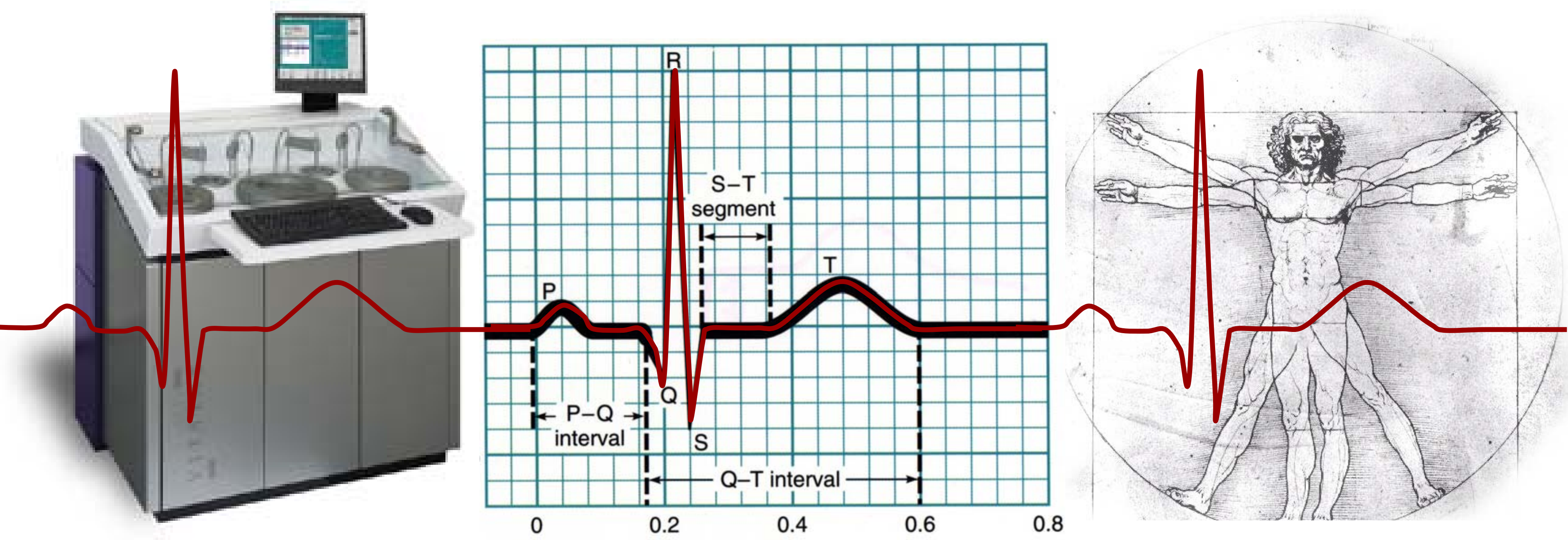
Principles of Biomedical Systems & Devices

Lecture 6: Biopotential Electrodes



This Week in PBS&D

- Electrodes and sensors used to detect biopotentials
  - Half-cell potential
  - Ag/AgCl Electrodes
- Electrode Behavior and Circuit Models
- Electrode Skin Interface
- Motion Artifacts
- Commonly used body surface electrodes
  - Metal plate electrodes
  - Suction electrodes
  - Floating electrodes
  - Flexible electrodes

Biomedical Sensors

- In vivo and in vitro measurements ➔ biomedical sensors
  - Physical
  - Electrical
  - Chemical
  - Biological
- Transducer: Convert biological information into a measurable and quantifiable electrical / optical / physical signal. It converts one form of energy into another
- Sensor: Convert a physical parameter into an electrical output
- Actuator: Convert electrical signal into a physical output
- Things we measure: dimensional / mechanical changes, chemical changes, electrical changes, thermal changes
- Biopotentials: Electrical changes

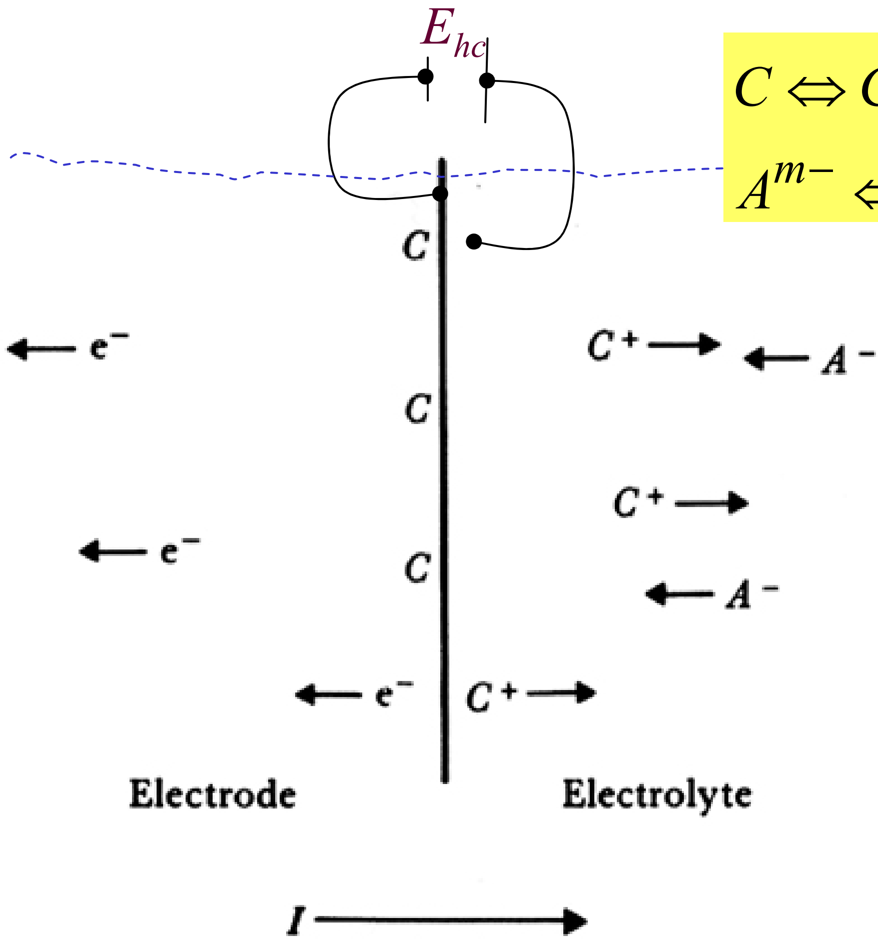
Biopotential Electrodes

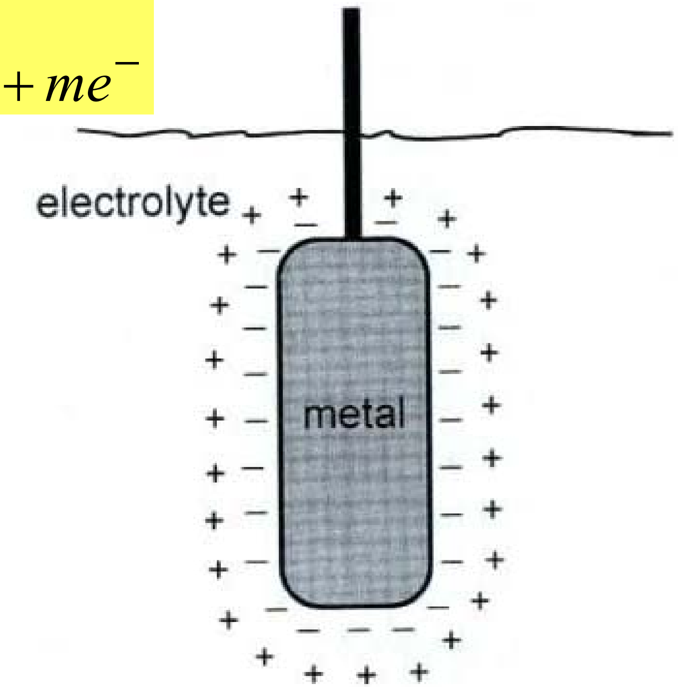
- Provide the interface necessary between the electronic changes in the body and the recording / measuring device.
- It is not a mere metal that conducts the electrical changes in the body, and hence it is not as trivial as it may seem, why…?
  - The current in the body is carried by ________________, whereas the current in wires are carried by ______________.
- Biopotential electrodes must have a transducer function!
- The interface required for the charge transfer is the electrode – electrolyte interface:
  - Electrode: some sort of metal with desired properties
  - Electrolyte: a conducting medium, specifically formulated for the electrode metal being used

Electrode – Electrolyte Interface

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

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





Electrode-electrolyte interface The current crosses it from left to right. The electrode consists of metallic atoms C. The electrolyte is an aqueous solution containing cations of the electrode metal C^{+} and anions A^{-}.

