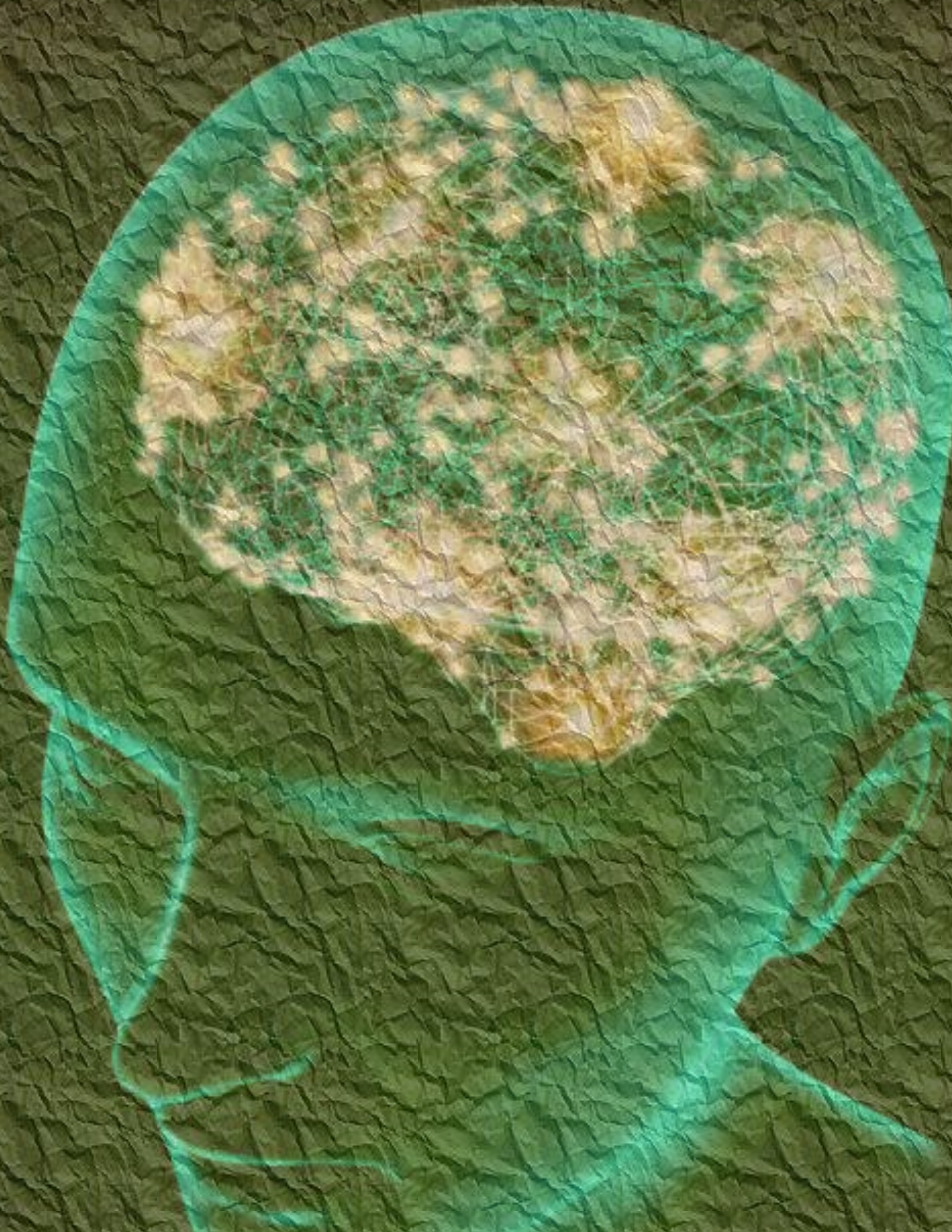
# BIOPOTENTIAL ELECTRODE

IDA MARIA BINTI MOHD YUSOFF

1st Ed



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Ida Maria binti Mohd Yusoff

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**UNIT PENERBITAN**

Politeknik Sultan Salahuddin Abdul Aziz Shah
Persiaran Usahawan,
Seksyen U1,
40150 Shah Alam
Selangor

Telephone No. : 03 5163 4000
Fax No. : 03 5569 1903

# PREFACE

It gives great pleasure to release this book as a reference for students enrolled in Diploma in Electronic Engineering (Medical).

It has never been easy to accept this challenge. Effort and strength required to create this book. Many ideas presented in this book originated from classroom experiences.

This book contain selected topic for Chapter 2: Biopotential Amplifier. One of the features of this book is, that it does not have a textbook structure when the chapters, in order to be understood, need to be read in the sequence given. This book can be read based on interests, tastes, and preferences.

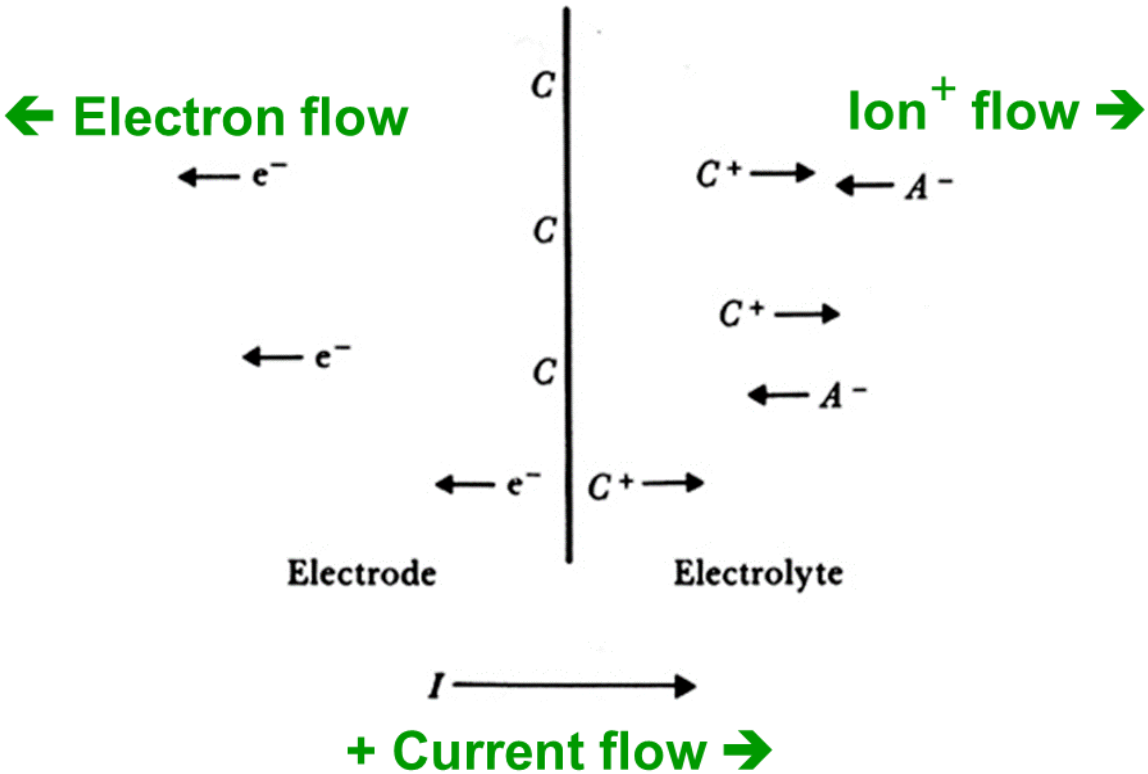
It is hope that this book will help readers understand more about this topic.

“YOLO, treasure it”

IDA MARIA BINTI MOHD YUSOFF
Department of Electrical Engineering
Politeknik Sultan Salahuddin Abdul Aziz Shah

# TABLE OF CONTENTS

# Current Flow at the Electrode-Electrolyte Interface



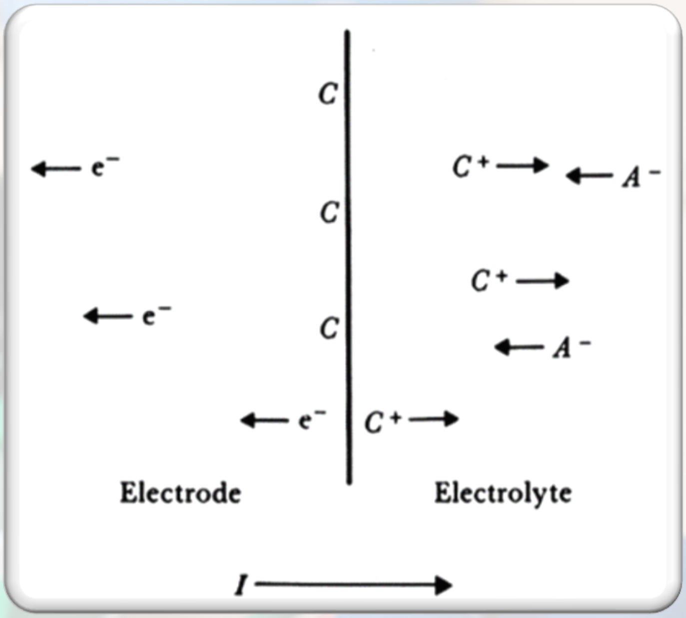

The current crosses it from left to right. The electrode consists of metallic atoms C. The electrolyte is an aqueous solution containing cations of the electrode metal $C^+$ and anions $A^-$

- Electrons move in opposite direction to current flow
- Cations (C+ ) move in same direction as current flow
- Anions (A– ) move in opposite direction of current flow
- Chemical oxidation (current flow right) - reduction (current flow left) reactions at the interface:

  $C \rightleftharpoons C^+ + e^-$

  $A^- \rightleftharpoons A + e^-$
- No current at equilibrium

# Half-Cell Potential

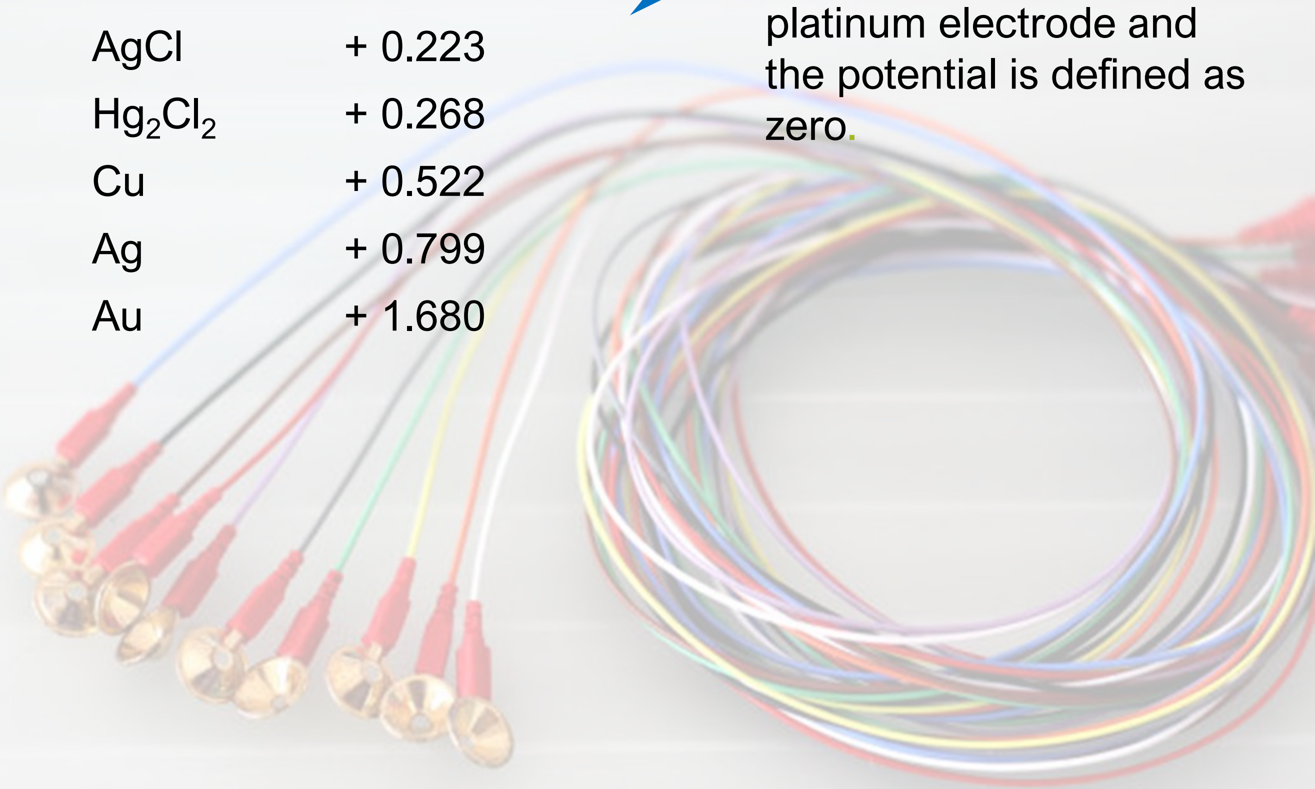



- When metal (C) contacts electrolyte, oxidation ($C \rightarrow C^{+} + e^{-}$) or reduction ($A^{-} \leftarrow A + e^{-}$) begins immediately.
- Local concentration of cations at the surface changes.
- Charge builds up in the regions.
- Electrolyte surrounding the metal assumes a different electric potential from the rest of the solution.
- This potential difference is called the half-cell potential ($E^{0}$).
- Separation of charge at the electrode-electrolyte interface results in a electric double layer (bilayer).
- Measuring the half-cell potential requires the use of a second reference electrode.
- By convention, the hydrogen electrode is chosen as the reference.

