

# Chapter 5-Webster Biopotential Electrodes Sina Shamekhi

Note:

Some of the figures in this presentation have been taken from reliable websites in the internet

## Biopotential Electrodes

Biopotential electrodes is a transducer that convert the body ionic current in the body into the traditional electronic current flowing in the electrode.

Biopotential electrode should be able to conduct small current across the interface between the body and the electronic measuring circuit.

### **Subjects covered in Chapter 5**

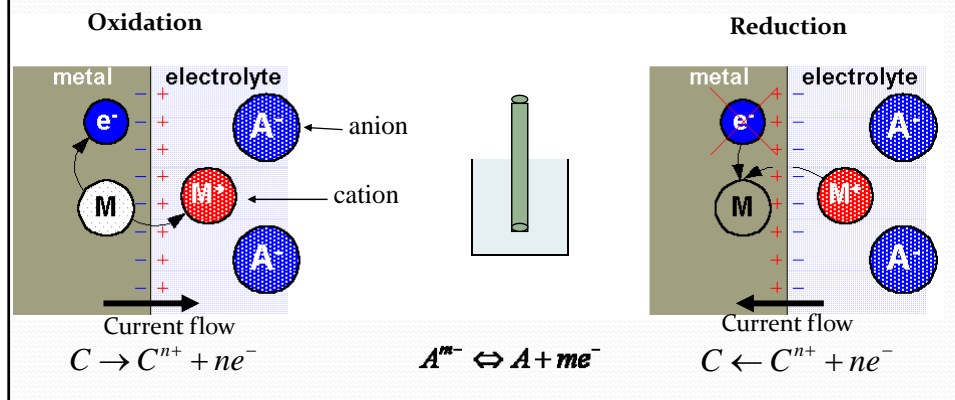
- Basic mechanism of transduction process
- Electrical characteristics of biopotential electrodes
- Different type of biopotential electrodes
- Electrodes used for ECG, EEG, MEG, and intracellular electrodes

## Electrode-Electrolyte Interface

Oxidation reaction causes atom to lose electron

Reduction reaction causes atom to gain electron

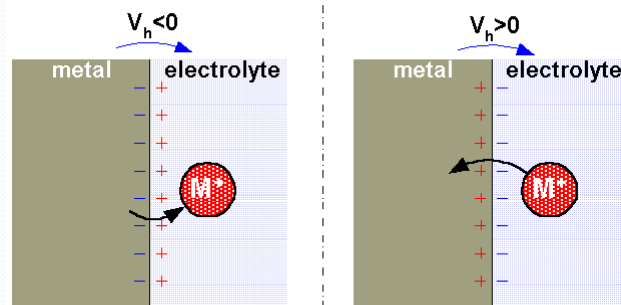
Oxidation is dominant when current flow from electrode to electrolyte, and reduction dominate when the current flow is the opposite.



## 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.

## Half-Cell Potential

reduction reaction	$E^\circ$ (V)	Half-cell potential for common electrode materials at 25 °C
$Al^{3+} + 3e^- \rightarrow Al$	-1.662	
$Zn^{2+} + 2e^- \rightarrow Zn$	-0.762	
$Cr^{3+} + 3e^- \rightarrow Cr$	-0.744	
$Fe^{2+} + 2e^- \rightarrow Fe$	-0.447	
$Cd^{2+} + 2e^- \rightarrow Cd$	-0.403	
$Ni^{2+} + 2e^- \rightarrow Ni$	-0.257	
$Pb^{2+} + 2e^- \rightarrow Pb$	-0.126	
$2H^+ + 2e^- \rightarrow H_2$	0.000	← Standard Hydrogen electrode
$AgCl + e^- \rightarrow Ag + Cl^-$	+0.222	
$Hg_2Cl_2 + 2e^- \rightarrow 2Hg + 2Cl^-$	+0.268	
$Cu^{2+} + 2e^- \rightarrow Cu$	+0.342	
$Cu^+ + e^- \rightarrow Cu$	+0.521	
$Ag^+ + e^- \rightarrow Ag$	+0.780	
$Au^{3+} + 3e^- \rightarrow Au$	+1.498	
$Au^+ + e^- \rightarrow Au$	+1.692	

Electrochemists have adopted the Half-Cell potential for hydrogen electrode to be zero. Half-Cell potential for any metal electrode is measured with respect to the hydrogen electrode.