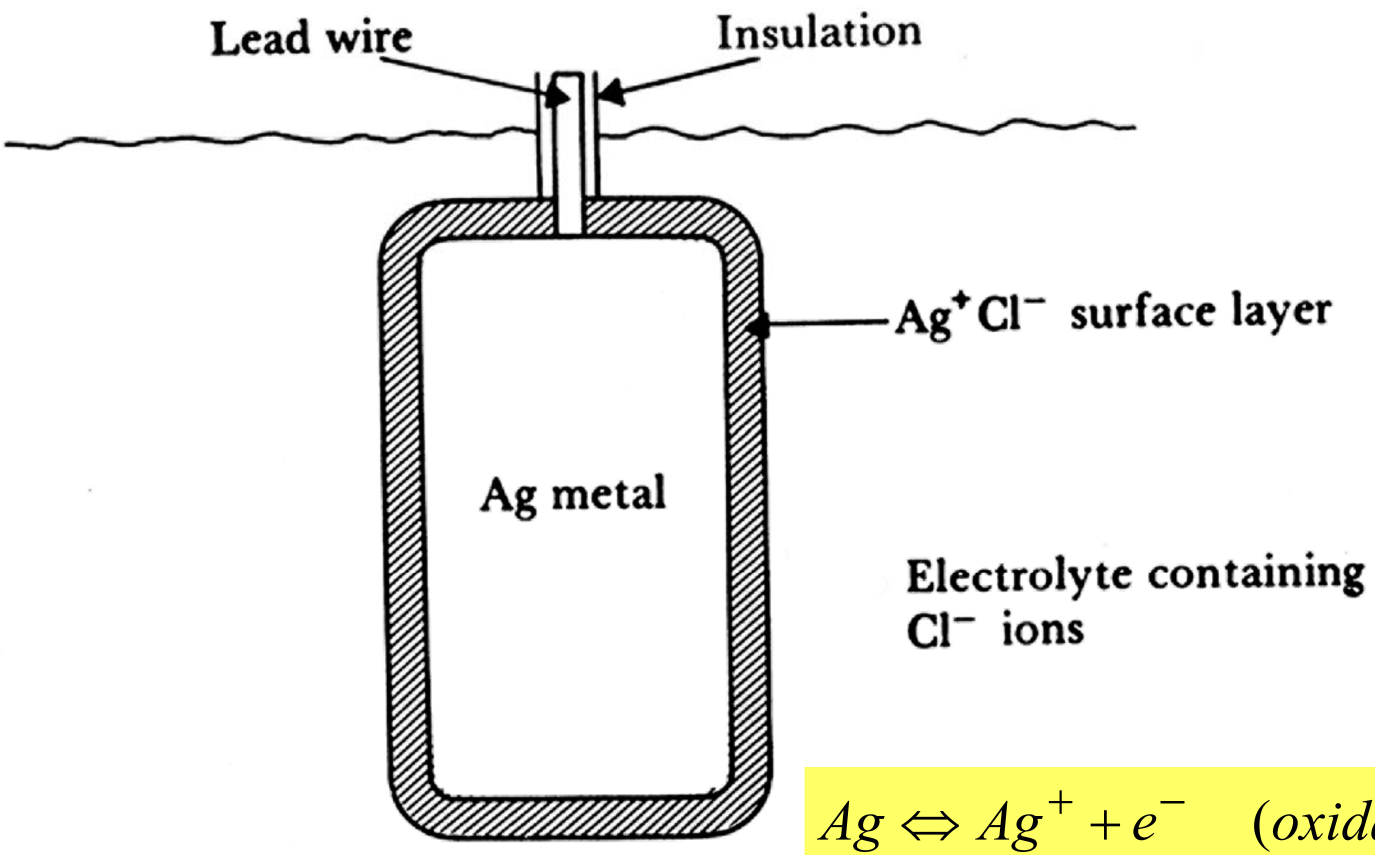
Half-Cell Potentials

Metal and Reaction	Potential E^0, V
$Al \rightarrow Al^{3+} + 3e^-$	-1.706
$Zn \rightarrow Zn^{2+} + 2e^-$	-0.763
$Cr \rightarrow Cr^{3+} + 3e^-$	-0.744
$Fe \rightarrow Fe^{2+} + 2e^-$	-0.409
$Cd \rightarrow Cd^{2+} + 2e^-$	-0.401
$Ni \rightarrow Ni^{2+} + 2e^-$	-0.230
$Pb \rightarrow Pb^{2+} + 2e^-$	-0.126
$Ag + Cl^- \rightarrow AgCl + e^-$	$+0.223$
$2Hg + 2Cl^- \rightarrow Hg_2Cl_2 + 2e^-$	$+0.268$
$Cu \rightarrow Cu^{2+} + 2e^-$	$+0.340$
$Cu \rightarrow Cu^{+} + e^-$	$+0.522$
$Ag \rightarrow Ag^{+} + e^-$	$+0.799$
$Au \rightarrow Au^{3+} + 3e^-$	$+1.420$
$Au \rightarrow Au^{+} + e^-$	$+1.680$

How would you measure the half-cell potential of an electrode?

Standard half-cell potentials, with reference to Hydrogen, at 25 ºC

Silver – Silver Chloride (Ag/AgCl)Electrodes



$$Ag \Leftrightarrow Ag^+ + e^- \quad (oxidation)$$

$$Ag^+ + Cl^- \Leftrightarrow AgCl \quad (reduction)$$

Ionic Activity
Relative half-Cell Potentials

$$E = E^0 + \frac{RT}{nF}\ln\left(a_c^{n+}\right)$$

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

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

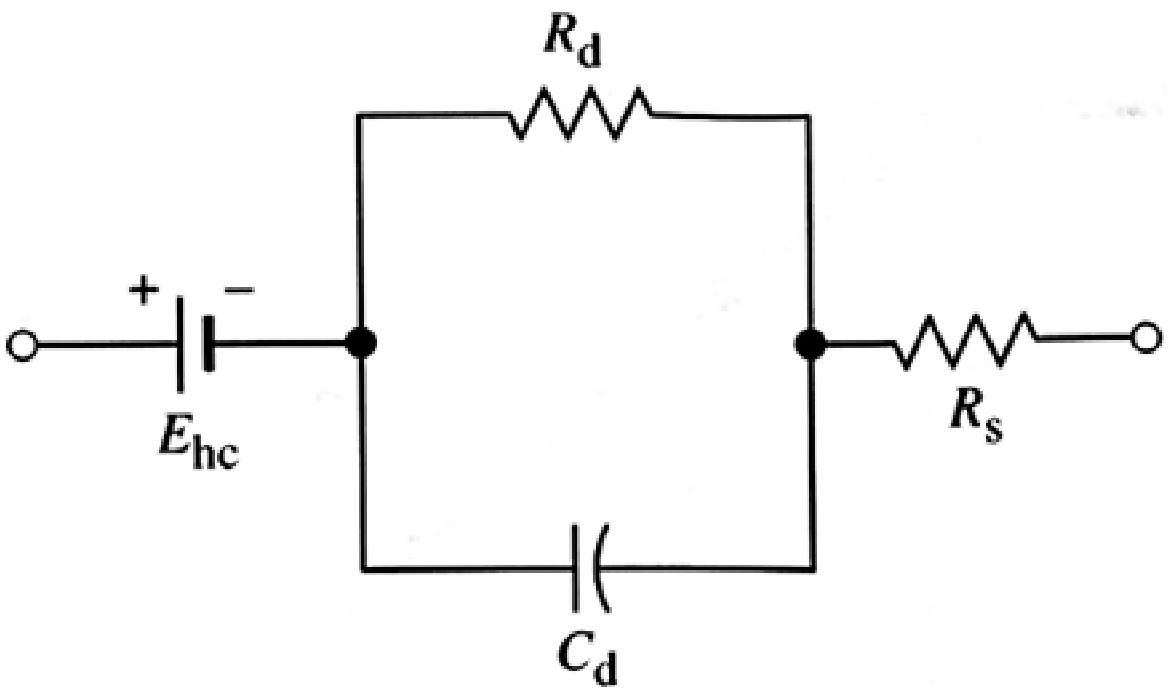
$$E_{Ag} = E^0_{Ag} + \frac{RT}{nF}\ln(Ks) - \frac{RT}{nF}\ln\left(a_{Cl^-}\right)$$

Why is this important…?

Electrode Behavior & Circuit Models

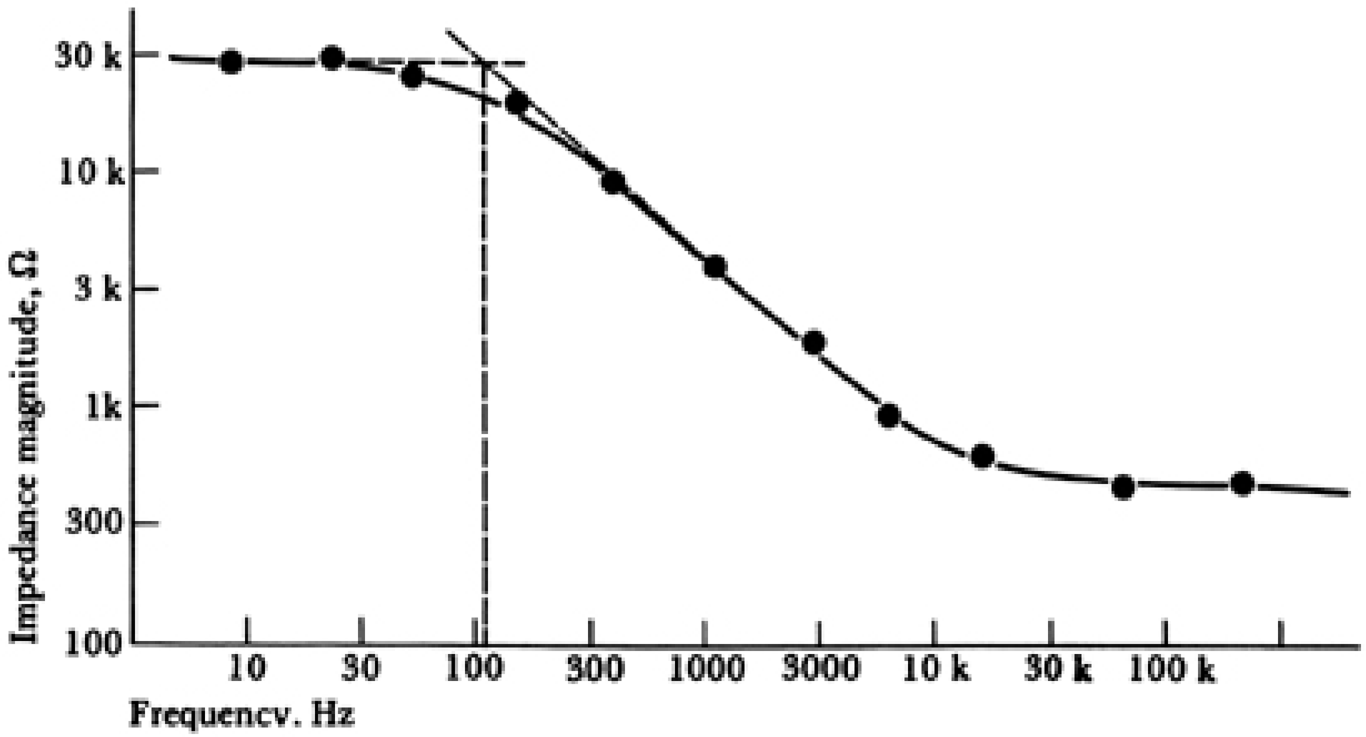
- What good is an electrode if we cannot come up with a network model of it?
- Empirical results
  - Nonlinear
  - Frequency dependent
  - Reactive behavior ➔ Capacitance at the electrode – electrolyte interface
  - Half-cell potential ➔ Voltage source
  - Metal electrode ➔ Resistive loss

