Kuwait University **Physics Department**

Physics 102
Midterm-1 Examination

Fall Semester 2024
October 26, 2024

Time: 11:00 a.m. – 12:30 p.m.

Name: ……………………………………… Student ID No: ……………………………

Instructors: Drs. Abdullah, Al-Mumin, Lajko, Sharma, & Vagenas

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Fundamental constants

$k = \dfrac{1}{4\pi\varepsilon_o} = 9.0\times10^{9}\ \text{N.m}^2/\text{C}^2$	(Coulomb constant)
$\varepsilon_o = 8.85\times10^{-12}\ \text{C}^2/(\text{N}\cdot\text{m}^2)$	(Permittivity of free space)
$\mu_0 = 4\pi\times10^{-7}\ \text{T.m/A}$	(Permeability of free space)
$\lvert e\rvert = 1.60\times10^{-19}\ \text{C}$	(Elementary unit of charge)
$N_A = 6.02\times10^{23}$	(Avogadro's number)
$g = 9.8\ \text{m/s}^2$	(Acceleration due to gravity)
$m_e = 9.11\times10^{-31}\ \text{kg}$	(Electron mass)
$m_p = 1.67\times10^{-27}\ \text{kg}$	(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									

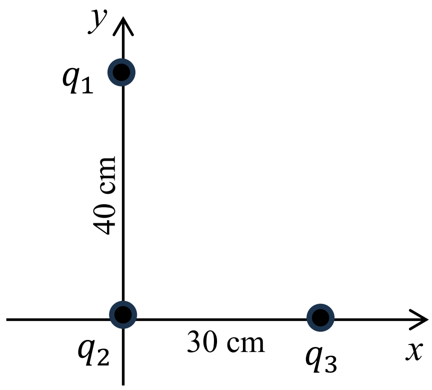
Ques.	1	2	3	4	5	6	7	8	Total	Grand Total
Marks										

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. Three charges $q_1 = 4.0\ \mu\text{C}$, $q_2 = -2.0\ \mu\text{C}$, and $q_3 = 5.0\ \mu\text{C}$ are placed on the xy-plane. What is the net force $\vec{F}$ on q_1? **[4 points]**

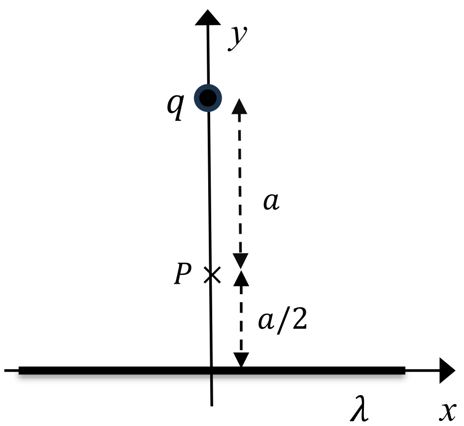


$$F_{12} = \frac{k|q_1 q_2|}{r_{12}^2} = \frac{9\times10^9\times4\times10^{-6}\times2\times10^{-6}}{0.40^2}\text{N} = 0.45\ \text{N}$$

$$F_{13} = \frac{k q_1 q_3}{r_{13}^2} = \frac{9\times10^9\times4\times10^{-6}\times5\times10^{-6}}{0.50^2}\text{N} = 0.72\ \text{N}$$

$$\vec{F}_x = -F_{13}\cos\theta\ \hat{\imath} = -0.432\ \text{N}\ \hat{\imath}$$
$$\vec{F}_y = (F_{13}\sin\theta - F_{12})\hat{\jmath} = (0.576 - 0.45)\ \hat{\jmath} = (0.126\ \text{N})\ \hat{\jmath}$$
$$\vec{F}_{net} = (-0.432\ \text{N})\ \hat{\imath} + (0.126\ \text{N})\ \hat{\jmath}$$

