Electric property of living cells

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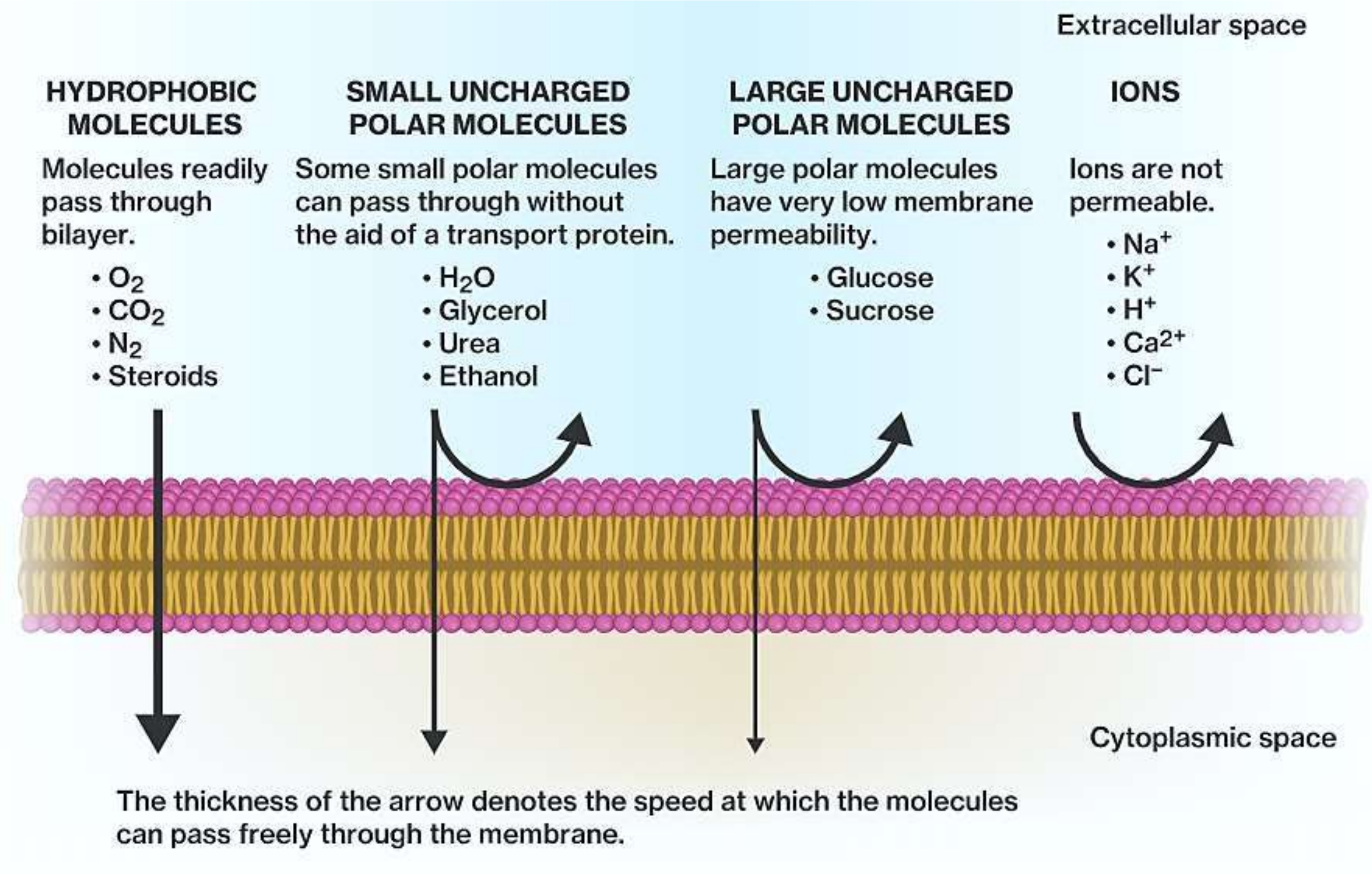
Cell membrane

- Cell membrane, also known as the plasma membrane, is found in all cells and separates the interior of the cell from the outside environment.
- It consists of the phospholipid bilayer that is semipermeable of 5 – 5.7nM width.
- It regulates the to and fro movements of solutes due to semipermeable properties.
- Phospholipid bilayer acts as a conductor to non-polar molecules like oxygen, carbon dioxide, nitrogen, benzene, and uncharged polar molecules like water, urea, and glycerol.
- Charged ions like H^+, Na^+, K^+, Cl^-, HCO_3_, etc., and uncharged molecules like glucose, amino acids, and nucleotides can’t pass hydrophobic fatty acid chains of the plasma membrane.
- These impermeable ions and molecules are transported by means of molecular transporter.

Cell membrane

Transport In & Out of the Cell

The cell membrane is **semi-permeable**, meaning it is a barrier to most, but not all molecules.



