Electrodes

Electrode:

- electrical conductor to make contact with a nonmetallic part of a circuit (definition).
- biosensor which converts:

voltage
(as ion
potential energy
– in tissue)

→

voltage
(as electron
potential energy
– in wires)

Electrodes

- Learning Outcomes
  - Types of electrodes
  - Anode / Cathode
  - Half-cell potentials
  - Polarizable electrodes
  - Non-polarizable electrodes
    - Ag/AgCl electrodes
  - Electrode circuit models

Electrodes

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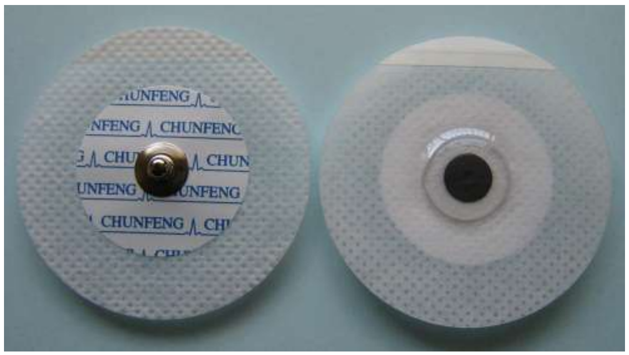
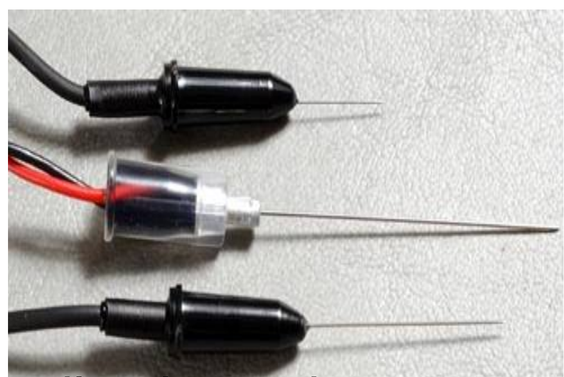
Types of electrodes

AgCl electrodes



ECG electrodes

Suction electrodes
source: Hughsun.com



Needle electrodes
source: biopac.com

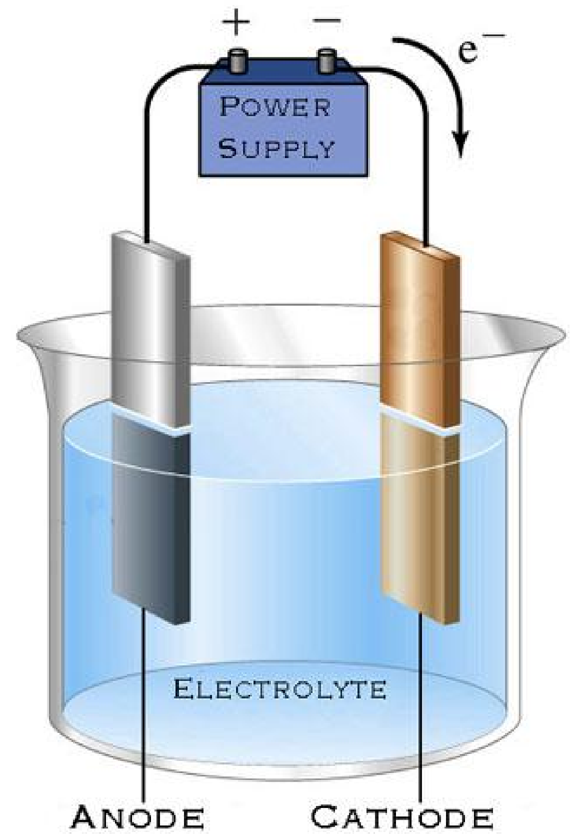
Stainless Steel electrodes

Also electrodes for

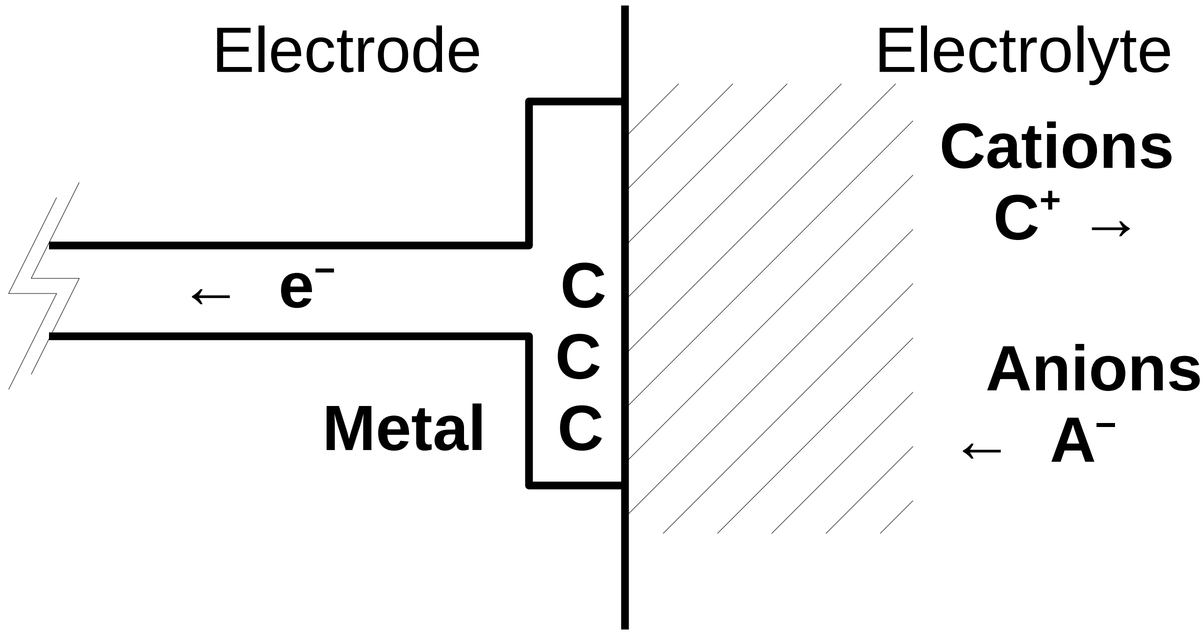
Stainless Steel electrodes
source: scenar-asia.com

Definitions: Anode/Cathode

- Anode: electrode at which electrons leave the cell (and oxidation occurs)
- Cathode: electrode at which electrons enter the cell (and reduction occurs)