# Half-Cell Potentials of Common Metals at 25 °C

| Metal | Potential $E^0$ (volts) |
|---|---|
| Al | - 1.706 |
| Zn | - 0.763 |
| Cr | - 0.744 |
| Fe | - 0.409 |
| Cd | - 0.401 |
| Ni | - 0.230 |
| Pb | - 0.126 |
| H | 0.000 |
| AgCl | + 0.223 |
| $Hg_2Cl_2$ | + 0.268 |
| Cu | + 0.522 |
| Ag | + 0.799 |
| Au | + 1.680 |

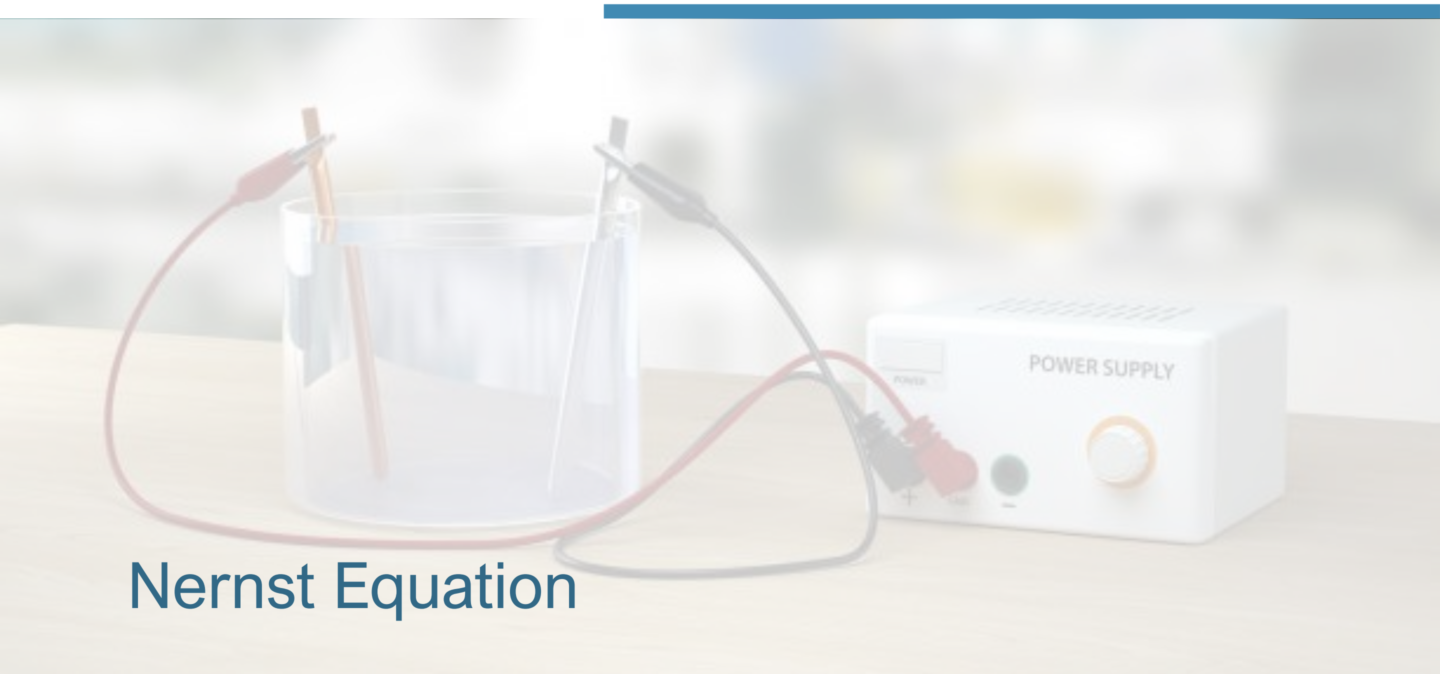
By definition: Hydrogen is bubbled over a platinum electrode and the potential is defined as zero.



# Electrode Polarization

- Standard half-cell potential ($E^0$):
    - Normally $E^0$ is an equilibrium value and assumes zero-current across the interface.
    - When current flows, the half-cell potential, $E^0$ , changes.
- Overpotential *($V_p$):*
    - Difference between non-zero current and zero-current half-cell potentials; also called the ***polarization potential ($V_p$).***
- Components of the overpotential ($V_p$):
    - ***Ohmic*** ($V_r$)***:*** Due to the resistance of the electrolyte (voltage drop along the path of ionic flow).
    - ***Concentration*** *($V_c$):* Due to a redistribution of the ions in the vicinity of the electrode-electrolyte interface (concentration changes).
    - ***Activation*** ($V_a$): Due to metal ions going into solution (must overcome an energy barrier, the activation energy) or due to metal plating out of solution onto the electrode (a second activation energy).

$$V_p = V_r + V_c + V_a$$




# Nernst Equation

- Governs the half-cell potential:

$$E = E^0 + \frac{RT}{nF}\ln(a_{C^{n+}})$$

where

*E* – half-cell potential

$E^0$ – standard half-cell potential

(the electrode in an electrolyte with unity activity at standard temperature)

*R* – universal gas constant [ 8.31 J/(mol K) ]

*T* – absolute temperature in K

*n* – valence of the electrode material

*F* – Faraday constant [ 96,500 C/(mol/valence) ]

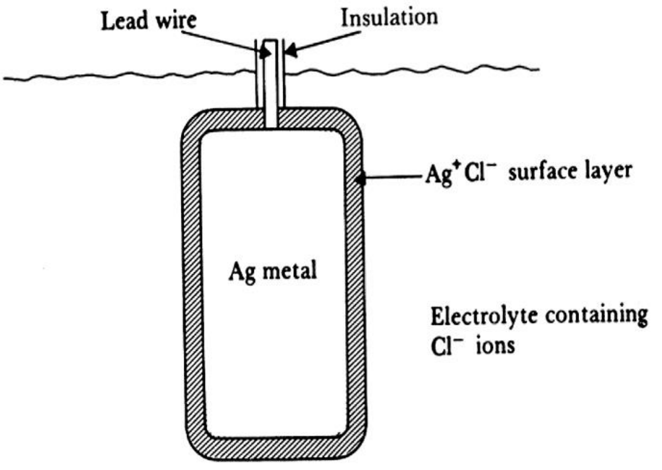
$a_{C^{n+}}$ – ionic activity of cation $C^{n+}$

(its availability to enter into a reaction)


# Polarizability & Electrodes

- Perfectly polarizable electrodes:
  - No charge crosses the electrode when current is applied
  - Noble metals are closest (like platinum and gold); they are difficult to oxidize and dissolve.
  - Current does not cross, but rather changes the concentration of ions at the interface.
  - Behave like a capacitor.
- Perfectly non-polarizable electrodes:
  - All charge freely crosses the interface when current is applied.
  - No overpotential is generated.
  - Behave like a resistor.
  - Silver/silver-chloride is a good non-polarizable electrode.


# The Classic Ag/AgCl Electrodes




A silver/silver chloride electrode, shown in cross section.

- <u>Features:</u>
  - Practical electrode, easy to fabricate.
  - Metal (Ag) electrode is coated with a layer of slightly soluble ionic compound of the metal and a suitable anion (Cl).
- <u>Reaction 1:</u> silver oxidizes at the Ag/AgCl interface

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

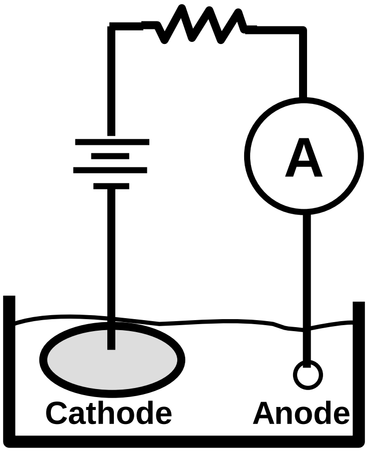
- <u>Reaction 2:</u> silver cations combine with chloride anions

$$Ag^{+} + Cl^{-} \rightleftharpoons AgCl$$

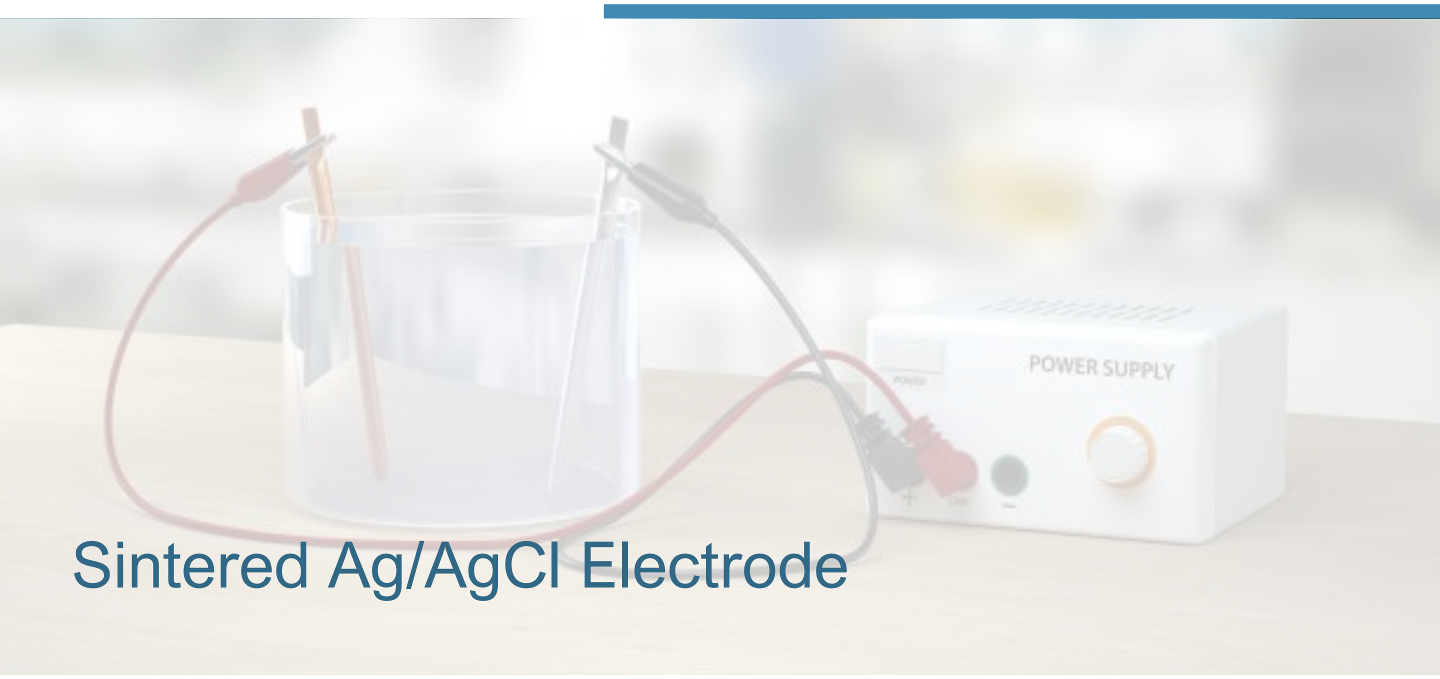
AgCl is only slightly soluble in water so most precipitates onto the electrode to form a surface coating.


# Ag/AgCl Fabrication

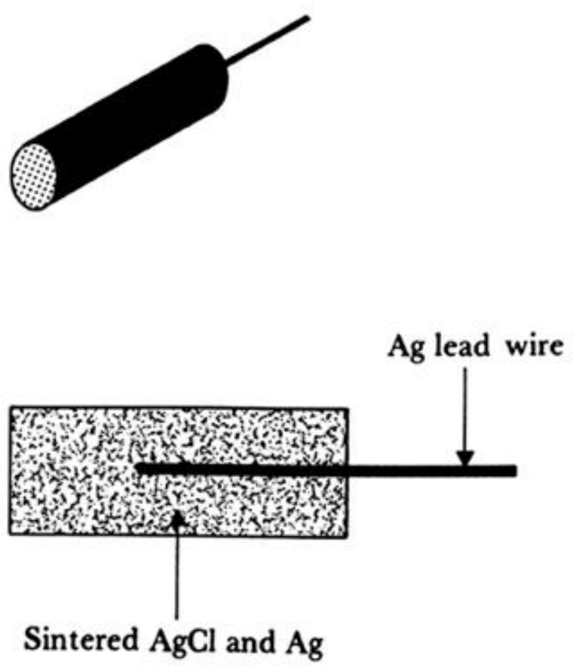
- Electrolytic process
- Large Ag/AgCl electrode serves as the cathode.
- Smaller Ag electrode to be chloridized serves as the anode.
- A 1.5 volt battery is the energy source.
- A resistor limits the current.
- A milliammeter measures the plating current.
- Reaction has an initial surge of current.
- When current approaches a steady state (about 10 μA), the process is terminated.




