Kuwait University **Physics Department**

Physics 102
Midterm 1 Examination

Spring Semester 2024
March 9, 2024

Time: 12:00 – 1:30 p.m.

Name: .... Student ID No: ....

Instructors**:** Drs. Alfailakawi, Lajko, Sharma, & Vagenas

Fundamental constants

$k = \frac{1}{4\pi\varepsilon_o} = 9.0\times10^9\ N.m^2/C^2$ (Coulomb constant)

$\varepsilon_o = 8.85 \times 10^{-12}\ C^2/(N \cdot m^2)$ (Permittivity of free space)

$\mu_0 = 4\pi \times 10^{-7}$ T .m/A (Permeability of free space)

$|e| = 1.60 \times 10^{-19}$ C (Elementary unit of charge)

$N_A = 6.02 \times 10^{23}$ (Avogadro's number)

$g = 9.8\ m/s^2$ (Acceleration due to gravity)

$m_e = 9.11 \times 10^{-31}$ kg (Electron mass)

$m_p = 1.67 \times 10^{-27}$ kg (Proton mass)

Prefixes of units

$m = 10^{-3}$ $\mu = 10^{-6}$ $n = 10^{-9}$ $p = 10^{-12}$
$k = 10^3$ $M = 10^6$ $G = 10^9$ $T = 10^{12}$

For use by Instructors only

Prob.	1	2	3	4	5	6	7	8	Total
Marks									

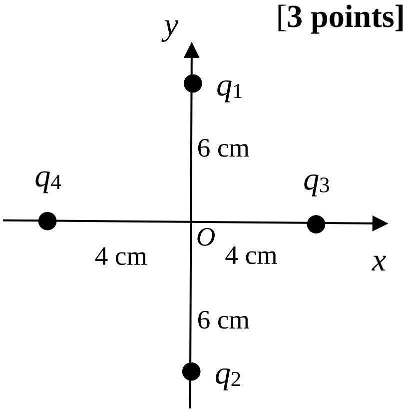
Ques.	1	2	3	4	5	6	7	8	Total
Marks									

Important:

1. Mobiles or other electronic devices are **strictly prohibited** during the exam.
2. Programmable calculators, which can store equations, are not allowed.
3. **Cheating incidents will be processed according to the university rules.**

PART I. Solve the following problems. Show your solutions in detail.

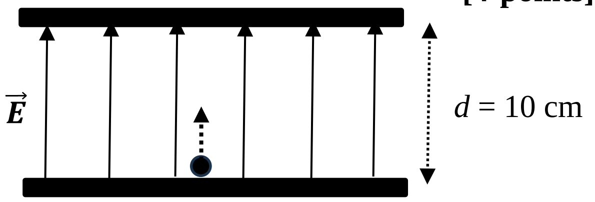
1. Four charges are placed as shown in the figure, $q_1 = q_2 = q_3 = 5$ nC, and $q_4 = -5$ nC. Calculate the net electric field $\vec{E}$ at the origin O. **[3 points]**



Since $q_1 = q_2 = 5$ nC, at the origin $E_y = 0$

$\vec{E} = E_x = 2 \times k\frac{q}{r^2}(-\hat{\imath}) = 5.6 \times 10^4$ N/C $(-\hat{\imath})$

2. A proton is released from rest in a uniform electric field as shown. What is the magnitude of the electric field E if the proton reaches the upper plate with a velocity $\vec{v} = 6 \times 10^6 \text{m/s}\,\hat{\jmath}$. Only the electric force is acting on the particle. **[4 points]**



