Electrodes

Bioelectric potentials generated in the body are ionic potentials, produced by ionic current flow. Efficient measurement of these ionic potentials requires that they have to be converted into electronic potentials before they can be measured by conventional methods. This led to the development of modern devices.

Devices converting ionic potentials into electronic potentials are called electrodes. Electrodes are feeding the bioelectric potentials into the input of the preamplifier. The type of electrode to be used depends upon the location and dimension of the bioelectric potential generator in the human body. The electrical characteristics of the electrodes specify the type of preamplifier. The type of electrode imposes constraints on the input characteristics of preamplifier. Generally the input impedance of the preamplifier should be very high so that the electrodes are not overloaded. That is why an instrumentation amplifier.

Electrode Theory

The voltage developed at a surface electrode - electrolyte interface is designated as the half cell potential or electrode potential. In the case of metal solution interface, an electrode potential. Results from the difference in rates between two opposing processes. They are the passage of ions from the metal into the solution and the combination of metallic ions in solution with electrons in the metal. Therefore, when a metal electrode comes into contact with an electrolyte (body fluid), as shown in Figure 5.1 (a), there is a tendency for the electrodes to discharge ions into solutions and from ions in the electrolyte. Figure 5.1 (b) shows the electrical equivalent circuit of a surface electrode when it is in contact with body surface.

The series resistance R in the equivalent circuit is electrolytic resistance. The equivalent impedance of the tissue electrode interface is expressed as:

$$\boldsymbol{Z = Z_1 + Z_2 + Z_3 = \frac{1}{Y_1} + Z_3 + \frac{1}{Y_2}}$$

Where Z1, is equivalent impedance of R1 and C1 , the electrical parameters of metal electrolyte interface .

Z2 is equivalent impedance of R2 and C2, the electrical parameters of electrolyte skin interface.

R, the resistance of electrolyte.