**Electrochemical Cell**

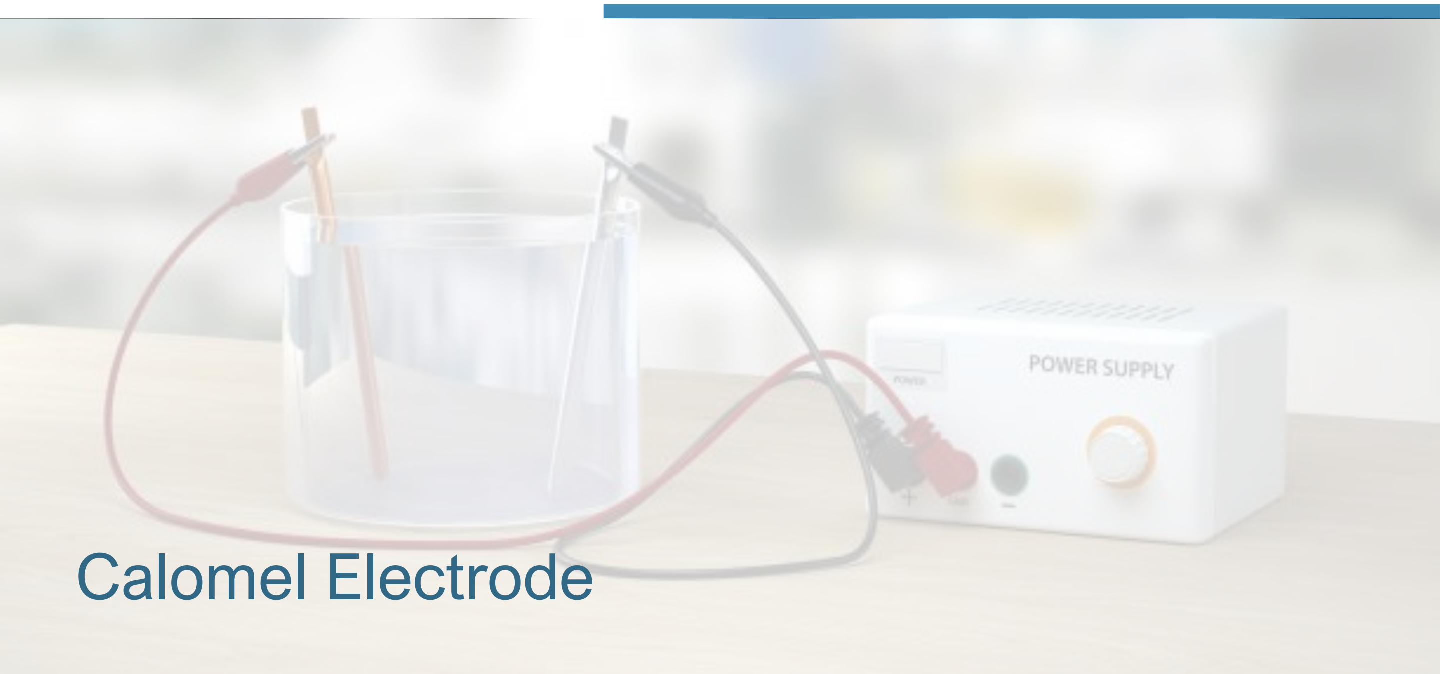



# Sintered Ag/AgCl Electrode

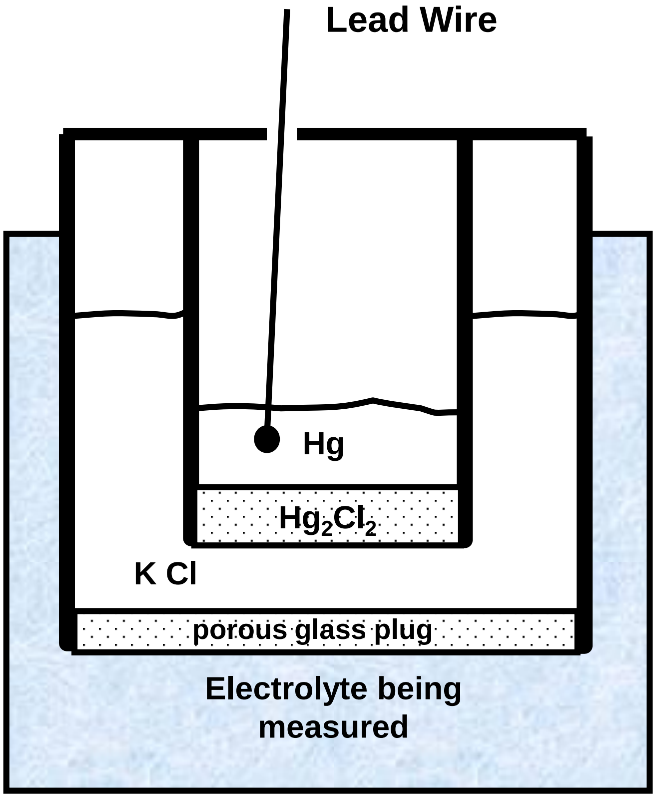



*<u>Sintering Process</u>*

- A mixture of Ag and AgCl powder is pressed into a pellet around a silver lead wire.
- Baked at 400 ºC for several hours.
- Known for great endurance (surface does not flake off as in the electrolytically generated electrodes).
- Silver powder is added to increase conductivity since AgCl is not a good conductor.




# Calomel Electrode




- Calomel is mercurous chloride ($Hg_2Cl_2$).
- Approaches *perfectly non-polarizing* behavior
- Used as a *reference* in pH measurements.
- Calomel paste is loaded into a porous glass plug at the end of a glass tube.
- Elemental Hg is placed on top with a lead wire.
- Tube is inserted into a saturated KCl solution in a second glass tube.
- A second porous glass plug forms a liquid-liquid interface with the analyte being measured.

# Understanding surface electrode transducer in biomedical application

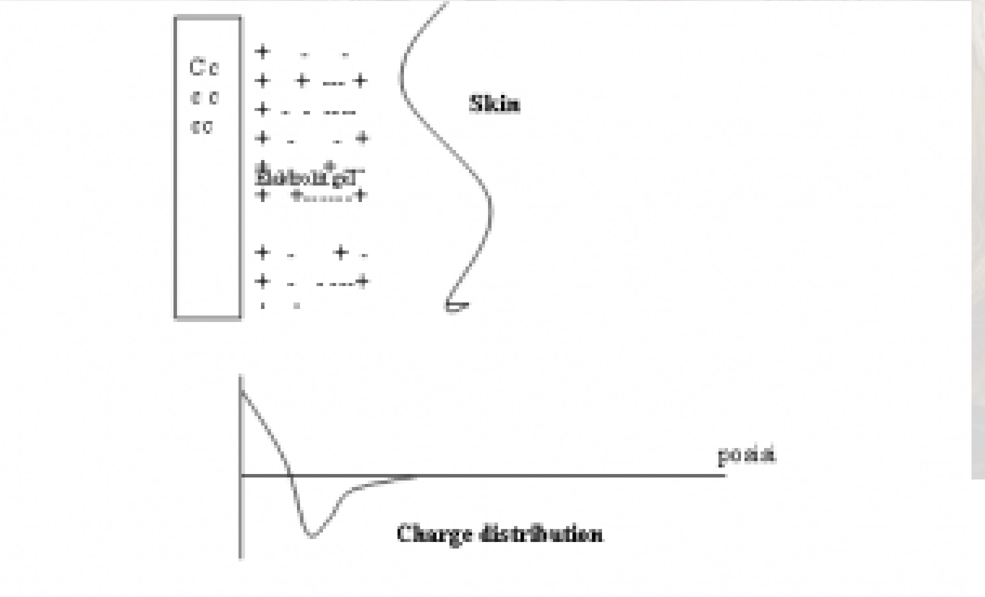
In human body, the electrical current agent is in form of ion and cation, by the way in biomedical instrumentation tool the agent of electrical current is in form of proton and electron.

So there are different agent of electrical current in human body an biomedical instrumentation tool. The main function of surface transducer is to bridge two different. So it is called as “transducer” because change the electrical current agent in biomedical instrumentation, from ion / cation become proton and electron.

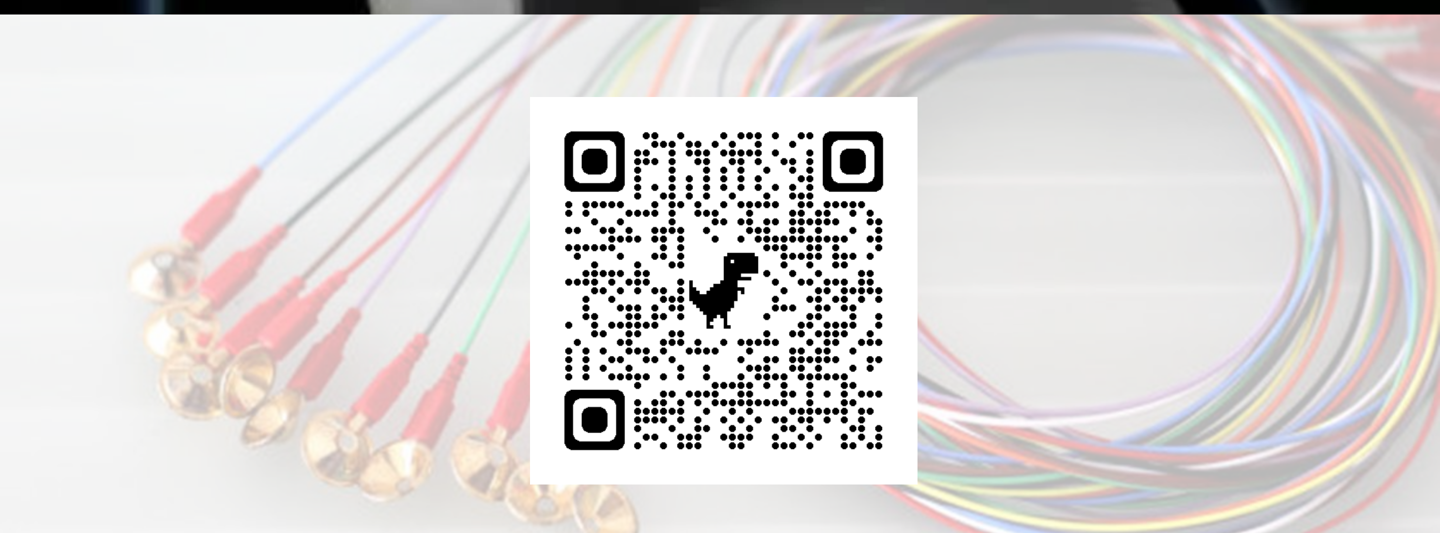
To do its job, surface biomedical transducer is scrub with electrical gel before applied to the patient.

# Charge distribution in surface electrode

Charge distribution in surface electrode
In electronic point of view, there are exist a charge profile between skin and the surface biomedical transducer. Picture below show this charge profile :

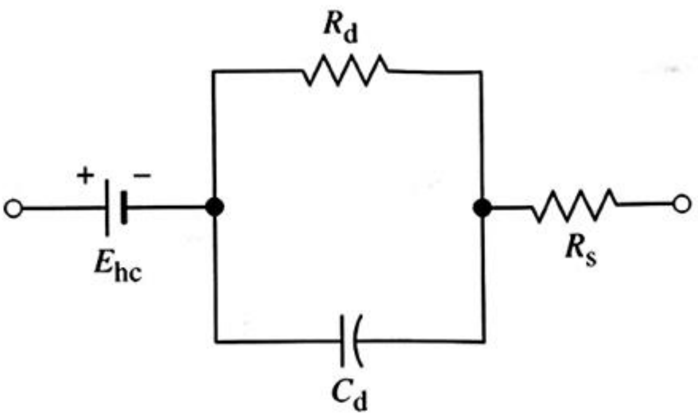


# How it’s made (video) : Medical Electrode

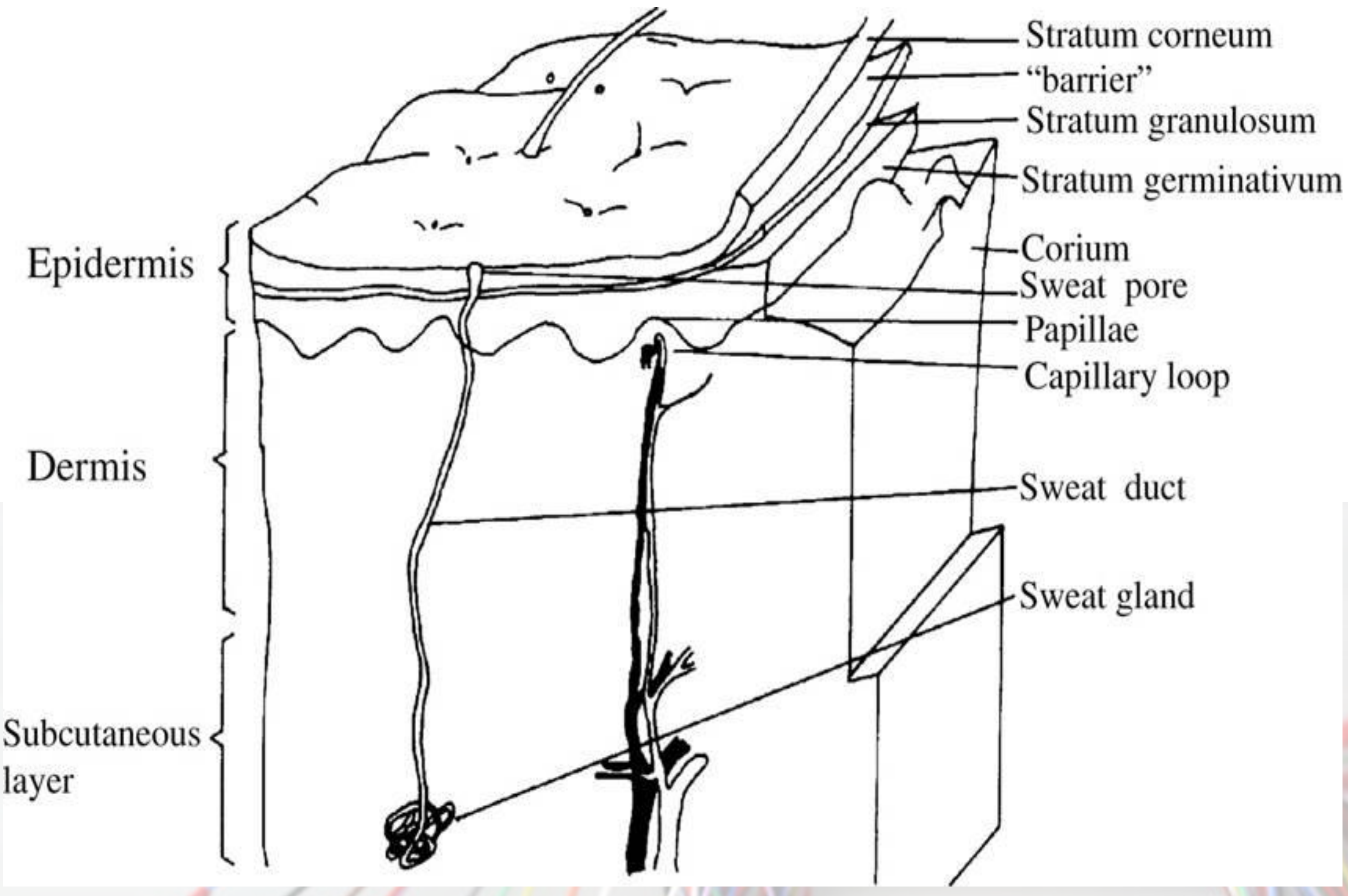
https://www.youtube.com/watch?v=sVKuMDI6sNg