Types of cells or tissue

There are two types of cells or tissue, which are as follows:

I. **Excitable cells or tissue:** The cells or tissue that can be stimulated by the external factor. Examples include muscles and nerves.

II. **Non-excitable cells or tissue:** The cells or tissues that can not be stimulated like excitable tissue, e.g. skin, bone, adipose tissue, connective tissue, and epithelial cells.

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Electric charges

- **Electric charges are due to the distribution of ions across the membrane or inside the cells in the cytoplasm.**
- **Electric charges can be found in either single or compound (multiple).**
- **They can be found inside the cells or outside the cells.**
- **Because some ions are able to move from the inside to the outside or from the outside to the inside, they are creating what we call the convection current.**
- **Charges are distributed differently in different zones of the cells.**
  - **The innermost zone (central zone) is negative because it has proteins and amino acids.**
  - **The inner zone, it is positive, it has cations such as potassium.**
  - **The outer zone, it is positive, it has ions such as sodium, calcium, and potassium.**
  - **The outermost zone which is negative, it has glycolipids.**

Electric charges across the cell membrane

- **Intracellular ► High potassium (K^+) and low sodium (Na^+)**
- **Extracellular ► Low potassium, high sodium, high calcium**

Electric current

Electric current is the flow of electric charge. The amount of electric current (in amperes) through some surface is defined as the amount of electric charge (in coulombs) flowing through that surface over time.

Electric current

- flows to the organism from external sources.
- is generated as a result of actions in the plasma membrane (excitable tissues)

Direct current (DC)

- is the constant flow of electric charge, the electric charge flow in the same direction.

Alternating current (AC)

- is a current whose magnitude and direction vary cyclically. A sine wave is a usual waveform of an AC.

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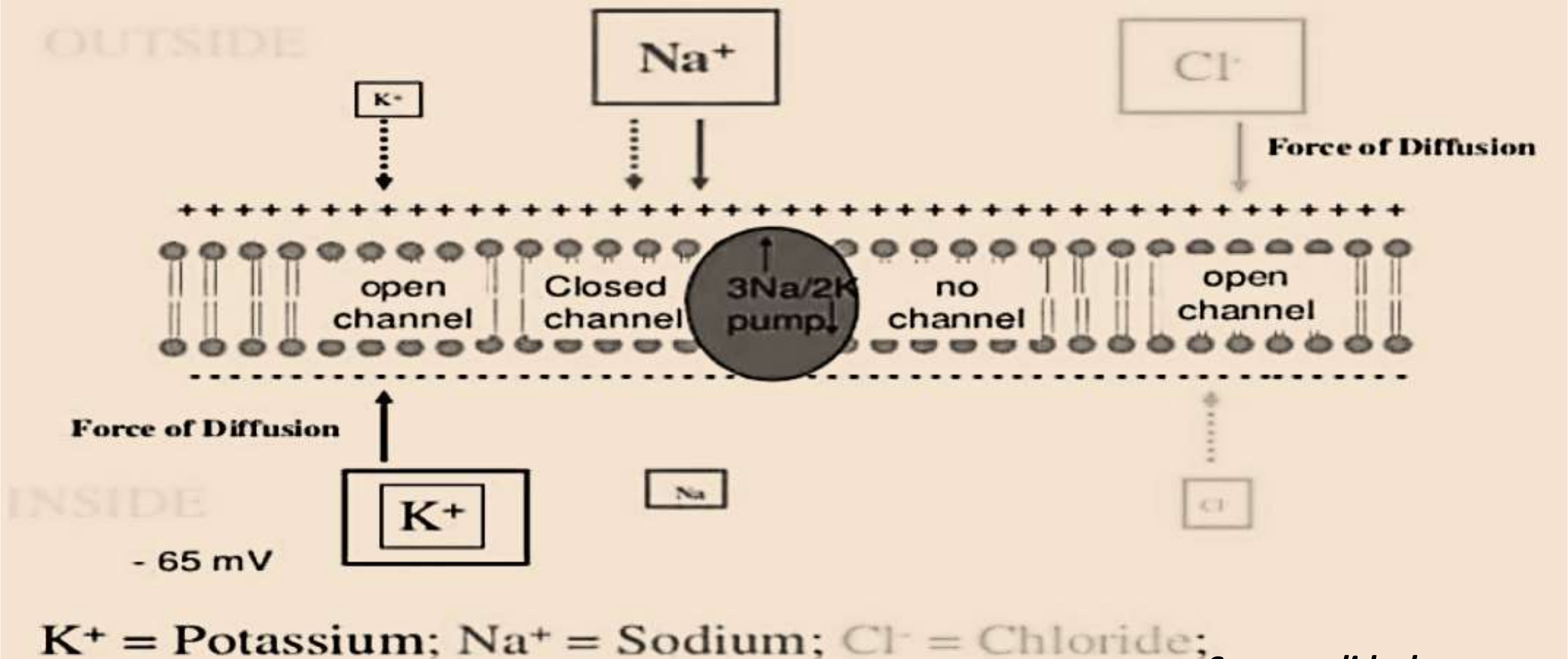
Electrical properties of living cells