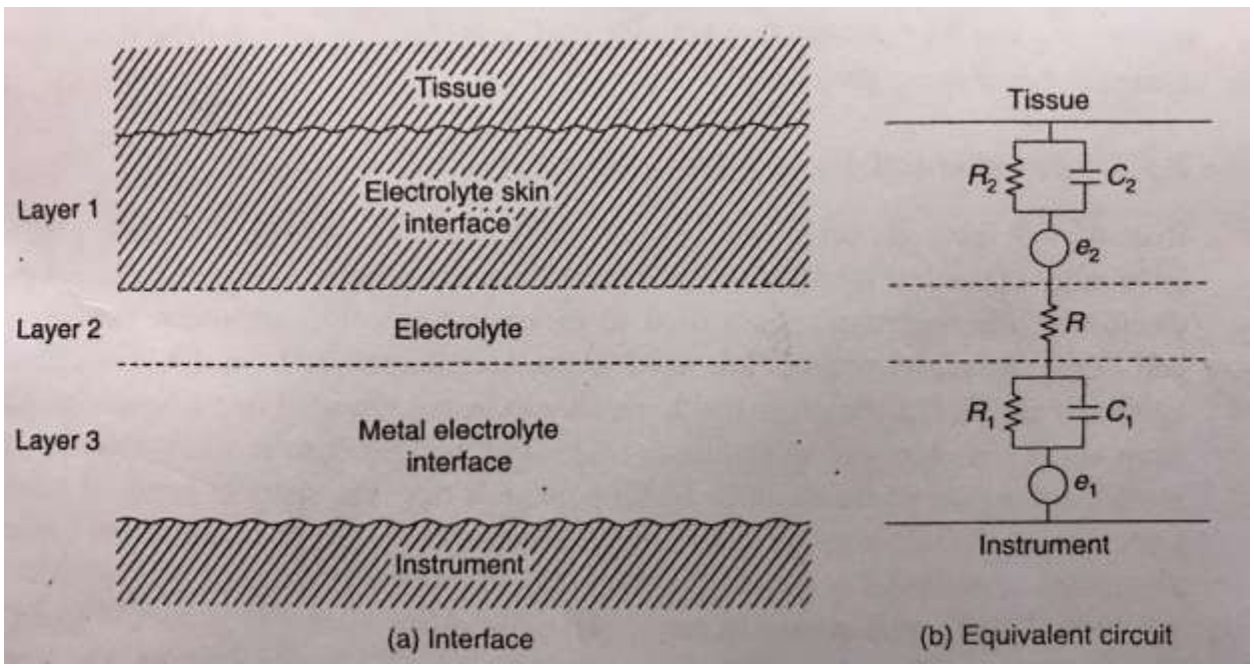

Figure 5.1 Tissue electrolyte skin interface.

The electrode-electrolyte interface resumbles a voltage source having half cell potential $e_1 + e_2$ which is due to charge gradient and *R*C network. The net result is the creation of a charge gradient, the special arrangement of ions which is called the electrical double layer or electrical double lager

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Helmholtz double layer as shown in figure 5.2 electrodes in which no net transfer of charge occurs across the metal-electrolyte interface are called perfectly polarized electrodes. Electrodes in which unhindered exchange of charge across the metal electrolyte interface are called perfectly non-polarizable electrodes.

In practice, electrodes have properties that lie between these idealized limits. In most cases, presence of an electrode potential would not be objectionable if it were stable. The variations constitute a source of variable noise voltage called artifact. Artifact threats the stability.

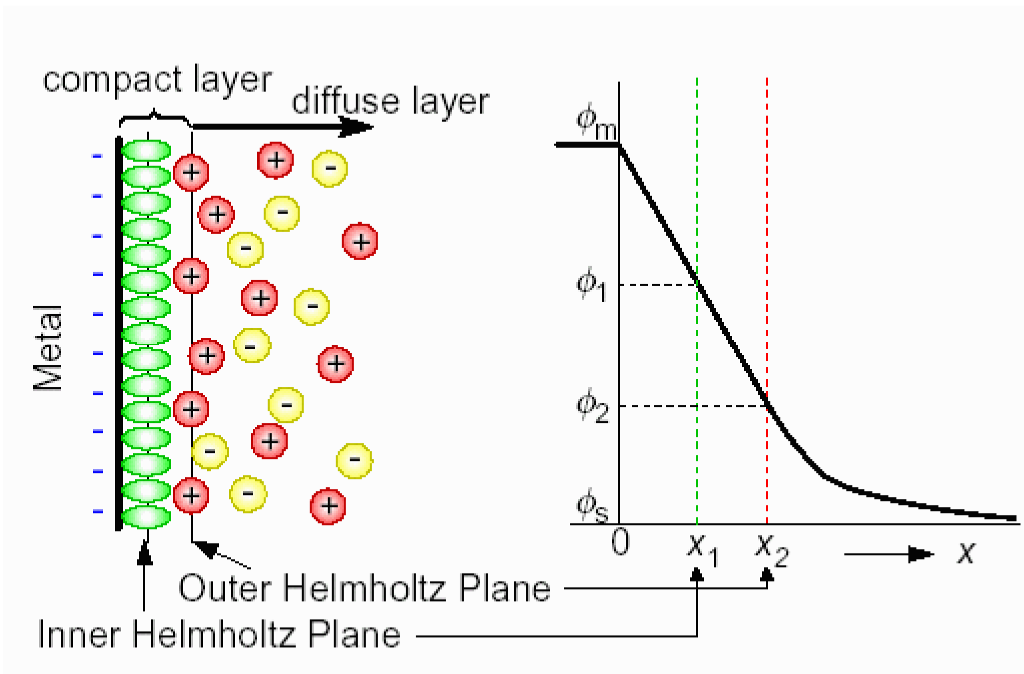

Figure 5.2 Electrical double layer

Another source of an electrode potential is the exchanges unequal ions across a membrane that is semipermeable to a given ion when the membrane separates liquid solution with different concentrations of those ions. An equation relating the potential across the membrane and the two concentrations of the ion is called the Nernst equation and can be state as follows: $E = \frac{-RT}{nf} \; ln \frac{C_1 F_1}{C_2 F_2}$

where *R* = Gas constant (8.315 x 107 ergs/mole/kelvin)
T = Absolute temperature in Kelvin, N = Valence of the ion (the number of electrons added or removed to Ionize the atoms, *F* = Faraday constant (96500 coulombs), C1 and C2 = Concentrations of the ion on the either sides of the membrane, *F*1 and *F*2 = Respective activity coefficients of the ion on the either sides of the membrane.

