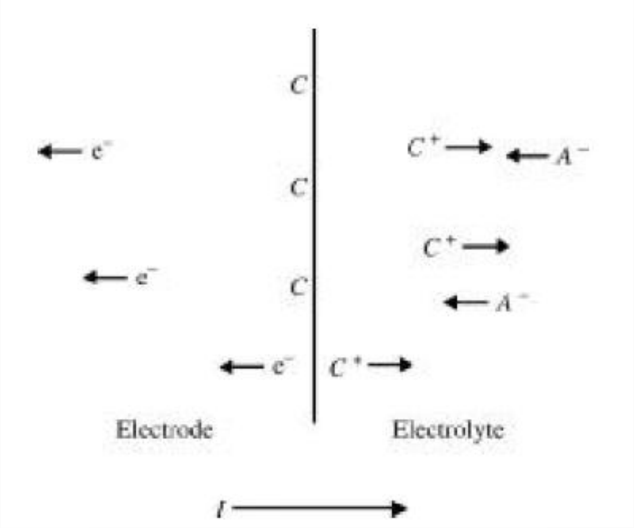
Electrodes for Medical Purposes

Electrodes-Electrolyte Interface

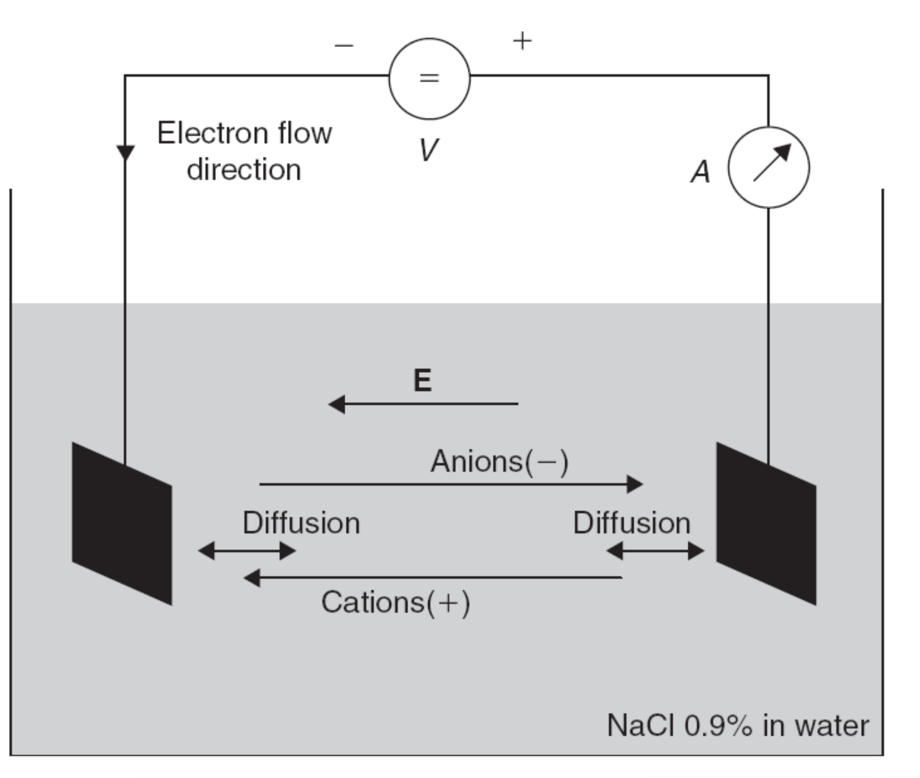
- **Electrode:** A solid electric conductor through which an electric current enters or leaves an electrolytic cell or other medium (Faraday, Michael (1834). "On Electrical Decomposition")



Electrode-electrolyte interface [2]

Electrodes-Electrolyte Interface

General Ionic Equations



a) $C \leftrightarrow C^{n+} + ne^{-}$

b) $A^{m-} \leftrightarrow A + me^{-}$

The basic electrolytic experiment, shown with material transport directions. [5]

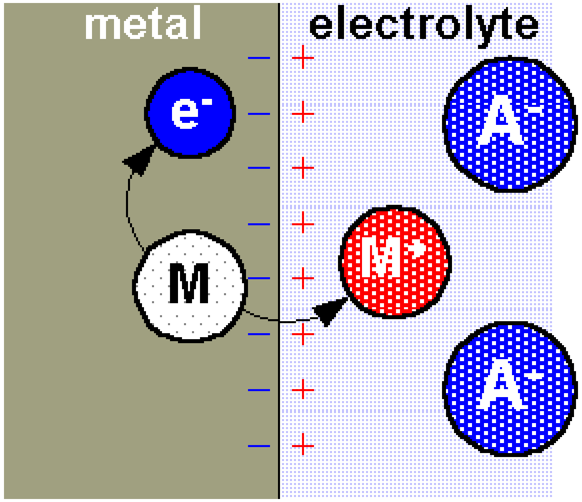
The dominating reaction can be inferred from the following :

- Current flow from electrode to electrolyte : Oxidation (Loss of e-)
- Current flow from electrolyte to electrode : Reduction (Gain of e-)

Electrodes-Electrolyte Interface

Metal cat-ion leaving into the electrolyte

No current flow



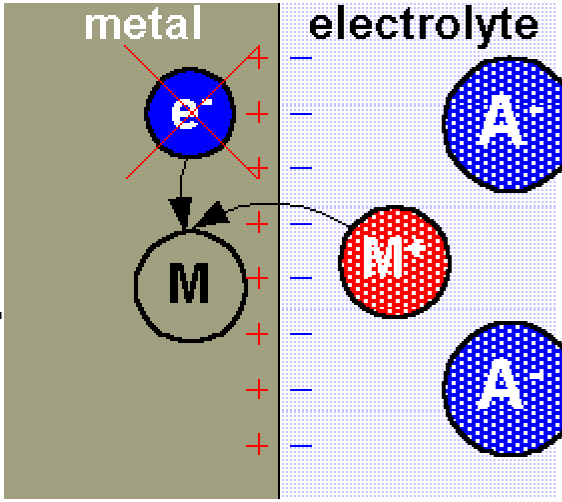
One atom M out of the metal is oxidized to form one cation M^+ and giving off one free electron e^- to the metal.

Electrodes-Electrolyte Interface

Metal cat-ion joining the metal

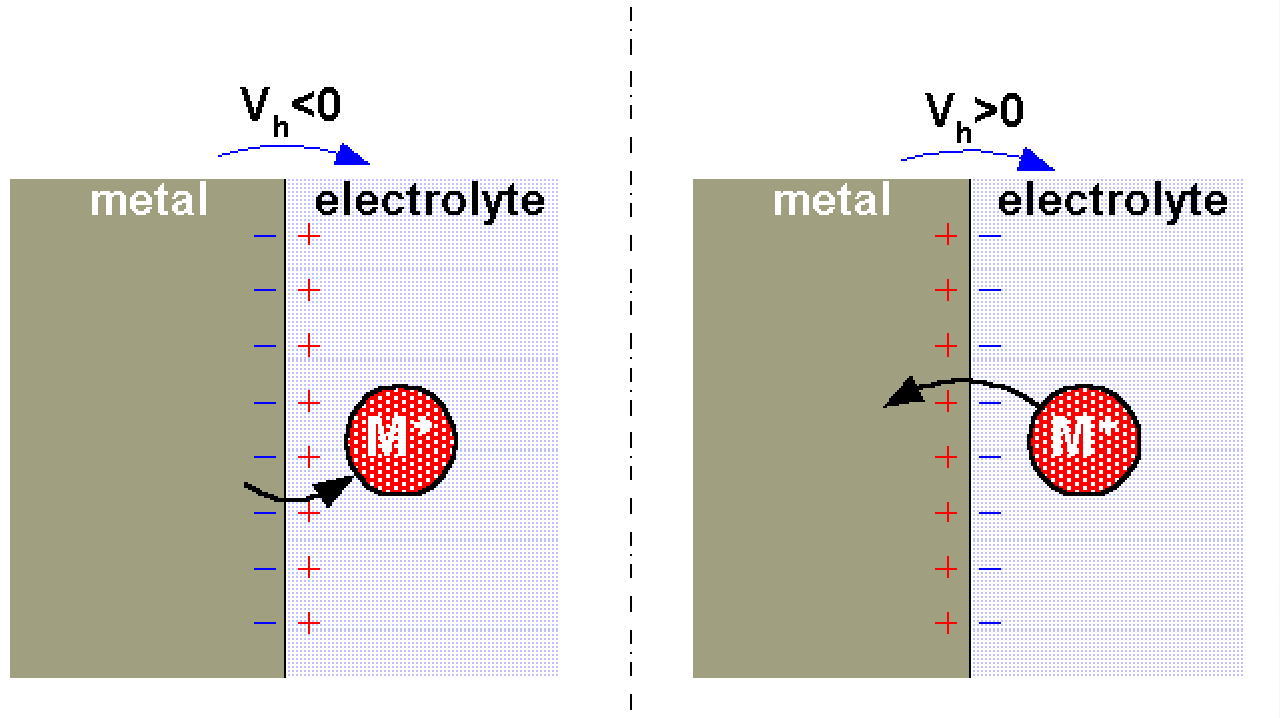
No current flow

One cation M^+ out of the
electrolyte becomes one
neutral atom M taking off
one free electron from the metal.