- Cell membranes are electrical insulators due to their phospholipid bilayer structure filled with saline fluid in a bath of saline.
- The conductance of the plasma membrane is much higher due to the presence of a number of all kinds of ion channels and other pores (several orders of magnitude even at rest).
- At the resting state, the cytoplasm of a cell has a higher negative charge than the extracellular matrix, and the membrane is said to be polarized and maintain a dipole across the membrane.
- This electric property of cell membrane may be,
  - *Passive electric properties: tissue's and organ's behavior in an electric field.*
  - *Active electric properties: Electricity as a result of organ activity.*
- In non-excitable cells, the membrane potential ranges from -20mV to -200mV.
- In excitable cells, such as neutrons and muscles, the membrane potential is about -70mV, and is called resting potential.

Membrane potential

- **Thus, the plasma membrane of all living cells has a membrane potential (polarized electrically).**
- **Due to difference in concentration and permeability of key ions, i.e., Na^+, K^+, and large intracellular proteins b/w ECF & ICF.**

- **Extracellular space and cytoplasm – electrical current is realized as a ions movement (electrolyte).**
- **Cell membrane inductance is lower than 108 times as extracellular space cytoplasm conductance.**
- **Membrane capacity: Cm 1uF.Cm$_{-2}$,**



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Determination of membrane potential

- **At thermodynamic equilibrium, the membrane potential is equal to the potassium equilibrium potential.**
- **The magnitude of potassium potential is given by the** Nernst equation**,**

$$E_K = \frac{RT}{ZF} ln \frac{[K^+]_0}{[K^+]_i}$$

Where, R = Gas constant = 1.987 cal/(degree mol)

T = Absolute temperature = 293 K at 20C

Z = Charge = 1

F = Faraday Constant = 96,000 coulombs/(mol V) =

$[K^+]_0$ = concentration of K^+ ions in the extracellular fluid

$[K^+]_i$ = concentration of K^+ ions in the intracellular fluid

Determination of membrane potential

TABLE 1 Comparison of the Resting Potentials in Different Types of Cells

Cell type	Resting potential (mV)
Neuron	–70
Skeletal muscle (mammalian)	–80
Skeletal Muscle (frog)	–90
Cardiac muscle (atrial and ventricular)	–80
Cardiac Purkinje fiber	–90
Atrioventricular nodal cell	–65
Sinoatrial nodal cell	–55
Smooth muscle cell	–55
Red blood cell (human)	–11

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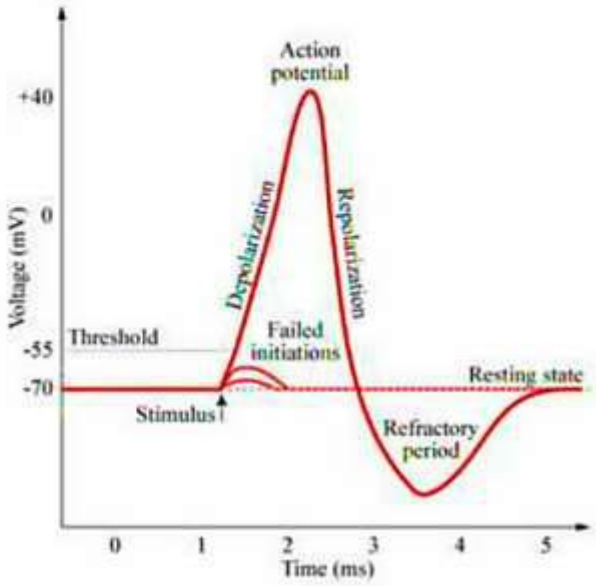
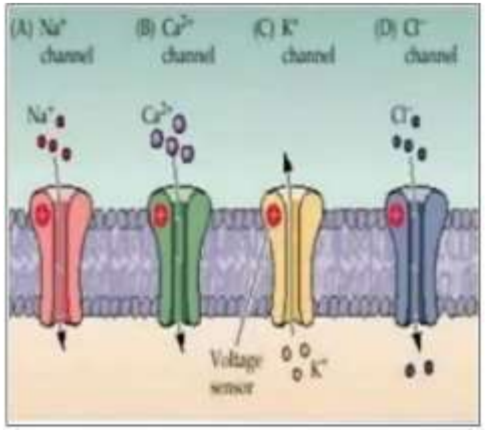
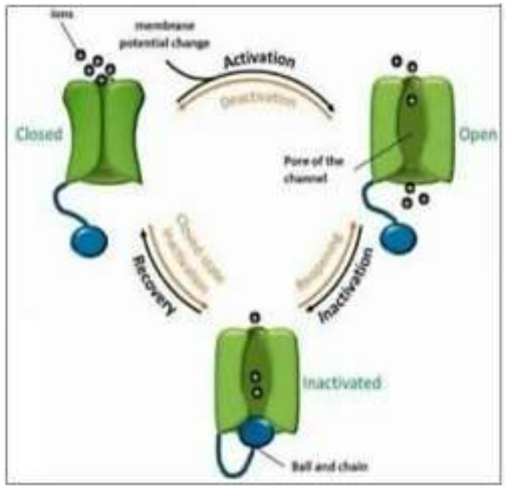
Action potential

