UNIT I

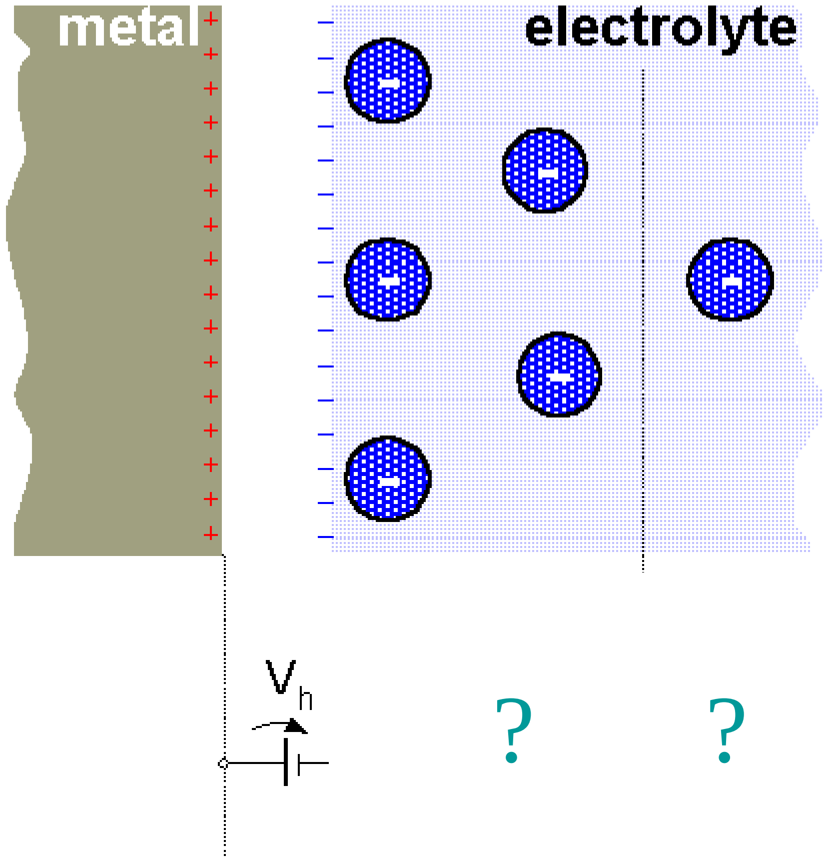
Bio potential generation and electrodes types

Introduction

- In order to measure and record potentials (currents) in the body, it is necessary to provide some **interface** between the body and the electronic measuring apparatus.
- Current flows in the measuring circuit for at least a **fraction of the period of time** over which the measurement is made.
- Bio potential electrodes is a **transducer** that convert the body ionic current in the body into the traditional electronic current flowing in the electrode.
- Current is carried in the body by **ions**, whereas it is carried in the electrode and its lead wire by **electrons**.

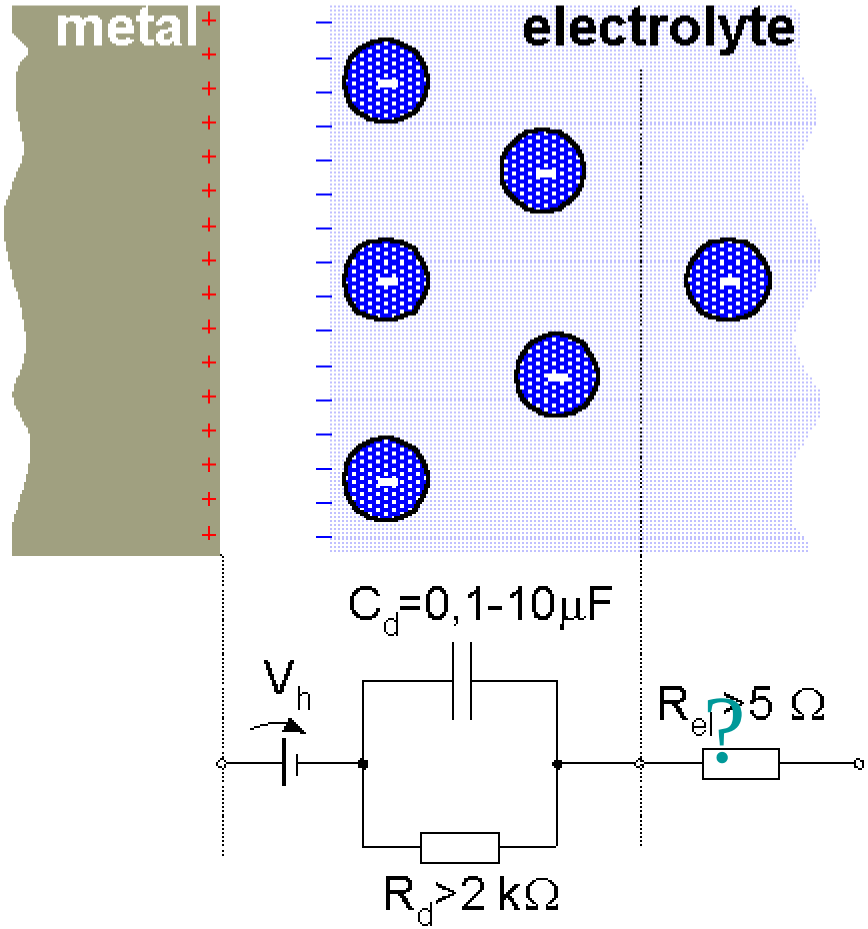
Electrode change an ionic current into an electronic current

electrical behaviour



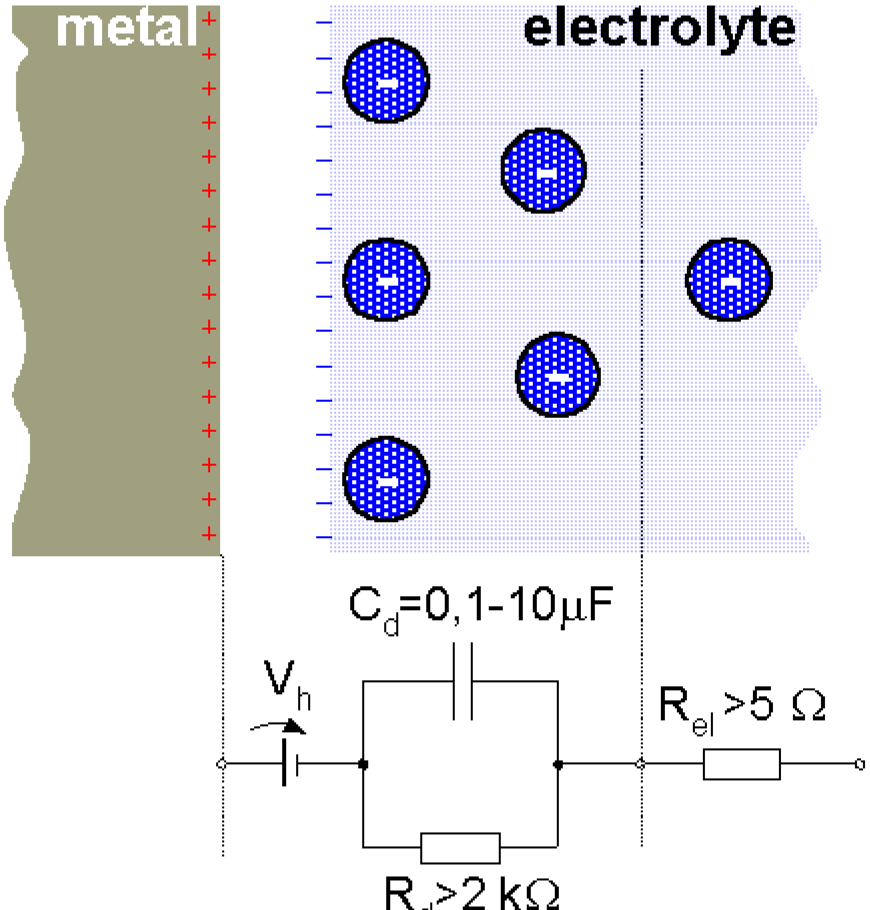
equivalent circuit

electrical behaviour



equivalent circuit

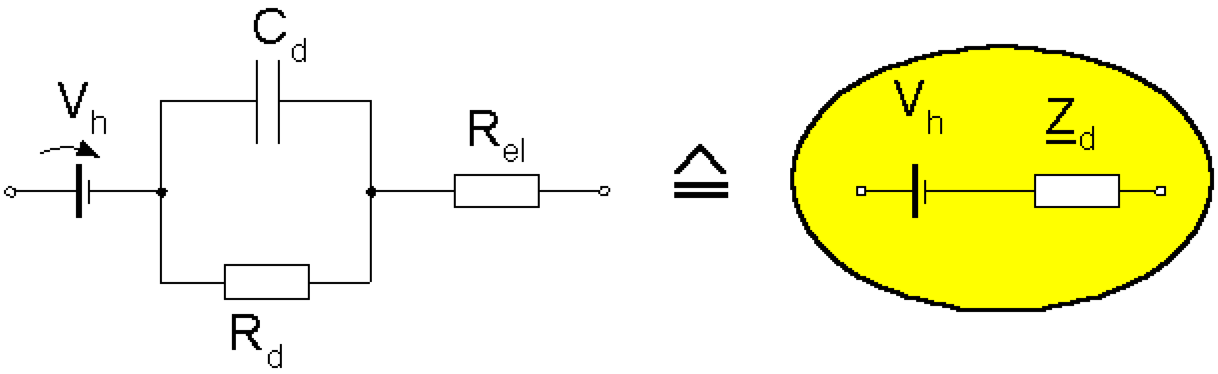
electrical behaviour



equivalent circuit

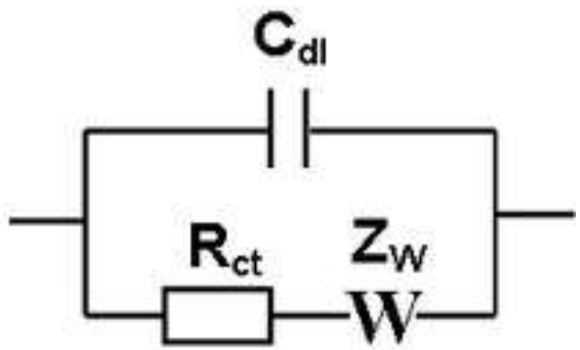
equivalent circuit

electrode-electrolyte



more precise approximation of double layer – Randles circuit

electrode-electrolyte



R_{ct} – active charge transfer resistance

W – Warburg element reflecting diffusion with impedance $Z_W = A_W/(j\omega)^{0.5}$

A_W – Warburg coefficient

Electrode-Electrolyte Interface

Oxidation reaction causes atom to lose electron
Reduction reaction causes atom to gain electron

Reduction

Oxidant + e^- ⟶ Product

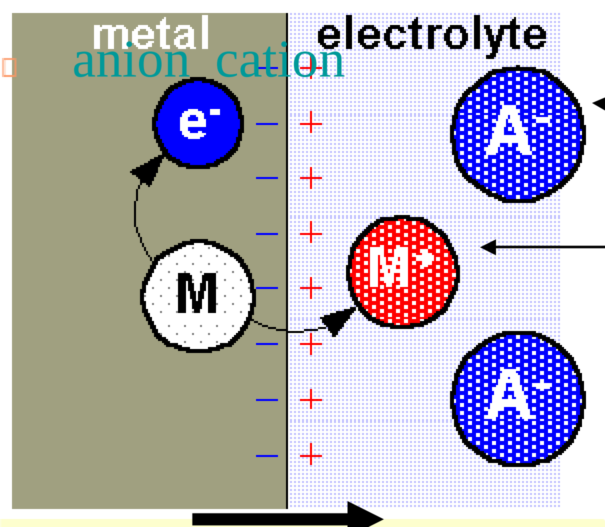
(Electrons **gained**; oxidation number **decreases**)