Electrode Behavior & Circuit Models



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 R_s is the series resistance associated with interface effects and due to resistance in the electrolyte.

Frequency Dependency



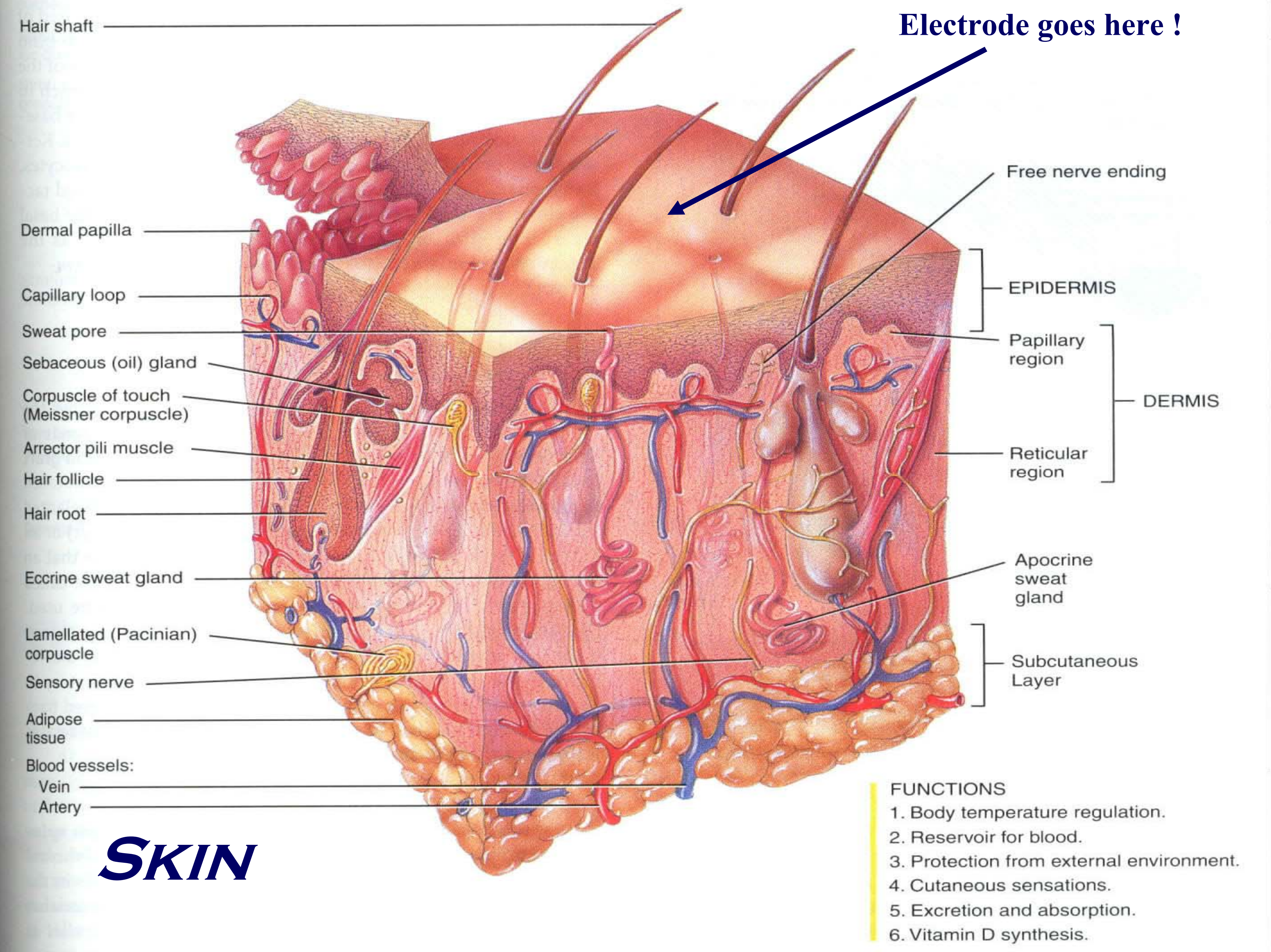
Experimentally determined magnitude of impedance as a function of frequency for electrodes.

Electrode – Skin Interface

- Apart from the electrode – electrolyte interface, there is also the skin interface.
- The skin consists of three layers, Epidermis, dermis and subcutaneous layer. We are most interested at epidermis, as that is the main contact with the electrode
  - Stratum corneum (I see dead cells…!)
  - Stratum granulosum
  - Stratum (basale) germinativum (where new skin cells form)

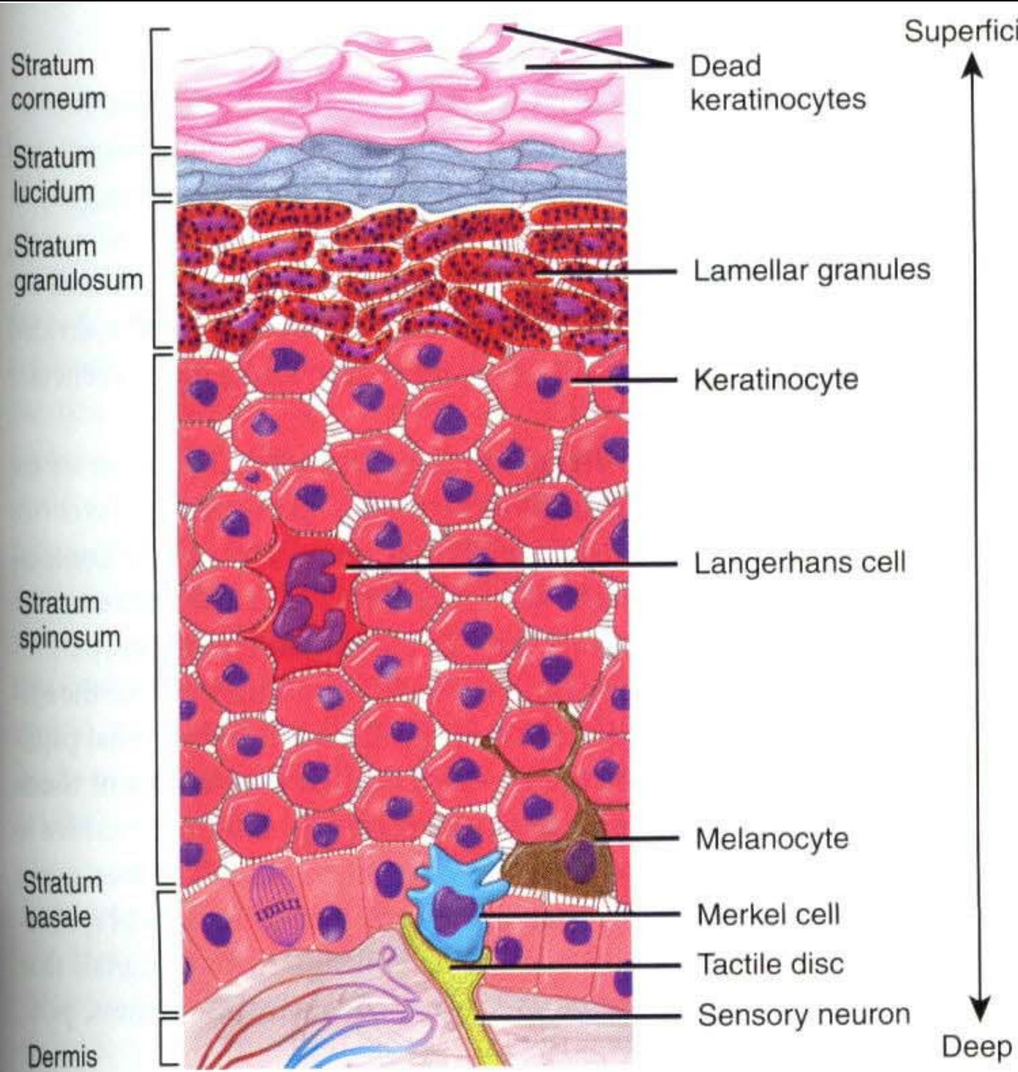
Direction of cell aging & movement

- Deep layers of skin consist of vascular and nervous components, as well as sweat glands, sweat ducts and hair follicles
  - With the exception of sweat glands, no particular characteristics affecting the electrode performance

