CHENNAI INSTITUTE OF TECHNOLOGY

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DEPARTMENT OF

ELECTRICAL AND ELECTRONICS ENGINEERING

V SEMESTER

OMD551 – BASICS OF BIOMEDICAL INSTRUMENTAION

Academic Year 2021-2022

Course Material Prepared By

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UNIT -1 BIOPOTENTIAL GENERATION AND ELECTRODES TYPES

1. ORIGIN OF BIOPOTENTIAL:

Bioelectric phenomenon is of immense importance to biomedical engineers because these potentials are routinely recorded in modern clinical practice. ECG (Electrocardiogram), EMG (Electromyogram), EEG (Electroencephalogram), ENG (Electroneurogram), EOG (Electro-oculogram), ERG (Electroretinogram), etc. are some examples of biopotentials.

THE RESTING AND ACTION POTENTIALS

- Certain types of cells within the body, such as nerve and muscle cells, are encased in a semi permeable membrane that permits some substances to pass through the membrane while others are kept out. 63.9
- Neither the exact structure of the membrane nor the mechanism by which its permeability is controlled is known, but the substances involved have been identified by experimentation.

Surrounding the cells of the body are the body fluids. These fluids are conductive solutions containing charged atoms known as ions. The principal ions are sodium (Na^+), potassium (K^+), and chloride (C^-).

The membrane of excitable cells readily permits entry of potassium and chloride ions but effectively blocks the entry of sodium ions.
Since the various ions seek a balance between the inside of the cell and the outside, both according to concentration and electric charge, the inability of the sodium to penetrate the membrane results in **two conditions.**

- First, the concentration of sodium ions inside the cell becomes much lower than in the intercellular fluid outside. Since the sodium ions are positive, this would tend to make the outside of the cell more positive than the inside.
- Second, in an attempt to balance the electric charge, additional potassium ions, which are also positive, enter the cell, causing a **higher concentration of potassium** on the inside than on the outside. This membrane potential is called the **resting potential** of the cell .
- Research investigators have reported measuring membrane potentials in various cells ranging from - 60 to - 100 mV.
- A cell in the resting state is said to be polarized.

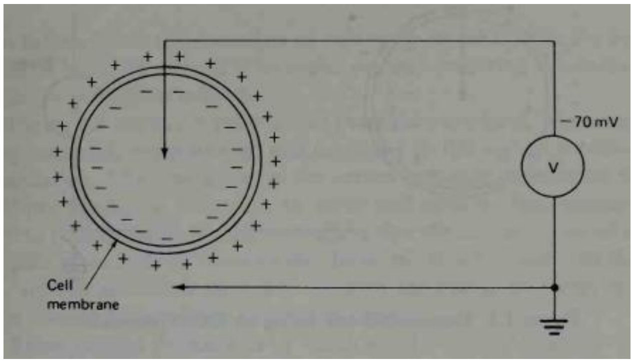


FIG Polarized cell with its resting potential

When a section of the cell membrane is excited by the flow of ionic current or by some form of externally applied energy, the membrane changes its characteristics and begins to allow some of the sodium ions to enter.

- This movement of sodium ions into the cell constitutes an ionic current flow that further reduces the barrier of the membrane to sodium ions.
- At the same time potassium ions, which were in higher concentration inside the cell during the resting state, try to leave the cell but are unable to move,
- The cell has a slightly positive potential on the inside due to the imbalance of potassium ions. This potential is known as the **action potential**.
- A cell that has been excited and that displays an action potential is said to be depolarized; the process of changing from the resting state to the action potential is called **depolarization.**

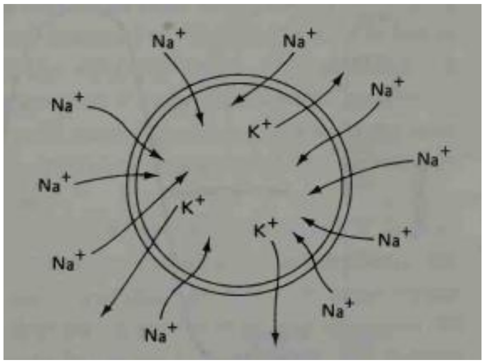


FIG Depolarization of a cell.