Biopotential Electrodes

Even though there are wide variety of electrodes used to measure bioelectric potentials, they can be broadly classified into three basic types: Microelectrodes, Skin surface electrodes and Needle electrodes. Microelectrodes are used to measure bioelectric potentials near or within a single cell. Skin surface electrodes are used to measure potentials from the skin surface as in ECG, EEG and EMG. On the other hand, needle electrodes are used to measure bioelectric potential deep under the skin. For example, needle electrodes are used in measuring the EEG potential from local region of the brain or EMG potentials from the specific group of muscles. All these three types of electrodes have the metal-electrolyte interface as discussed earlier. Across the electrodes, a potential is developed proportional to the exchange of ions between electrolyte of the human body and electrode metal. The equivalent circuit is shown in Figure (5.1 b). It is obvious that measurement of bioelectric potentials require two electrodes. The measured voltage is the difference between the instantaneous potentials of both electrodes, 1.e., algebraic sum of e_1, and e_2. If the two electrodes are made up of same material, then the potential across the electrodes is the potential between the two measurement points of the human body. If the two electrodes are made up of different materials, then the potential developed at the electrodes are not nullified. The electrodes may produce a dc voltage which causes current through electrodes and through the signal conditioning circuit. The de voltage generated across the dissimilar metal electrodes is called electrode offset voltage. The resulting current is often mistaken as a bioelectric potential. In some cases, electrodes made up of same material also produce a small offset voltage. In addition to offset voltage, a voltage fluctuation may exist due to the chemical activity within the electrodes. This type of noise can be reduced by the proper choice of materials or by the special electrolyte coating or electrolyte gel.

The electrical equivalent circuit of tissue-electrode-electrolyte interface is a RC circuit as shown in Figure 5.1(b). Hence, it is frequency sensitive, the electrode impedance may vary due to dc polarization. Polarization effect may be reduced by increasing the input impedance of the signal conditioning circuit. Area of cross-section and mechanical shape of the electrode also affects the electrode impedance. Typical impedance of larger electrodes varies from 2 kilo ohm to 10 kilo ohm. In the case of needle electrodes, it has much higher impedance values. For better results the input impedance of the signal conditioning circuit must have very high impedance than the electrode impedance.

Microelectrodes

Microelectrodes are either metal or micropipette type. Both types of electrodes are with sufficiently thin tips so as to penetrate a cell to read the bioelectric potential inside the cell.

The tip of the microelectrodes should be designed in such a way that it has to penetrate the cell without damaging it. Metal microelectrodes are formed by the electrolytic etching of a thin fine tungsten or stainless steel wire. In addition to etching, the wire is coated with an insulating_material except at the thin tip. The impedance of the electrode can be lowered by doing some electrolytic process on the tip, where the metal ion interface is taking place. Micropipette type is made up of glass. The tip is drawn to a desired diameter about

1 micrometre.

A typical microelectrode is shown in Figure 5.3 Note that the metallic thin film coating is provided outside the thin tip. Resin insulation is provided above this thin metallic film except at the tip.