# Equivalent circuit for a biopotential electrode in contact with an electrolyte

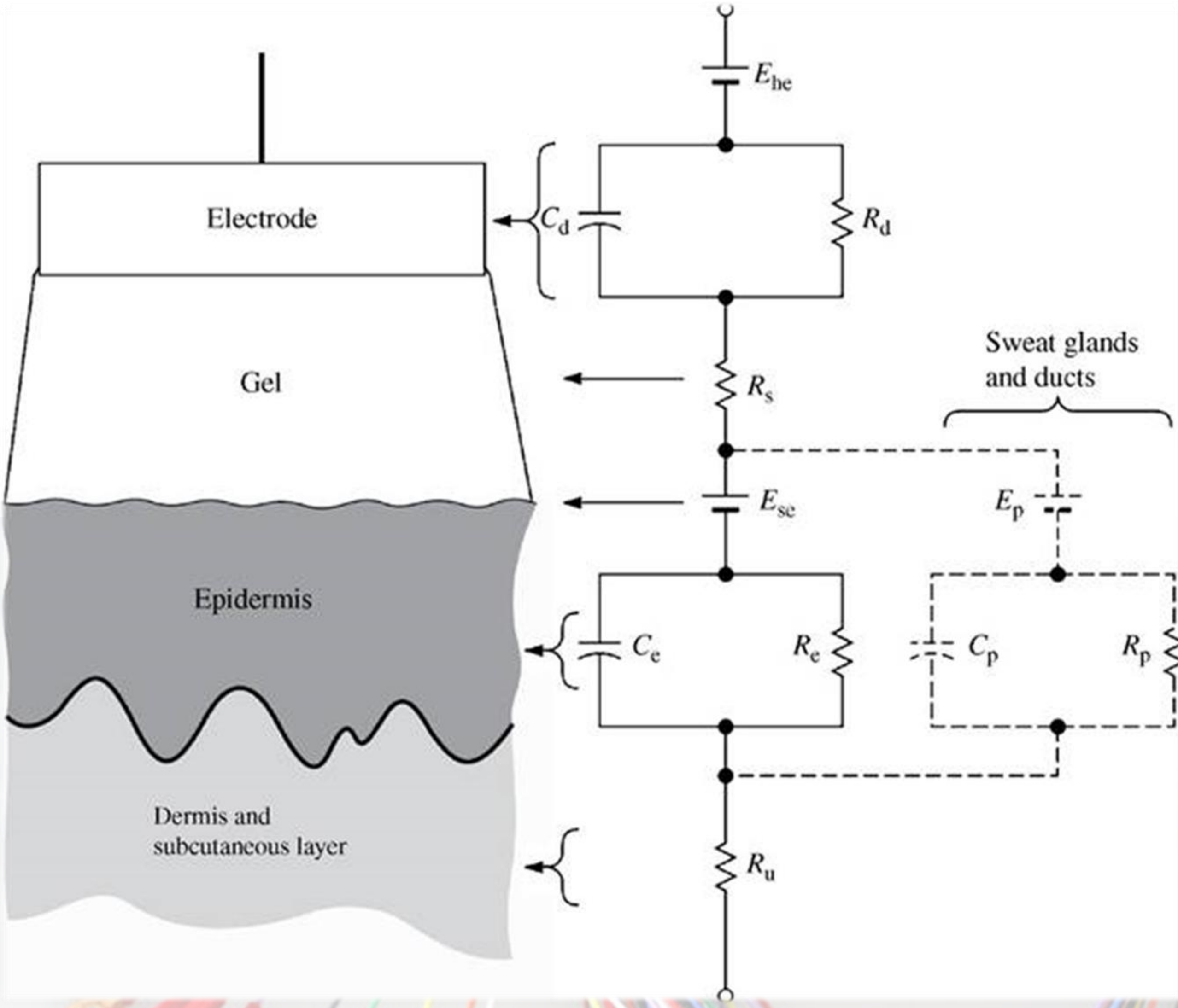



- $E_{hc}$ is the half-cell potential
- $C_d$ is the capacitance of the electric double layer (polarizable electrode properties).
- $R_d$ is resistance to current flow across the electrode-electrolyte interface (non-polarizable electrode properties).
- $R_s$ is the series resistance associated with the conductivity of the electrolyte.
- At high frequencies: $R_s$
- At low frequencies: $R_d + R_s$

# Magnified section of skin, showing the various layers



# A body-surface electrode is placed against skin, showing the total electrical equivalent circuit



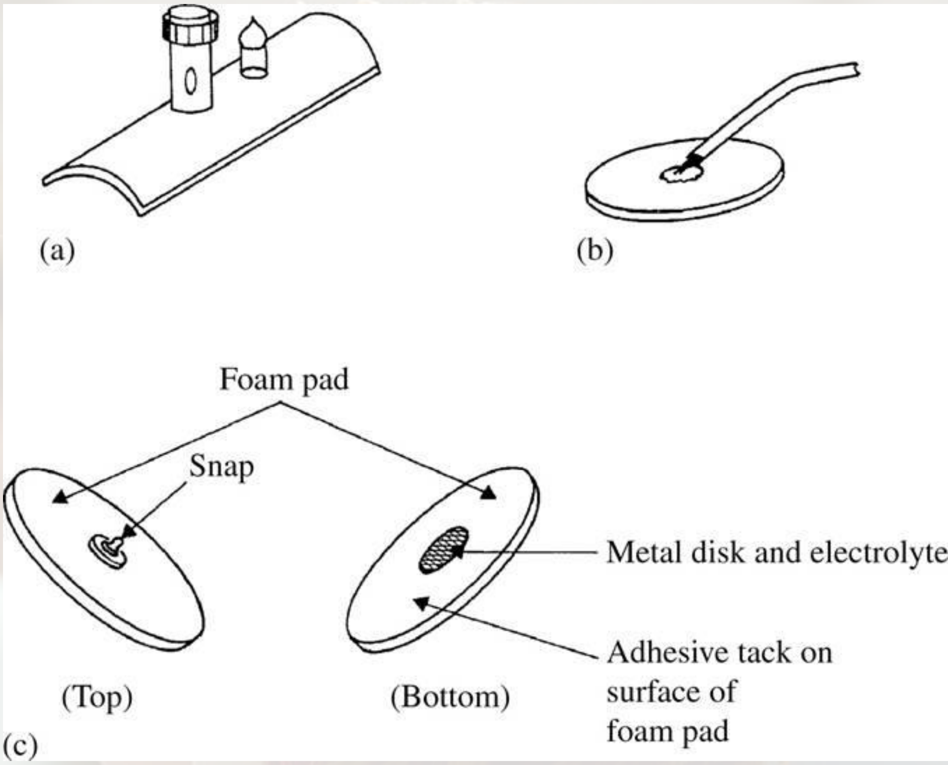

Each circuit above is at approximately the same level at which the physical process that it represents would be in the left-hand diagram.

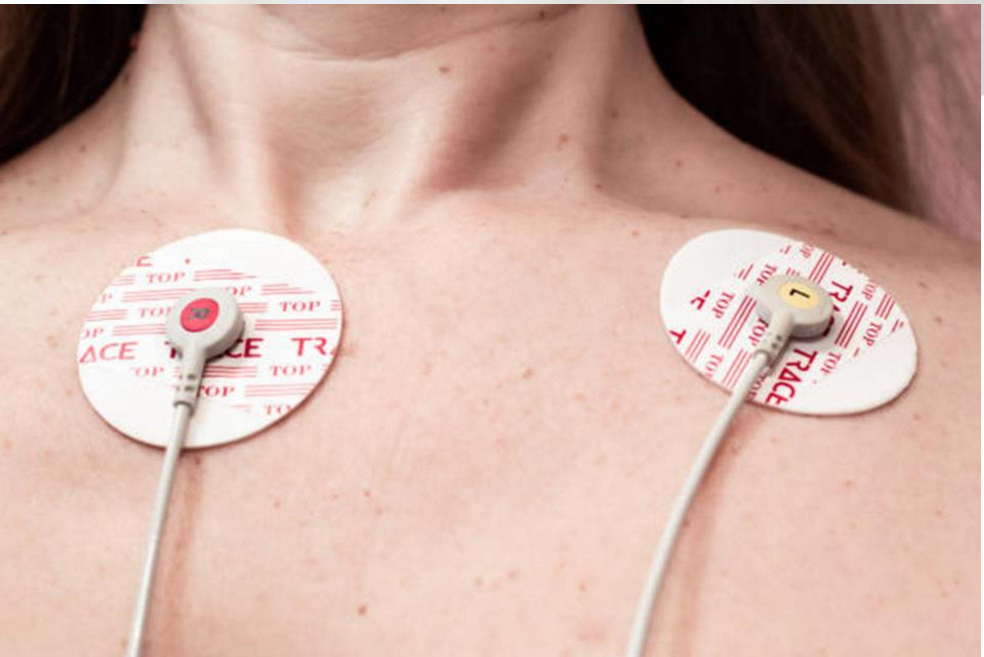
# Body-surface biopotential electrodes

(a) Metal-plate electrode used for application to limbs,

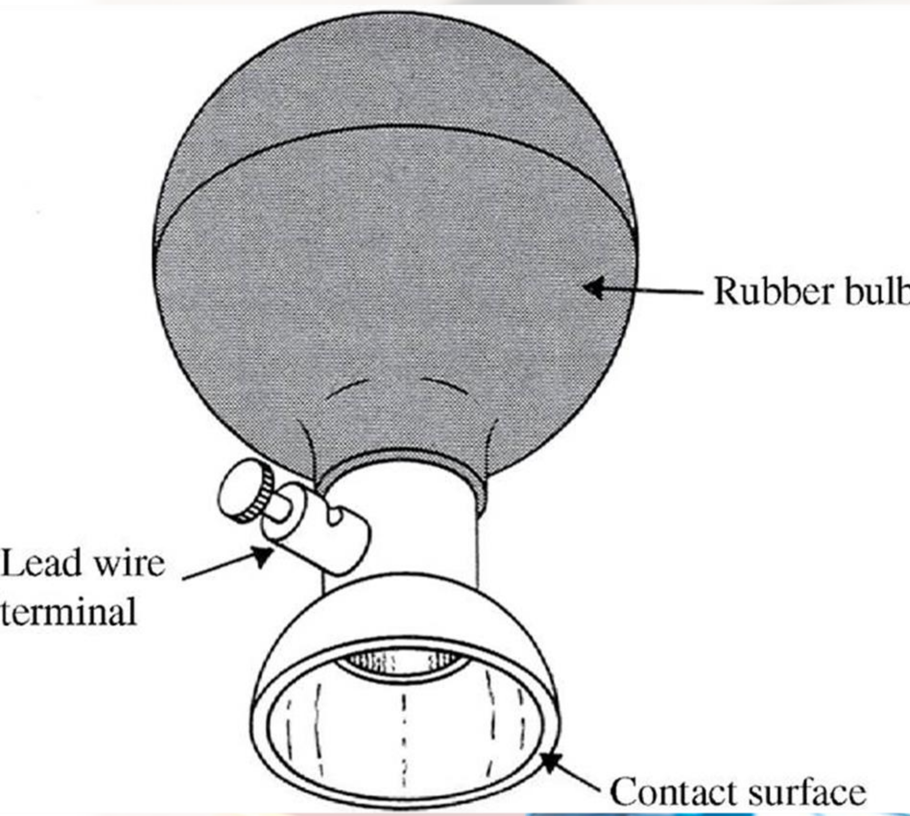
(b) Metal-disk electrode applied with surgical tape,