- Na^+ ions rush into the cell while K^+ ions attempt to leave.
- Once the rush of sodium ions through the cell membrane has stopped (a new state of equilibrium is reached), the ionic currents that lowered the barrier to sodium ions are no longer present

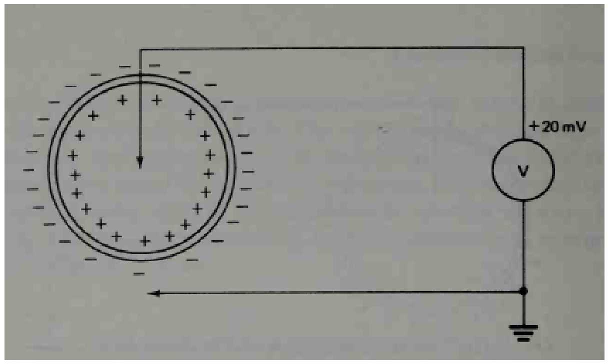


FIG Depolarized cell during an action potential.

- By an active process, called a sodium pump, the sodium ions are quickly transported to the outside of the cell, and the cell again becomes polarized and assumes its resting potential. This process is called **repolarization**.

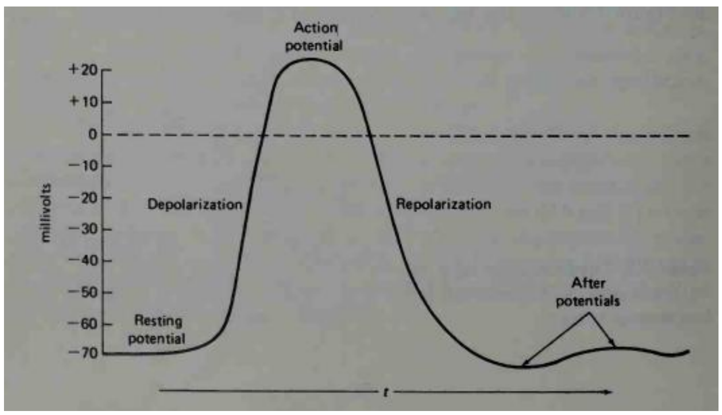


FIG Waveform of the action potential. (Time scale varies with type of cell.)

- It shows a typical action-potential waveform, beginning at the resting potential, depolarizing, and returning to the resting potential after repolarization.

PROPAGATION OF ACTION POTENTIALS

- When a cell is excited and generates an action potential ionic currents begin to flow. This process can, in turn, excite neighboring cells or adjacent areas of the same cell.
- The rate at which an action potential moves down a fiber or is propagated from cell to cell is called the **propagation rate**.
- In nerve fibers the propagation rate is also called the **nerve conduction rate, or conduction velocity.**

The usual velocity range in nerves is from 20 to 140 meters per second (m/sec). Propagation through heart muscle is slower, with an average rate from 0.2 to 0.4 m/sec.

Special time-delay fibers between the atria and ventricles of the heart cause action potentials to propagate at an even slower rate, 0.03 to 0.05 m/sec.

2. TYPES OF ELECTRODES

A wide variety of electrodes can be used to measure bioelectric events, but nearly all can be classified as belonging to one of three basic types:

1 . **Microelectrodes:** Electrodes used to measure bioelectric potentials near or within a single cell.
2. **Skin surface electrodes**: Electrodes used to measure ECG, EEG, and EMG potentials from the surface of the skin.
3. **Needle electrodes:** Electrodes used to penetrate the skin to record EEG potentials from a local region of the brain or EMG potentials from a specific group of muscles.

- All three types of biopotential electrodes have the metal-electrolyte interface. In each case, an electrode potential is developed across the interface, proportional to the exchange of ions between the metal and the electrolytes of the body.
- The double layer of charge at the interface acts as a capacitor.

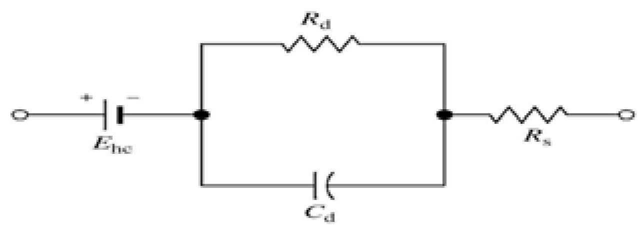
Measurement of bioelectric potentials requires two electrodes

- If the two electrodes are of the same type, the difference is usually small
- If the two electrodes are different, however, they may produce a significant dc voltage that can cause current to flow through both electrodes as well as through the input circuit of the amplifier to which they are connected.