## 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.

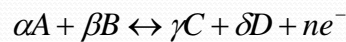
$$E = -\frac{RT}{nF} \ln \left[ \frac{a_1}{a_2} \right]$$

$a_1$  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



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

## The Silver/Silver Chloride Electrode

Advantage of Ag/AgCl is that it is stable in liquid that has large quantity of  $\text{Cl}^-$  such as the biological fluid.

For biological fluid where  $\text{Cl}^-$  ion is relatively high

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

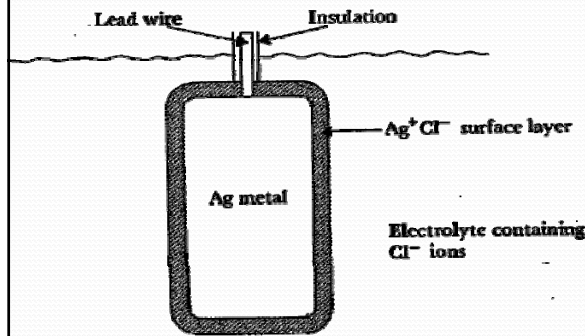
$$E = E_{\text{Ag}}^0 + \frac{RT}{nF} \ln[a_{\text{Ag}^+}]$$

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

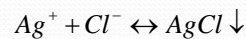
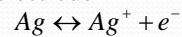
is solubility product

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

constant                      effective



Performance of this electrode



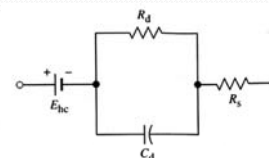
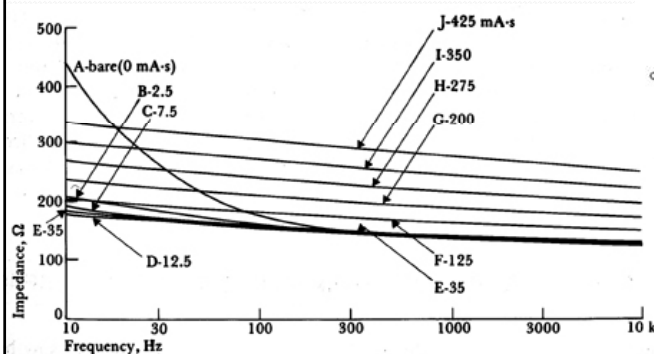
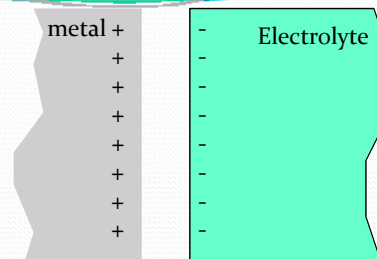
## Electrode Behavior and Circuit Models