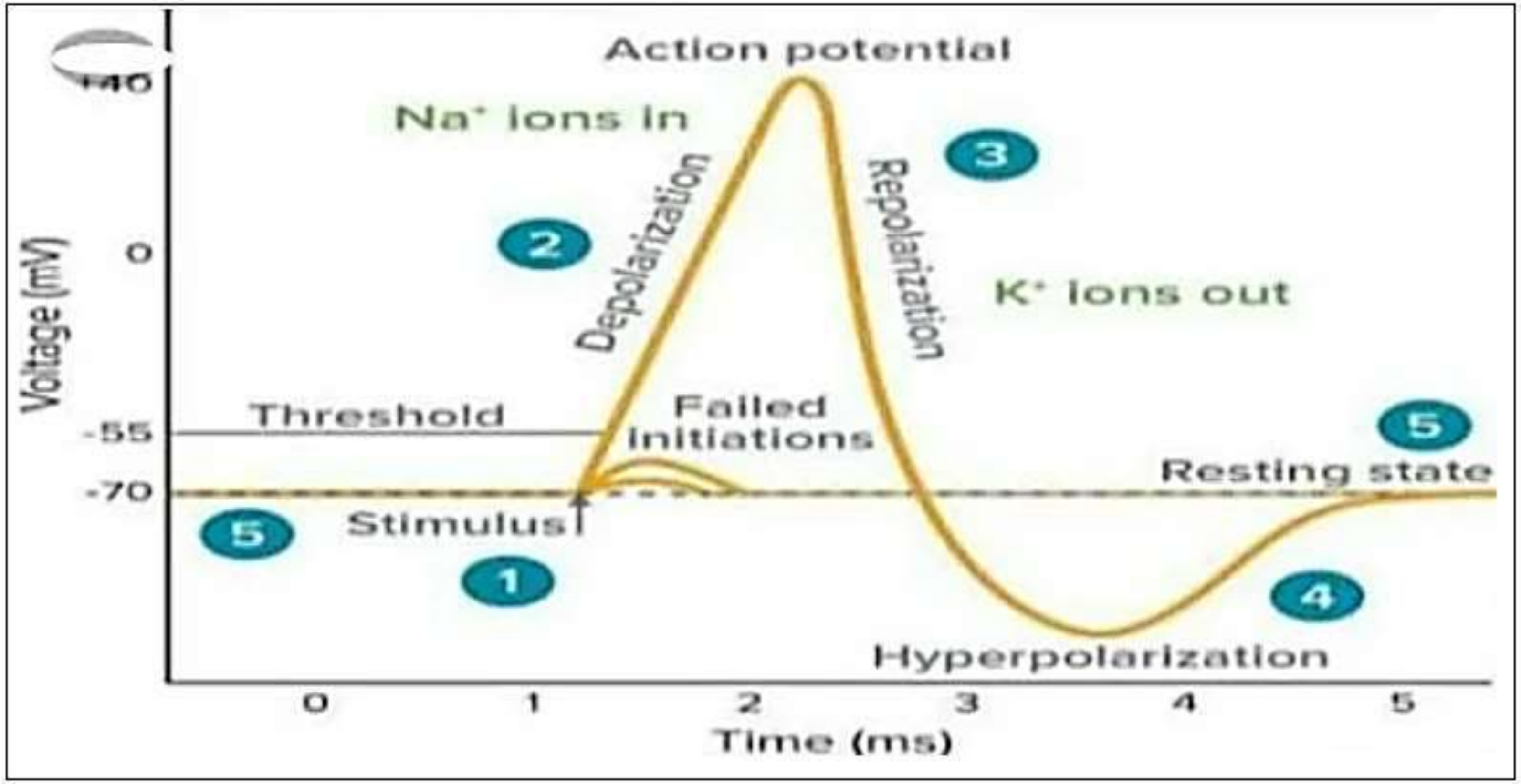
- **It is simply a sudden rise in electrical activity across the membrane that is created by a depolarizing current.**
- **It is initiated by a series of successive stimuli and generated by Na^+ and K^+ (a single stimulus can't lead to action potential) – known as** <u>all-or-none law</u>**.**
- **Stimulus may be a hormone, neurotransmitter, or simply mechanical stimulus.**
- <u>Depolarization</u> **is immediately followed by** <u>repolarization</u>**, which is mediated by the voltage-gated K_+ channels and voltage-gated Cl^- channels.**
- **The gap period between repolarization and depolarization by successive stimuli is called the** <u>refractory period</u>**. In the refractory period, cells can not be stimulated again.**