Half Cell Potential

metal:	Li	Al	Fe	Pb	H	Ag/AgCl	Cu	Ag	Pt	Au
V_h / Volt	*-3,0*		*negativ*		0	*0,223*		*positiv*		*1,68*



Nernst Equation

For arbitrary concentration and temperature

$$E = E_h + (RT/nF) \cdot \ln(a_{red}/a_{ox})$$

E – redox equilibrium electrode potential with no current flow

E_h – Half-cell potential

R = 8.314 J /(mol*K) – molar gas constant

T – absolute temperature

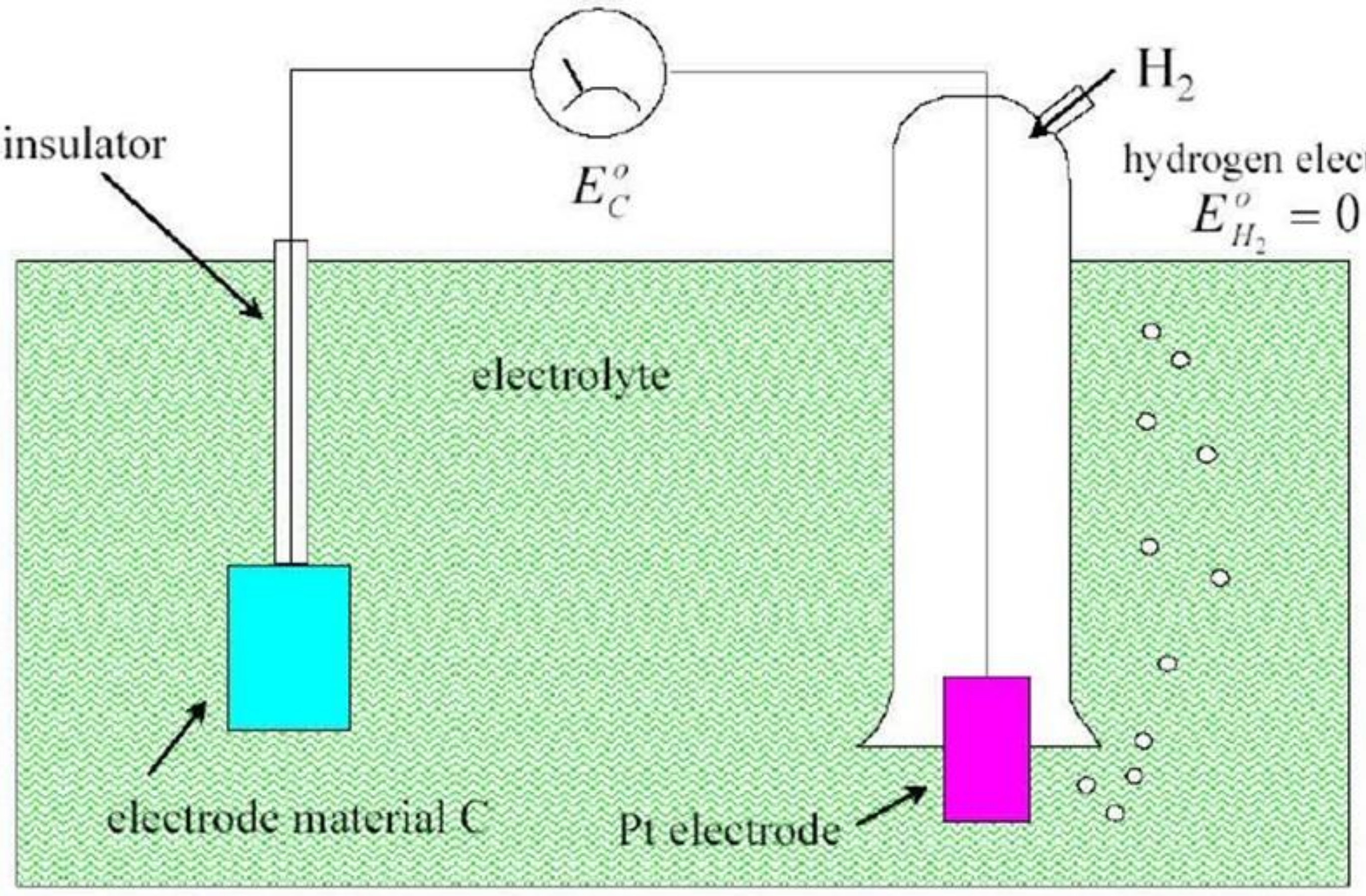
n – valence electrons

F = 96485 C/mol – Faraday's constant

a_{red} – Reduction activity

a_{ox} – Oxidation activity

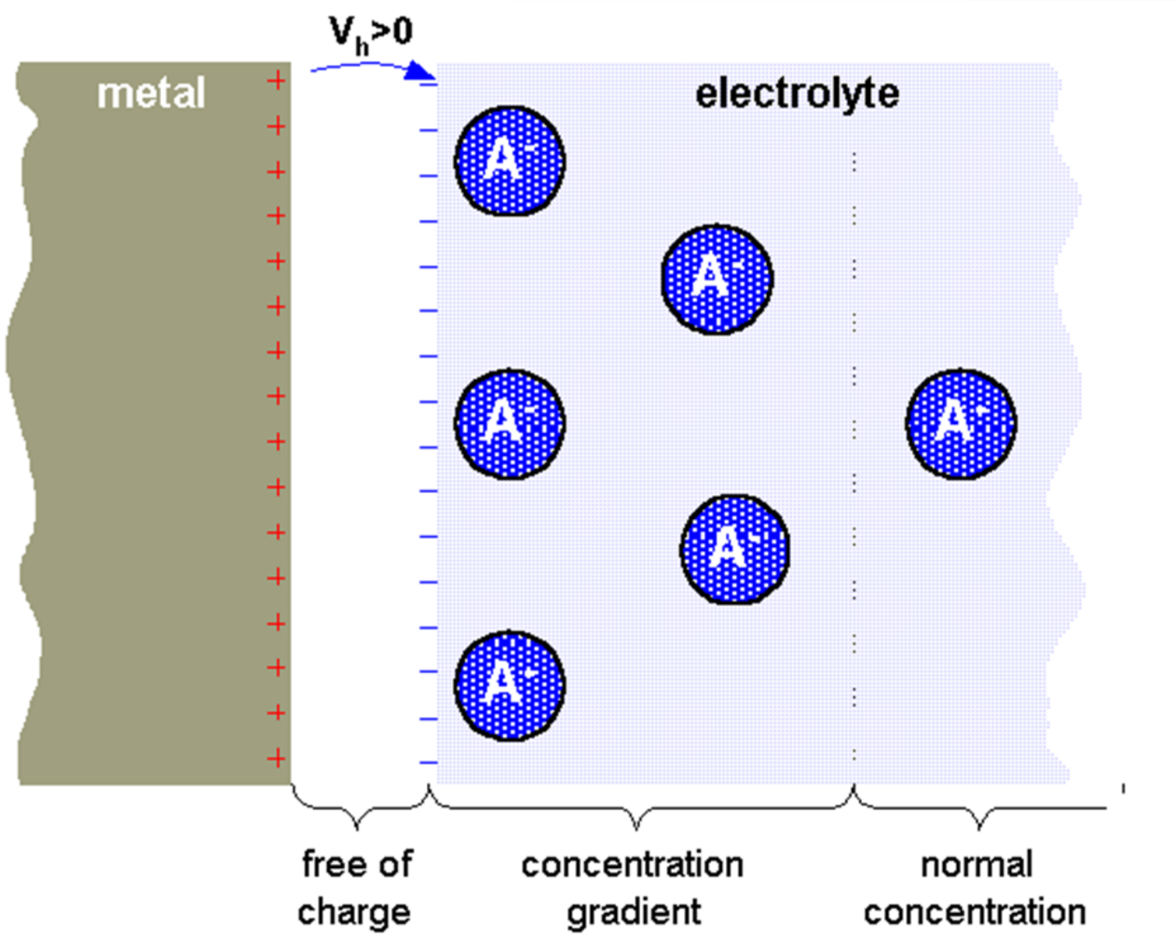
Measuring Half Cell Potential



Note: Electrode material is metal + salt or polymer selective membrane

Electrode double layer

No current flow



Polarization

- **with current** flowing the half-cell voltage changes this voltage change is called **overpotential** or **polarization.**

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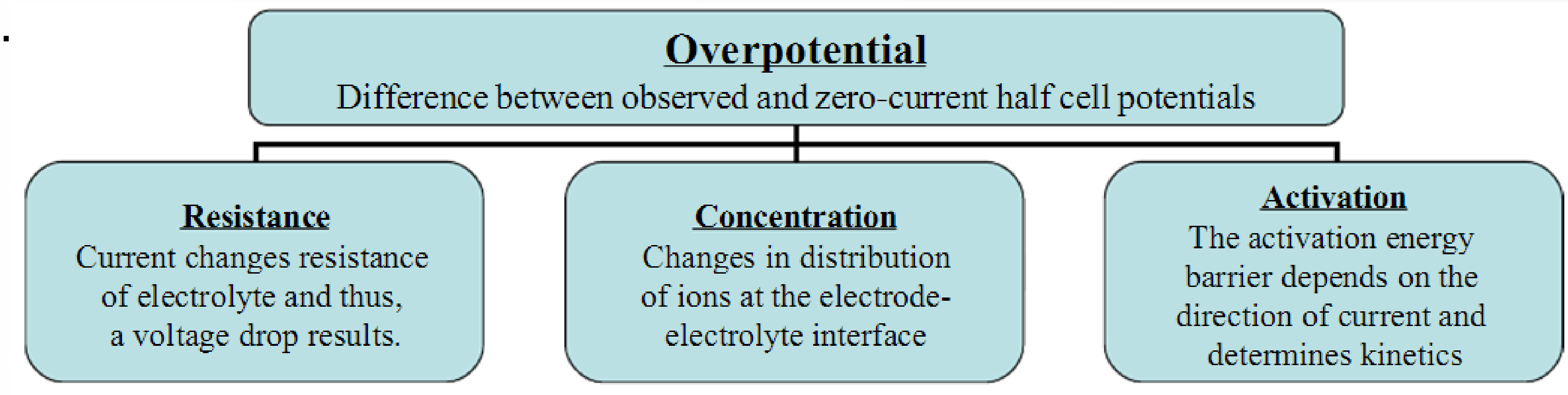


$$V_p = V_r + V_c + V_a$$

- V_a: activation, depends on direction of reaction
- V_c: concentration (change in double layer)
- V_r: ohmic (voltage drop)

Polarizable and Non-Polarizable Electrodes

- **Perfectly Polarizable Electrodes**

The current across the interface is a displacement current and the electrode behaves like a capacitor. No electrodes' ions transfer. Instead, the ions and electrons (of the solution) at the surface of the metal become polarized. The charges orient at the interface to create an electric double layer; the metal then acts like a capacitor.

