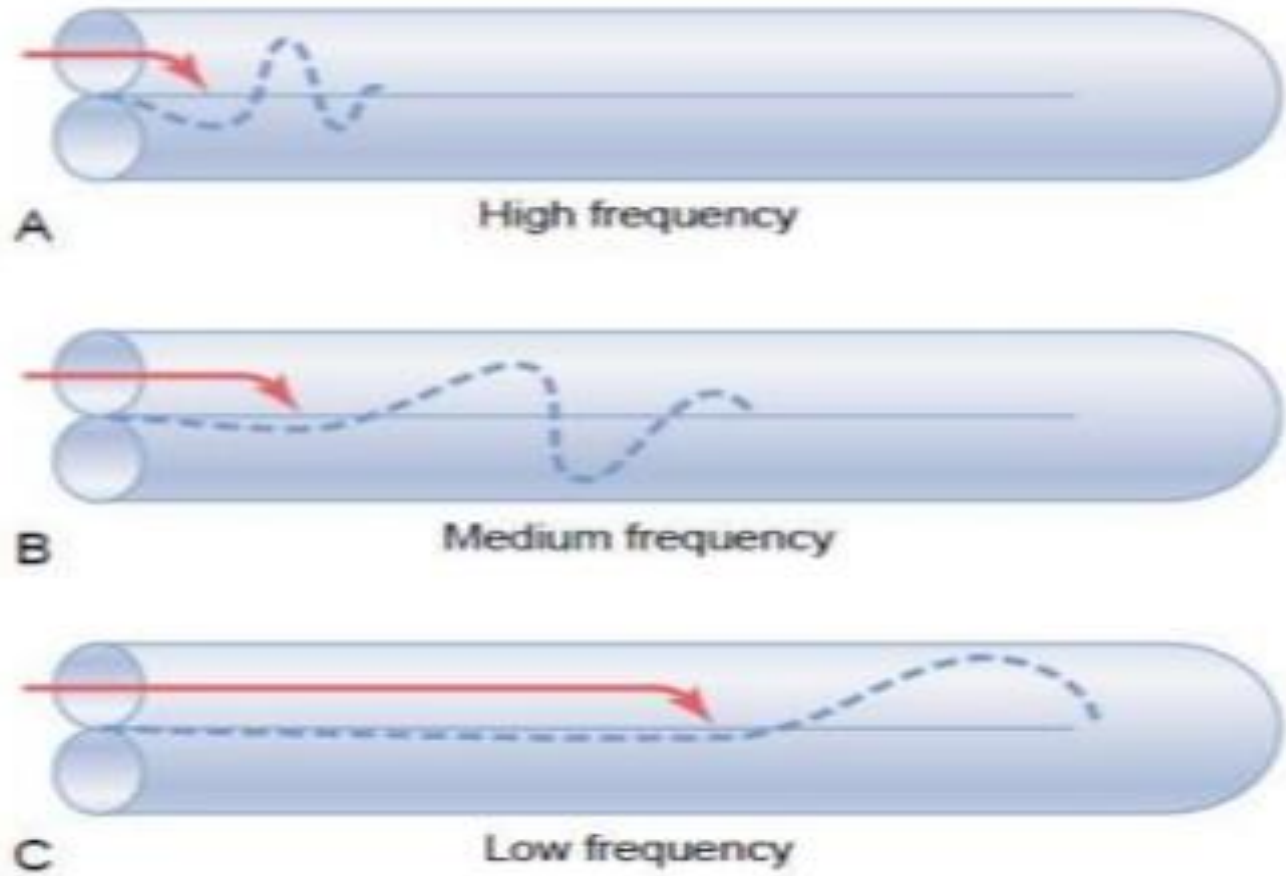
- Vibrations pass to the scala tympani.
- As sound frequency increases, pressure waves of the perilymph are transmitted through the vestibular membrane and through the basilar membrane.
- sound waves entering at the oval window is to cause the basilar membrane to bend in the direction of the round window
- Movements of perilymph travel to the base of cochlea where they displace the round window.
- This makes the cochlear ducts to be displaced which move the tectorial membrane
- During this a shearing force is created, causes moving and bending of the stereocilia.