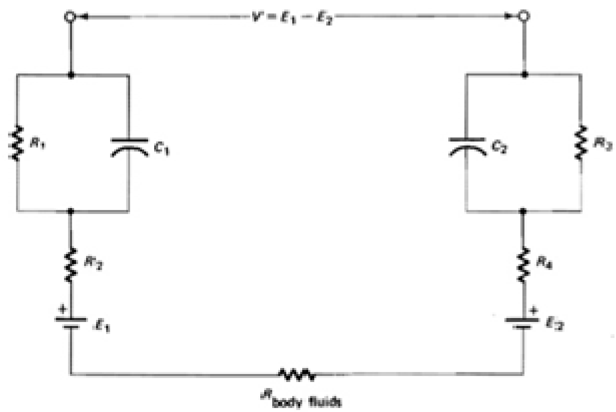
The dc voltage due to the difference in electrode potentials is called the **electrode offset voltage.**

- This type of electrode is prepared by electrolytically coating a piece of pure silver with silver chloride.
- The coating is normally done by placing a cleaned piece of silver into a bromide-free sodium chloride solution.
- A second piece of silver is also placed in the solution, and the two are connected to a voltage source such that the electrode to be chlorided is made positive with respect to the other.
- The impedance is frequency-dependent because of the effect of the capacitance. Furthermore, both the electrode potential and the impedance are varied by an effect called **polarization.**

Surface electrodes generally have impedances of 2 to 10 KOhms, whereas small needle electrodes and microelectrodes have much higher impedances. Reading or recording the potentials measured by the electrodes, the input impedance of the amplifier must be several times that of the electrodes.



Equivalent circuit of biopotential electrode interface



Measurement of biopotentials with two electrodes –equivalent circuit

Microelectrodes

Microelectrodes are electrodes with tips sufficiently small to penetrate a single cell in order to obtain readings from within the cell. The tip must be small enough to permit penetration without damaging the cell.

Micro electrodes are divided into **Metallic and non metallic**

Non metallic micro electrode is called micropipette

Microelectrodes are generally of two types:

- Metal
- Micropipette.

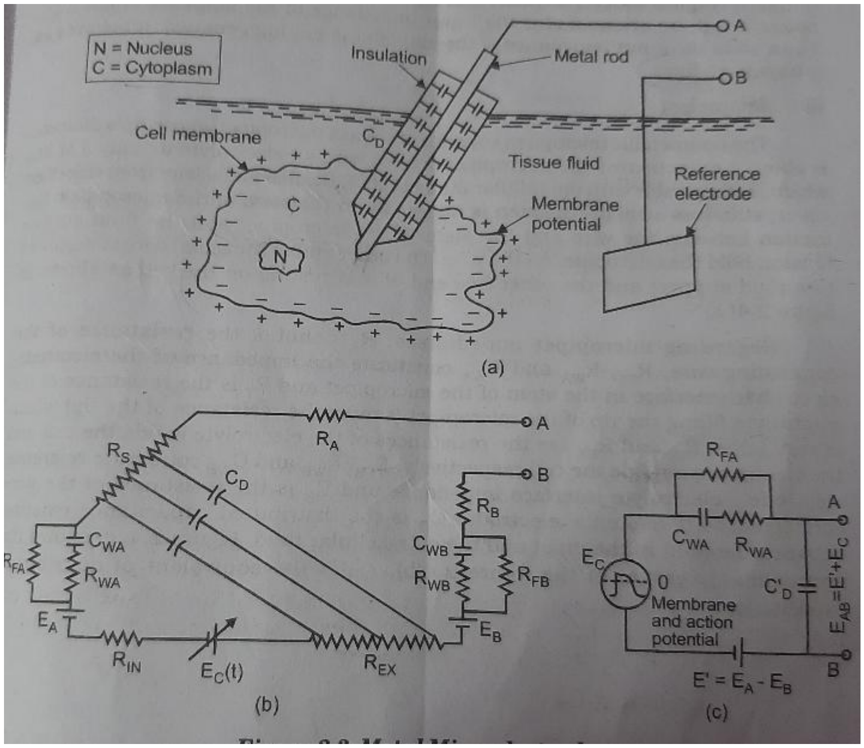
Metal microelectrodes

- Metal microelectrodes are formed by electrolytic ally etching the tip of a fine tungsten or stainless steel wire to a fine point. This technique is known electro pointing.
- The metal microelectrodes are coated almost to the micro tip with an insulating material.

