Sahand University of Technology

Lecture 3
Biopotential Electrodes

Dr. Shamekhi
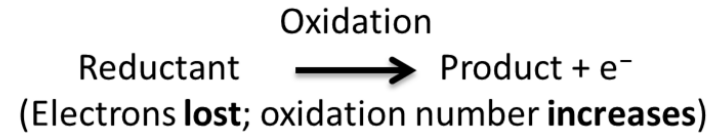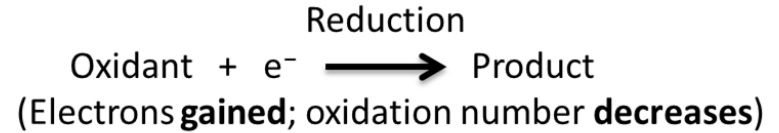**Summer 2016**

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.

- Biopotential 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**.

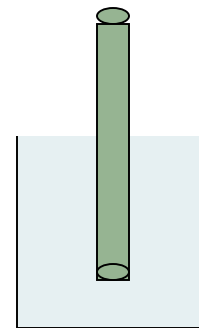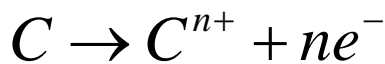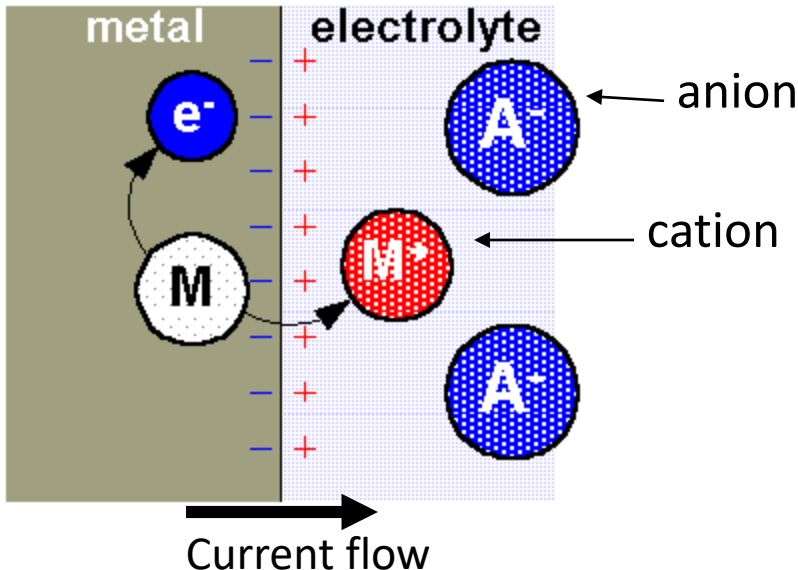**Electrode change an ionic current into an electronic current**

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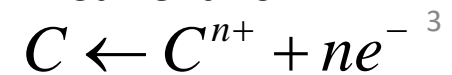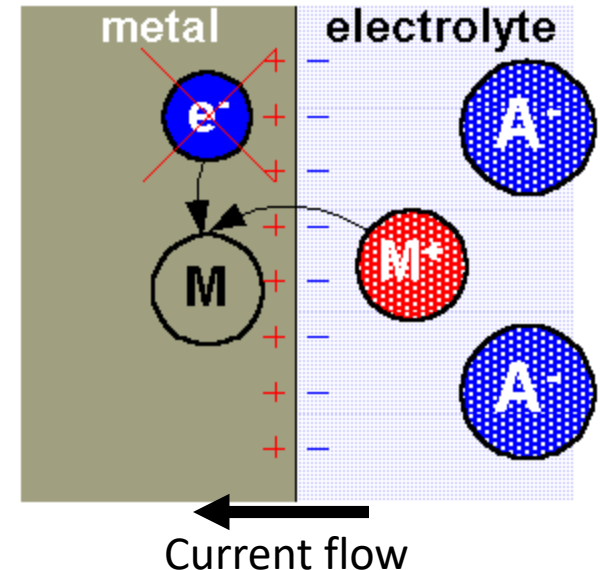(Electrons **lost**; oxidation number **increases**)

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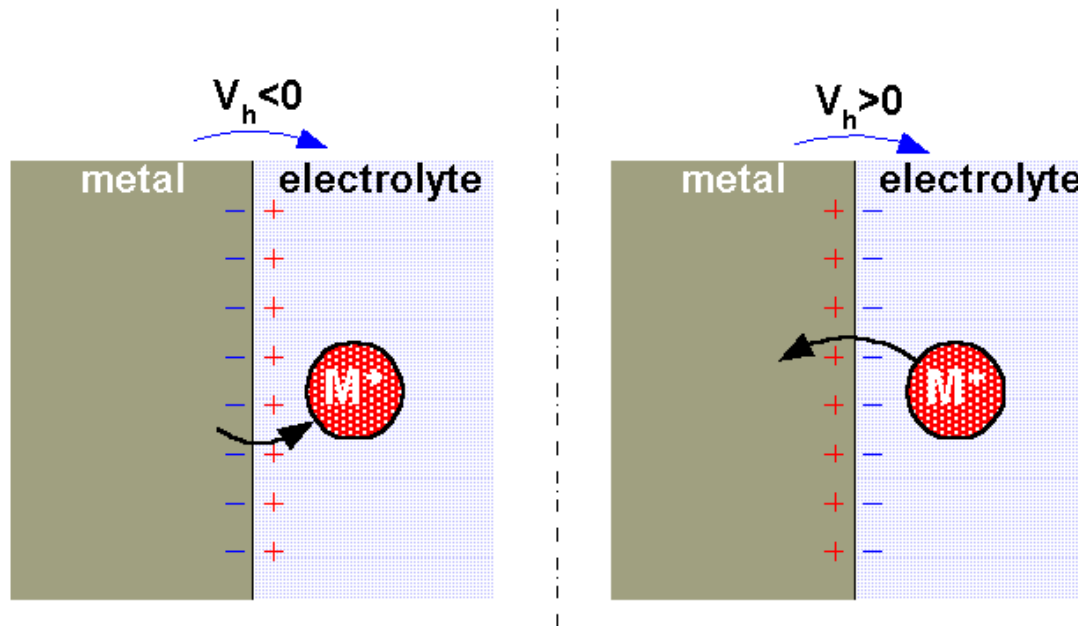
Oxidation

Reduction

anion

cation

Current flow

Current flow

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

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

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

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.
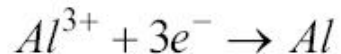
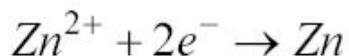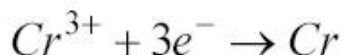| reduction reaction	$E^o\ (V)$
$Al^{3+} + 3e^- \rightarrow Al$	-1.662
$Zn^{2+} + 2e^- \rightarrow Zn$	-0.762
$Cr^{3+} + 3e^- \rightarrow Cr$	-0.744
$Fe^{2+} + 2e^- \rightarrow Fe$	-0.447
$Cd^{2+} + 2e^- \rightarrow Cd$	-0.403
$Ni^{2+} + 2e^- \rightarrow Ni$	-0.257
$Pb^{2+} + 2e^- \rightarrow Pb$	-0.126
$2H^+ + 2e^- \rightarrow H_2$	0.000
$AgCl + e^- \rightarrow Ag + Cl^-$	$+0.222$
$Hg_2Cl_2 + 2e^- \rightarrow 2Hg + 2Cl^-$	$+0.268$
$Cu^{2+} + 2e^- \rightarrow Cu$	$+0.342$
$Cu^+ + e^- \rightarrow Cu$	$+0.521$
$Ag^+ + e^- \rightarrow Ag$	$+0.780$
$Au^{3+} + 3e^- \rightarrow Au$	$+1.498$
$Au^+ + e^- \rightarrow Au$	$+1.692$

Half-cell potential for common electrode materials at 25 °C
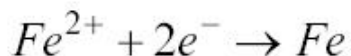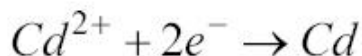
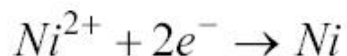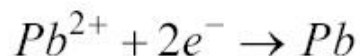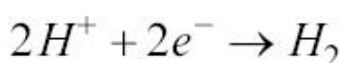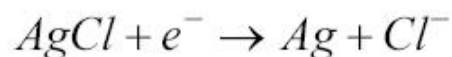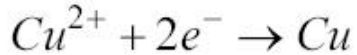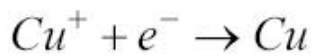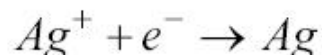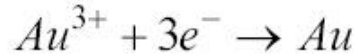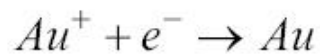Electrochemists have adopted the Half-Cell potential for hydrogen electrode to be zero. Half-Cell potential for any metal electrode is measured with respect to the hydrogen electrode. **(Why?)**

⟵ Standard Hydrogen electrode

The more **negative/positive** the half-cell EMF, the **greater/smaller** the tendency of the reductant to donate electrons (Oxidation), and the **smaller/greater** the tendency of the oxidant to accept electrons (Reduction).

