Physics 4L, Spring 2010— Problem set 5
Due Tuesday 2 March in class
Self-test problem due Thursday 4 March in class.

Problems and questions from Wolfson:
Chapter 23: “For Thought and Discussion” 13
Chapter 23: problems 18 (assume the molecule is in air, not any kind of dielectric), 20, 36, 48, and 59 with the following addition: also find the energy stored in the capacitor when ΔV_{cap} = 500 V (the “working voltage” of a capacitor is the maximum ΔV_{cap} that can be applied without the electric field strength becoming great enough to cause dielectric breakdown of whatever is between the plates). Note that the answer in the back of the book for this problem is wrong.

For problem 36, note that the mass density of gasoline is 670 kg/m^3 and Appendix C provides the other information you need.

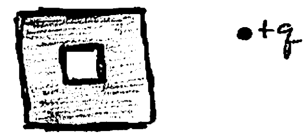
Additional problems and questions:
1. Explain briefly why (a) the electric field is zero in the bulk of a conductor at electrostatic equilibrium;
(b) a conductor at electrostatic equilibrium is an equipotential;
(c) the electric field at the surface of a conductor must be perpendicular to the surface.

2. (Adaptation of Wolfson Ch. 20 question 13) Look at Figure 20.25 (p. 343). Dipoles A and B are both located in the field of a charged particle $+Q$ as shown in the figure. For each of A and B: Explain whether the dipole tends to rotate due to the electric field of $+Q$, and if so, which way (clockwise/counterclockwise). Also explain whether there is a net force on the dipole, and if so, in what direction. Describe the motion of the dipole if it is released from rest.

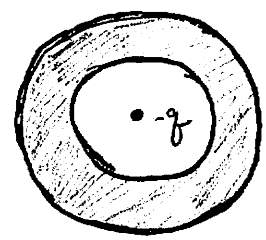
3. One sodium chloride (NaCl) “molecule” consists of a Na^+ ion of charge +e and a Cl^- ion of charge –e separated by a distance of 0.24 nm. For this problem, assume that the ions are embedded in the same lipid material as a cell membrane ($\kappa = 8$).
(*a*) Find the amount of work by an external force required to remove one ion to infinitely far away from the other) of this molecule. This quantity is sometimes called the binding energy of a molecule. Compare to the binding energy in air ($\kappa = 1$) and in water ($\kappa = 80$). (If we worked out the values in air and water in class you can just quote those values.)
(*b*) Suppose the charges of the Na^+ and Cl were doubled to +2e and -2e respectively. By what factor would the binding energy change? Explain briefly.

Problem 4 appears on the next page.

4. (a) A hollow conducting box is placed near a pointlike particle with charge $+q$. The box has no net charge and there is no charge inside the box. Sketch electric field lines for this arrangement and indicate how charge is arranged on the surface of the box. If the electric field is zero anywhere, indicate that clearly. Explain your answer briefly.



(b) A pointlike particle with charge $-q$ is placed at the center of a conducting sphere with a hole in the center. Sketch electric field lines for this arrangement and indicate how charge is arranged on the sphere. Also give the total amount of charge on the inner and outer surfaces of the hollow conducting sphere. If the electric field is zero anywhere, indicate that clearly. Explain your answer briefly.



Self-test problem, PS 5 DUE THURS March 4   Name ___________________________

You may spend up to 30 minutes on this problem. Do your work on this sheet and turn it in separately. Do not work with others or refer to the textbook, though you may consult the equation sheet posted online. Your score on this problem will not be included in your homework grade; it is solely for feedback to you. (However, you *will* receive credit for one homework problem for completing it.)

Consider the electrical properties of the charge layers on either side of the cell membrane, taking into account the polarization of the lipid material of the membrane. The potential difference between the inside and outside of a cell is 110 mV (outside is positive relative to inside). The membrane is approximately 5 nm thick and the dielectric constant of the membrane is 8.

(*a*) Find the magnitude of the charge density σ_{ions} of the ions on either side of the membrane.

(*b*) If the cell membrane dielectric constant was 3 (as in Wolfson problem 60) instead of 8, would your answer to (*a*) change, and if so, by what factor would it change? (What number would you multiply your answer to (a) by to get the correct charge density?) Explain briefly.

(*c*) Consider moving three Na^+ ions from the inside to the outside of the cell. Find the change in electric potential energy associated with this process, and give a qualitative explanation for the sign of your answer (i.e. why electric potential energy is lost or gained, or remains the same).

(Problem continued on the back)

(*d*) Would the change in electric potential energy you found in (*c*) change if the membrane dielectric constant was 3 instead of 8? If so, by what factor would it change? Explain briefly.