Electrode / Electrolyte interface



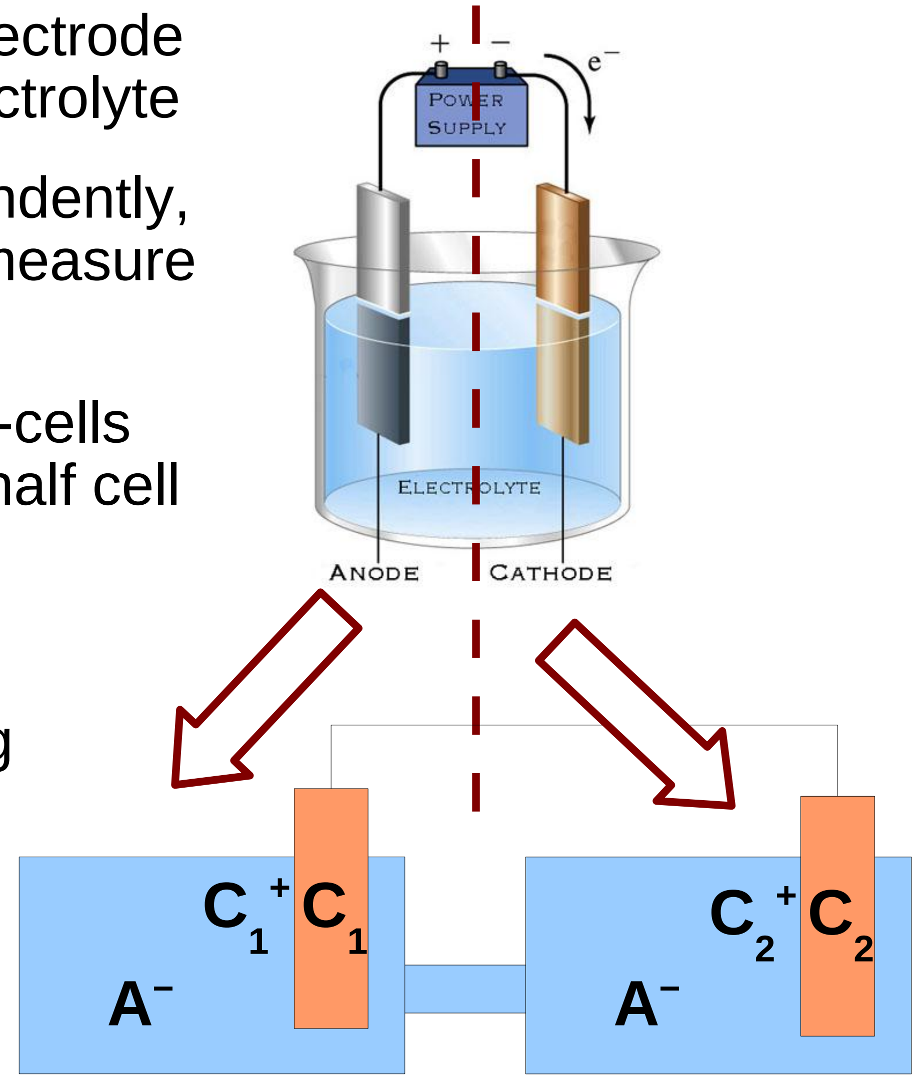
Electrode is a transducer. Electrochemical reaction is:

$$C \rightleftharpoons C^{n+} + ne^{-} \qquad \text{Cation takes } n \text{ e}^{-}$$

$$A^{m-} \rightleftharpoons A \;+ me^{-} \qquad \text{Anion takes } m \text{ e}^{-}$$

Half Cell Potential

- **half cell** contains a conductive electrode and a surrounding conductive electrolyte
- We analyze each half cell independently, but note that it is not possible to measure one physically
- Idea is that when we connect half-cells together electrically, we can add half cell potential from each electrode
    - Electrodes with wires
    - Electrolytes by physical mixing



Electrodes

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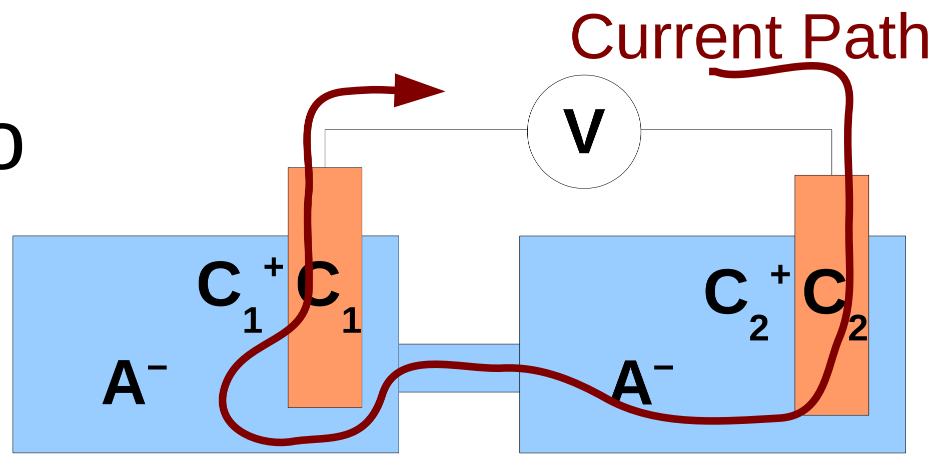
Reduction Potential

- In order to calculate the cell potential, we need to look up the “reduction potential” for both half-reactions in a table



Half - Reaction	E^0
$C_1^{n_1+} + n_1 e^- \Rightarrow C_1$	V_1
$C_2^{n_2+} + n_2 e^- \Rightarrow C_2$	V_2

Electrons reach C_1

$$C_1 \Rightarrow C_1^{n_1+} + n_1 e^-$$

e^- create ions A^-

A^- travel in solution

A^- release e^- which

Combine with A^-

$$C_2^{n_2+} + n_2 e^- \Rightarrow C_2$$

- Cell Potential is $V_2 - V_1$

Table and Questions

Comments:

- Don't use number of electrons in cell potential calculations
- Potential varies with temperature and concentration

Question:

- An aluminum and a zinc wire touch a patient area covered by saline solution. Estimate the voltage from the Al to the Zn wire.

Half – Reaction	***E⁰***
$Cl_2 + 2e^- \rightarrow 2Cl^-$	**1.36**
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	1.23
$Ag^+ + e^- \rightarrow Ag$	0.80
$Fe_3^+ + e^- \rightarrow Fe_2^+$	0.77
$2H^+ + 2e^- \rightarrow H_2$	0.00
$Zn_2^+ + 2e^- \rightarrow Zn$	–0.76
$Al_3^+ + 3e^- \rightarrow Al$	–1.66

Source: www.science.uwaterloo.ca/ ~cchieh/cact//tools/rdvolt.html

Electrode Potential Differences

- Polarization Voltage: Voltage across the electrode

$$V_p = V_r + V_c + V_a$$

- V_r : ohmic effect $\Delta V = IR$
  - R: electrical resistance across electrode
  - R may not be linear (and may depend on I)
- V_c : concentration effect
  - Current changes the distribution of ions
  - changes the half cell potential via change in log($[C^{n+}]$)
- V_a : Activation
  - Activation is the energy to convert metal → ion → solution

Electrodes

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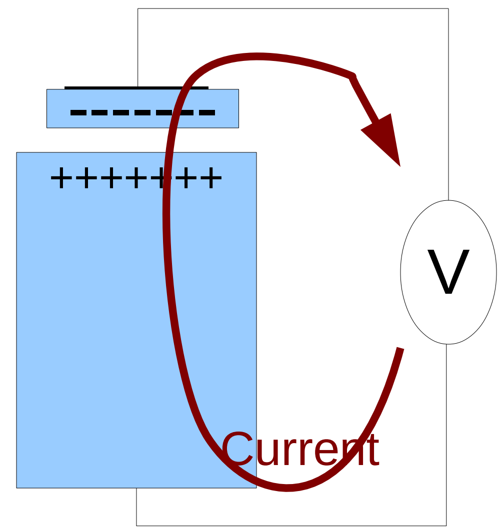
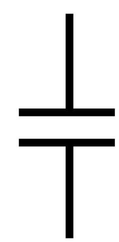
Polarizable electrodes