  E_A - metal electrode-electrolyte potential at the microelectrode tip

  E_B - reference electrode - electrolyte potential

  E_C - variable cell membrane potential



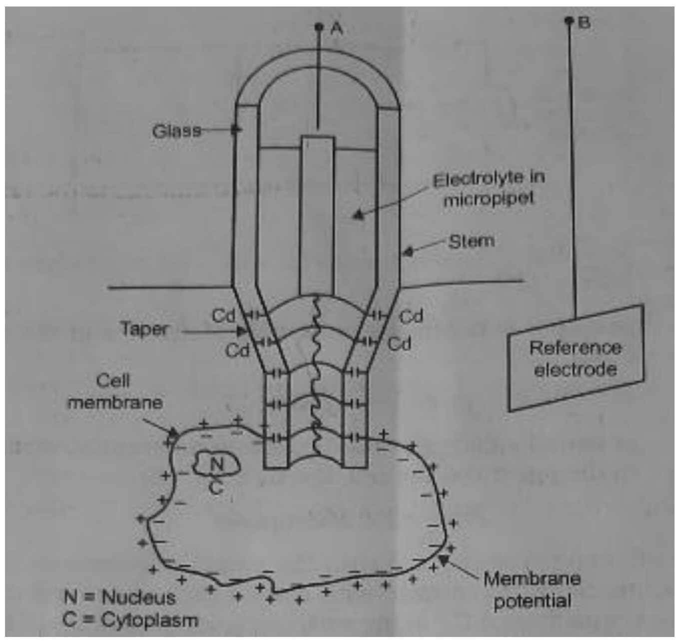
- Figure A shows the position of electrodes and Fig B is the electrical equivalent of Fig A.

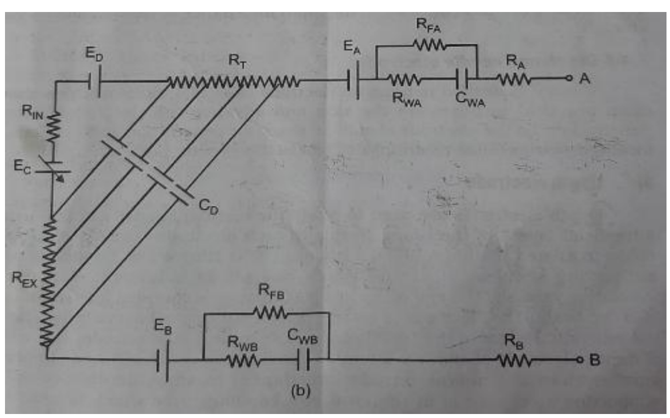
The measurement of bioelectric potential requires two electrodes ,the voltage measured is really the difference between the instantaneous potentials of the microelectrode and the reference electrode and its sum of three potentials as shown in fig B such that

- R_A denotes the resistance of the connecting wire which is negligible, R_s denotes the resistance of the shaft of the microelectrode which is also negligible.
- R_{FA}, R_{WA}, and C_{WA} constitute the impedance of the microelectrode tip - intracellular fluid interface; R_{IN} is the resistance of the intracellular fluid and R_B is the resistance of the wire connected to the reference electrode.
- R_{FB}, R_{WB} and C_{WB} constitute the impedance of the reference electrode -extracellular fluid interface and R_{EX} is the resistance of the extracellular fluid
- C_D is the distributed capacitance between the insulated shaft of the microelectrode and extracellular fluid.
- The capacitance between the tip of the microelectrode and intracellular fluid is negligible because of the potential difference across it does not change.
- The impedance of the microelectrode tip is inversely proportional to the area of the tip and frequency.
- Thus when the input impedance of the amplifier is not high enough, it behaves as a high pass filter.

Micropipet

- The non metallic micropipet consists of a glass micropipet whose tip's diameter is about 1 micrometer and its filled with a electrolyte usually 3 M KCL which is compatible with the cellular fluids.
- A thin flexible metal wire from chlorided silver, stainless steel or tungsten is inserted into the stem of the micropipet.
- The friction between the wire and the stem of the micropipet and the fluid surface tension hold the micropipet on the wire. The other end of the metal wire is mounted to a rigid support and the other free end of it in resting on the cell.

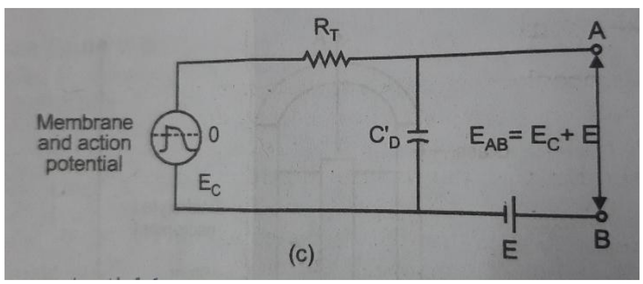




E_A - potential between the metal wire and electrolyte filled in the micropipet.
E_B - potential between the reference electrode and the extracellular fluid.

