Physics of Medical Devices

Second lecture

Biopotential electrodes II

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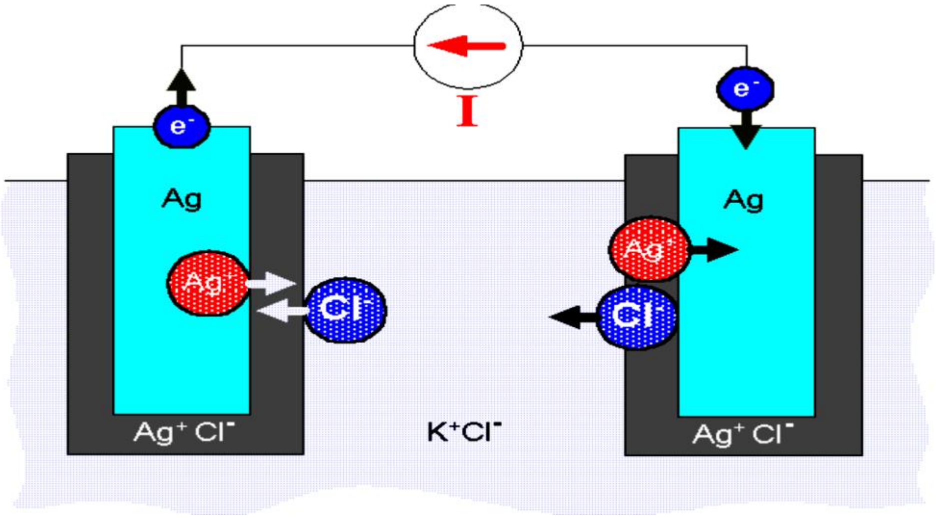
2021- 2022

The Silver-Silver Chloride Electrode



Electrolytic process - Ag/AgCl electrode fabrication

- Consists of a metal coated with a layer of a slightly soluble ionic compound of that metal with a suitable anion.
- Whole structure is immersed in an electrolyte containing the anion in relatively high concentrations.
- AgCl layer is to be deposited serves as anode.
- Ag having a surface area much greater than that of the anode serves as cathode.

Q: why Ag/AgCl electrodes are used in ECG and other devises?

Because are non-polarized electrodes they allow current to pass across the interface between the electrolyte and electrode. The AgCl layer lowers the impedance of electrode this is important at low frequencies.

Q: what are the advantages of silver chloride electrode?

1. Widely used (used for biopotential recording).
2. Stable.
3. Low noise (at low frequency).
4. Nontoxic.
5. Small motion artifact
6. Quite robust.

Q: An AgCl surface is grown on an Ag electrode by the electrolytic process. The current passing through the cell is measured and recorded during the growth of the AgCl layer and is found to be represented by the equation:

$$I = 100\,\mathrm{mA}\, e^{-t/10\,\mathrm{s}}$$

Find

a. if the reaction is allowed to run for a long period of time, so that the current at the end of this period is essentially zero, how much charge is removed from the battery during this reaction?

Answer

The total charge crossing the electrode- electrolyte interface during the reaction is:

$$q = \int_0^\infty i\,dt = 100\,\mathrm{mA} \int_0^\infty e^{-t/10}\,dt = 1\,\mathrm{C}$$

b. how many grams of AgCl are deposited on the Ag electrodes surface by this reaction?

Answer

One molecule of AgCl is deposited for each electron. The number of atoms deposited is

$$N = \frac{1\,\mathrm{C}}{1.6 \times 10^{-19}\,\mathrm{C/atom}} = 6.25 \times 10^{8}\ \mathrm{atoms}$$

The number of moles can be found by dividing by Avogadro's number.

$$N = \frac{6.25 \times 10^{18}}{6.03 \times 10^{23}} = 1.036 \times 10^{-5}\ \text{mol}$$

The molecular weight of AgCl is 148.2, therefore the mass of AgCl formed is

$$143.2 \text{ x } 1.036 \text{ x } 10^{-5} = 1.48 \text{ x } 10^{-3} \text{ g}$$

c. the chloride electrode is now placed into a beaker containing 1 L of 0.9 molar NaCl solution. How much AgCl will be dissolved?