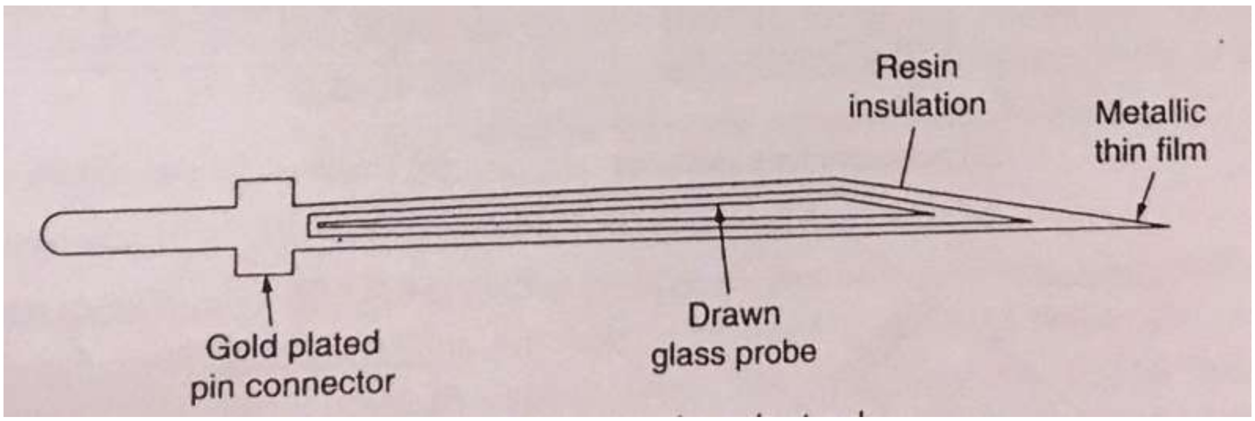

Figure 5.3 A microelectrode.

Skin Surface Electrodes

It is available in various types and sizes. For all bioelectric potential easurements, except ECG, any type can be used. Larger electrodes are employed for ECG, whereas smaller electrodes are used in EEG and EMG measurements. In olden days (before 1917) saline solution was used to measure ECG. The patient was instructed to place his hand and feet in saline solution containers. The difficulties such as restricted position of the subject and spilling electrolyte were removed when the metal plate electrodes were introduced in 1917. Initially these electrodes were used along with soaked cotton pads for electrical contact with the skin. Nowadays conductive jelly or paste are being used along with the metal electrodes. The main difficulty in using the plate electrode is movement of the electrode due to slippage. Any small movement may increase the impedance and alter the electrode potential.

Metal plate electrode

Rectangular o*r* circular plates made up of German silver (Nickel silver alloy) or nickel platen steel are employed as metal plate electrodes. Typical impedance of the electrode is in few hundred ohms. DC resistance varies from 2 kilo ohm to 10 kilo ohm. Figure 5.4 shows typical metal plate electrode. A terminal is placed on its outer surface for lead wire.

