

Physics of Medical Devices

First lecture

Biopotential electrodes

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1. Introduction

✚ What is a biopotential?

Bioelectrical potentials or bio potentials represent electrical potentials generated in the tissues or individual cells of living organisms. The bio potentials play the most important role in the process of excitation and inhibition of cells.

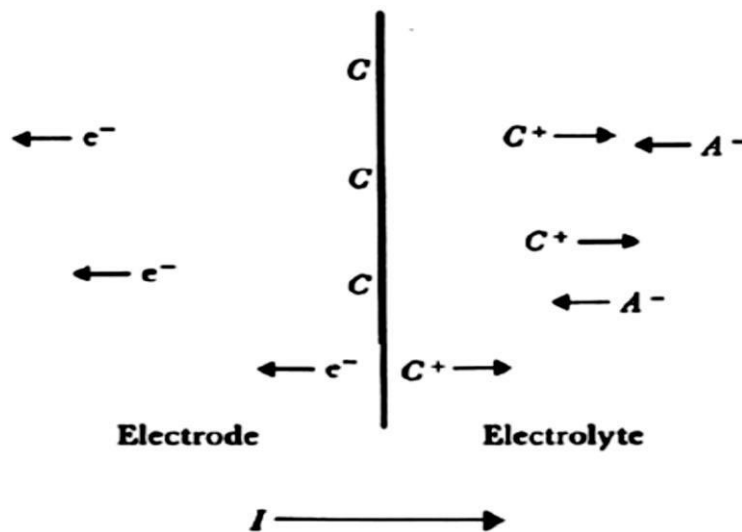
✚ Biopotential electrodes

✚ Interface between the body and the electronic measuring circuit

✚ Transducer: ionic current in the body \leftrightarrow electronic current in the circuit

2. The Electrode-Electrolyte Interface

❖ Net current crossing the electrode-electrolyte interface



✚ Electrons moving in an opposite direction of the current

✚ Cations (C^+) moving in the same direction as the current

✚ Anions (A^-) moving in an opposite direction of the current

✚ Chemical reactions at the interface (“ \rightarrow ”: oxidation and “ \leftarrow ”: reduction)

- $C \leftrightarrow C^{n+} + ne^-$
- $A^{m-} \leftrightarrow A + me^-$

❖ States of the interface

✚ “→” = “←” ⇒ dynamic equilibrium ⇒ zero net current

✚ “→” > “←” ⇒ oxidation dominates ⇒ nonzero net current from electrode to electrolyte.

✚ “→” < “←” ⇒ reduction dominates ⇒ nonzero net current from electrolyte to electrode.

❖ Equilibrium standard half-cell potential (at zero net current and at standard condition).

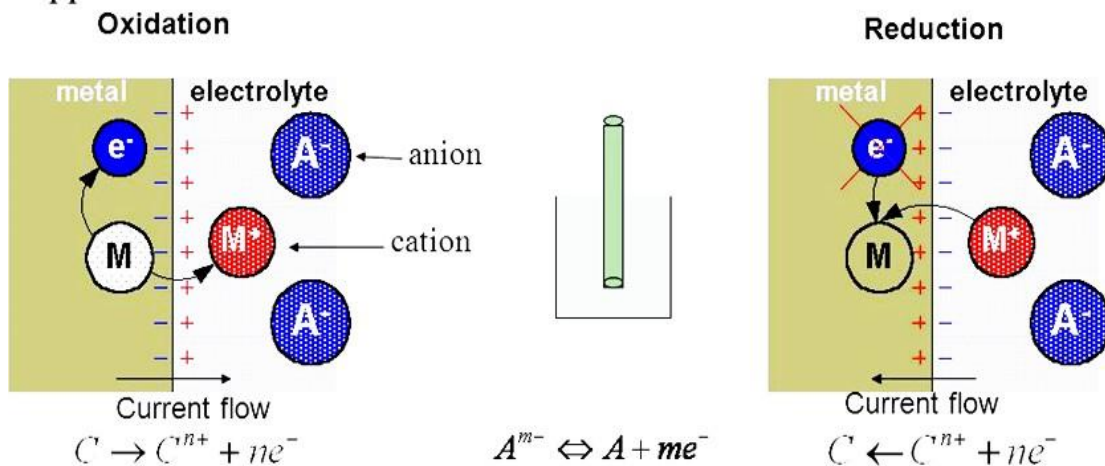
✚ At the initial moment of contact, chemical reaction occurs ⇒ changes in local distribution and concentration of C^+ and A^- at the interface ⇒ charge neutrality is not maintained at the interface ⇒ potential difference between the interface and the rest of the electrolyte.