Answer

For AgCl the solubility product is K_S = 1.56 x 10^{-10} at 25C°. The activity and concentration are about the same at these low concentrations. Thus

$$[Ag^+][Cl^-] = 1.56\text{x } 10^{-10}$$

Since $[Cl^-]$ in the NaCl solution is 0.9 mole/liter, the dissolved Ag will be

$$[Ag^+] = 1.73 \text{ x } 10^{-10} \text{ mol/liter}$$

In terms of mass this will be 1.73 x 10^{-10} x 143.2 = 2.47 x 10^{-8} g.

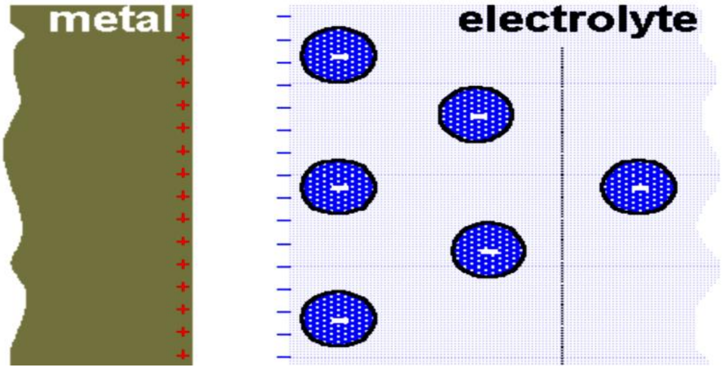
H.W: 1. Design a system for electrolytically forming Ag/AgCl electrode. Give chemical reactions that occur at both electrodes.

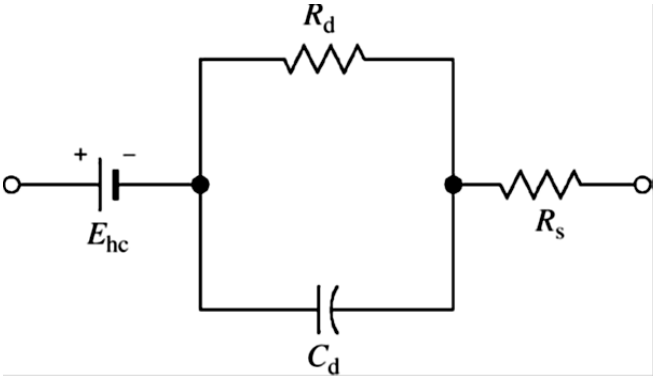
H.W: 2. Design an Ag/AgCl electrode that will pass 150 mC of charge without removing all the AgCl. Calculate the mass of AgCl required.

Electrode behavior and circuit model

- Current–voltage characteristics of the electrode–electrolyte interface are found to be nonlinear.
- Nonlinear elements are required for modeling electrode behavior.