**Advantages:**

- Low Noise (vs. Metal Electrodes) esp. ECG
- Biocompatible

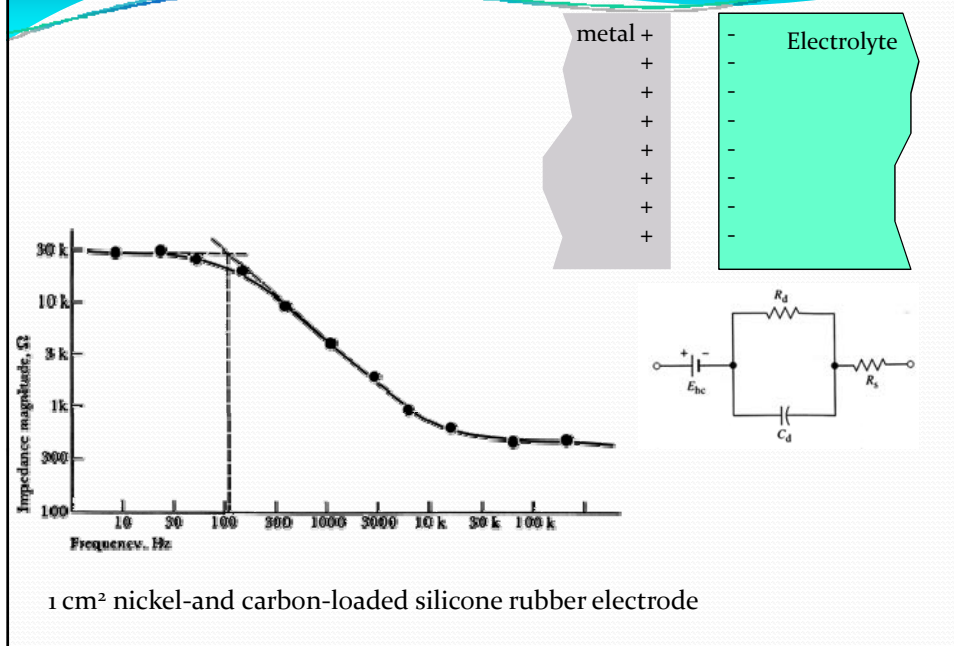
**The characteristic of an electrode is**

- Sensitive to current density
- waveform and frequency dependent



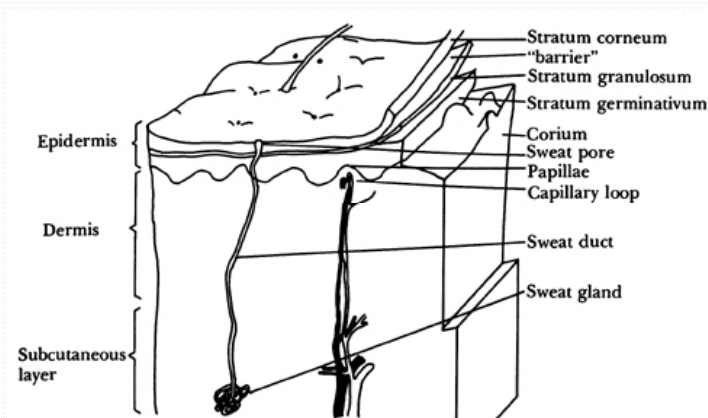
$R_d$  and  $C_d$  make up the impedance associated with electrode-electrolyte interface and polarization effects.  $R_s$  is associated with interface effects and due to resistance in the electrolyte.

## Electrode Behavior and Circuit Models



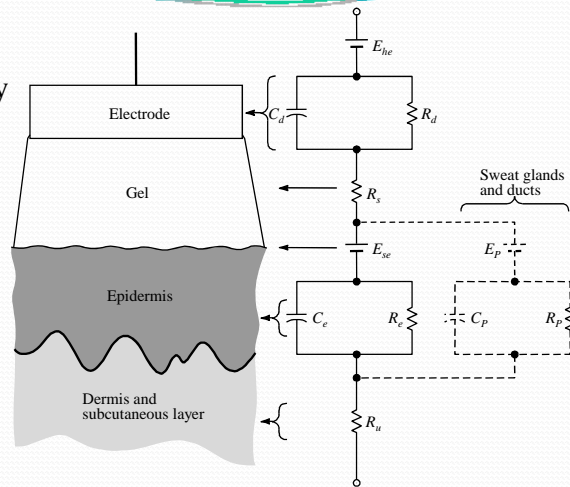
## The Electrode-Skin Interface and Motion Artifact

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



## The Electrode-Skin Interface

For  $1 \text{ cm}^2$ , skin impedance reduces from approximately  $200 \text{ K}\Omega$  at  $1 \text{ Hz}$  to  $200 \Omega$  at  $1 \text{ MHz}$ .



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.

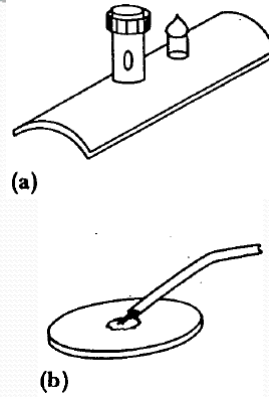
## Motion Artifact

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.