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.

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

$$\alpha A + \beta B \leftrightarrow \gamma C + \delta D + ne^-$$
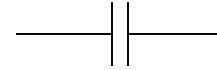
The Nernst equation for half cell potential is

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

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

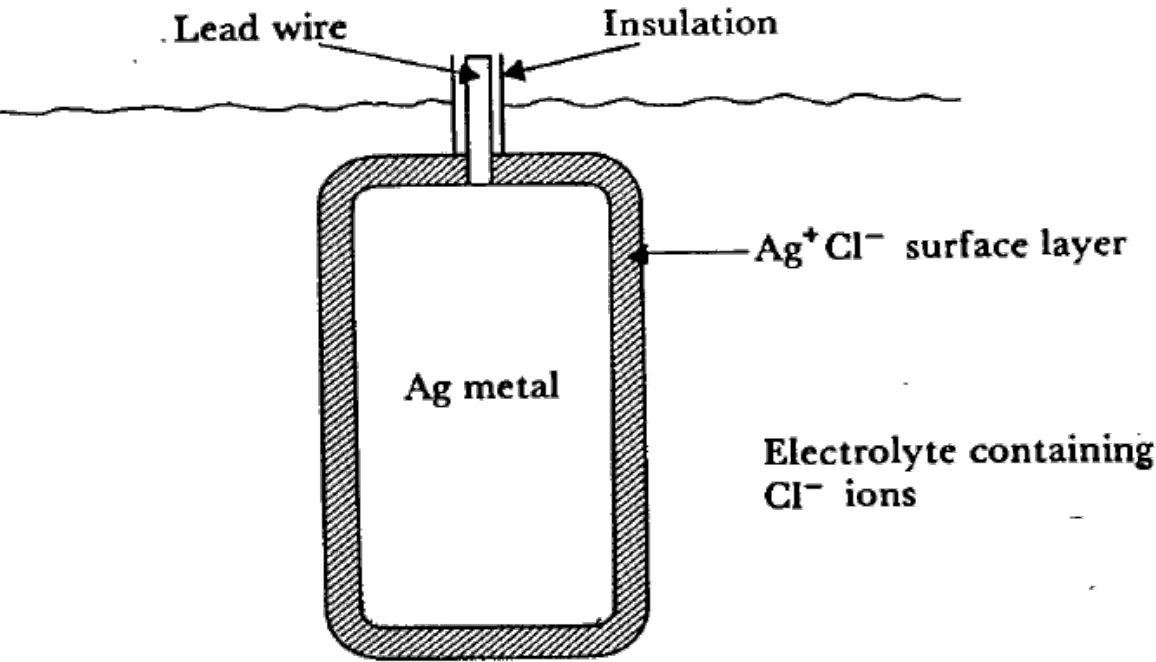## Perfectly Non-Polarizable Electrode
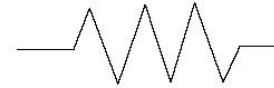
Electrodes in which current passes freely across the electrode-electrolyte interface, requiring no energy to make the transition. These electrodes see no overpotentials. **Example:** Ag/AgCl Electrode

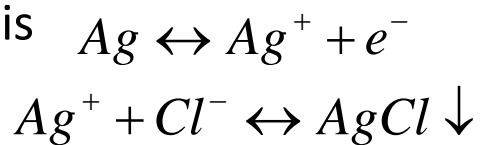Example: Ag-AgCl is used in recording while Pt is used in stimulation

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 solubility product

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

Performance of this electrode

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

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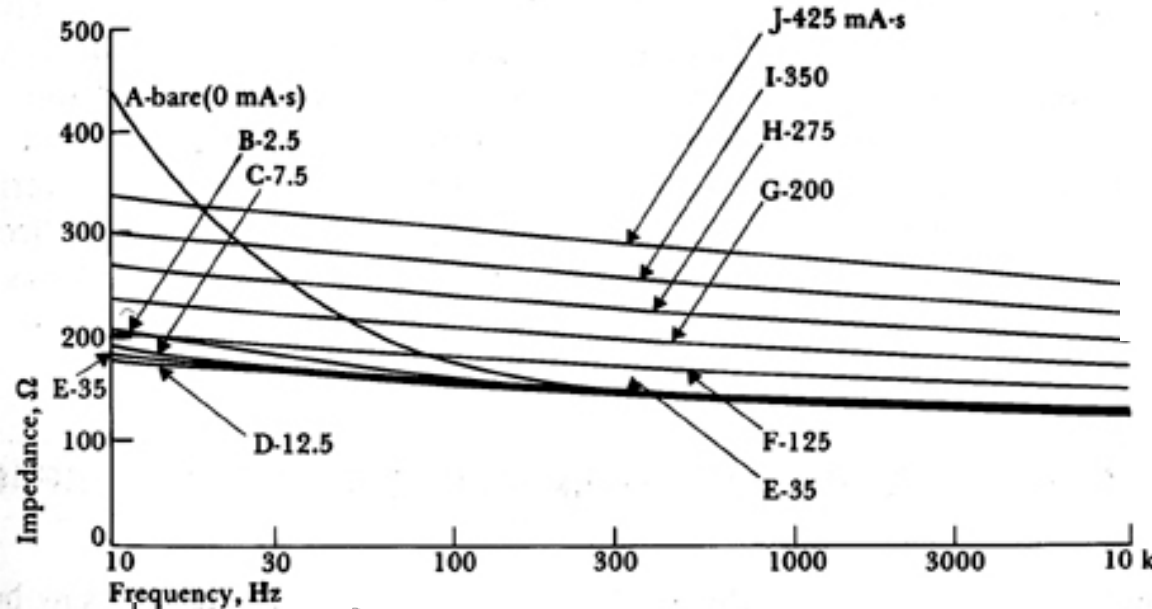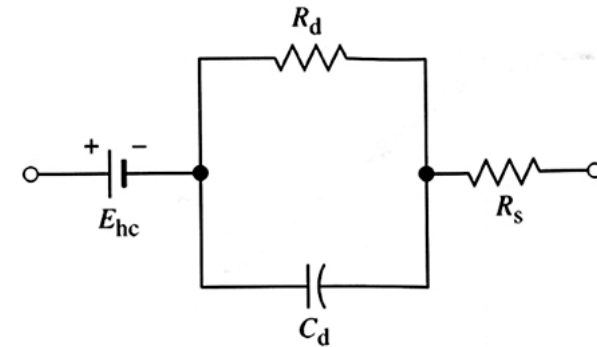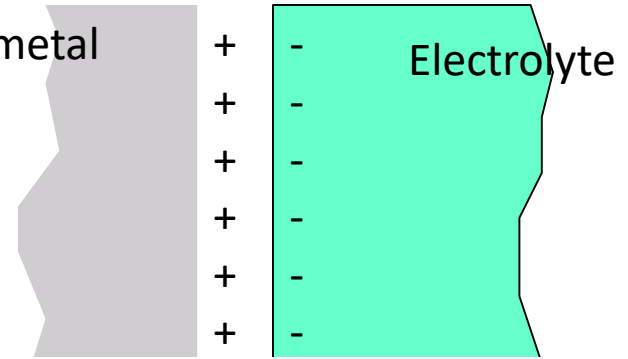
constant

effective

Advantages:

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

–Biocompatible

The characteristic of an electrode is

-Sensitive to current density

- waveform and frequency dependent

metal   +   -   Electrolyte
             +   -
             +   -
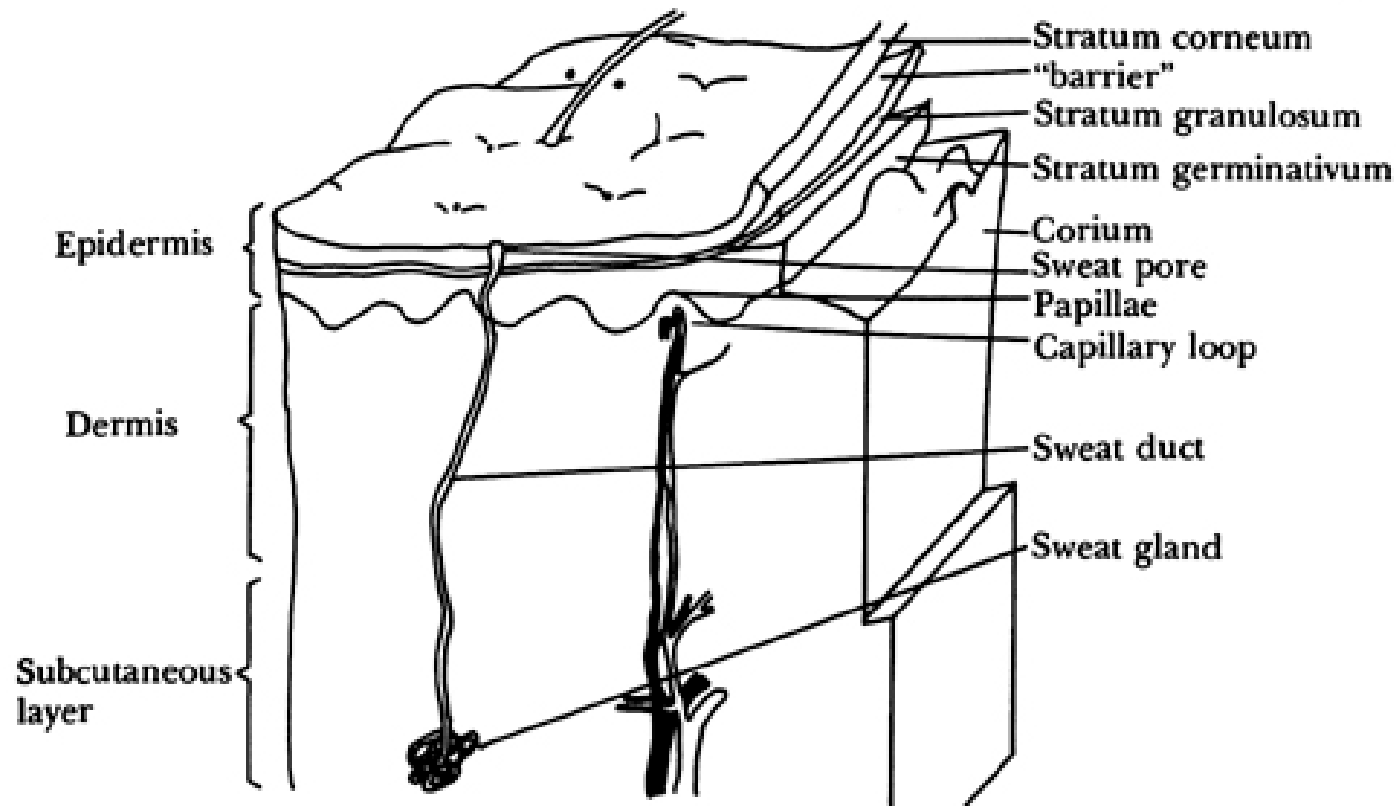   +   -
             +   -
             +   -
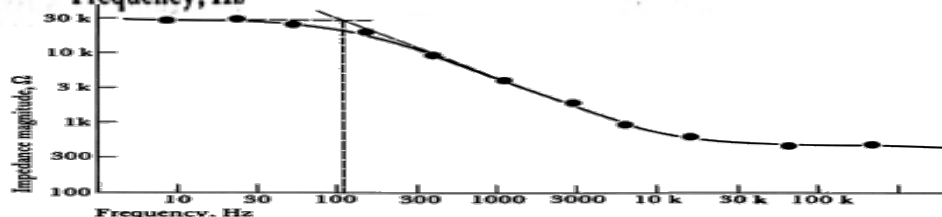
R_d and C_d make up the impedance associated with electrode-electrolyte interface and polarization effects. R_s is associated with interface effects and due to resistance in the electrolyte.
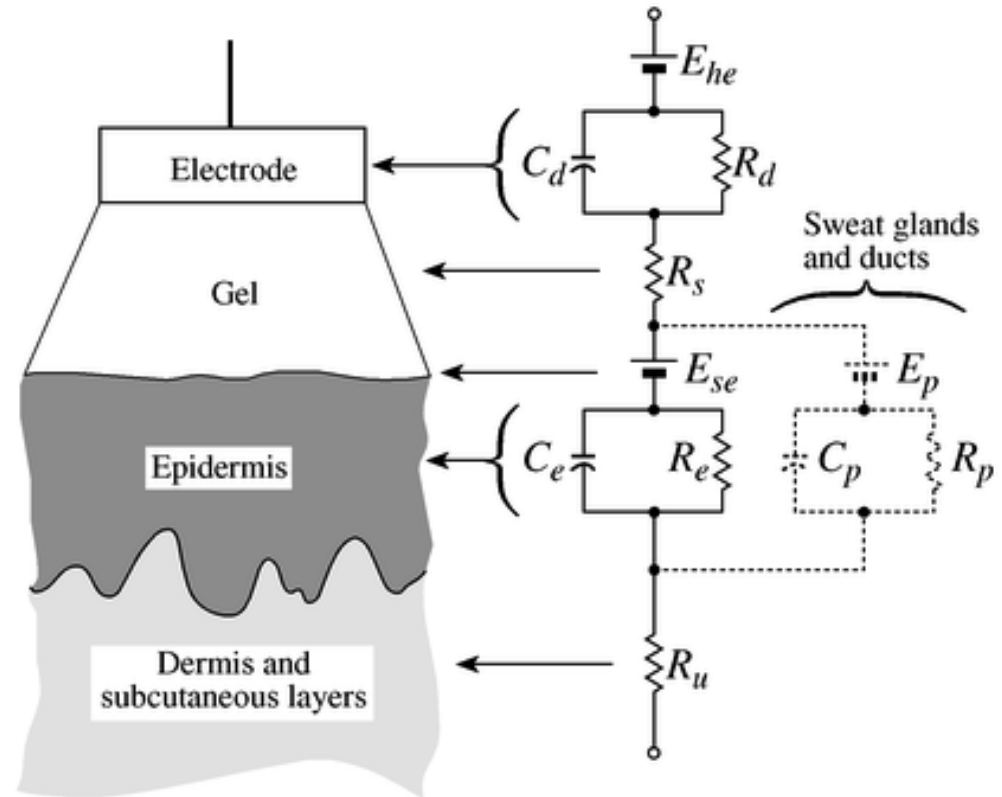
Transparent electrolyte gel containing Cl- is used to maintain good contact between the electrode and the skin.

For 1 cm^2, 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

•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.
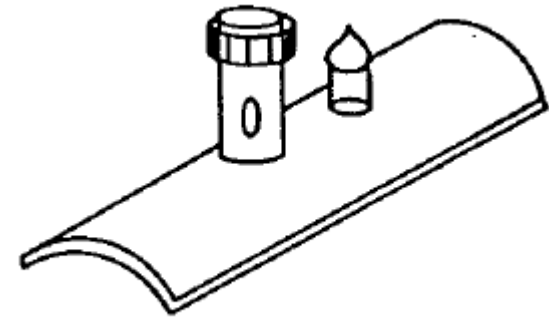
(a)

(b)

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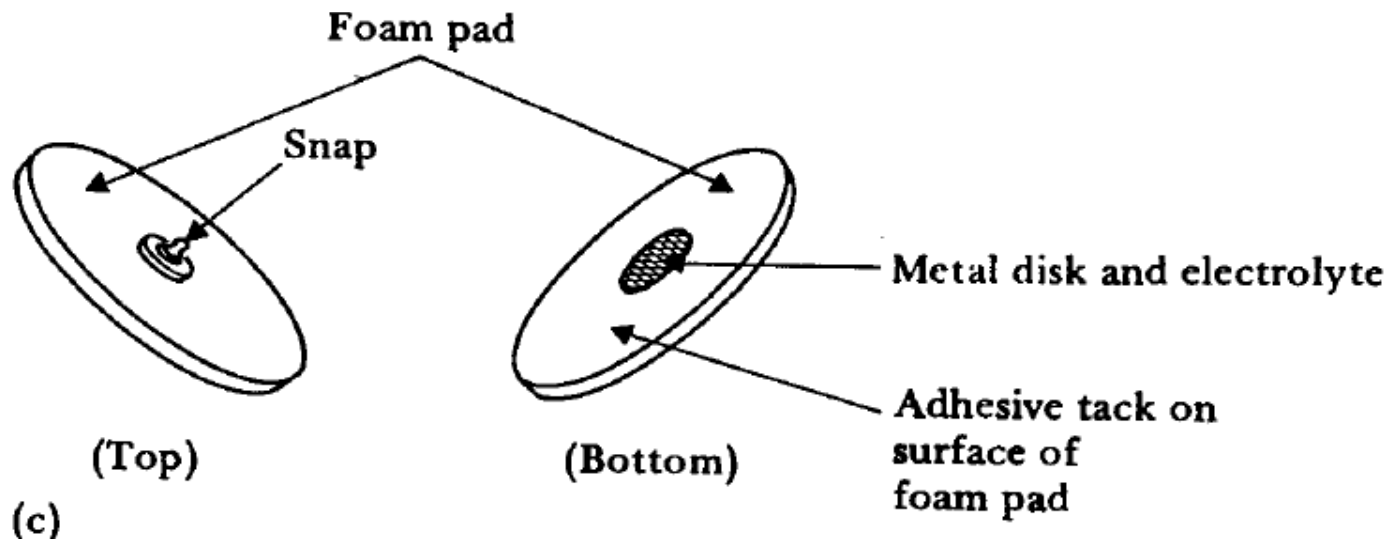
Disposable foam-pad electrodes, often used with electrocardiograph monitoring apparatus.