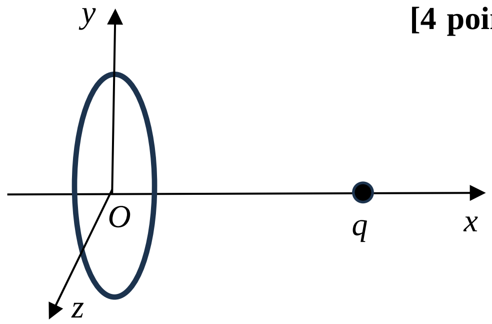
$v_y^2 = v_{0y}^2 + 2a_y\,\Delta y$

$a_y = 1.8 \times 10^{14}$ m/s^2

$F_y = m_p\,a_y = 3.00 \times 10^{-13}$ N

$E_y = \frac{F_y}{q} = 1.88 \times 10^6$ N/C

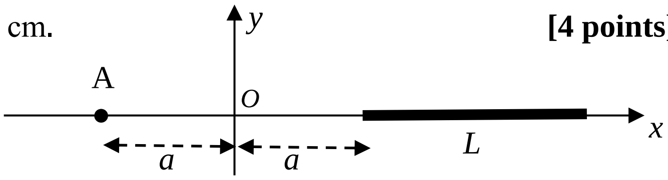
3. A charge $q = 3.5$ μC is located along the axis of a ring at 0.65 m from its centre. The ring has radius 0.10 m, and a charge -12.0 μC is distributed uniformly around it. What is the magnitude and direction of the force on the charge q? **[4 points]**



$$\vec{E}_{\text{ring}} = k\frac{|Q|x}{(x^2+a^2)^{3/2}}(-\hat{\imath})$$
$$= -\frac{9\times10^9\times12.0\times10^{-6}\times0.65}{(0.65^2+0.10^2)^{3/2}}\,\hat{\imath}\text{ N/C}$$
$$= -2.47\times10^5\hat{\imath}\text{ N/C}$$

$$\vec{F} = q\vec{E} = 3.5\times10^{-6}\times -2.47\times10^5\,\hat{\imath}\text{ N}$$
$$= -0.86\,\hat{\imath}\text{ N}$$

4. A charge $Q = 30$ μC is uniformly distributed along a rod of length $L = 1.0$ m on the x-axis, as shown. Calculate the electric field $\vec{E}$ at point A. Take $a = 10$ cm. **[4 points]**



$$\lambda = \frac{Q}{L} = \frac{30\ \mu\text{C}}{1.0\text{ m}} = 3.0\times10^{-5}\text{C/m}$$

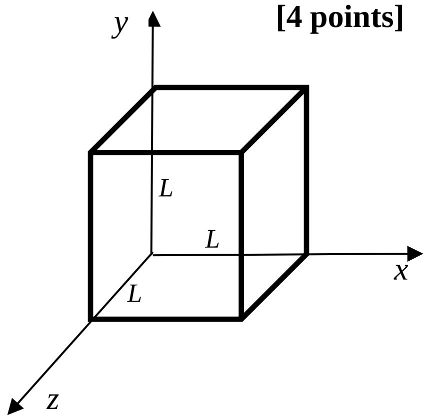
$$d\vec{E} = \frac{kdQ}{r^2}(-\hat{\imath}) = \frac{k\lambda dx}{(x+a)^2}(-\hat{\imath})$$

$$\vec{E} = \int_a^{a+L}\frac{k\lambda dx}{(x+a)^2}(-\hat{\imath})$$

$$= k\lambda\left[-\frac{1}{x+a}\right]_a^{a+L} = k\lambda\left[\frac{1}{2a}-\frac{1}{L+2a}\right]\ (\hat{\imath})$$

$$\vec{E} = 1.13\times10^6\text{ N/C }(-\hat{\imath})$$

5. A cube of sides L = 0.40 m, shown in the figure, has charges enclosed in it. The electric field thus produced is given by $\vec{E} = (0.30\text{ m} + 0.50\,x) \times 10^6\text{ N/C}\cdot\text{m}\,\hat{\imath}$, where x is in meters. What is the charge enclosed in the cube? **[4 points]**



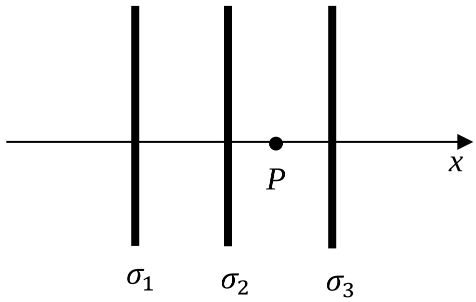
Flux through all faces except the left and the right faces is zero.