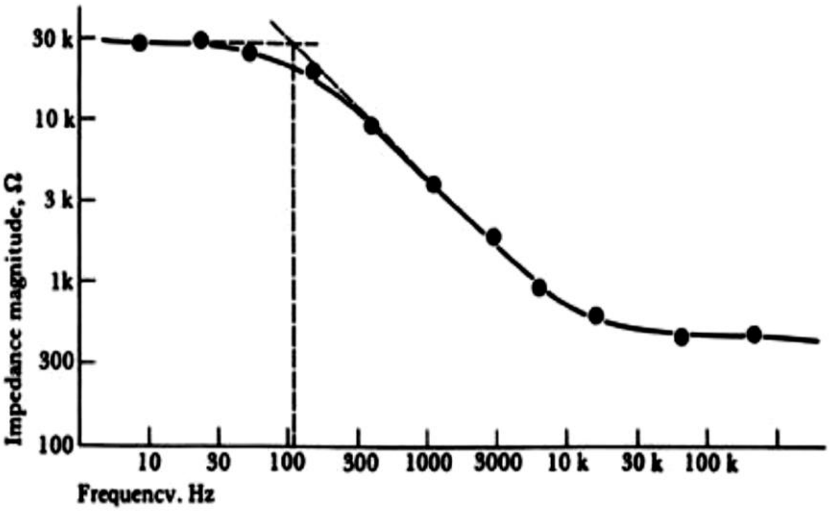
- Characteristics of an electrode are sensitive to the current passing through the electrode,
- Electrode characteristics at relatively high current densities can be considerably different from those at low current densities.
- Characteristics of electrodes are also waveform-dependent.
- When sinusoidal currents are used to measure the electrode’s circuit behavior, the characteristics are also frequency-dependent.
- Dc voltage source: HCP
- *Cd* : capacitance across the charge double layer, change with frequency, current density, electrode material, and electrolyte concentration
- R_d : leakage resistance across the charge double layer, change with frequency, current density, electrode material, and electrolyte concentration
- R_s : resistance of electrolyte, change with electrolyte concentration





Electrode impedance is frequency dependent

- At high frequencies, where $1/wC << Rd$, the impedance is constant at Rs.
- At low frequencies, where $1/wC >> Rd$, the impedance is again constant but its value is larger, being $Rs + Rd$.
- At frequencies between these extremes, the electrode impedance is frequency-dependent.



Electrode skin interface

- Interface between the electrode–electrolyte and the skin needs to be considered to understand the behavior of the electrodes.
- In coupling an electrode to the skin, we generally use transparent electrolyte gel containing Cl^- as the principal anion to maintain good contact.
- The interface between this gel and the electrode is an electrode–electrolyte interface.
- However, the interface between the electrolyte and the skin is different.
- The skin consists of three principle layers:

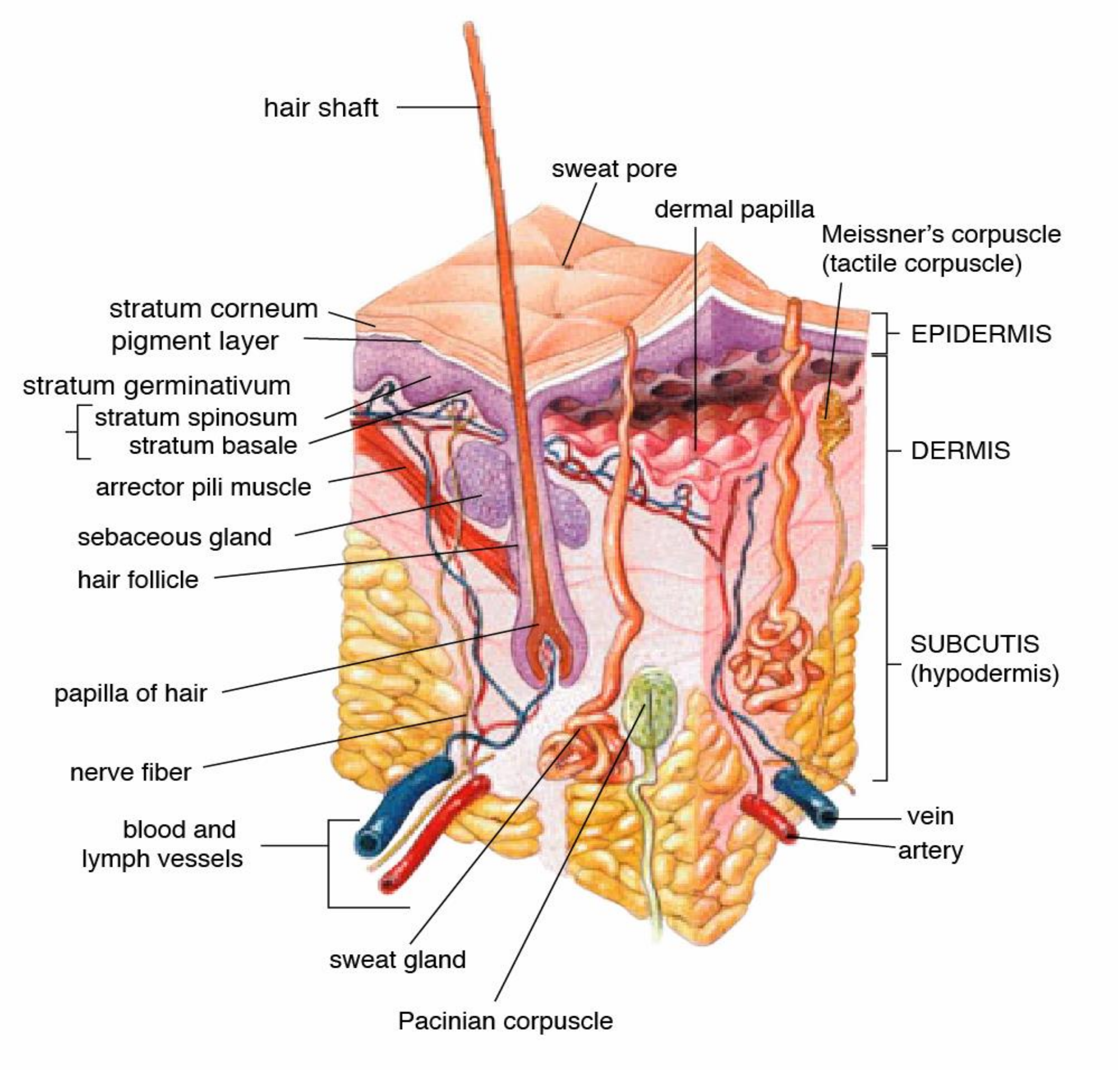
1. Outermost layer ***epidermis*** consists of three sublayer:

- Stratum corneum: outermost layer of dead cells, constantly removed
- Stratum granulosum: cells begin to die and loose nuclear material
- Stratum germinativum: cells divide and grow and displaced outward