Rubber bulb

Lead wire terminal

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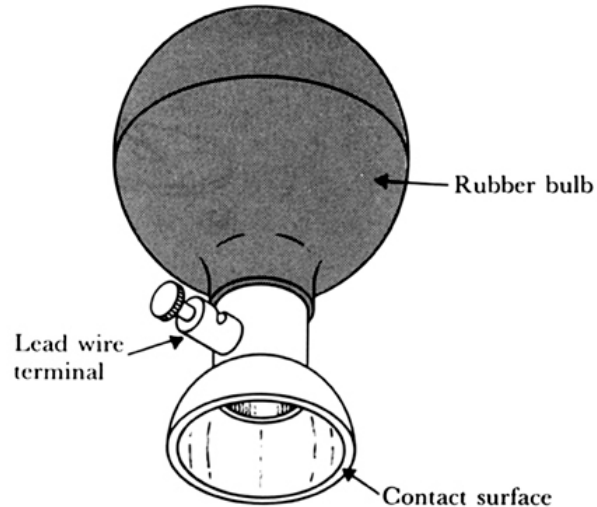
A metallic suction electrode is often used as a precordial electrode on clinical electrocardiographs. **No need for strap or adhesive** and can be **used frequently**. **Higher source impedance** since the contact area is small

- No straps or adhesives required
- Precordial (chest) ECG
- Can only be used for short periods

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 (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)**
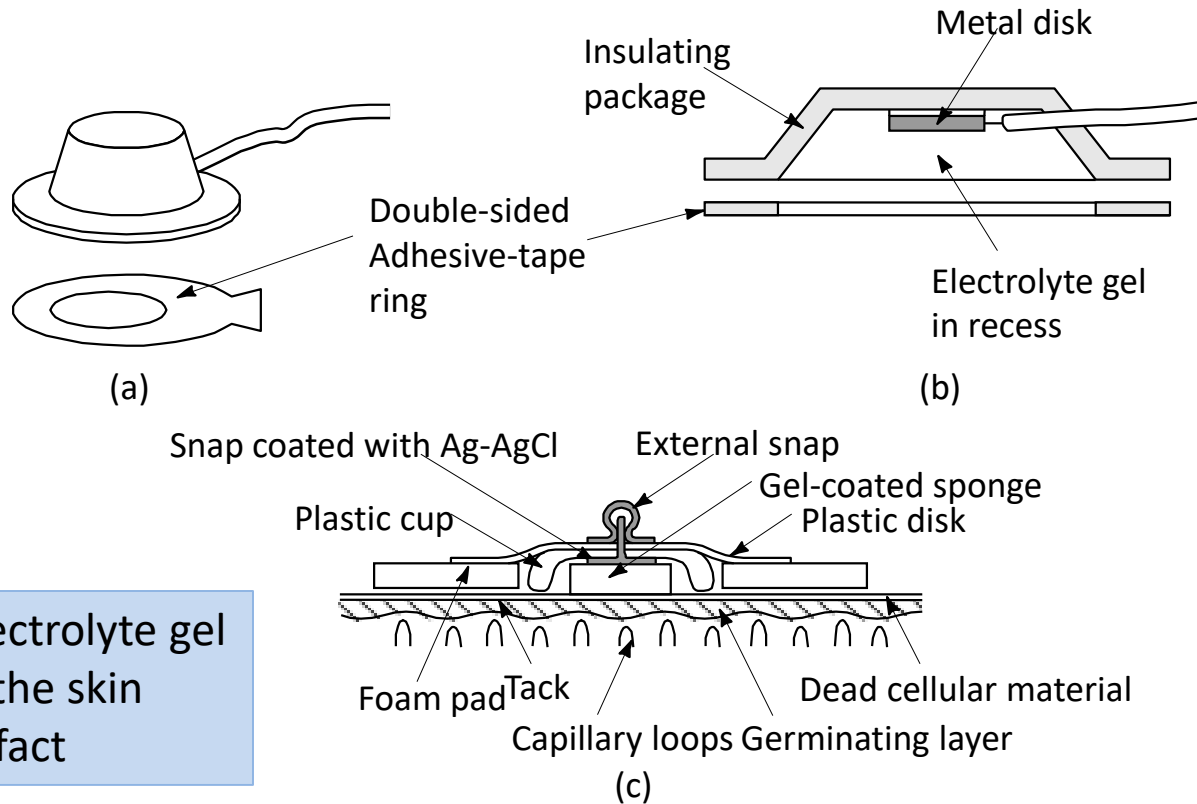
- Swimming in the electrolyte gel
- not in contact with the skin
- Reduce Motion Artifact

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).
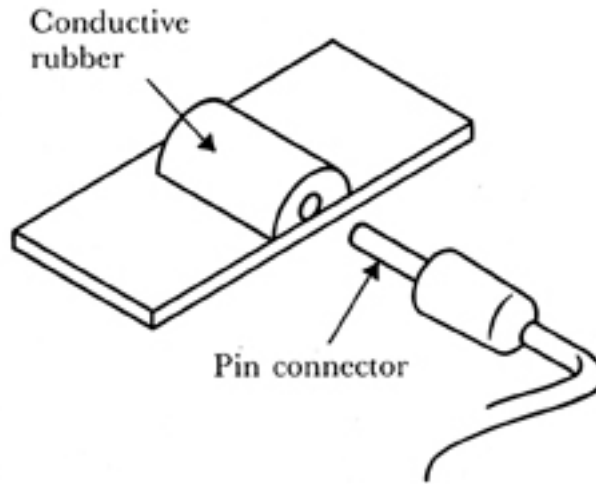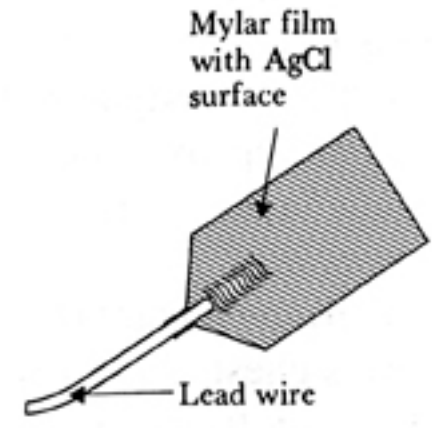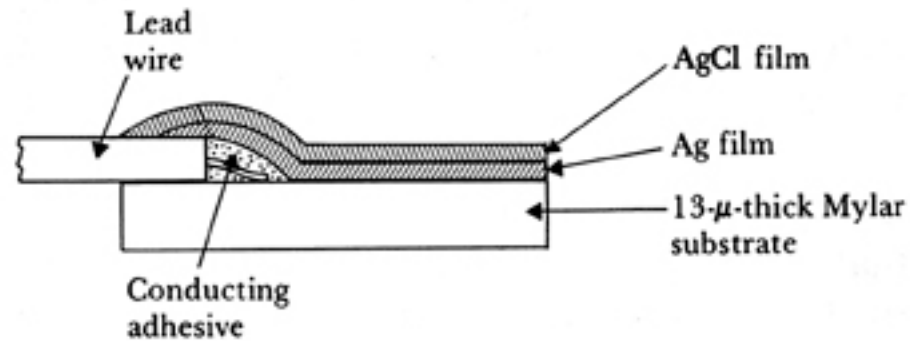
Used for **newborn infants**.
Compatible with X-ray
Electrolyte hydrogel material is used to hold electrodes to the skin.