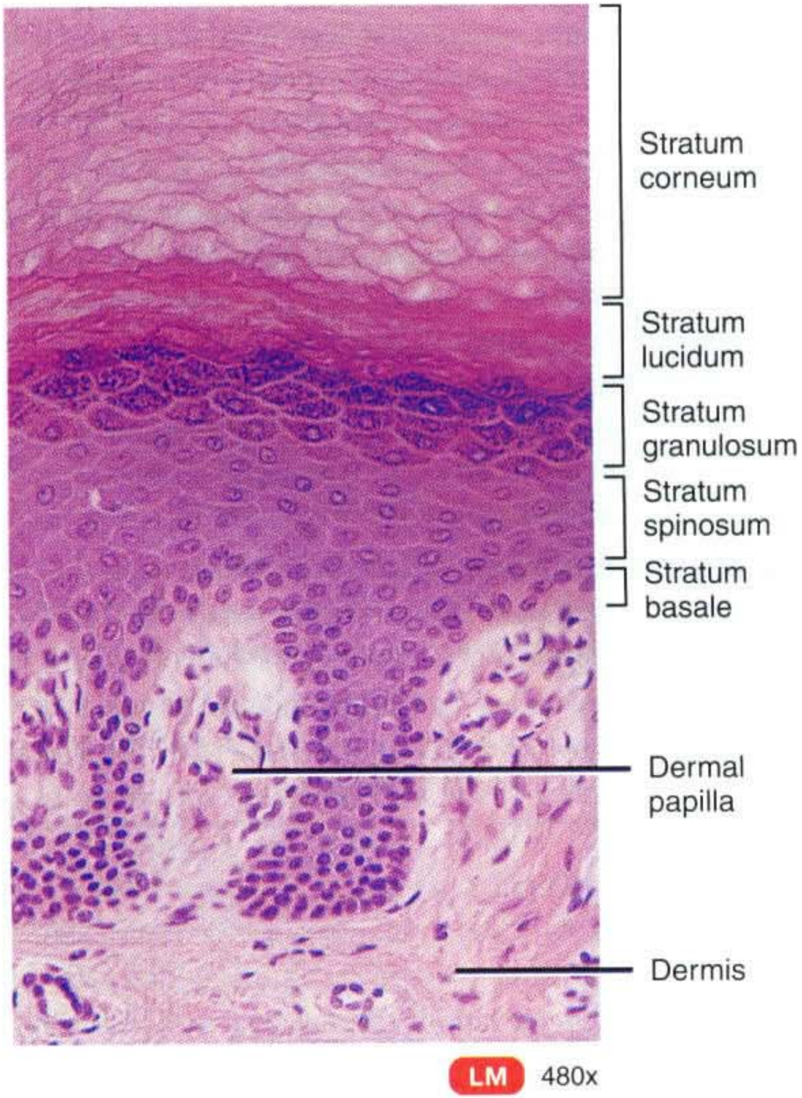

Electrode goes here !
Hair shaft
Dermal papilla
Capillary loop
Sweat pore
Sebaceous (oil) gland
Corpuscle of touch
(Meissner corpuscle)
Arrector pili muscle
Hair follicle
Hair root
Eccrine sweat gland
Lamellated (Pacinian)
corpuscle
Sensory nerve
Adipose
tissue
Blood vessels:
Vein
Artery
Free nerve ending
EPIDERMIS
Papillary
region
DERMIS
Reticular
region
Apocrine
sweat
gland
Subcutaneous
Layer
FUNCTIONS
1. Body temperature regulation.
2. Reservoir for blood.
3. Protection from external environment.
4. Cutaneous sensations.
5. Excretion and absorption.
6. Vitamin D synthesis.

Skin

Dermis

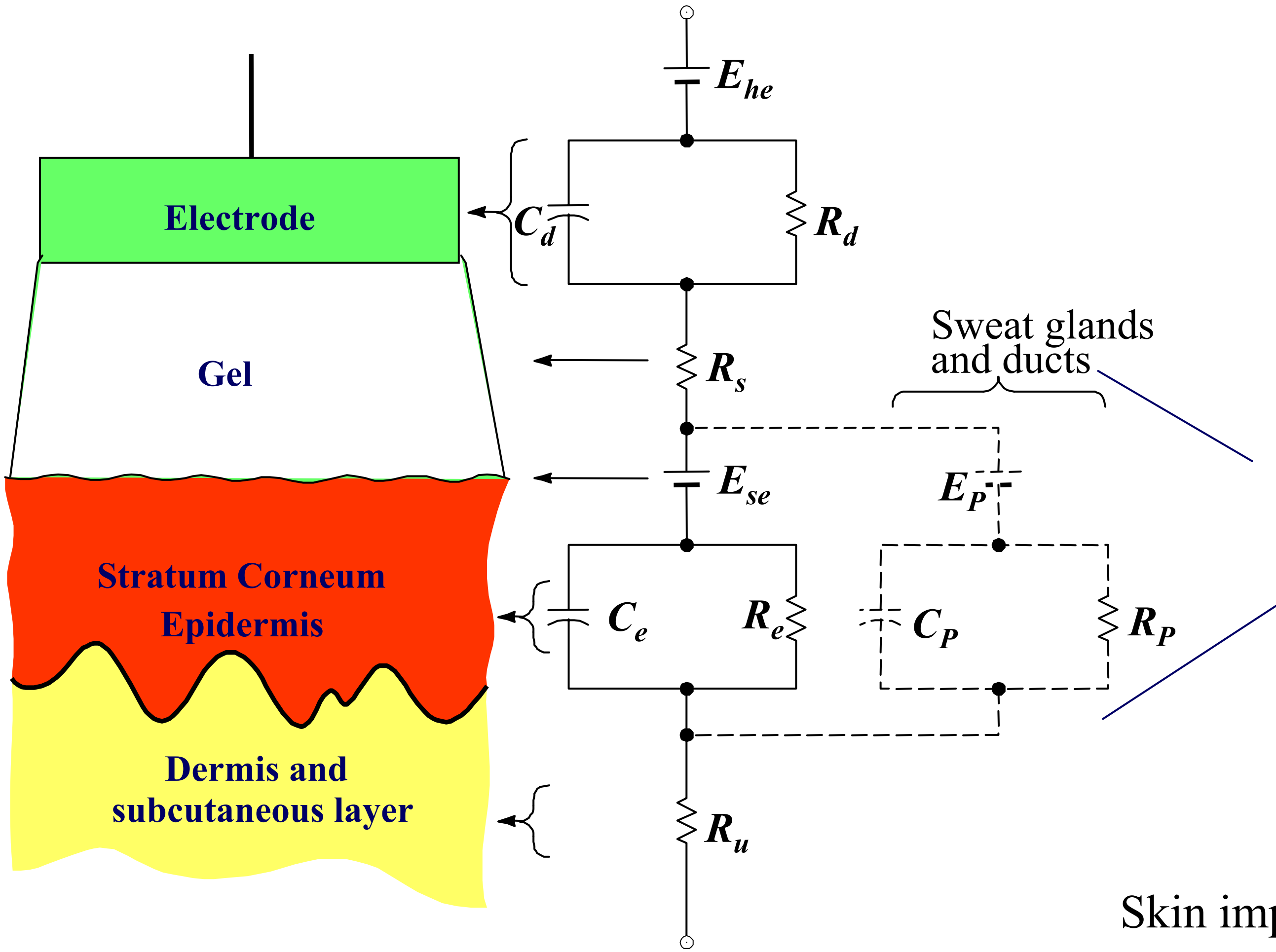


(a) Four principal cell types in epidermis



(b) Photomicrograph of a portion of skin

YEP…YOU GUESSED IT RIGHT (THE ELECTRIC MODEL…)



If only we could get rid of these ….

Skin impedance for 1cm^2 patch:
200kΩ @1Hz
200 Ω @ 1MHz

Motion Artifacts

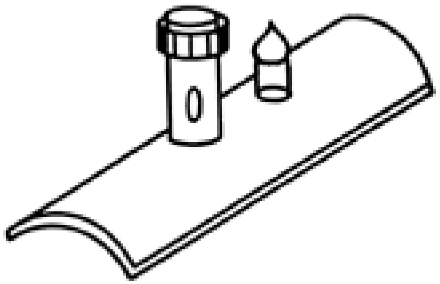
- Electrode moves ➔ Charge distribution gets screwed up!
- Charge distribution gets screwed up… ➔ Signal goes wild !
- Signal goes wild ➔ Measurement goes off the window
- Measurement goes off the window ➔ patient dies !

- Using non-polarizable electrodes (Ag/AgCl) reduce the low frequency noise created by motion artifacts ➔ ECG, EEG should use such electrodes (it can be filtered out of EMG)
- However, the gel-skin contact also creates motion artifacts, and the Ag/AgCl electrodes can’t do damn anything about it…!
- What to do…?

