BIO POTENTIAL AND BIO ELECTRODES

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Contents

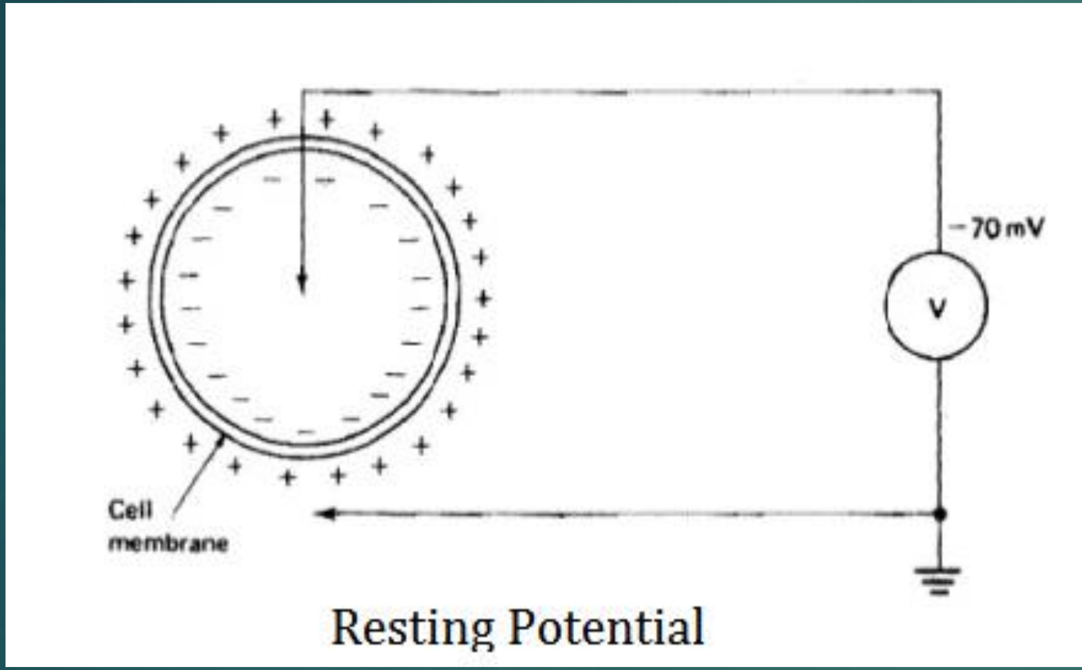
Bio Potential

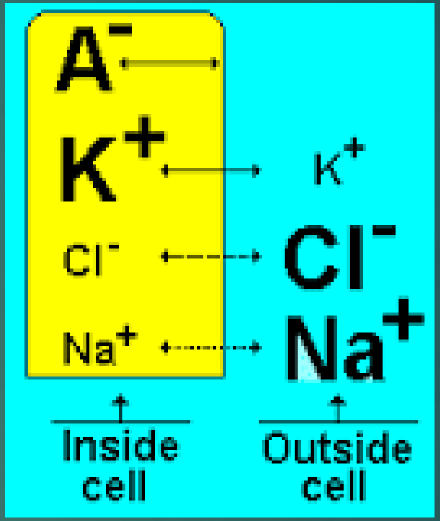
- An electric potential that is measured between points in living cells, tissues, and organisms, and which accompanies all biochemical processes.
- It describes the transfer of information between and within cells.

Resting (Membrane) Potential:

- It is the electrical potential of a neuron or other excitable cell relative to its surroundings when not stimulated (at rest) or involved in passage of an impulse.
- The resting membrane potential of a neuron is about -70 mV (mV=millivolt) - this means that the inside of the neuron is 70 mV less than the outside.
- At rest, there are relatively more sodium ions outside the neuron and more potassium ions inside that neuron.
- RMP is a product of the distribution of charged particles (ions).
- There are numerous numbers of ions in the cells, positively charged ions called cations (e.g., Na+, K+, Mg2+, Ca2+) and negatively charged ions called anions (e.g., Cl- and proteins that act as anions).

Resting (Membrane) Potential:

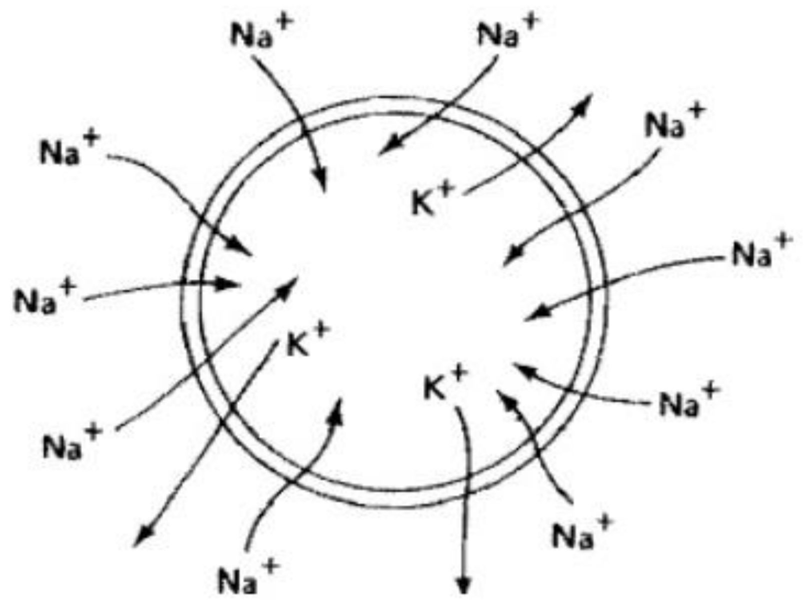




Action Potential:

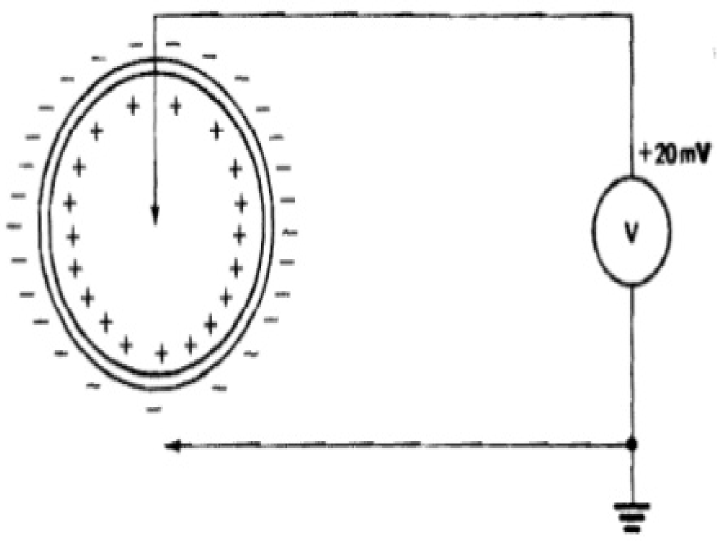
- It is the change in electrical potential associated with the passage of an impulse along the membrane of a muscle cell or nerve cell.
- The maximum value of action potential is generally 30 mV.
- The action potential is an explosion of electrical activity that is created by a depolarizing current.
- This means that some event (a stimulus) causes the resting potential to move toward 0 mV.
- When the depolarization reaches about -55 mV a neuron will fire an action potential. This is the threshold.

Action Potential:



Action Potential

Depolarized Cell during Action Potential



Propagation of Action Potential:

- The action potential generated at the axon hillock propagates as a wave along the axon.
- The currents flowing inwards at a point on the axon during an action potential spread out along the axon, and depolarize the adjacent sections of its membrane.
- The currents flowing inwards at a point on the axon during an action potential spread out along the axon, and depolarize the adjacent sections of its membrane.
- The absolute refractory period keeps the direction of propagation unidirectional.

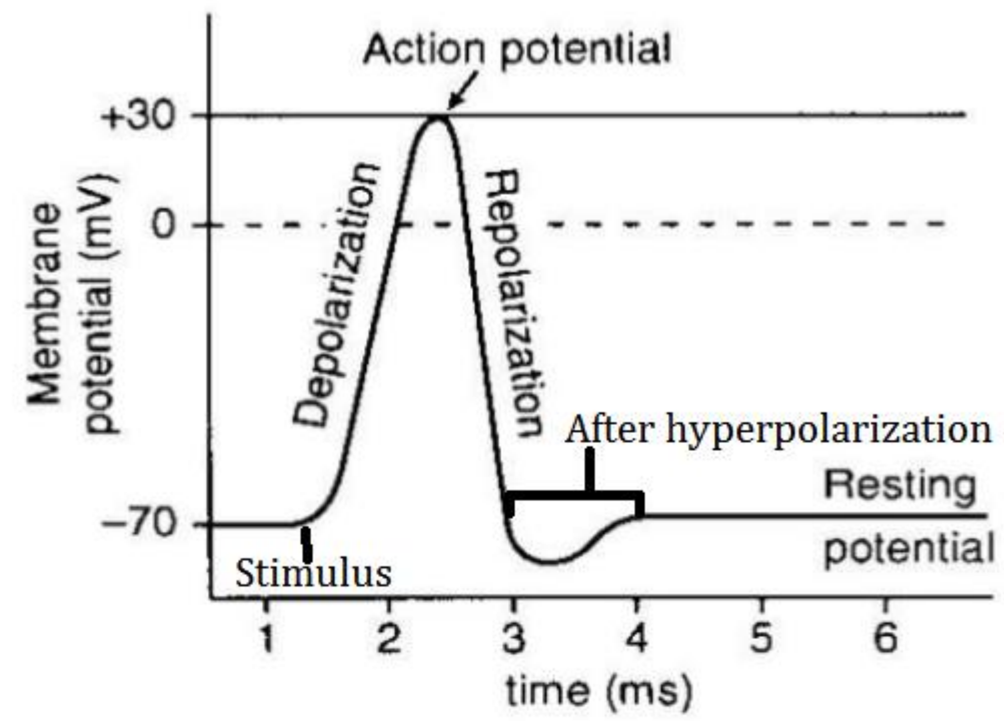
Propagation of Action Potential:

- Neurons send messages electrochemically. This means that chemicals produce electrical signals.
- The important ions in the nervous system are sodium and potassium (both have 1 positive charge, +), calcium (has 2 positive charges, ++) and chloride (has a negative charge, -).
- As sodium ions are more on the outside, and the inside of the neuron is negative relative to the outside, sodium ions rush into the neuron.
- When the potassium channel opens, potassium rushes out of the cell, reversing the depolarization.

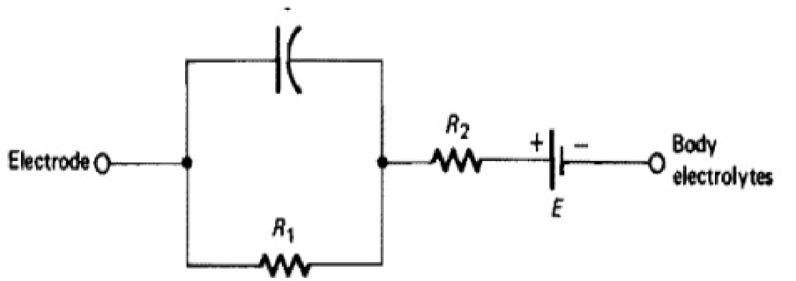
Propagation of Action Potential:

- A cell in the resting state is called polarized.
- The process of changing from the resting state to the action potential is called depolarization and the process of returning back to the resting state is called repolarization.
- During the process of repolarization, sodium pump pushes three sodium ions quickly out of the cell for every two potassium ions it puts in.
- Following the generation of action potential, there is a small gap within which the cell cannot respond to any new stimulus and this period is called the absolute refractory period which lasts for about 1ms.
- Beyond this point is the relative refractory period when cells do respond but the stimulus needed is much stronger and this may last for several milliseconds.
- Measurement methods which are based on bio potential are ECG, EEG, EMG, EOG, VCG and several others.