- In a polarizable electrode, no actual current flows (only displacement current)
- In polarizable electrodes, the electrode metal cannot ionize into solution
- After current flows for a while, a charge builds up on the electrodes, preventing further current flow.
- Examples
  - Platinum electrodes
  - Stainless steel electrodes



polarizable Model is a capacitor



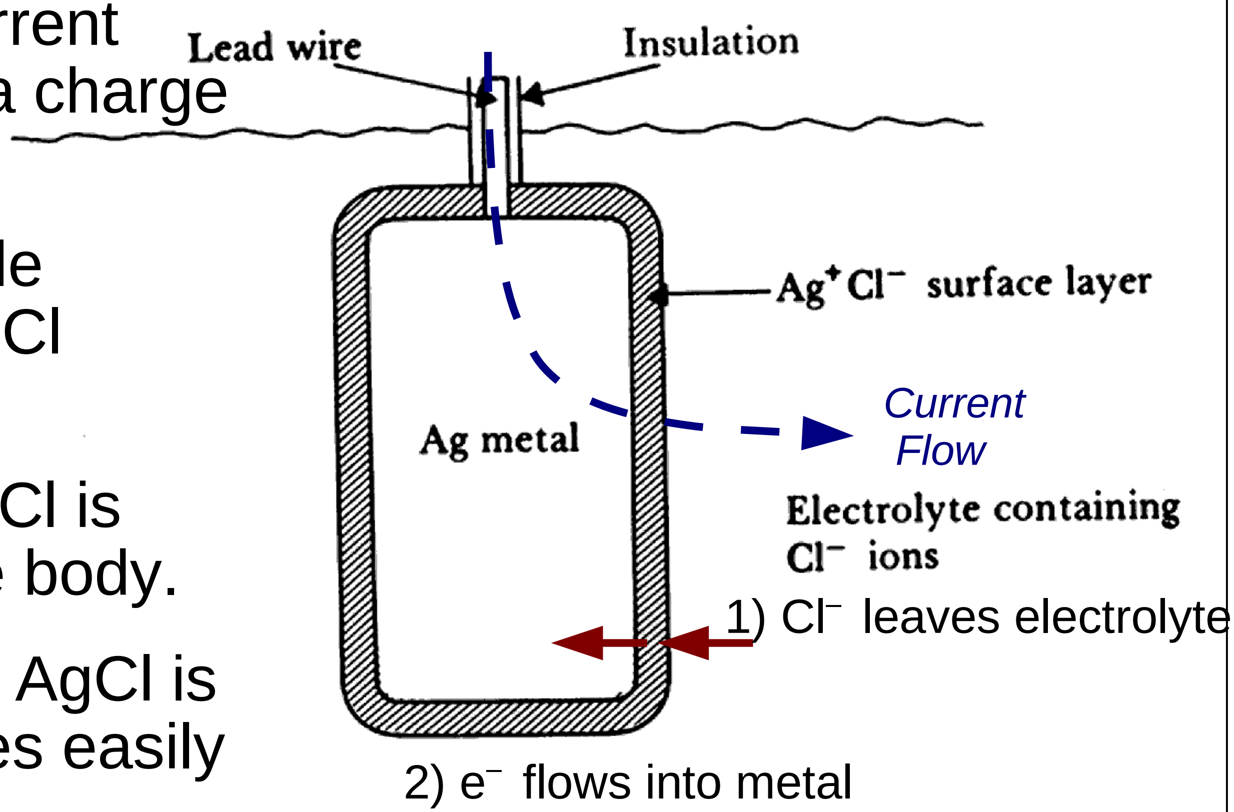
Non-polarizable Electrodes

The non-poliarizable electrode is designed to let DC current flow and not build up a charge layer.

The main non-poliarizable electrode is the Ag/AgCl electrode

Choice of Cl is because Cl is common -ve ion in the body.

Choice of Ag is because AgCl is a salt which dissociates easily



e^{-} leaves: $Ag \rightarrow Ag^{+} + e^{-}$

Ag^{+} combines: $Ag^{+} + Cl^{-} \rightarrow AgCl$

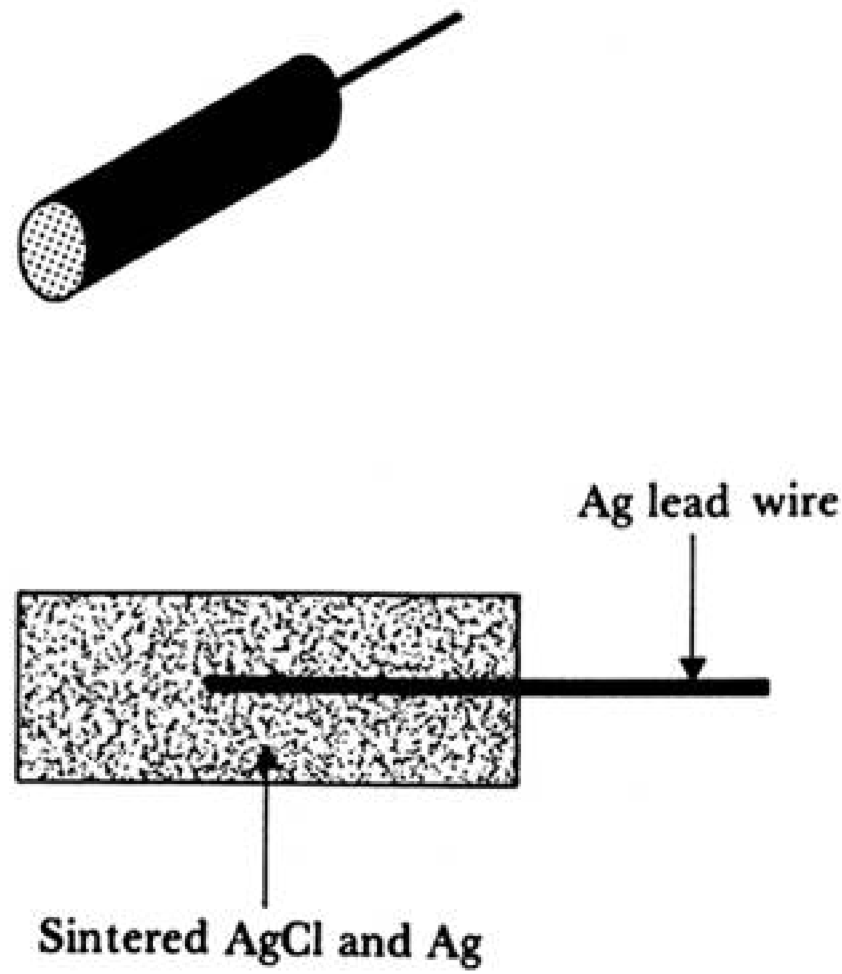
Questions

- What is a double-layer at the electrode surface
- Why do we consider an electrode to be a transducer, since it just measures voltage.
- Why are Platinum or Stainless Steel electrodes polarizable? What are some other properties of Platinum or Stainless Steel?
- If you use a SS electrode on the handle bars of an exercise bicycle to measure heart rate what kind of effects can you get?
- Some Scales use SS electrodes on the bath mat to estimate body fat. A current is passed through the body to measure resistance. What frequencies should be chosen for the current stimulation?
- If we run a Ag/AgCl electrode in one polarity for a long time, what happens?
- Why is it important that Ag/AgCl electrodes use Cl ions?