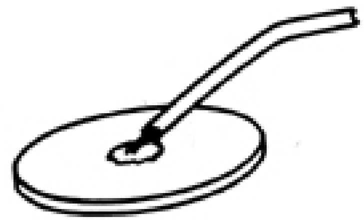
Commonly Used Biopotential Electrodes

- Metal plate electrodes
  - Large surface: Ancient, therefore still used, ECG
  - Metal disk: EMG, EEG smaller diameters, w/stainless steel, platinum or gold coated → motion artifacts
  - Disposable foam-pad: Cheap!, minimum prep time → Hospitals, ECG
- Suction electrodes
  - No straps or adhesives required, precordial (chest) ECG, can only be used for short periods only
- Floating electrodes
  - Their metal disk is recessed, swimming in the electrolyte gel, so it is not in contact with the skin → reduces motion artifact
- Flexible electrodes
  - Since body contours are often irregular, regularly shaped rigid electrodes may not always work, particularly with infants. Polymer or nylon with silver deposits, or carbon filled silicon rubber in the form of a thin film (Mylar film)
- Internal electrodes
  - Trust me, you don't wanna know!

Body-surface biopotential electrodes

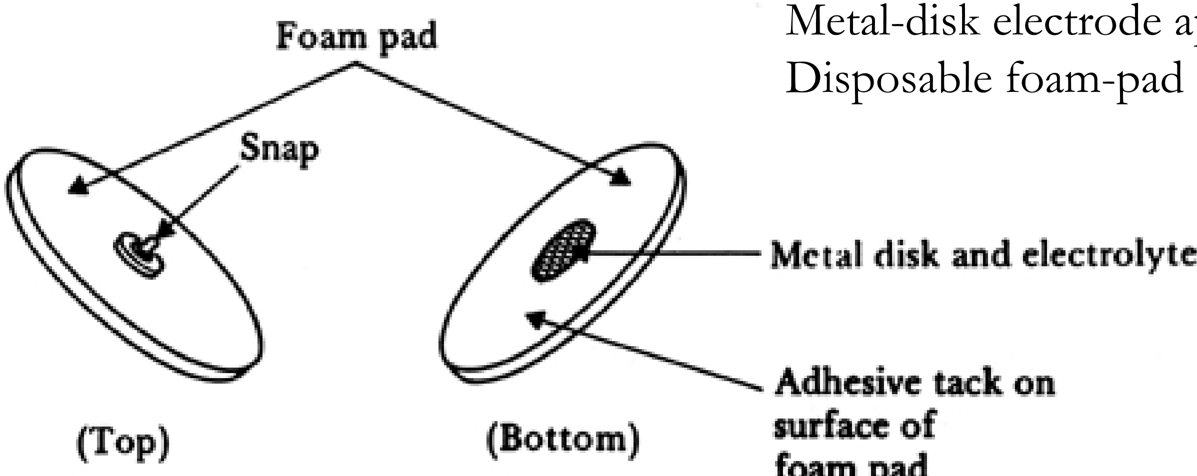


(a)



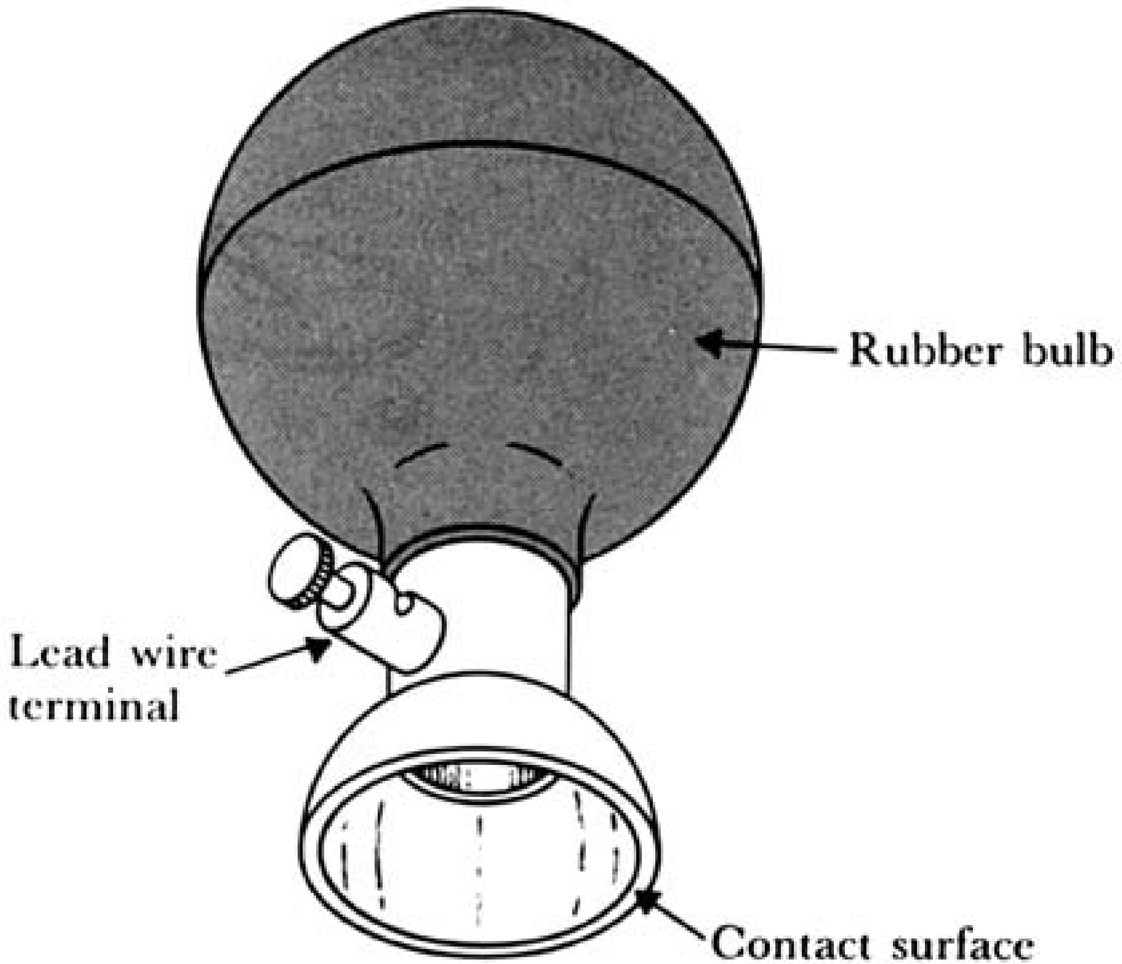
(b)

(a) Metal-plate electrode used for application to limbs.
Metal-disk electrode applied with surgical tape.
Disposable foam-pad electrodes, often used with ECG

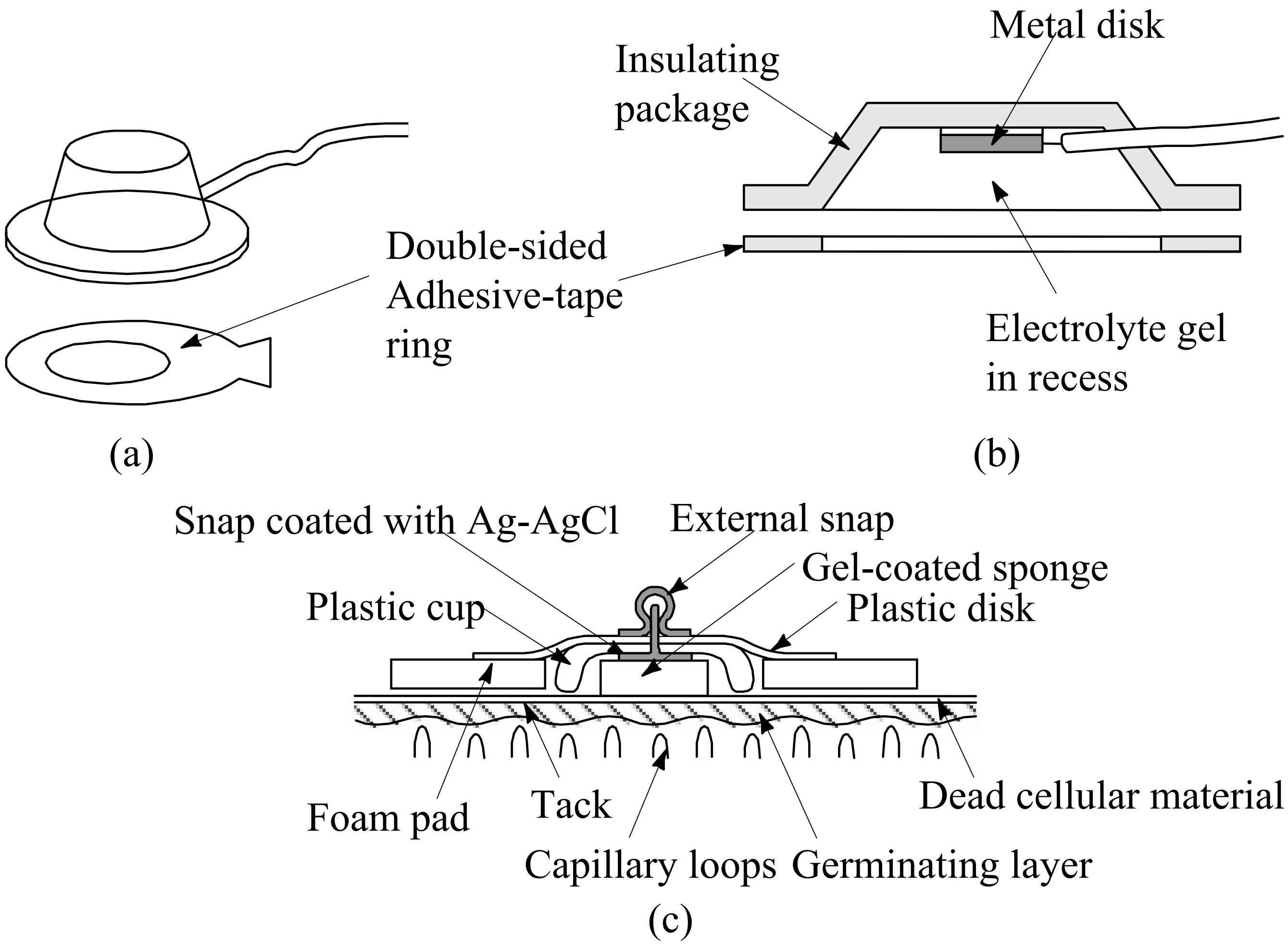


(c)