✚ Charge redistribution (separation of charge) ⇒ electric double layer

Oxidation reaction causes atom to lose electron

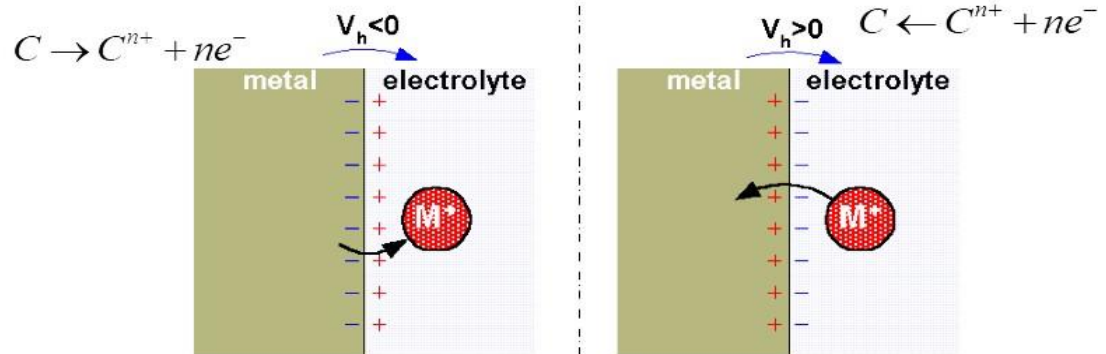
Reduction reaction causes atom to gain electron

Oxidation is dominant when the current flow is from electrode to electrolyte, and reduction dominates when the current flow is in the opposite.



Half-Cell potential is determined by

- Metal involved
- Concentration of its ion in solution
- Temperature
- And other second order factor



Certain mechanism separate charges at the metal-electrolyte interface results in one type of charge is dominant on the surface of the metal and the opposite charge is concentrated at the immediately adjacent electrolyte.

3. Polarization

- ❖ **Polarizability** is simply a measure of the dependence of the electron transfer rate on the electrode potential.

Half cell potential is altered when there is current flowing in the electrode due to electrode polarization.

Overpotential is the difference between the observed half-cell potential with current flow and the equilibrium zero-current half-cell potential.

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.

$$V_p = E^0 + V_R + V_C + V_A$$

where

V_p = total potential, or polarization potential, of the electrode

E^0 = half-cell potential

V_r = ohmic overpotential

V_c = concentration overpotential

V_a = activation overpotential

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 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.

Note: ionic activity most of the time equal the concentration of the ion

If the activity is not unity (activity does not equal concentration) then the cell potential is $C \rightarrow C^{n+} + ne^-$ $E = E_0 + \frac{RT}{nF} \ln [a_{C^{n+}}]$

For the general oxidation-reduction reaction, the Nernst equation for half cell potential is



4. Polarizable and Non-polarizable Electrodes

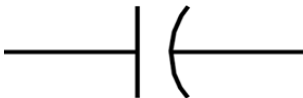

❖ Two types of electrode:

✚ Perfectly polarizable electrode

- ✓ Behaves like a capacitor
- ✓ Only displacement current
- ✓ Electrode made of noble metals such as platinum
- ✓ Concentration overpotential dominates

- ✚ Perfectly non-polarizable electrode
 - ✓ No overpotential
 - ✓ Current passes freely
 - ✓ Ag/AgCl electrode and calomel electrode

☒ Comparison between Polarizable Electrode and Non-Polarizable Electrode

Polarizable Electrode	Non-Polarizable Electrode
	
<ul style="list-style-type: none"> • No charge crosses the electrode when current is applied • Current does not cross, but rather changes the concentration of ions at the interface. • Noble metals are closest (like platinum and gold); they are difficult to oxidize and dissolve. • Behave like a capacitor. 	<ul style="list-style-type: none"> • All charge freely crosses the interface when current is applied. • No overpotential is generated. • Silver/silver-chloride is a good non-polarizable electrode. • Behave like a resistor.

5. The Silver-Silver Chloride Electrode

- Nonpolarizable electrode
- Electrode: Ag with AgCl coating
- Electrolyte: saturated with AgCl
- Chemical reactions:

$$\text{Ag} \leftrightarrow \text{Ag}^+ + e^-$$

$$\text{Ag}^+ + \text{Cl}^- \leftrightarrow \text{AgCl} \downarrow \text{ (deposit on the electrode)}$$

- Solubility product is constant and is the rate of precipitation and of returning to solution of AgCl. At equilibrium condition, $K_s = a_{\text{Ag}^+} \times a_{\text{Cl}^-} \approx 10^{-10}$. Since $a_{\text{Cl}^-} \approx 1$ in biological solution, $a_{\text{Ag}^+} \approx 10^{-10}$.
- HCP is $E = E_{\text{Ag}}^0 + \frac{RT}{nF} \ln(a_{\text{Ag}^+}) = E_{\text{Ag}}^0 + \frac{RT}{nF} \ln(K_s) - \frac{RT}{nF} \ln(a_{\text{Cl}^-})$. Since, in biological solution, $a_{\text{Cl}^-} \approx 1$, HCP of Ag/AgCl electrode is very stable.
- Fabrication
 - Electrolytic process (anode: Ag electrode, cathode: large Ag plate, solution: KCl or NaCl, source: 1.5 V battery)
 - Sintering process: Ag wire and powder of Ag and AgCl in a cylinder \Rightarrow baking at 400 °C for several hours \Rightarrow pellet electrode
- Used for most biopotential recordings, low noise, stable, small motion artifact

