Mid Term Exam 2
Phys 248
Mar 13, 2009

Print your name and ID number clearly above.
To receive full credit you must show all your work. If you only provide your final answer and do not show your work you will only receive partial credit, even for a correct final answer.

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**Useful constants:**
Planck constant $h = 6.626 \times 10^{-34} \text{ J s}$
Reduced Planck constant $\hbar = 1.054 \times 10^{-34} \text{ J s}$
Permittivity of free space: $\varepsilon_0 = 8.854 \times 10^{-12} \text{C}^2\text{N}^{-1}\text{m}^{-2}$
hc = 1240 eV nm
$\hbar c = 197.3 \text{ eV nm}$
c = $3 \times 10^8 \text{ m/s}$
1 eV = $1.6 \times 10^{-19} \text{ J}$
k e$^2$ = 1.44 eV nm
$m_e = \text{electron mass} = 9.11 \times 10^{-31} \text{ kg} = 0.511 \text{ MeV/c}^2$
Problem 1: Short electrostatics problems.
1. Four point charges are located as shown in the figure. The distance of each charge from the origin of the reference frame is \( d = 12 \text{ cm} \) and \( Q = 3 \text{nC} \).
   a) Calculate the magnitude and direction of the net force on a point charge \( Q' = -2 \text{nC} \) placed at the origin.
   b) Calculate the electric potential at the origin.
2. An electric dipole with ±3 nC charges at a distance of 10 nm forms an angle of \( \theta = 30^\circ \) respect to the direction of the applied uniform electric field of 10 N/C.

A) What is the torque (direction and magnitude) on the dipole? In what direction will the dipole rotate?

B) What is the work that the E-field has to do to bring the dipole in its stable equilibrium position?

3. For a uniformly charged sphere of radius R and total charge Q, calculate the electric field at a distance R/2 from the surface of the sphere to the electric field at a distance R/2 from the center of the sphere.
4. Consider the thin ring of radius $a = 1.0 \text{ cm}$ and uniform charge density $\lambda = -1.0 \text{ mC/m}$ in the figure.
   a) What is the electric field in the point $P$ in the figure at a distance $2a$ from its center?
   b) What is the work an external agent has to do to bring a charge of $1 \mu \text{C}$ to that point (starting from infinity)?
**Problem 2: Capacitance**

The plates of a parallel plate capacitor of area $A = 400 \text{ cm}^2$ are separated by a distance $d_0 = 5\text{ cm}$. The charge on the plates is $\pm 3 \mu\text{C}$. A metal slab of thickness $d = 1 \text{ cm}$ and area $A$ is fully inserted between the plates in such a way that the slab is parallel to the capacitor plates.

A) What is the electric field in the 3 regions of space I, II, III in the figure?

B) What is the induced charge density on the conductor slab surfaces?

C) What is the capacitance of this system of conductors?

D) What is the work you have to do to pull the upper plate farther apart by an additional distance $h = 3 \text{ cm}$?
Problem 3: Bohr model.

Muons are identical to electrons except for their masses ($m_\mu = 105.7 \text{ MeV}/c^2$). A muon can be captured by a proton to form a “muonic hydrogen atom.” This atom can be described by the Bohr model once $m_e$ is replaced by $m_\mu$. (You may neglect effects that result from the finite mass of the proton.)

A) Calculate the radius of the first Bohr orbit of this atom.
B) Calculate the magnitude of the lowest energy state.
C) What is the shortest wavelength in the Lyman series for this atom?