CHAPTER 4:

Bioelectric Potentials

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Two basic types of potentials exist within the living body:

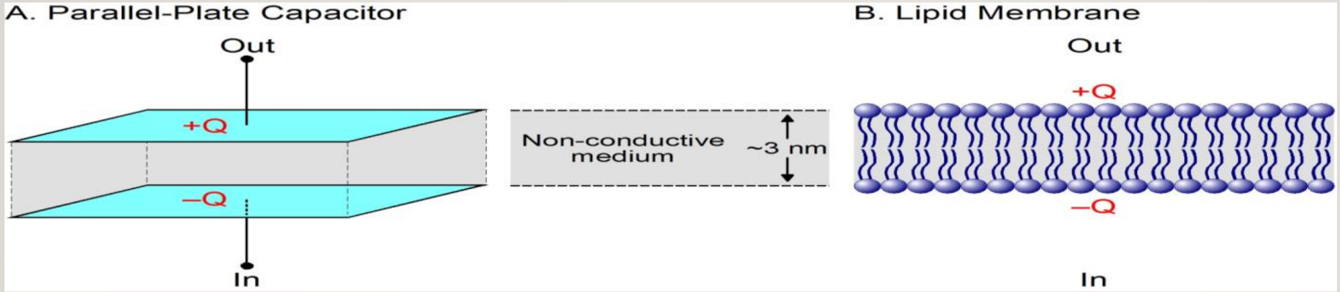
First is the resting potential (R.P), this potential can be measured at any time between interior and exterior of a cell. This potential is steady and constant as soon as the cell is in its living state.

As a special type of this potential, a potential called the injury potential, which is arises between injured and the intact points.

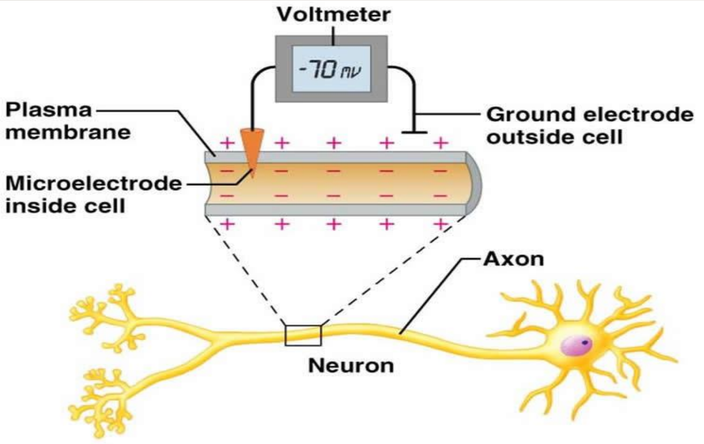
Second, there are the potentials which accompanying= enclosed the conduction of impulses over nerves, muscles and other cells, and the surface manifestation of these potentials including the electrocardiography[ECG]=H, electro-encephalograph[B], and electromyography[M]. This potential is usually called conduction or action potential which is rapidly changing potential.

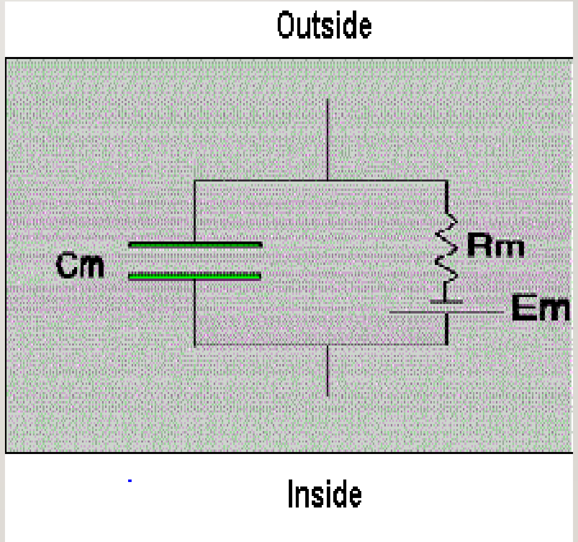
It was found that the plasma membrane is a dielectric of high resistance (R_m), and it is surrounded by a negative and positive charges (negative inside) forming what is known as resting potential (R.P) .

As we know the electric condenser is an insulator (dielectric) surrounded by two different charges, then the living cell membrane has a capacitance property (C_m).