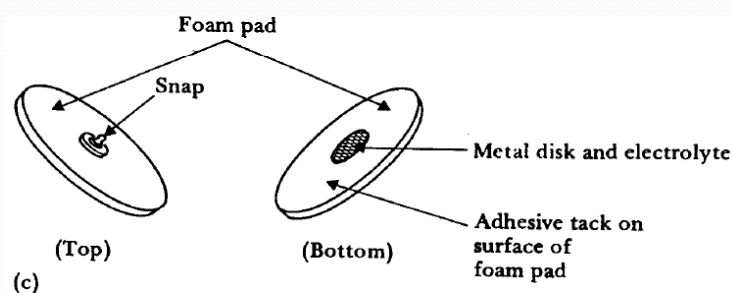
## Metal-Plate Electrodes

- **German silver** (a nickel-silver alloy)
- Before it is attached to the body, its concave surface is covered with **electrolyte gel**
- Motion Artifacts
- This structure can be used as a **chest** electrode for recording the ECG or in cardiac monitoring for **long-term** recordings.
- Electrodes used in monitoring **EMGs** or **EEGs** are generally **smaller** in diameter than those used in recording **ECGs**.
- (b) The **thinness** of the foil allows it to **conform** to the **shape** of the body surface. Also, because it is so **thin**, the **cost** can be kept relatively **low**.



**Body-surface biopotential electrodes** (a) Metal-plate electrode used for application to limbs. (b) Metal-disk electrode applied with surgical tape.

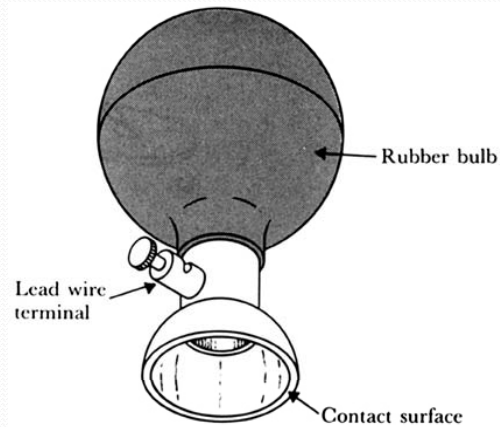
## Disposable Foam-Pad Electrodes



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

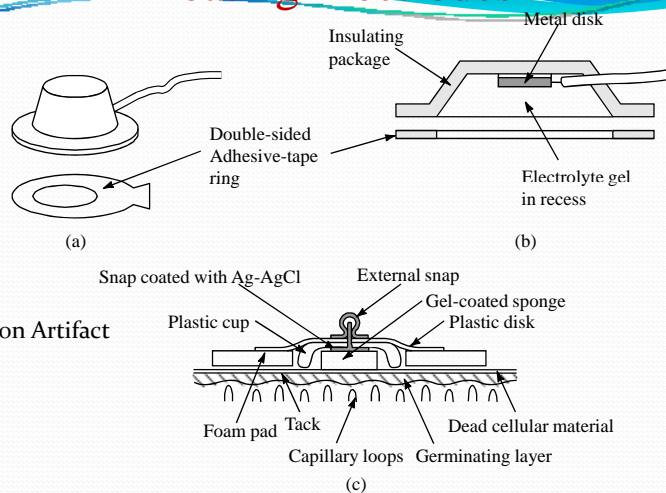


## Suction Electrodes



A metallic suction electrode is often used as a precordial electrode on clinical electrocardiographs. **No need for strap or adhesive** and can be **used frequently**. **Higher source impedance** since the contact area is small

