1^{st} **Midterm - April 4, 2009**

Name and Surname:
Student ID:
Department:
Signature:

You should show your work. You will lose points if you do not put the right units and put the vector signs for vectors.

Discussion:

Each question is 10 points. Any equation you use will cost you 2 points.

1. Argue that, in equilibrium and in the absence of magnetic fields, there can not be any electric field inside a metal. Neither inside the bulk of the metal, nor in any cavity inside the metal. Argue also that the electric field on the surface of the metal has to be perpendicular to the metal.

2. Explain action-at-a-distance and how the field concept is used to avoid action-at-a-distance.

Short Questions:

3. Consider a parallel plate capacitor made of two large conducting plates of area A separated by a distance d. If, at a given instant, there is a current I charging the capacitor, what is the rate of change of the electric field between the plates (assume that the electric field is uniform, first calculate the electric field between the plates using Gauss' Law).(10 points)

4. Consider the circuit shown in Fig. (1). Write down the Kirchoff' equations for this circuit that would allow you to determine the currents passing through all the wires. (You do not need to solve the equations). (15 points)

Calculations:

Instructions: In this part, your solution should include 3 parts: In the 1^{st} part, explain what you understand the question asks. In the 2^{nd} part, explain your strategy in solving the problem. In the 3^{rd} part, solve the problem. If you skip any of the parts, the rest of your answer will not be considered for grading.

5. Consider a linear semi-infinite positive charge distribution along the x-axis, and a linear semi-infinite negative charge distribution along the y axis.Assume that the linear charge densities are $+\lambda$ and $-\lambda$ respectively. Calculate the electric field at an arbitrary point (x_0, y_0) where $x_0, y_0 > 0$. (20 points).

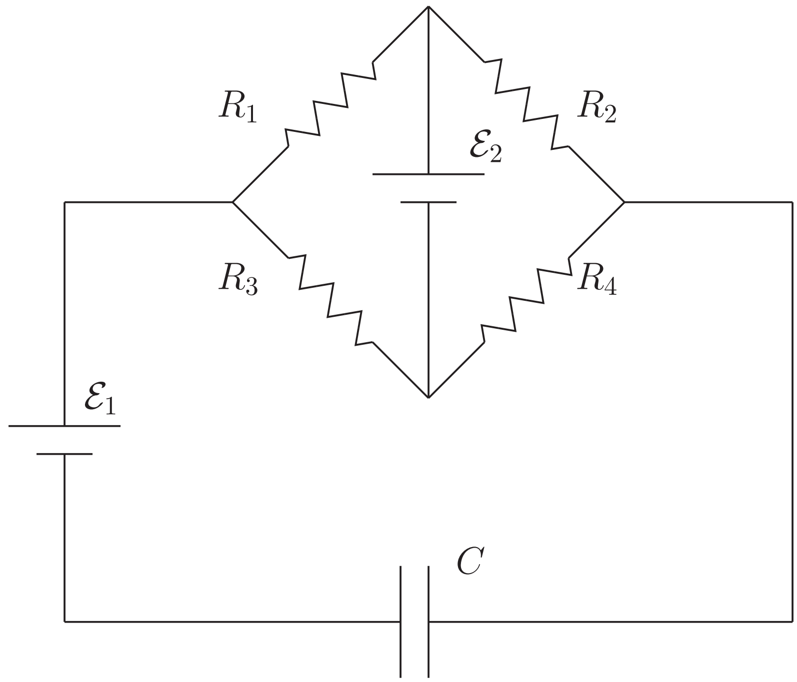

Figure 1: Circuit for Q4

6. Consider a sphere that has a uniform mass density ρ and a positive charge density σ. The sphere has a radius R and at a point on the surface is attached a rope of length $2R$. The other end of the rope is attached to a vertical wall that has a uniform positive surface charge density λ. Under the action of both the gravity of the Earth and the electrostatic repulsion between the wall, the sphere will come to equilibrium when the rope makes an angle θ with the wall. Calculate θ (20 points) (First find a relation between ρ, σ, λ and R such that if it is satisfied, the sphere will touch the wall. If it is not satisfied, the sphere will start hanging in air. Find θ for both of these cases.)

7. Consider a zone of space where there is a uniform magnetic field (take the z axis such that the magnetic field points in the positive z axis). Assume a metallic rod of length L is inside the magnetic field such that it lies along the y axis and moves with a velocity $\vec{v}$ in the positive x direction. As the rod moves, both the positive nuclei and the electrons will feel a force but since only the electrons are free to move, they will move along the wire and accumulate on one end of the rod,leaving the other end, positively charged. What will be the electric field inside the metal when the system reaches steady state? (20 points)

8. In an paper published in the journal *Nature* (Vol 434, p 1115), it is claimed by scientists in UCLA that fusion of nuclei is obtained in a tabletop experiment. In the experiment, they utilize lithium tantalate crystal soaked in deuterium gas. By heating the crystal rapidly, they claim to obtain a potential difference larger than 100.000 V across 1 cm. Deuterium is a hydrogen atom with an additional neutron. (25 points)
   (a) What is the electric field created inside the crystal? (5 points)
   (b) What is the acceleration of the deuterium nucleus? (5 points)
   (c) If one deuterium nucleus accelerates under this electric field for a distance of 1 cm and hits head on to another deuterium nucleus at rest, what is the distance of closest approach of the two nuclei? (Note that there is nothing that keeps the other nuclei at rest. During the collision process, ignore any other effects). (10 points)
   (d) For the fusion to occur, the distance between the two nuclei should be less than a few fm's ($1\ fm = 10^{-15}m$). Will the two nuclei fuse? (5 points)

Some numerical coefficients:

$$\begin{aligned} e &= 1.6 \times 10^{-19}\ C \\ m_D &= 3.34 \times 10^{-27}\ kg \\ \frac{1}{4\pi\epsilon_0} &= 9.0 \times 10^9 Nm^2/C^2 \\ \frac{\mu_0}{4\pi} &= 10^{-7}\ N/A^2 \end{aligned} \tag{1}$$

Coulomb Law: $\vec{F}^E = \frac{1}{4\pi\epsilon_0}\frac{qq'}{r^2}\hat{r}$
Magnetic force between two moving particles: $\vec{F}_M = \frac{\mu_0}{4\pi}\frac{qq'}{r^2}\vec{v} \times (\vec{v}' \times \hat{r})$
Gauss' Law: $\oint \vec{E} \cdot d\vec{S} = \frac{Q}{\epsilon}$
Faraday's Law: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$
$\oint \vec{E} \cdot d\vec{l} = 0$, $\oint \vec{B} \cdot d\vec{S} = 0$