On the basis of such evidences, the living cell membrane can be represented by an equivalent circuit as shown in figure, which consists of a source of potential (E_m), resistance (R_m) and capacitance (C_m)

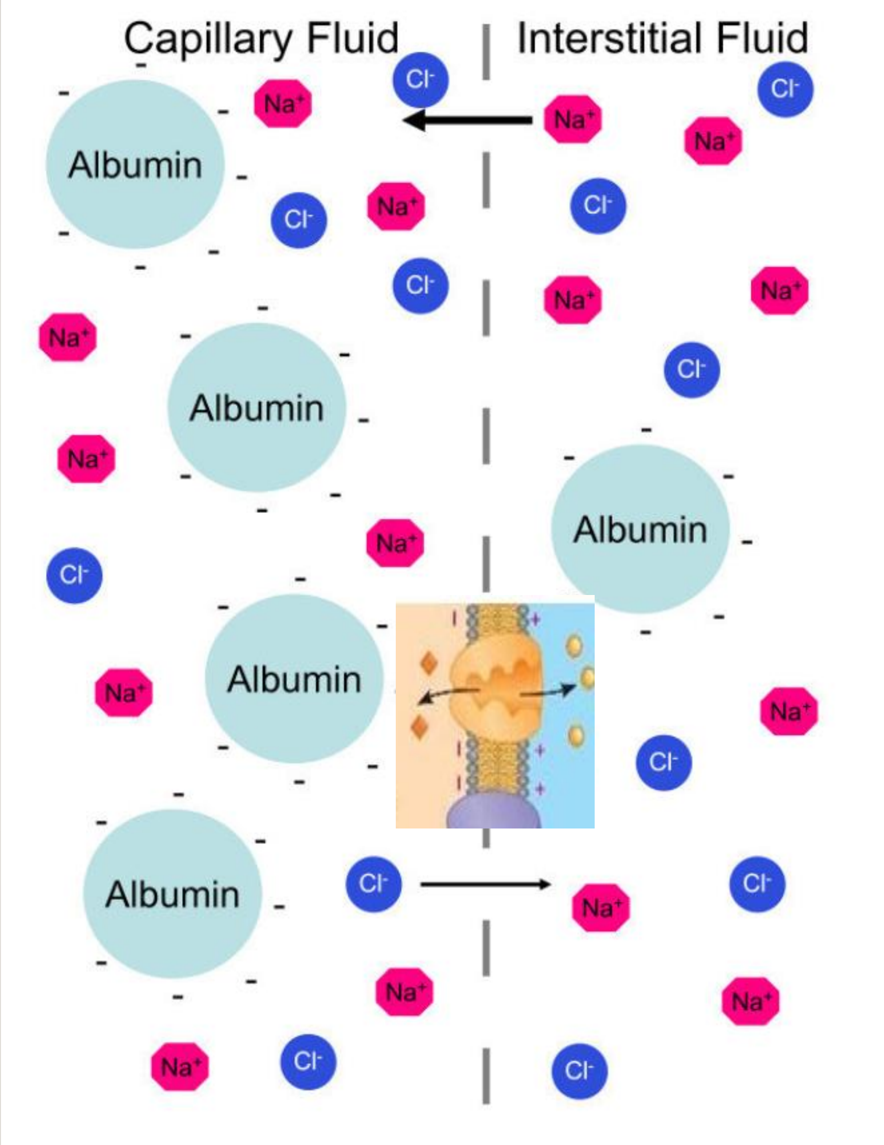




Ions distribution and Donnan equilibrium

Donnan introduced a classical theory accounting for a differential of ions across a membrane which is permeable to some ions and impermeable to others. Not all membranes are permeable to the same solutes. Most erythrocytes are permeable to anions, while nerve cells are permeable to potassium but not sodium

For example, the large anion proteins in are not permeable to cell membrane . Because small cation [+]are attracted, but are not bound to the proteins, small anions will cross capillary walls away from the anionic proteins more readily than small cations.
Thus, some ionic species can pass through the barrier while others cannot. The electric potential arising between two such solutions is called the Donnan potential.



Donnan proposed the given ratios of ions distribution across membranes in resting state.

