SYDE 544: Biomedical Measurement and Signal Processing

Assignment 1: Origin of Biopotentials

Instructor: Steven Pretty

Due Date: Wednesday, Jan 25th, 2023 (11:59 PM, EST)

Instructions: Solutions to the following problems should be submitted to the LEARN drop box in PDF format. For problems 5 - 7, executable Matlab scripts, which can be utilized to reproduce your results must also be submitted to the LEARN drop box.

Part 1: Equilibrium Potential of Ions and Resting Membrane Potentials (8 points)

1. When we were evaluating the equilibrium potential for specific ions during the lecture, we calculated the equilibrium potential of *K+* and *Na+* using the Nerst equation. Calculate the equilibrium potentials of chloride and calcium. (2 points)

Ion	Concentration outside (in mM)	Concentration inside (in mM)	Ratio Out : In
K^+	5	100	1 : 20
Na^+	150	15	10 : 1
Ca^{2+}	2	0.0002	10,000 : 1
Cl^-	150	13	11.5 : 1

2. When we were calculating resting membrane potential during the lecture, we did not consider chloride ions. Based on your result from Question 1, why is this simplification justified? Hint: Calculate the resting membrane potential of a cell impermeable to *Cl* and analyze the dynamics if this cell were to become permeable to *Cl*. (2 points)

3. Modify the Goldman equation introduced in lecture to include chloride and demonstrate that the resting membrane potential is relatively insensitive to the membrane permeability to *Cl*. (2 points)

4. When the brain is deprived of oxygen the mitochondria within the neurons can no longer produce ATP. What effect will this have on the resting membrane potentials of these cells and the brain? Why? (2 points)

Part 2: Modelling the Dynamics of a Single Neuron (12 points)

5. In lecture we reviewed the Hodgkin-Huxley model of a neuron. Recall m, n, and h are the gating variables which model the dynamics of the voltage gated ion channels responsible for the development of action potentials. Let x = m, n, or h. The derivate of x with respect to time can be stated as:

$$\frac{dx}{dt} = \alpha_x(V_m)(1-x) - \beta_x(V_m) * x$$

where V_m is the membrane voltage, $\alpha_x(V_m)$ is the probability of a closed channel opening, and $\beta_x(V_m)$ is the probability of an open channel closing at V_m. Complete the attached Matlab functions (ah, am, an, bh, bm_, bn) using the following relationships based on experimental data: (2 points)

$$\propto_n = \frac{0.01(v+50)}{1-\exp\left(\frac{-(v+50)}{10}\right)} \qquad \propto_m = \frac{0.1(v+35)}{1-\exp\left(\frac{-(v+35)}{10}\right)} \qquad \alpha_h = 0.07\exp\left(-0.05(v+60)\right)$$

$$\beta_n = 0.125\exp\left(\frac{-(v+60)}{80}\right) \qquad \beta_m = 4.0\exp\left(-0.0556(v+60)\right) \qquad \beta_h = \frac{1}{1+\exp\left(-0.1(v+30)\right)}$$

6. Utilizing the equations from lecture, complete the calculations at lines: 8-9; 25-30; and 33-36 in the attached Hodgkin-Huxley Matlab function (HH). (4 points)

7. Finally, calculate the resting membrane potential (line 13) in the main Matlab script (SYDE544Assignment1). Include plots of the simulated membrane potential and gating variables over time by completing lines 29-39. Relate your gating variables to the conductance of sodium and potassium. What do the time varying changes in conductance represent over the course of an action potential? Include additional plot(s) as appropriate. (6 points)