E_C - variable cell membrane potential
E_D - potential exiting at the tip due to different electrolytes present in the pipet and the cell
$E=E_A+E_B+E_D$.

- R_A denotes the resistance of the connecting wire.
- R_{FA}, R_{WA} , C_{WA} constitute the impedance of the electrode electrolyte interface in the stem of the micropipet.
- R_{IN} and R_{EX} is the resistance of the electrolyte inside the cell and the electrolyte outside the cell.
- R_{FB}, R_{WB} and C_{WB} constitute reference electrode –electrolyte interface impedance
- R_B is the resistance of the wire connected to the reference electrode.
- C_D is the distributed capacitance existing between the fluid in the pipet and the extracellular fluid.
- C'_D is the equivalent of distributed capacitance.



When the micropipet is coupled with the amplifier terminals A and B, then the membrane potential Ec is coupled with it via a high series resistance 'R_T' and a moderate shunt capacitance C_D along with electrode potentials.

Surface Electrodes

- Electrodes used to obtain bioelectric potentials from the surface of the body are found in many sizes and forms. Although any type of surface electrode can be used to sense EGG, EEG, or EMG potentials.
- The larger electrodes are usually associated with EGG, since localization of the measurement is not important, whereas smaller electrodes are used in EEG and EMG measurements.
- A great improvement over the **immersion electrodes** were the plate electrodes. Originally, these electrodes were separated from the subject's skin by cotton or felt pads soaked in a strong saline solution. Later a conductive jelly or paste (an electrolyte)

replaced the soaked pads and metal was allowed to contact the skin through a thin coat of jelly.

- Another fairly old type of electrode still in use is the **suction-cup electrode** shown, In this type, only the rim actually contacts the skin.
- One of the difficulties in using plate electrodes is the possibility of electrode slippage or movement.
- The use of adhesive backing and a surface resembling a **nutmeg grater** that penetrates the skin to lower the contact impedance and reduce the likelihood of slippage.

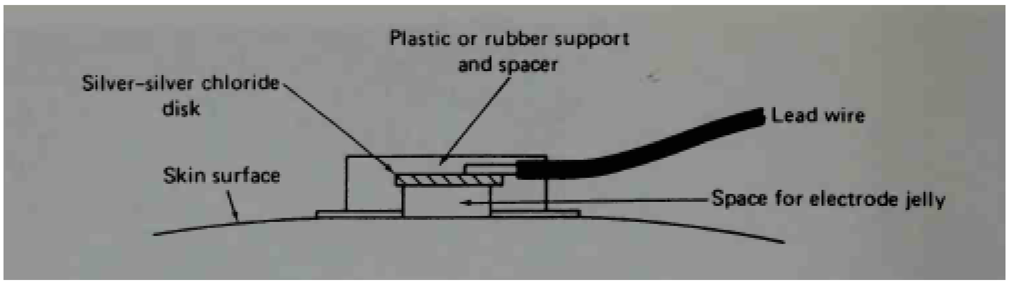


Diagram of floating type skin surface electrode

- A new type of electrode, **the floating electrode**, was introduced in varying forms by several manufacturers.
- The principle of this electrode is to practically eliminate movement artifact by avoiding any direct contact of the metal with the skin.
- Special problems encountered in the monitoring of the ECG of astronauts during long periods of time, and under conditions of perspiration and considerable movement, led to the development **of spray-on electrodes.**
- Various types of disposable electrodes have been introduced in recent years to eliminate the requirement for cleaning and care after each use.
- Some **disposable electrodes** can be reused several times, their cost is usually low enough that cleaning for reuse is not warranted.
- Larger area surface electrodes are used to sense ECG potentials and smaller area surface electrodes are used to sense EEG and EMG potentials

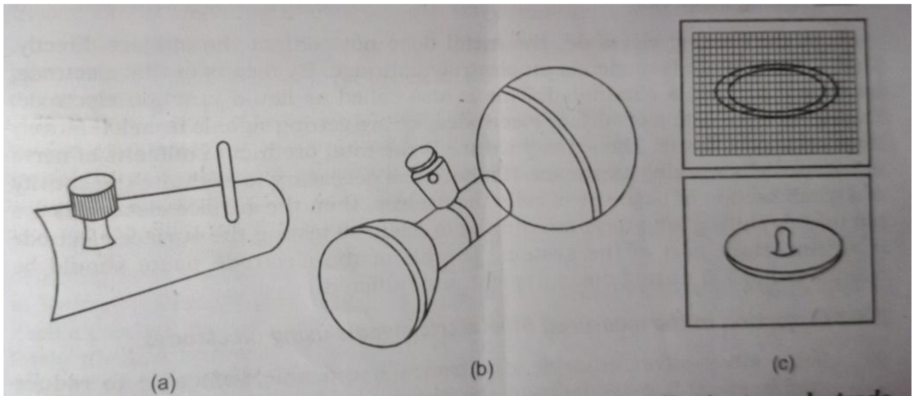
Types for Surface Electrodes:

Metal Plate Electrodes:

- Rectangular(3.5cm x 5 cm) and circular (4.75 dia) plates from German silver, nickel silver or nickel plated steel are used as surface electrodes in ECG measurement

Suction Cup Electrode:

- It will suit for attachment to flat surfaces of the body and to regions where the underlying tissue is soft.
- This electrode has a small area because only the rim is in contact with the skin.



a) Metal Plate electrode b) Suction up electrode and c) Adhesive tape electrode

Figure 2.5: Surface electrodes

Adhesive Tape Electrode:

- The pressure of the surface electrode against the skin may squeeze the electrode paste out. To avoid this problem, adhesive tape electrode is used.

Multipoint Electrode:

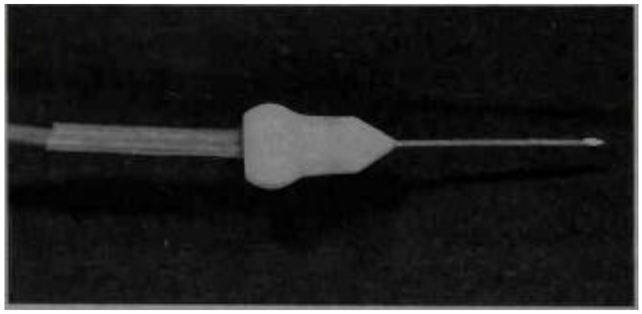
- The multipoint electrode is the very practical electrode for ECG measurements and it contains nearly 1000 fine active contact points.

Floating Electrode:

- In the floating electrode, the metal does not contact the subject directly and contact is made via an electrolyte bridge. By means of this electrode movement artifact is eliminated. This is also called as liquid junction electrode.
- The pH of the electrode paste should be maintained at 7.0 during measurement and buffered.

DEPTH AND NEEDLE ELECTRODES

- Depth electrodes are used to study the electrical of the neurons in superficial layers of the brain.
- The depth electrode impedance is smaller than the microelectrode impedance.
- To reduce interface impedance and, consequently, movement artifacts, some electro encephalographers use small sub dermal needles to penetrate the scalp for EEG measurements.
- These needle electrodes, are not inserted into the brain;
- In animal research longer needles are actually inserted into the brain to obtain localized measurement of potentials from a specific part of the brain.
- Longer needles precisely located by means of a map or atlas of the brain special instrument, called **a stereotaxic instrument**, is used to hold the animal's head and guide the placement of electrodes.



- Needle electrodes for EMG- consist merely of fine insulated wires, placed so that their tips, which are bare, are in contact with the nerve, muscle, or other tissue.
- The wires are either surgically implanted or introduced by means of a hypodermic needle that is later withdrawn, leaving the wire electrode in place.
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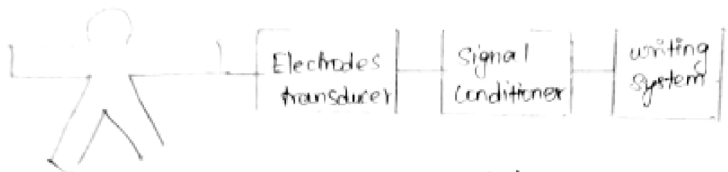
3.RECORDING PROBLEMS-MEASUREMENT WITH TWO ELECTRODES

Recording Problems - Measurement with Two electrodes:

Recording Systems:

Recorders provide a permanent visual trace or record of an applied electrical signal.



It consists of 3 important components such as.

1. Electrode or transducer
2. Signal Conditioner
3. writing System.

Transducer:

The electrode picks up the bioelectric potentials whereas the transducer converts the physiological signal to be measured into a usable electrical output.

Signal conditioner:-

The signal conditioner converts the output of the electrode/ into an electrical quantity.

writing systems:

The writing system provides a visible graphic representation of the quantity of the physiological variable of interest.

Types of Recorders:

Recorders are selected according to the frequency response of the data, accuracy, requirements, the type of chart record that is desired and the number of data channels that must be recorded on a single piece of chart paper.

