



ROHINI

COLLEGE OF ENGINEERING AND TECHNOLOGY

Approved by AICTE and affiliated to Anna University Chennai (An ISO Certified Institution)

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DEPARTMENT OF BIOMEDICAL ENGINEERING

BM3491 Biomedical Instrumentation

UNIT-I ELECTRODE CONFIGURATIONS

1.2 Electrode Configuration

- i. Devices that convert ionic potentials into electronic potentials are called electrodes.
- ii. The interface of metallic ions in solution with their associated metals results in an electrical potential that is called the electrode potential.
- iii. This potential is a result of the difference in diffusion rates of ions into and out of the metal. Equilibrium is produced by the formation of a layer of charge at the interface. This charge is really a double layer, with the layer nearest the metal being of one polarity and the layer next to the solution being of opposite polarity.
- iv. Non-metallic materials, such as hydrogen, also have electrode potentials when interfaced with their associated ions in solution.
- v. It is impossible to determine the absolute electrode potential of a single electrode, for measurement of the potential across the electrode and its ionic solution would require placing another metallic interface in the solution.
- vi. Therefore, all electrode potentials are given as relative values and must be stated in terms of some reference. By international agreement, the normal hydrogen electrode was chosen as the reference standard and arbitrarily assigned an electrode potential of zero volt.
- vii. All the electrode potentials listed in Table are given with respect to the hydrogen electrode. They represent the potentials that would be obtained across the stated electrode and a hydrogen electrode if both were placed in a suitable ionic solution.

- viii. Another source of an electrode potential is the unequal exchange of ions across a membrane that is semipermeable to a given ion when the membrane separates Liquid solutions with different concentrations of that ion.
- ix. An equation relating the potential across the membrane and the two concentrations of the ion is called the **Nernst equation** and can be stated as follows:

$$E = -\frac{RT}{nF} \ln \frac{C_1 f_1}{C_2 f_2}$$

R = gas constant (8.315×10^7 ergs/mole/degree Kelvin)

T = absolute temperature, degrees Kelvin

n = valence of the ion (the number of electrons added or removed to ionize the atom)

F = Faraday constant (96,500 coulombs)

C_1, C_2 = two concentrations of the ion on the two sides of the membrane

f_1, f_2 = respective activity coefficients of the ion on the two sides of the membrane

In electrodes used for the measurement of bioelectric potentials, the electrode potential occurs at the interface of a metal and an electrolyte, whereas in biochemical transducers both membrane barriers and metalelectrolyte interfaces are used.

1.1.2 Biopotential 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 described in the previous section.
 - 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. Thus, the equivalent circuit of biopotential electrode in contact with the body consists of a voltage in series with a resistance-capacitance network of the type shown in Figure.
- ❑ Since measurement of bioelectric potentials requires two electrodes, the voltage measured is really the difference between the instantaneous potentials of the two electrodes, as shown in Figure.
- ❑ If the two electrodes are of the same type, the difference is usually small and depends essentially on the actual difference of ionic potential between the two points of the body from which measurements are being taken.
- ❑ 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. The resulting current is often mistaken for a true physiological event. Even two electrodes of the same material may produce a small electrode offset voltage.
- ❑ In addition to the electrode offset voltage, experiments have shown that the chemical activity that takes place within an electrode can cause voltage fluctuations to appear without any physiological input. Such variations may appear as noise on a bioelectric signal. This noise can be reduced by proper choice of materials or, in most cases, by special treatment, such as coating the electrodes by some electrolytic method to improve stability.
- ❑ It has been found that, electrochemically, the silver-silver chloride electrode very stable. 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 silver ions combine with the chloride ions from the salt to produce neutral silver chloride molecules that coat the silver electrode.
- ❑ Some variations in the process are used to produce electrodes with specific characteristics.

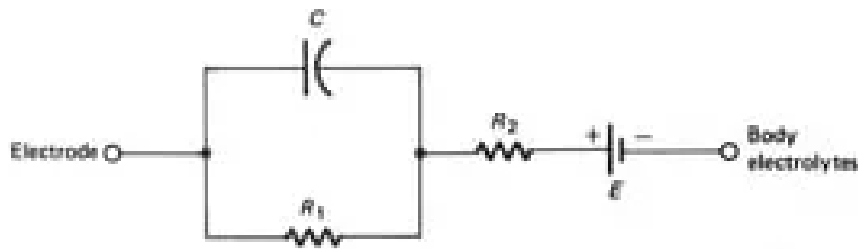


Fig. 1.1.1 Equivalent circuit of biopotential electrode interface.