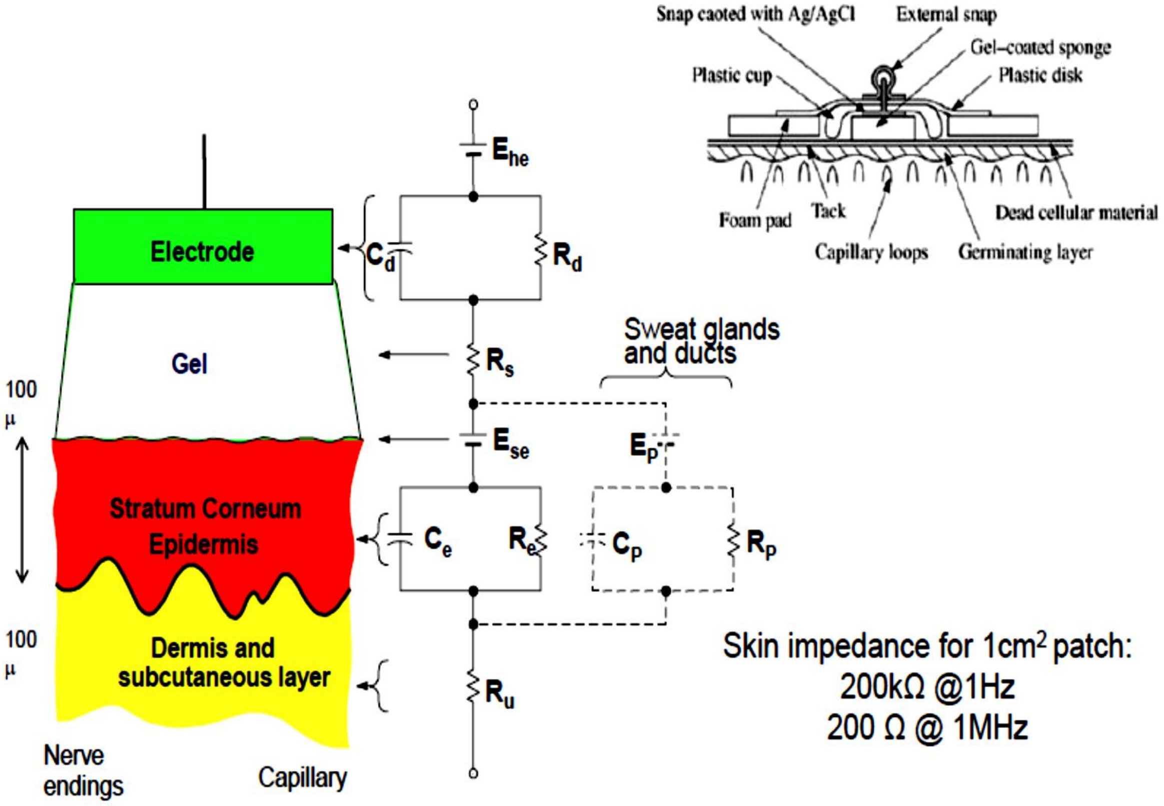
2. Dermis

3. Subcutaneous layer

- The deeper layers of the skin contain the vascular and nervous components, sweat glands, sweat ducts, hair follicles



Electrode Skin Interface



Skin impedance for 1cm² patch:
200kΩ @1Hz
200 Ω @ 1MHz

- ❖ The series resistance *R*s is now the effective resistance associated with interface effects of the gel between the electrode and the skin.
- ❖ Considering stratum corneum, as a membrane that is semipermeable to ions,
- ❖ So if there is a difference in ionic concentration across this membrane, there is a potential difference E_{se}, which is given by the Nernst equation.
- ❖ Epidermal layer has electric impedance that behaves as a parallel RC circuit.
- ❖ For 1 cm^2, skin impedance reduces from approximately 200 kΩ at 1 Hz to 200 Ω at 1 MHz.
- ❖ The dermis and the subcutaneous layer under it behave in general as pure resistances. They generate negligible dc potentials.

Reducing the effect of stratum corneum

- Minimize the effect of the stratum corneum by removing it, or at least a part of it, from under the electrode.
- Various ways:
  - ✓ vigorous rubbing with a pad soaked in acetone
  - ✓ Abrading the stratum corneum with sandpaper to puncture it.
- This process tends to short out E_{se}, C_e, and R_e
- Improve stability of the signal, but the stratum corneum can regenerate in as short a time as 24 h.
- Contribution of the sweat glands and sweat ducts.
  - The fluid secreted by sweat glands contains Na^+, K^+, and Cl^- ions, the concentrations of which differ from those in the extracellular fluid.
  - There is a potential difference between the lumen of the sweat duct and the dermis and subcutaneous layers.

- There also is a parallel R_pC_p combination in series with this potential that represents the wall of the sweat gland and duct, as shown by the broken lines.
- These components are considered when the electrodes are used to measure the electro-dermal response.
- These components are often neglected when we consider biopotential electrodes.

Motion Artifact

- In addition to the half-cell potential E_{hc}, the electrolyte gel–skin potential E_{se} can also cause motion artifact if it varies with movement of the electrode.
- Variations of this potential indeed do represent a major source of motion artifact in Ag/AgCl skin electrodes.

- This artifact can be significantly reduced when the stratum corneum is removed by mechanical abrasion with a fine abrasive paper.
- This method also helps to reduce the epidermal component of the skin impedance.
- However, that removal of the body's outer protective barrier makes that region of skin more susceptible to irritation from the electrolyte gel.
- Stretching the skin changes this skin potential by 5 to 10 mV, and this change appears as motion artifact.