Circle your lab day and time.

Your name: ____________________

TA name: ____________________

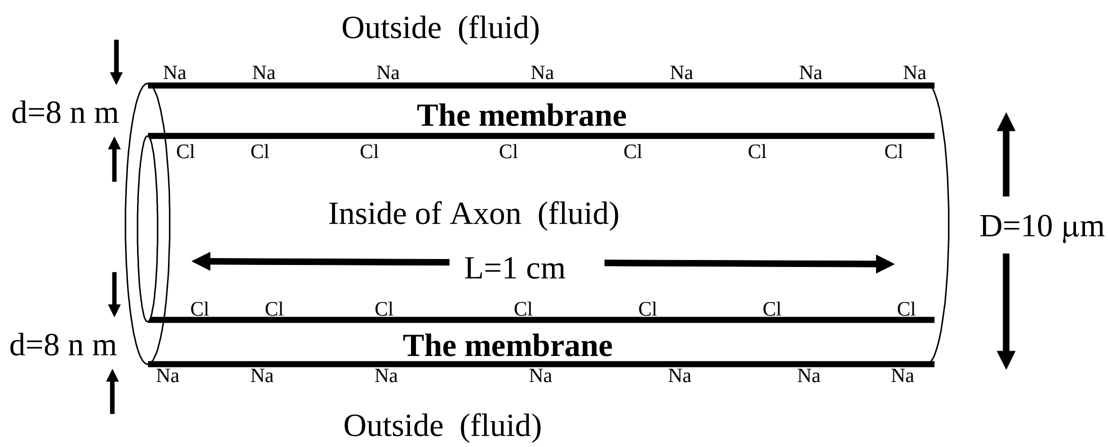
Tue	Tue	Tue	Wed	Thu	Thu	Fri
10-12	12-2	2-4	12-2	10-12	12-2	12-2

Written HW 2: Nerve cell
(due Thurs, Sep 21, 2012 at 2 PM)

Turn in this written homework in the appropriate slot in the brown Homework Cabinet at the entrance of the HelpRoom, Duane G2B90. Please STAPLE pages together, and **put your name and TA name at the top of every page!**

In all written homework, you will be graded on the clarity and completeness of your answer. ***No credit*** *will be given for an answer in a calculation without a derivation, even if the answer is correct. A calculation without units is also incorrect.*

While a neuron (nerve cell) is a complicated biological device much of its behavior can be modeled as a simple electrostatic device: a capacitor. It is a fluid-filled tube that is surrounded by another fluid. Both fluids contain ions (electrically charged atoms) of sodium (Na), potassium (K), and chlorine (Cl). Each sodium or potassium ion has one elementary unit of positive charge (+e) while each chlorine ion has one elementary unit of negative charge (-e). The wall of the nerve cell, the "membrane", separates the two fluids. The membrane is a barrier, and prevents ions from passing through it. When a neuron is close to being prepared to fire an impulse there are more sodium ions on the outside of the membrane than on the inside of it. This means that there also must be a net excess of chlorine atoms on the inside membrane. In a somewhat simplified picture that still captures the physics quite well, other than these ions attached to the membrane, the *bulk* of both fluids, and the membrane itself, can be considered as electrically neutral.



The dimensions of an axon are given in the figure, the membrane thickness is about d=8 nm thick (that's "nano-meters"). The axon itself is a cylinder about D=10 μm in diameter (that's "micro-meters"), and a small axon might be L=1 cm long.

1. The picture above doesn't look like our usual parallel plate capacitor, it looks like a CYLINDER. But you can think of it as a parallel plate capacitor that has been rolled up. (Try to picture this!).

   a) We normally describe a parallel plate capacitor in terms of three key things: the area of the charged plates, the distance between the plates, and the signs of the charges on the plates. Redraw the axon and show us the SIGN of the electric charges near the membrane, and then clearly describe what we should use as the "distance between the plates" and “effective area”, if we want to model the axon as a simple parallel plate capacitor.

   b) The magnitude of the potential difference across the membrane in the resting state is about 80 mV. Which region is at the LOWER potential, the inside or the outside? How do you know?

   c) What is the magnitude of the electric field inside the membrane?

2. In order to finish charging up the membrane the cell has small pumps that push more Na ions from the inside of the cell to the outside.

   a) Does the nerve do positive or negative work on the sodium ions during this transfer? Why?

   b) How much work does it take to carry one single sodium ion across the membrane? Answer in electron volts (eV).

   c) For each transfer of three sodium atoms the cell uses one molecule of its fuel called ATP. Each molecule of this fuel contains about 0.3 eV of energy. Comparing this number to the answer you got in b), does it seem like the sodium pump is very "energy efficient"? (Briefly, explain your reasoning)

   d) After many more sodium atoms are transferred what happens to the voltage difference voltage difference across the cell membrane.

3. When the nerve cell "fires", the pumping mechanism described above turns off, and Na ions are suddenly allowed to pass through its walls through purely electrostatic forces.

   a) Which way do they move - into or out of the axon? Why?

   b) After many sodium ions have "poured through", describe qualitatively what happens to the voltage difference from outside to inside the cell.

4. Describe briefly in words and/or formulas why the resting nerve has stored electrostatic potential energy. Make a numerical calculation of this energy, expressing it in eV (refer to section 17-9 in your textbook for help). How many glucose molecules would this nerve cell have to consume to charge up (each glucose molecule gives a cell 30 ATP molecules to use)? Use this to comment on why thinking a lot can be tiring.