$K_i/K_o = 20$

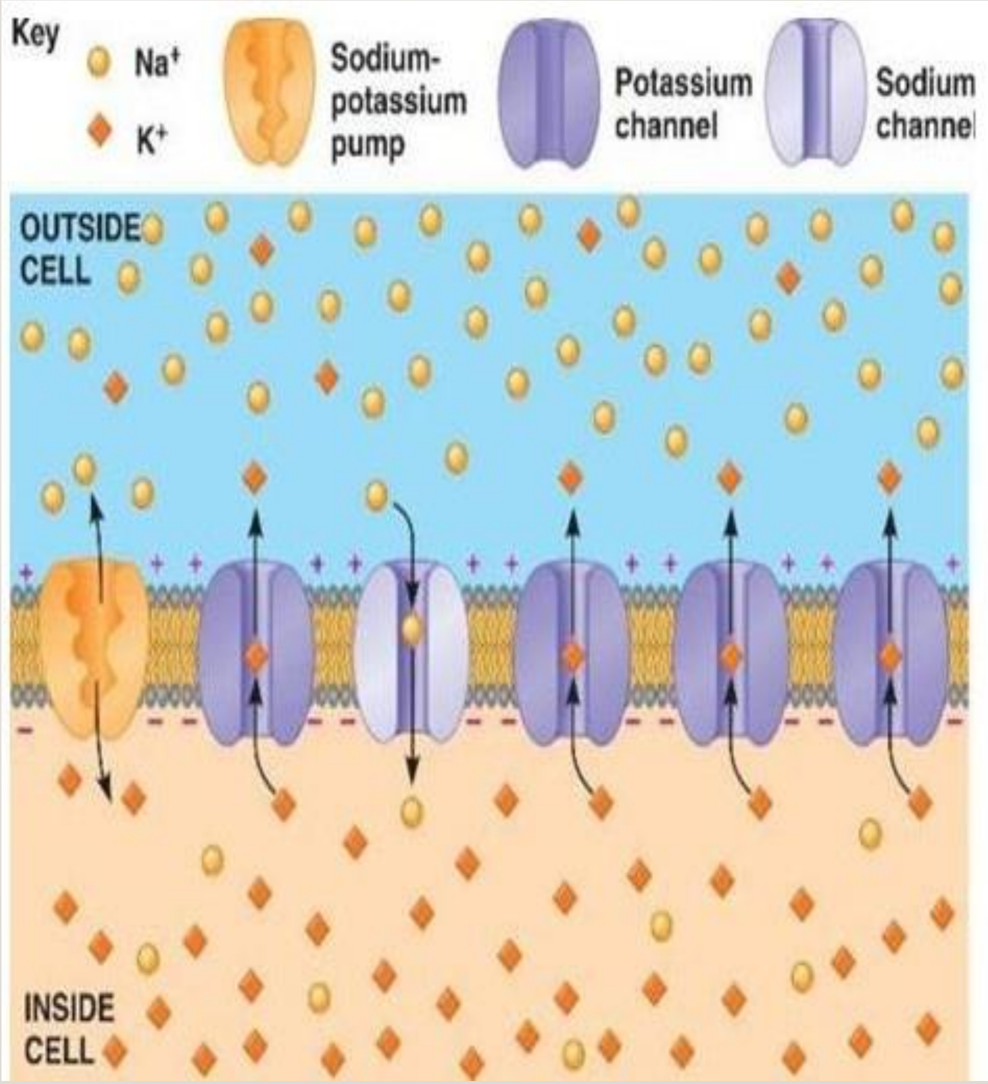
$Na_o/Na_i = 10$

$Cl_o/Cl_i = 11.5$

Ion	Concentration outside (in mM)	Concentration inside (in mM)	Ratio Out : In
K^+	5	100	1 : 20
Na^+	150	15	10 : 1
Ca^{2+}	2	0.0002	10,000 : 1
Cl^-	150	13	11.5 : 1

I- RESTING POTENTIAL (R.P)

- For all living cells, both in animals and plants, there was found out a potential difference between the internal and external medium of a cell (inside is negative) . Its value ranging from 50 to 100 mV. This potential is recorded in the state of rest of the cell and therefore is called intracellular resting potential or simply resting potential.