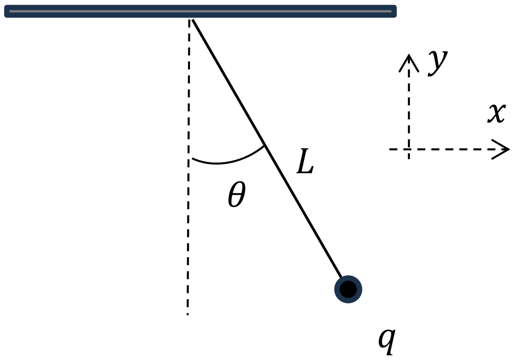
2. An infinite line charge with uniform linear charge density $\lambda = -4.0\ \text{nC/m}$ lies along the x-axis. A point charge $q = -8.0$ nC is located above it, as shown. What is the net electric field, $\vec{E}$, at point P, if $a = 0.40$ m? **[3 points]**



$$E_q = \frac{k|q|}{a^2} = \frac{9\times10^9\times8.0\times10^{-9}}{0.40^2}\frac{\text{N}}{\text{C}} = 450\ \text{N/C}$$
$$E_\lambda = \frac{|\lambda|}{2\pi\epsilon_0(\frac{a}{2})} = \frac{4.0\times10^{-9}}{2\times\pi\times8.85\times10^{-12}\times0.20}\frac{\text{N}}{\text{C}} = 359.7$$
N/C

$$\vec{E}_{net} = E_q\hat{\imath} - E_\lambda\hat{\imath} = (90.3\frac{\text{N}}{\text{C}})\ \hat{\imath}$$

3. A small ball with charge $q = -3.0$ nC and mass $m = 6.0 \times 10^{-8}$ kg hangs from the ceiling by an insulating massless string of length $L = 30$ cm. When the uniform electric field $\vec{E} = (-100 \text{ N/C})\,\hat{\imath}$ is applied, the string makes an angle θ with the vertical line. What is the angle θ? **[4 points]**



$F = |q|E$

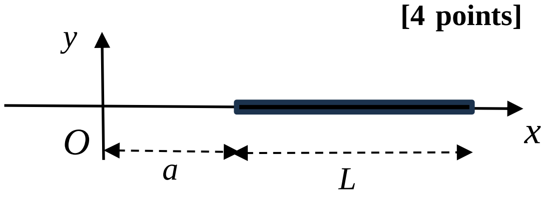
$F_x = |q|E - T\sin\theta = 0 \rightarrow T\sin\theta = |q|E \quad (1)$

$F_y = T\cos\theta - mg = 0 \quad \rightarrow T\cos\theta = mg \quad (2)$

Dividing Eq. (1) by Eq. (2): $\tan\theta = \frac{|q|E}{mg}$

$$\theta = \tan^{-1}\left(\frac{|q|E}{mg}\right) = \tan^{-1}\left(\frac{3.0\times10^{-9}\times100}{6.0\times10^{-8}\times9.8}\right) = 27.03°$$

4. A line charge of length L = 0.40 m, with charge $Q = -12.0$ μC distributed uniformly along its length, lies along the x-axis at a distance a = 0.20 m from the origin, as shown. Derive the formula for the electric field, $\vec{E}$, at the origin due to the line charge. What is the magnitude and direction of the electric field? **[4 points]**



$\lambda = \frac{Q}{L} = \frac{-12 \text{ μC}}{0.40 \text{ m}} = -3.0 \times 10^{-5}$ C/m

$d\vec{E} = \frac{k|dQ|}{r^2}(\hat{\imath}) = (\frac{k|\lambda|dx}{x^2})\hat{\imath}$

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

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

$\vec{E} = (9.0 \times 10^5 \text{ N/C})\,\hat{\imath}$

5. A sphere of radius a = 0.10 m with a uniform volume charge density ρ = +5.20 μC/m^3 is inside a concentric *conducting* shell of inner radius b = 0.20 m and outer radius c = 0.30 m, as shown. The net charge on the shell is q_{net} = −30.0 nC. What is the net electric field $\vec{E}$ at a distance r = 0.40 m from the centre of the sphere?