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.
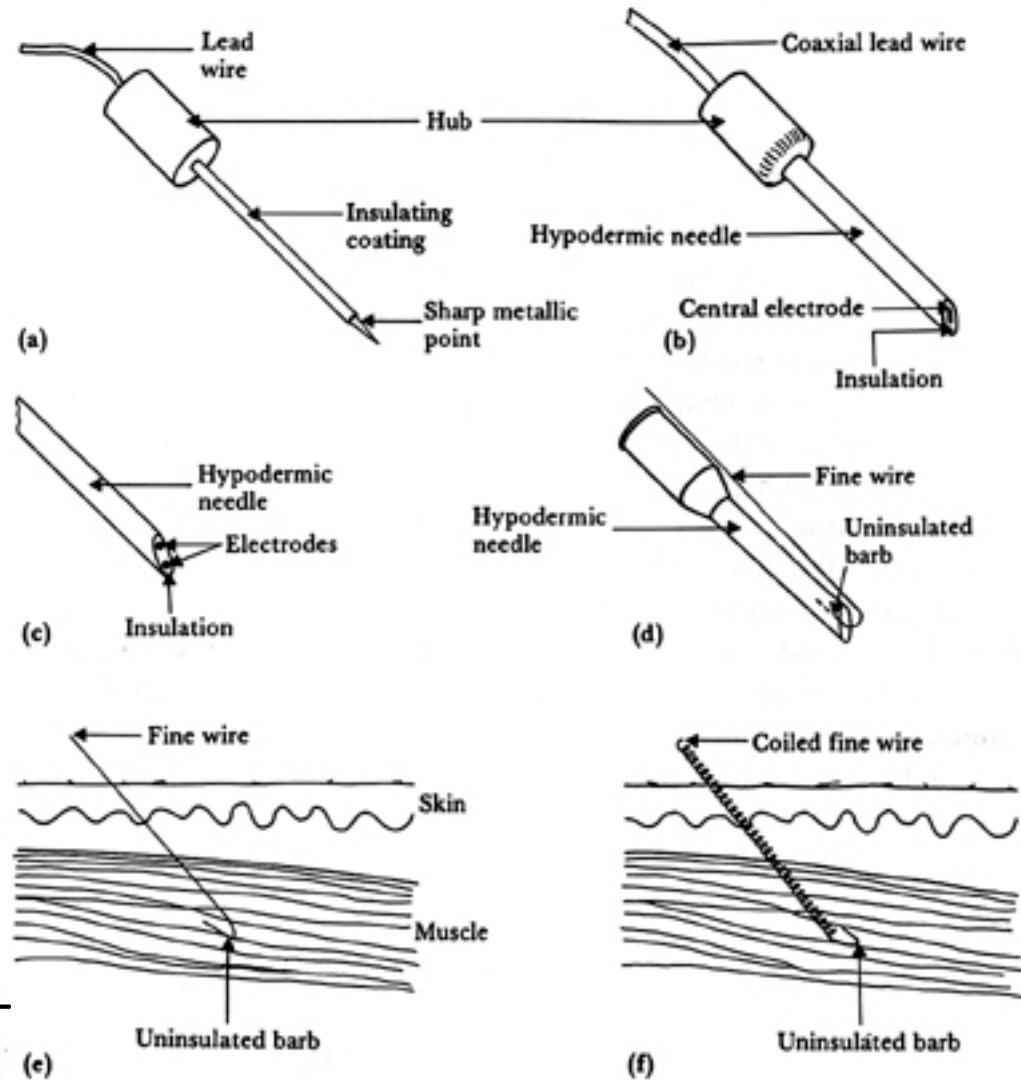
For EMG Recording
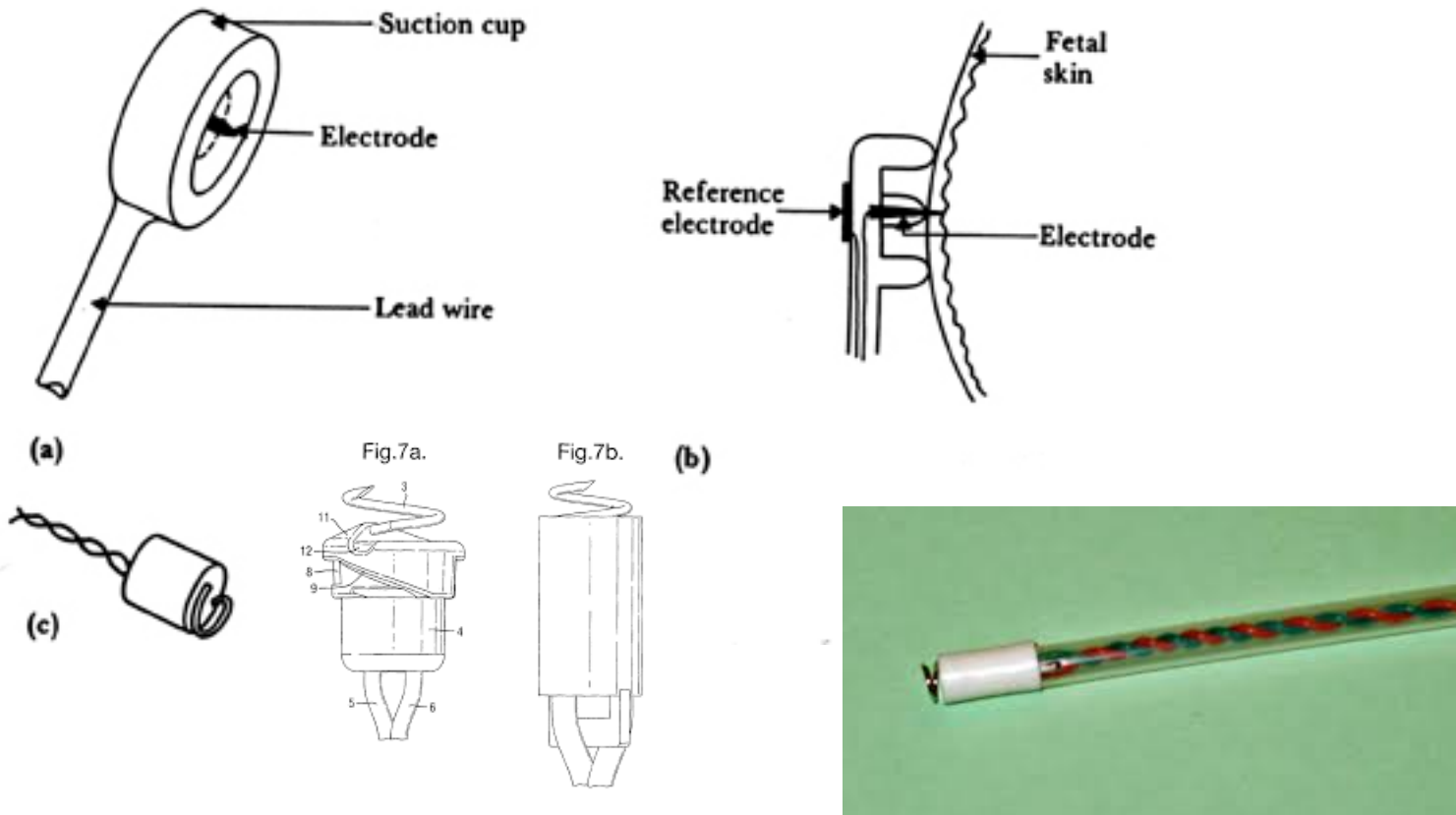
Electrodes for detecting fetal electrocardiogram during labor, by means of intracutaneous needles (a) Suction electrode. (b) Cross-sectional view of suction electrode in place, showing penetration of probe through epidermis. (c) Helical electrode, which is attached to fetal skin by corkscrew type action.
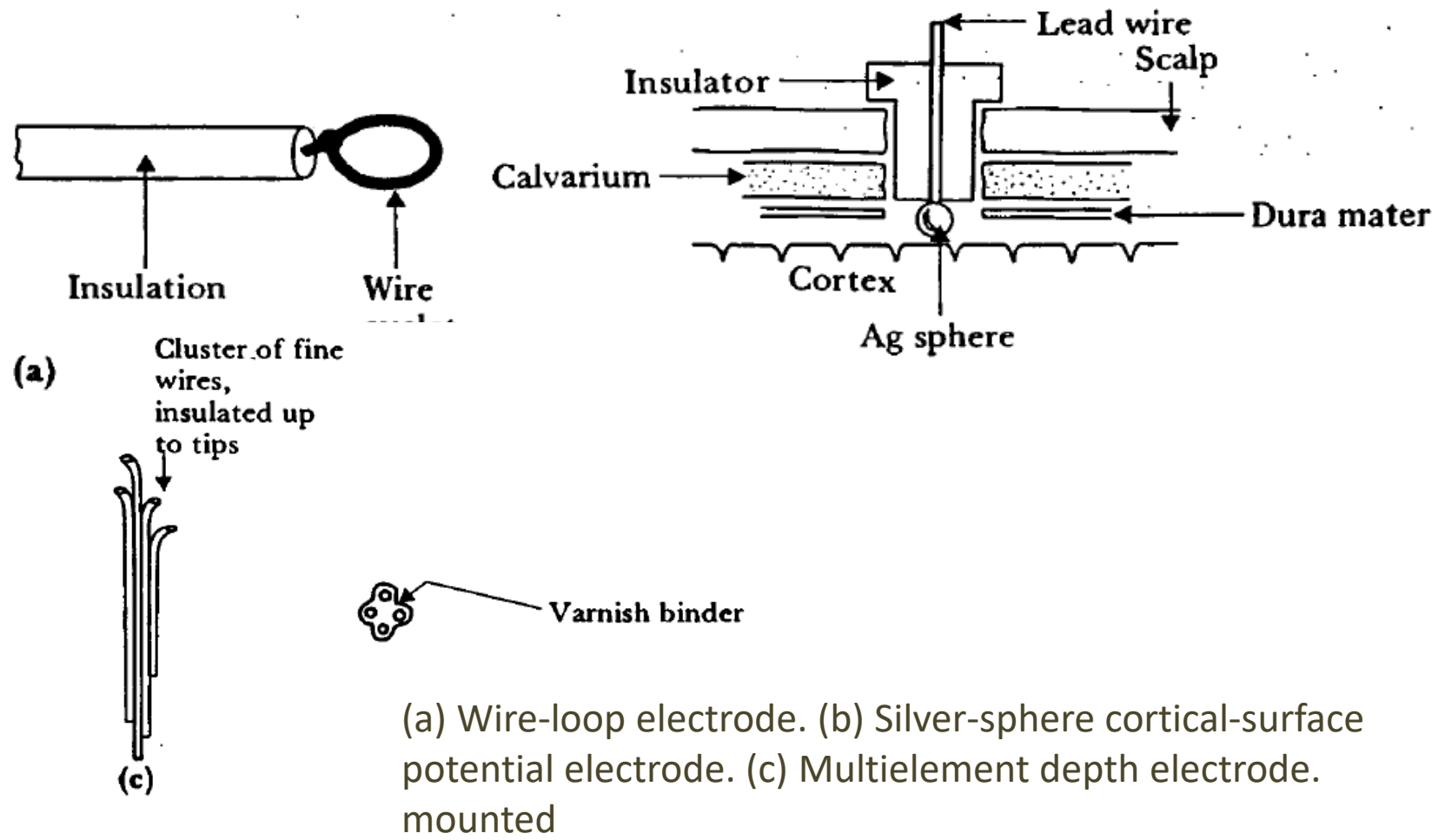
(a) Wire-loop electrode. (b) Silver-sphere cortical-surface potential electrode. (c) Multielement depth electrode. mounted
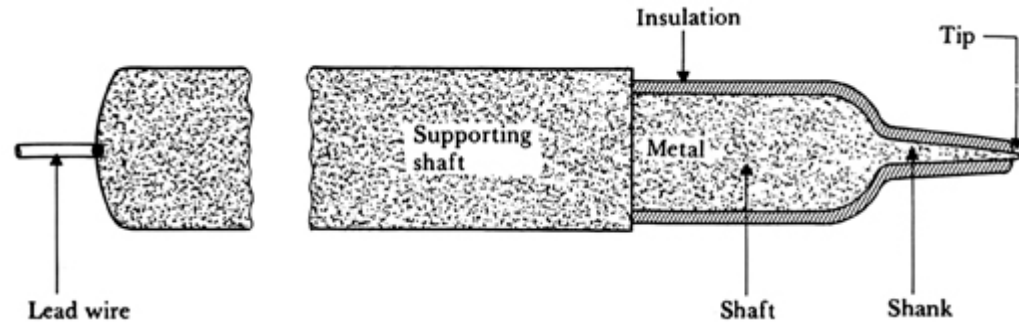
(a) One-dimensional plunge electrode array 10mm long, 0.5mm wide, and 125μm thick, used to measure potential distribution in the beating myocardium