Oxidation

Reductant ⟶ Product + e^-

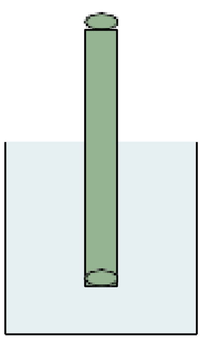
(Electrons **lost**; oxidation number **increases**)

- Oxidation is dominant when current flow from electrode to electrolyte, and reduction dominate when the current flow is the
- **Oxidation** **Reduction**
- anion cation

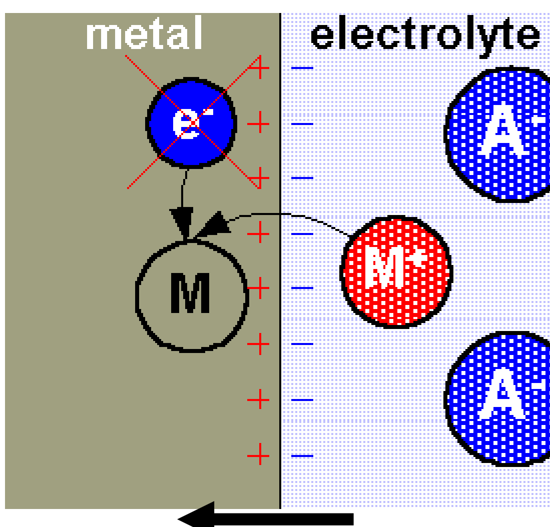


Current flow

$$C \rightarrow C^{n+} + ne^-$$



$$A^{m-} \Leftrightarrow A + me^-$$



Current flow

$$C \leftarrow C^{n+} + ne^-$$

Half-Cell Potential

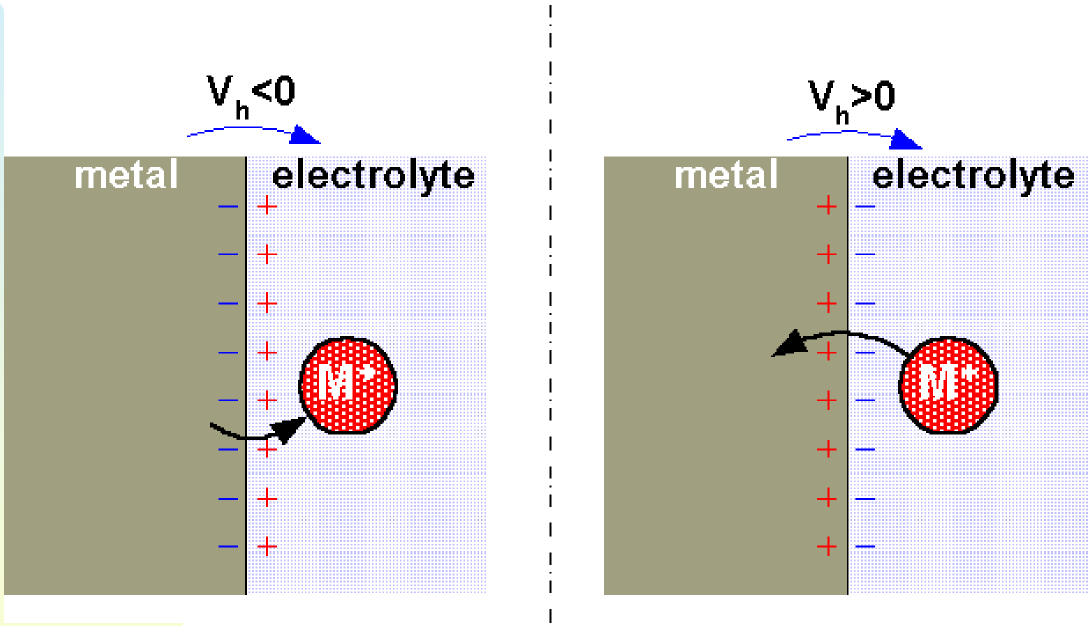
Half-Cell potential is determined by

-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.

Polarization

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

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.

$$V_p = V_R + V_C + V_A$$

Note: Polarization and impedance of the electrode are two of the most important electrode properties to consider

Half Cell Potential and Nernst Equation

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

For the general oxidation-reduction reaction

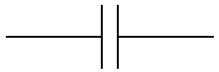
$$\alpha A + \beta B \leftrightarrow \gamma C + \delta D + ne^-$$

The Nernst equation for half cell potential is

$$E = E^0 + \frac{RT}{nF}\ln\left[\frac{a_C^\gamma a_D^\delta}{a_A^\alpha a_B^\beta}\right]$$

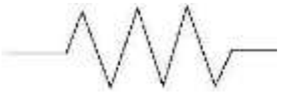
Polarizable and Nonpolarizable Electrodes

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

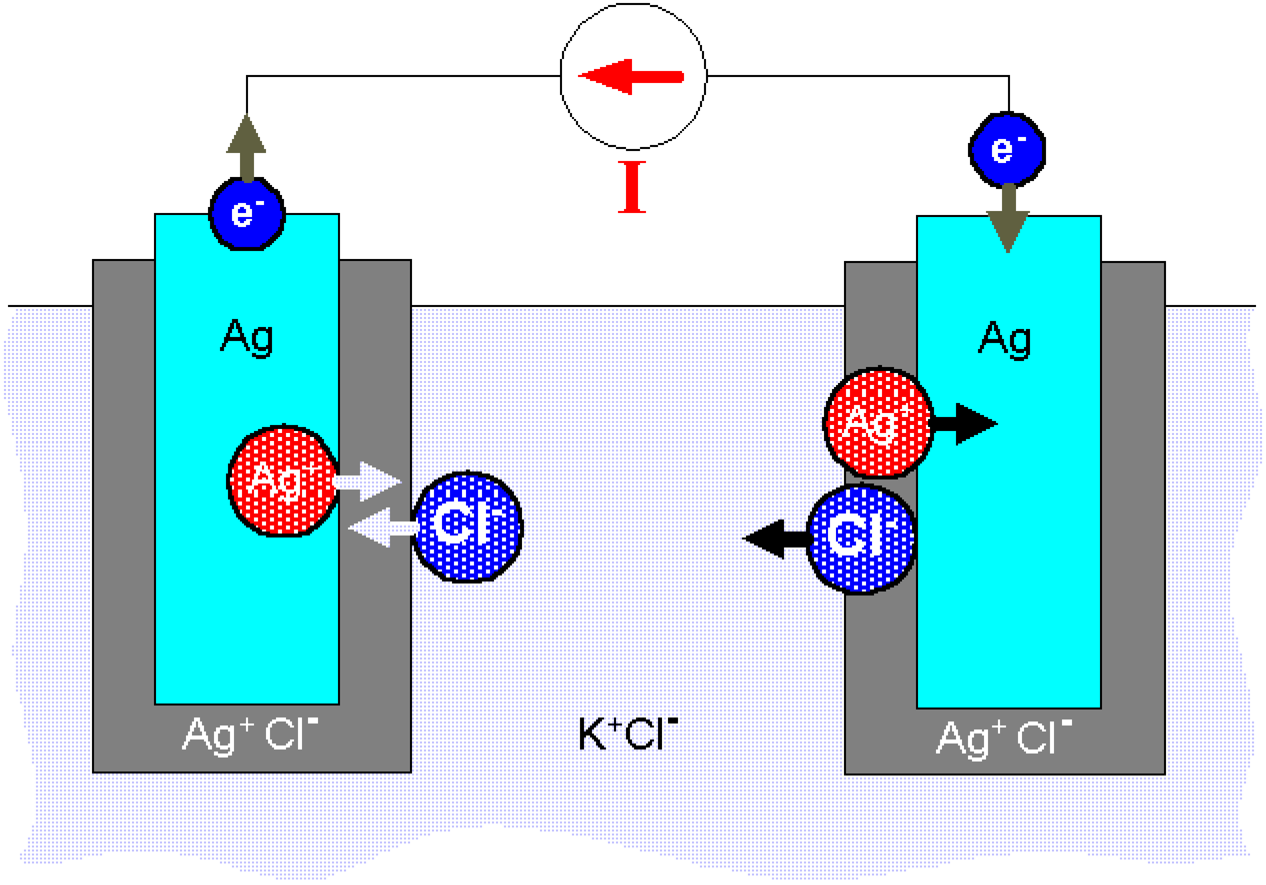


Electrodes in which current passes freely across the electrode-electrolyte interface, requiring no energy to make the transition. These electrodes see no overpotentials. **Example:** Ag/AgCl Electrode

Example: Ag-AgCl is used in recording while Pt is used in stimulation

chemical reactions

silver / silver chloride

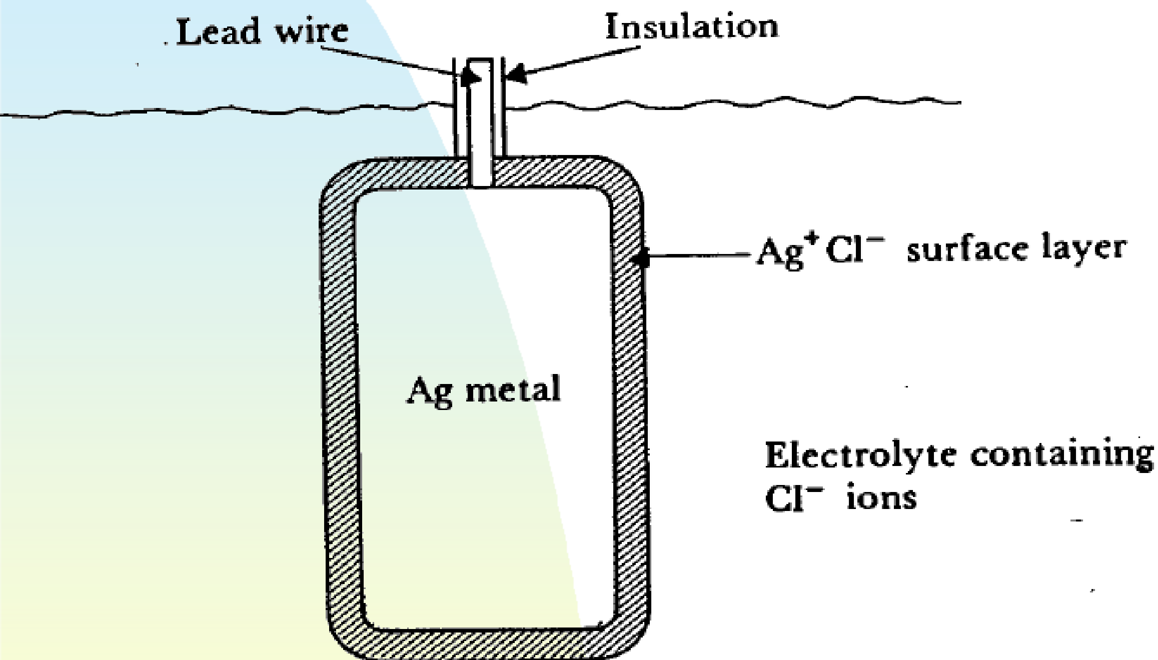


The Silver/Silver Chloride Electrode

Advantage of Ag/AgCl is that it is stable in liquid that has large quantity of Cl- such as the biological fluid.