Action potential







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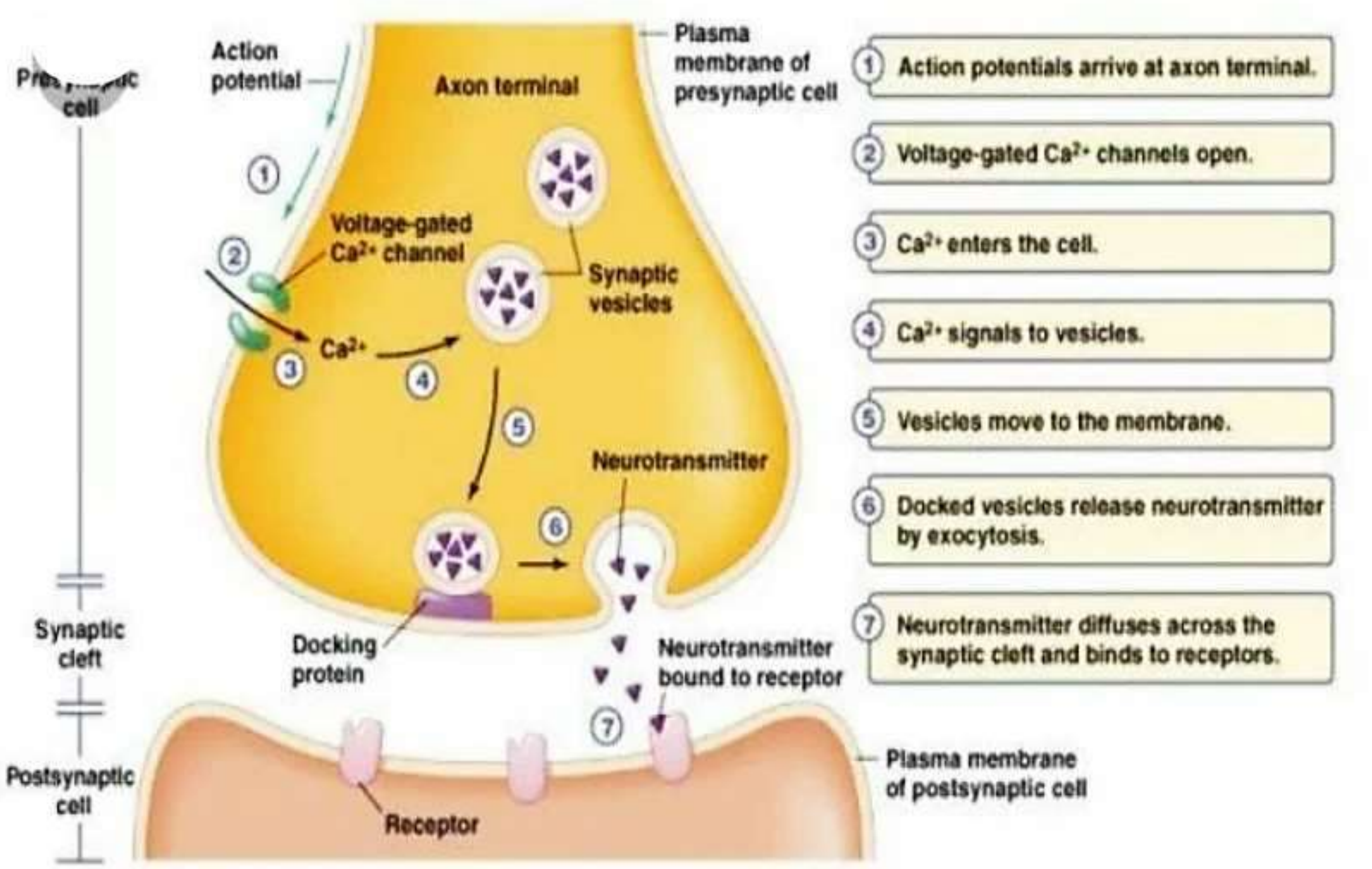
Transmission of nerve impulse



- Information come to the nerve through dendrites → nucleus of te cell → axon → dendrites of the other cell.
- Saltatory transmission happens in myelinated axons due to the presence of nodes of Ranvier. The nerve impulse is faster ithe n myelinated nerve fiber.
- Impulses within the nerve move in one direction (orthodromic).