## Floating Electrodes

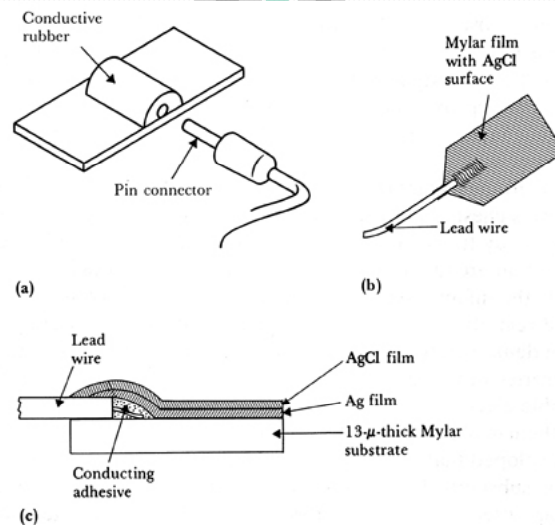


•Reduce Motion Artifact

Examples of floating metal body-surface electrodes (a) Recessed electrode with top-hat structure. (b) Cross-sectional view of the electrode in (a). (c) Cross-sectional view of a disposable recessed electrode of the same general structure shown in Figure 5.9(c). The recess in this electrode is formed from an open foam disk, saturated with electrolyte gel and placed over the metal electrode. **Minimize motion artifact**

## 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**.

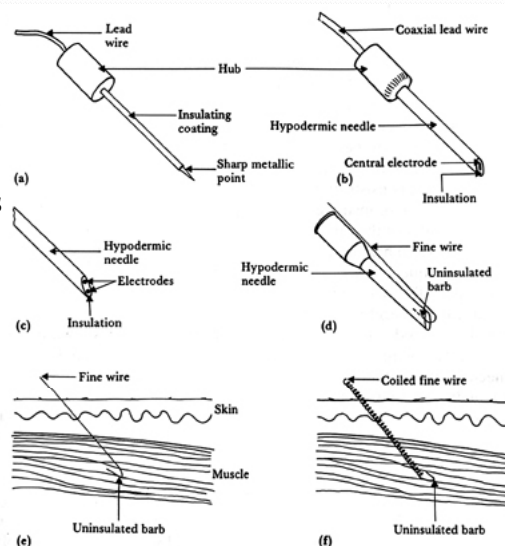
**Compatible with X-ray**

Electrolyte hydrogel material is used to hold electrodes to the skin.

## Internal Electrodes

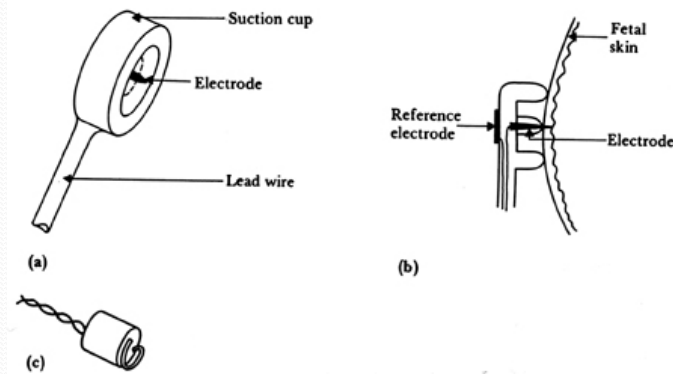
No electrolyte-skin interface  
No electrolyte gel is required

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.



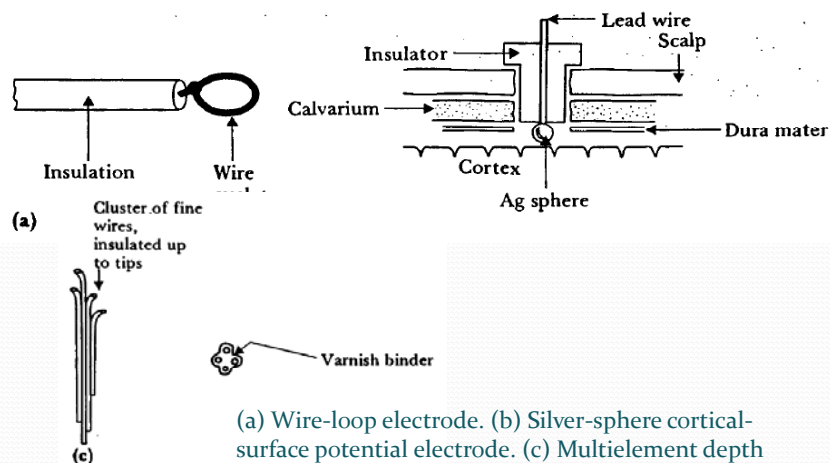
For EMG Recording

## Internal Electrodes



**Electrodes for detecting fetal electrocardiogram during labor, by means of intracutaneous needles** (a) Suction electrode. (b) Cross-sectional view of suction electrode in place, showing penetration of probe through epidermis. (c) Helical electrode, which is attached to fetal skin by corkscrew type action.