For biological fluid where Cl- ion is relatively high

$$a_{Cl^-} \approx 1$$



$$E = E^0_{Ag} + \frac{RT}{nF} \ln\left[a_{Ag^+}\right]$$

$$K_s = a_{Ag^+} \times a_{Cl^-} = 10^{-10}$$

is solubilityproduct

$$E = E^0_{Ag} + \frac{RT}{nF} \ln\left[\frac{K_s}{a_{Cl^-}}\right]$$

constant

effective

Performance of this electrode

$$Ag \leftrightarrow Ag^+ + e^-$$

$$Ag^+ + Cl^- \leftrightarrow AgCl\downarrow$$

Electrode Behavior and Circuit Models

Advantages:

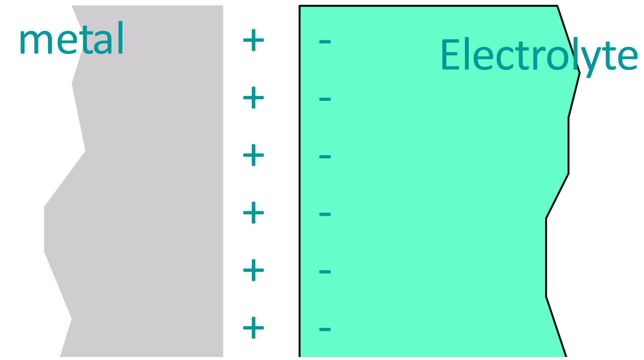
–Low Noise (vs. Metal Electrodes) esp. ECG

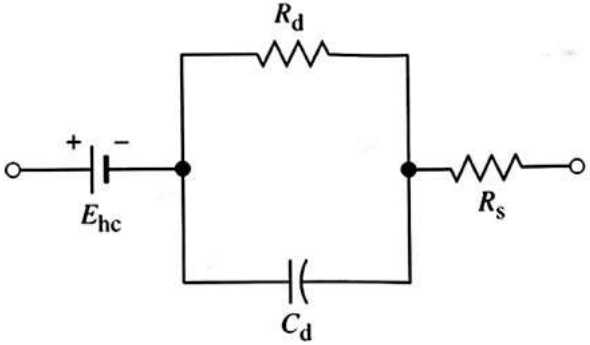
–Biocompatible

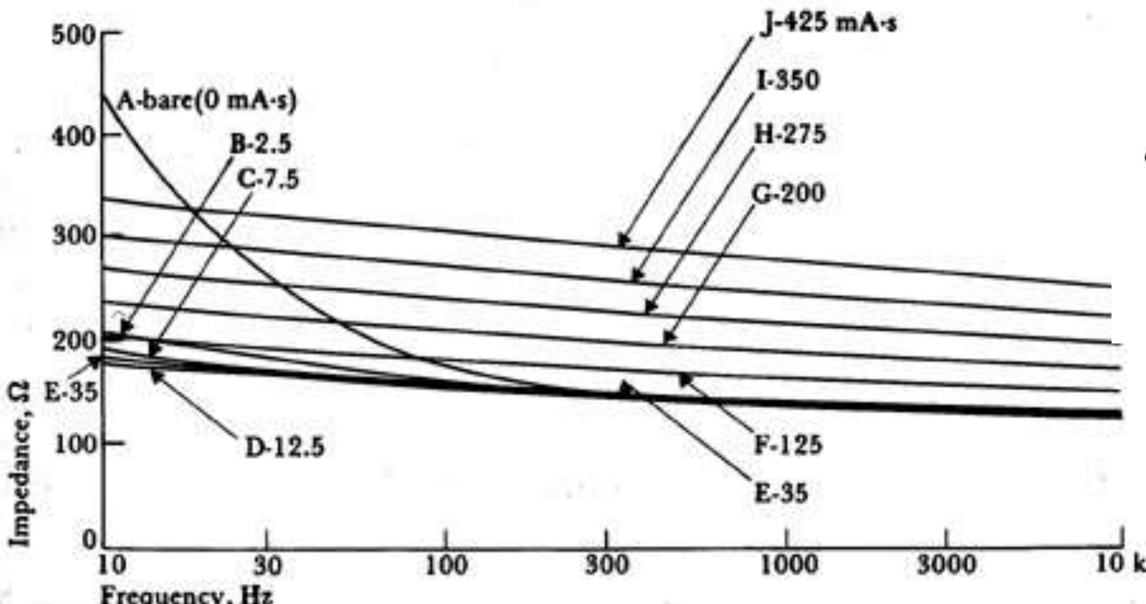
The characteristic of an electrode is

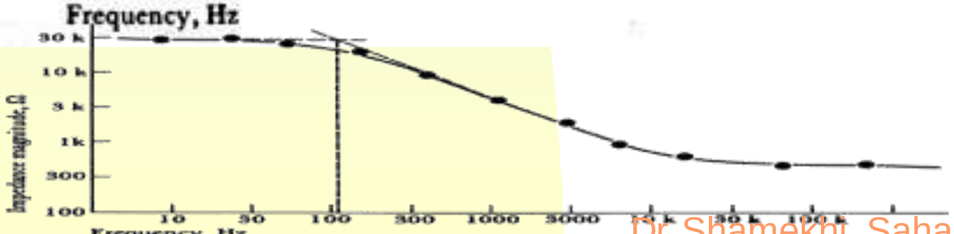
-Sensitive to current density

- waveform and frequency dependent





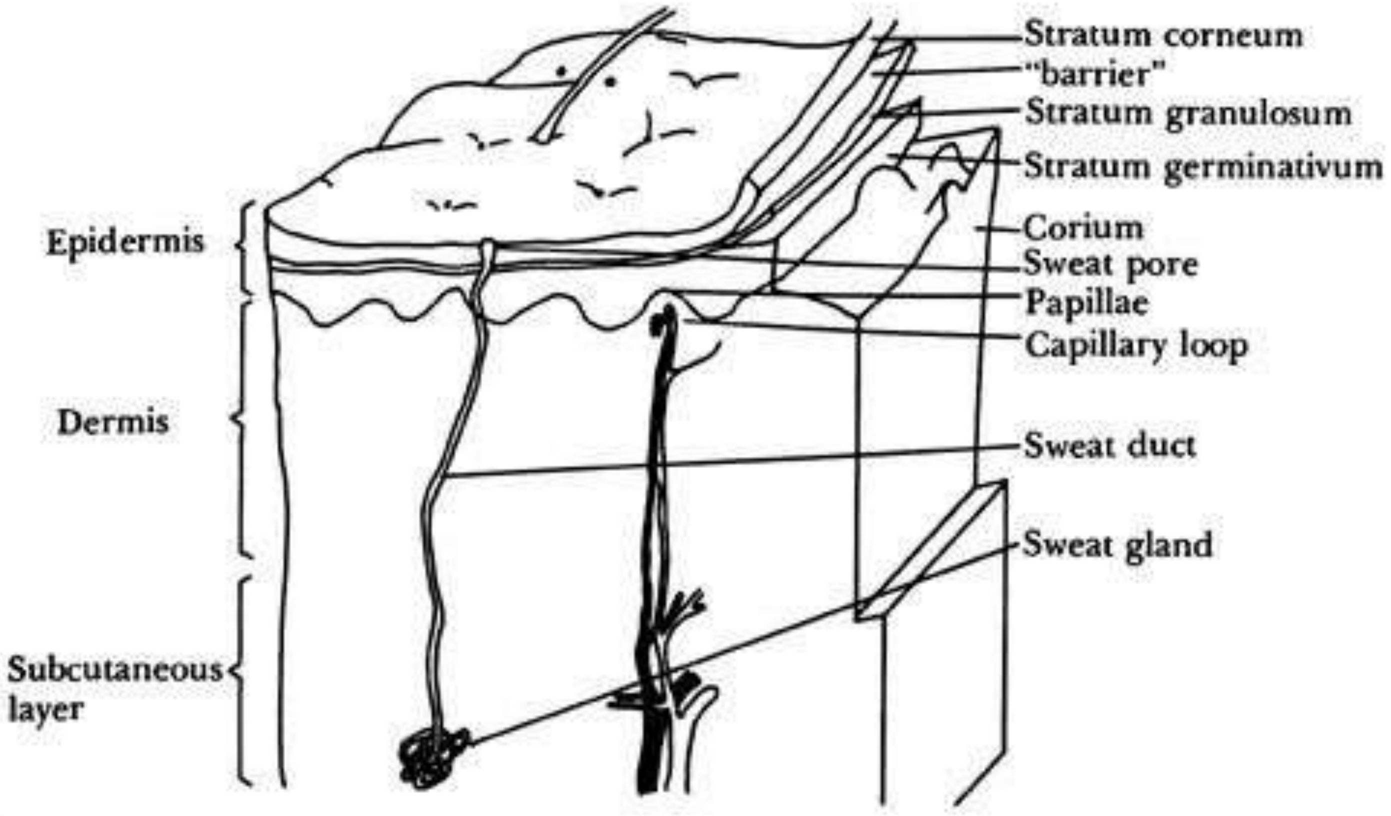




R_d and C_d make up the impedance associated with electrode-electrolyte interface and polarization effects. R_s is associated with interface effects and due to resistance in the electrolyte.

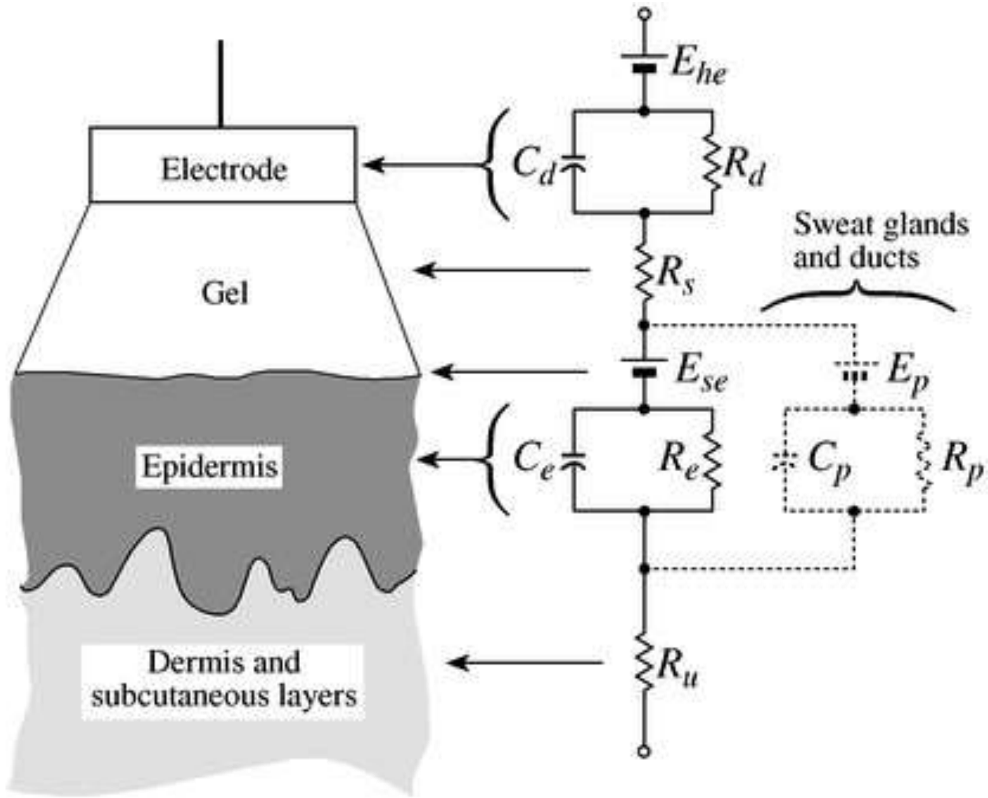
The Electrode-Skin Interface

Transparent electrolyte gel containing Cl- is used to maintain good contact between the electrode and the skin.