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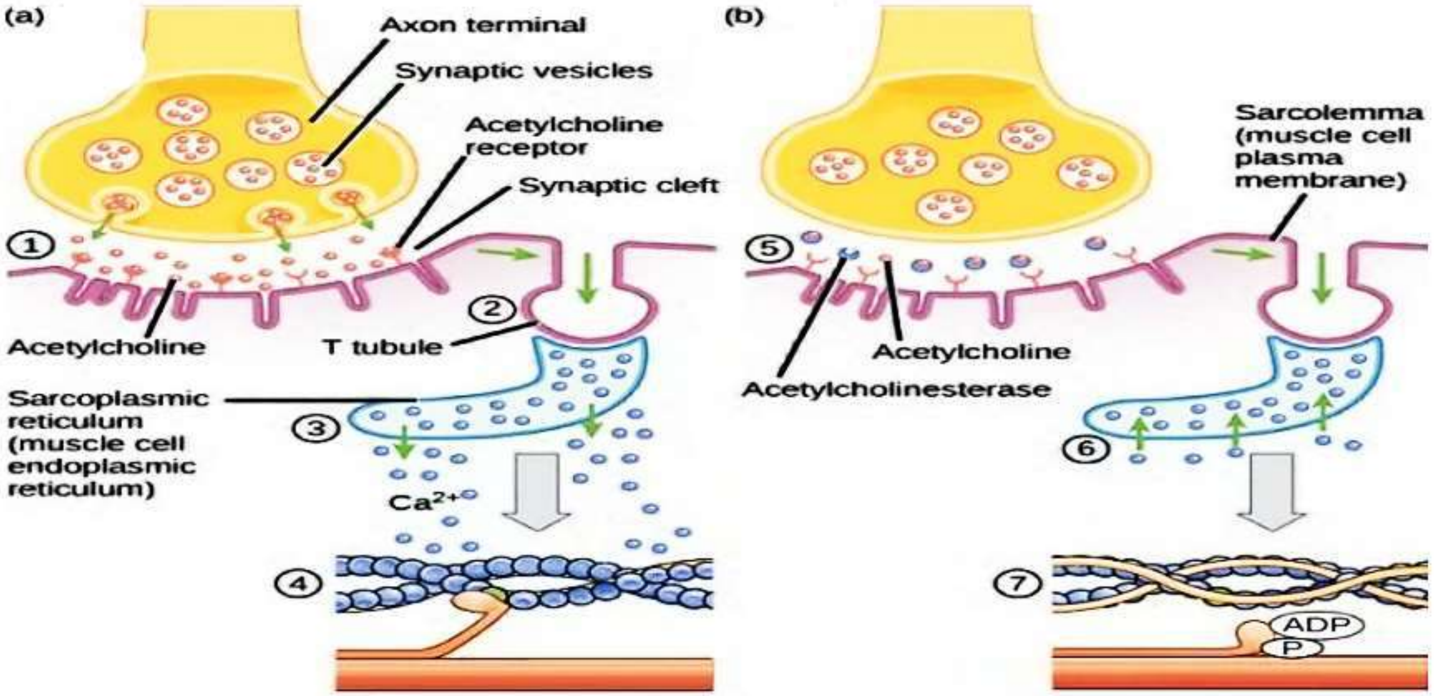
Action potential in muscle contrcation



1. Acetylcholine released from the axon terminal binds to receptors on the sarcolemma.
2. An action potential is generated and travels down the T tubule.
3. Ca^{2+} is released from the sarcoplasmic reticulum in response to the change in voltage.
4. Ca^{2+} binds troponin; Cross-bridges form

5. Acetylcholinesterase removes acetylcholine from the synaptic cleft.
6. Ca^{2+} is transported back into the sarcoplasmic reticulum.
7. Tropomyosin binds active sites on actin causing the cross-bridge to detach.