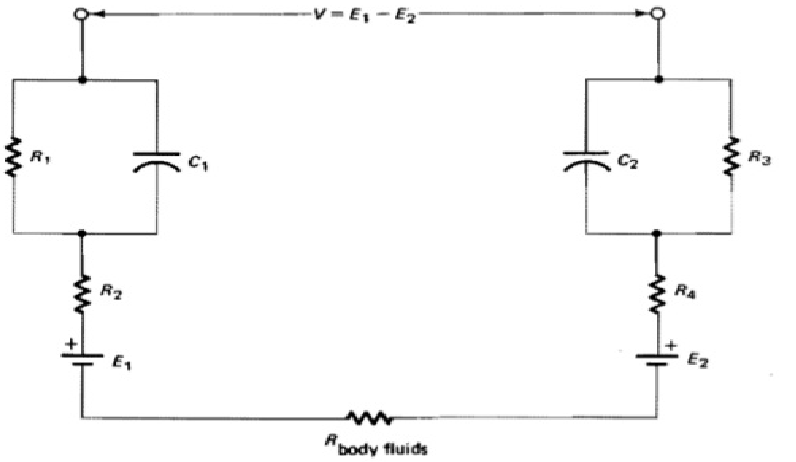
Propagation of Action Potential:



Bio Electric Potential



Bio Pot Electrode Interface Equivalent Circuit



Bio Pot Measurement with Two Electrodes - Equivalent

Synaptic Transmission:

- Synaptic Transmission is the process by which signalling molecules called neurotransmitters are released by a neuron (the presynaptic neuron), and bind to and activate the receptors of another neuron (the postsynaptic neuron).
- Neurotransmission is essential for the process of communication between two neurons.
- Synaptic Transmission relies on:
- The availability of the neurotransmitter; the release of the neurotransmitter by exocytosis;
- The binding of the postsynaptic receptor by the neurotransmitter;
- The functional response of the postsynaptic cell;
- The subsequent removal or deactivation of the neurotransmitter.

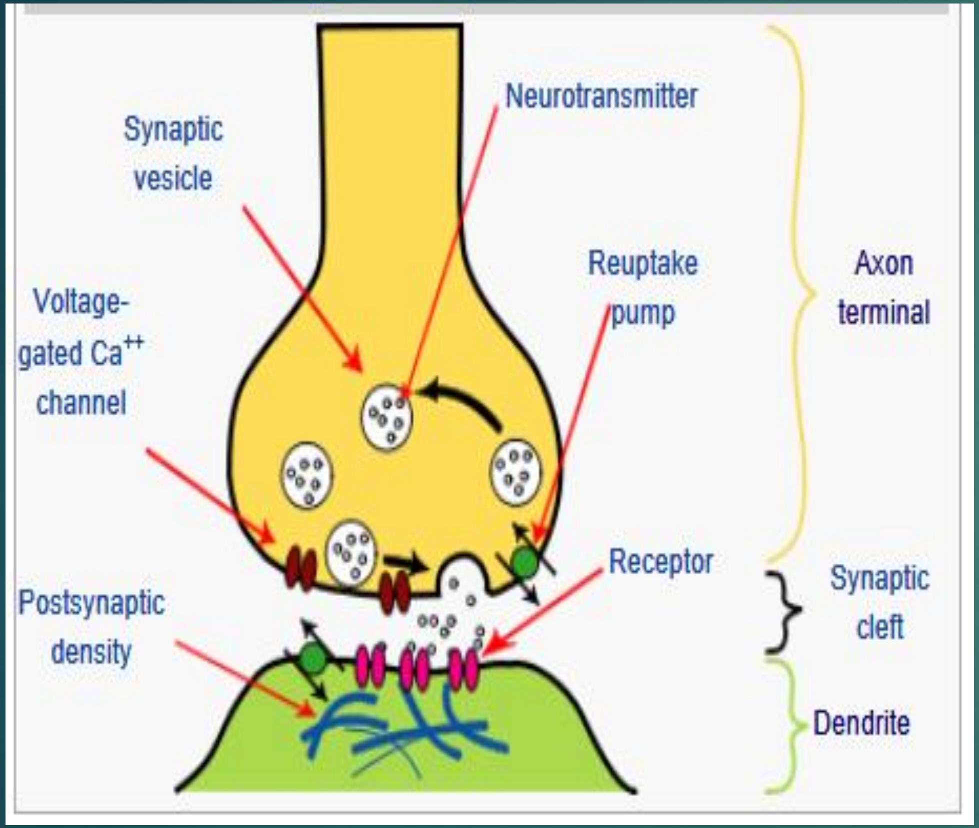
Synaptic Transmission:

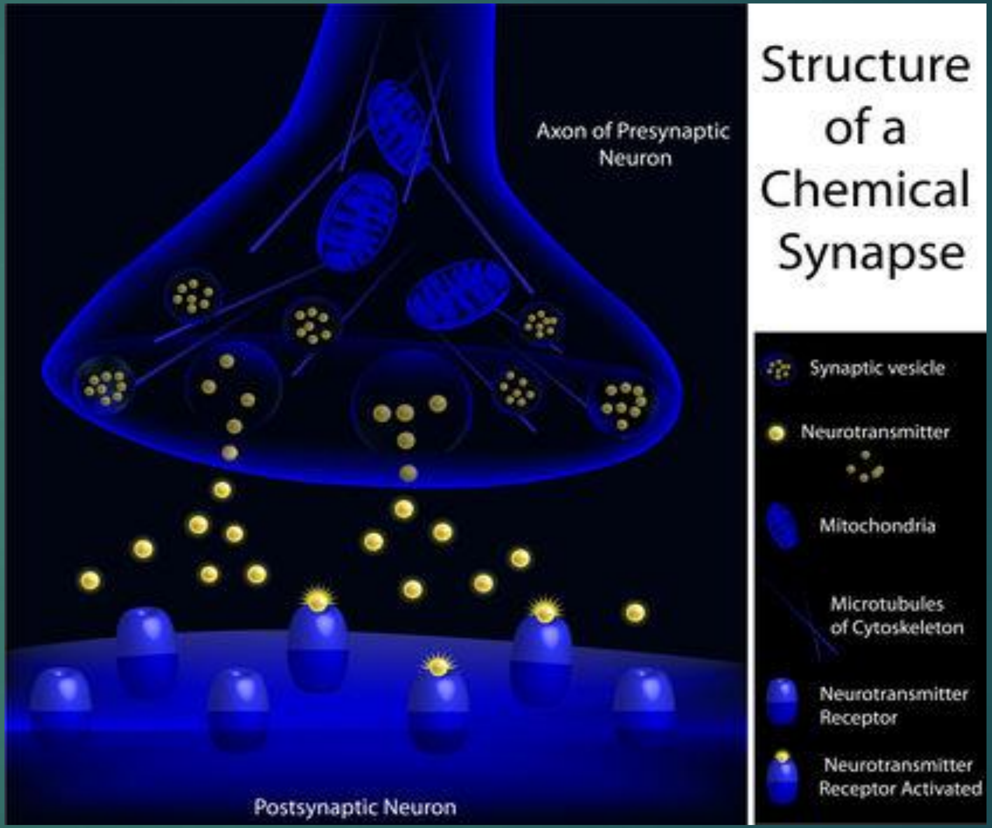
- When the action potential reaches the end of the axon and the axon terminals, it creates membranous sacs, called vesicles, to move toward the membrane of the axon terminal.
- The membrane of the vesicle fuses with the membrane of the axon terminal, enabling the vesicle to release its contents into the synaptic space.
- When a nerve impulse reaches the synapse at the end of a neuron, it cannot pass directly to the next one.
- Instead, it triggers the neuron to release a chemical neurotransmitter.
- The neurotransmitter drifts across the gap between the two neurons.