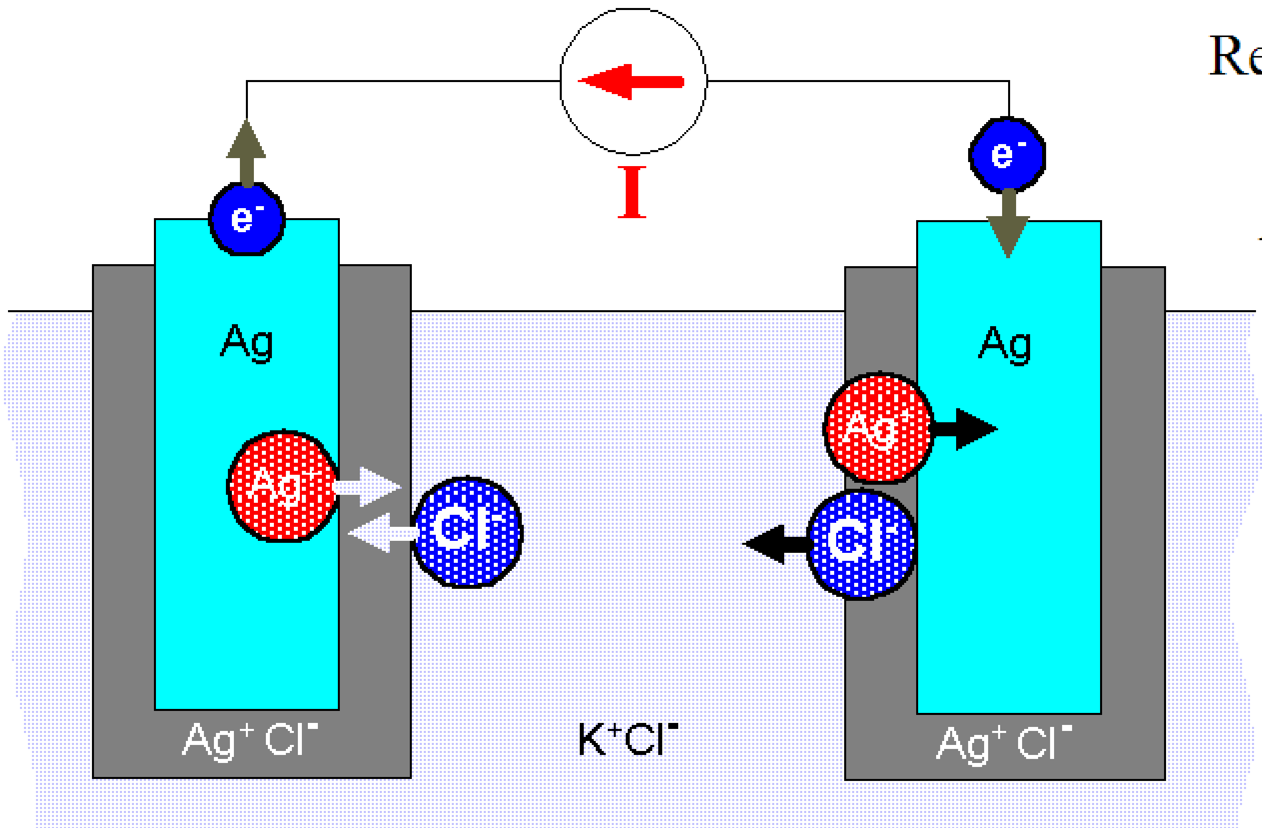
Example : Silver/silver chloride (Ag/AgCl) electrode, Platinum (Pt) electrode, metal electrodes.[5]

- **Perfectly Non-Polarizable Electrode**

Current passes freely across the electrode-electrolyte interface, requiring no energy to make the transition. No overpotentials. Non-polarizable electrodes are reversible (ions in the solution are charged and discharged).

Example: Silver/silver chloride (Ag/AgCl) electrode. Mercury/mercurous chloride (Hg/Hg_2Cl_2) (Calomel).

Ag/AgCl Electrode



Relevant ionic equations

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

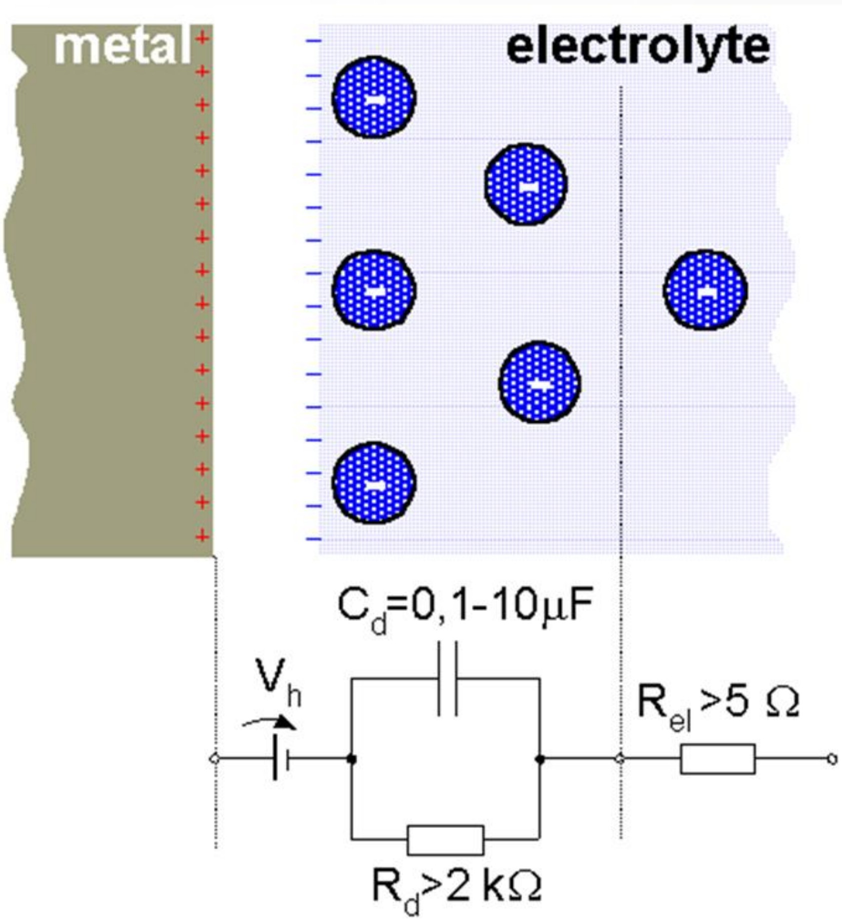
$$Ag^{+} + Cl^{-} \leftrightarrow AgCl \downarrow$$

- Fabrication of Ag/AgCl electrodes

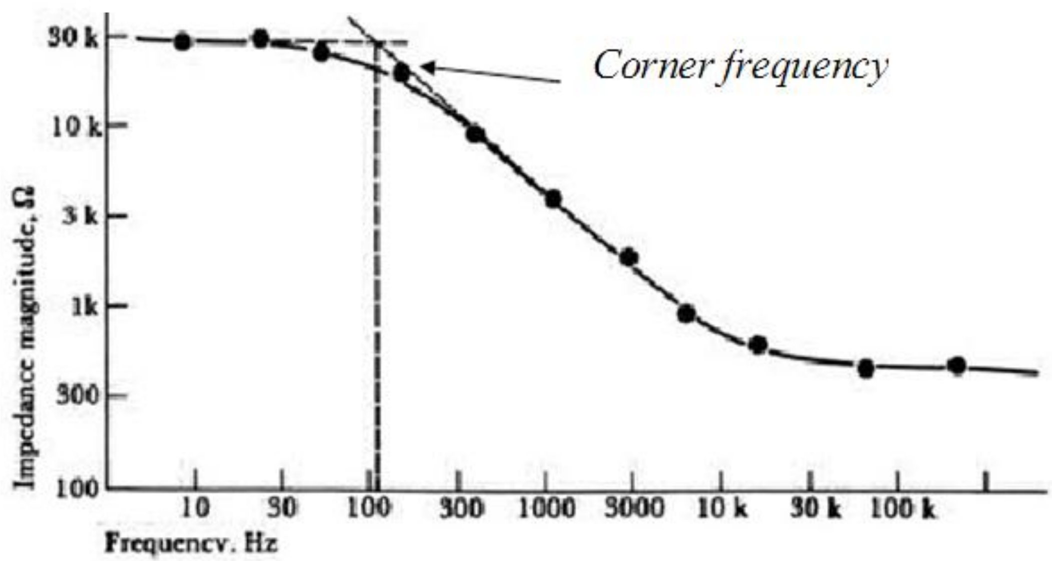
1.Electrolytic deposition of AgCl

2.Sintering process forming pellet electrodes

Equivalent Circuit



C_d : capacitance of electrode-eletrolyte interface
R_d : resistance of electrode-eletrolyte interface
R_{el} : resistance of electrode lead wire
V_h : cell potential for electrode