1- Origin of resting potential

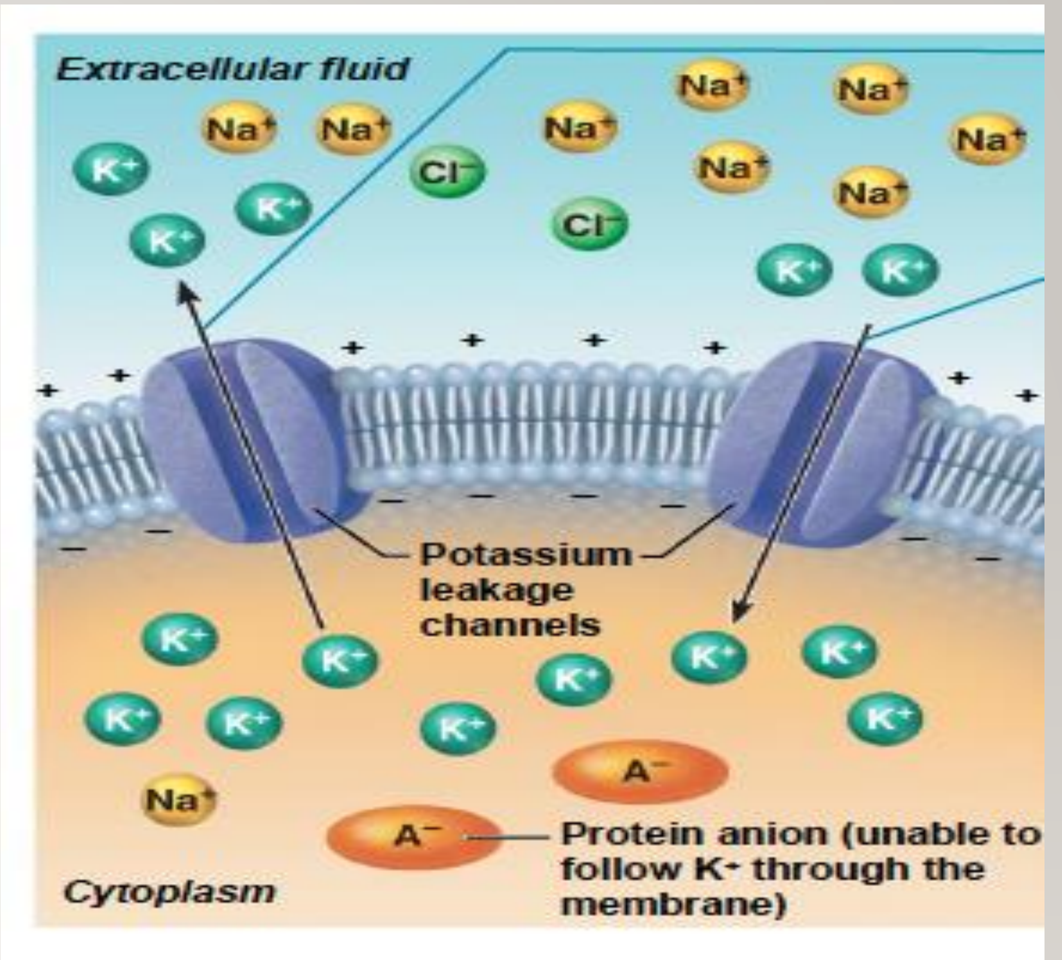
a- Difference in concentrations of Na^+,K^+ ,and Cl^-

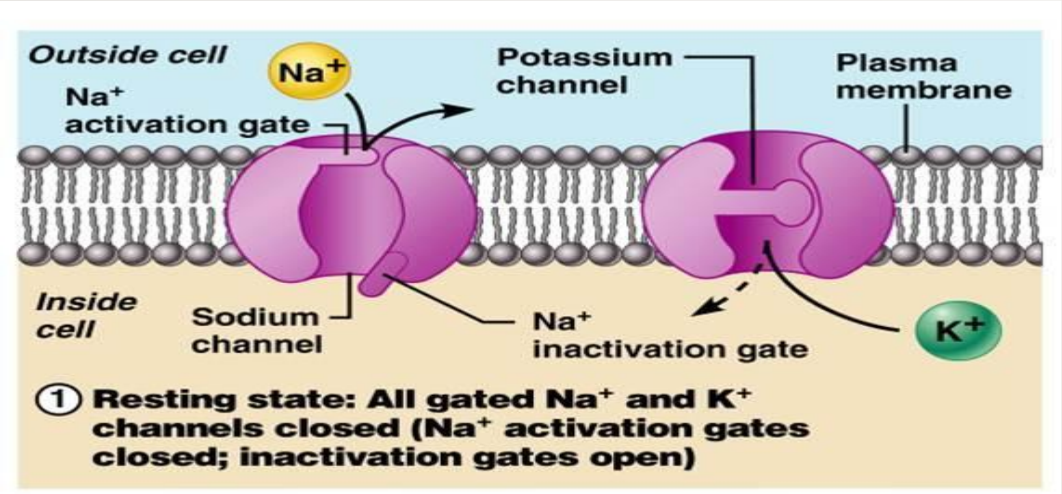
Between interior and exterior.

b- Permeability of membrane.

c- High concentrations of proteins and anions inside cell.

d- Active transport (Na^+-K^+ pump).





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2- Characteristics of resting potential

a- Constant potential

b- Its magnitude is about -90mV (exterior is +ve and interior is –ve).

c- It depends mainly on K^+ a, Na^+ , and Cl^- ions concentration.

c- Indicates the physiological condition of cell.