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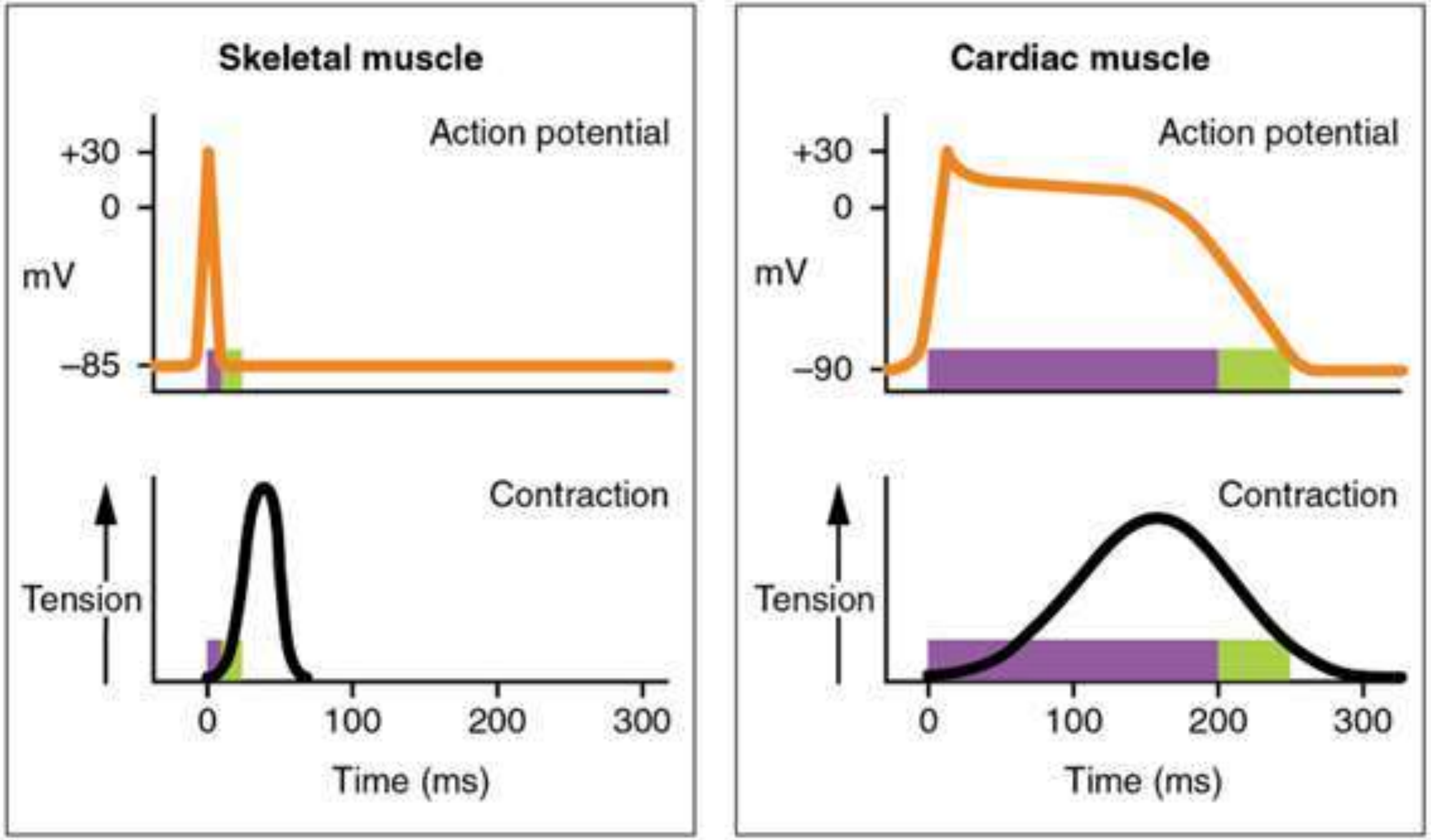
Action potential in skeletal & cardiac muscles



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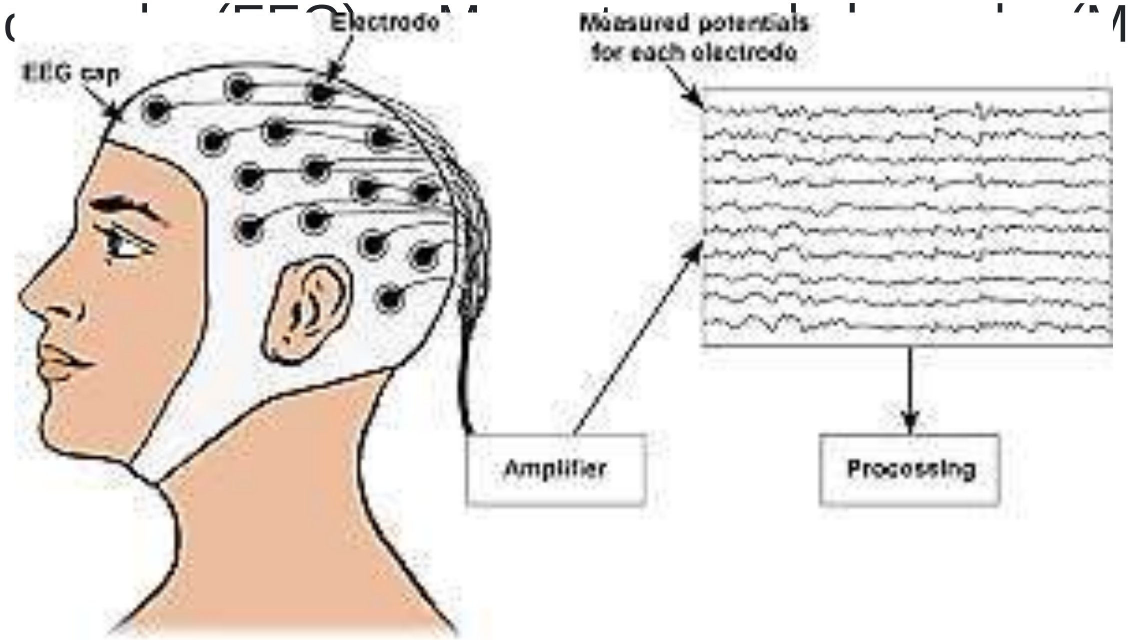
Electrical activity of organ