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



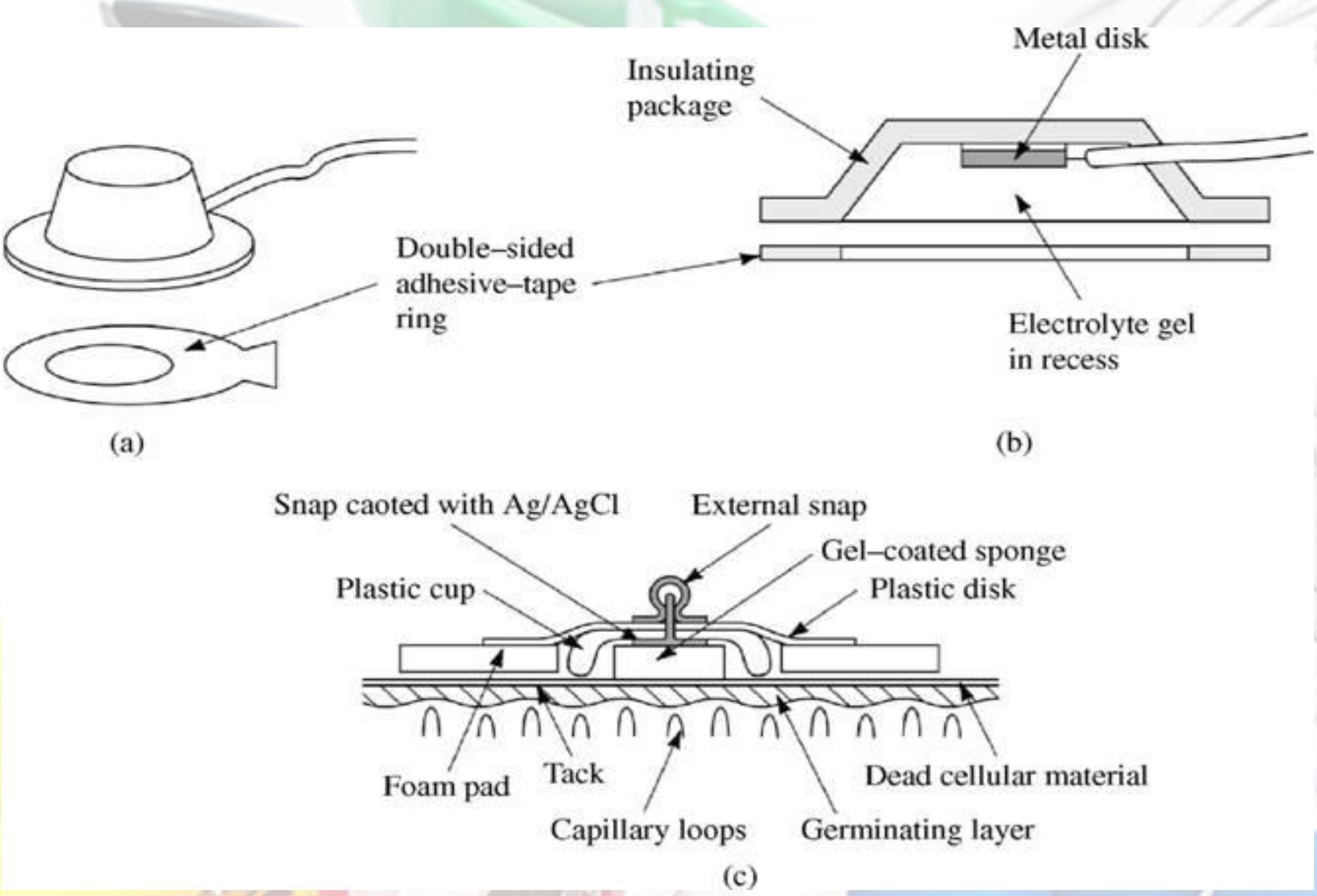



# Metallic suction electrode



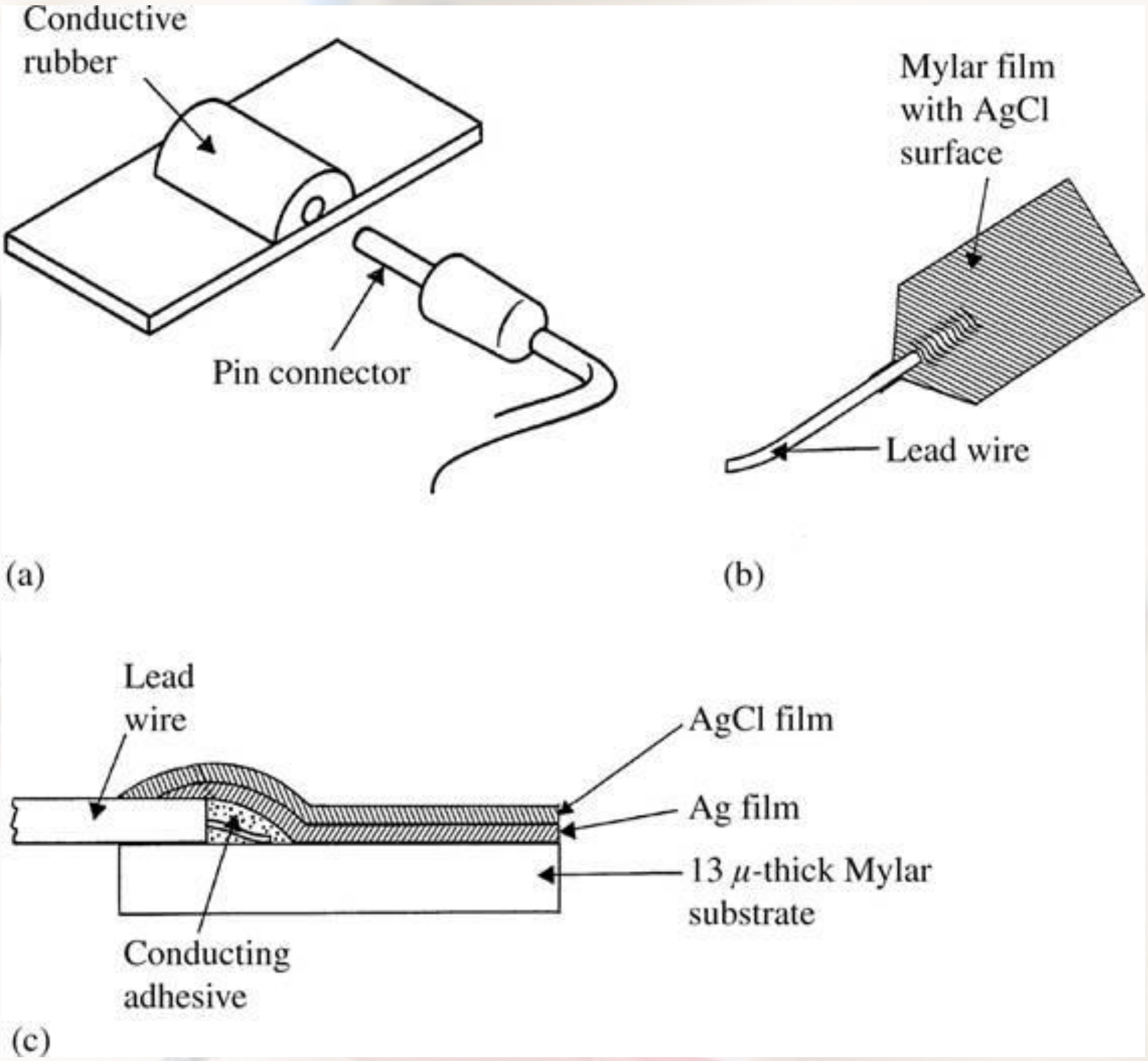

A metallic suction electrode is often used as a precordial electrode on clinical electrocardiographs

# 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 (c) in slide 17. The recess in this electrode is formed from an open foam disk, saturated with electrolyte gel and placed over the metal electrode.

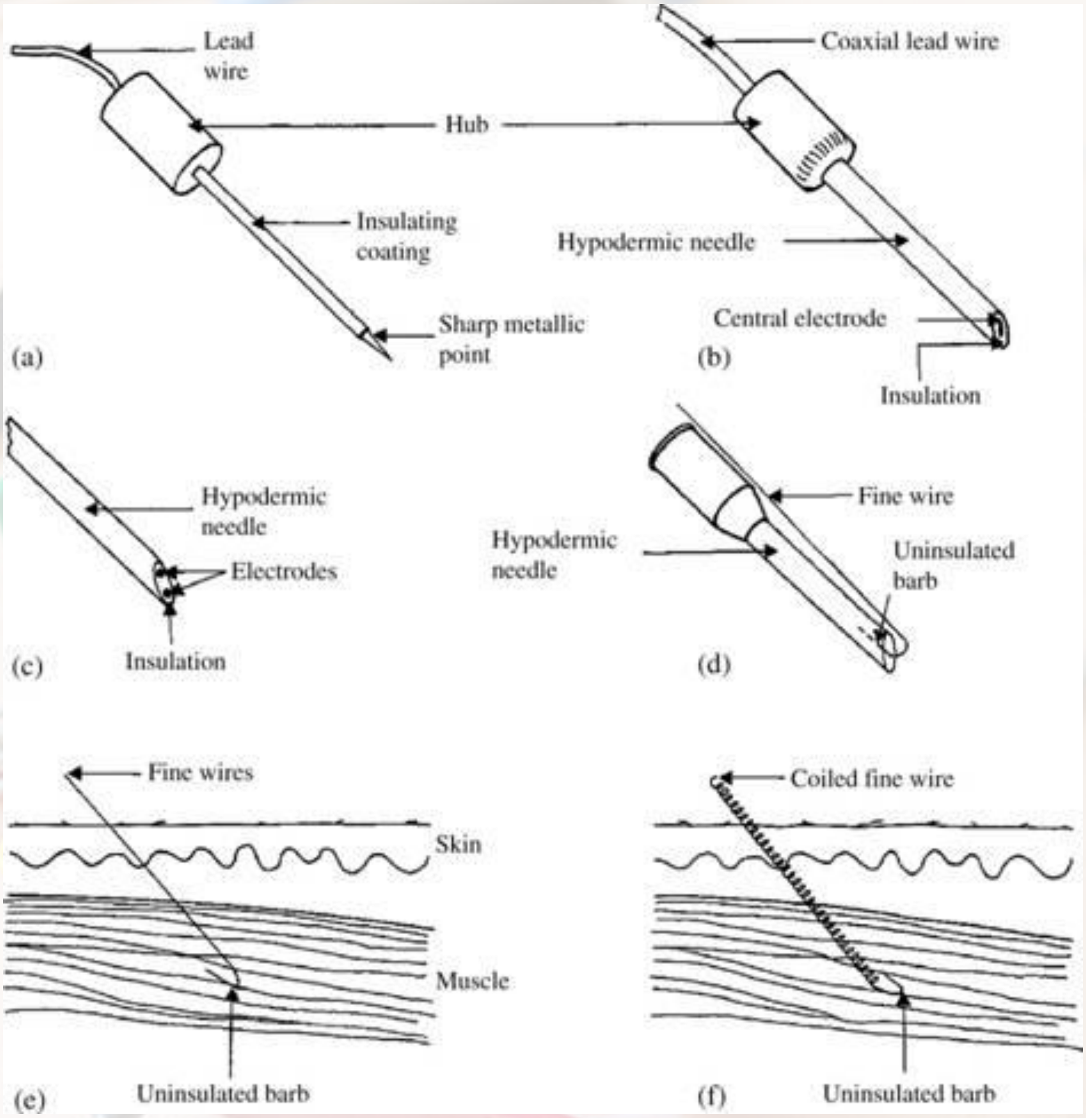
# Flexible body-surface electrodes




(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).

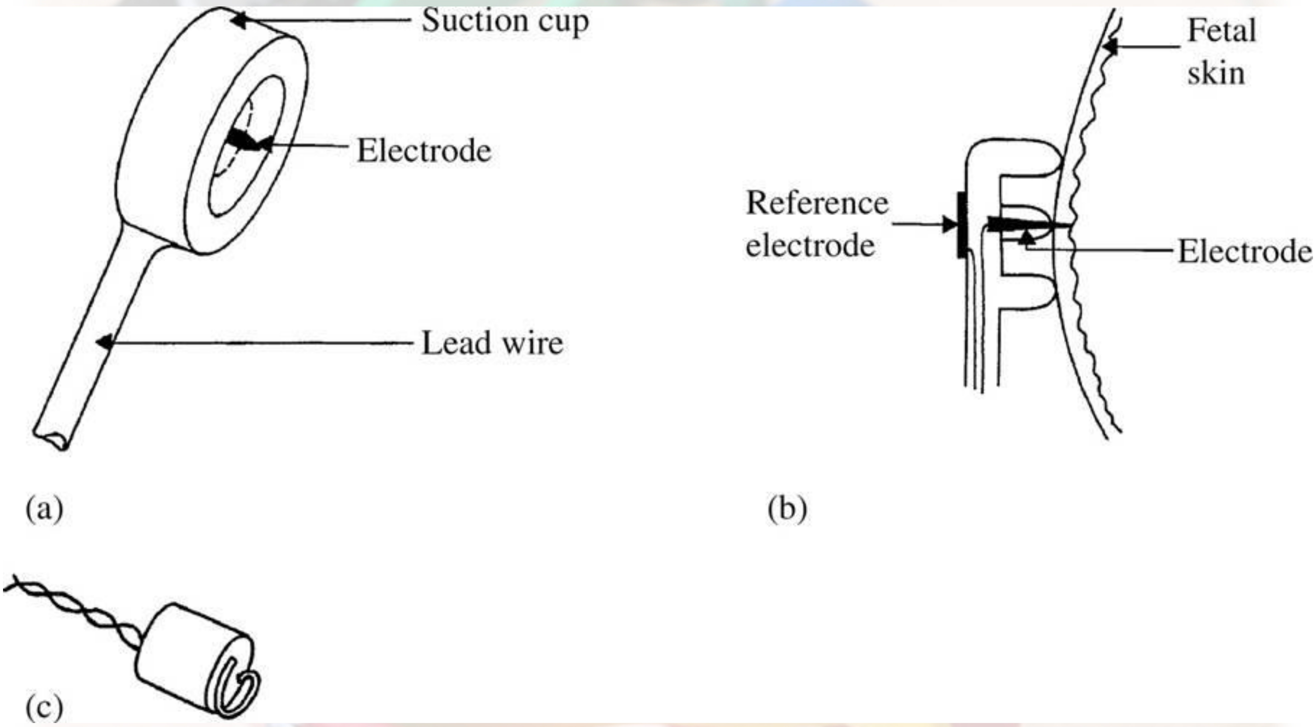
[Parts (b) and (c) are from International Federation for Medical and Biological Engineering. *Digest of the 10th ICMBE,* 1973.]

# Needle and wire electrodes for percutaneous measurement of biopotentials



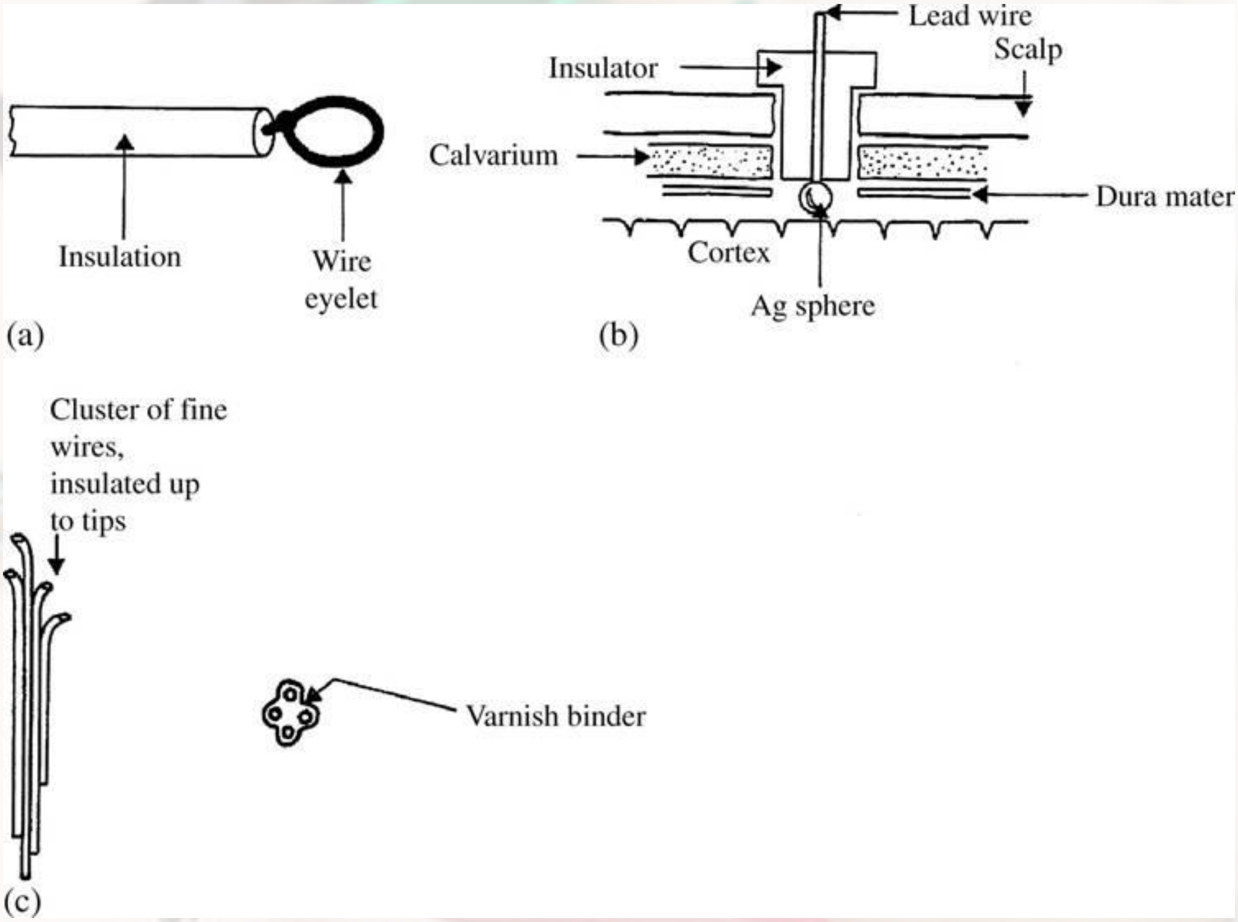

(a) Insulated needle electrode,
(b) Coaxial needle electrode,
(c) Bipolar coaxial electrode,
(d) Fine-wire electrode connected to hypodermic needle, before being inserted,
(e) Cross-sectional view of skin and muscle, showing fine-wire electrode in place,
(f) Cross-sectional view of skin and muscle, showing coiled fine-wire electrode in place.