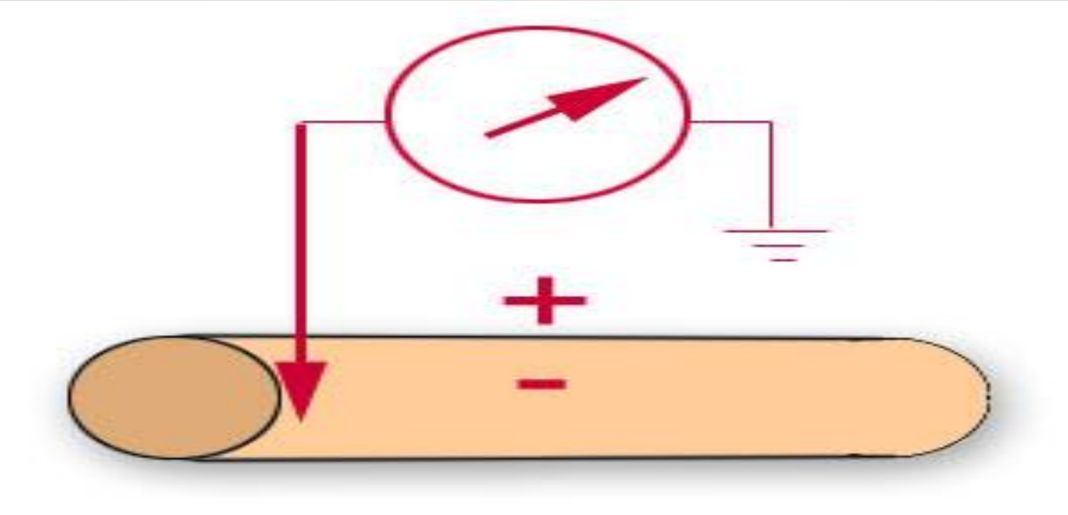
3- Electrode technique

Electrode is a conductor serves as a terminal connection between the tissue and the stimulation or recording instrument. For that it must be small in diameter with respect to the cell.

Different types of electrodes are used in electrophysiology.

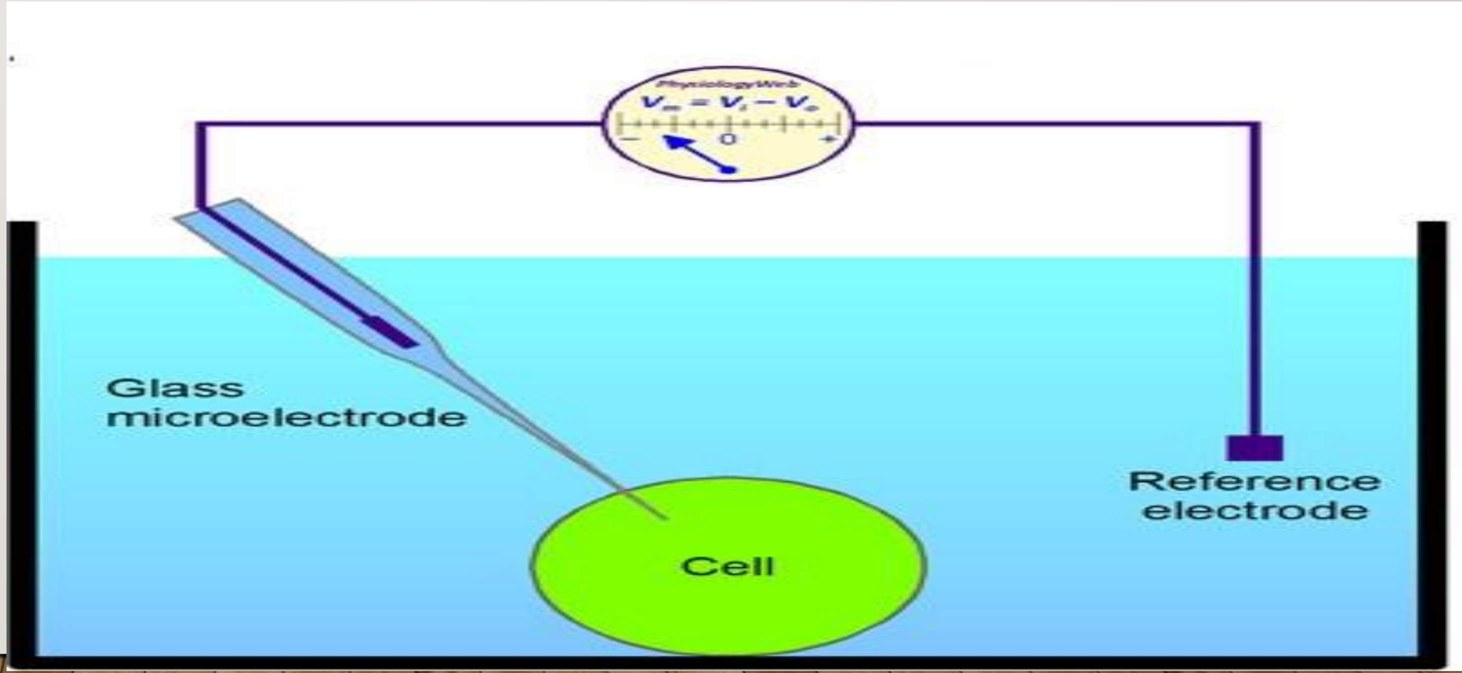
A- Metal electrodes

Simple metals are often used as electrodes such as silver, platinum, nickel, stainless steel.....etc., having the form of wire, discs or plates.



