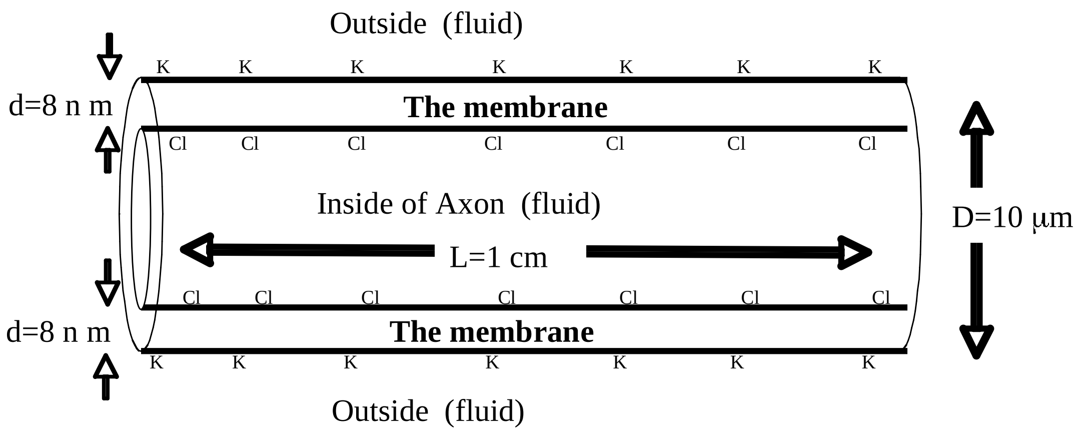
Your name: ____________________ **TA name:** ____________________

Written HW 2: Nerve cell
(due Thurs, Feb 12, 2009 at 5 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.*

A nerve cell is an electrostatic device, in many ways just a simple capacitor. It is a fluid-filled tube that is surrounded by another fluid. Both fluids contain ions (electrically charged atoms) of sodium, 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 can prevent ions from passing through it. They can also attach to it.) When the nerve cell is in its resting state, the outside of the membrane has more potassium ions attached to it than chlorine ions. The inside wall of the membrane has more chlorine ions than potassium ions. Other than the ions attached to the membrane, the *bulk* of both fluids, and the membrane itself, can be considered as electrically neutral. (See the (very crude!) picture.)



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 (that's "micro-meters") in diameter, and a small axon might be L=1 cm long. The membrane is filled with a dielectric (dielectric constant: $\kappa = 3$).

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 “effective area" and "distance between the plates", 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) Using the numbers above, make a quantitative estimate of the total charge Q on the outer wall of the axon. (Give it in Coulombs, and also in the total number of potassium (K) ions.)

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

2. Describe briefly in words and/or formulas why the resting nerve has stored electrostatic potential energy. Make a simple numerical calculation of this energy (express it in eV). Bearing in mind that 1 eV is a typical "chemical energy", does this seem like a *lot* of stored energy to you, or a *little*?

3. In its resting state the nerve pumps sodium ions (each having one elementary unit of positive charge (e^+)) out of the cell.

   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? (Again, answer in eV. Does this seem like a lot of work, or a little?)

4. When the nerve cell “fires,” it abruptly allows sodium ions to pass through its walls.

   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.