Study Guide for Midterm 1

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Instructions: Work each problem *before* checking your answer with the key (to follow on Moodle).

1 Memory Bank

1. $m = \rho V$ ... Mass is the density times the volume
2. $V = \frac{4}{3}\pi r^3$ ... The volume of a sphere
3. $\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$ ... Coulomb Force
4. $k = 9 \times 10^9$ N C^{-2} m^2 ... Remember $k = 1/(4\pi\epsilon_0)$.
5. $q_e = 1.6 \times 10^{-19}$ C ... Charge of an electron/proton
6. Atomic mass: the number of grams per mole of a substance
7. $N_A = 6.03 \times 10^{23}$ ... Avagadro's number
8. $\vec{F} = q\vec{E}$ ... Electric field and charge
9. $\vec{E}(z) = \frac{\sigma}{\epsilon_0}\hat{z}$ ... Electric field of two oppositely charge planes each with charge density σ
10. $\epsilon_0 \approx 8.85 \times 10^{-12}$ F/m
11. $dE = \int k dq/r^2$ ... Remember that dq takes the form below
12. $dq = \lambda dx$ ... Linear charge density (C/m)
13. $\vec{E} \cdot \vec{A} = Q_{enc}/\epsilon_0$ ... Gauss' Law, constant electric field over the surface area.
14. $U = q\Delta V$ ... Potential energy and voltage
15. 1 eV: an electron-Volt is the amount of energy one electron gains through 1 V.
16. $V(r) = k\frac{q}{r}$ ... Voltage of a point charge
17. $\vec{E} = -\frac{\Delta V}{\Delta x}$ ... E-field is the slope or change in voltage with respect to distance
18. $V(x) = -Ex + V_0$ ... Voltage is linear between two charge planes
19. $Q = CV$ ... Definition of capacitance
20. $C = \frac{\epsilon_0 A}{d}$ ... Capacitance of a parallel plate capacitor
21. $C_{tot}^{-1} = C_1^{-1} + C_2^{-2}$ ... Adding two capacitors *in series.*
22. $C_{tot} = C_1 + C_2$ ... Adding two capacitors *in parallel.*

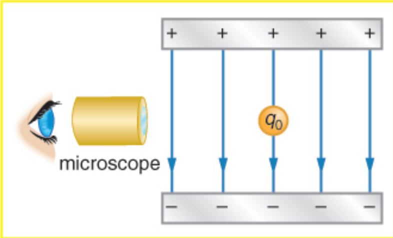

Figure 1: The classic Millikan oil drop experiment was a measurement of the charge of an electron.

2 Electric Charge and Electric Fields

1. (a) A certain lightning bolt moves 40.0 C of charge. To how many electrons does this correspond? (b) Suppose a speck of dust in an oil drop experiment[1] has 10^{12} protons in it and has a net charge of -5.00 nC (a very large charge for a small speck). How many electrons does it have?

2. (a) Two charges exert $F_C = 5.00$ N of force on each other. What will F_C be if the distance between them triples? (b) If one charge is 1 nC, and the other is 2 nC, what is the distance between them if $F_C = 5.00$ N?

3. The classic Millikan oil drop experiment was the first to measure accurately the electron charge. Oil drops were suspended against the gravitational force by a vertical electric field. (See Fig. 1.) The drops have radius 1.0μm, and a density of 920 kg/m^3. (a) Find the weight of the drop. (b) If the drop has a single excess electron, find the electric field strength needed to balance its weight.

4. Suppose three electrons are arranged in an equilateral triangle 0.1 nm on a side (see Fig. 2). (a) What is the electric field **vector** at the location of the top charge? (b) Where is the electric field zero?

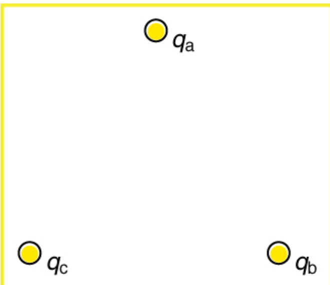

Figure 2: An equilateral triangle, 0.1 nm on a side (internal angles are 60 degrees).

5. (a) Using Coulomb's Law, show that the electric field at point P in Fig. 3 is (a) strictly in the vertical direction $\hat{k}$, (b) is proportional to $1/z$ if the line of charge is infinite. (c) **Bonus:** use Gauss' law to derive the electric field assuming a cylindrical Gaussian surface as the $\vec{A}$ piece.

3 Potential Energy and Voltage

1. What is the electric field across an 10.00 nm thick membrane if (a) the voltage across it is 50 mV? You may assume a uniform electric field. (b) Suppose this cell membrane is part of a nerve cell. How much energy would an electron gain if dropped through the 50 mV voltage and accelerated across the cell freely? Express your anser

[1] A great paper topic, by the way: the Millikan oil drop experiment.

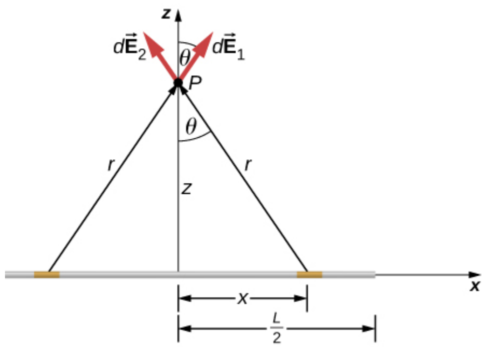

Figure 3: A line of charge with charge density λ.

in electron-Volts (eV).

2. **Think back to the PhET simulations of parallel lines of charge.** Suppose a parallel plate capacitor is formed from a positive plate and a negative plate of charge. The plates' areas A are the same, and the plates' charges ($\pm Q$), and charge densities ($\pm Q/A = \pm\sigma$) are the same as well. (a) Write the expression for the electric field between the plates? (b) Suppose $Q = 1$ nC, and $A = 10$ mm^2. What is the value of the electric field between the plates? (c) Suppose 0 volts corresponds to the location of the negative plate. Draw the voltage as a function of distance between the plates. (d) What is the voltage near the positive plate, if the plates are are separated by a distance $d = 1$ mm?

4 Capacitors

1. What is the capacitance of the capacitor in the previous problem?

2. (a) Consider the same capacitor again, and suppose a second identical capacitor is connected *in parallel* with it. What is the total capacitance? (b) How much charge would the pair of capacitors store if the voltage across them was 5 volts?

3. How much energy in Joules would this charge have if it was all put to work?