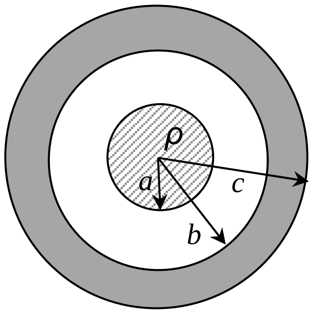
[4 points]

$q_{sph} = \frac{4}{3}\pi a^3 \rho = 2.18 \times 10^{-8}$ C = 21.8 nC

q_{encl} = (21.8 − 30.0) nC = − 8.2 nC

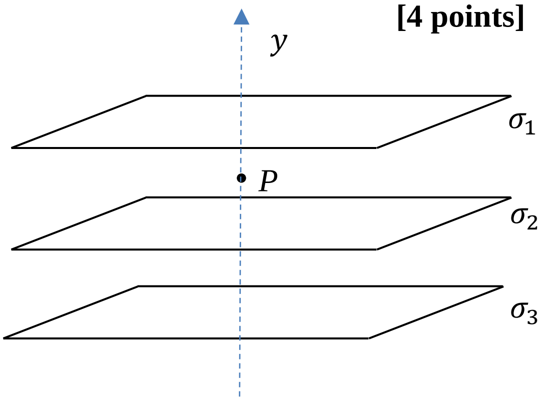
$E = k\frac{q_{encl}}{r^2} = -461$ N/C

Direction: inward



6. Three large *non-conducting* sheets carry uniform charge densities σ_1 = −3.54 nC/m^2, and σ_2 = +7.08 nC/m^2 and σ_3. What is the sign and magnitude of σ_3 so that the net electric field at point P is $\vec{E}$ = (300 N/C) $\hat{j}$?

[4 points]



$\vec{E}_1 = \frac{|\sigma_1|}{2\varepsilon_0}\hat{j} = \frac{3.54\times10^{-9}\text{ C/m2}}{2\times8.85\times10^{-12}\text{ C}^2\text{ / (N·m2)}}$ = (200 N/C) $\hat{j}$

$\vec{E}_2 = \frac{|\sigma_2|}{2\varepsilon_0}\hat{j} = \frac{7.08\times10^{-9}\text{ C/m2}}{2\times8.85\times10^{-12}\text{ C}^2\text{ / (N·m2)}}$ = (400 N/C) $\hat{j}$

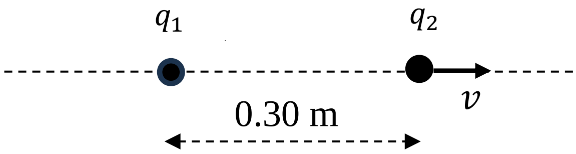
$\vec{E}_1 + \vec{E}_2 + \vec{E}_3$ = (300 N/C) $\hat{j}$

(200 N/C) $\hat{j}$ +(400 N/C) $\hat{j} + \vec{E}_3 = (300\,\frac{\text{N}}{\text{C}})\,\hat{j}$

$\vec{E}_3$ = (−300 N/C) $\hat{j}$ $= \frac{\sigma_3}{2\varepsilon_0}\hat{j}$

σ_3 = −5.31 nC/m^2; (sign = negative)

7. A charge $q_1 = 3.5$ μC is held at rest. Another charge $q_2 = -2.4$ μC of mass $m = 2.0 \times 10^{-12}$ kg moves away from q_1 with a speed of $v = 3.6 \times 10^5$ m/s when it is at a distance 0.30 m, as shown. At what distance from q_1 will q_2 stop momentarily? **[4 points]**