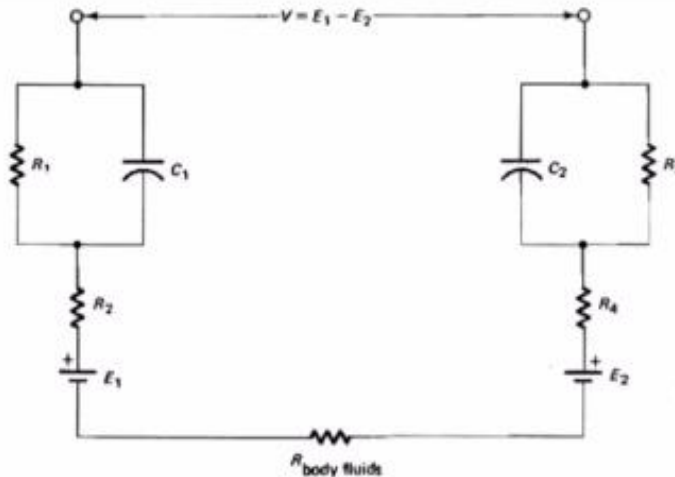


Fig. 1.1.2 Measurement of biopotentials with two electrodes—equivalent circuit.

The resistance-capacitance networks shown in Figures 1.1.1 and 1.1.2 represent the impedance of the electrodes (one of their most important characteristics) as fixed values of resistance and capacitance. Unfortunately, the impedance is not constant. 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 metalelectrolyte interface. The effect is much like that of charging a battery with the polarity of the charge opposing the flow of current that generates the charge. Some electrodes are designed to avoid or reduce polarization. If the amplifier to which the electrodes are connected has an extremely high input impedance, the effect of polarization or any other change in electrode impedance is minimized.

Size and type of electrode are also important in determining the electrode impedance. Larger electrodes tend to have lower impedances. Surface electrodes generally have impedances of 2 to 10 kΩ, whereas small needle electrodes and

microelectrodes have much higher impedances. For best results in reading or recording the potentials measured by the electrodes, the input impedance of the amplifier must be several times that of the electrodes.

1.1.3 Skin Interface Impedance:

- i. The bioelectrical events are usually recorded by means of metallic electrodes placed on the surface of the body. The electrical activity generated by various muscles and nerves within the body is conducted to the electrode sites through the body tissues, reaches the electrodes through the skin electrode transition and is then conducted by direct wire connection to the input circuit of the recording machine.
- ii. The impedance at the electrode-skin junction comes in the overall circuitry of the recording machine and, therefore, has significant effect on the final record. Skin electrode impedance is known as the contact impedance and is of a value much greater than the electrical impedance of the body tissue as measured beneath the skin.
- iii. The outer horny layer of the skin is responsible for the bulk of the skin contact impedance and, therefore, a careful skin preparation is essential in order to obtain best results.

1.1.4 Polarization Effects of Electrodes:

- i. If a low voltage is applied to two electrodes placed in a solution, the electrical double layers are disturbed. Depending on the metals constituting the electrodes, a steady flow of current may or may not take place.
- ii. In some metal/liquid interfaces, the electrical double layer gets temporarily disturbed by the externally applied voltage, and therefore, a very small current flows after the first surge, thus indicating a high resistance. This type of electrode will not permit the measurement of steady or slowly varying potentials in the tissues. They are said to, be **polarized or nonreversible**.
- iii. Thus, the phenomenon of polarization affects the electro-chemical double layer on the electrode surface and manifests itself in changing the value of the impedance and voltage source representing the transition layer. Parsons (1964) stated that electrodes in which no net transfer of charge takes place

across the metal-electrolyte interface can be termed as **perfectly polarized**. Those in which unhindered exchange of charge is possible are called **non-polarizable or reversible** electrodes. The ionic double layer in metals of these electrodes is such that they allow considerable current to flow when a small voltage is applied, thus offering a low resistance.