Construction of AgCl electrodes: 1) Sintering

Sintering

- Pressure and heat applied to powdered Ag/AgCl onto Ag lead wire.
- Ag powder increases conductivity
- Results in stronger electrode



Electrodes

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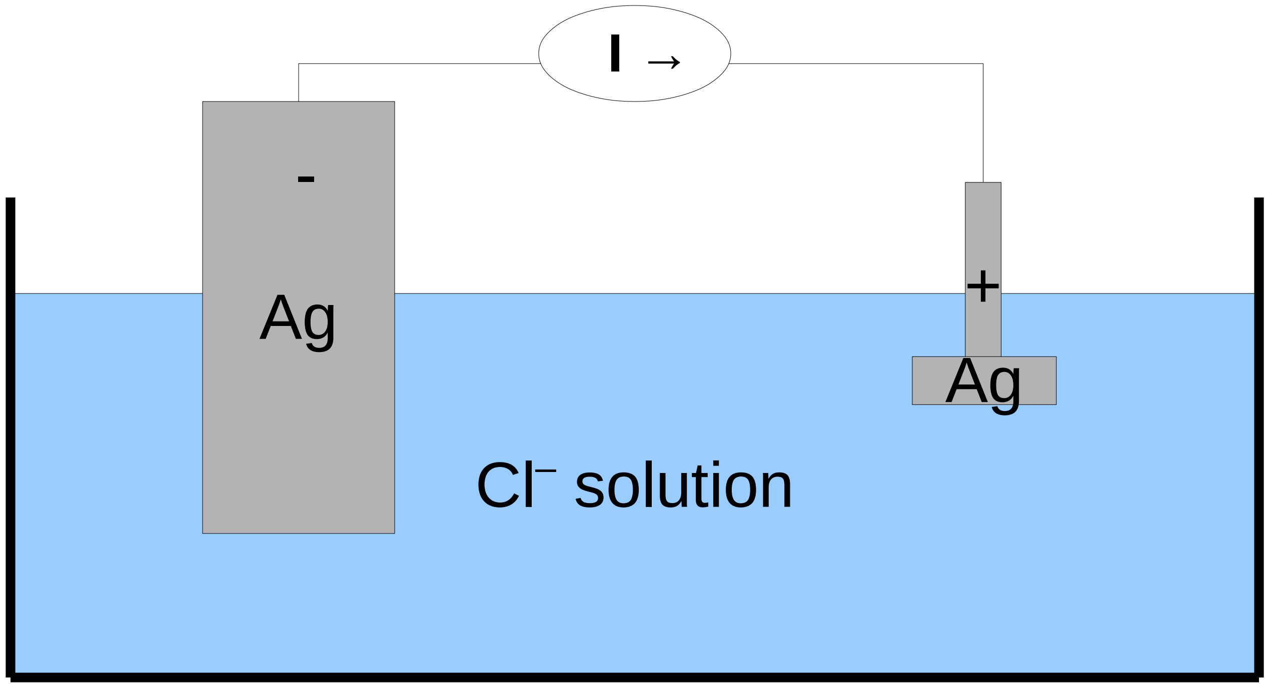
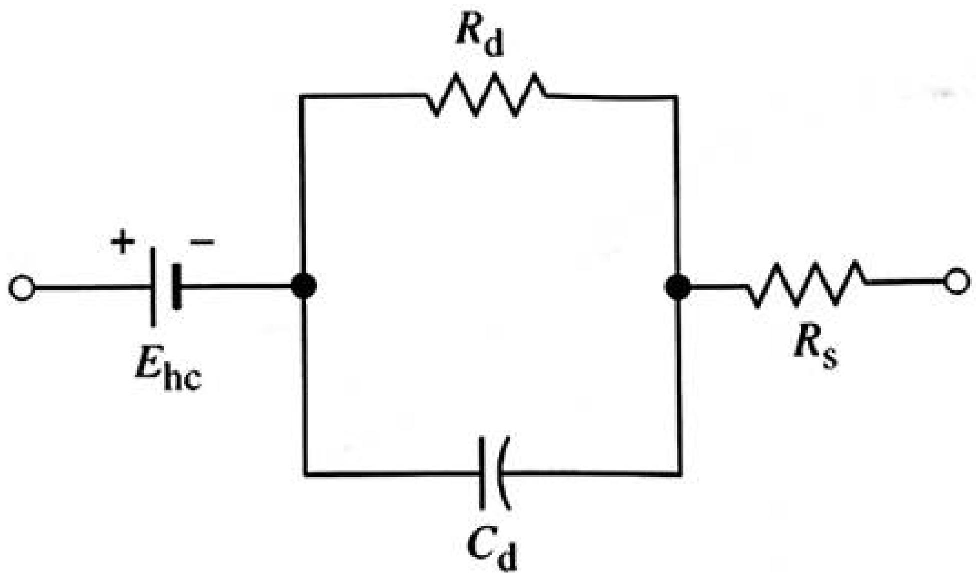
Construction of AgCl electrodes: 2) Electrolytic



Electrolytic construction deposits a layer of AgCl onto the Ag electrode.
Current drops as AgCl layer thickens

Electrode Circuit Models



Half Cell   Electrode - Electrolyte   Electrolyte

Equivalent circuit for a biopotential electrode in contact with an electrolyte E_{hc} is the half-cell potential, R_d and C_d make up the impedance associated with the electrode-electrolyte interface and polarization effects, and R_s is the series resistance associated with interface effects and due to resistance in the electrolyte.

Electrodes

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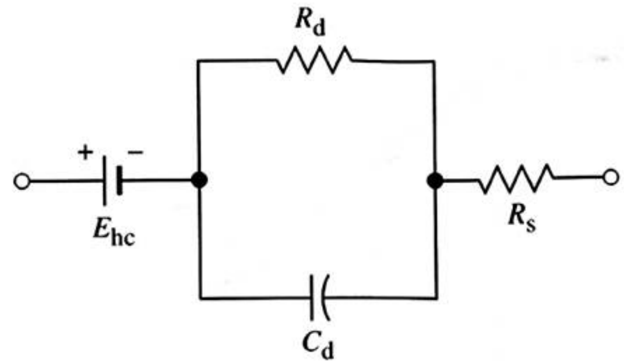
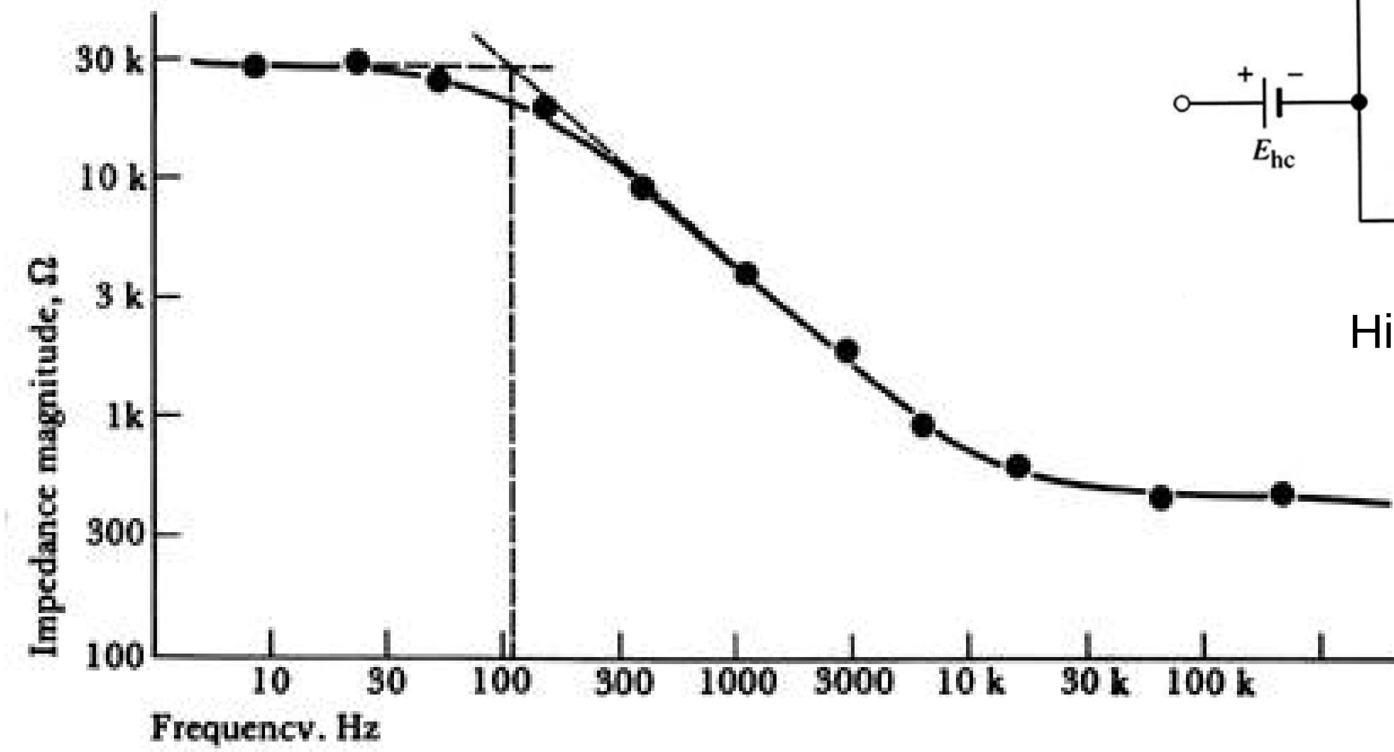
Impedance of electrodes