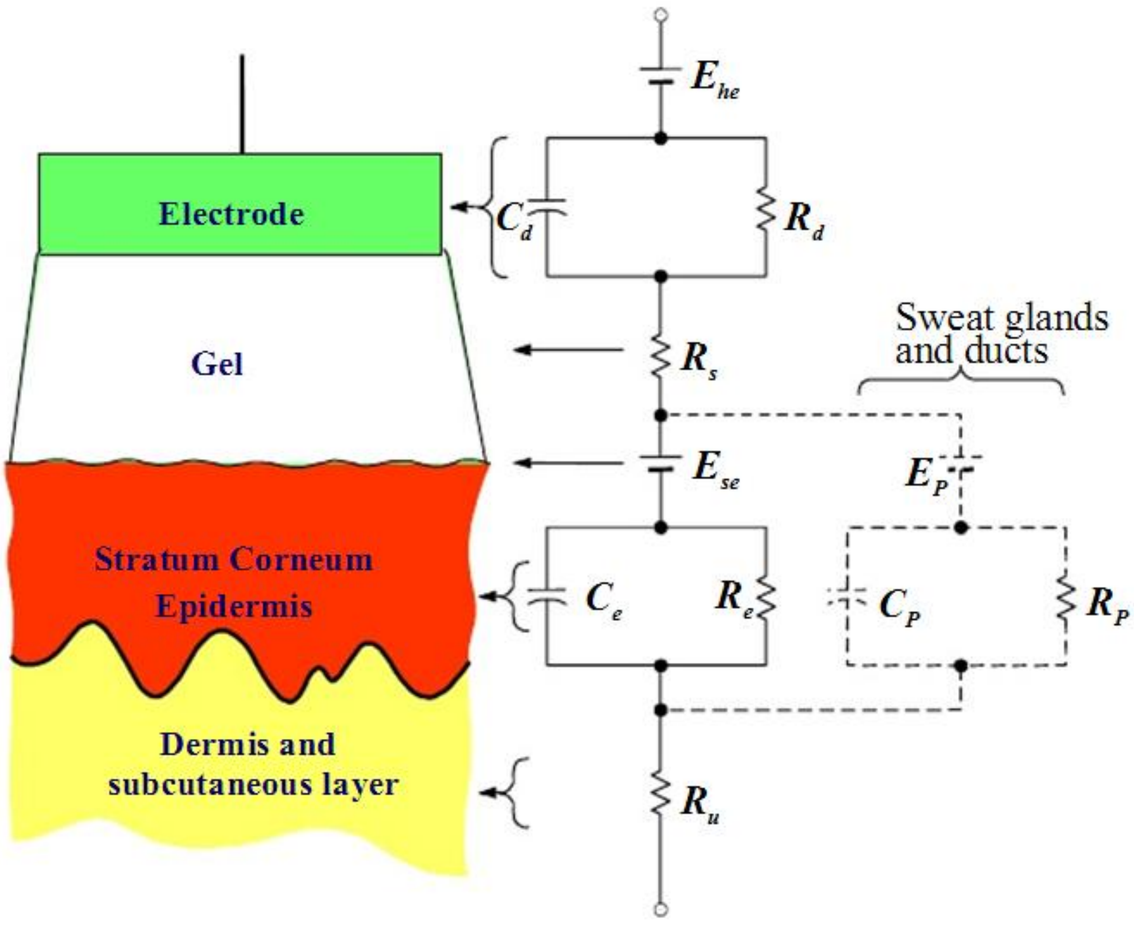
Frequency Response

Examples of Applications

TABLE 48.4 Examples of Applications of Biopotential Electrodes [6]

Application	Biopotential	Type of Electrode
Cardiac monitoring	ECG	Ag/AgCl with sponge
		Ag/AgCl with hydrogel
Infant cardiopulmonary monitoring	ECG impedance	Ag/AgCl with sponge
		Ag/AgCl with hydrogel
		Thin-film
		Filled elastomer dry
Sleep encephalography	EEG	Gold cups
		Ag/AgCl cups
		Active electrodes
Diagnostic muscle activity	EMG	Needle
Cardiac electrograms	Electrogram	Intracardiac probe
Implanted telemetry of biopotentials	ECG	Stainless steel wire loops
	EMG	Platinum disks
Eye movement	EOG	Ag/AgCl with hydrogel

Electrode Skin Interface



- Alternation of skin transport (to deliver drugs through Pores) can be done by laser, ultrasound or by iontophoresis
- Skin impedance for 1cm 2 patch:

200kΩ @1Hz

200 Ω @ 1MHz

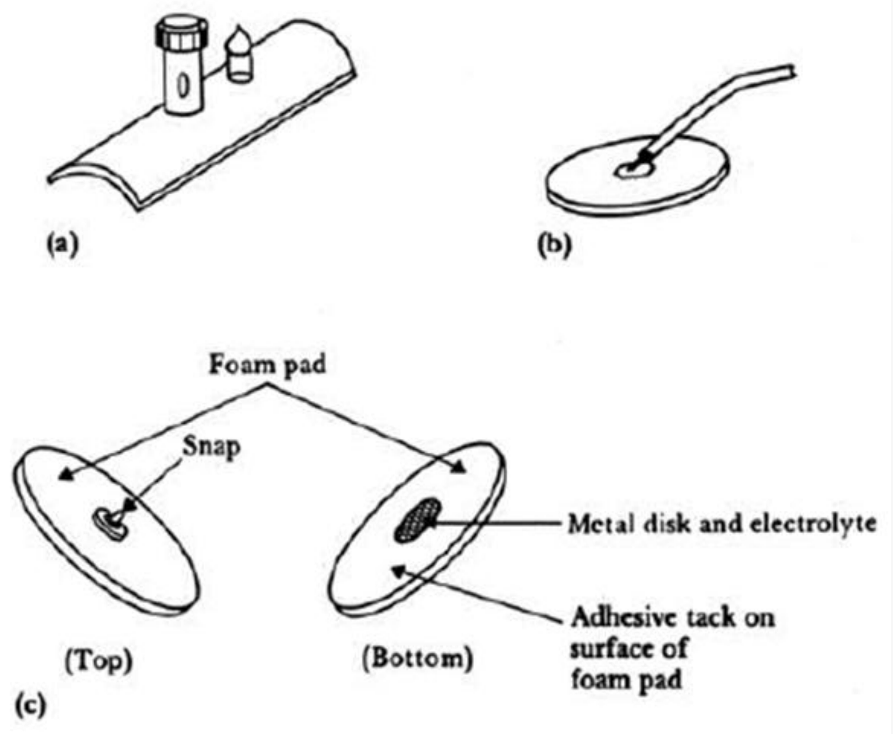
Surface Electrodes

- **Metal plate electrodes**

(a) Metal-plate electrode used for application to limbs. Still use in ECG.

(b) Metal-disk electrode applied with surgical tape. Metal disk with stainless steel; platinum or gold coated EMG, EEG

(c)Disposable foam-pad electrodes, often used with ECG



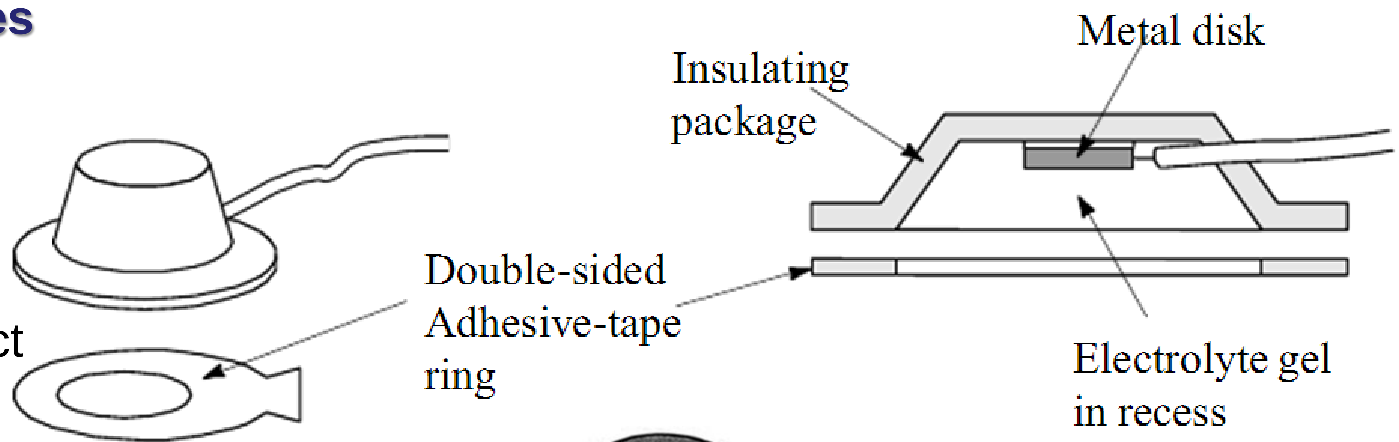
Surface Electrodes

- **Floating electrodes**

-metal disk in the electrolyte gel

-not in contact with the skin

-reduces motion artifact

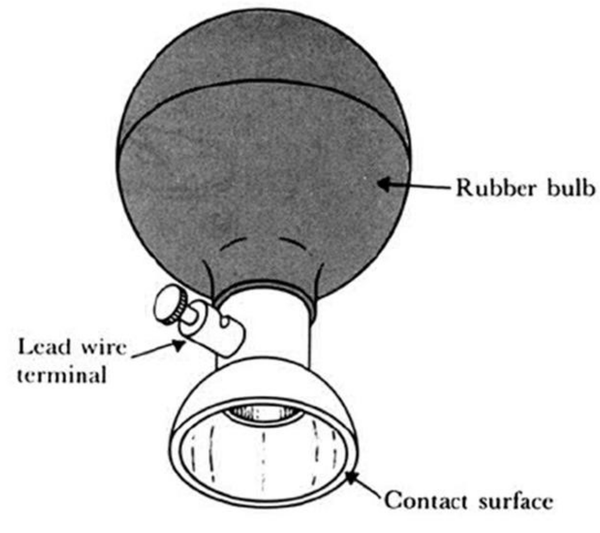


- **Suction electrodes**

-No straps or adhesives required

-precordial (chest) ECG

-can only be used for short periods



Suction Electrode

Surface Electrodes

- **Flexible electrodes**

-Body contours are often irregular

-Regularly shaped rigid electrodes may not always work.