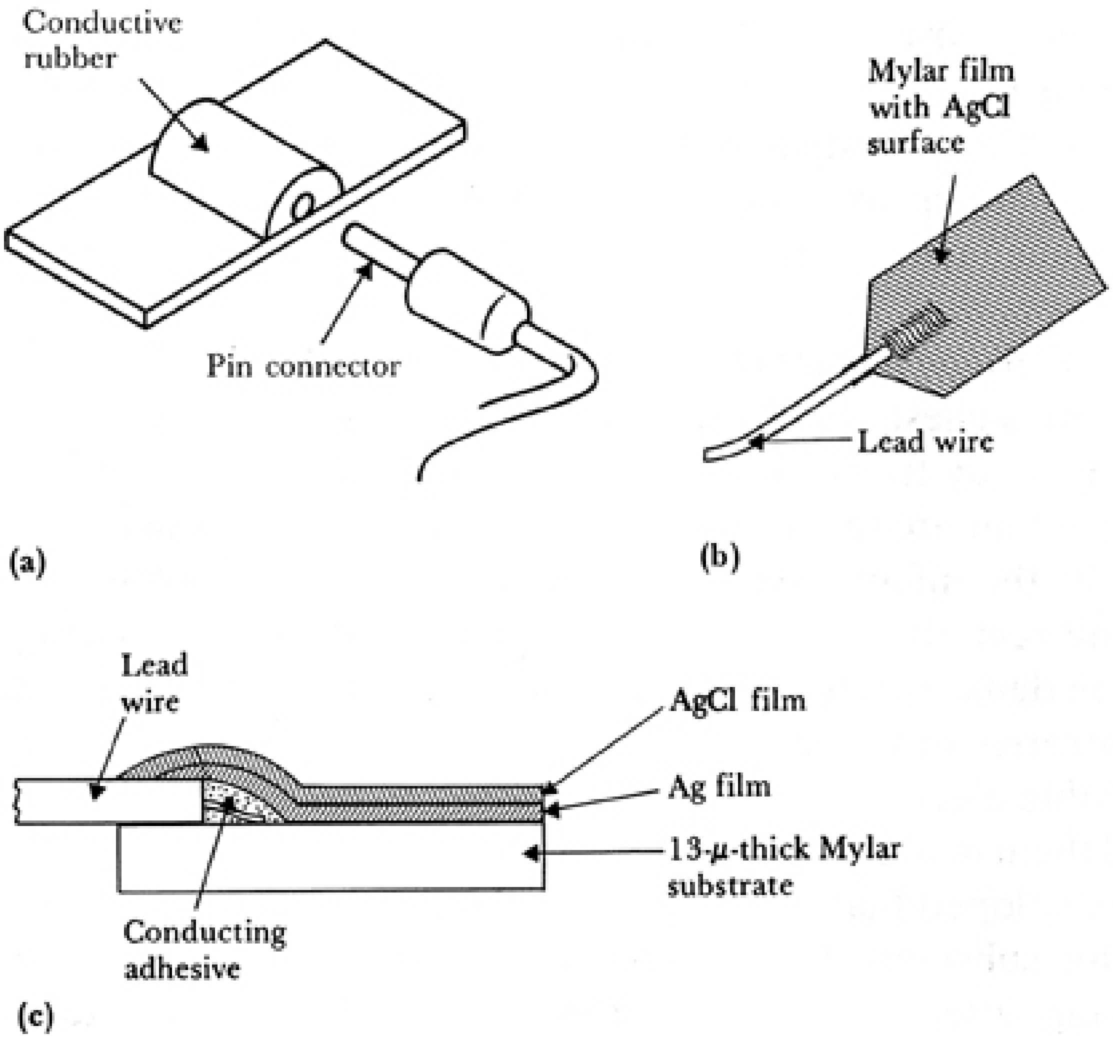
Suction Electrode



Floating Electrodes



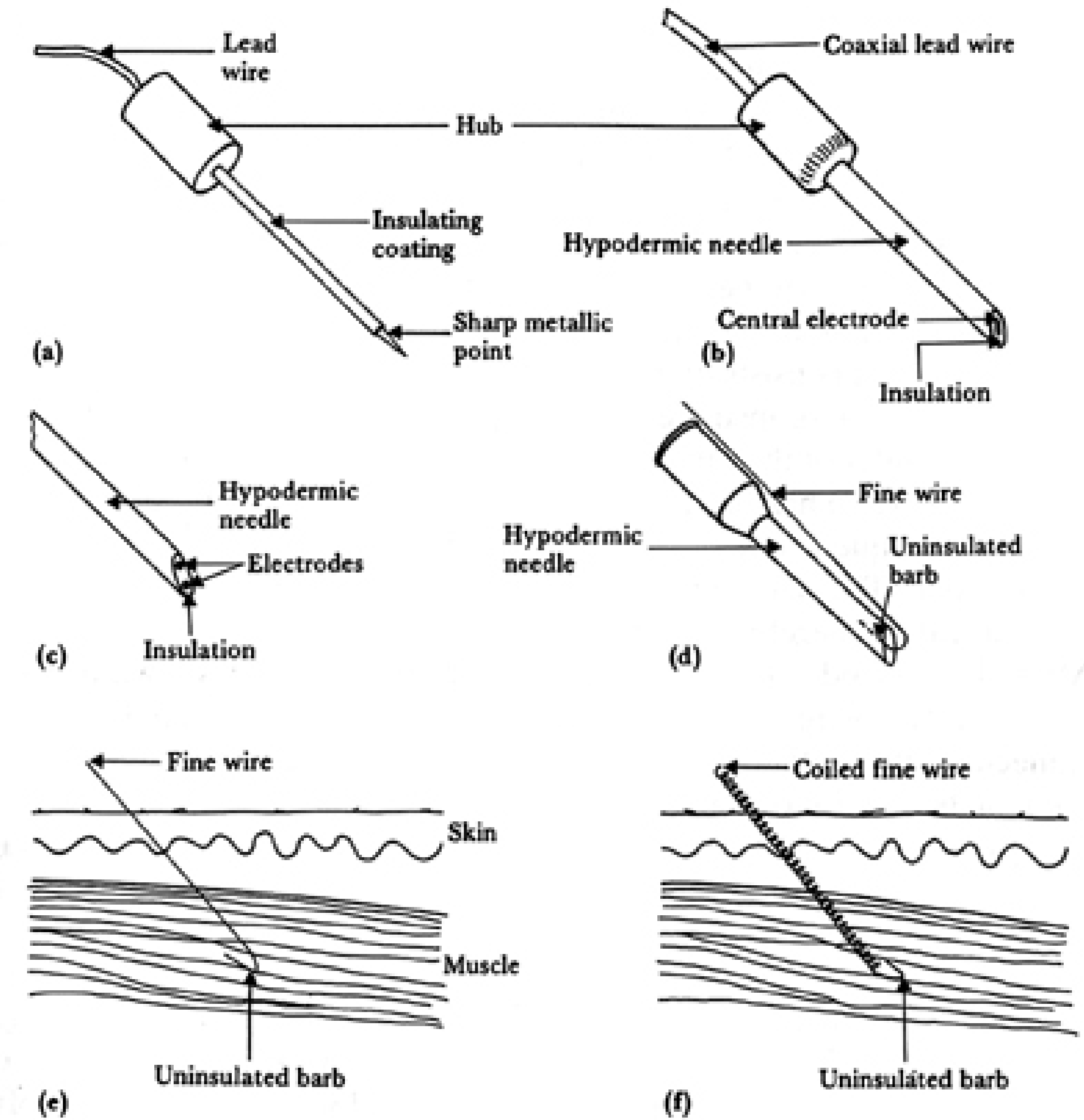
Flexible Electrodes



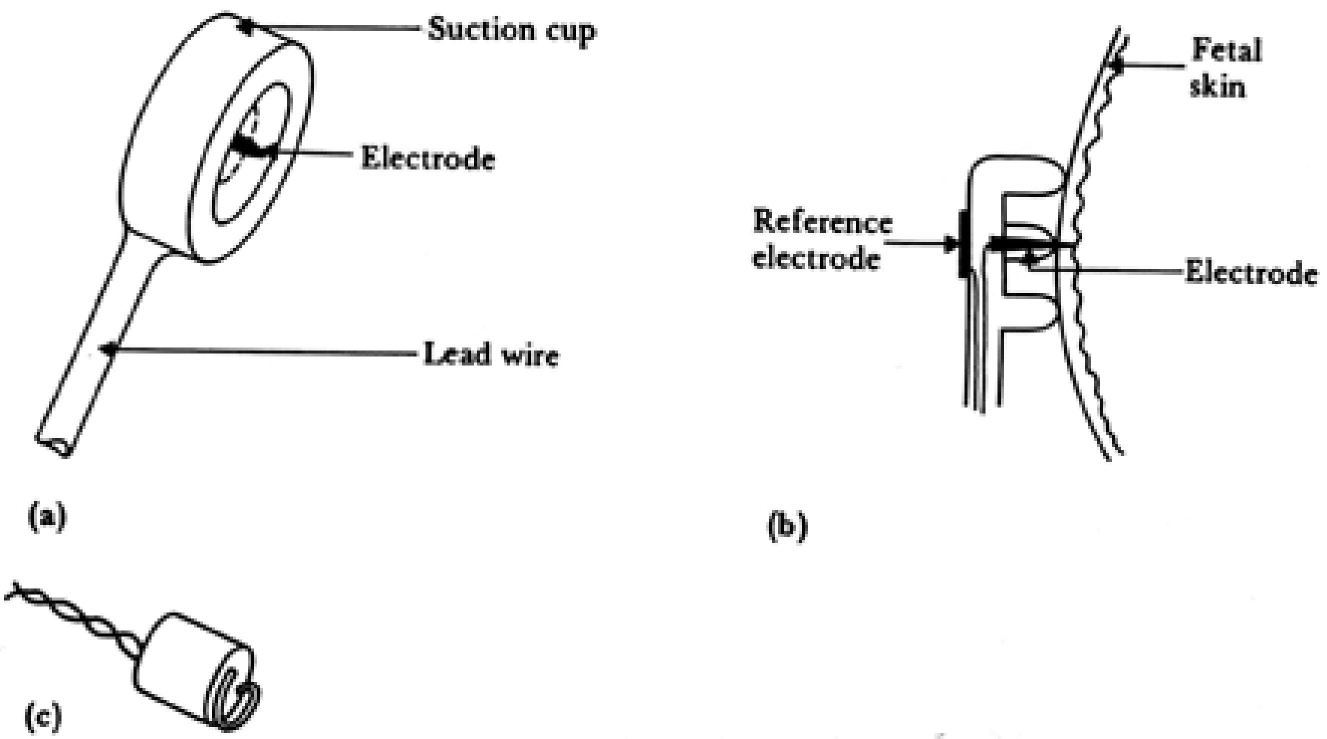
(a) Carbon-filled silicone rubber electrode. (b) Flexible thin-film neonatal electrode. (c) Cross-sectional view of the thin-film electrode in (b).