B-Capillary electrodes

These are glass tubes pulled at one end to form a capillary with a tip diameter less than 0.5um. These electrodes are made from pyrex glass using a microelectrode puller machine and are filled by a solution of 3M KCl . The solution in the tube and the capillary tip are the actual electrode.



4- Measurement of resting potential

There are two intracellular methods of recording the resting potential.

A- Huxley method

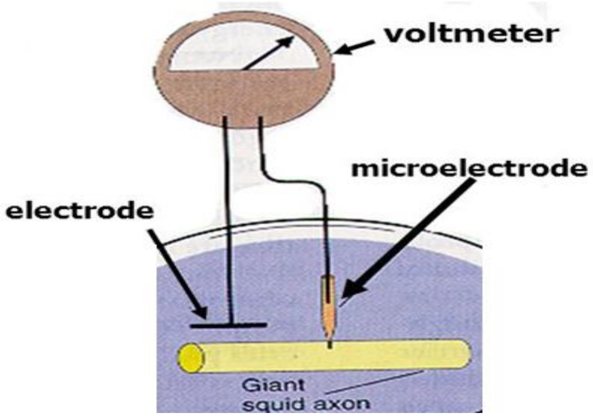
In this method Huxley introduced an active electrode inside the fibre tissue and another electrode on the outer surface.

The two electrodes were connected to a voltmeter to measure R.P.

This method is applied to fibres of sufficiently great diameter such as the giant fibre of squid.

Hodgkin-Huxley Expts, 1952

Squid Giant Axon



Few neurons, large diameter

Large enough to insert microelectrodes

Stimulating microelectrodes (inject current) to disturb cell with electrical stimuli

Recording microelectrodes

B-The universal method

In this method an active glass microelectrode of diameter less than 0.5 um and fluid with 3M KCl is introduced inside the cell across its surface membrane. The reference electrode

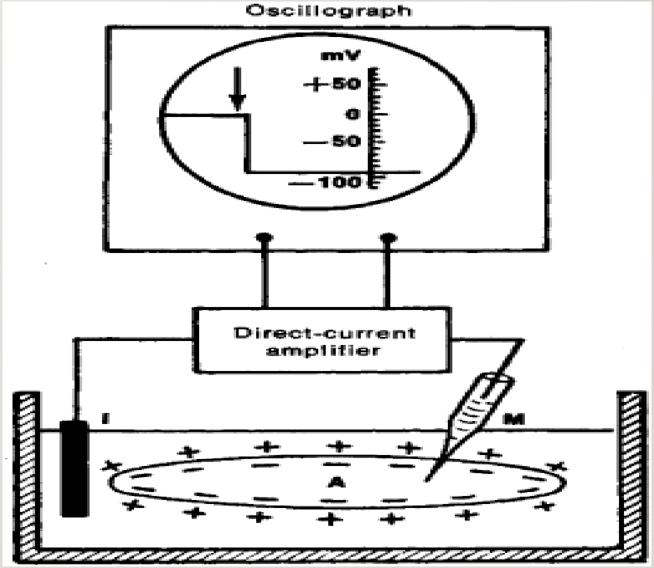
(Ag-AgCl) is placed in

the extracellular fluid.

The arrangement used in

this method is ad shown

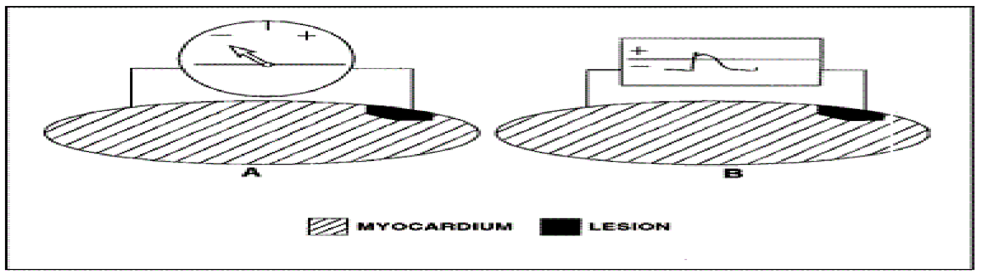
In the following figure.