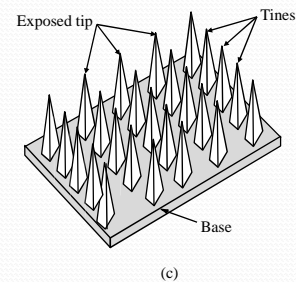
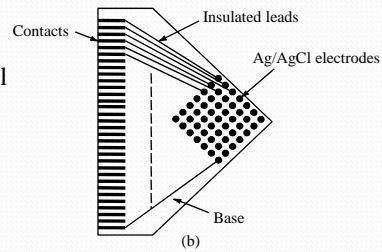
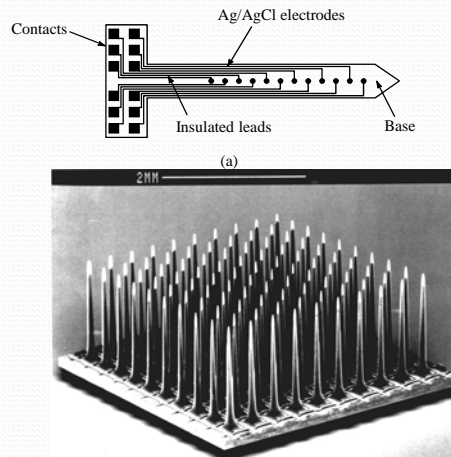
## Implantable electrodes



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

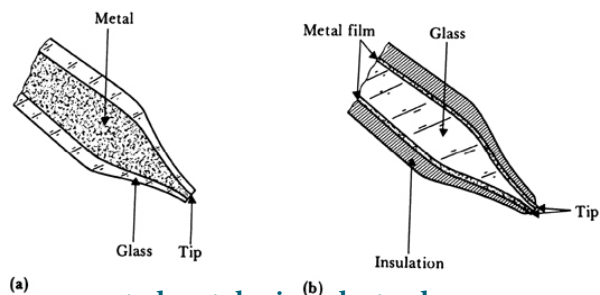
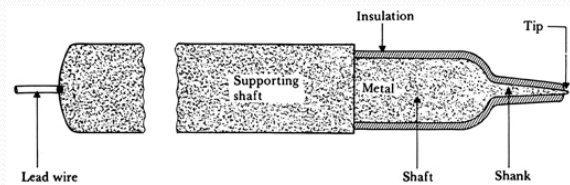
## Electrode Arrays

(a) One-dimensional plunge electrode array 10mm long, 0.5mm wide, and 125 $\mu$ m thick, used to measure potential distribution in the beating myocardium (b) Two-dimensional array, used to map epicardial potential and (c) Three-dimensional array, each tine is 1.5 mm