The Electrode-Skin Interface

For 1 cm², skin impedance reduces from approximately 200KΩ at 1Hz to 200Ω at 1MHz.



A body-surface electrode is placed against skin, showing the total electrical equivalent circuit obtained in this situation. Each circuit element on the right is at approximately the same level at which the physical process that it represents would be in the left-hand diagram.

Motion Artifact

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 nonpolarizable 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 nonpolarizable electrode to avoid signals due to motion artifact.

Must be considered:

–good adhesive connection to skin

–skin cleaning

–floating electrode

Electrodes:

- Types:

  »3 types

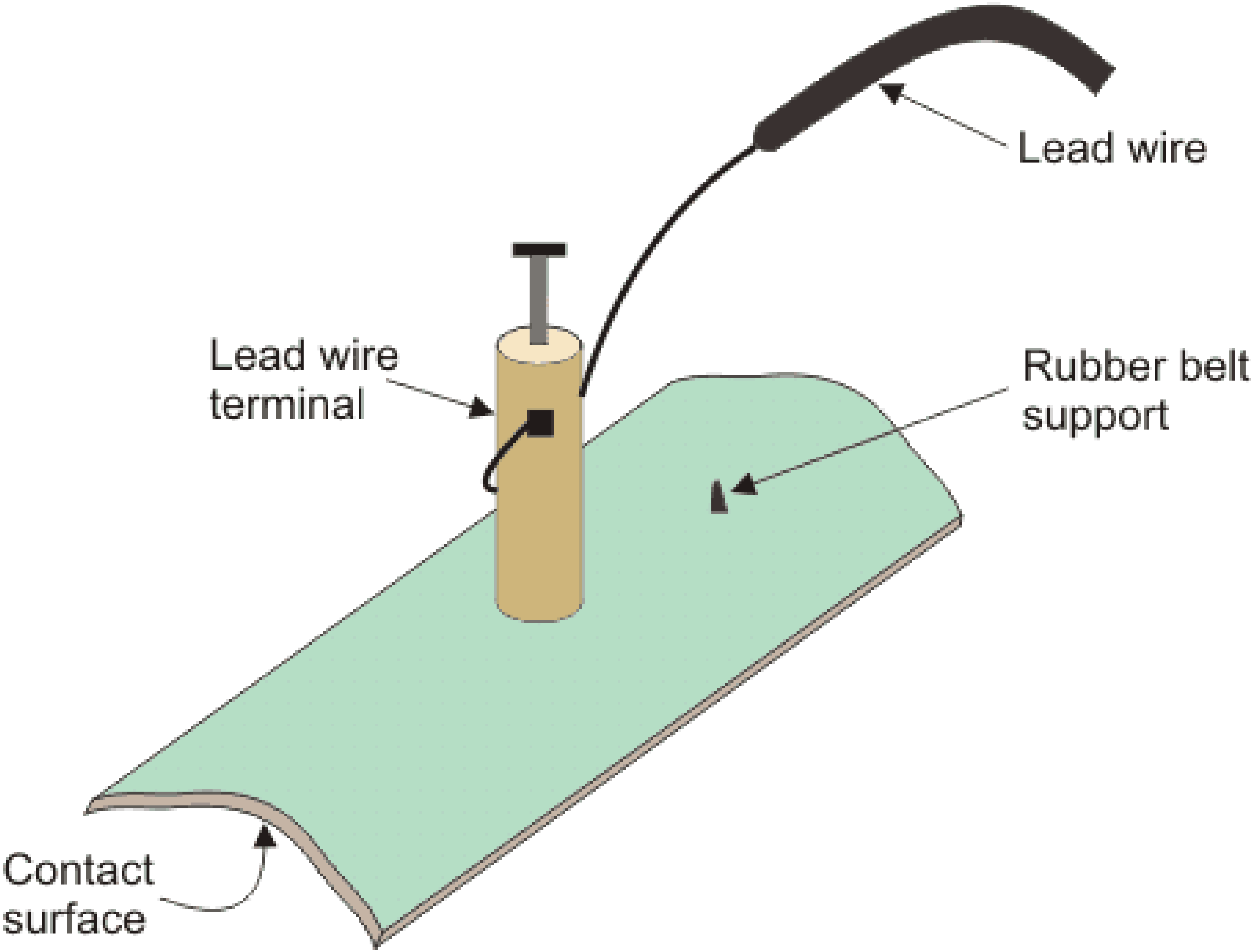
- Micro electrode
- Depth & needle electrodes
- Surface electrodes

Surface electrodes:

- Larger area electrodes : ECG potentials
- Smaller area electrodes: EEG & EMG potentials
- Types:
    - » Metal plate electrodes
    - » Suction cup electrode
    - » Adhesive tape electrode
    - » Multipoint electrode
    - » Floating electrode

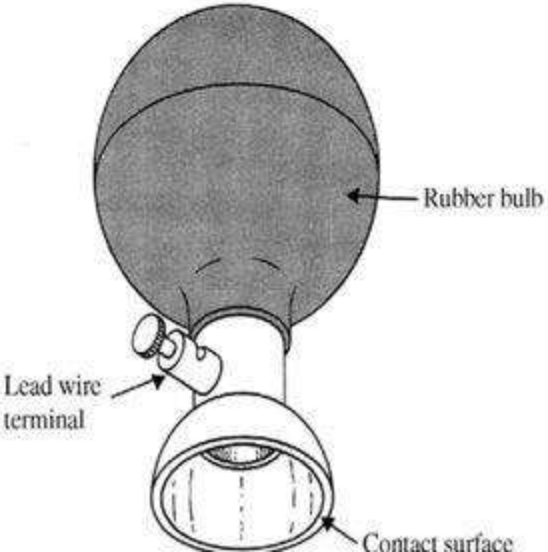
Metal plate electrodes:

- Rectangular (3.5 cm x 5 cm) & circular (4.75 diameter) in shape
- German silver, nickel silver, nickel plated steel
- ECG measurements


Lead wire
Lead wire
terminal
Rubber belt
support
Contact
surface

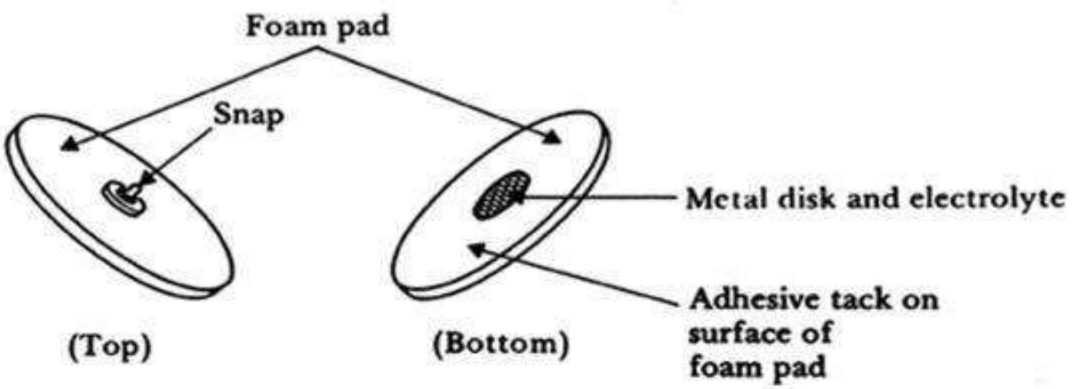
Suction Cup electrode:

- Flat surfaces of the body and to regions where the underlying tissue is soft
- Physically large but only rim (smaller area) is in contact to the skin

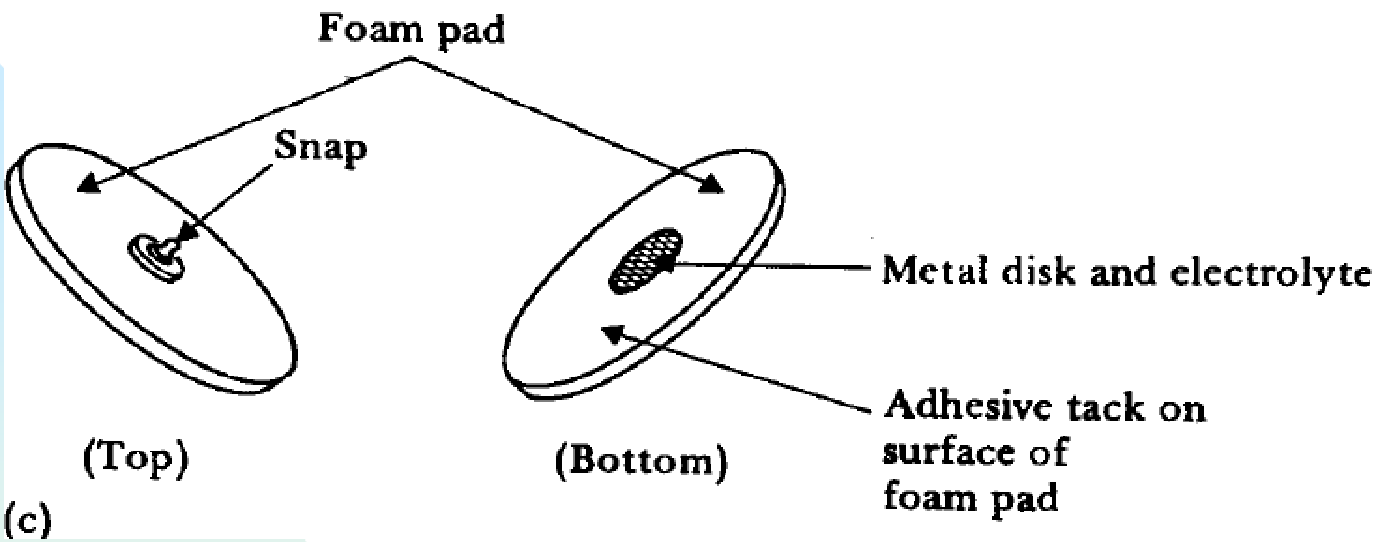


Adhesive tape electrode:

- The pressure of the surface electrode against the skin may squeeze the electrode paste out
- So, this type of electrodes are used
- Light metallic screen backed by a pad for electrode paste