Low freq behaviour

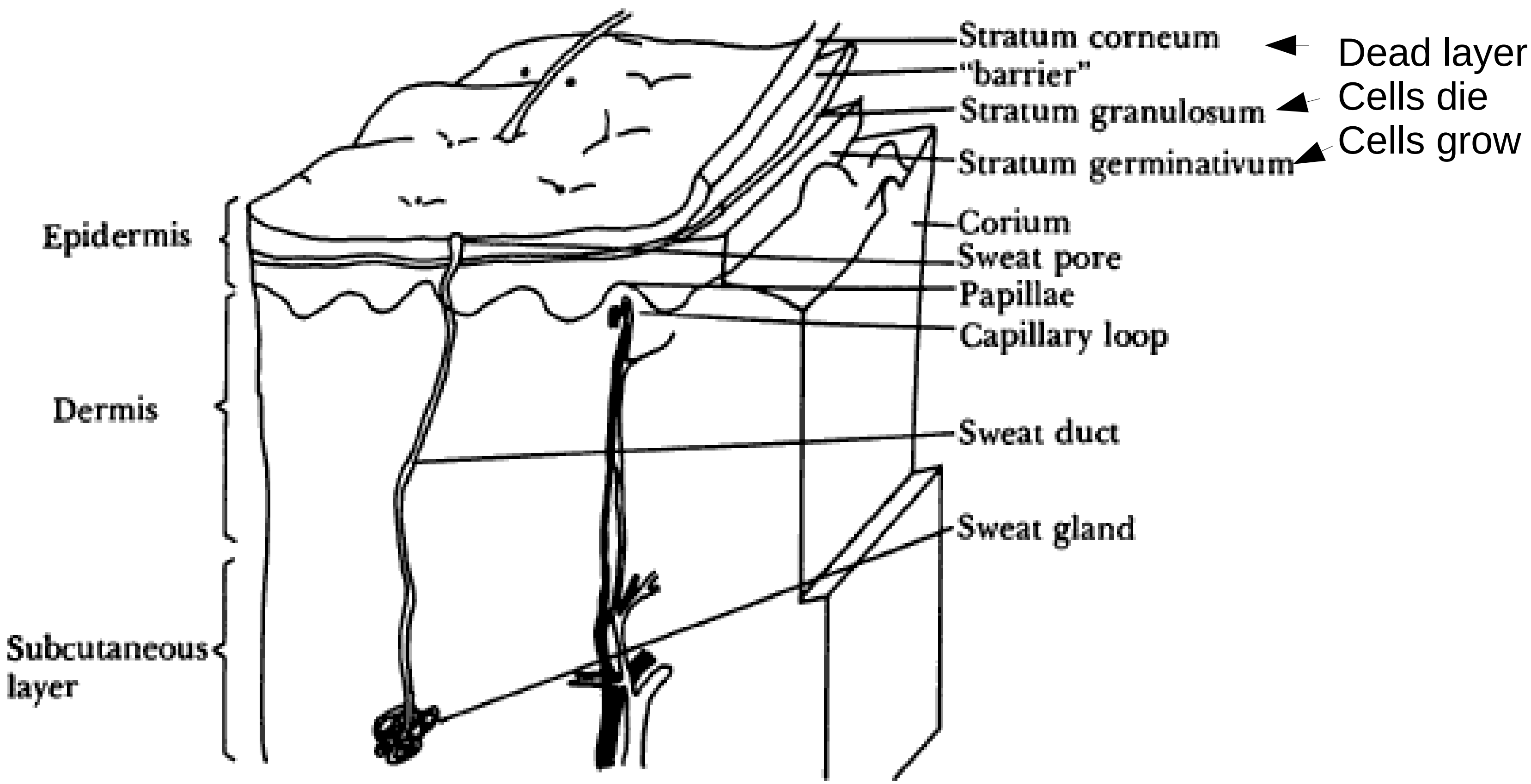


High freq behaviour

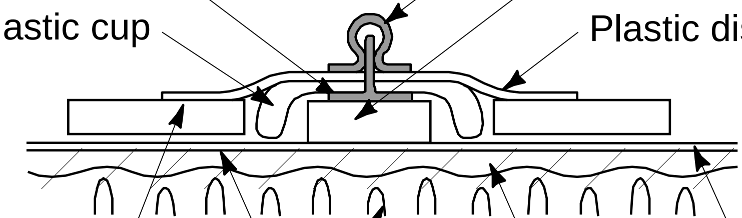


Experimentally determined magnitude of impedance as a function of frequency for electrodes.

Electrode-skin interface



Body Surface Electrodes



Issues

- Size
  - smaller for EEG / EMG / Infants
  - larger for ECG
- Hygene
  - disposable
- Speed of application
  - prepackaged/pregelled
- Radio-opaque
- Useable for defibrillation

Electrodes

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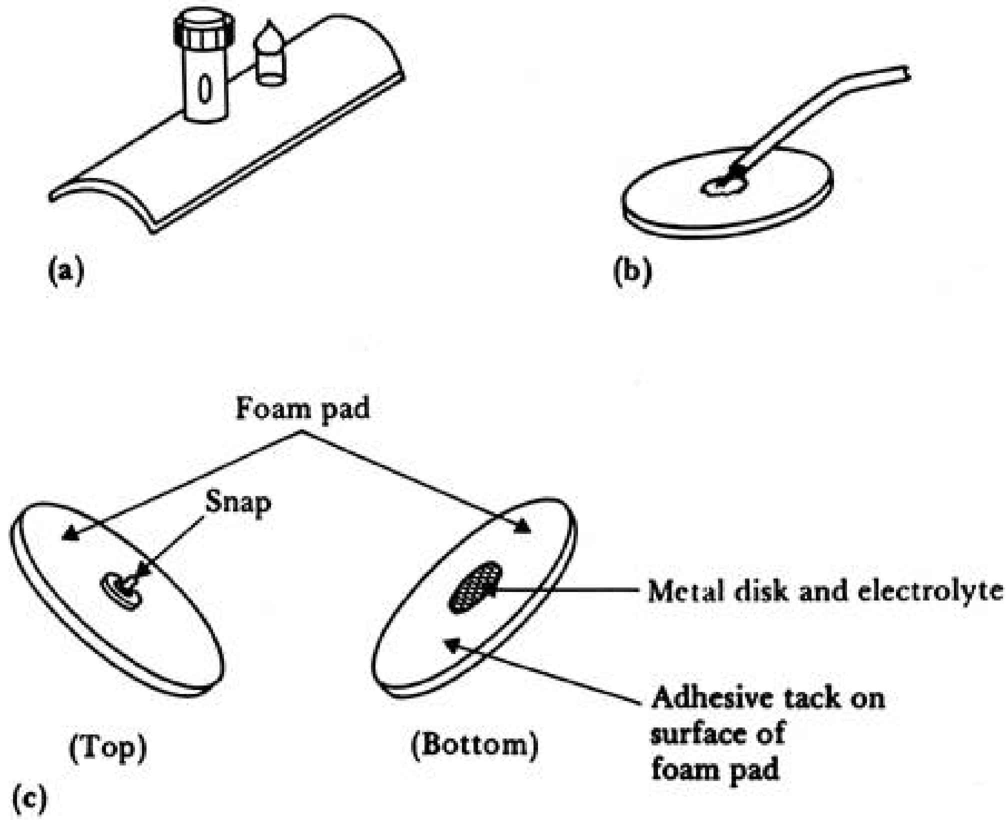
Body Surface Electrodes



Body-surface biopotential electrodes (a) Metal-plate electrode used for application to limbs. (b) Metal-disk electrode applied with surgical tape. (c) Disposable foam-pad electrodes, often used with electrocardiograph monitoring apparatus.

