BENG 186B Winter 2025 HW #3

Due *Friday, Feb 7* at 11:59pm on Canvas (Gradescope)

Parts of the homework done collectively in-class (Friday, January 31) are indicated below with **[IC]**.

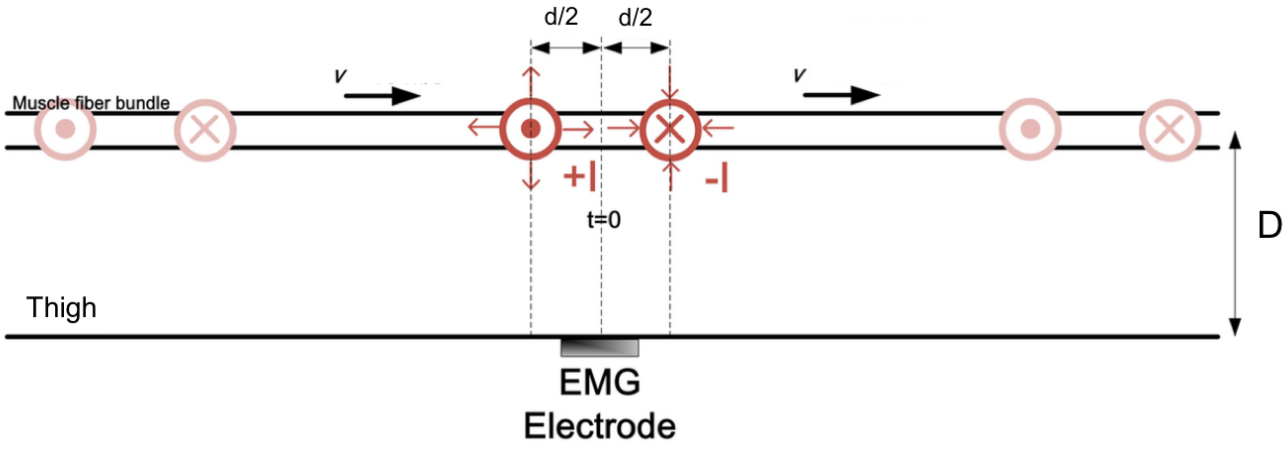
1. [**15 pts**] A nerve fiber is placed in a bathing solution whose composition is identical to extracellular fluid in the body. After the preparation equilibrates at 37 °C, a microelectrode inserted into the nerve fiber records a potential difference across the nerve membrane, interior to the cell with reference to the extracellular bathing solution, as -80 mV. The composition of the intracellular fluid and the extracellular fluid (bathing solution) is shown below.

Ion	Intracellular Fluid	Extracellular Fluid
Na^+	10 mmol/L	100 mmol/L
K^+	120 mmol/L	5 mmol/L
Cl^-	100 mmol/L	120 mmol/L

   (a) **[IC]** [5 pts] Which ion is closest to electrochemical equilibrium?

   (b) [10 pts] What can be concluded about relative permeabilities of the nerve membrane to Na^+ and K^+, if it is known that the membrane is practically impermeable to Cl^- under these conditions?

2. [**25 pts**] The patellar reflex causes the quadriceps muscle to contract in response to the patellar tendon being struck. You are interested in measuring the magnitude of the reflex response using EMG. Consider the propagation of an action potential along a muscle fiber bundle in the thigh. The action potential travels at a velocity $v = 10$ m/s. Model the current entering the muscle from the extracellular medium at the action potential onset as a current monopole $-I$ traveling at v, and a second current exiting the muscle at repolarization as a current monopole $+I$ following at a distance $d = 1$ cm. An electrode on the arm surface at a distance $D = 5$ cm from the muscle measures the EMG signal relative to body ground. Assume a volume conductivity $\sigma = 0.1\ \Omega^{-1}\text{m}^{-1}$. You measure an action potential magnitude of $V_{max} = 100\ \mu$V.



   (a) **[IC]** [5 pts] What value of current I would you expect for the current monopoles to yield the given action potential magnitude?

   (b) [20 pts] Plot the EMG signal as a function of time as the action potential goes by.

3. **Design Problem [60 pts]:** Biopotential amplifiers are voltage amplifiers typically used in electrophysiological experiments to increase the amplitude of weak electrical signals of biological origin-picked up by an electrode in contact with surrounding tissue. Design a biopotential amplifier for measuring neural signals that takes in voltage as its input and has an input impedance greater than 1 GΩ, so as to avoid loading of the biopotential signal being measured. The output impedance of the amplifier should be sufficiently low to drive an external 1 kΩ load with minimal distortion. The voltage gain should be greater than 1,000 over the signal frequency band in order to resolve low-amplitude biopotential signals. The signal frequency band ranges from 0.1 Hz to 1 kHz, and the voltage gain should attenuate outside of this range in order to suppress noise and interference from unwanted signals and motion artifacts. You have a 1.2V battery available, and can use any number of opamps, resistors, and capacitors.

   As before, specify all component values and other parameters to quantify your design, and explain your reasoning behind design choices based on the specifications. You may find it useful to check the operation of your circuit and observe its behavior using an electronic simulator such as the Falstad Java applet with several circuit examples posted at https://www.falstad.com/circuit/.