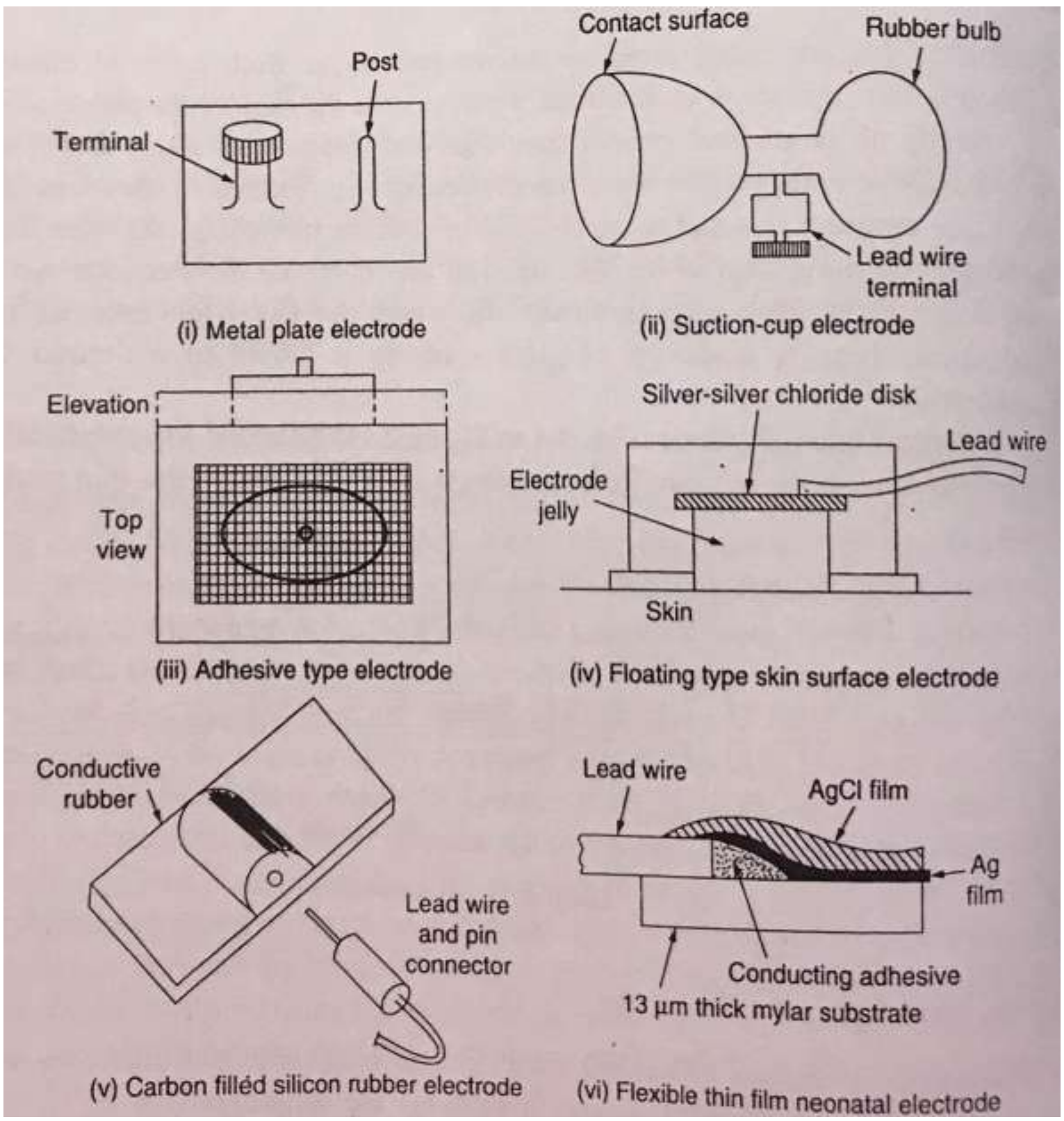

Figure 5.4 Typical metal plate electrodes.

A post placed on the same side to connect a rubber strap to the electrode and to hold it in place on an arm or leg. For better results, the metal surface is made up of concave shape. Before attaching it to the body, its concave surface is covered with electrolyte gel. A second common variation in the metal plate electrode is the circular disk shape. Sometimes the electrode is protected by a layer of insulating material like epoxy or polyvinyl chloride. This can be used as a chest electrode for ECG recording.

Suction-cup electrode

Metal plate electrode requires straps or adhesives for holding it in place. In this type, a modification is made to hold at one place for sufficient duration.
However, it cannot be held for long duration due to irritation in the skin. It is frequently used as a electrode in ECG. As illustrated in Figure 5.4(ii), it consists of hallow metallic cylindrical electrode that makes contact with the skin. A lead wire terminal is provided in the hollow metallic cylinder. A rubber suction bulb fits over the hollow cylinder is squeezed to place the hollow metallic base on the chest wall. Even though the electrode is large, its contacting surface is very small. Therefore, it has large impedance.

Adhesive tape electrode

As shown in Figure 5.4 (iii), it consists of a relatively large disk of plastic foam material with a silver-plated flexible plate on one side and silver-plated snap clothing on the other side. This silver-plated disk acts as an electrode. A silver chloride coat may be made on the electrode. A layer of electrolyte gel with an adhesive is coated over the electrode. A protective release paper is provided over this adhesive coat. Finally, it is packed in a foil cover so that to avoid evaporation of water component in the gel. This electrode can be used as a peel and paste type. There is no need of any special skill to use this electrode.