Electrodes

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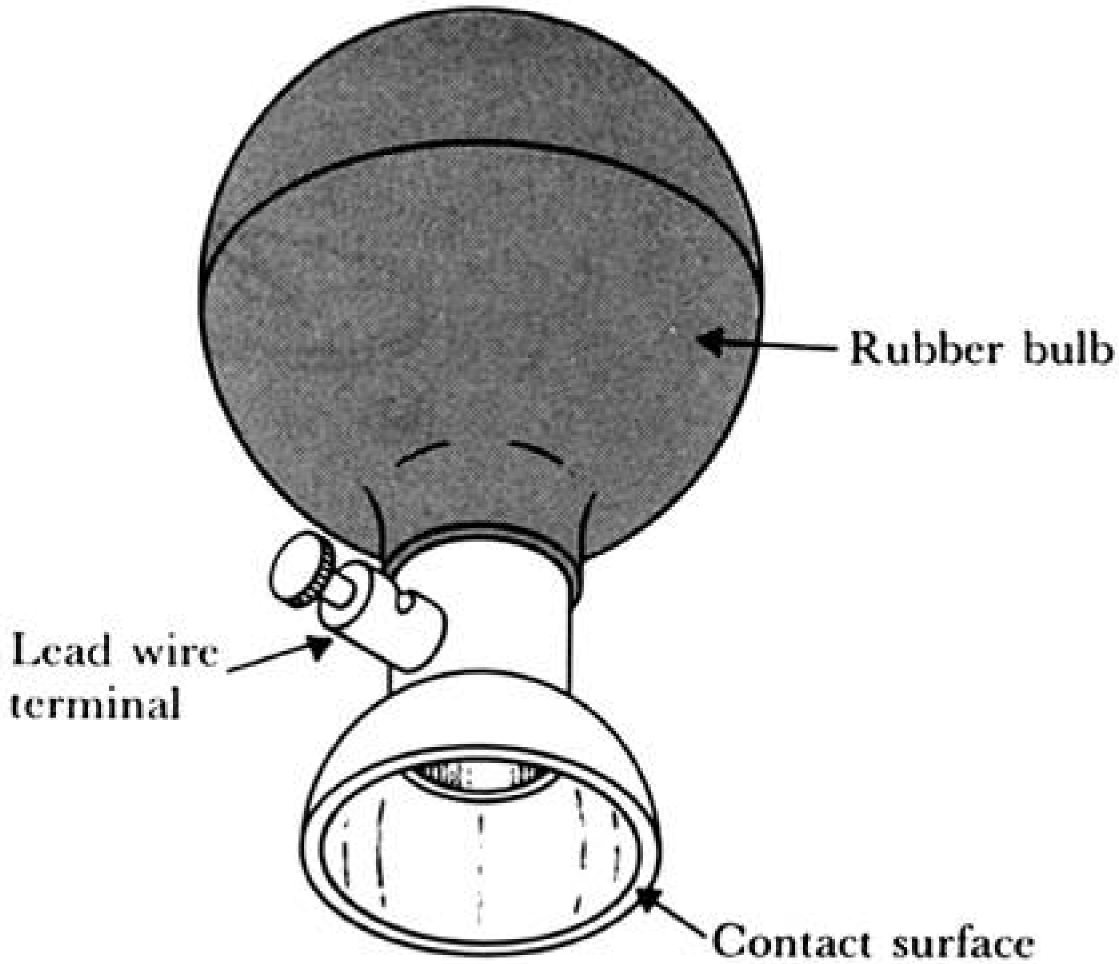
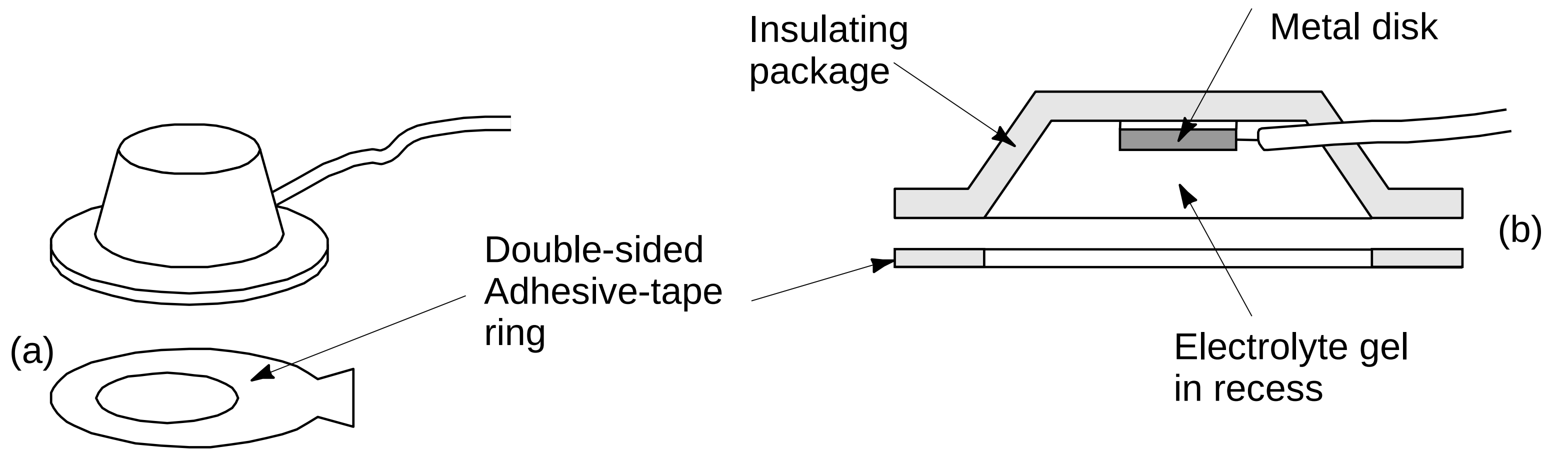
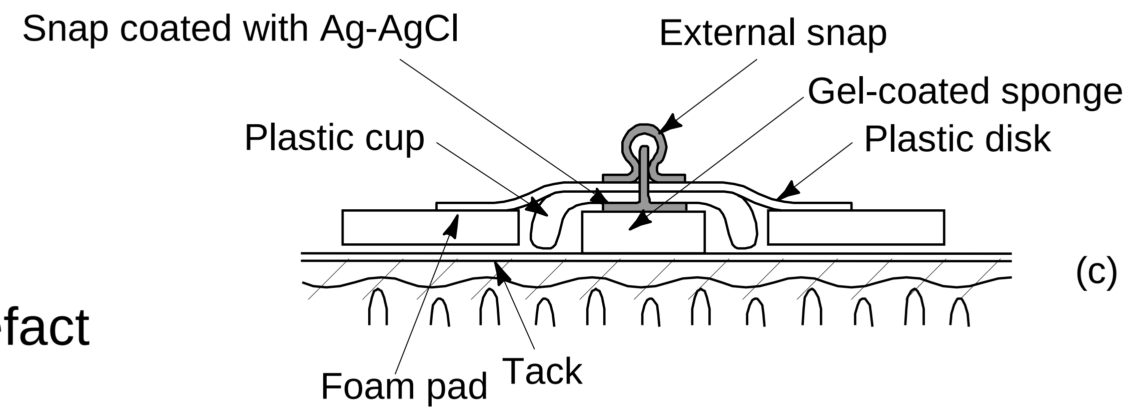
Metallic suction electrode