- Action potential then enables signals to travel very rapidly along with the neuron fiber.
- When large numbers of neurons show synchronized activity, the electric fields generated can be large enough to detect outside the skull, using Electroencephalo … (MEG).



Difference between electric & bioelectric

Bioelectrci circuit	Electric circuit
➢ Electric charge in a wet environment. ➢ Uses atoms and ions. ➢ Components of the circuit are always changing. ➢ There is a continuous leakage. ➢ There need to be areas of charge difference. ➢ Short pathway. ➢ Energy is needed all the time. ➢ Slower, the response rate is in milliseconds.	➢ Electric charge in a dry environment. ➢ Uses electrons only. ➢ Need occasional replacement of components. ➢ Move electric charges without leakage (or there will be a shock) ➢ Long pathway. ➢ Energy is needed only when the circuit is working. ➢ Fatser, the response rate is in a nanosecond.

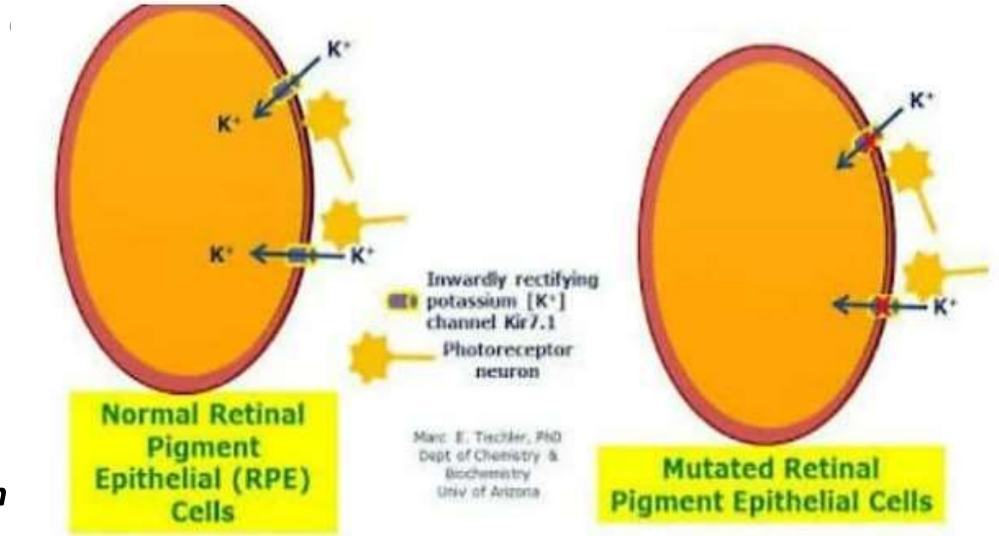
Uses of bioelectricity

Bioelectricity can be used in two ways; evaluation and treatment.

1. Evaluation: Used to evaluate some abnormality in the body, such as ECG, EEG, and EMG
   a. Electrocardiogram (ECG) – Record the activity of the heart.
   b. Electroencephalogram (EEG) – Used to record the electrical activity of the brain.
   c. Electromyogram: Used to observe the muscle functions.
2. Treatment: Used for the treatment of several ailments.
   a. In some diseases, the second messenger may not be working because it is not getting impulses from the first messenger – electricity is given to initiate or change cell function.
   b. In some diseases, there could be a first messenger but the signals the cell receives are weak – electricity is used to strengthen the weak current so that cell function could be modified.
   c. Other uses – to educate a nerve or muscle, to relieve pain and other symptoms like a spasm, swelling edem, etc., to improve neural growth (inflammation around the nerve), heating tissues, and in iontophoresis,

Conclusion

- Membrane's electrical properties are of utmost importance for the continuous communication among different cells and tissues, normal functioning of all the physiological processes, and maintaining body homeostasis and shape.
- Any mutation in the gene encoding the transport proteins carrying the ions across the membrane, may lead to the disbalance in the electric potential between extracellular fluid and cytosol, resulting in diseases like cystic fibrosis, Snowflake vitreoretinal degeneration, Barter syndrome, Alzheimer's disease,
- These diseases can only be corrected by the replacement of mutated genes.



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