Synaptic Transmission:

- There are three ways in which neurotransmitter is deactivated:
- Reuptake- reabsorption (reenter) of the neurotransmitter into the neuron through channels in the membrane.
- Enzymatic degradation- destruction of the neurotransmitter into a substance which has no effect on the receptor channel with special chemicals called enzymes.
- Diffusion- The neurotransmitter becoming detached from the receptor and drifting out of the synaptic cleft.

Synaptic Transmission:





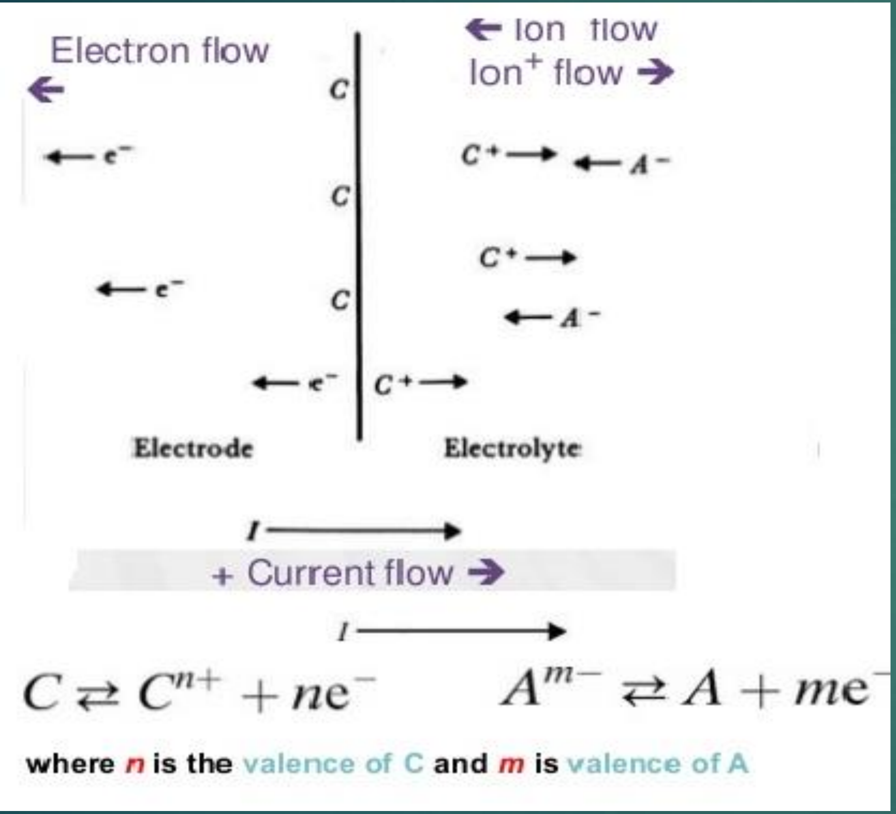
Bio Electrodes:

- **Bio electrodes** function as an interface between biological structures and electronic systems.
- Electrical activity within the biological structure is either sensed or stimulated.
- The electrical systems are either passively sensing (measuring) or actively stimulating (inducing) electrical potentials within the biological structure or unit.
- Bioelectric potentials generated in our body are ionic potentials and it is necessary to convert these ionic potentials into electronic potentials before they can be measured by conventional methods.
- Devices that convert ionic potential into electronic potential are called electrodes.
- A transducer that converts the body ionic current in the body into the traditional electronic current flowing in the electrode is a Bio Electrode.

Bio Electrodes:

- Able to conduct small current across the interface between the body and the electronic measuring circuit.
- Oxidation is dominant when the current flow is from electrode to electrolyte, and reduction dominate when the current flow is in the opposite.
- The net current that crosses the interface, passing from the electrode to electrolyte consist of
  - Electrons moving in a direction opposite to that of current in the electrode.
  - Cations moving in the same direction.
  - Anions moving in direction opposite to that of current in electrolyte.

Bio Electrodes:



Signal	Frequency Range (Hz)	Amplitude Range (mV)
ECG	0.01 – 100	0.05 – 3
EEG	0.1 – 80	0.001 – 1
EOG	0.01 – 10	0.001 – 0.3
EMG	50 – 3000	0.01 – 100

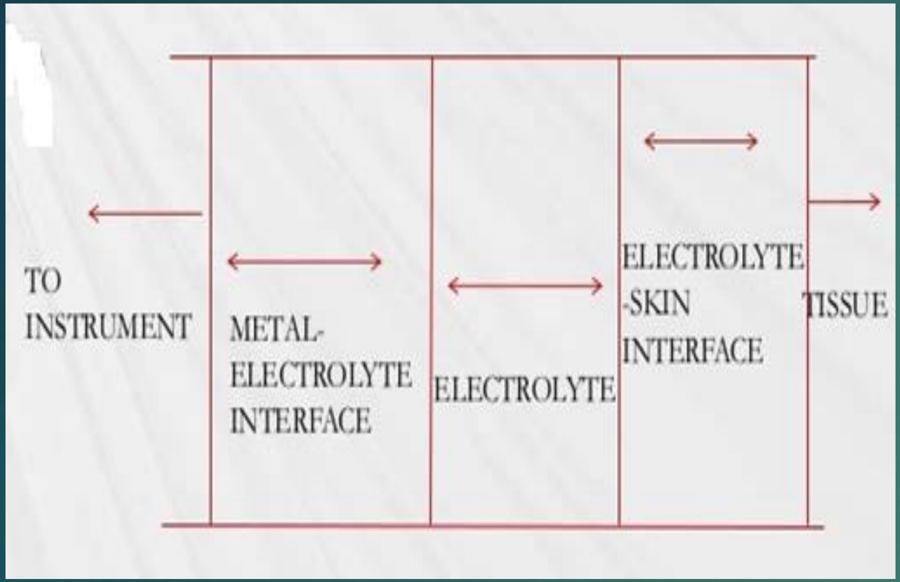
Properties of Bio Electrodes:

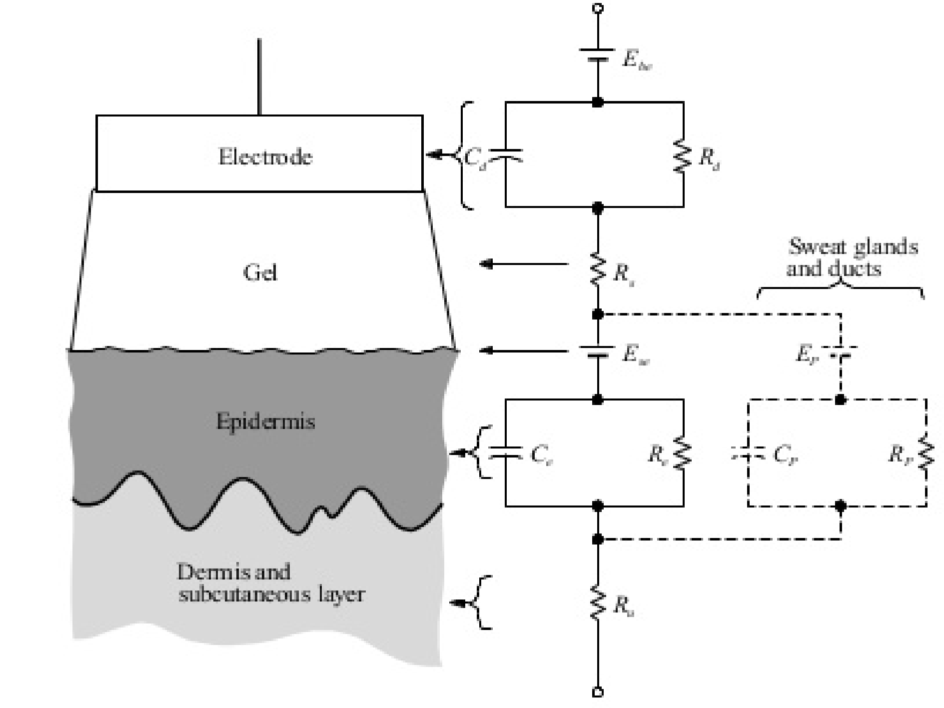
- Good conductors.
- Low impedance.
- Should not polarize when a current flows through them.
- Should establish a good contact with the body and not cause motion.
- Should not cause itching swelling or discomfort to the patient.
- Metal should not be toxic.
- Mechanically rugged.
- Easy to clean.

Electrode – Skin/Tissue Interface

- Interface between body and electronic measuring device.
- Conducts current across the interface.
- Ions carry current in the body.
- Electrodes are capable of changing ionic current into electronic current.
- Termed as Electrode – Electrolyte or Electrode – Tissue Interface.

Electrode – Skin/Tissue Interface





Skin Impedance reduces from 200 KΩ at 1 Hz to 200 Ω at 1 MHz, for 1 sq. cm.

Half Cell Potential

- The potential difference that is caused by the ability of electrons to flow from one half cell to the other.
- Electrons are able to move between electrodes as the chemical reaction is a redox reaction.
- Half cell potential is altered when there is current flowing in the electrode due to electrode polarization.
- When the metal comes in contact with solution, the electrolyte surrounding the metal is at different electric potential from rest of the solution.
- A second electrode is required to find half-cell potential- hydrogen
- Half-Cell potential is determined by
  - Metal involved
  - Concentration of its ion in solution
  - Temperature

Nernst Equation in context of Half Cell Potential

- Nernst Equation governs the half-cell potential.
- When two ionic solutions of different concentration are separated by semipermeable membrane, an electric potential exists across the membrane.

$$E = -\frac{RT}{nF}\ln\left[\frac{a_1}{a_2}\right]$$

- a_1 and a_2 are the ionic activity of the ions on each side of the membrane.
- Ionic activity is the availability of an ionic species in solution to enter into a reaction.

Polarization

- Normally Standard Half Cell Potential (E0) is an equilibrium value and assumes zero-current across the interface.
- When current flows, the half-cell potential, E 0 , changes.
- Overpotential (V p): Difference between non-zero current and zero-current half-cell potentials; also called the polarization potential.
- Ohmic Overpotential (V r) : Due to the resistance of the electrolyte (voltage drop along the path of ionic flow).
- Concentration Overpotential (V c): Due to a redistribution of the ions in the vicinity of the electrode-electrolyte interface (concentration changes).
- Activation Overpotential (V a): Due to metal ions going into solution (must overcome an energy barrier, the activation energy) or due to metal plating out of solution onto the electrode (a second activation energy).

Mechanism Contributed to Overpotential

- Ohmic overpotential: Voltage drop along the path of the current, and current changes resistance of electrolyte and thus, a voltage drop does not follow ohm's law.
- Concentration overpotential: Current changes the distribution of ions at the electrode-electrolyte interface
- Activation overpotential: Current changes the rate of oxidation and reduction. Since the activation energy barriers for oxidation and reduction are different, the net activation energy depends on the direction of current and this difference appear as voltage.

$$V_p = V_R + V_C + V_A$$

Polarizable Electrodes

- Perfectly Polarizable Electrodes

Electrodes in which no actual charge crosses the electrode-electrolyte interface when a current is applied.

The current across the interface is a displacement current and the electrode behaves like a capacitor.

Overpotential is due concentration.

- Example: Platinum electrode

- Perfectly Non-Polarizable Electrode

Electrodes in which current passes freely across the electrode-electrolyte interface, requiring no energy to make the transition.

These electrodes see no overpotentials.