Floating electrodes



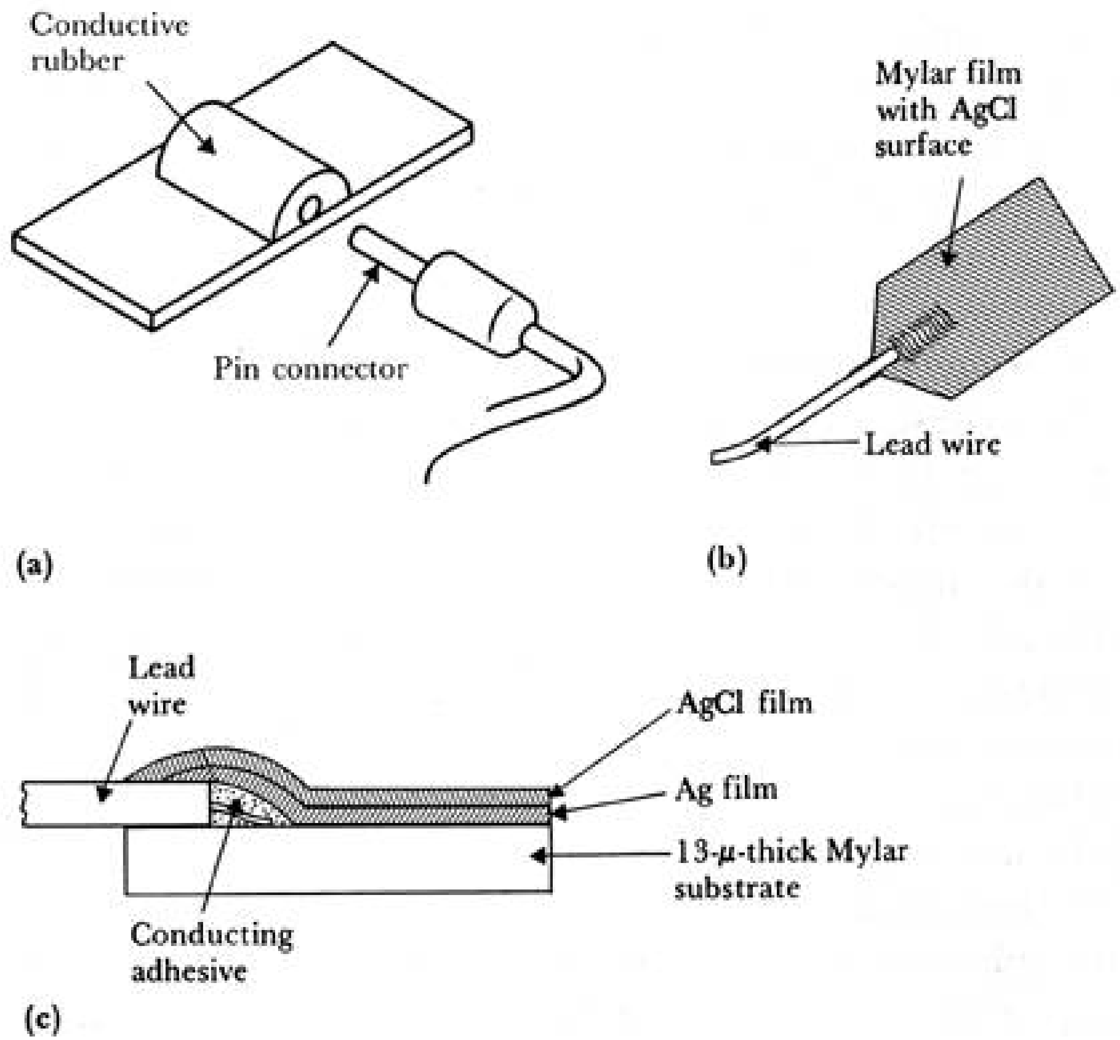
Idea:
- stabilize mechanical interface at AgCl/gel
- reduced movement of double layer => reduced motion artefact



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.

Flexible electrodes

Figure 5.12 Flexible body-surface electrodes (a) Carbon-filled silicone rubber electrode. (b) Flexible thin-film neonatal electrode (after Neuman, 1973). (c) Cross-sectional view of the thin-film electrode in (b). [Parts (b) and (c) are from International Federation for Medical and Biological Engineering. *Digest of the 10th ICMBE*, 1973.]



Electrodes

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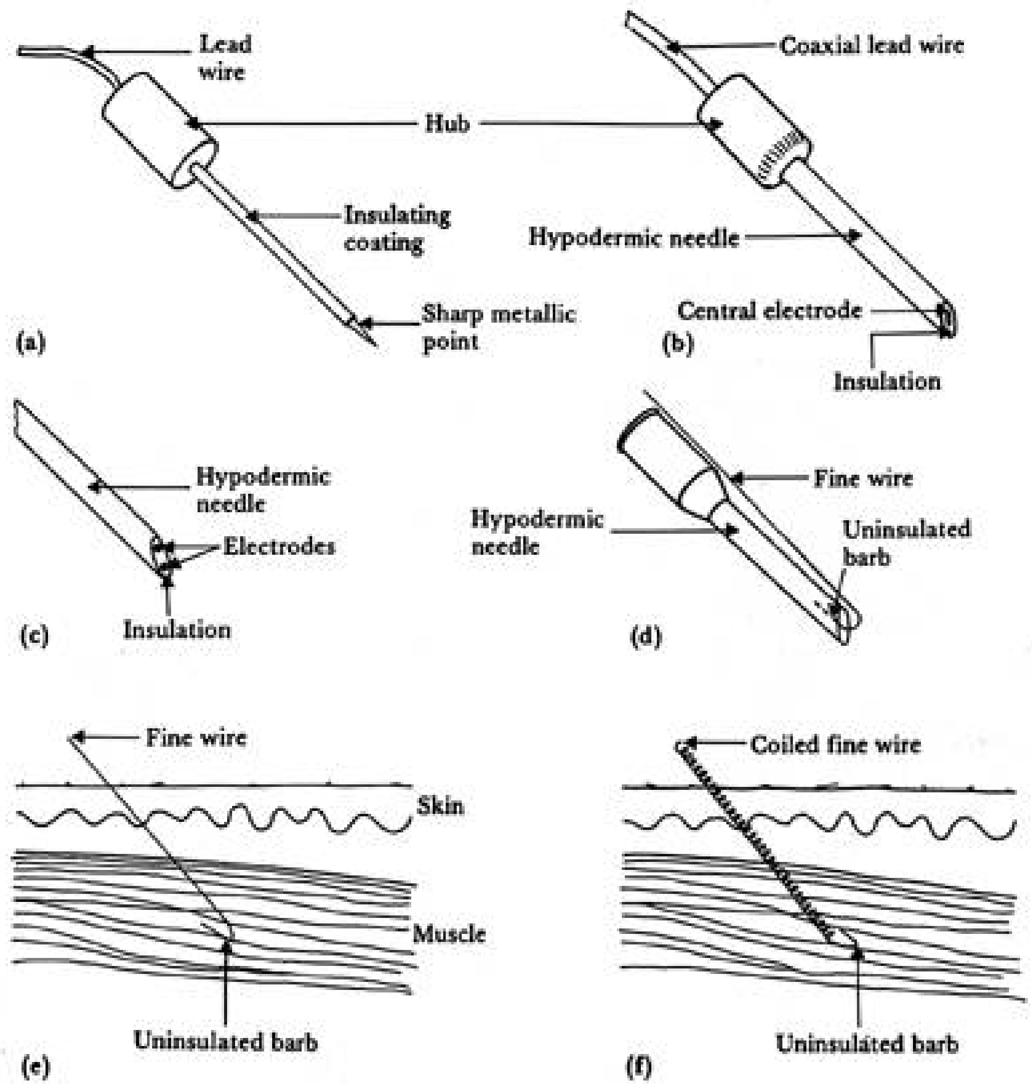
Needle electrodes

Internal Electrodes

- Percutaneous – pierces skin
- Internal – both electrode + amplifier are internal

Advantages of internal electrodes

- no electrode/skin interface
- behaviour is entirely electrode/electrolyte
- closer to phenomena of interest



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.