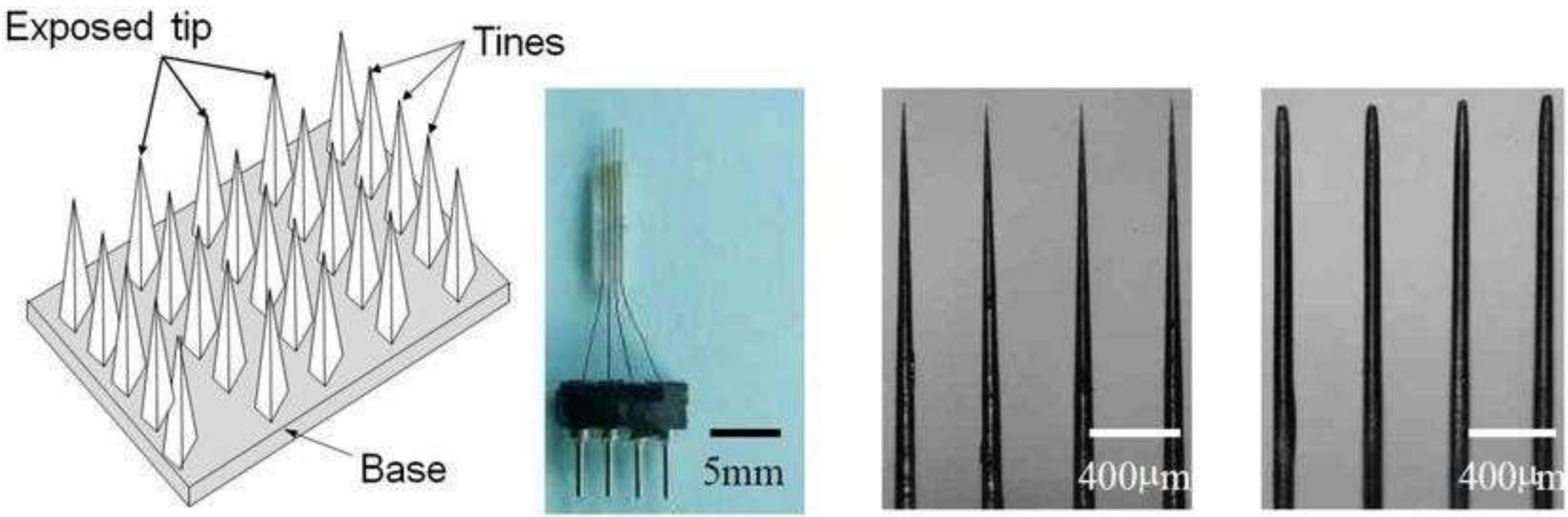
Disposable Foam-Pad Electrodes



Disposable foam-pad electrodes, often used with electrocardiograph monitoring apparatus.

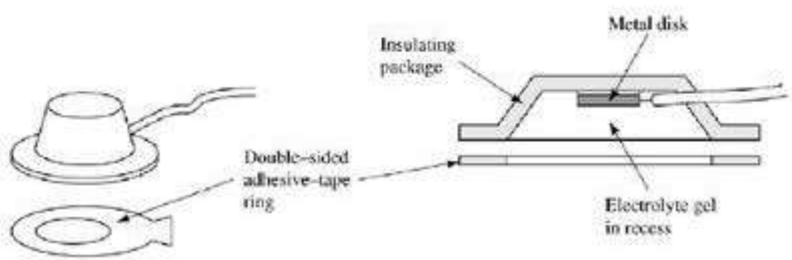
Multipoint electrode:

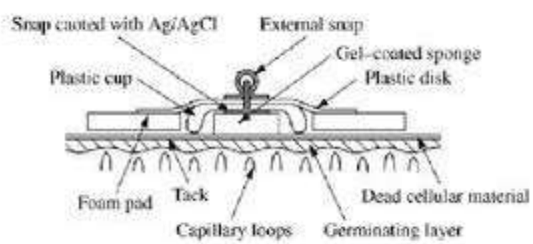
- ECG measurement
- Nearly 1000 fine active contact points



Floating electrode:

- Metal does not contact the subject directly but via electrolytic bridge
- Also called as liquid junction electrode
- Movement artifact is eliminated

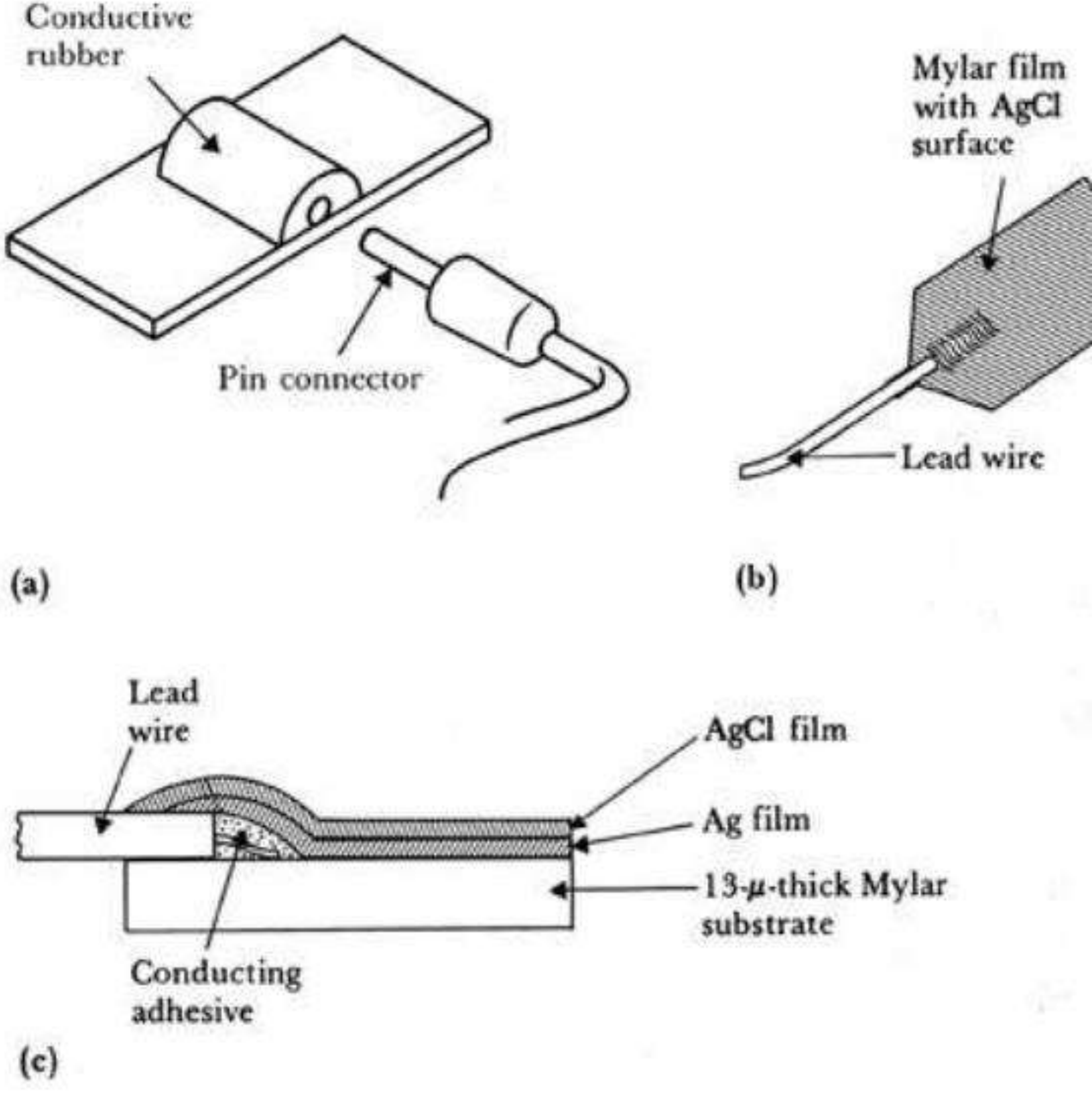




Body-Surface Recording Electrode

Flexible Electrodes

Flexible body-surface electrodes (a) Carbon-filled silicone rubber electrode. (b) Flexible thin-film neonatal electrode.
(c) Cross-sectional view of the thin-film electrode in (b).



Used for **newborn infants.**
Compatible with X-ray

NEEDLE ELECTRODES

***Needle electrodes are generally used in clinical electro myography, neuro graphy and other electrophysiological investigations under the skin and in the deeper tissues*.**

- Material used: Stainless steel which is preferred due to its mechanical solidity and low price.

- These electrodes are generally designed to be fully auto clavable and should be thoroughly sterilized before use

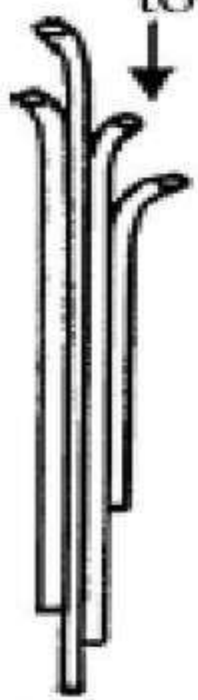
- Different types of needle electrodes are used for electro myographic work.

Depth & needle electrode:

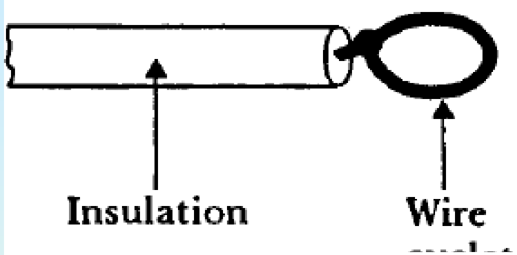
Depth electrode:

- Used to study the electrical activity of the neurons in superficial layers of the brain & also the oxygen tension
- Bundle of Teflon insulated platinum (90%) & Iridium (10%) alloy wires
- End of supporting wire is rounded
- Active area : 0.5 mm^2

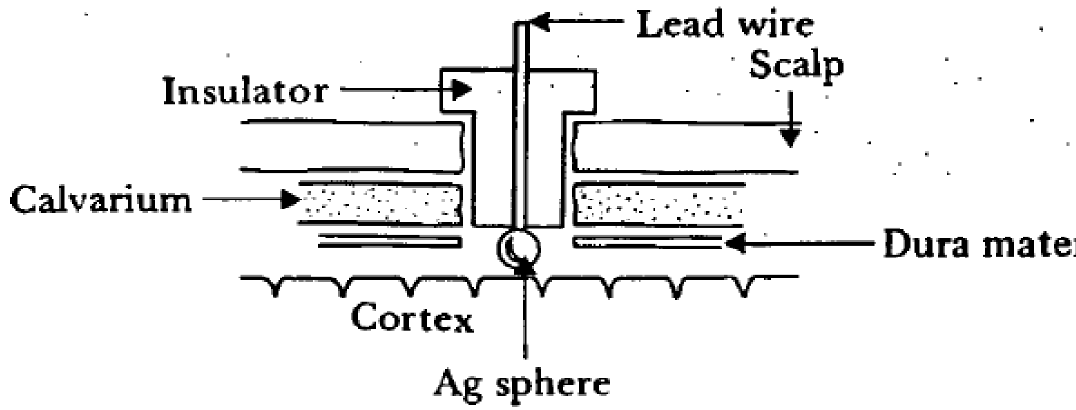
Depth electrode:

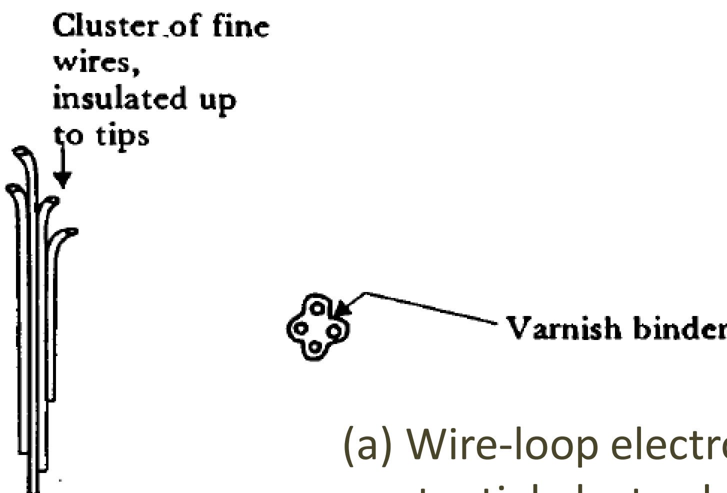


Implantable electrodes



(a)





(c)

(a) Wire-loop electrode. (b) Silver-sphere cortical-surface potential electrode. (c) Multielement depth electrode. mounted

Needle electrode:

- Electroneurography
- Resembles medicine dropper or hypodermic needle
- Bend at one end and is inserted through the lumen and is advanced into the muscle
- Needle is withdrawn and the bent wire is resting inside the muscle

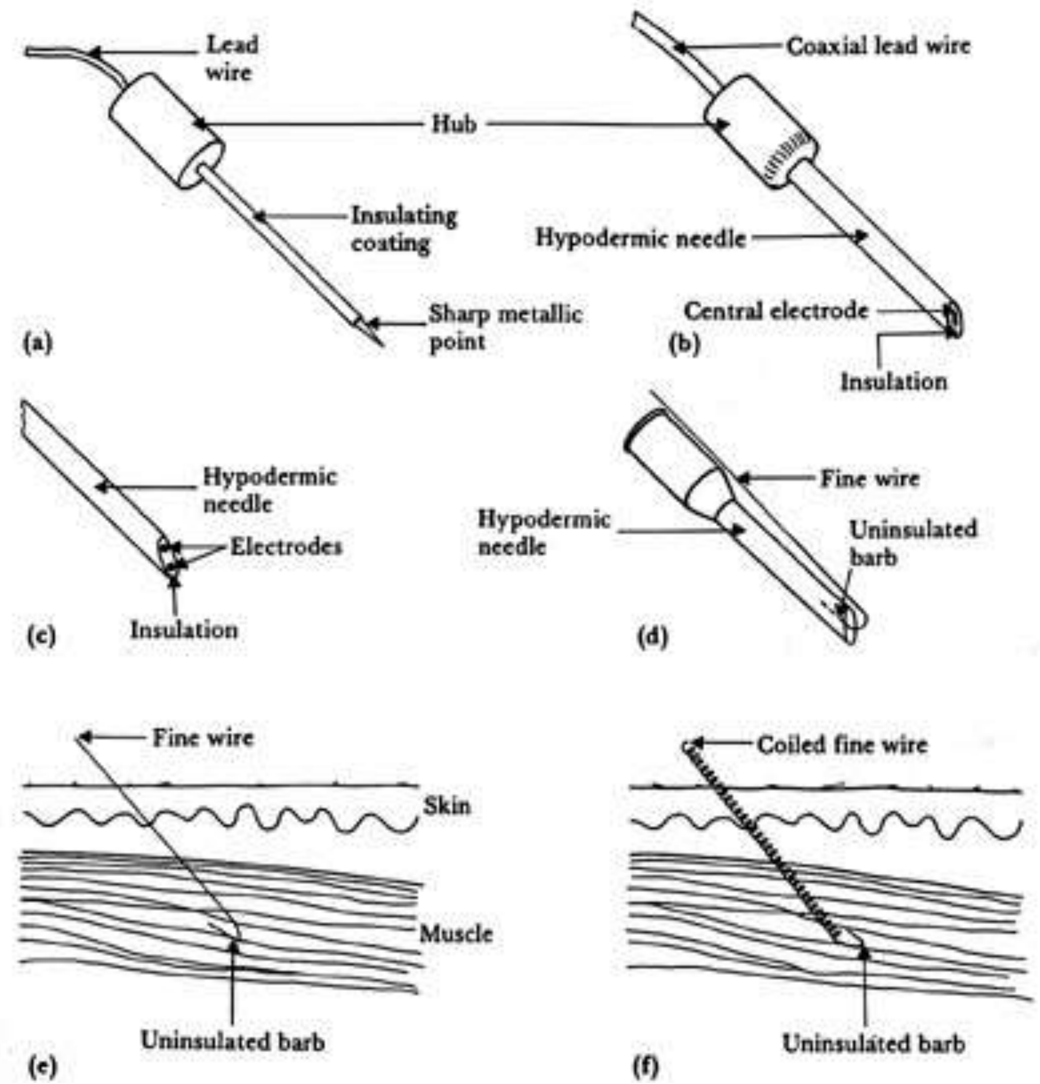
Types of electrodes

- *Monopolar needle electrodes*
- *Bipolar needle electrodes*
- *Concentric (coaxial) core needle electrode*
- *Multielement needle electrode*

Internal Electrodes

No electrolyte-skin interface
No electrolyte gel is required

Needle and wire electrodes for percutaneous measurement of biopotentials
(a)Insulated needle electrode.
(b)Coaxial needle electrode.
(c)Bipolar coaxial electrode.
(d)Fine-wire electrode connected to hypodermic needle, before being inserted.
(e)Cross-sectional view of skin and muscle, showing coiled fine- wire electrode in place.



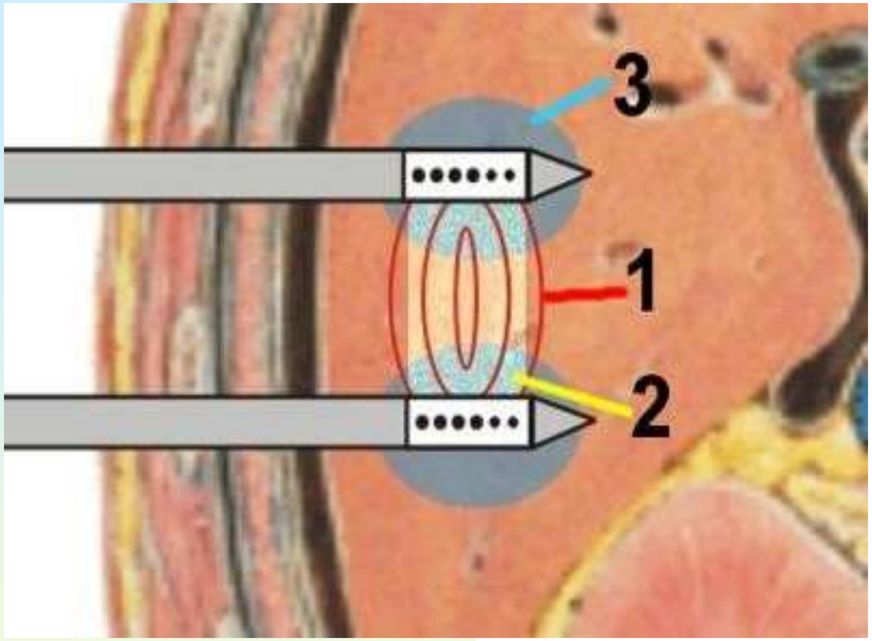
For EMG Recording

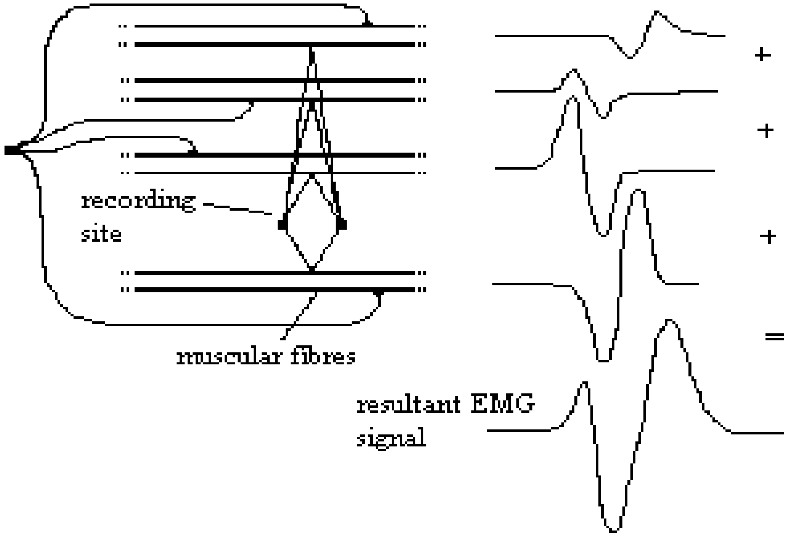
MONOPOLAR NEEDLE ELECTRODE

- Consists of Teflon coated stainless steel wire which is barely a tip

- The coating recedes after being used for several times and the electrode must be discarded when this occurs. They are also color coded.

BIOPOLAR (DOUBLE COAXIAL) NEEDLE ELECTRODE)

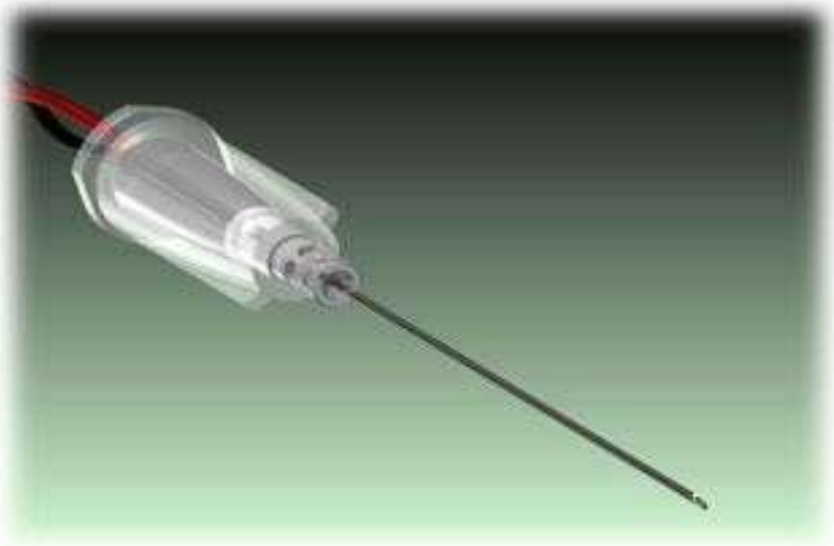




The synthesis of a motor unit action potential, as recorded by bipolar needle electrodes

- Contains two insulated wires within a metal cannula (is a tube that can be inserted into the body, often for the delivery or removal of fluid).
- The two wires are bared at the tip and provide the contacts to the patient.
- The cannula acts as the ground
- These electrodes are electrically symmetrical and have no sense of polarity.

CONCENTRIC(COAXIAL) CORE NEEDLE ELECTRODE



- Contains both the active and reference electrode within the same structure.
- Consists of an insulated wire contained within an hypodermic needle.
- The inner wire is exposed at the tip which forms one electrode.
- These needles have very stable electrical characteristics and are convenient to use.
- These electrodes are made by moulding fine platinum wire into hypodermic needle having outside diameter less than 0.6mm.
- One end is bevelled to expose he end of wire and provide easy penetration.
- The surface area of the exposed tip is less than 00005mm sq.