- Example: Ag/AgCl Electrode

Motion Artefact:

- Blurring of a radiographic image, produced by respiratory, muscular, or other movement of the patient.
- When polarizable electrode is in contact with an electrolyte, a double layer of charge forms at the interface.
- Movement of the electrode will disturb the distribution of the charge and results in a momentary change in the half cell potential until equilibrium is reached again.
- Motion artifact is less minimum for non-polarizable electrodes.
- Signal due to motion has low frequency so it can be filtered out when measuring a biological signal of high frequency component such as EMG or axon action potential.
- However, for ECG, EEG and EOG whose frequencies are low it is recommended to use non-polarizable electrode to avoid signals due to motion artifact.

Electrode Types

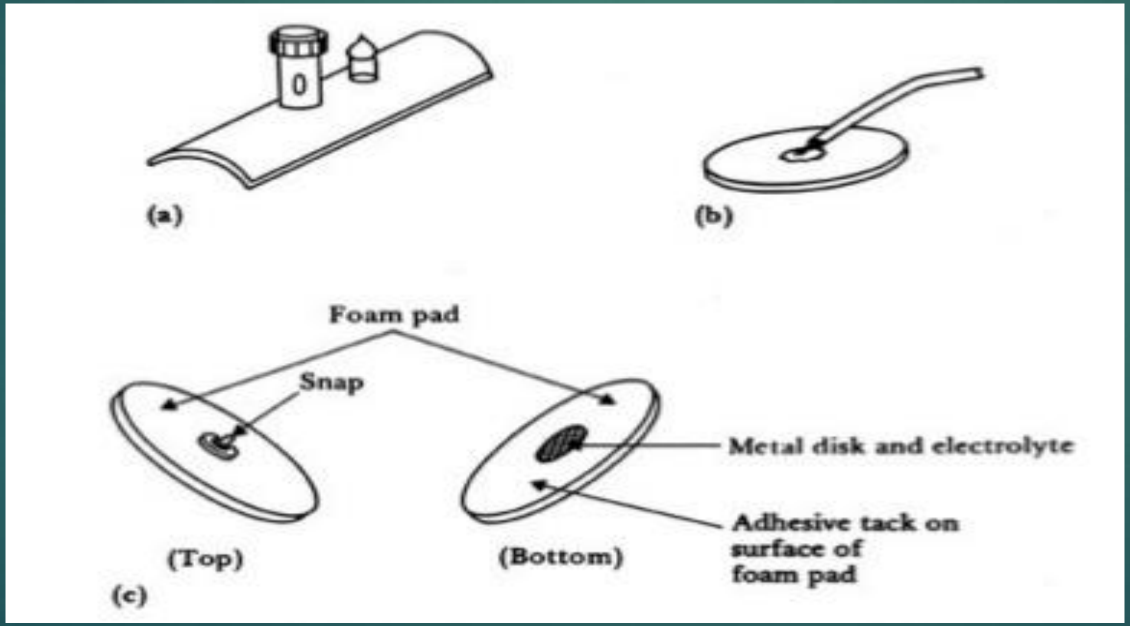
- Surface Electrode
  - Metal Plate
  - Floating Electrodes
  - Flexible Electrodes
- Microelectrodes:
- Internal Electrode:
- Needle Electrode

Electrodes Types - Surface

- Primarily used in ECG, EEG and EMG
- With conductive path between metal and skin being electrolyte paste or jelly.
- Sub types are
  - Metal
  - Suction
  - Floating
  - Flexible

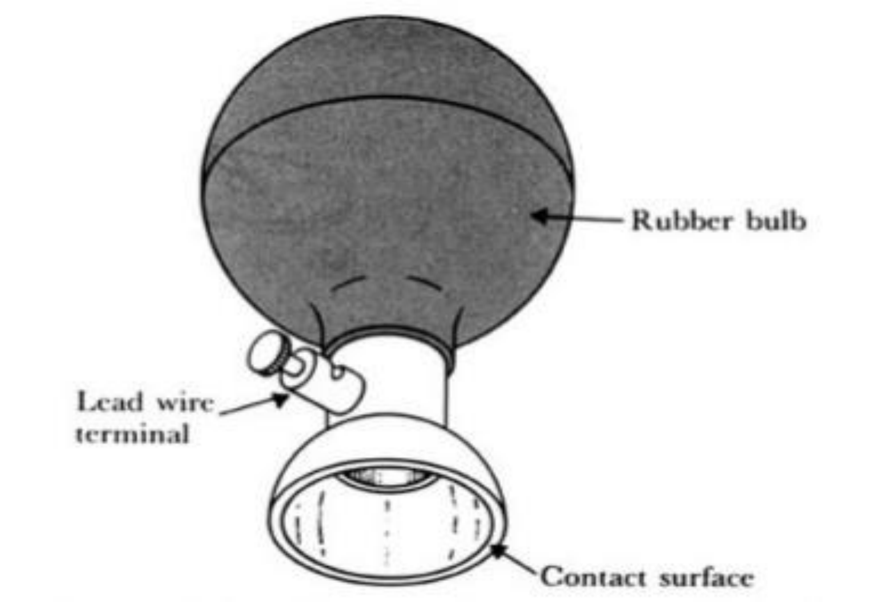
Electrode Types – Surface - Metal

- Metal-plate electrode used for application to limbs.
- Metal-disk electrode applied with surgical tape.
- Disposable foam-pad electrodes, often used with electrocardiograph monitoring apparatus.