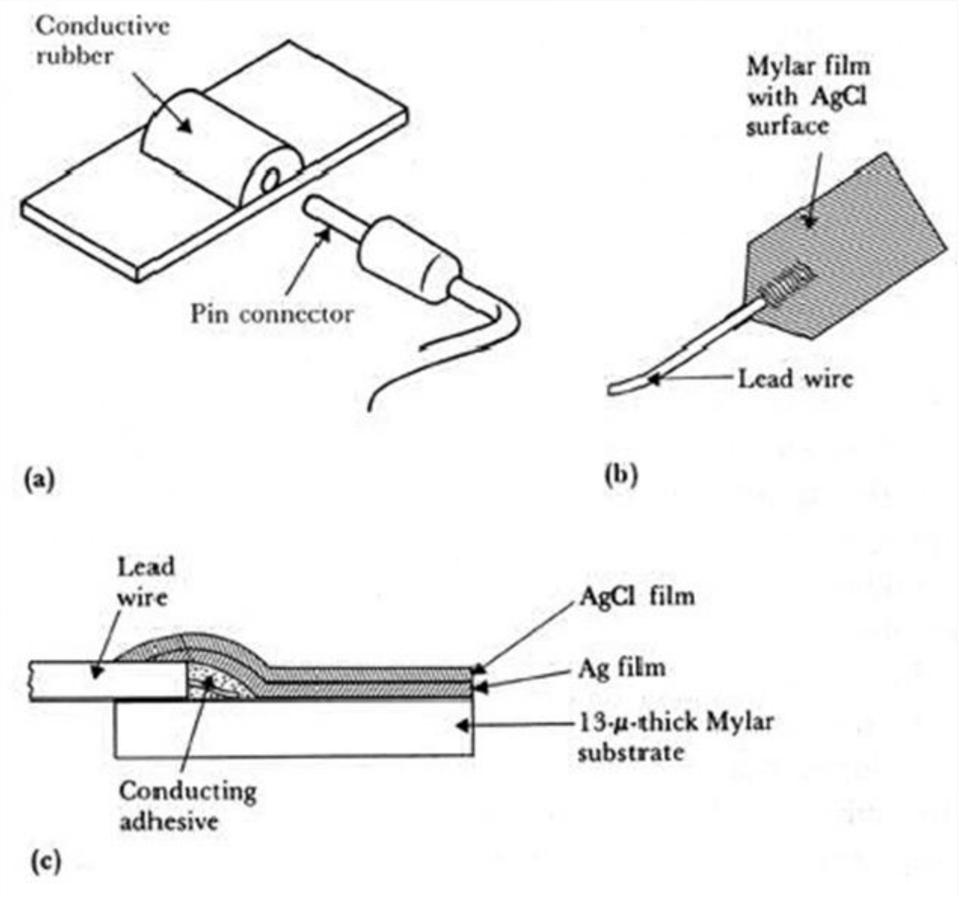
-Special case : infants

-Material : Polymer or nylon with silver, Carbon filled silicon rubber (Mylar film)

(a) Carbon-filled silicone rubber electrode.

(b) Flexible thin-film neonatal electrode.

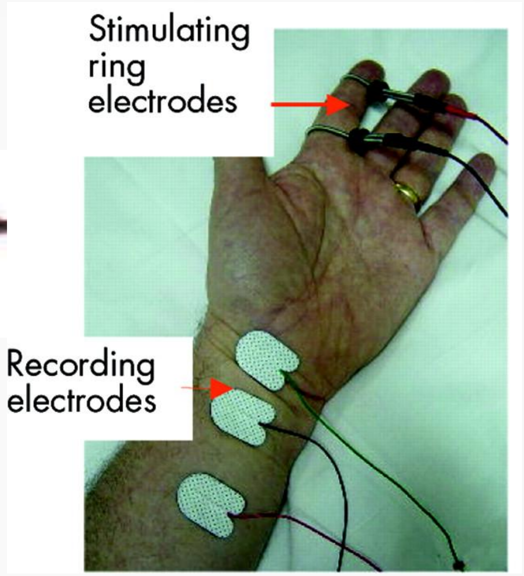
(c) Cross-sectional view of the thin-film electrode in (b).



Surface Electrodes (EMG)

- **Clips electrodes**

- **Ring electrodes**



- **Bipolar Felt Pad Stimulator/Electrode**

- **Bar electrodes**

Internal Electrodes

- **Needle and wire electrodes**

for percutaneous measurement of biopotentials

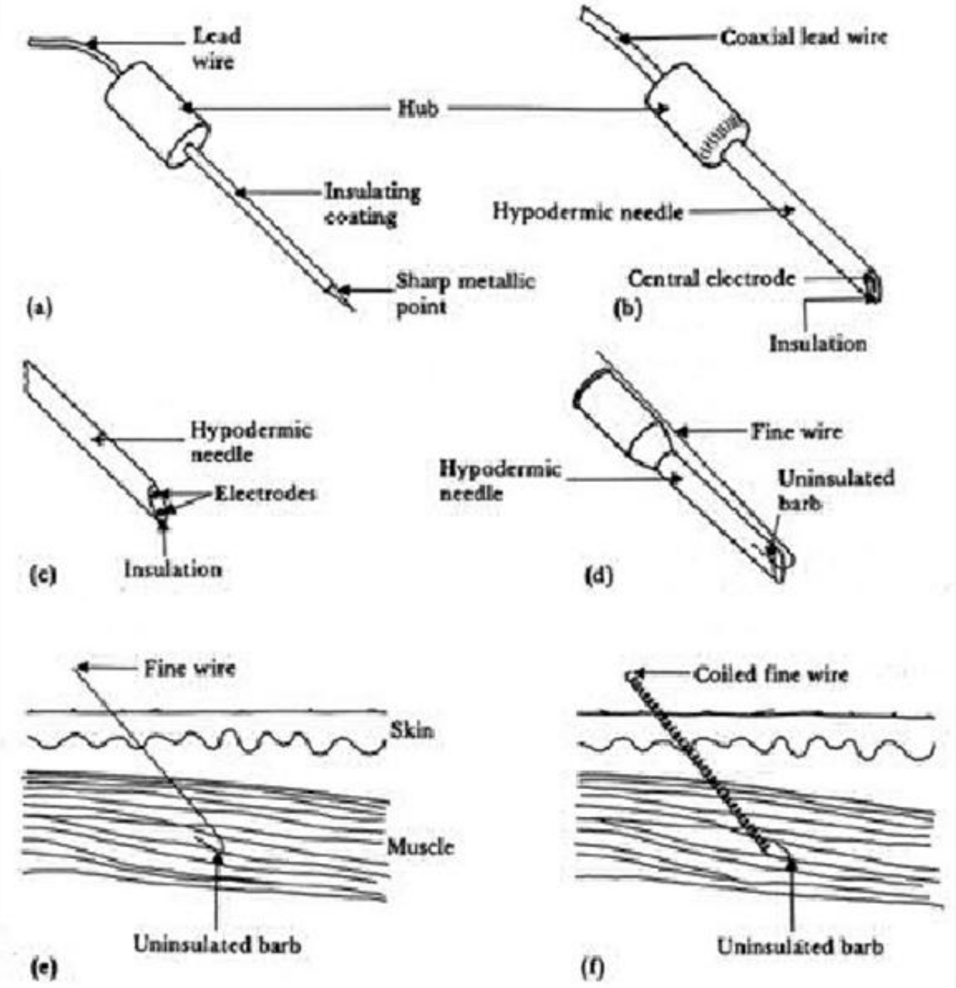
(a) Insulated needle electrode.

(b) Coaxial needle electrode.

(c) Bipolar coaxial electrode.

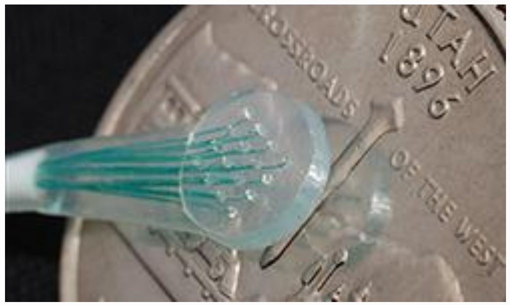
(d) Fine-wire electrode connected to hypodermic needle, before being inserted.

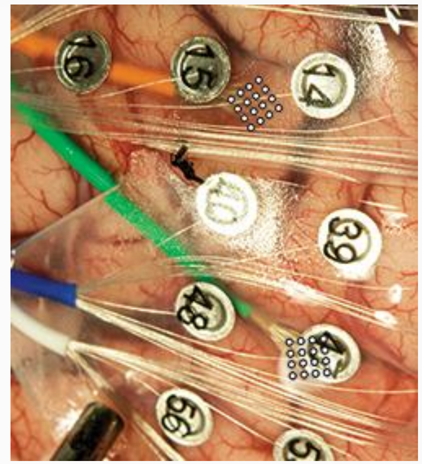
(e) Cross-sectional view of skin and muscle, showing coiled fine-wire electrode in place.