As soon as the glass microelectrode holes the cell membrane, the oscillograph beam is immediately deflected down from its original position and becomes stabilized at a new level , thus detecting a potential difference between the exterior and interior of cell (i.e. the resting potential)

5- The injury potential

When two electrodes are placed at the surface of a living nerve fibre, and if the area under one of these electrodes is crushed a potential arises. Such potential called the injury potential. This potential is not stable but changes with respect to time from the injury instant, and also on the distance between the active electrode and the injured part.



A) Sketch of the injury potential; B) Sketch of the action potential obtained through the injury technique.

The probable explanation for the existence of this potential is that injury destroys the selective permeability of the cellular membrane, reducing the membrane's electrical resistance.

III- ACTION POTENTIAL (A.P)

When the membrane of a cell is sufficiently stimulated, it release some of the stored energy. As a result the interior potential of the cell is quickly changes, this change on potential is called action potential.

https://www.youtube.com/watch?v=FEHNIELPb0s

1-Types of stimulus

The stimulus may be electrical, chemical, mechanical, heat, radiation, ….etc.

The electrical stimulus is the most preferable, because it can be controlled easily in magnitude and time of application.

2- Stimulus effect

The stimulus effect may be classified into three types according to the response of the cell or tissue to the stimulus:

A- Subthreshold stimulus: which has a small strength and can cause a local effect doesn't able to propagate from the place of stimulation, even if the time of stimulation is increased.

B- Threshold stimulus: which is suitable in magnitude and time to stimulate the cell or tissue and the response can propagate from place to another.

C- Superthreshold stimulus: which has high values in magnitude and time and may cause damage or death of cells.

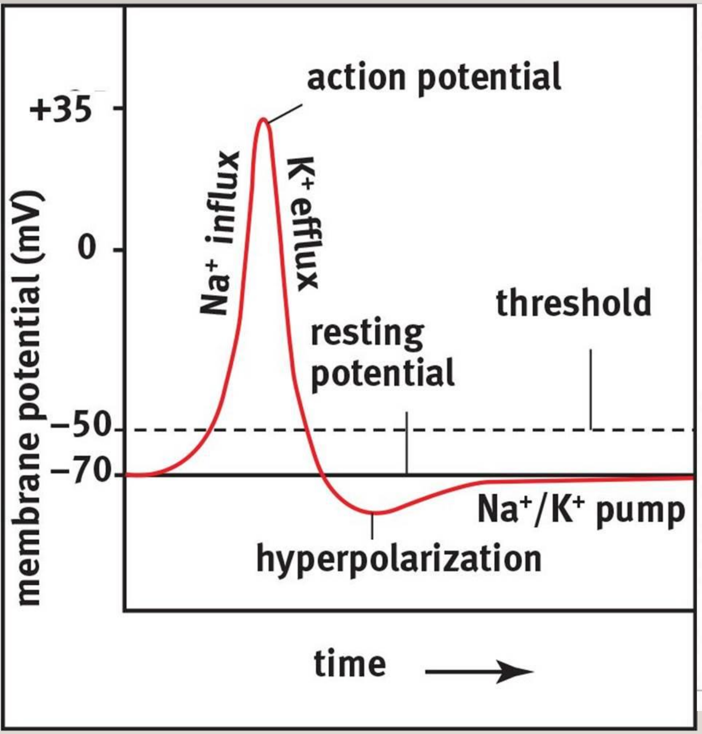
- In general any stimulus can increase the membrane permeability to Na^+ ions, is threshold and can produce action potential.

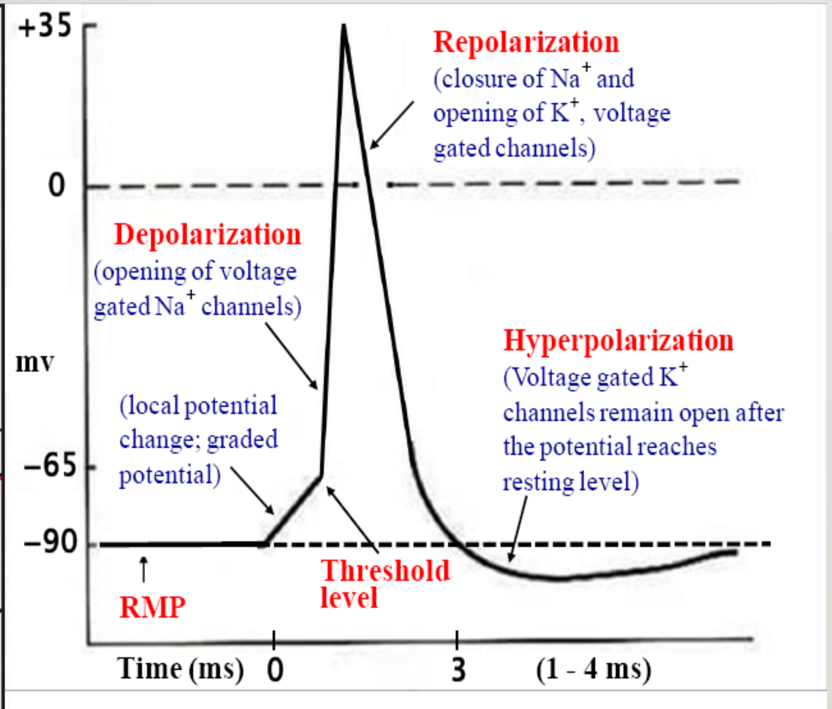
3-Intracellular action potential (Depolarization- Repolarization process)

