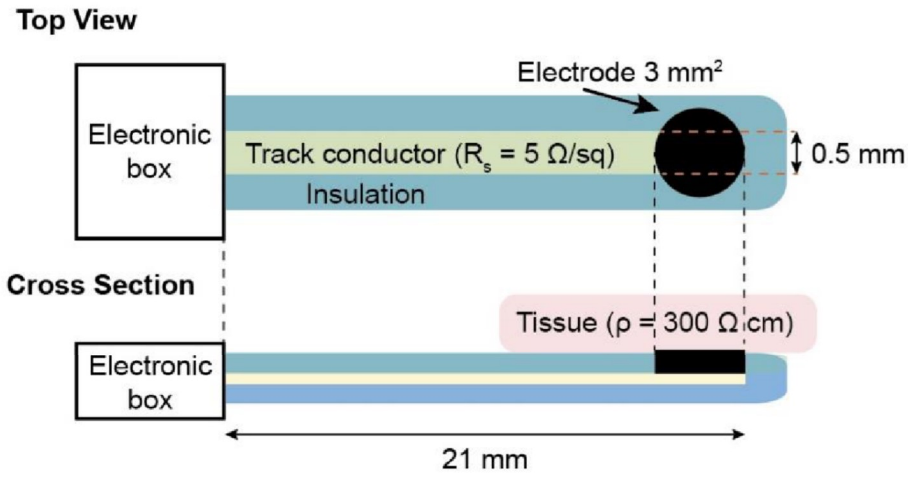
Neural Electrodes - Exercise set A

Exercise 1. Electrical stimulation and safety

Consider the electrode system illustrated below. The electrode has a coating which is ideally polarizable with an ESA of 4.5 mm^2, i.e. the electrode coating does not allow charge transfer across the electrode-tissue interface.



a. You would like to use this electrode to stimulate a specific circular region of the brain, of area A = 3 mm^2. Previous studies have shown efficacy with pulses of charge density q = 25 $\mu C.cm^{-2}$. Use Shannon's law to estimate whether the proposed stimulation protocol is safe. Assume k = 1.75.

b. You decide to use the proposed geometry (A = 3 mm^2). You choose a cathodic-first, biphasic, symmetric stimulation waveform that delivers charge with a pulse-width PW = 0.6 ms and inter-phase delay of 0.01 ms. Draw quantitative 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 2. Electrochemical impedance

Electrochemical impedance spectroscopy is an important characterization technique that enables the electrical behavior of an electrode to be measured and modeled. Consider again the electrode system illustrated in exercise 1, this time immersed in saline solution (ρ = 60 Ω.cm). The electrode coating is the same with a capacitance of 20 μF/cm², which 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 30.

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

Exercise 3. Subthreshold 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 the Cl^-, K^+ and Na^+, respectively, and 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? T = 37 °C.