- Ion channels open, depolarizing the hair cells, releasing glutamate that stimulates the sensory neuron .
- Greater bending of stereocilia, the increased frequency of AP produced.
- Nerve impulses in cochlear nerve travel to brain stem and on to the auditory areas of cerebral cortex, where it is interpreted as sound





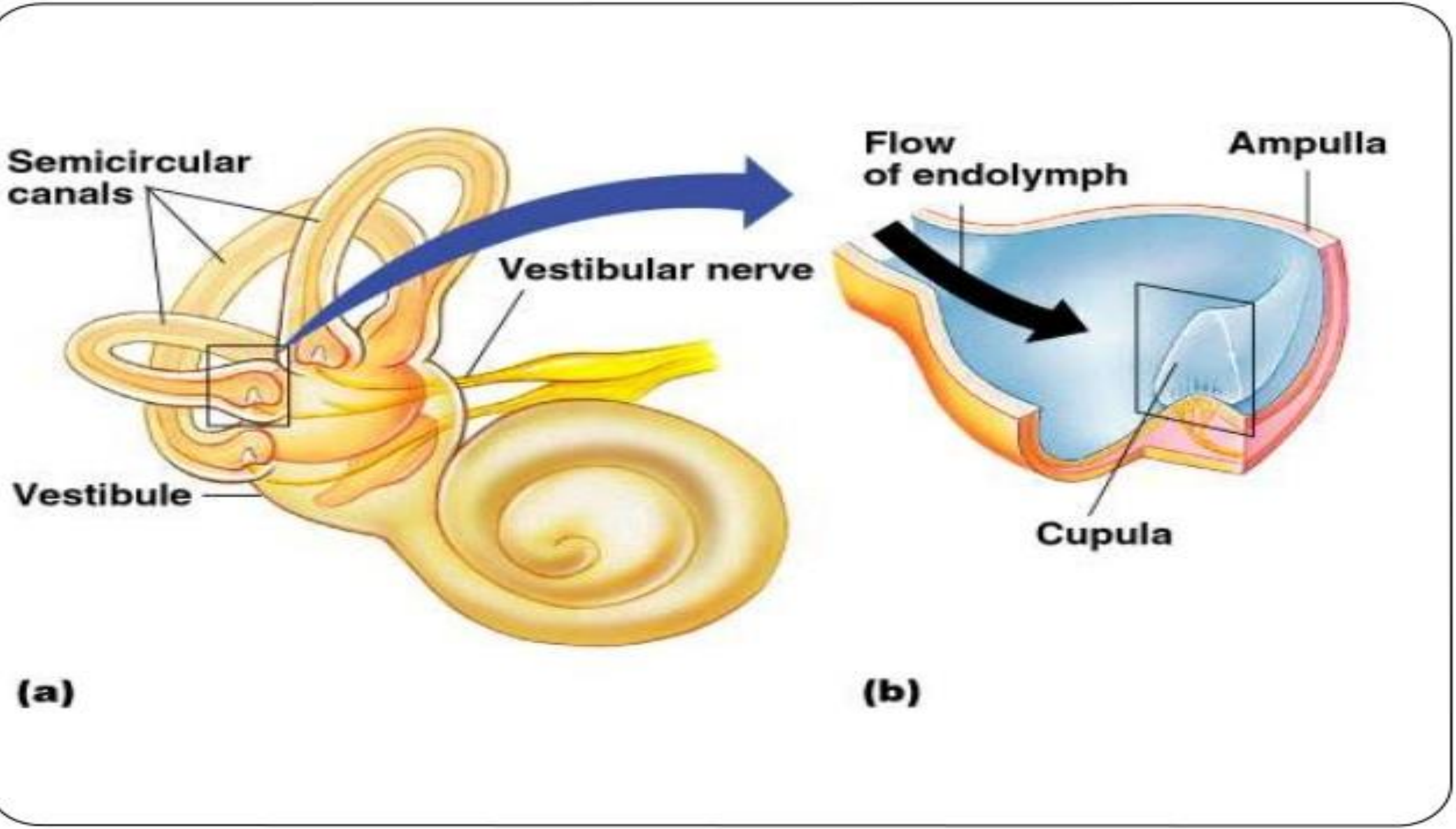
Pattern of Vibration of the Basilar Membrane for Different Sound Frequencies



Vestibular Apparatus and Equilibrium

Vestibular apparatus maintains the body (mainly the head) at equilibrium (at balance) and stabilizing the eyes relative to the environment