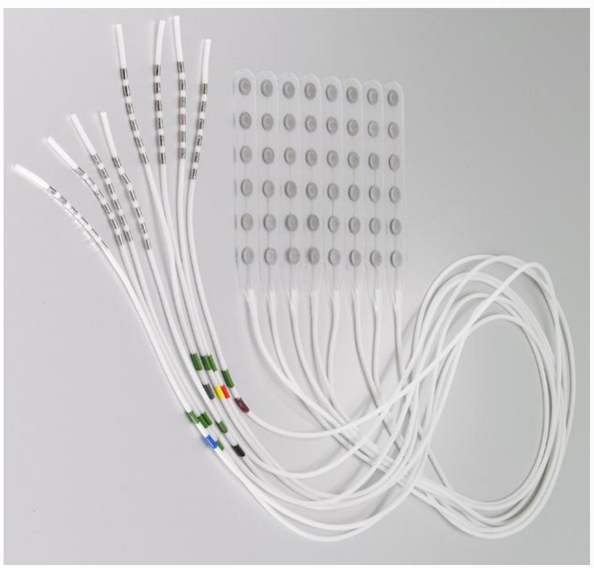
Internal Electrodes

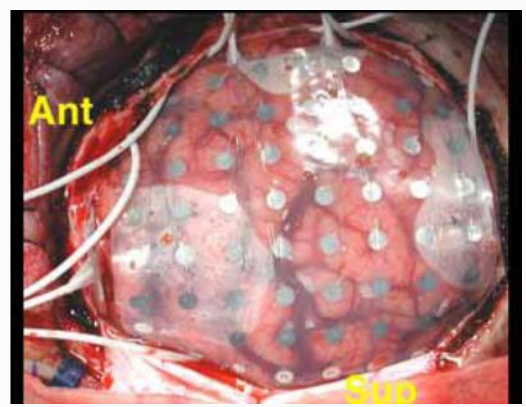
- **Electrocorticographic electrodes**





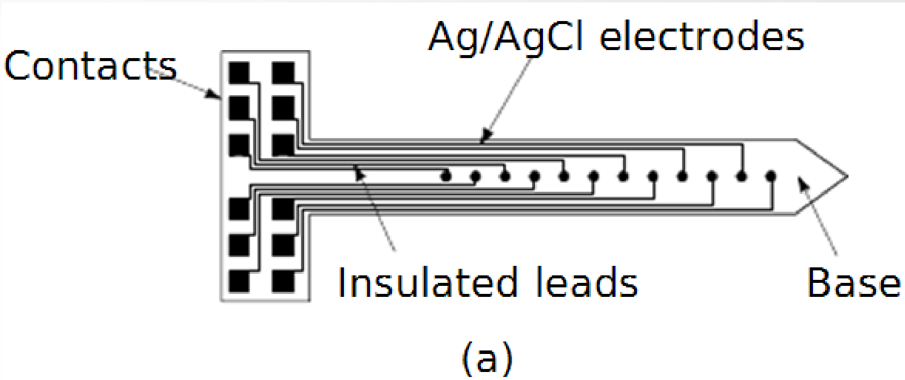
micro-electrocorticography (micro-ECoG) grid (Spencer Kellis)

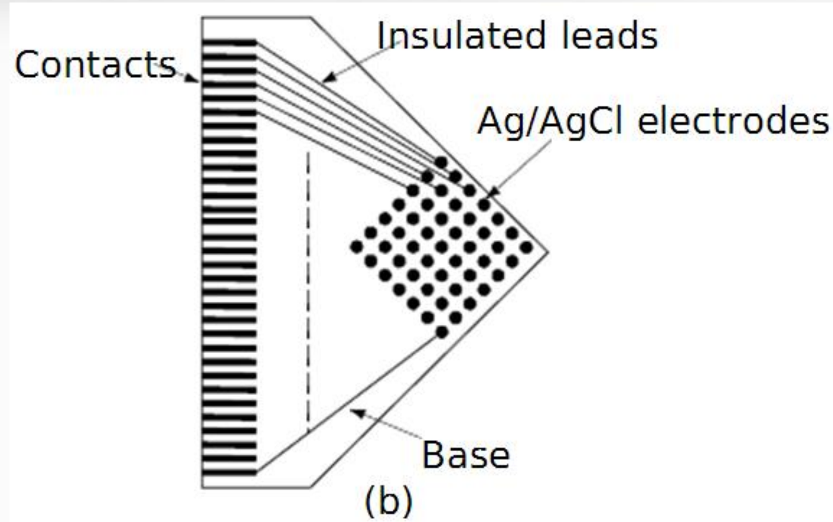


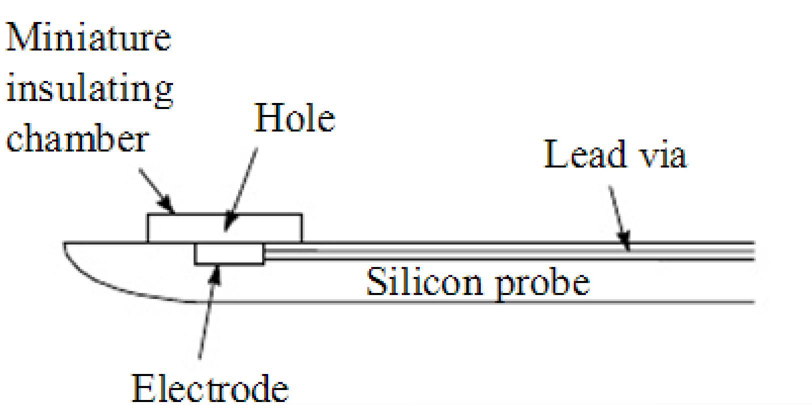


Human ECoG Grids for Epilepsy. Courtesy of Daniel Moran, biomedical engineering, School of Engineering & Applied Science, Washington Univ., St. Louis

Electrode Arrays





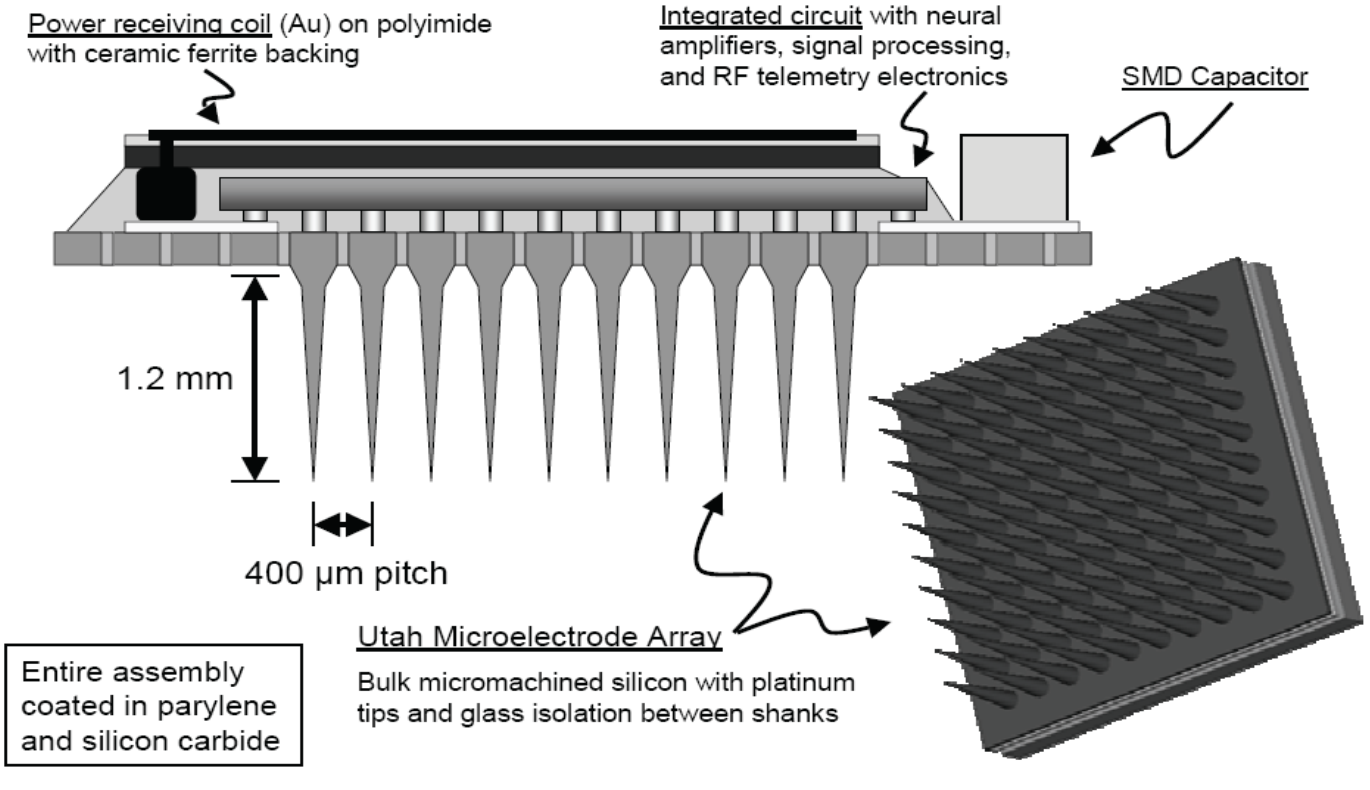


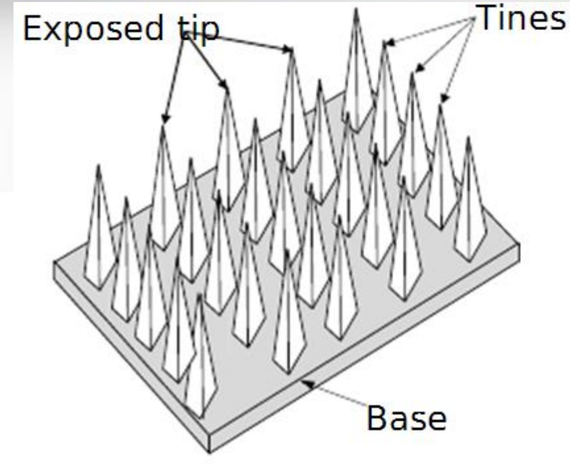
(a) One-dimensional plunge electrode array.

(b) Two-dimensional array

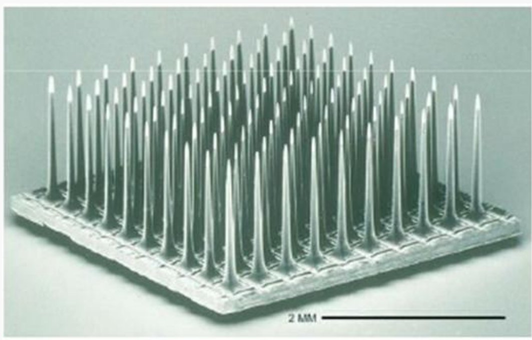
Electrode Arrays

(c) Three-dimensional array





(c)



Utah Microelectrode array. Courtesy of University of Utah and Cyberkinetics Inc.