# Electrodes for detecting fetal electrocardiogram during labor, by means of intracutaneous needles



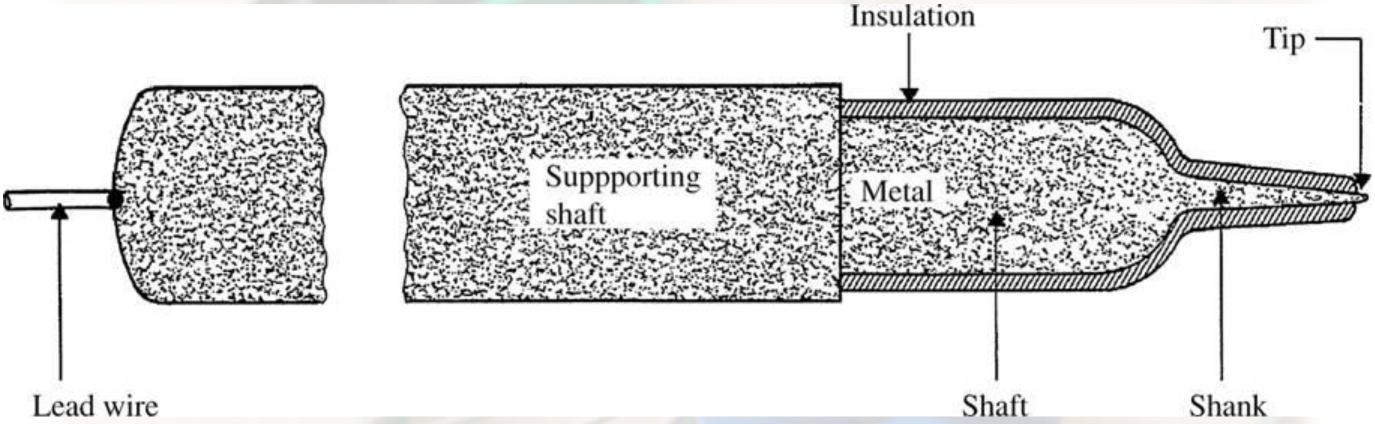

(a) Suction electrode,
(b) Cross-sectional view of suction electrode in place, showing penetration of probe through epidermis,
(c) Helical electrode, that is attached to fetal skin by corkscrew-type action.

# Implantable electrodes for detecting biopotentials




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

# The structure of a metal microelectrode for intracellular recordings

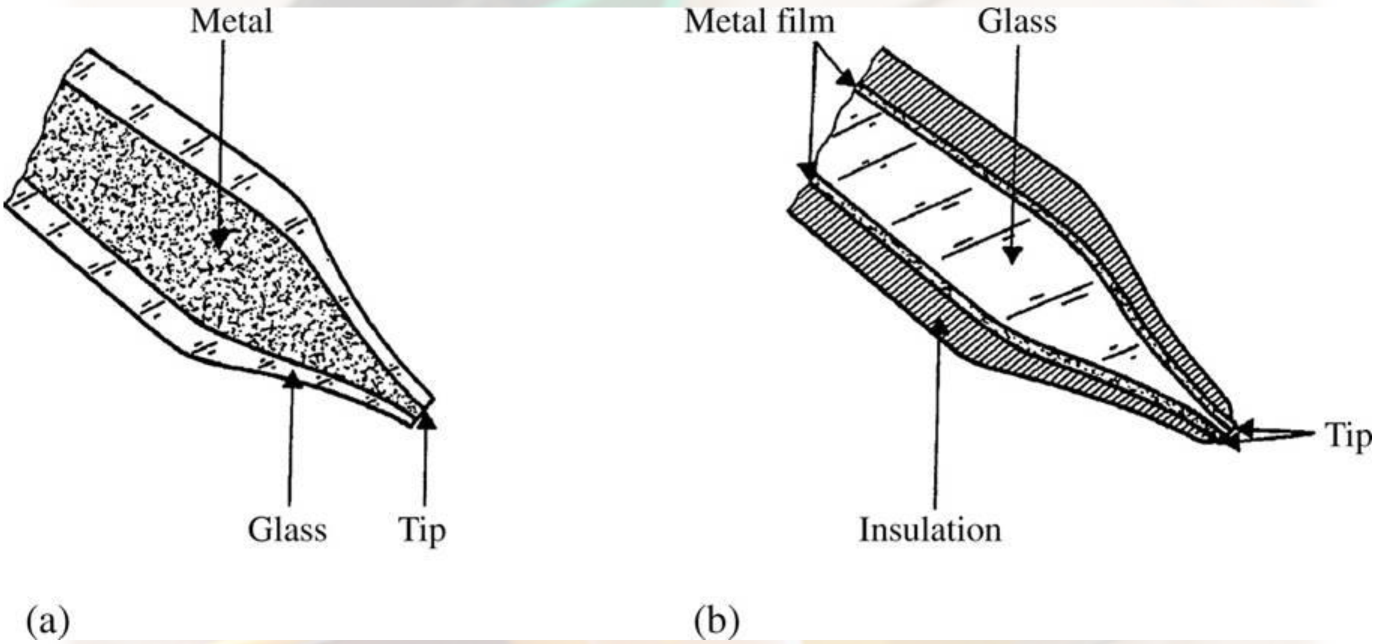



$$\frac{C_{dl}}{L} = \frac{2\pi\varepsilon_r\varepsilon_0}{\ln D/d}$$

Capacitance per unit length

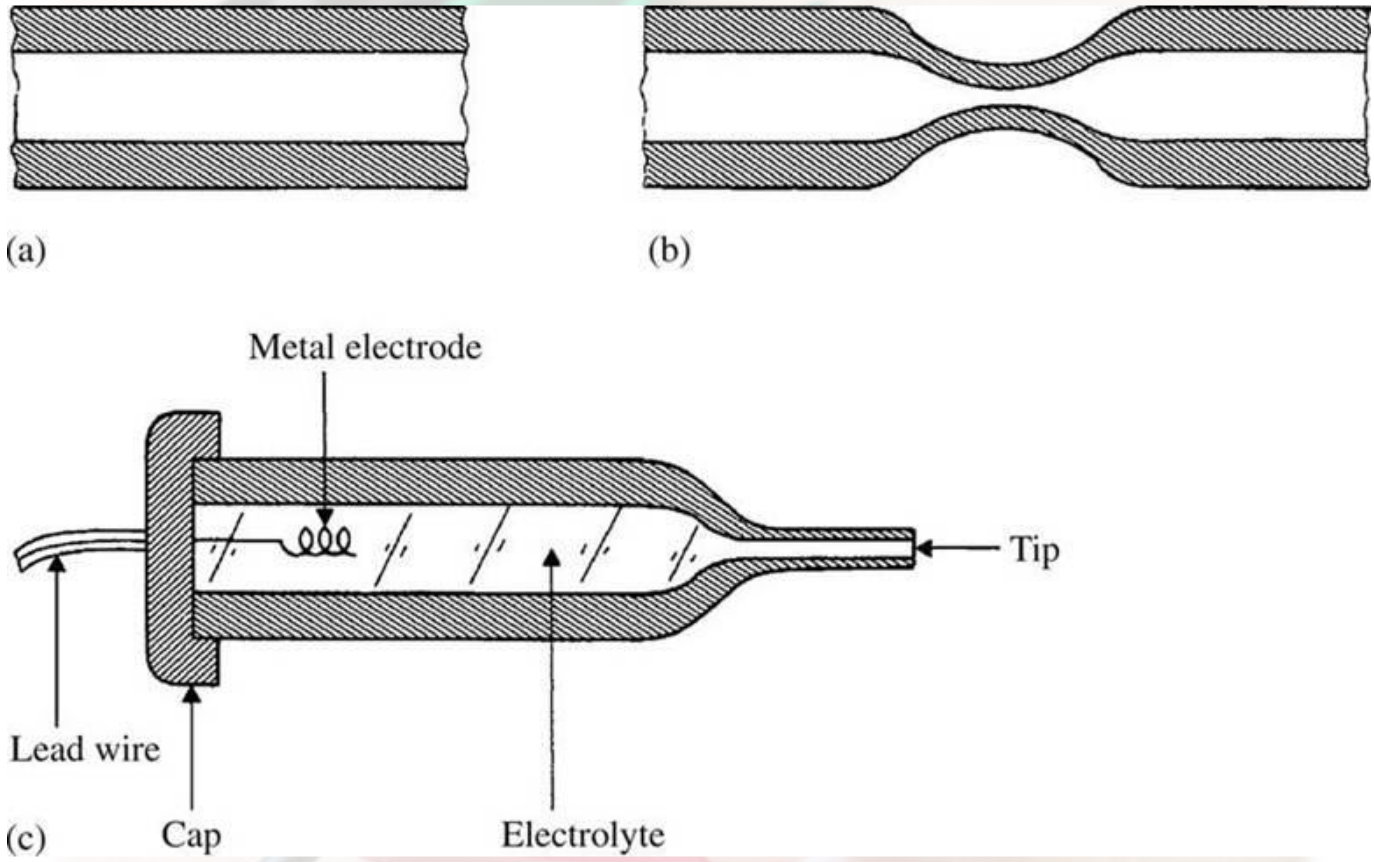
$\varepsilon_0$ = dielectric constant of free space
$\varepsilon_r$ = relative dielectric constant of insulation material
D = diameter of cylinder consisting of electrode plus insulation
D = diameter of electrode
L = length of shank

# Structures of two supported metal microelectrodes



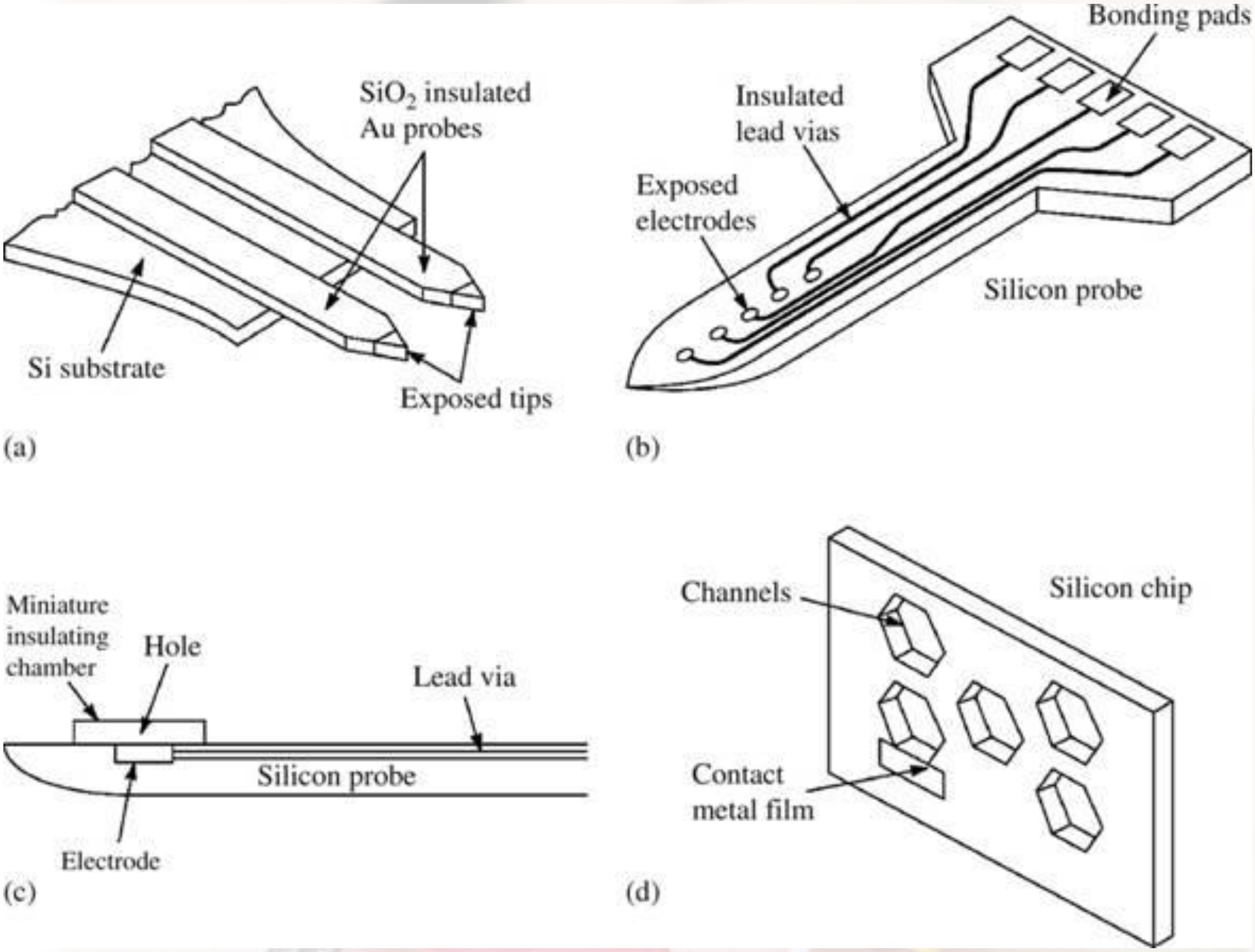

(a) Metal-filled glass micropipet.
(b) Glass micropipet or probe, coated with metal film.

# A glass micropipet electrode filled with an electrolytic solution



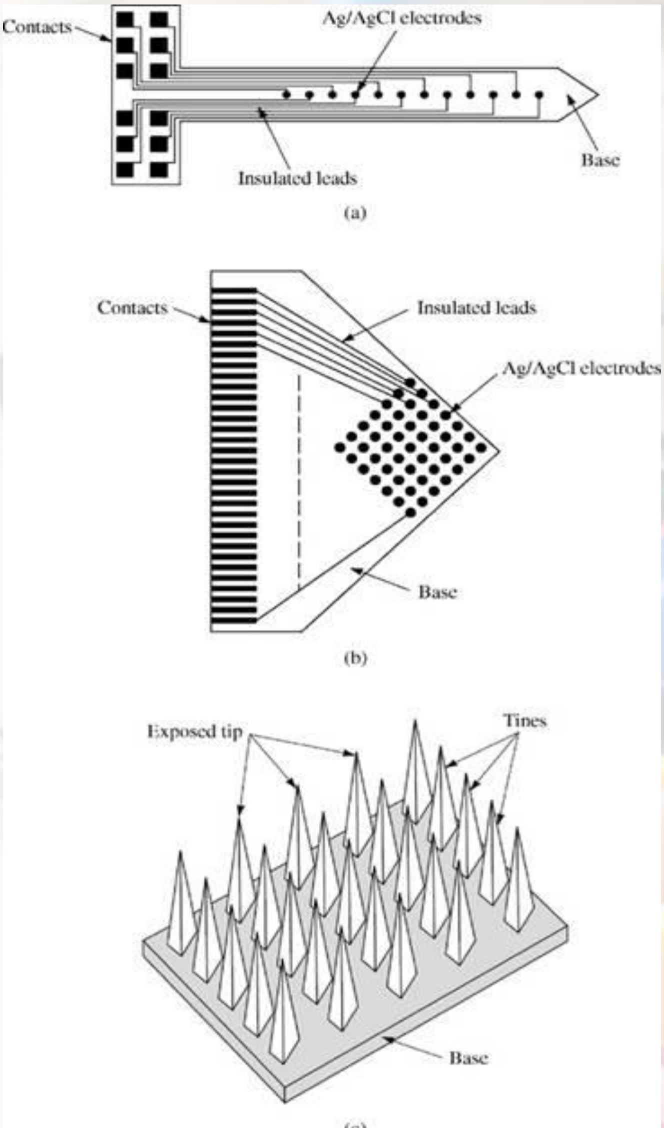

(a) Section of fine-bore glass capillary,
(b) Capillary narrowed through heating and stretching,
(c) Final structure of glass-pipet microelectrode.