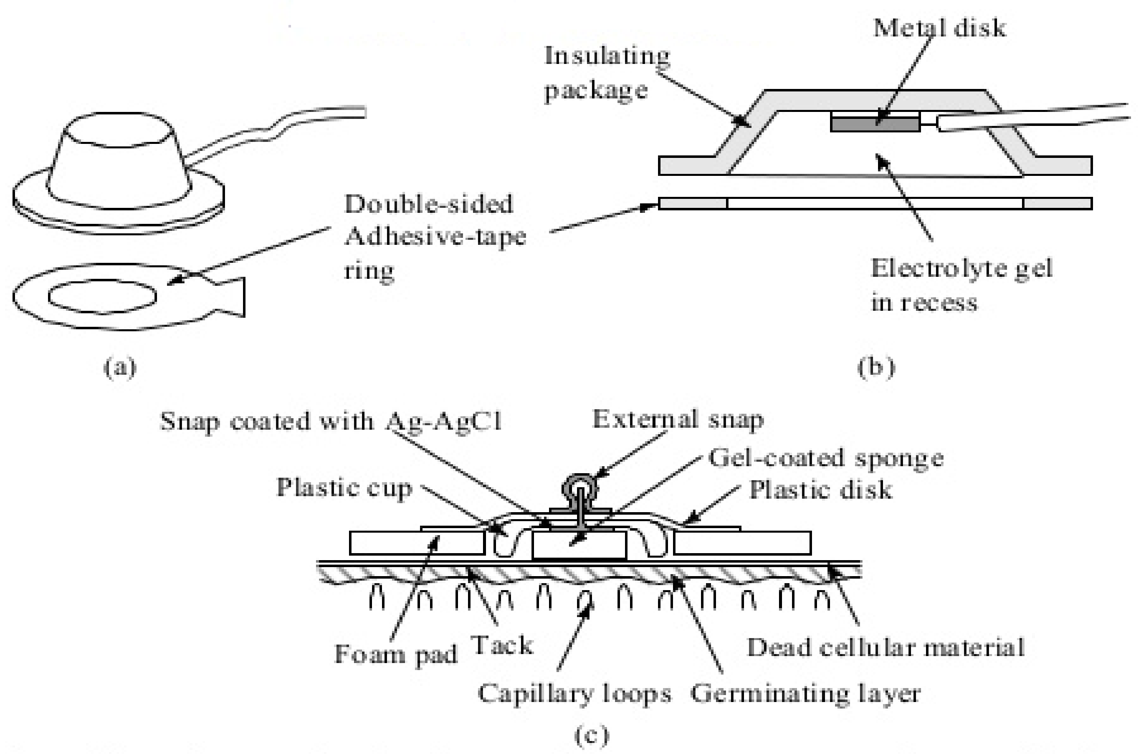
Electrode Types – Surface - Suction

- A metallic suction electrode is often used as a precordial electrode on clinical electrocardiographs.
- No need for strap or adhesive and can be used frequently.
- Higher source impedance since the contact area is small.



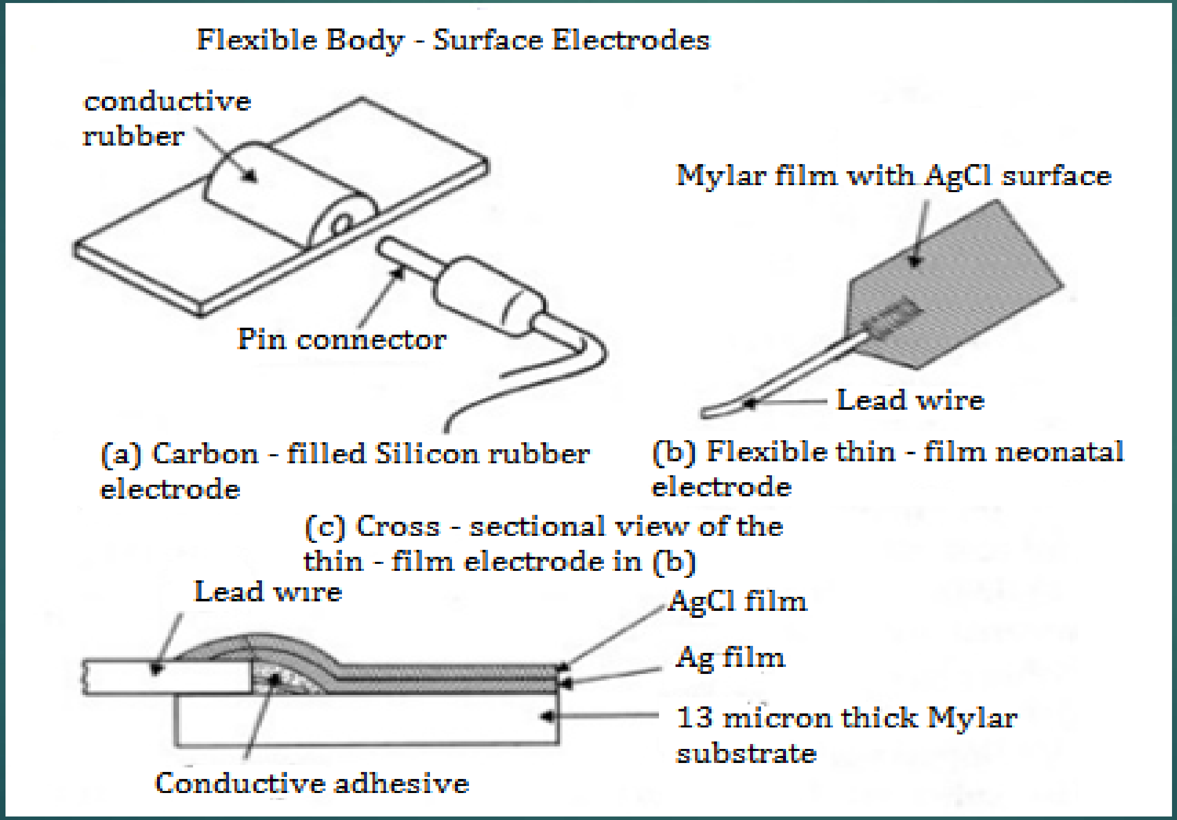
Electrode Types – Surface - Floating

- The recess in this electrode is formed from an open foam disk, saturated with electrolyte gel and placed over the metal electrode.
- Minimize motion artifact.



Electrode Types – Surface - Flexible

- Used for newborn infants
- Compatible with X - ray

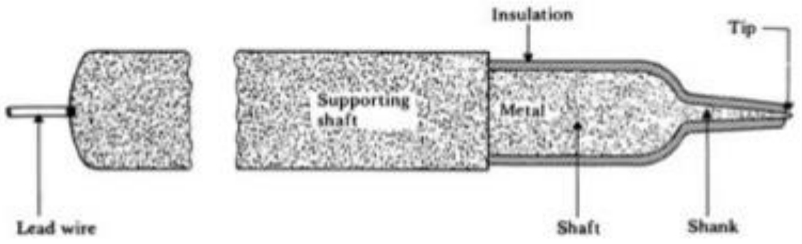


Microelectrodes:

- It is an electrode of very small size, used in electrophysiology for either recording of neural signals or electrical stimulation of nervous tissue.
- MEAs are Circuit less chips
- Sufficiently small to be placed into cell.
- Sufficiently strong to penetrate cell membranes.
- Tip diameter: 0.05 – 10 microns.
- CMOS based MEA (Microelectrode Array) have high spatial and temporal resolution at excellent signal quality.
- Useful to access the behavior of electrogenic cells.