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.

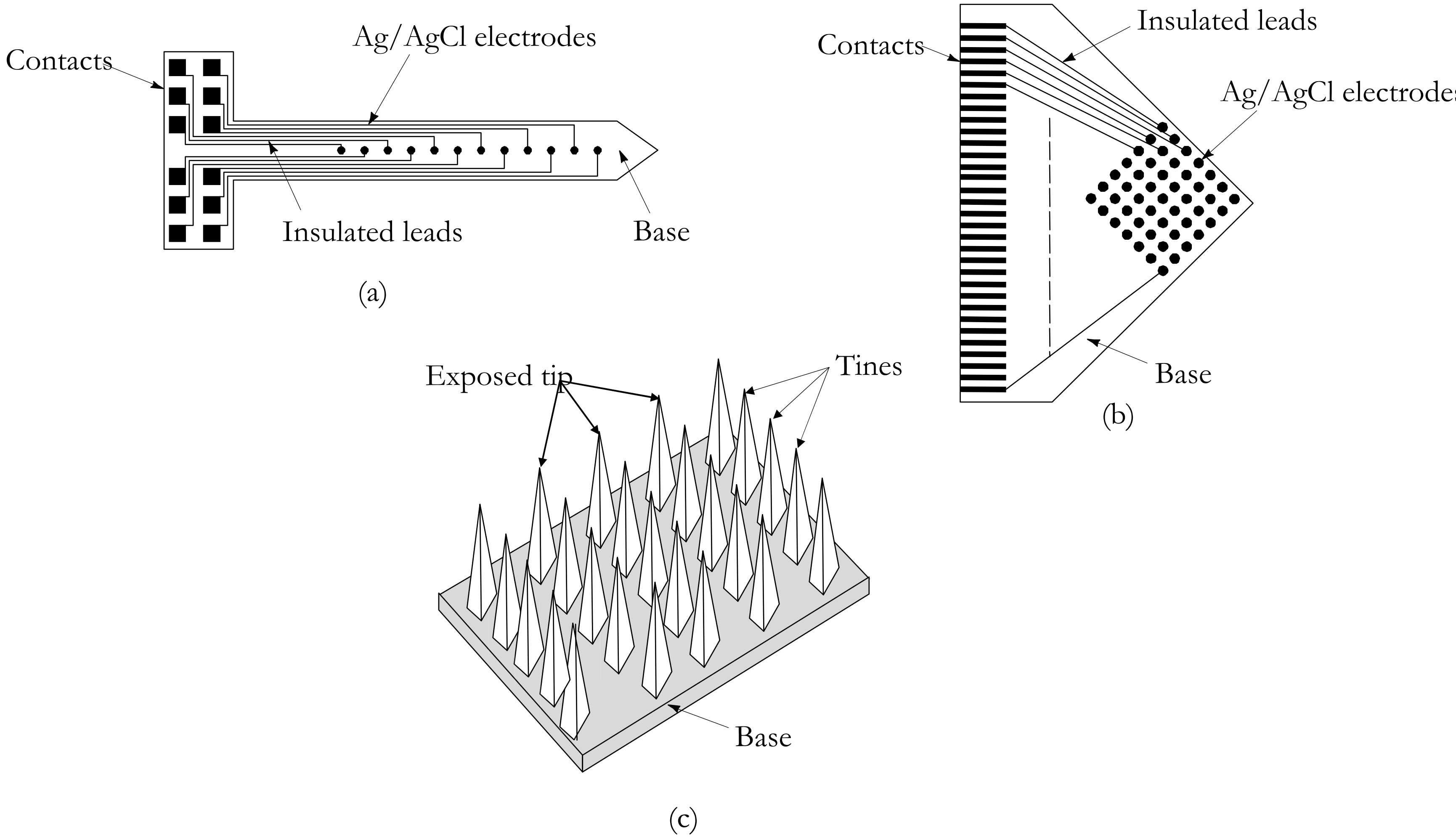


Fetal ECG Electrodes



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.

Electrode Arrays

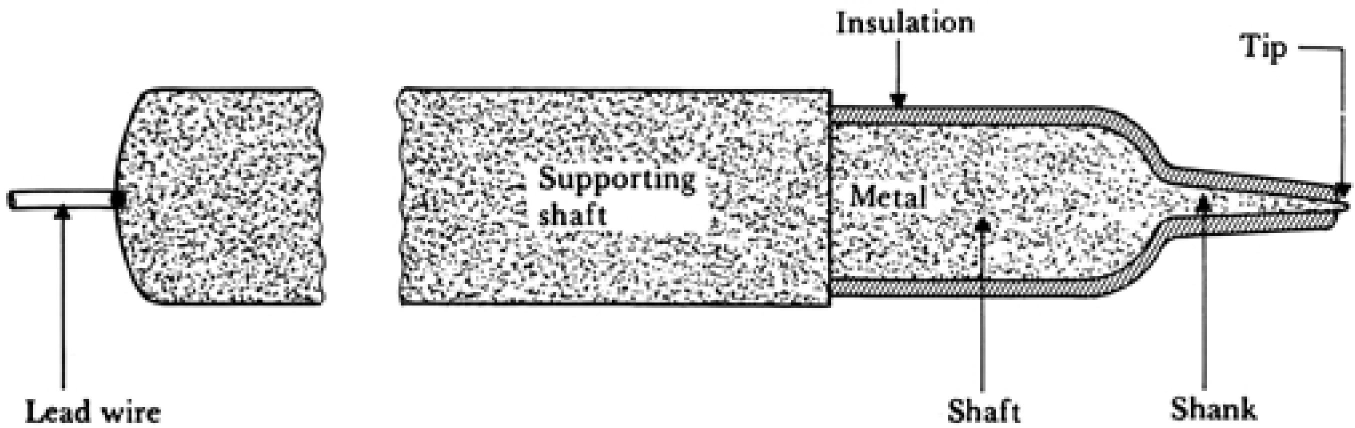


Examples of microfabricated electrode arrays. (a) One-dimensional plunge electrode array, (b) Two-dimensional array, and (c) Three-dimensional array