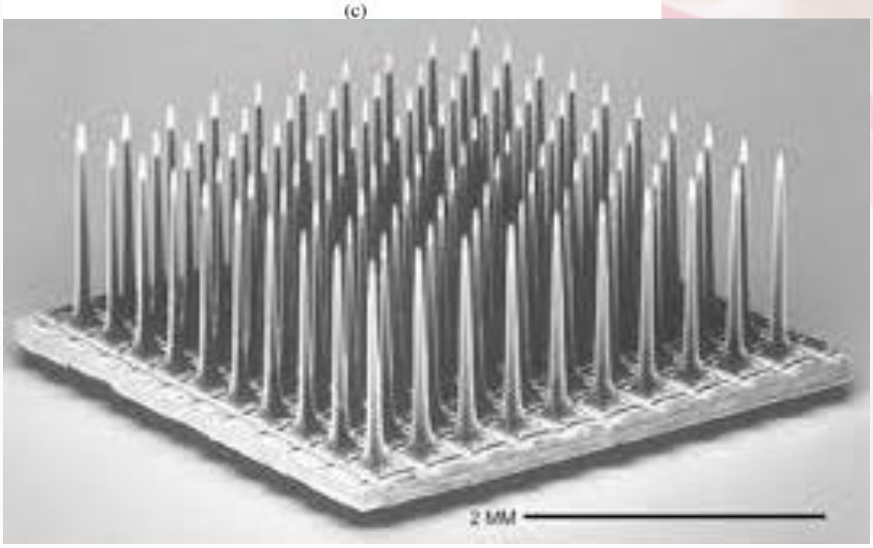
# Different types of microelectrodes fabricated using microelectronic technology




(a) Beam-lead multiple electrode. (Based on Figure 7 in K. D. Wise, J. B. Angell, and A. Starr, “An Integrated Circuit Approach to Extracellular Microelectrodes.” Reprinted with permission from *IEEE Trans. Biomed. Eng.,* 1970, BME-17, pp. 238–246.)
(b) Multielectrode silicon probe after Drake *et al.*
(c) Multiple-chamber electrode after Prohaska et al.
(d) Peripheral-nerve electrode based on the design of Edell.

# Examples of microfabricated electrode arrays



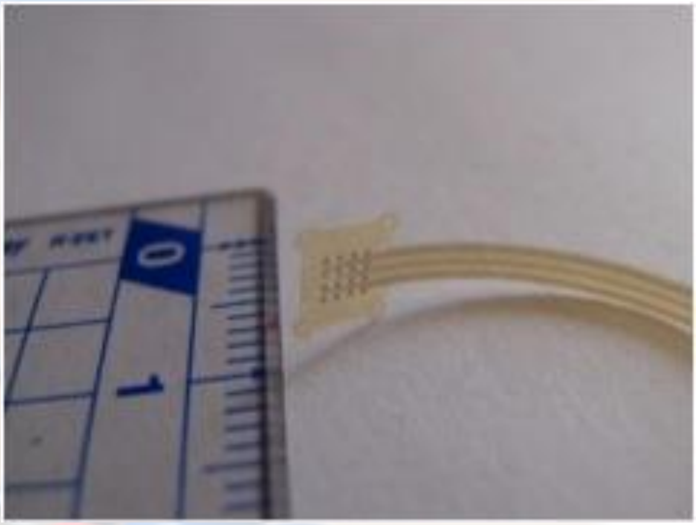




(a) One-dimensional plunge electrode array (after Mastrototaro *et al.,* 1992),

(b) Two-dimensional array, and

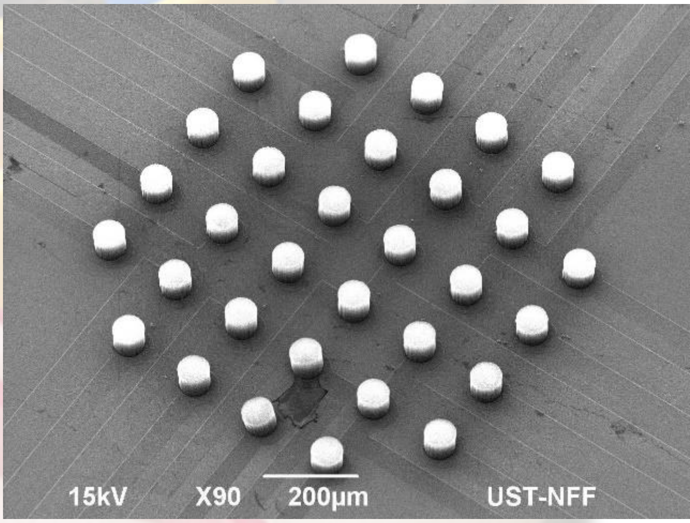
(c) Three-dimensional array (after Campbell *et al.,* 1991).

# Microelectrodes



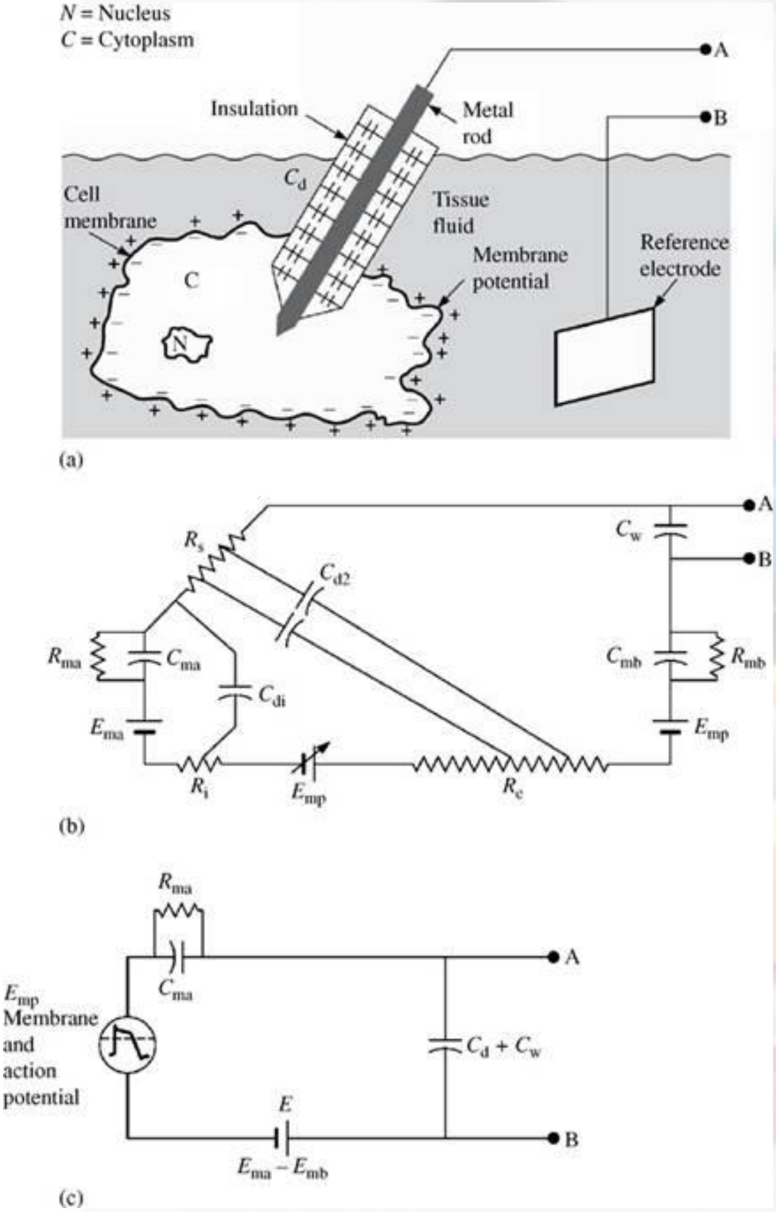

Polyimide microelectrode for neural stimulation, size 5 mm x 5 mm


An array of 16 microelectrodes - known as a microECoG grid - is arranged in a four-by-four array and shown next to a US quarter-dollar coin with a Utah state design on its 'tail' side. University of Utah researchers placed two such microelectrode grids over speech areas of a patient's brain and used them to decode brain signals into words. The technology someday might help severely paralyzed patients 'speak' with their thoughts, which would be converted into a computerized voice.
Credit: Spencer Kellis, University of Utah (click to enlarge)




A 32-electrode array, each of which is 60 um diameter (picture courtesy to Adam Khalifa, HKUST)

# Equivalent circuit of metal microelectrode

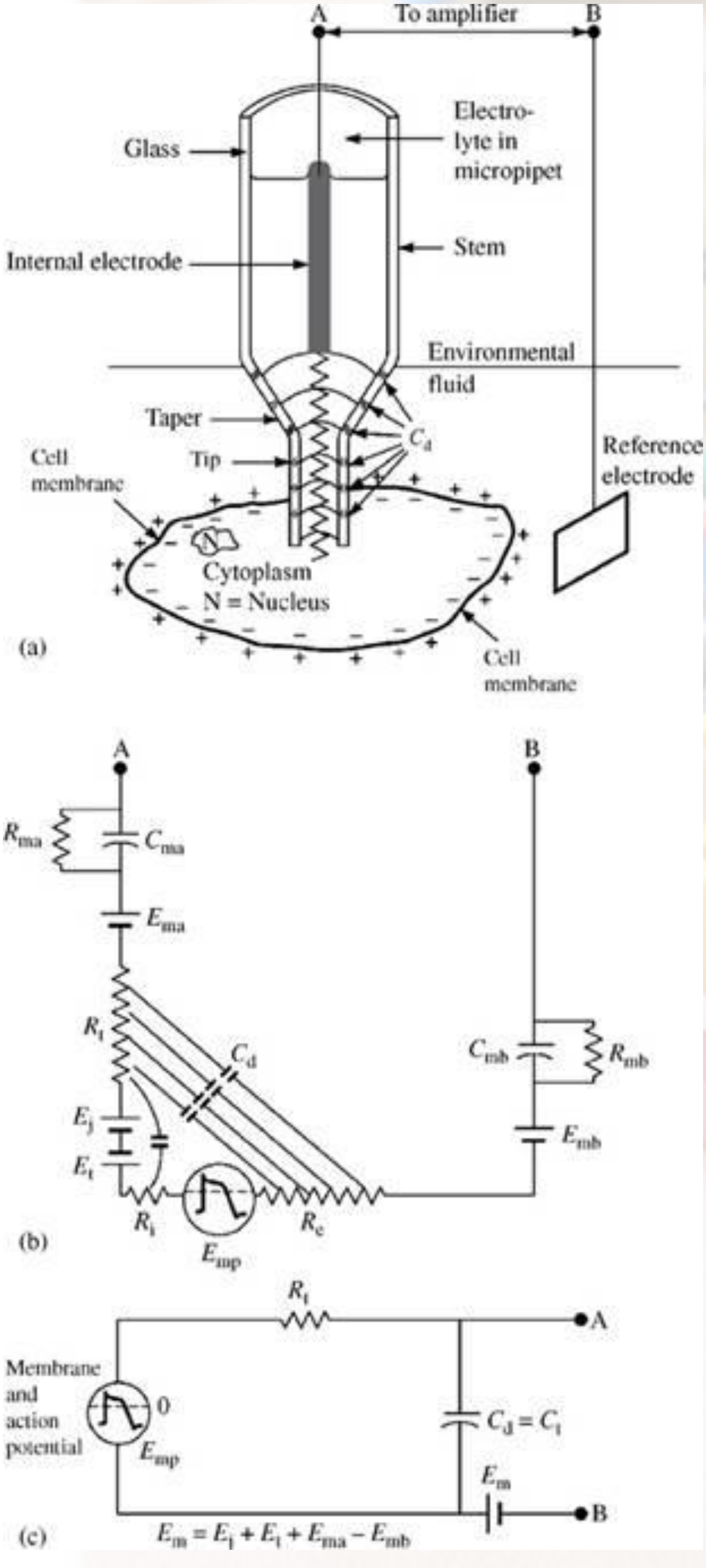



(a) Electrode with tip placed within a cell, showing origin of distributed capacitance,

(b) Equivalent circuit for the situation in (a),

(c) Simplified equivalent circuit. (From L. A. Geddes, *Electrodes and the Measurement of Bioelectric Events,* Wiley-Interscience, 1972. Used with permission of John Wiley and Sons, New York.)