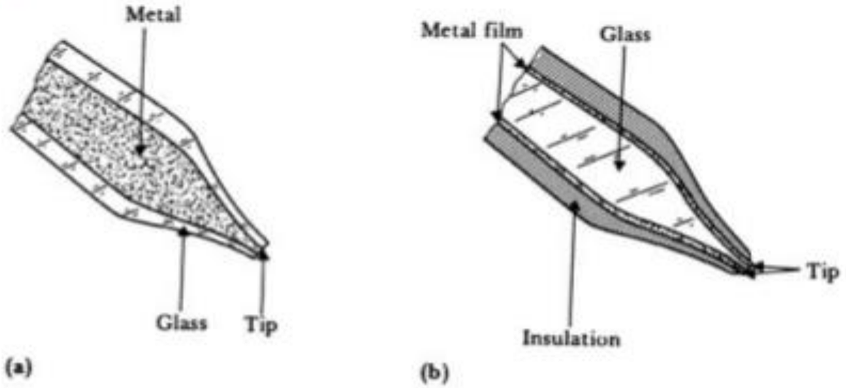
Microelectrodes:

The structure of a metal microelectrode for intracellular recordings.



(a) Metal - filled glass micropipet.

(b) Glass micropipet or probe coated with metal film



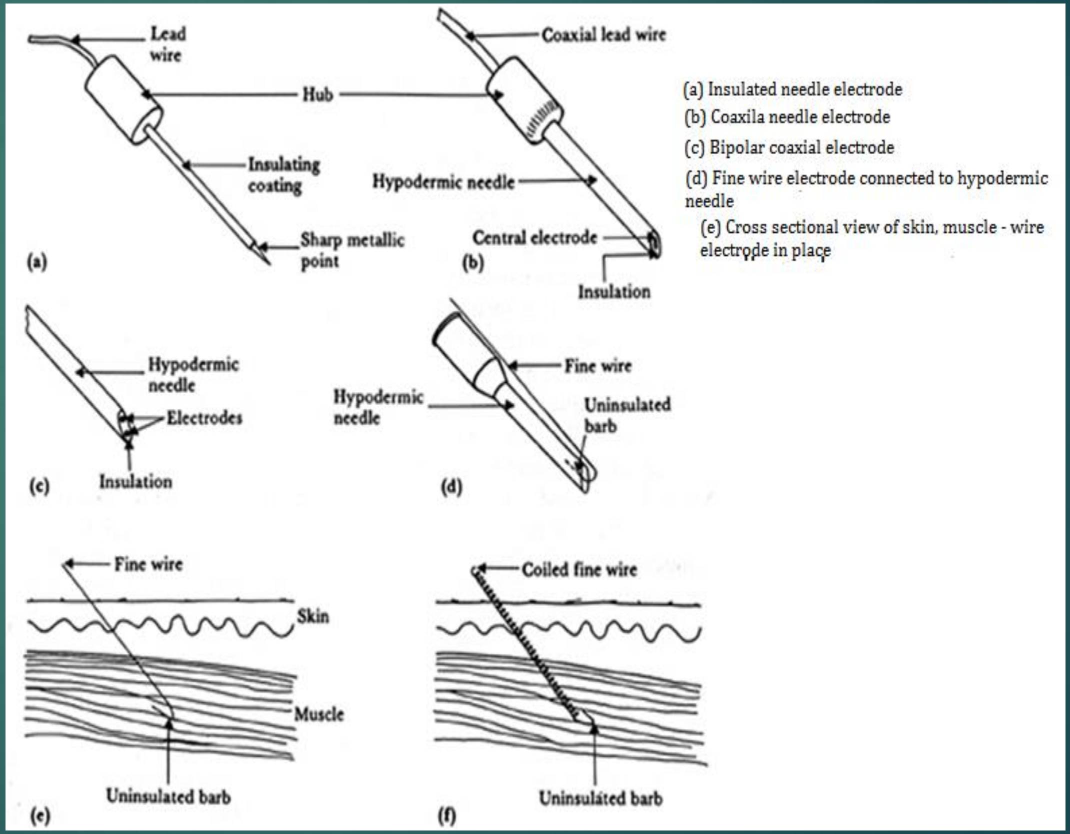
$$\frac{C_{dl}}{L} = \frac{2\pi\varepsilon_r\varepsilon_0}{\ln D/d}$$

Capacitance per unit length

ε_0 = dielectric constant of free space
ε_r = relative dielectric constant of insulation material
D = diameter of cylinder consisting of electrode plus insulation
D = diameter of electrode
L = length of shank

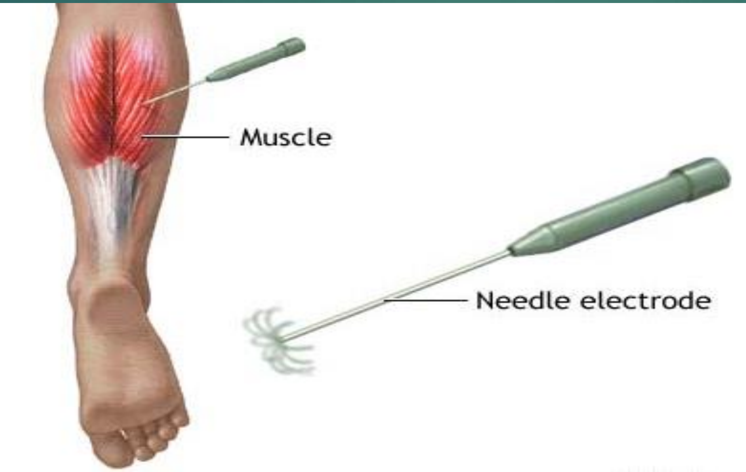
Internal Electrode:

- For detecting fetal electrocardiogram during labour, by means of intracutaneous needles.
- No electrolyte – skin interface.
- No electrolytic gel is required.



Needle Electrodes

- It penetrates the skin to record the potentials.
- It reduces interface impedance.
- Single wire inside the needle which acts as the unipolar electrode measuring potential at the point of contact.
- Types are concentric, bipolar and monopolar.



Applications of Bio Electrodes

- Cardiac Monitoring
- Infant Cardiopulmonary Monitoring
- Sleep Encephalography
- Diagnostic Muscle Activity
- Cardiac Electrogram
- Implanted Telemetry of Biopotentials
- Eye Movement

References

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