Floating type electrodes

Any displacement in the electrode may produce artifact in the electrodes. Use of non polarizable electrodes like silver/silver chloride will reduce the artifacts to some extent. To reduce the artifacts further, floating type electrodes may be used. Another name of this electrode is top hat electrode. As shown in Figure 5.4 (iv), the electrode does not come in direct contact with the skin. Instead, the gel in the cavity is in contact with the skin. There is no mechanical movement of the gel even though the metal electrode moves. Therefore, there is no artifact. A single use disposable type can also be obtained with simple modification.

Flexible electrodes

Solid electrodes are not conforming to the change in the body surface topography. This leads to the additional motion artifact. This problem is avoided in flexible electrodes. Figure 5.4 (e) shows a typical flexible electrode. A carbon filled silicon rubber compound thin strip is used as the active part of the electrode. A lead wire is provided through pin connector as shown in Figure 5.4 (v). It can be used similar to metal plate electrodes. Flexible electrodes are useful to measure ECG and respiration of premature infants. Metal electrodes may cause skin ulceration and may not confirm to the shape of the infant's chest.

Needle Electrodes

Needle electrodes may also be called internal electrodes. It is a percutaneous electrode type in which the electrode pieces through the skin into the body. No electrolyte gel is required maintain the interface between the patient and electrode. The extracellular fluid itself acts as the interface between patient and electrode. Figure 5.5 shows various types of percutaneous needle electrodes.

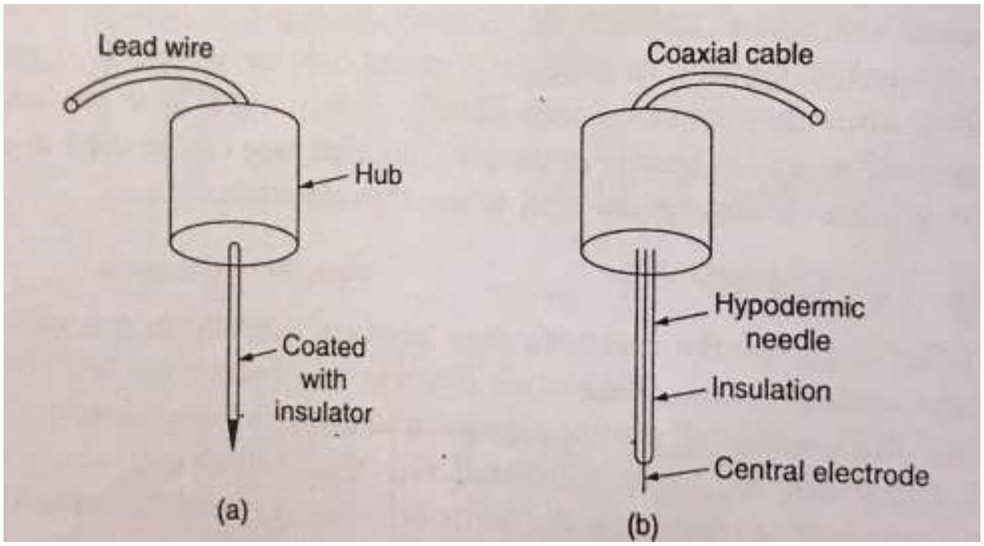

Figure 5.5 Needle electrodes.

The basic needle electrode is made of stainless steel with sharp tip as shown Figure 5.5(a). The shank of the needle is insulated by a coating. A lead wire is connected the other end and encapsulated by a hub. It is used in EMG. A modification, as shown in Figure 5.5 (b) in the electrode is carried out to use in the continuous monitoring of ECG. It consists of a small-gauge hypodermic needle that has a fine insulated wire running down the centre of its lumen and filling the remainder of the lumen with an insulating material such as an epoxy resin. In EEG measurements, these types of small sub dermal needle electrodes are used by penetrating the scalp. It reduces interface impedance and movement artifacts. They are not inserted into the brain instead they merely penetrate the skin.