(b) Two-dimensional array, used to map epicardial potential and
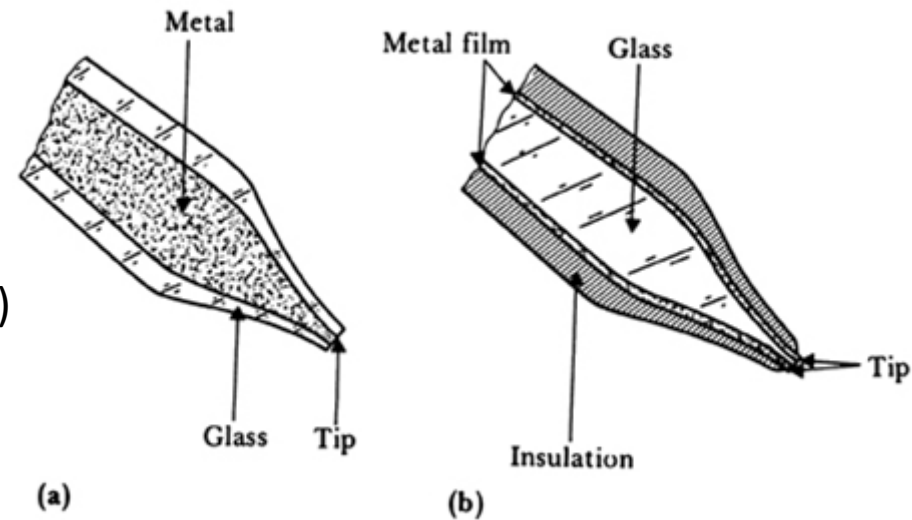
(c) Three-dimensional array, each tine is 1,5 mm
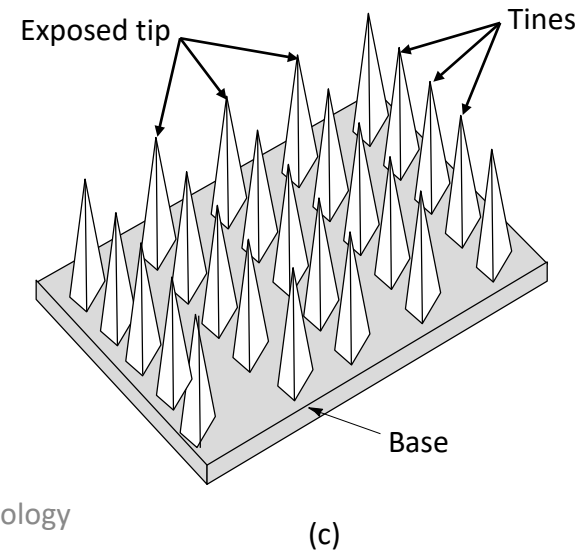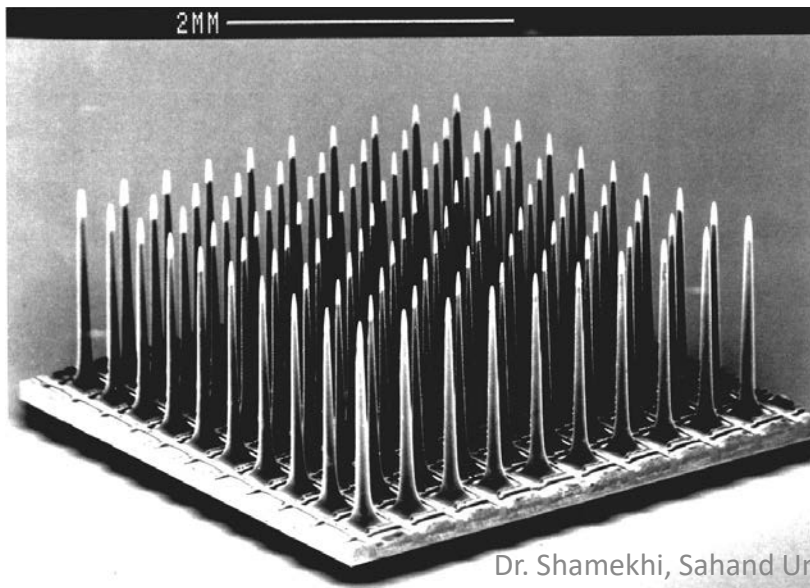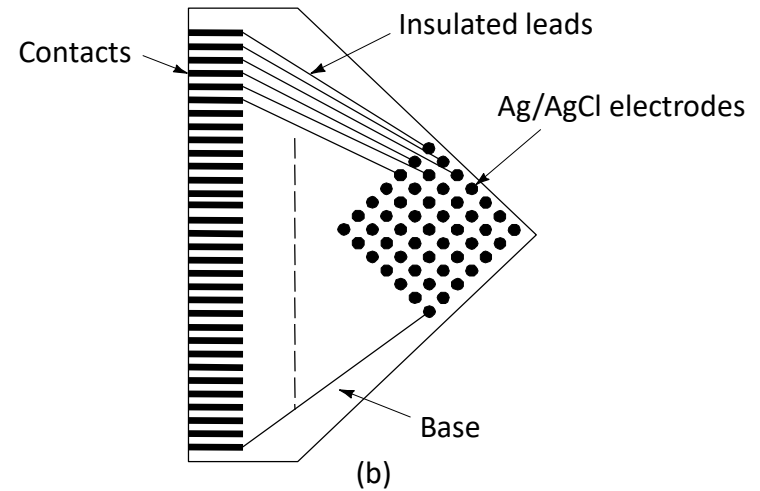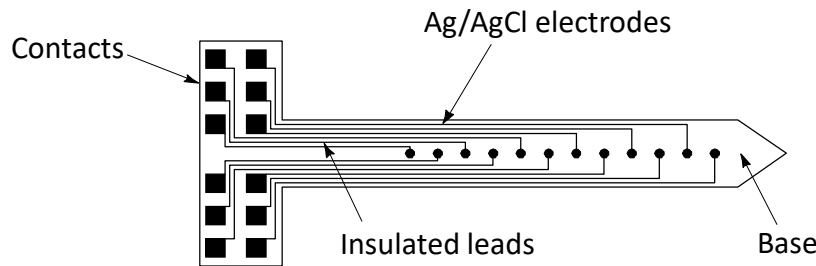
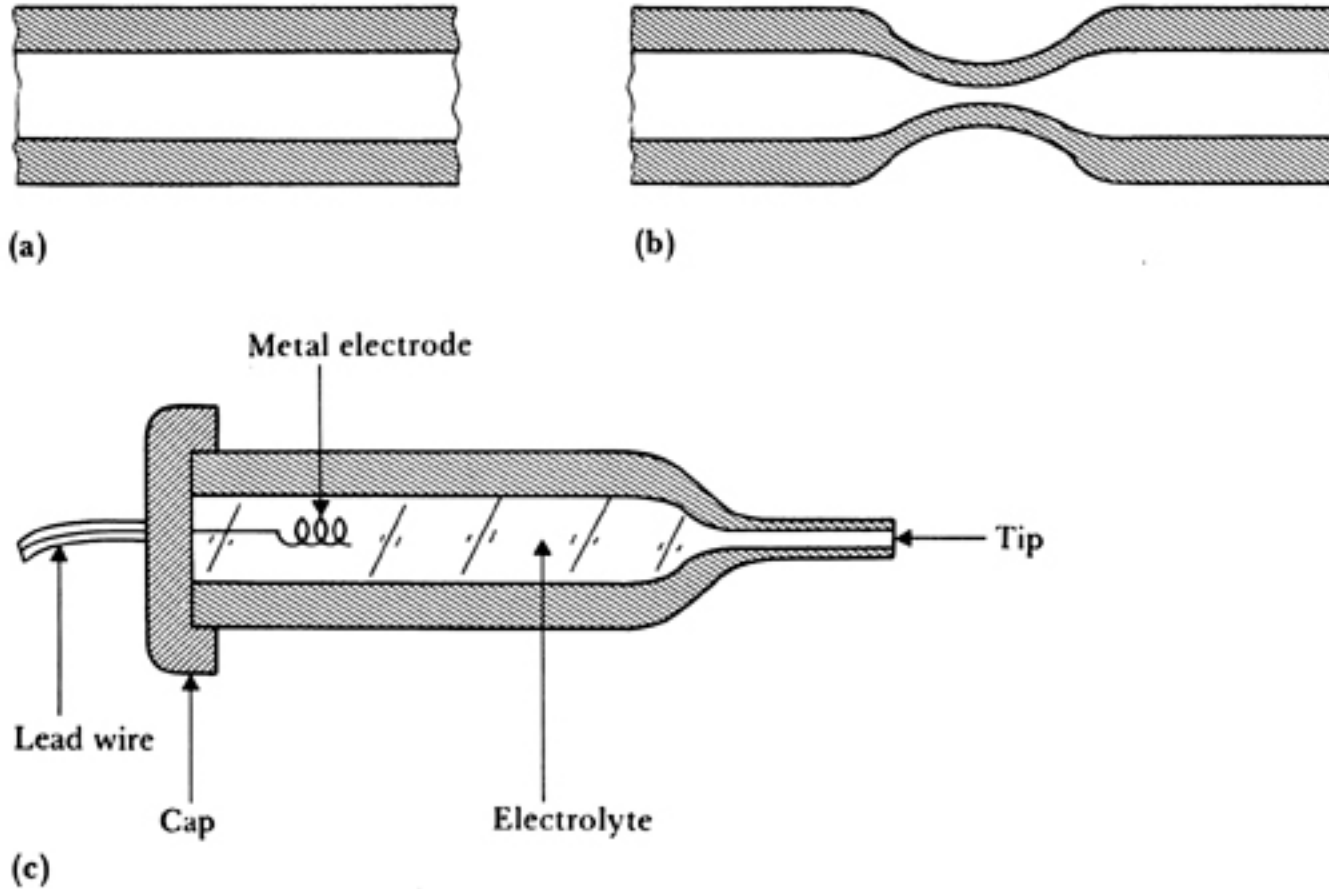The structure of a metal microelectrode for intracellular recordings.