- Equilibrium has two functional parts
  - Static equilibrium
    - Receptors in the vestibule
      - Maintenance of the position of the body (mainly the head) relative to the force of gravity
  - Dynamic equilibrium
    - Receptors in the semicircular canals
      - Maintenance of the position of the body (mainly the head) in response to sudden movements such as rotation, acceleration, and deceleration


Semicircular canals
Vestibular nerve
Vestibule
(a)
Flow of endolymph
Ampulla
Cupula
(b)

Otolithic organs

VESTIBULE

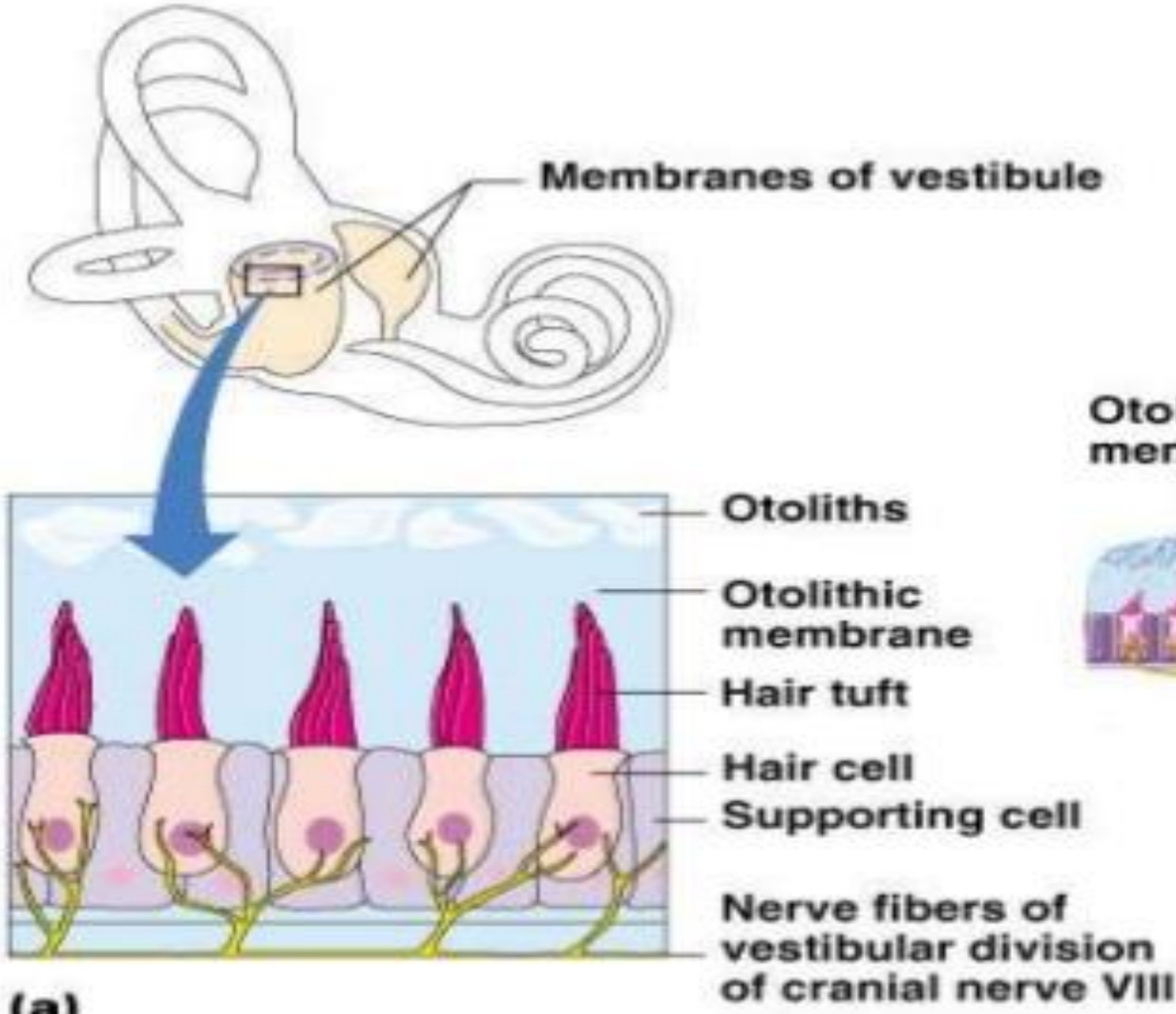
- **Utricle and saccule- static equilibrium**
- **Semicircular canals- dynamic equilibrium**
- **Utricle :** an irregular, oblong membranous sac located on the medial wall of the vestibule
  - More sensitive to horizontal acceleration
- **Saccule:** flattened, irregularly-shaped membranous sac located in the medial wall of the bony vestibule
- **Maculae – Receptors within the vestibule**
  - consist of sensory hair cells and supporting cells.
- Each sensory hair cell has one kinocilium and many stereocilia (embedded in a gelatinous membranecalled ***otolithic membrane)***