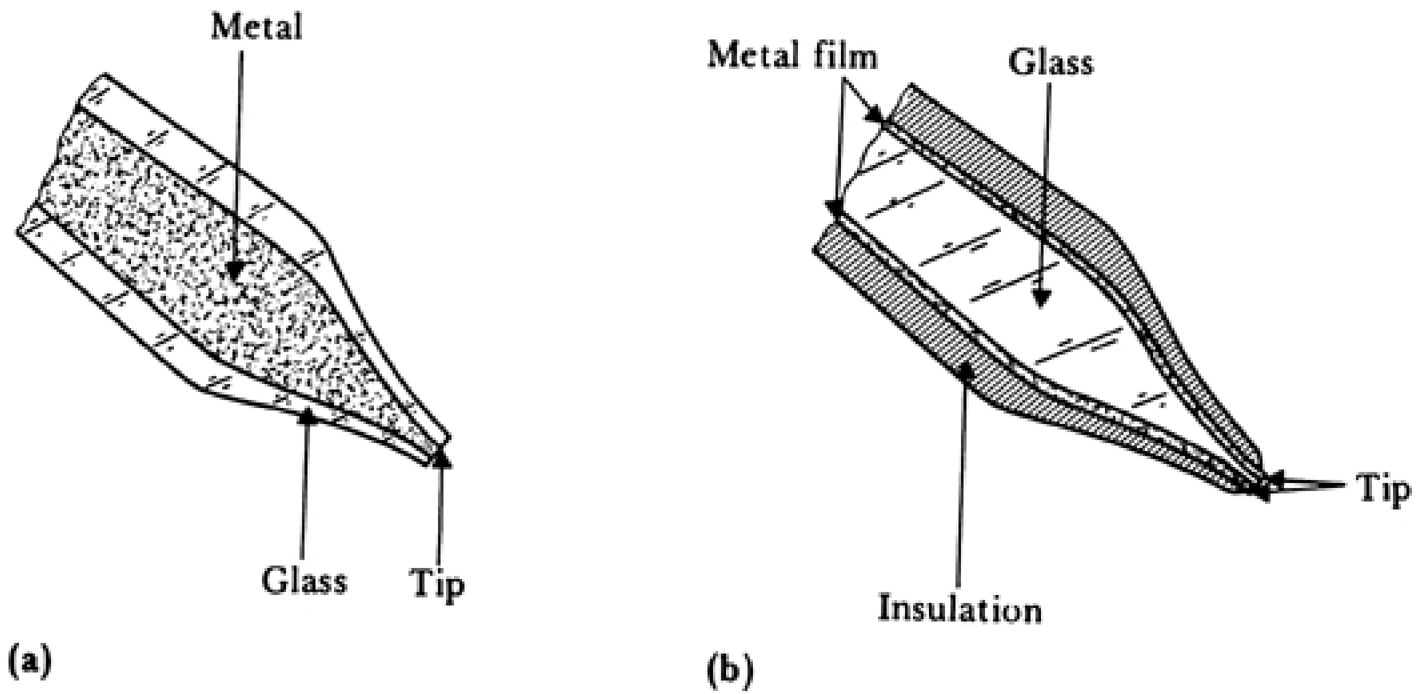
Microelectrodes

- Measure potential difference across cell membrane
  - Small enough to be placed into cell
  - Strong enough to penetrate cell membrane
  - Tip diameter: 0.05 – 10 micrometers
- 3 major types
  - Solid metal
  - Metal contained within/outside glass needle
  - Glass micropipet

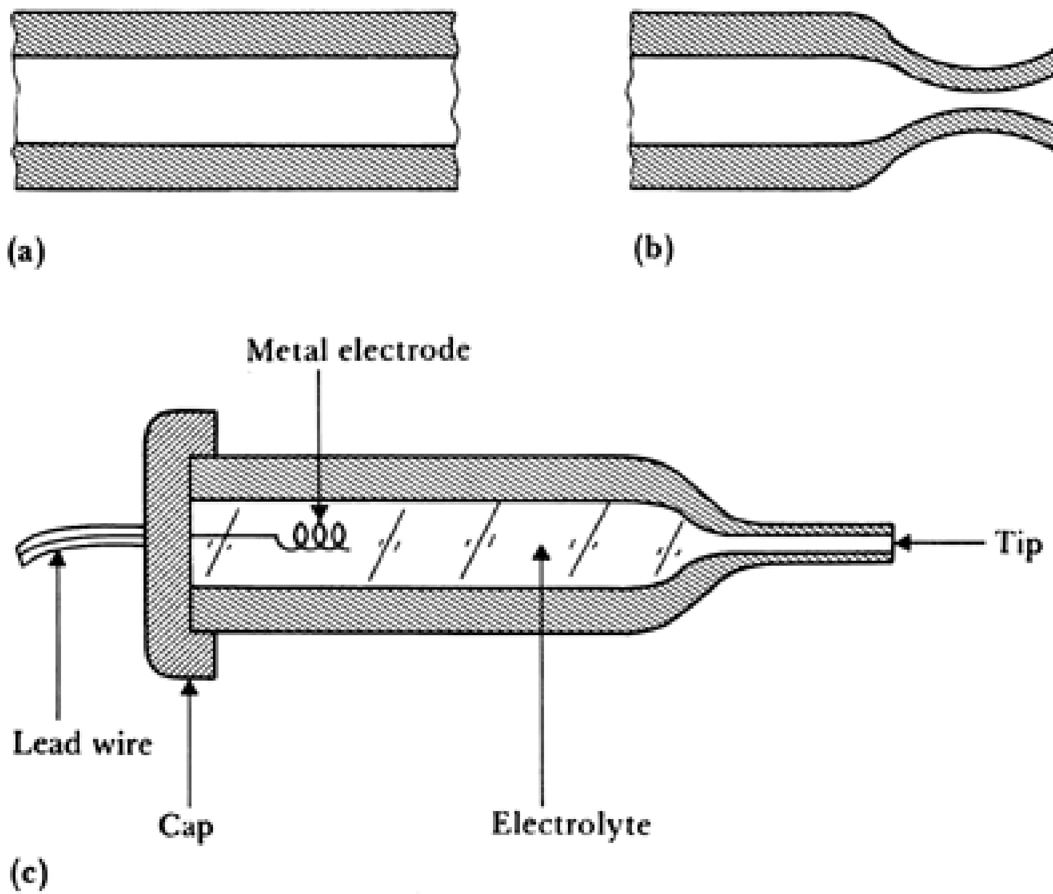
Metal Microelectrodes



Metal Supported Microelectrodes

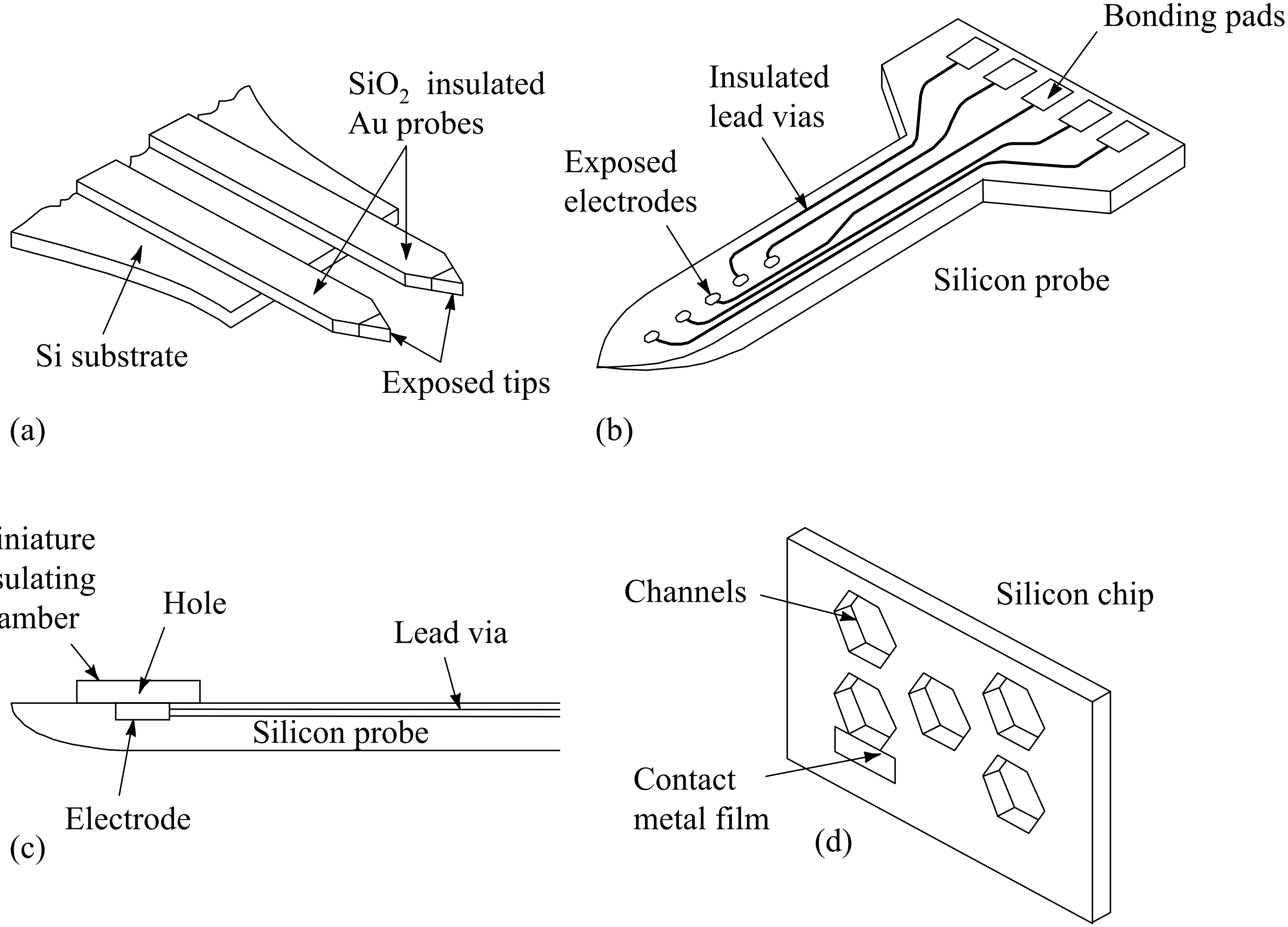


Glass Micropipet



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.

MICROELECTRONIC TECHNOLOGY FOR MICROELECTRODES



Different types of microelectrodes fabricated using microelectronic technology (a) Beam-lead multiple electrode. (b) Multielectrode silicon probe (c) Multiple-chamber electrode. (d) Peripheral-nerve electrode