Exercise 1 - Neural Membranes and Electrodes

Exercise 1. Nernst potential

The Nernst equilibrium potential of bicarbonate (HCO3-) is -12.55mV. This means that the concentration of that molecule is _______ outside the cellular membrane compared to inside.

A) Higher
B) Lower
C) Equal

Exercise 2. Membrane phenomena

a. What is the Nernst equation? Give the names of all the quantities that are present and their respective units. What phenomena does it explain?

b. A special single-cell organism that lives in a natural mineral water spring has permeabilities of 0.09, 1.00 and 0.04 for Cl^-, K^+ and Na^+, respectively. The following concentrations (in mmol/mm^3):$[Cl^-]_i$=178, $[Cl^-]_o$=0.47, $[K^+]_i$=135, $[K^+]_o$=83, $[Na^+]_i$=0.05, $[Na^+]_o$=118.
Which direction (inwards/outwards of the cell membrane) do the Cl^- ions move passively (not actively, i.e., via pumps)? T = 37 °C.

Exercise 3. Equivalent model of an electrode

Consider three electrode systems: A, B, and C.

- System A has an ideally polarizable electrode with no charge transfer, and its impedance components at 1 kHz are as follows: Rtrack = 8’000 Ω, Rspread = 1’000 Ω and |Z_Ci| = 2’000 Ω
- For system B, the surface area of the electrode is increased by a factor of 10 compared to system A through roughening.
- For system C, instead of roughening the electrodes, the track width of system A is increased by a factor of x.

a) Determine x such that the impedance at 1 kHz of systems B and C are equal.
b) Can we say that systems B and C are equivalent when used for stimulation? Justify your answer.

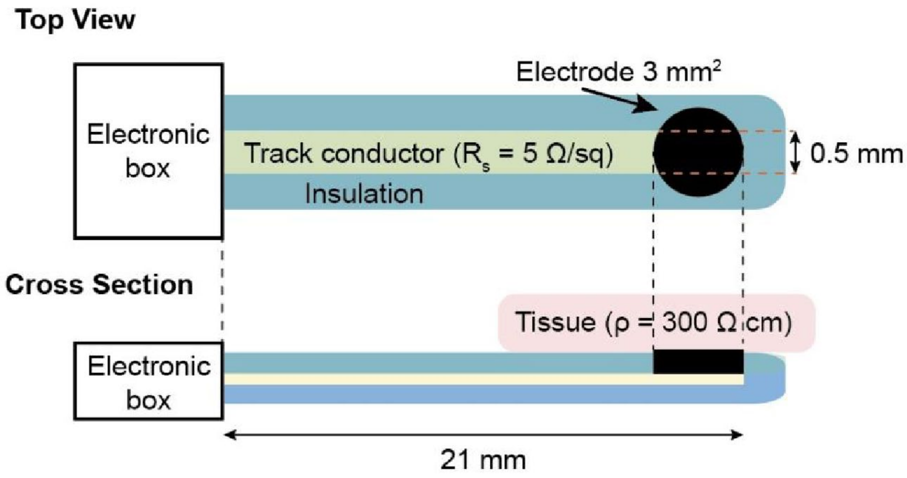
Exercise 4. Electrode characterization

Which of the following statements correctly describes the Cathodic Charge Storage Capacity (CSC) of an electrode?

A) CSC refers to the maximum voltage an electrode can sustain without damage.
B) CSC measures the resistance of an electrode to electrical currents.
C) CSC represents the maximum charge an electrode can store during cathodic polarization.
D) CSC indicates the speed at which an electrode can discharge stored energy.

Exercise 5. Electrical stimulation waveforms

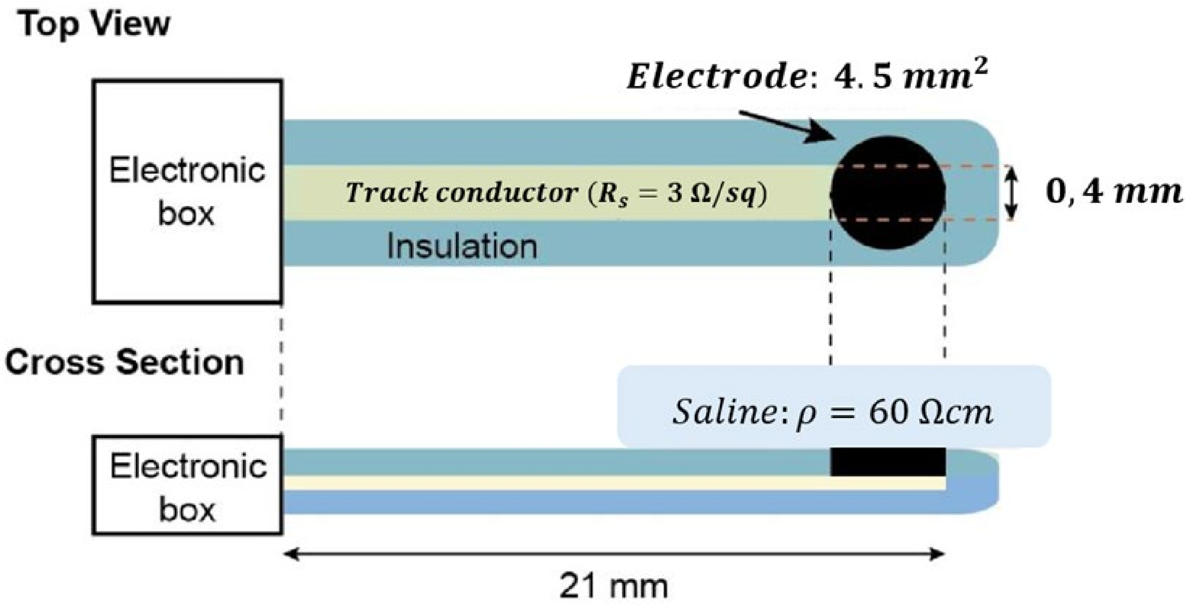
Consider the electrode system illustrated below. The electrode is coated such that it is ideally polarizable (i.e., there is no charge transfer across the electrode-tissue interface), and you would like to use this electrode to deliver charge over an area A = 3 mm^2. You choose a cathodic-first, biphasic, symmetric stimulation waveform that delivers a charge density q = 25 µC.cm^{-2}, with a pulse-width PW = 0.6 ms and inter-phase delay of 0.01 ms.



Draw qualitative overlaid diagrams of the current and voltage waveforms during brain stimulation. Use the quantities illustrated in the figure above to provide an approximate estimation of the access voltage Va in the voltage transient curve. Ignore the concentration overpotential.

Exercise 6. Electrochemical impedance

Electrochemical impedance spectroscopy is an important characterization technique that enables the electrical behavior of an electrode to be measured and modeled. Consider the electrode system illustrated below; it is immersed in a saline solution (**ρ = 60 Ωcm**). The electrode coating determines a capacitance of **10 μF/cm²** and it is electrochemically inert.



a. Draw an equivalent circuit model of the electrode system based on the Randles cell. Identify the electrical components and their physical meaning.

b. You would like to decrease the electrode impedance by applying a machining process that can roughen the electrode surface and increase its surface area by a factor of **15**.

1. Quantify the resulting impedance modulus of the whole system at **1 MHz** and at **1 Hz**.
2. Plot the new impedance spectrum after the roughening process and compare it to the previous spectrum.