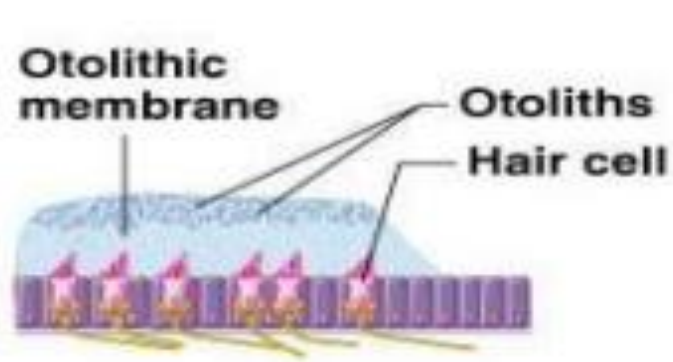
- **Semicircular Canals**
  - Provide information about rotational acceleration.
  - Project in 3 different planes.
  - Each canal contains a semicircular duct (Endolymph Movement inside it).
  - At the base is the **crista ampullaris (**enlarged swellings at base of each canal communicating with utricles)

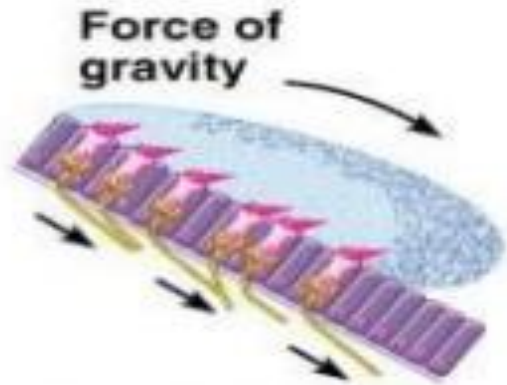
Static Equilibrium

- Maculae – receptors within the vestibule
  - Report on the position of the head with respect to the pull of gravity when the body is not moving (static = rest)
- Anatomy of the maculae
  - Hair cells are embedded in the otolithic membrane
  - Otoliths (tiny stones) float in a gel around the hair cells
  - Movements cause otoliths to bend the hair cells → sends impulses along the vestibular nerve to the cerebellum of the brain

Function of Maculae

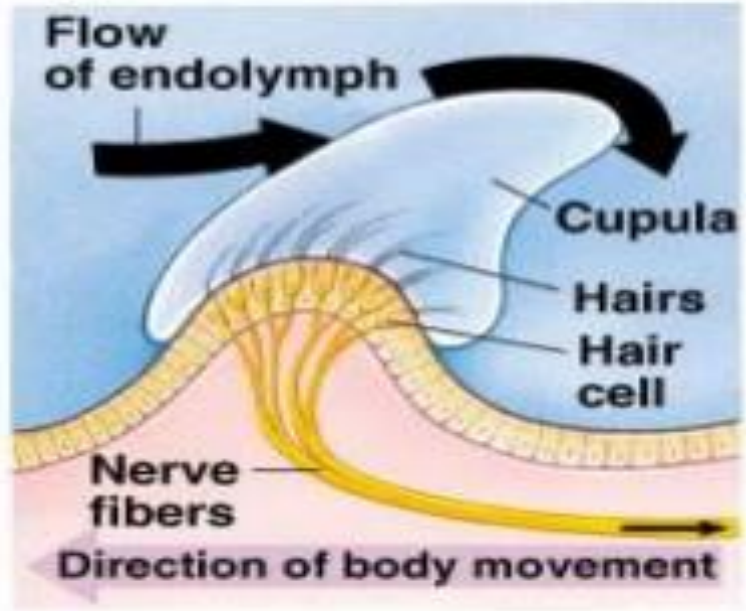






Dynamic Equilibrium

- Responds to angular or rotatory movements of the head
- Crista ampullaris – receptors found within the semicircular canals
  - Tuft of hair cells are covered with a gelatinous cap called the cupula



(c)

THANK YOU