1. Potentiometric Recorders.
2. Direct writing ac Recorders.
3. Inkjet Recorder
4. Electrostatic Recorder
5. Thermal Array Recorder

Potentiometric Recorders:

It usually provide a frequency Response of 1HZ at 25cm Peak to peak or upto 6HZ at reduced amplitude.

Direct writing ac Recorders:

-> It provide a frequency response up to 60 HZ at 40mm peak to Peak or up to 200Hz at reduced amplitude.

-> The most common type of direct recorder is the Stylus type.

Inkjet Recorder:

It gives frequency response upto 1000HZ & employs inexpensive Plain paper as the writing System makes use of a jet of ink.

Electrostatic Recorder:

It employs an electrostatic writing Process and works for frequencies upto 10KHZ. Peak to peak amplitude 0.1% at 1000HZ, 0.2% at 1500 HZ, 2% at 5000 HZ, 20% at 15KHZ.

Thermal Array Recorder:

The accuracy of peak to peak amplitude 0.2% upto 32HZ 2% at 100HZ & 20% at 320HZ.

Problems Encountered in Measuring a Living System:

(1) Inaccessibility of Variable to measurement:

-> It is greatest difficulty.

-> for example Neuro chemical activity of brain, it is impossible to place transducer So we need to do indirect Measurements.

2) Variability of data :

-> Majority of physiological variables are non-deterministic means varies with respect to time.

3) Lack of Knowledge of Interrelationship

-> Physiological measurements with large tolerence are often accepted by the physician because of lack of this knowledge.

4) Effect of Transducer :

-> Transducer can be considered as a device converting one form of energy to another form.

->The output in the form of electrical parameters like current, capacitance, voltage, change in Resistance.

5) Artifacts :

-> The Random noise generated within the ~~measurement~~ Instrument, electrical interference (50/60 Hz), cross talk and all other unwanted variations.

6) Safety considerations :

-> Hospital safety requires that extra Caution must be taken in the design of any measurement system to Protect the patient.

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THE SILVER/SILVER CHLORIDE ELECTRODE

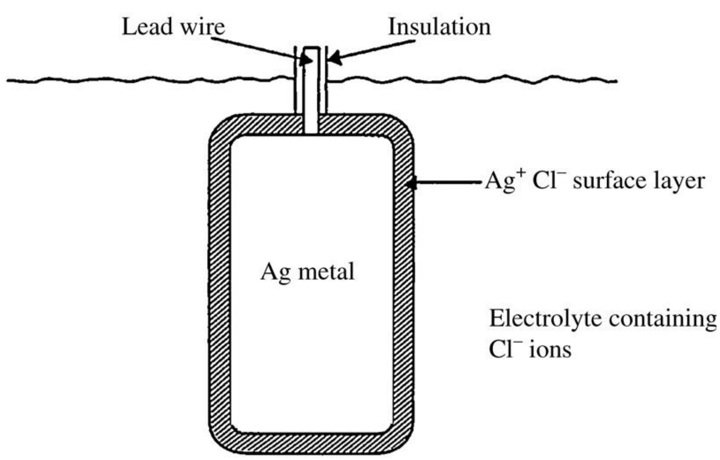
- The silver/silver chloride (Ag/AgCl) electrode is a practical electrode that approaches the characteristics of a perfectly non-polarizable electrode which consists of a metal coated with a layer of a slightly soluble ionic compound of that metal with a suitable anion,
- The whole structure is immersed in an electrolyte containing the anion in relatively high concentrations.
- A silver metal base with attached insulated lead wire is coated with a layer of the ionic compound AgCl.
- The electrode is then immersed in an electrolyte bath in which the principal anion of the electrolyte is Cl.The behavior of the Ag/AgCl electrode is governed by two chemical reactions.

$$Ag \rightleftharpoons Ag^+ + e^-$$
$$Ag^+ + Cl^- \rightleftharpoons AgCl \downarrow$$

- The first involves the oxidation of silver atoms on the electrode surface to silver ions in solution at the interface.
- The second reaction occurs immediately after the formation of Ag^+ ions. These ions combine with Cl-ions already in solution to form the ionic compound AgCl.Silver chloride's rate of precipitation and of returning to solution is a constant Ks known as the solubility product.

$$a_{Ag^+} \times a_{Cl^-} = K_s$$

- Under equilibrium conditions the ionic activities of the Ag^+ and Cl^- ions must be such that their product is the solubility product.



(FIG)A silver/silver chloride electrode, shown in cross section.