Microelectrode

- **Measure potential difference across cell membrane**
  eg. Intracellular electrode, Extracellular electrode.
  Tip diameter: 0.05 – 10 microns
- **Types**

– Solid metal

– Supported metal (metal contained within/outside glass needle)

– Glass micropipette (Ag-AgCl in potassium chloride chloride (KCl) solution)

Electrical Properties of Microelectrodes

- **Features**

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 or Heating

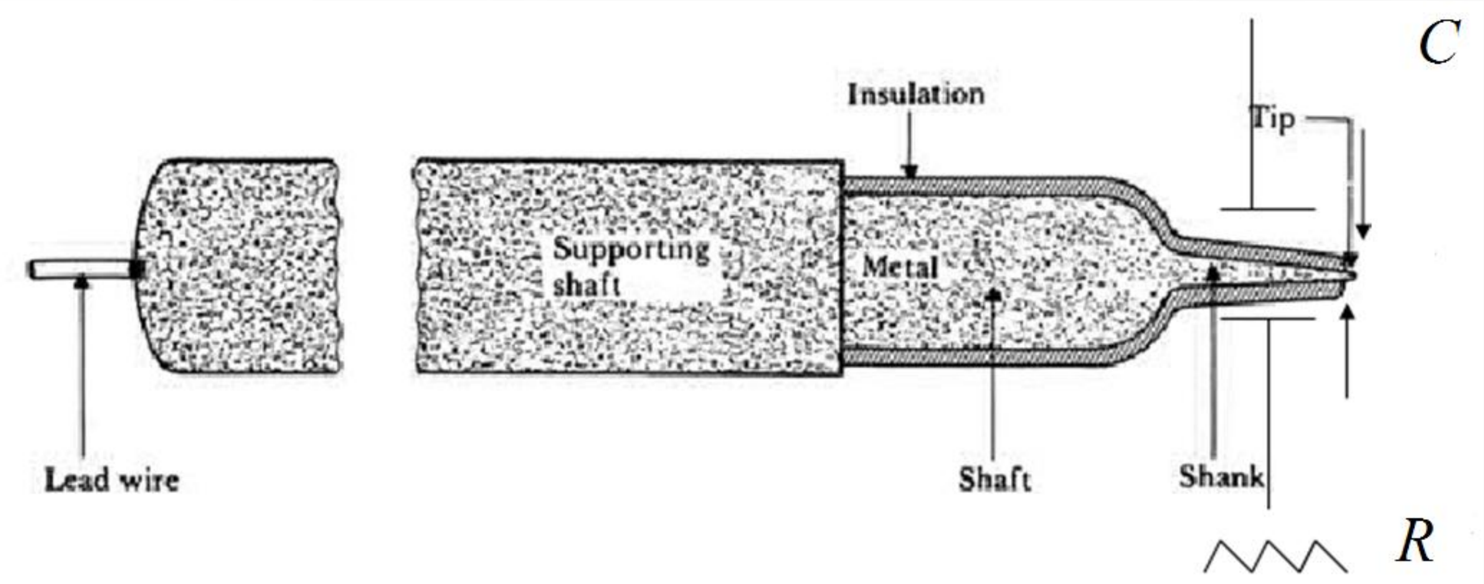
- **Types of stimulating electrodes**

1.Pacing 2.Ablation 3.Defibrillation

Platinum electrodes: neural recording and stimulation

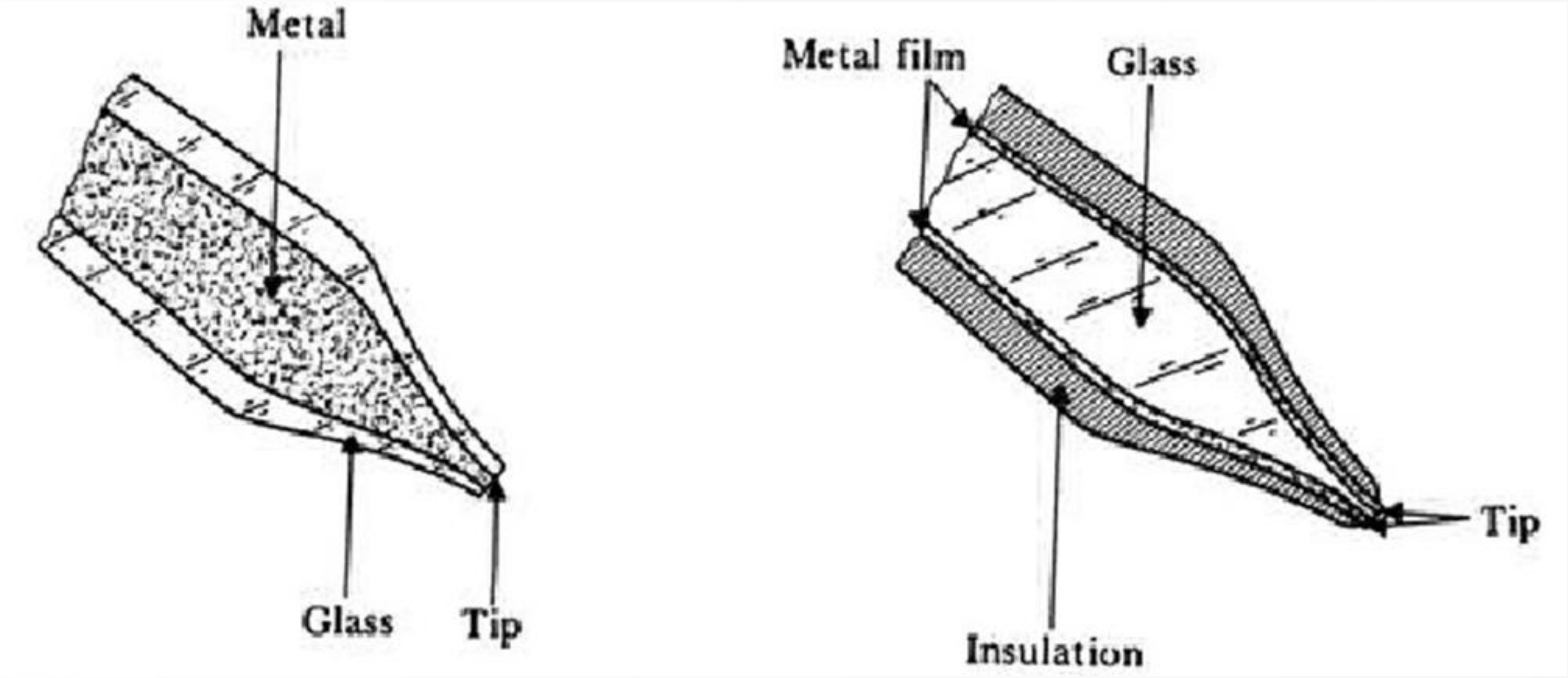
Steel electrodes: pacemakers and defibrillators

Metal Microelectrodes



- Extracellular recording – typically in brain where you are interested in recording the firing of neurons(spikes).Use metal electrode+insulation -> goes to high impedance amplifier…negative capacitance amplifier

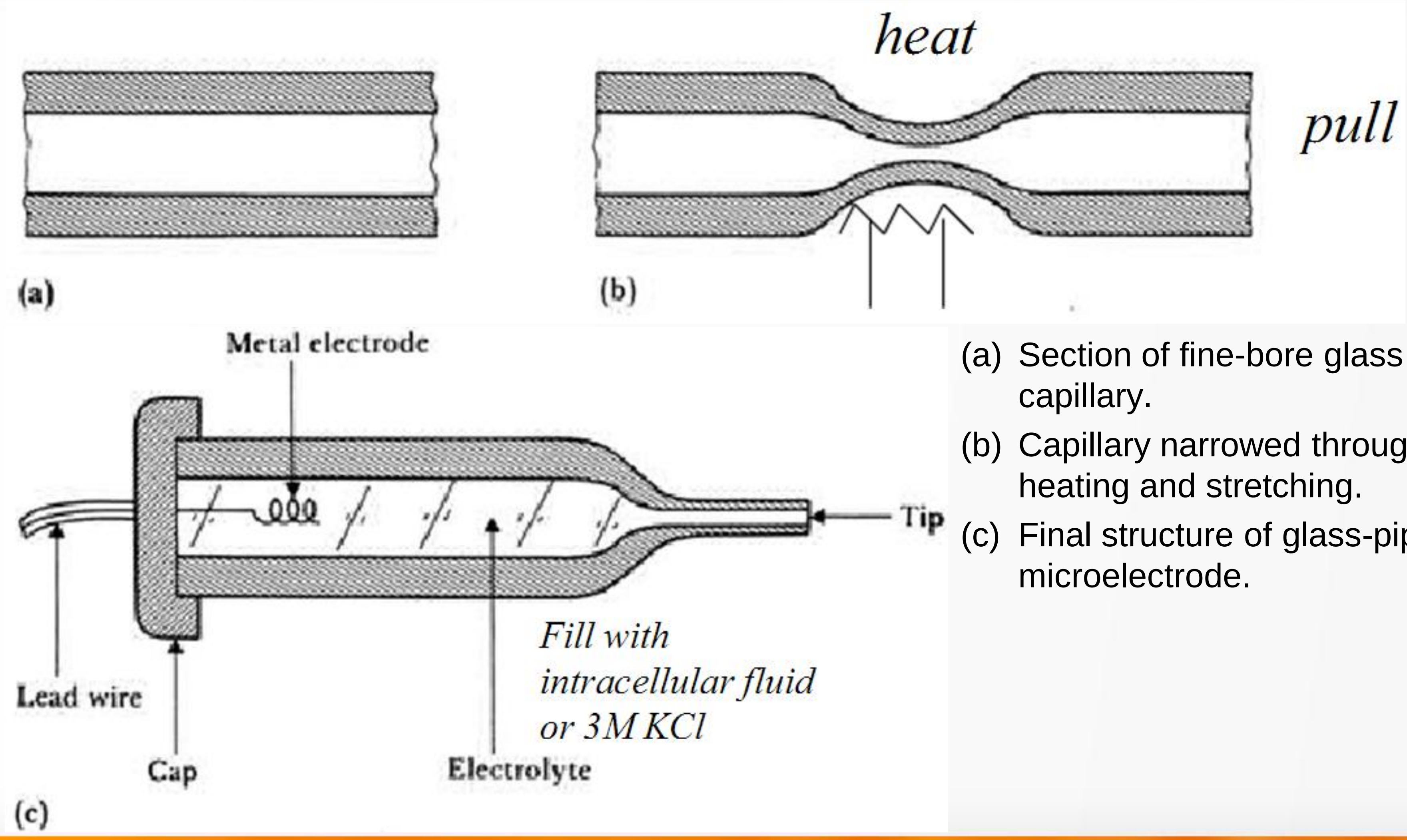
Metal Supported Microelectrodes



(a) Metal inside glass (b) Glass inside metal

Intracellular recording – typically for recording from cells, such as cardiac myocyte Need high impedance amplifier…negative capacitance amplifier!