$\phi_{\text{total}} = (0.30 \times 10^6\hat{\imath}).(-L^2\hat{\imath}) +$
$(0.30 + 0.5 \times 0.40) \times 10^6\hat{\imath}.(L^2\hat{\imath})$
$= -4.8 \times 10^4 + 8.0 \times 10^4$

$\phi_{total} = \dfrac{q_{\text{encl}}}{\varepsilon_0}$

$q_{\text{encl}} = \varepsilon_0\phi_{total} = 8.85 \times 10^{-12} \times 3.2 \times 10^4$
$= 2.8 \times 10^{-7}\,C$

6. Three large sheets carry uniform surface charge densities $\sigma_1 = +1.770\text{ nC/m}^2$, $\sigma_2 = -0.885\text{ nC/m}^2$ and $\sigma_3 = +1.770\text{ nC/m}^2$. What is the net electric field $\vec{E}$ at point P? **[4 Points]**



$\vec{E}_1 = \frac{|\sigma_1|}{2\epsilon_0}\,\hat{\imath} = \frac{1.770\times10^{-9}}{2\times8.85\times10^{-12}}\hat{\imath} = 100\,\hat{\imath}\text{ N/C}$

$\vec{E}_2 = \frac{|\sigma_2|}{2\epsilon_0}(-\hat{\imath}) = -\frac{0.885\times10^{-9}}{2\times8.85\times10^{-12}}\hat{\imath} = -50\,\hat{\imath}\text{ N/C}$

$\vec{E}_3 = \frac{|\sigma_3|}{2\epsilon_0}(-\hat{\imath}) = -\frac{1.770\times10^{-9}}{2\times8.85\times10^{-12}}\hat{\imath} = -100\,\hat{\imath}\text{ N/C}$

$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 = = -50\,\hat{\imath}\text{ N/C}$

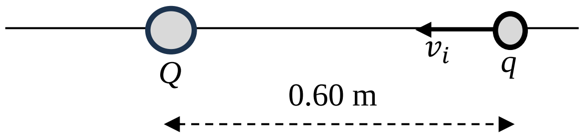
7. A solid non-conducting sphere of radius 0.45 m has a volume charge density $\rho = 7.5 \times 10^{-6}\ \mathrm{C/m^3}$. What is the magnitude and direction of electric field at a point 0.30 m from the centre of the sphere? **[3 points]**

$$\rho = \frac{Q}{V} \rightarrow Q = \rho . V = \rho . \frac{4}{3}\pi R^3 = 2.9 \times 10^{-6}\ \mathrm{C}$$

$$E = k\frac{Qr}{R^3} = \frac{9\times10^9\times2.86\times10^{-6}\times0.30}{0.45^3} = 8.5 \times 10^4\ \mathrm{N/C}$$

Direction: Radially outwards.

8. A charge Q = 6.0 µC is held at rest. Another charge q = 3.0 µC with mass $m = 7.0 \times 10^{-12}$ kg moves with a speed $v_i = 4.6 \times 10^5\ \mathrm{m/s}$ toward Q when it is at a distance 0.60 m. What will be the speed of q when it reaches a distance 0.30 m from Q? **[4 points]**



$$K_f + U_f = K_i + U_i$$
$$\frac{1}{2}mv_f^2 + k\frac{Qq}{r_f} = \frac{1}{2}mv_i^2 + k\frac{Qq}{r_i}$$
$$\frac{1}{2}mv_f^2 + 0.54 = 0.74 + 0.27\ \mathrm{J}$$
$$\frac{1}{2}mv_f^2 = 0.47\ \mathrm{J}$$
$$v_f = \sqrt{\frac{2\times0.47}{7.0\times10^{-12}}} = 3.7 \times 10^5\ \mathrm{m/s}$$

PART II : Conceptual Questions (each carries 1 point). Tick the best answer.

1. Two charged particles of identical mass m and with charges $Q_1 > Q_2$ which are close to each other are released from rest. If a_1 and a_2 respectively are the magnitudes of their accelerations, it must be:

   a. $a_1 < a_2$.

   b. $a_1 = a_2$.

   c. $a_1 > a_2$.

   d. $a_1 = a_2 = 0$.