# Equivalent circuit of glass micropipet microelectrode




(a) Electrode with its tip placed within a cell, showing the origin of distributed capacitance,

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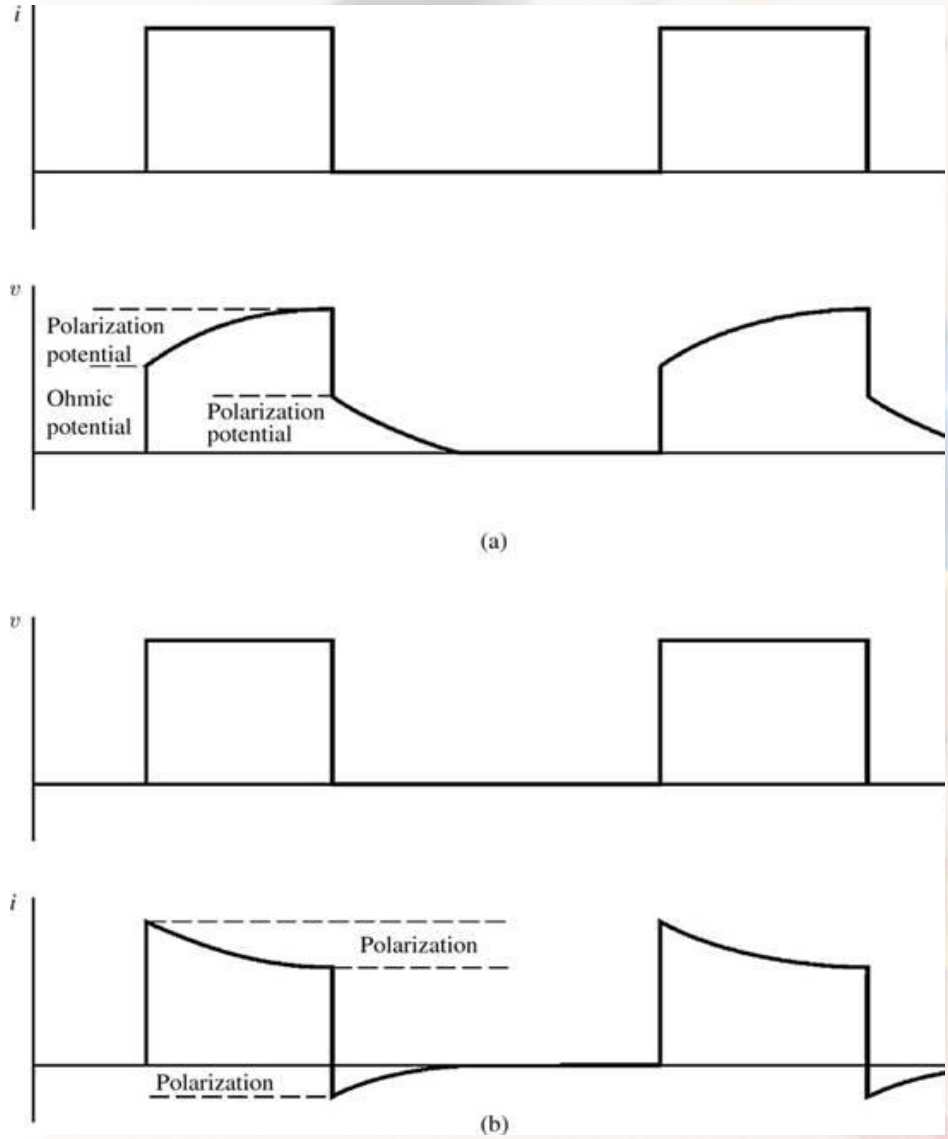
(c) Simplified equivalent circuit. (From L. A. Geddes, *Electrodes and the Measurement of Bioelectric Events,* Wiley-Interscience, 1972. Used with permission of John Wiley and Sons, New York.)

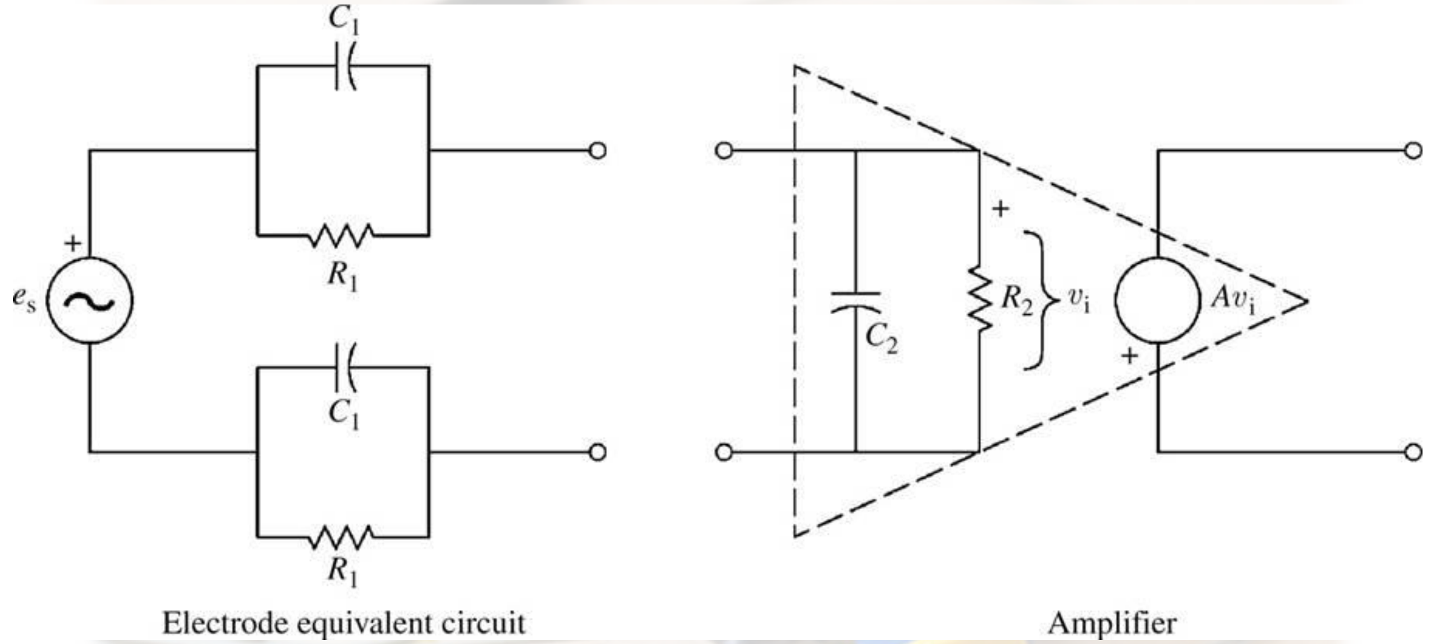
# Current and voltage waveforms seen with electrodes used for electric stimulation



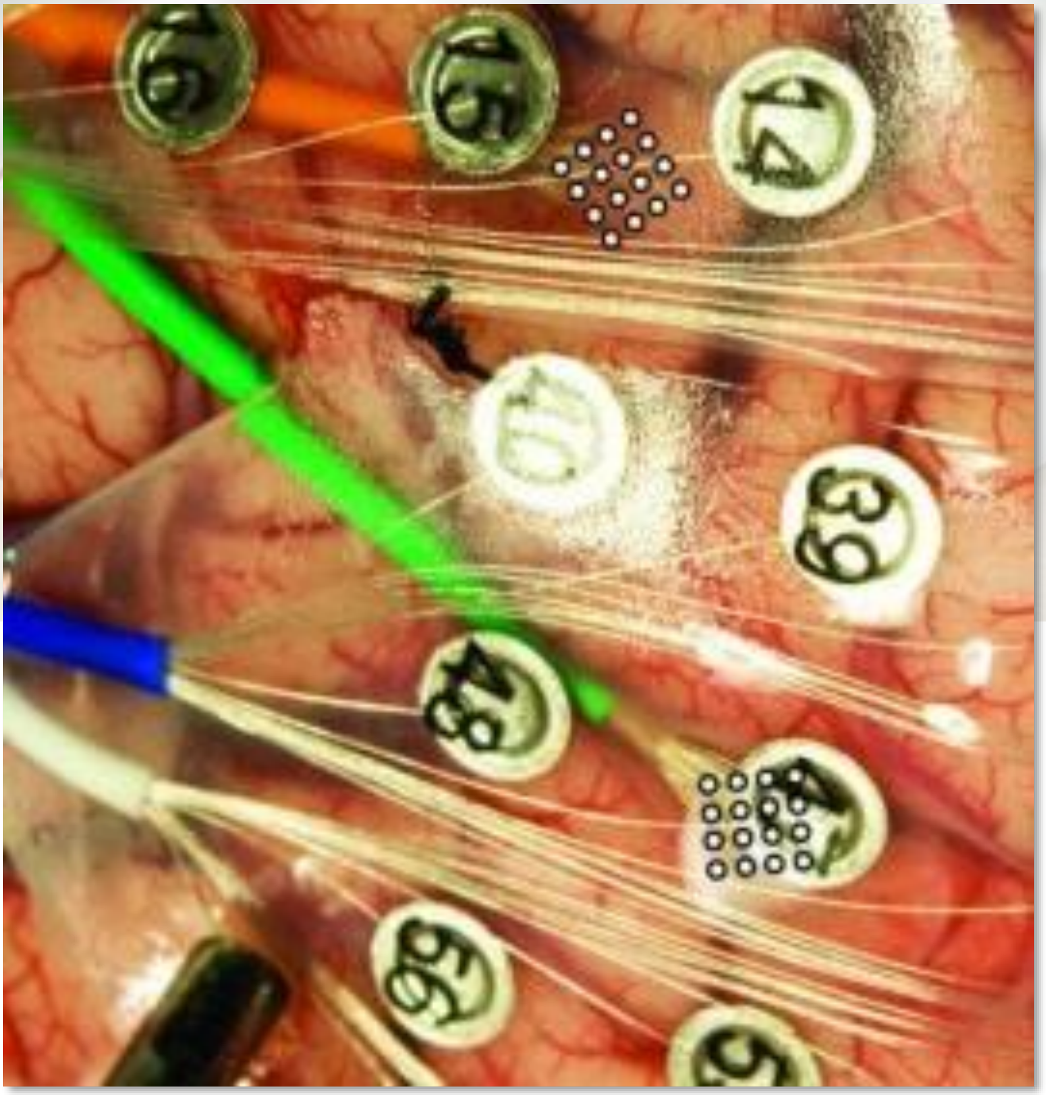

(a) Constant-current stimulation,

(b) Constant-voltage stimulation.

# Needle type EMG electrode




Simplified equivalent circuit of a Needle type EMG electrode pair and equivalent circuit of the input stage of an amplifier




This photo shows two kinds of electrodes sitting atop a severely epileptic patient's brain after part of his skull was removed temporarily. The larger, numbered, button-like electrodes are ECoGs used by surgeons to locate and then remove brain areas responsible for severe epileptic seizures. While the patient had to undergo that procedure, he volunteered to let researchers place two small grids - each with 16 tiny 'microECoG' electrodes - over two brain areas responsible for speech. These grids are at the end of the green and orange wire bundles, and the grids are represented by two sets of 16 white dots since the actual grids cannot be seen easily in the photo. University of Utah scientists used the microelectrodes to translate speech-related brain signals into actual words - a step toward future machines to allow severely paralyzed people to speak.

Credit: University of Utah Department of Neurosurgery

# Questions

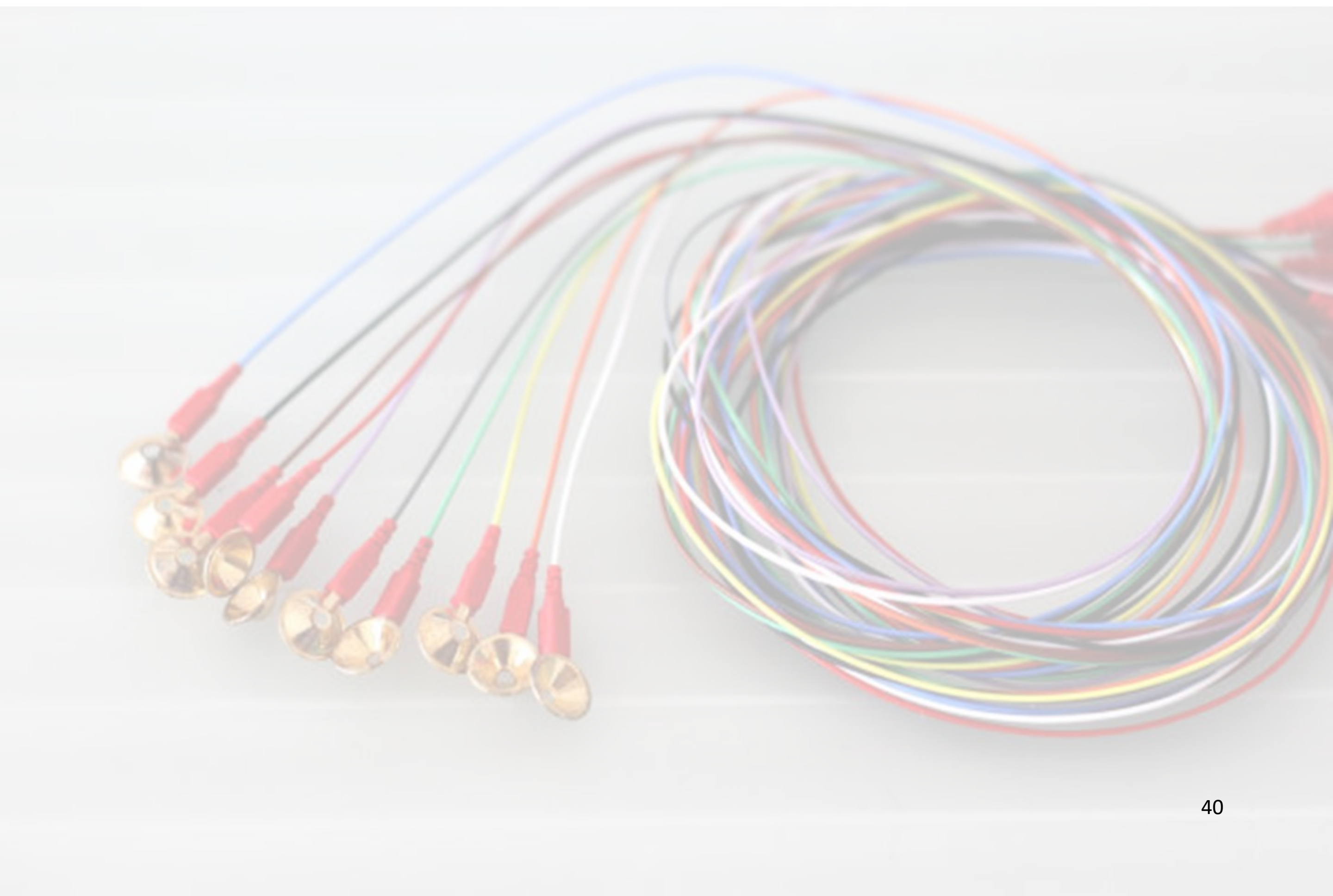
1. Name the electrodes used for recording EMG and ECG

2. What is the purpose of electrode paste?

3. Give the different types of electrodes?

4. Give the different types of Surface electrodes?

5. What is the need of electrodes?



# Answers

1. Electrodes used for recording EMG are

    (a) Needle electrodes

    (b) Surface electrodes

    Electrodes used for recording ECG are

    (a) Limb electrodes

    (b) Floating electrodes

    (c) Metallic suction electrodes

    (d) Pasteless electrodes/Disposable electrodes

2. The electrode paste decreases the impedance of the contact the artifacts resulting from the movement of the electrode or patient.

3. Microelectrodes, Depth and needle electrodes, Surface electrodes.

4. Metal Plate electrodes

    Suction cup electrodes

    Adhesive tape electrodes

    Multi point electrodes

    Floating electrodes

5. Electrodes make a transfer from the ionic conduction in the tissue to the electronic conduction which is necessary for making measurement. Electrodes play an important part in the recording of bioelectric signals.

# References

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