Types

1- Solid metal (Tungsten microelectrodes)

2- Supported metal

(metal contained within/outside glass needle)

3- Glass micropipette

(with Ag-AgCl electrode metal)

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

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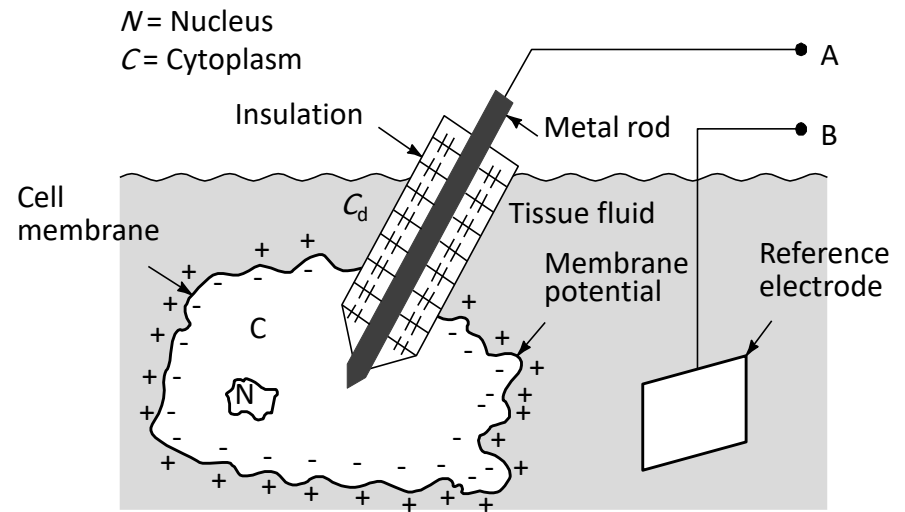
Used in studying the electrophysiology of excitable cells by measure potential differences across the cell membrane.

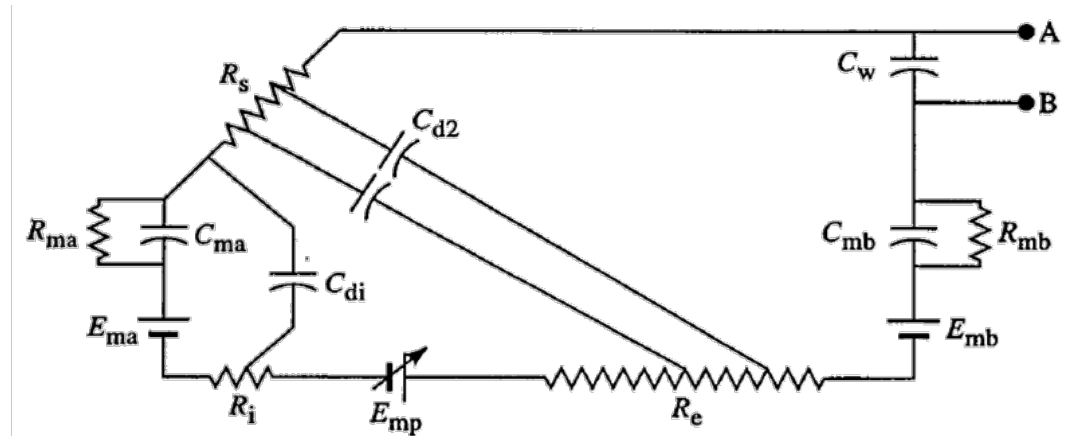Electrode need to be small and strong to penetrate the cell membrane without damaging the cell.
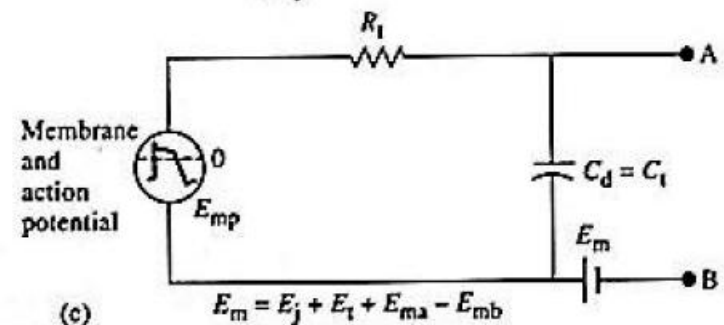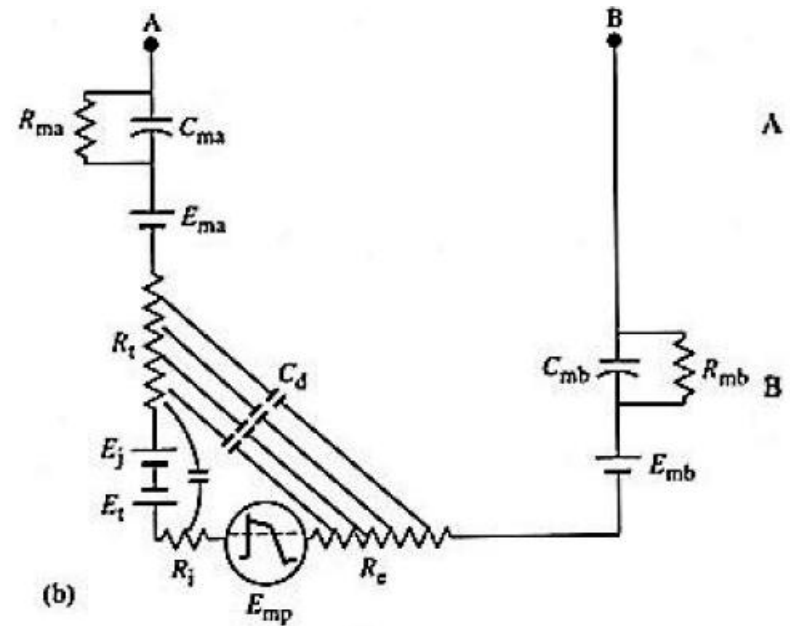
Tip diameters = 0.05 to 10 μm