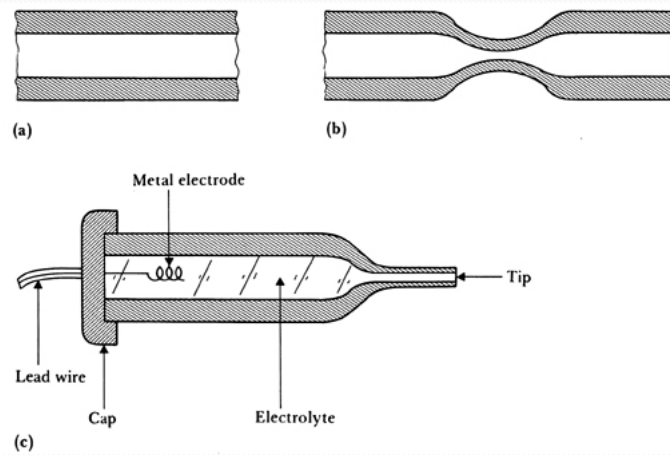
## Microelectrodes

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



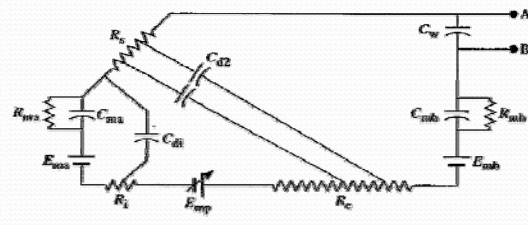
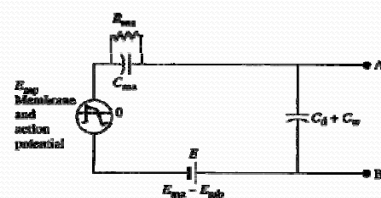
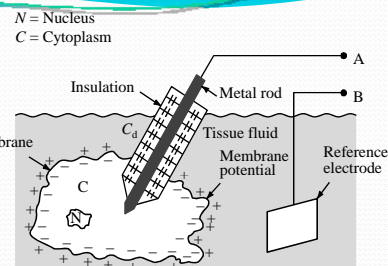
A glass micropipet electrode filled with an electrolytic solution (a) Section of fine-bore glass capillary. (b) Capillary narrowed through heating and stretching. (c) Final structure of glass-pipet microelectrode.

## Microelectrodes

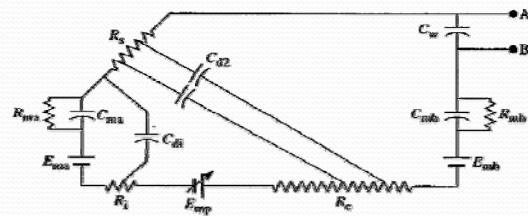
Used in studying the electrophysiology of excitable cells by measure potential differences across the cell membrane.

Electrode need to be small and strong to penetrate the cell membrane without damaging the cell.

Tip diameters = 0.05 to 10  $\mu\text{m}$



## Microelectrodes



- $R_s$ : resistance of the metal
- $C_d$ : The metal is coated with an insulating material over all but its most distal tip
  - $C_{d2}$ : outside
  - $C_{di}$ : inside
- Metal-electrolyte interface,  $R_{ma}$ ,  $C_{ma}$ , and  $E_{ma}$
- Reference electrode:  $C_{mb}$ ,  $R_{mb}$ , and  $E_{mb}$
- $R_i$ : electrolyte within the cell membrane
- $R_e$ : extracellular fluid
- $C_w$ : lead wires Cap.
- $E_{mp}$ : The cell membrane variable potential

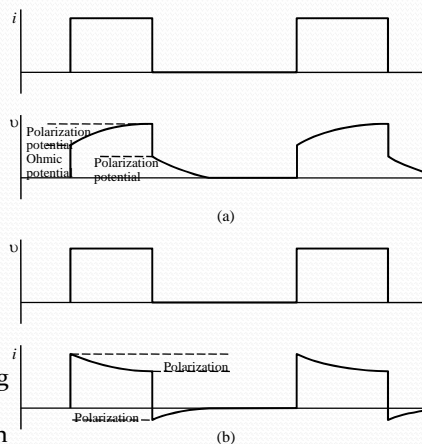
## Electrodes For Electric Stimulation of Tissue

(a): Const-Current the voltage response. voltage pulse is not constant. polarization occurs.

The initial rise in voltage corresponding to edge of the current pulse (voltage - drop across the resistive components).

The voltage continues to rise with the constant current. This is due to the establishment of a change in the distribution of charge concentration

(b): the current corresponding to the rising edge of the voltage pulse jump in a large step and, as the distribution of the polarization charge becomes established, to fall back to a lower steady-state value



Current and voltage waveforms seen with electrodes used for electric stimulation

(a) Constant-current stimulation. (b) Constant-voltage stimulation.