Micro electrodes: Intra cellular electrodes

- Used to measure the potential near or within cell
- Features:

  Smaller dimension (0.5 to 5 microns)
- Types:

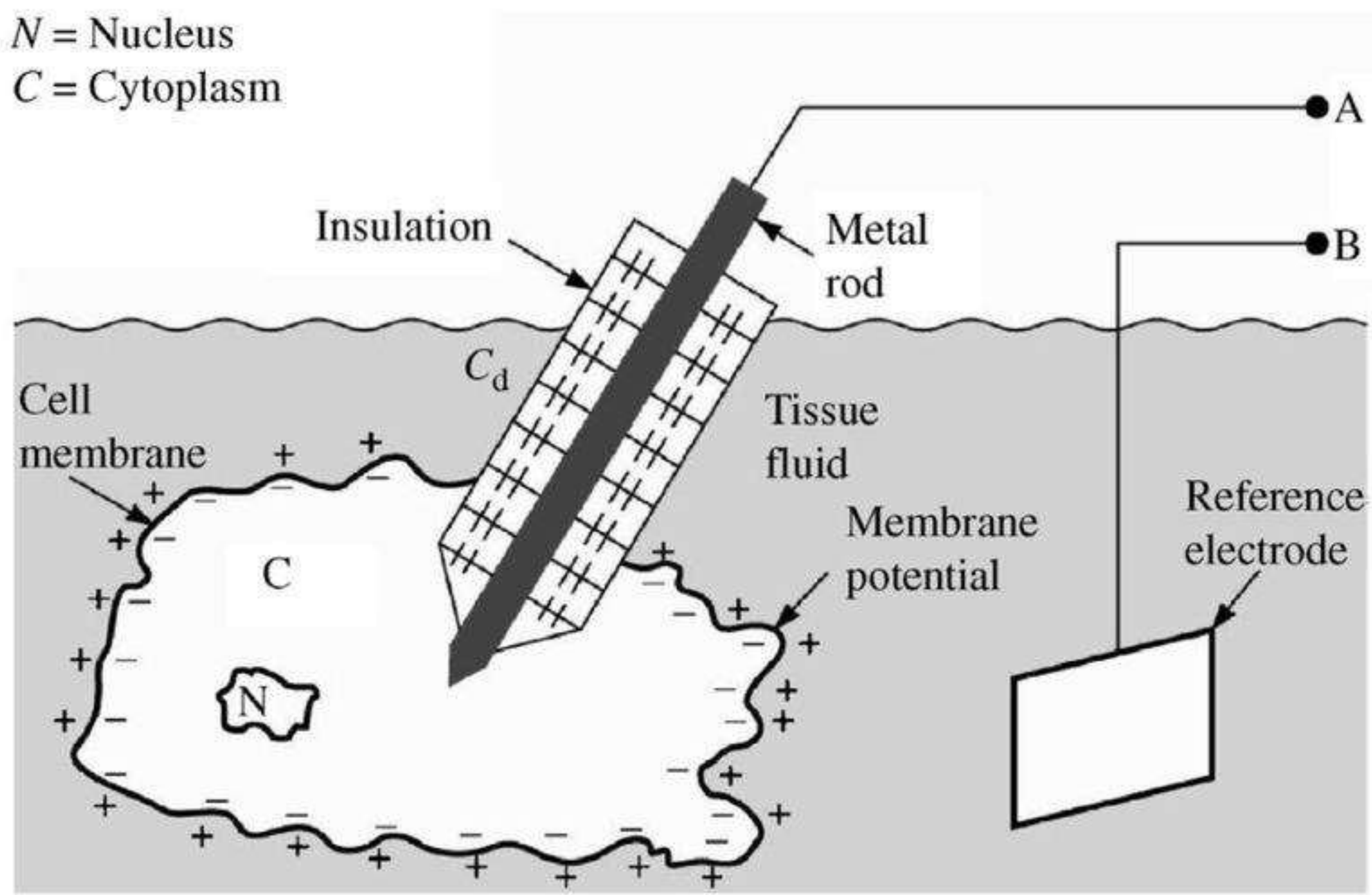
  »Metallic

  »Non metallic (Micropipet)

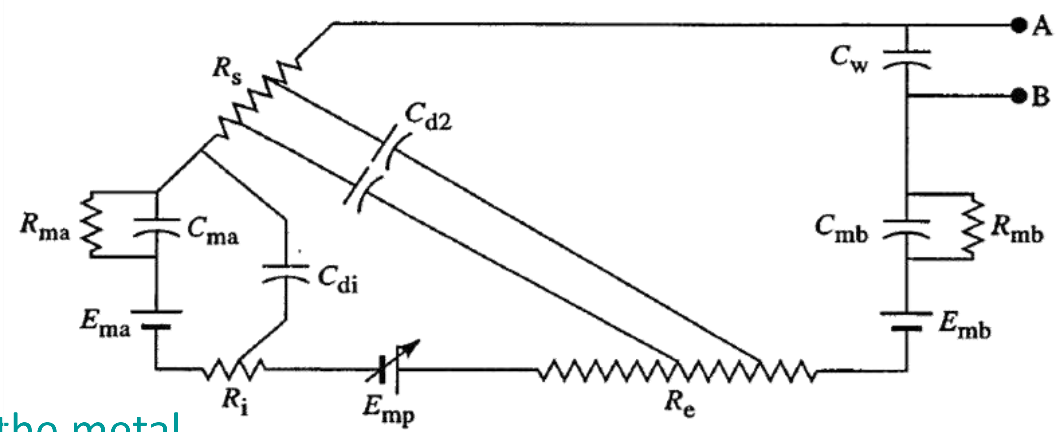
Metal microelectrode:

- Formed by electrolytically etching the tip of **fine Tungsten or stainless steel**
- **Electropointing**
- Coated with insulating material
- Chloriding the tip : reduce the impedance

Metal electrode:



Microelectrodes



•***Rs** :resistance* of the metal

•**Cd**: The metal is coated with an insulating material over all but its most distal tip

***Cd2**: outside **Cdi**: inside*

•Metal-electrolyte interface, ***Rma, Cma, and Ema***

•Reference electrode: **Cmb, *Rmb, and Emb***

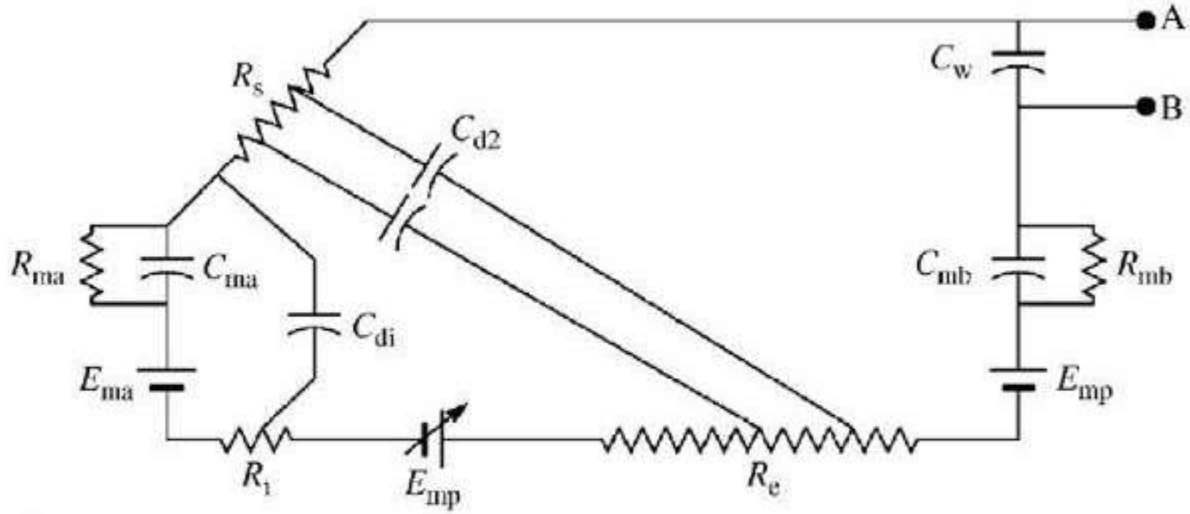
•***Ri**: electrolyte within the cell membrane*

•***Re**: extracellular fluid*

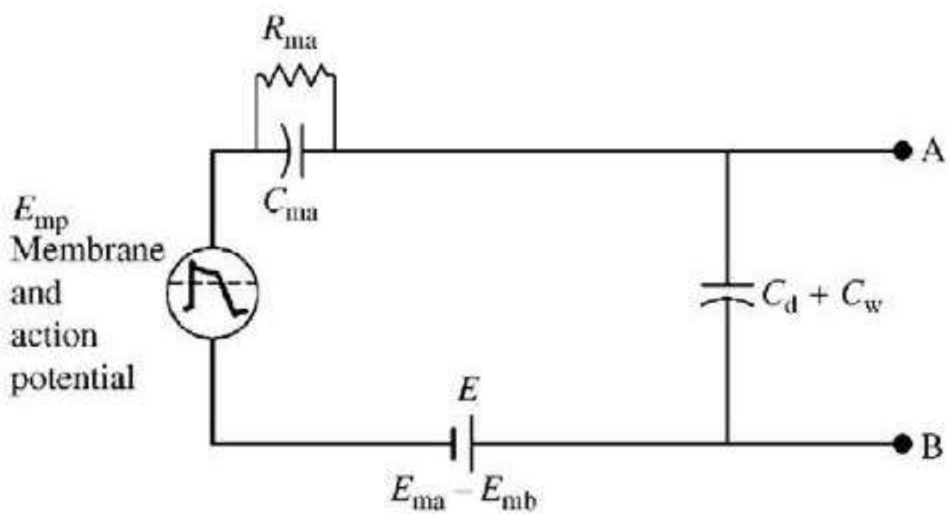
•***Cw***: lead wires Cap.

•***Emp**:* The cell membrane variable potential

Metal electrode – electrical equivalent:



(b)

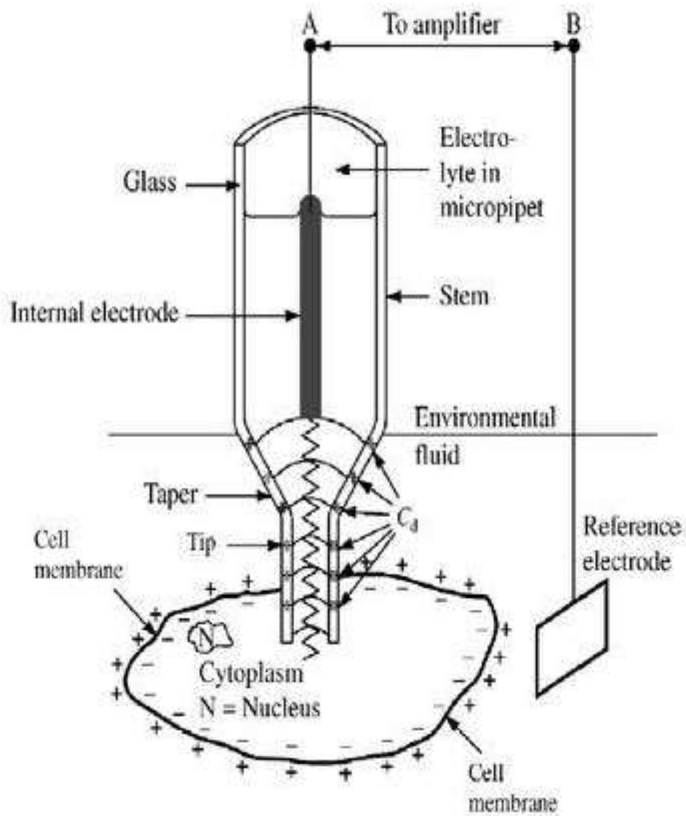


Contd.