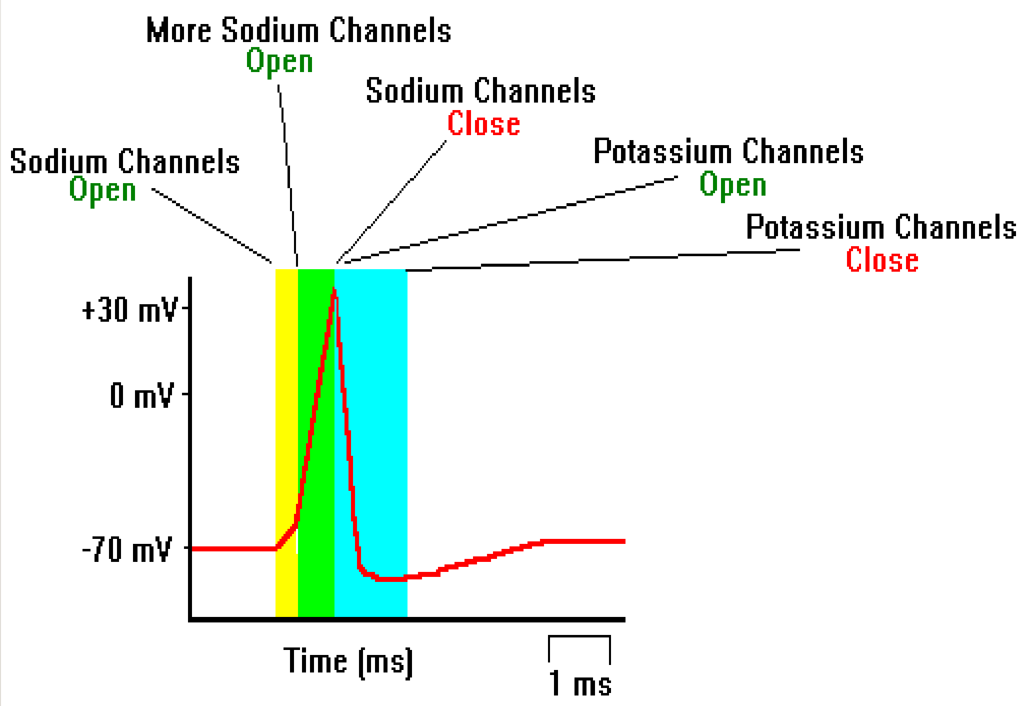
When a membrane of a nerve cell is sufficiently stimulated it release some of the stored energy. The interior potential of the cell quickly rises from about -90 mV to about +20 to +30 mV. This process is called **depolarization.**

During depolarization (**Na^+ influx**) , the cell membrane becomes permeable to Na^+ ions and the permeability increases with time, driving the interior potential positive. As the interior potential reaches +20 to +30, the **repolarization** process begins by the migration of K^+ ions outward (**K^+ efflux**). This migration of K^+ ions causes the interior potential to return negative again. Na^+-K^+ pump starts to work nearly at -60mV by taking 3Na^+ ions outward and replacing them by 2 K^+ ions (inward), this process continues until the interior potential reaches -90mV again (resting potential).

The voltage pulse produced by depolarization-repolarization (**Na^+ influx-K^+ efflux)** process is called <u>action potential</u>.







Refractory period

During the absolute **refractory period**, the neuron cannot be excited to generate a second action potential (no matter how intense the stimulus). ... This recovery **period** is the relative **refractory period during** which a stronger than normal stimulus is needed to initiate a new action potential

The relative Refractory period

During hyperpolarization Na channels are closed and the inactivation gate opens. There is no change in Na flow but now they could be opened again. While Na channels could open, it would take a larger than usual stimulus to reach threshold because the cell is hyperpolarized due to the K still leaving the cell