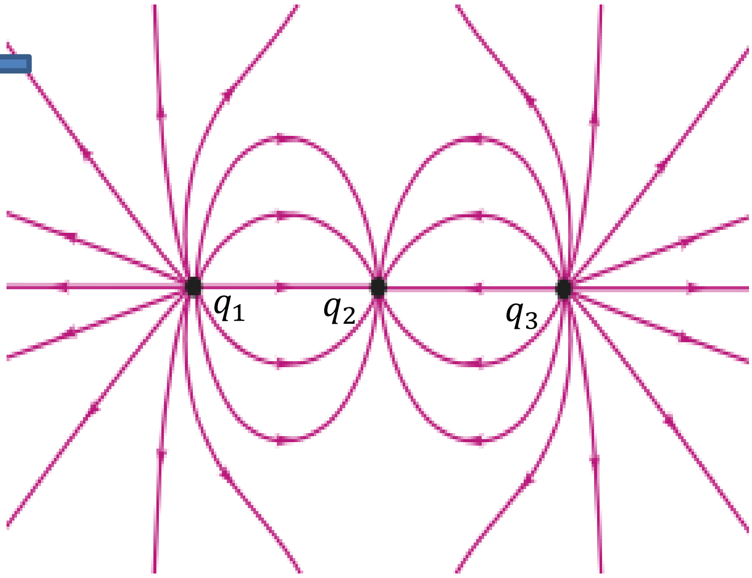
2. The electric field due to q_1, q_2, and q_3 are as shown in the figure. Which statement is true?

   a. $q_1, q_2, q_3 > 0$.

   b. $q_1, q_3 > 0$ and $q_2 < 0$.

   c. $q_1, q_3 < 0$ and $q_2 > 0$.

   d. $q_1, q_2, q_3 < 0$.



3. The amount of force per unit positive charge is:

   a. The electric field.

   b. The electric field line.

   c. The electric flux.

   d. The Coulomb's force.

4. A charge Q is uniformly distributed over the surface of a cube of side L. The surface charge density of the cube is:

   a. $\sigma = \frac{Q}{L^2}$.

   b. $\sigma = 4\frac{Q}{L^2}$.

   c. $\sigma = \frac{Q}{6\,L^2}$.

   d. $\sigma = \frac{Q}{(2L)^2}$.

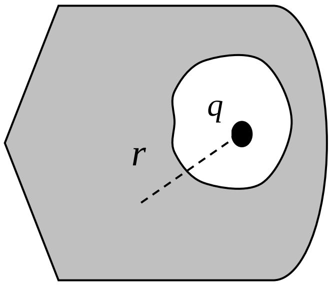
5. A charge q is placed in the cavity of an uncharged conductor. The electric field at a distance r from the charge, as shown in the figure, is:

a. $E = k\frac{q}{r^2}$.

b. $E = 4/3\pi q r^2$.

c. $E = 0$.

d. $E = -k\frac{q}{r^2}$.



6. A charge $-q$ is placed at the centre of a conducting spherical shell having a net charge $+2q$. What is the charge on the outer surface of the shell?

a. $-2q$.

b. $-q$.

c. $+2q$.

d. $+q$.

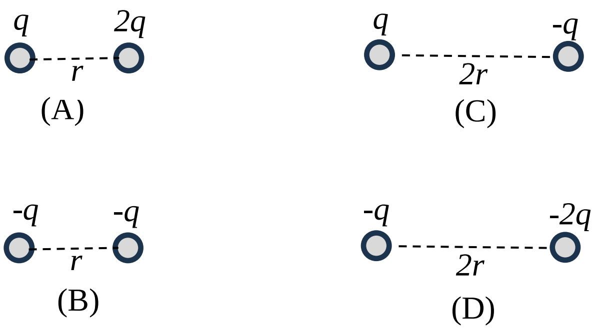
7. Four systems of particles are shown below. Which statement is true for their electric potential energies?

a. $U_A > U_B > U_C > U_D$

b. $U_A > U_B = U_D > U_C$

c. $U_D > U_C > U_A > U_B$

d. $U_A > U_C > U_B > U_D$



8. Three enclosed surfaces S_1, S_2 and S_3 are shown. What is the flux of electric field through S_2?

a. $\Phi_E = \frac{q}{\epsilon_0}$

b. $\Phi_E = \frac{-2q}{\epsilon_0}$

c. $\Phi_E = \frac{2q}{\epsilon_0}$

d. $\Phi_E = \frac{-q}{\epsilon_0}$