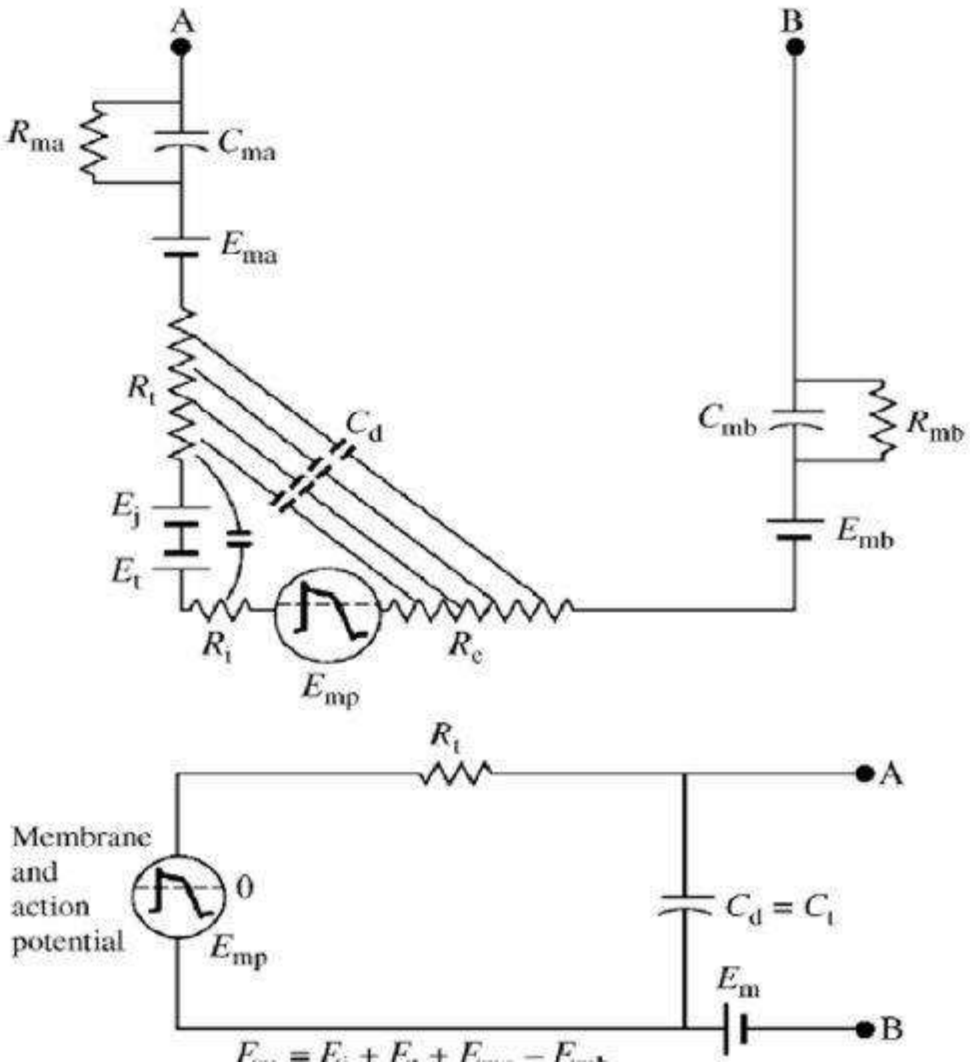
- Impedance of microelectrode is inversely proportional to the area of the tip & frequency.
- Z_{in} of the amplifier should be high : if not, behaves like a high pass filter

Micropipet (Non metallic electrode):

- 1 micrometre
- Filled with electrolyte 3 M KCL

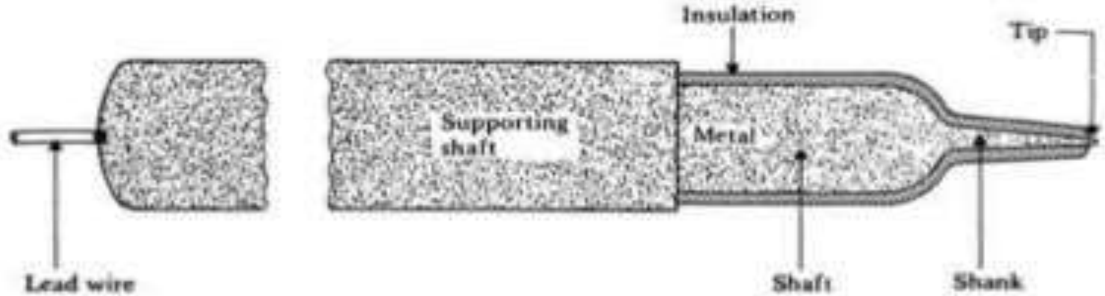


Micropipet – electrical equivalent:



Microelectrodes

The structure of a metal microelectrode for intracellular recordings.



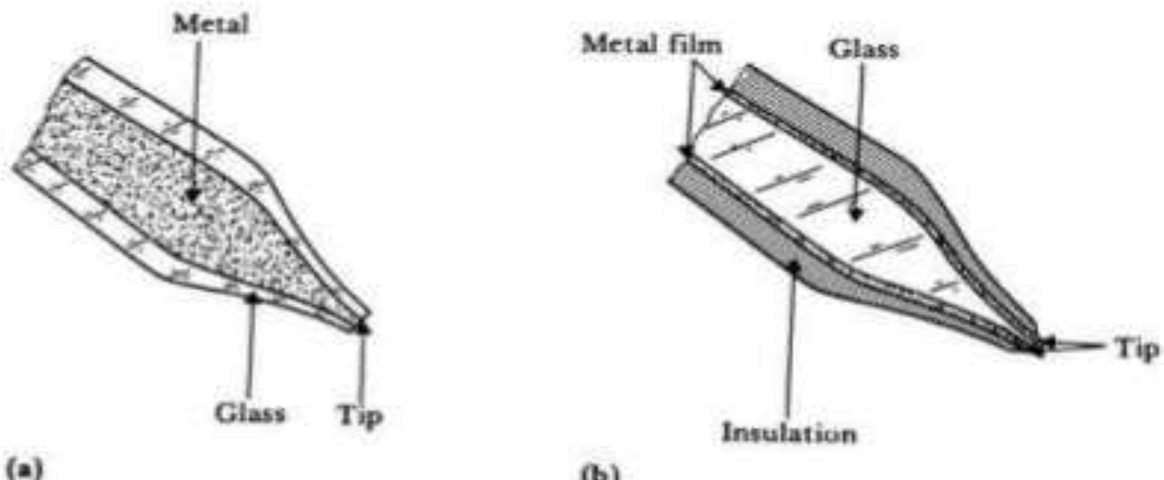
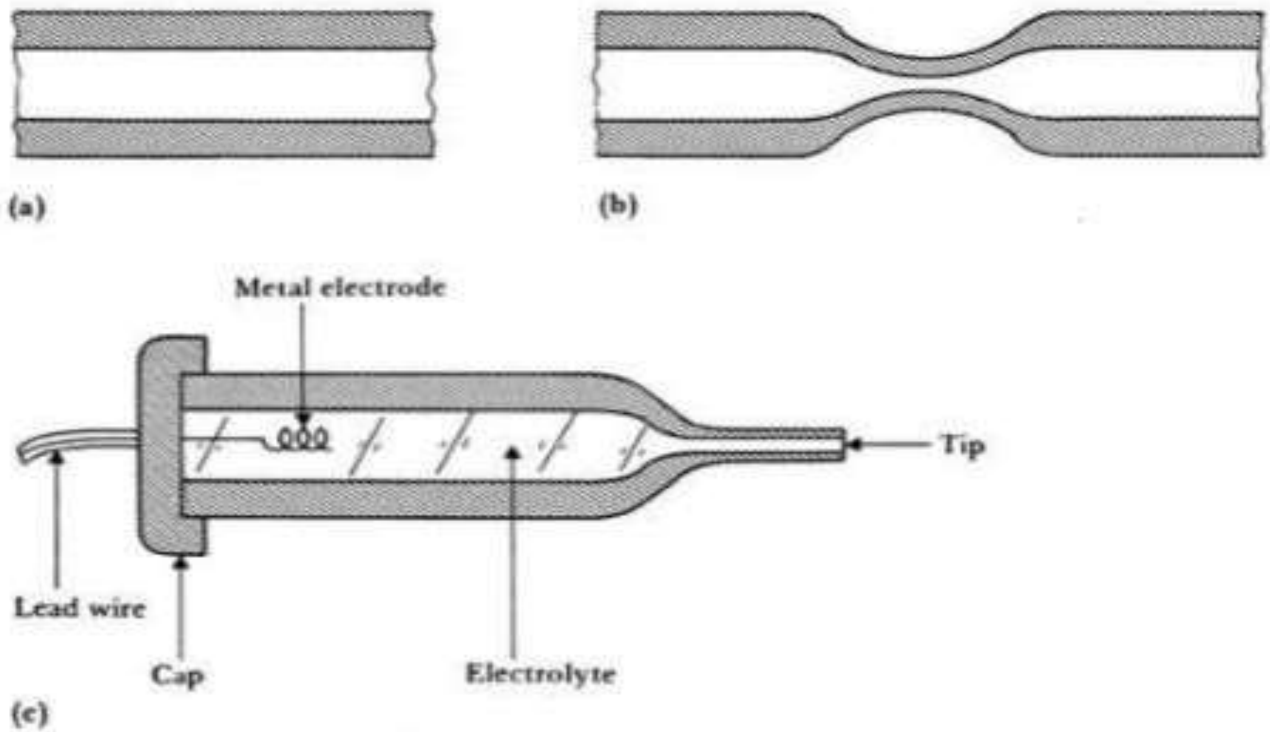


Figure 5.18 Structures of two supported metal microelectrodes (a) Metal-filled glass micropipet. (b) Glass micropipet or probe, coated with metal film.

Microelectrodes



A glass micropipet electrode filled with an electrolytic solution (a) Section of fine-bore glass capillary. (b) Capillary narrowed through heating and stretching. (c) Final structure of glass-pipet microelectrode.

Recording problems

- **Electrode-electrolyte noise**
- **Noise at the electrolyte**
- **skin interface**
- **Motion artifact**
- **Electric and magnetic field interference**
- **Thermal noise**
- **Amplifier noise**
- **Noise from additional bioelectric events**
- **Other noise sources**

Silver –Silver Chloride electrodes

- Half cell potential is 2.5 mv only
- Reduces the noise voltage and Increases the stability electrochemically
- Stabilizes the half cell potential- no movement artifacts(variable electrochemical voltage)
- Reduce the low frequency electrode- electrolyte impedance
-

Distortion in signals:

- Ag-Agcl electrode uses shielded cable to reduce **interference**
- **Johnson noise** (random movement of charge carriers) or **ohmic noise** (ohmic component of the electrode impedance) : micro electrodes
- **Movement artifacts** : equal half cell potential and high impedance will minimize the artifacts (floating electrodes)
- **Distortion** : movement of low current density

Contd..

Using large area electrode and bio electric recorder of high input impedance the distortion in the wave form is reduced