- iv. Although polarizable electrodes are becoming less common, they are still in use. They usually employ stainless steel and are used for resting ECGs or other situations where there is small likelihood that the electrodes would be exposed to a large pulse of energy (such as a defibrillation discharge) in which case they would retain a residual charge, become polarized, and will no longer transmit the relatively small bioelectric signals, thus becoming useless.
- v. Non-polarizing electrodes on the other hand, are designed to rapidly dissipate any charge imbalance induced by powerful electrical discharges such as a defibrillation procedure. Rapid depolarization enables the immediate reappearance of bioelectric signals on the monitor after defibrillation. For this reason, non-polarizing electrodes have become the electrodes of choice for monitoring in the intensive care units and stress testing procedures. Historically, these electrodes employ a conducting metal with a **silver/silver-chloride (Ag/AgCl)** surface in contact with the conducting gel.
- vi. The choice of metals for electrodes is not determined only by their susceptibility to polarization, but other factors such as mechanical properties, skin irritation or skin staining, etc. have also to be taken into consideration.

1.1.5 Non-polarizable electrodes:

A non-polarizable electrode is an electrode that does not undergo a significant change in potential when a current is applied. In other words, it does not contribute to the polarization effects commonly observed in some other types of electrodes. Polarization typically refers to the change in electrode potential caused by the buildup of reaction products or changes in the local environment during electrochemical processes.

Non-polarizable electrodes are often used in electrochemical measurements where the focus is on studying the behavior of the solution or the material being

analysed, rather than the electrode itself. These electrodes are designed to minimize any changes in potential and provide a stable reference point for the measurement.

Common examples of non-polarizable electrodes include:

1. **Saturated Calomel Electrode (SCE):** It is a reference electrode widely used in electrochemical experiments. The SCE is based on a mercury/mercurous chloride ($\text{Hg}/\text{Hg}_2\text{Cl}_2$) system and is considered non-polarizable under certain conditions.
2. **Silver/Silver Chloride Electrode (Ag/AgCl):** Another common reference electrode that is non-polarizable under certain conditions. It consists of a silver wire coated with silver chloride.

These electrodes are chosen for their stability and minimal interference with the electrochemical processes occurring in the system under investigation. Non-polarizable electrodes play a crucial role in accurate and reliable electrochemical measurements in various fields, including analytical chemistry, corrosion studies, and bio electrochemistry.

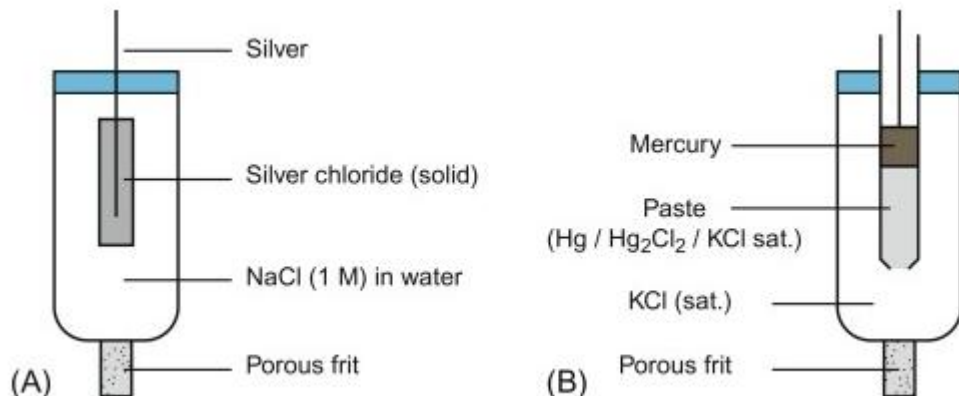


Fig. Reference electrodes: (A) silver-silver chloride electrode and (B) saturated-calomel electrode

- i. The characteristic of an ideal polarizable electrode is that no faraday current flow when the electrode potential is varied. This type of electrodes usually can be used as Working or Counter electrodes.

- ii. The feature of a non-polarizable electrode is once the electrode potential be changed, the Faraday current flows out. In generally, this type of electrodes can be used as Reference electrodes.
- iii. An ideal polarizable electrode can be represented by a capacitor (condenser) in equivalent circuit as shown in Fig. However, the extremely weak current flows at an actual polarizable electrode indeed. Therefore, a high value resistance (R_{hi}) is required to parallel with the capacitor to represent the actual polarizable electrode in equivalent circuit.
- iv. If a redox species coexists with the polarizable electrode, the redox reaction of species is occurred on the electrode surface and the Faraday current flows under the certain potential. In this case, a potential depending variable resistance (R_F) should be added to the equivalent circuit in parallel. Furthermore, the effect of the species diffusion should be included, and a Warburg Impedance element is connected to Faraday resistance (R_F) in equivalent circuit.