UNIT 1 - QUESTION BANK

1. Name different types of surface electrodes used for biomedical instrumentation system.
   Metal plate electrodes

Floating electrodes
Suction electrodes
Adhesive electrodes
Multipoint electrodes

2. What are the salient features of needle electrode? (Nov – 2010, Dec - 2018)

   Cannot be modeled as a series resistance and capacitance
   The body/electrode has a highly nonlinear response to stimulation
   Large currents can cause Cavitations,
   Cell damage or Heating

3. Mention the types of microelectrodes. What are their applications?(May - 2016)

   Types of micro electrode
   1. Metal micro electrodes
   2. Micropipet electrode

   Applications of microelectrodes
   (1) Potential recording;
   (2) Current injection;
   (3) Introduction into the cell of ion selective resins for measuring potential or determining the free concentration of cytosolic constituents.

4. Draw the equivalent circuit for a bio potential electrode in contact with an electrolyte? (May-2017)

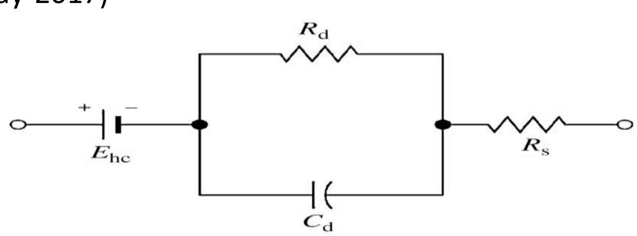


Figure 5.4 Equivalent circuit for a biopotential electrode in contact with an electrolyte *E*hc is the half-cell potential, *R*d and *C*d make up the impedance associated with the electrode-electrolyte interface and polarization effects, and *R*s is the series resistance associated with interface effects and due to resistance in the electrolyte.

5. What is bio electric potential? (Dec - 2018)

   Certain systems of the body generate their own monitoring signals conveying useful information about the functions they represent. Such signals are bio electric potentials and are related to nerve conduction, brain activity, heart beat etc

6. List different types of EEG waveforms.

   Alpha waves, Beta waves, Theta waves and delta waves.

7. Define Polarization.

   The impedance is frequency-dependent because of the effect of the capacitance. Furthermore, both the electrode potential and the impedance are varied by an effect called polarization. Polarization is the result of direct current passing through the metal electrolyte interface.

8. Define action and resting potential. (NOV/DEC 2017)

   To balance the electric charge, additional potassium ions, which are also positive, enter the cell, causing a **higher concentration of potassium** on the inside than on the outside. This membrane potential is called **the resting potential of the** cell .

   The cell has a slightly positive potential on the inside due to the imbalance of potassium ions. This potential is known as the **action potential**

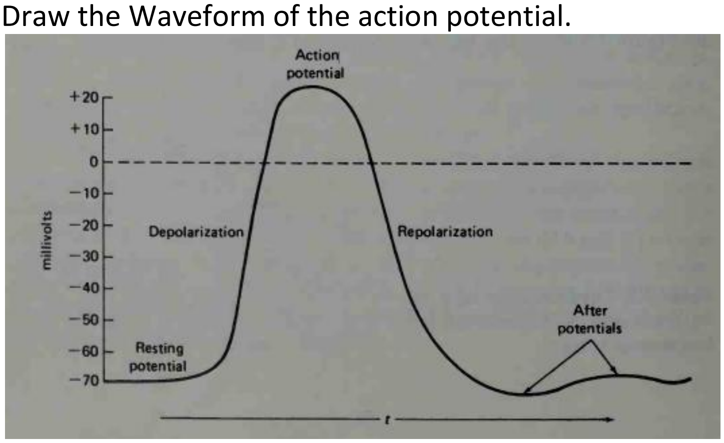
9. Define depolarization.

   A cell that has been excited and that displays an action potential is said to be depolarized; the process of changing from the resting state to the action potential is called **depolarization.**

10. What is repolarization?

    By an active process, called a sodium pump, the sodium ions are quickly transported to the outside of the cell, and the cell again becomes polarized and assumes its resting potential. This process is called **repolarization**

11. Draw the Waveform of the action potential.



12. What is called propogation rate?

    The rate at which an action potential moves down a fiber or is propagated from cell to cell is called the **propagation rate**.

13. Define electrode offset voltage.

    The dc voltage due to the difference in electrode potentials is called the **electrode offset voltage.**

14. What is bioelectric potential? (NOV/DEC 2018)
    Certain systems of the body generate their own monitoring signals conveying useful information about the functions they represent. Such signals are bio electric potentials and are related to nerve conduction, brain activity, heart beat etc.