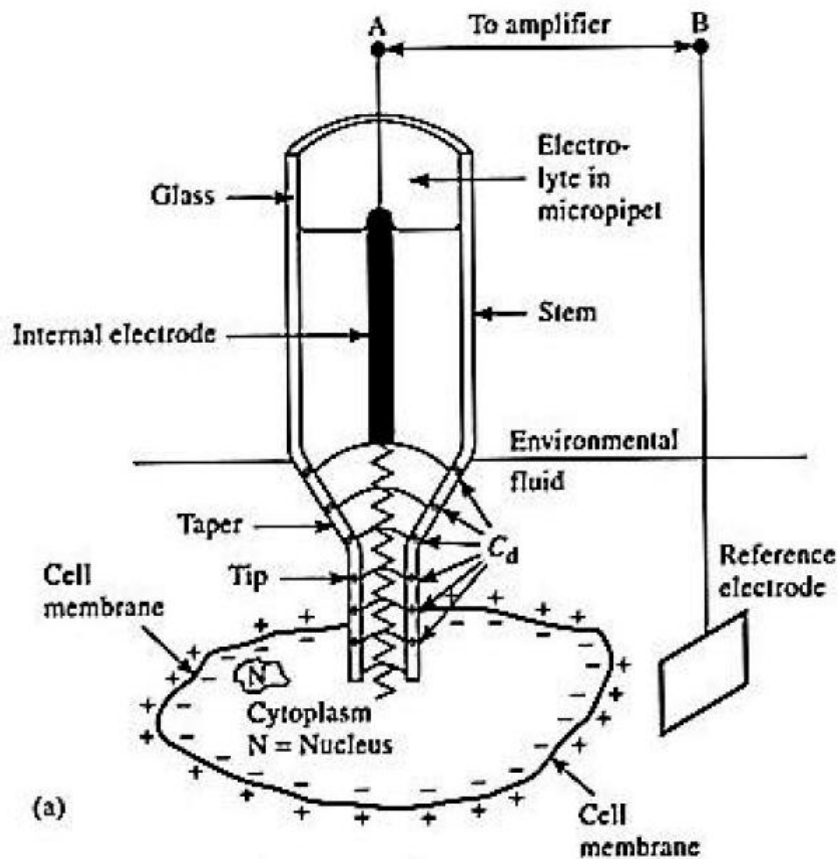

N = Nucleus
C = Cytoplasm
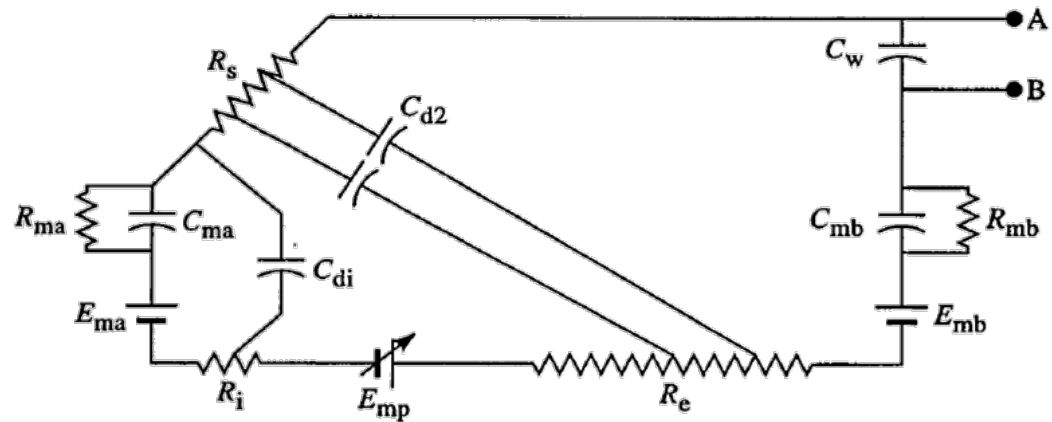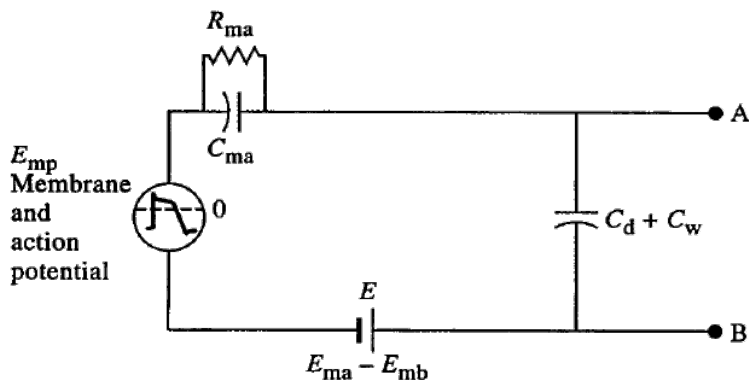
Microelectrodes

- *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

Glass Micropipette Microelectrode

**(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
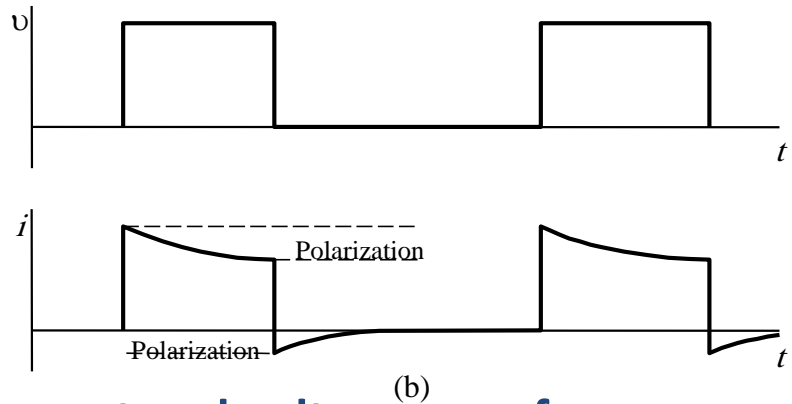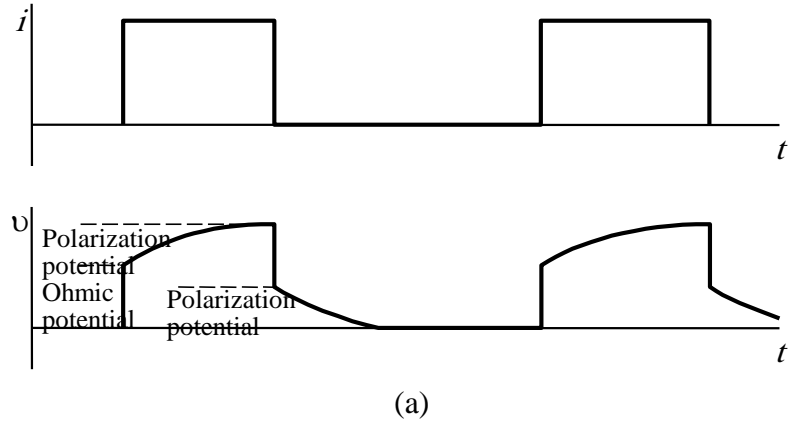
**Current and voltage waveforms seen
with electrodes used for electric
stimulation**
(a) Constant-current stimulation.
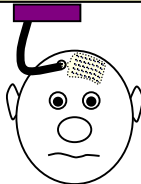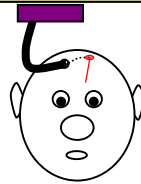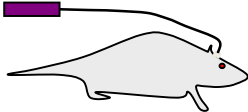(b) Constant-voltage stimulation.
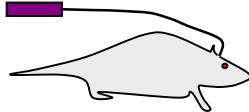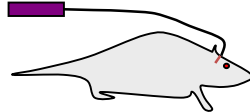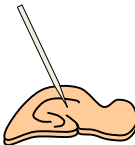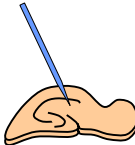
Stimulating Electrodes

Points
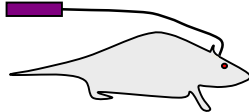
- Cannot be modeled as a series resistance and capacitance (there is no single useful model)
- The body/electrode has a highly nonlinear response to stimulation
- Large currents can cause
  - Cavitation
  - Cell damage
  - Heating

Platinum electrodes:

Applications: neural stimulation
Steel electrodes for pacemakers

Types of neural microsystems applications

	External electrodes	Subdural electrodes	Micro-electrodes	Microsensors	
Human level				–	In vivo applications
Animal level					
Tissue slice level	–	–			In vitro applications
Cellular level	–	–			