PHYS 102 General Physics II – Midterm 1
October 19, 2015 Monday 17:45 -19:45

Please read!

- Count to make sure that there are 5 pages in the question booklet
- Check your name and surname on front page, and student ID number on each page, and sign each page.
- This examination is conducted with closed books and notes.
- Put all your personal belongings underneath your seat and make sure that pages of books or notebooks are not open.
- Absolutely no talking or exchanging anything (like rulers, erasers) during the exam.
- You must show all your work to get credit; you will not be given any points unless you show the details of your work (this applies even if your final answer is correct!).
- Write neatly and clearly; unreadable answers will not be given any credit.
- If you need more writing space, use the backs of the question pages and put down the appropriate pointer marks.
- Make sure that you include units in your results.
- Make sure that you label the axis and have units in your plots.
- You are not allowed to use calculators during this exam.
- Only the answers in the boxes will be graded and NO partial credit will be given. No points will be given to unjustified answers. Incomplete calculations will not be graded.
1. [7 pts] A positive charge $q_1$ is at the origin and another positive charge $q_2$ is at $x = d$ on the x-axis ($q_1 \neq q_2$). We put a third charge so that all three charges are in electrostatic equilibrium. Determine the sign and the position of the third charge in terms of $q_1$, $q_2$ and $d$.

<table>
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<th>Sign:</th>
<th>Position:</th>
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2. [8 pts] An infinite rod with uniform charge per unit length, $\lambda = 5 \, \mu\text{C/m}$ extends on the x-axis at a distance $d = 50\text{cm}$ from the origin as shown in the figure. A point charge $q$ is placed $x = -d$. Calculate $q$ if the electric field at the origin is zero.

![Diagram of rod and point charge]

\[ q = \] 

3. [10 pts] An electric dipole $\vec{p} = p\hat{i}$ is placed in an uniform electric field $\vec{E} = -3E_0\hat{i} - 4E_0\hat{j}$. The dipole is free to rotate about its axis.

a. Calculate the initial potential energy of the dipole.

b. Suppose the dipole reaches the stable electrostatic equilibrium. Calculate the potential energy of the dipole in this equilibrium.

| a) | b) |
4. [4 pts] Extract the unit of $\varepsilon_0$ in SI unit system from an electrostatic law. Express your answer in terms of the units N, C, m.

5. [9 pts] A point charge $Q$ is located on the x-axis at $x=2$ m and a second point charge $-2Q$ is on the y-axis at $y=1$ m. What is the total electric flux due to these two point charges through a spherical surface centered at the origin with radius (a) 0.5 m, (b) 1.5 m, (c) 2.5 m. Express your answers as a function of $Q$ and $\varepsilon_0$.

6. [12 pts] A conducting spherical shell with inner radius $b$ and outer radius $2b$ has a positive point charge $Q$ located at its center. The total charge on the shell is $-3Q$ and the shell is insulated from its surroundings.

   a) Calculate the electric field (magnitude and direction) in terms of $Q$ and distance $b$ for the following radial distances from the center of the spherical shell: (i) $r=0.5b$; (ii) $r=1.5b$, (iii) $r=3b$.

   b) What are the surface charge densities on the (i) inner surface of the spherical shell; and (ii) outer surface of the spherical shell?
7. [8 pts.] A charged particle \( q = 5 \mu C \) is moved on the x-axis from the origin \( a(x = 0, y = 0) \) to point \( b(x = 20 \text{ cm}, y = 0) \) in a uniform electric field \( \vec{E} = -3E_0 \hat{i} - 4E_0 \hat{j} \), where \( E_0 = 10 \text{ N/C} \).
   a. Calculate the change in the electric potential energy of the particle in Joules.

   \[
   \Delta U = \quad
   \]

   b. The particle then moves from point \( b \) to point \( c(x = 20 \text{ cm}, y) \). If the potential difference between the origin and the point \( c \) is \( V_{ac} = 0 \), what is the value of \( y \)?

   \[ y = \quad \]

8. [7 pts.] Four charges have each equal magnitude and their sum is equal to zero. The charges are placed one by one at the vertices of a regular tetrahedron of edge length \( L \). Calculate the potential energy of this arrangement of charges. (A regular tetrahedron has four identical equilateral triangular faces as shown in the figure) (Hint: Use the potential energy between two charges and the superposition principle)

   \[
   U = \quad
   \]

9. [10 pts.] A conducting solid sphere of radius \( R \) with charge \( +3q \) is at the center of a conducting hollow sphere of inner radius \( 3R \) and outer radius \( 4R \). The hollow sphere has charge \( -q \). Take the origin as the center of the spheres. Take the potential at infinity as zero.
   a. Calculate the potential at the origin.
   b. Suppose that a conducting thin wire is connected between the spheres. How much charge flows through the wire?
   c. In part b, calculate the new potential at the origin when electrostatic equilibrium is reached (i.e. after the charge flow is completed).

   (You may use the electric field and the potential formula of uniformly charged spherical conductors without derivation)

   a) 
   b) 
   c)
10. [6 pts] Two parallel-plate capacitors are identical except for plate separations. $C_1$ has plate separation $d$ while $C_2$ has plate separation $2d$. $C_1$ and $C_2$ are charged by the same voltage source. Answer the following questions with $C_1$ or $C_2$.

Which capacitor has a stronger electric field between the plates?

Which capacitor has a greater charge?

Which capacitor stores more energy?

11. [9 pts] The capacitor $C_1= C$ is initially charged to a potential difference $V_0$ while the switch $S$ is open. Capacitors $C_2=2C$ and $C_3=C$ are initially uncharged. Then, $C_1$ is first disconnected from the voltage source, then the switch $S$ is closed and a new steady state is reached. Find the final charges and potentials of $C_1$, $C_2$, and $C_3$. Express your answers in terms of $C$ and $V_0$.

$$Q_1 = \quad Q_2 = \quad Q_3 =$$

$$V_1 = \quad V_2 = \quad V_3 =$$

12. [10 pts] a) A parallel plate capacitor with two flat plates, each with area $A$, separated by a distance $d$ in vacuum has capacitance $C_0$. Then a dielectric slab with dielectric constant $K$ and thickness $d/2$ is inserted between the plates, parallel to the plates. Express the equivalent capacitance of the system in terms of $K$, $d$, $C_0$.

$$C =$$

b) Assume the capacitor in part a) stores a charge $Q$, initially before the dielectric slab inserted. What is the work done by an external force in inserting the dielectric slab between the plates of the capacitor? Express your answers in terms of $Q$, $K$, $d$, $C_0$.

$$W =$$