Electrodes

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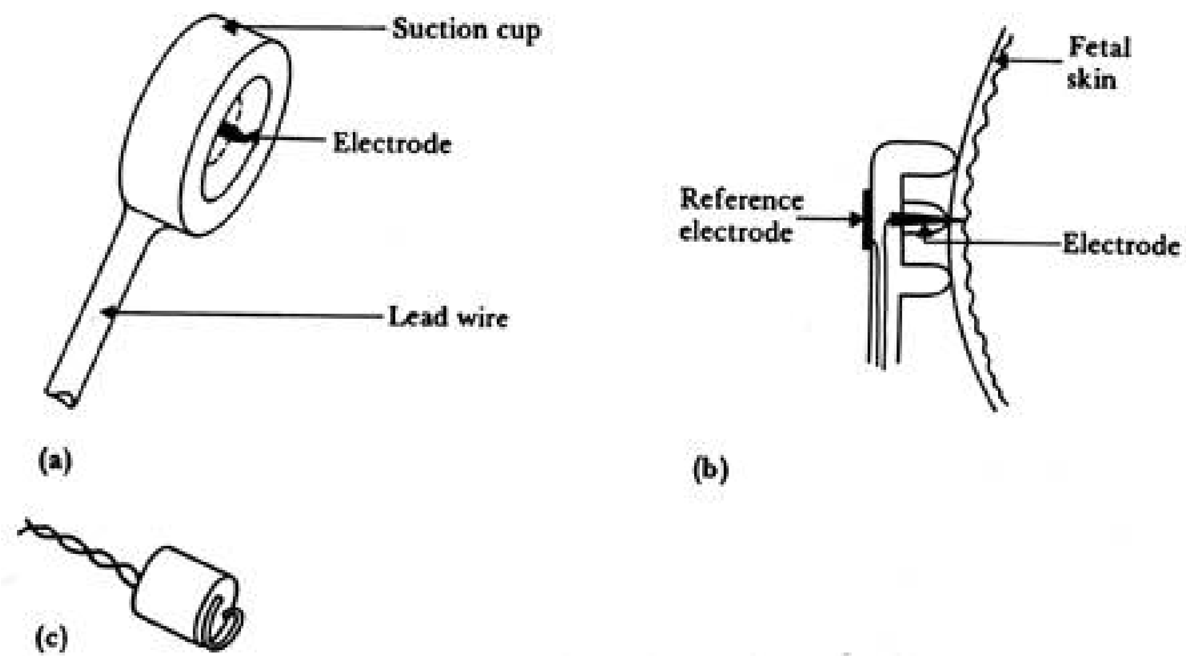
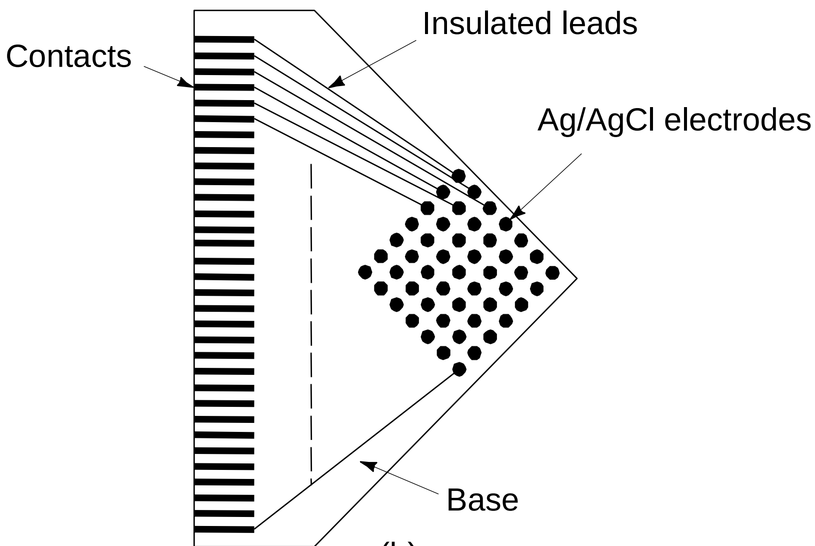
Other electrode applications

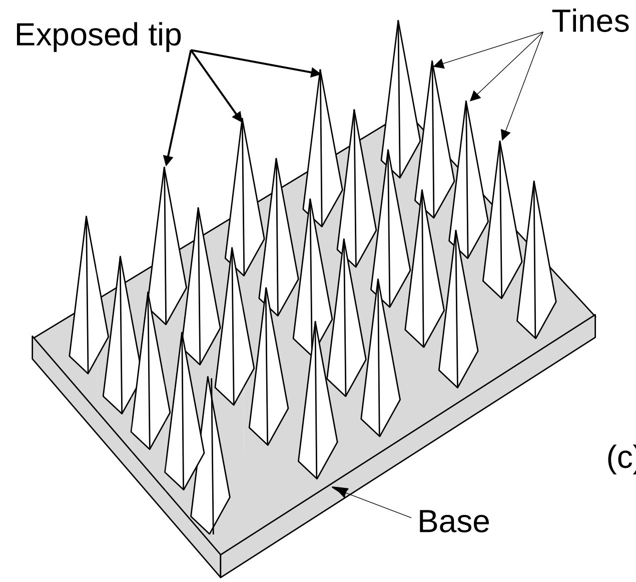


Electrodes for detecting fetal electrocardiogram during labor, by means of intracutaneous needles (a) Suction electrode. (b) Cross-sectional view of suction electrode in place, showing penetration of probe through epidermis. (c) Helical electrode, which is attached to fetal skin by corkscrew type action.

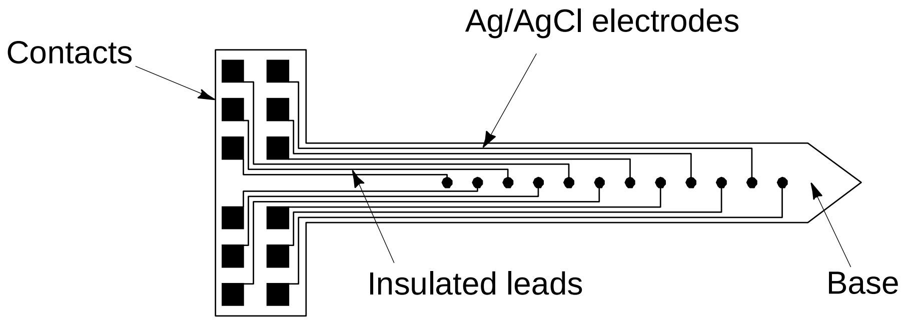
Electrode Arrays



(b)



(c)



(a)

Electrode arrays allow much more detailed measurements using the same electrode placement effort. (a) 1d “plunge” array, (b) 2D array, (c) 3D array