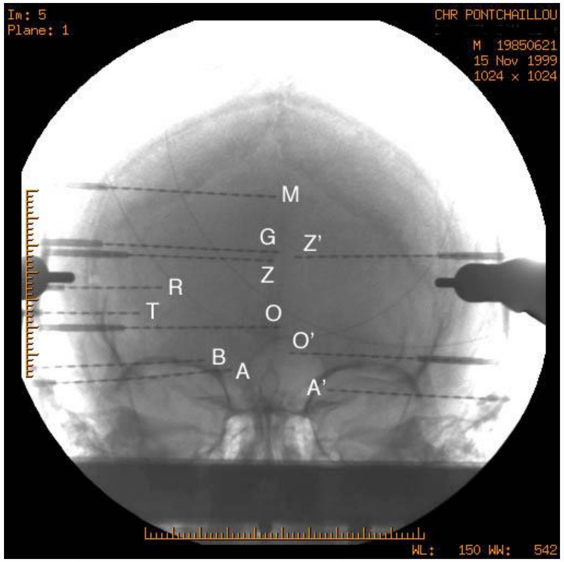
Glass Micropipette filled with an electrolytic solution



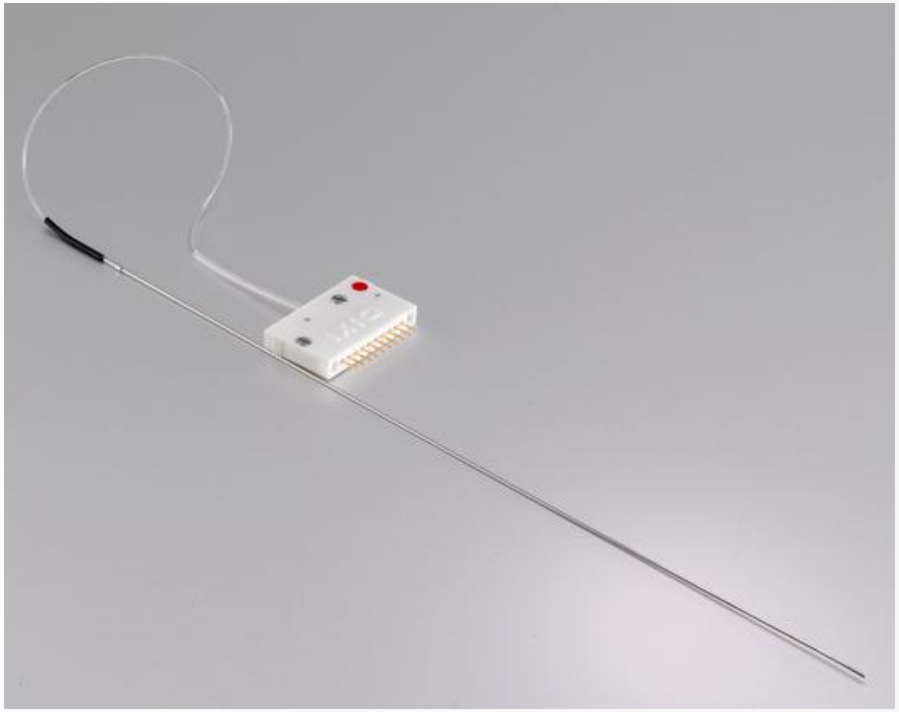
(a) Section of fine-bore glass capillary.
(b) Capillary narrowed through heating and stretching.
(c) Final structure of glass-pipet microelectrode.

Microelectrodes

- **Intracerebral Electrode**

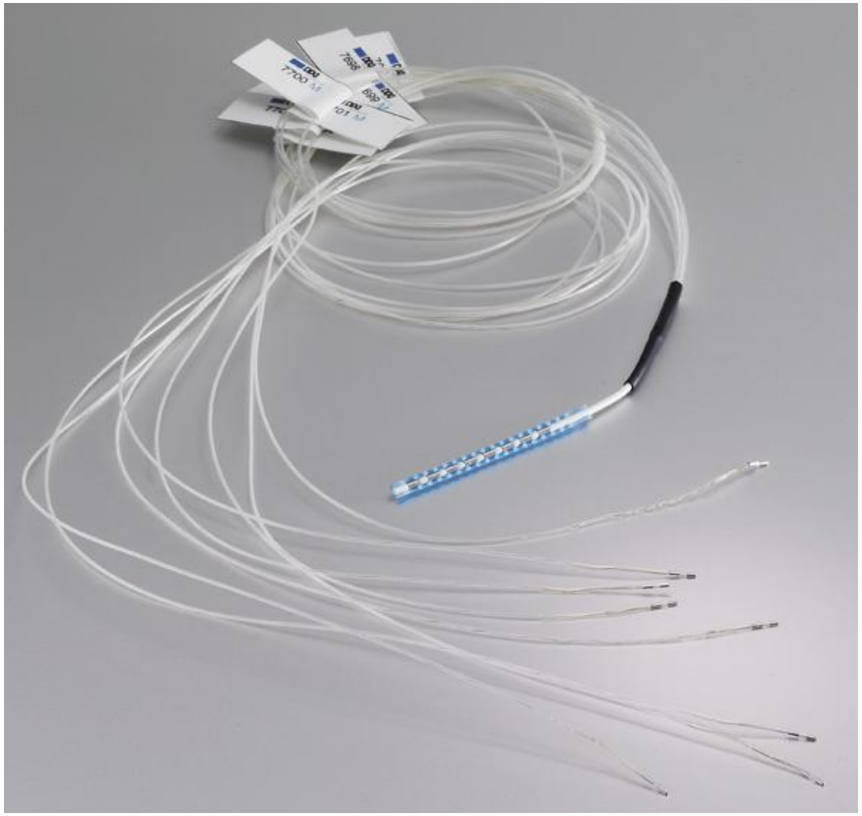


- **Electrodes for movement disorder surgery**

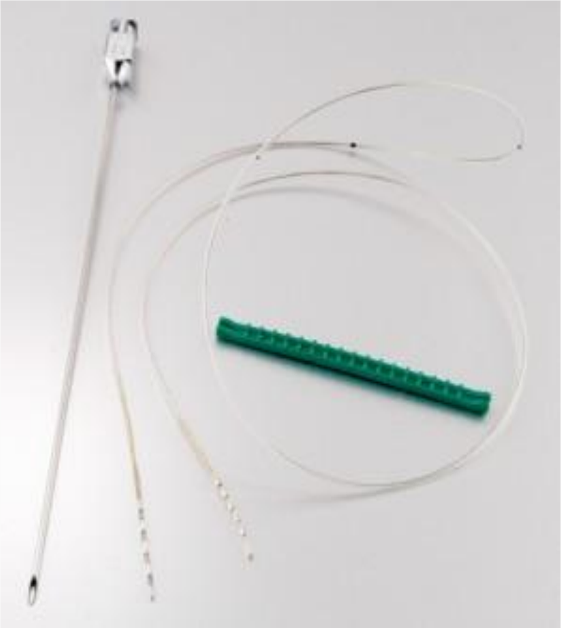


Microelectrodes

- Epidural electrode



- Foramen Ovale Electrodes



http://www.diximedical.net

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3. Introduction to Medical Electronics Applications, D. Jennings
4. Medical Device Technologies: A Systems Based Overview Using Engineering Standards, Gail D. Baura
5. Bioimpedance and Bioelectricity Basics, Orjan G. Martinsen
6. The Biomedical Engineering Handbook, Joseph D. Bronzino
7. http://www.diximedical.net

- **$Cu(s) + Zn^{+2} \leftrightarrow Cu^{+2} + Zn(s)$**
- $Cu(s) \leftrightarrow Cu^{+2} + 2e^-$ (oxidation)
- $Zn^{+2} + 2e^- \leftrightarrow Zn(s)$ (reduction)
- There are two types of electrochemical cells: **galvanic**(ones that spontaneously produce electrical energy) and **electrolytic**(ones that consume electrical energy).
- $E = E^{o\prime} + (2.303 / RTnF)\log([Ox]/[Red])$
- NernstEquation
- $a_x = \gamma[x]$

Problems

- Describe one “innovative” scheme for recording breathing or respiration. The applications might be respirometry/spirometry, athelets knowing what their heart rate is, paralyzed individuals who have difficulty breathing needing a respiratory sensor to stimulate and control phrenic nerve. You may select one of these or other applications, and then identify a suitable sensor. The design (develop suitable circuit) for interfacing to the sensor to get respiratory signal.
- We would like to have a quadriplegic automatic control over the lighting in the room. Design a basic circuit to detect room light level and turn on a lamp when the light level falls below a set limit. You may consider a suitable sensor for light and you should consider a design that compares the sensor output to some predetermined threshold and produces a high voltage or delivers power to the lamp.