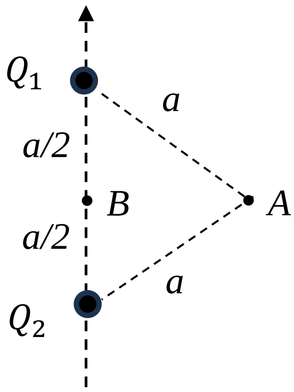
$K_i + U_i = K_f + U_f$

$\frac{1}{2}mv_i^2 + k\frac{q_1q_2}{r_i} = \frac{1}{2}mv_f^2 + k\frac{q_1q_2}{r_f}$

$0.13\text{J} - 0.252\text{ J} = 0 + k\frac{q_1q_2}{r_f}$

$r_f = 0.62$ m

8. Two charges Q_1 = −5.0 μC and Q_2 = 8.0 μC are located, as shown. How much work is done by the electric force to move a charge q = 2.0 μC from point A to point B? Given, a = 0.20 m. **[5 points]**



$V_A = k\frac{Q_1}{a} + k\frac{Q_2}{a}$

$= -2.25 \times 10^5\text{ V} + 3.60 \times 10^5\text{ V} = 1.35 \times 10^5\text{ V}$

$V_B = k\frac{Q_1}{0.5a} + k\frac{Q_2}{0.5a}$

$= -4.5 \times 10^5\text{ V} + 7.2 \times 10^5\text{ V} = 2.7 \times 10^5\text{ V}$

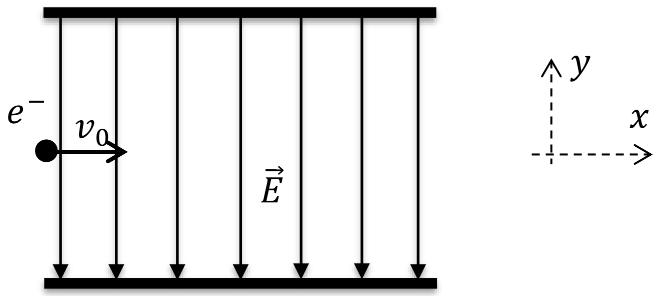
$W = -\Delta U = -q\Delta V = -q(V_B - V_A)$

$= -(2.0\ \mu\text{C})(2.7 - 1.35) \times 10^5 = -0.27$ J

Since the potential energy increases, the work must be

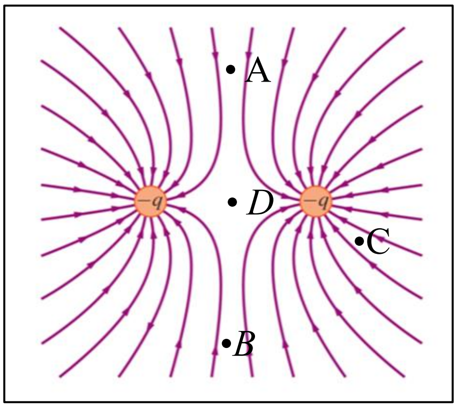
PART II : Conceptual Questions (each carries 1 point). Tick the best answer.

1. An *electron* is moving in a uniform electric field $\vec{E}$, as shown, and no other forces are present in the problem. Assume the electron has an initial velocity $v_0\hat{\imath}$. What is the direction of acceleration, $\vec{a}$, of the electron due to the electric field?



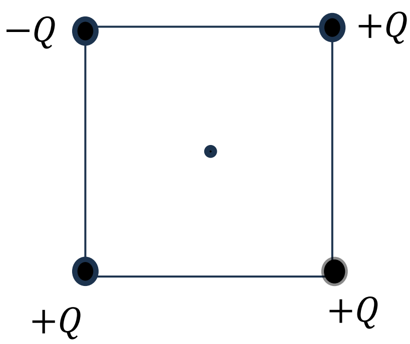
a) $\vec{a} = a\,\hat{\imath}$.
b) $\vec{a} = -a\,\hat{\imath}$.
c) $\vec{a} = a\,\hat{\jmath}$. (ans)
d) $\vec{a} = -a\,\hat{\jmath}$.

2. At what point is the electric field the smallest in magnitude?



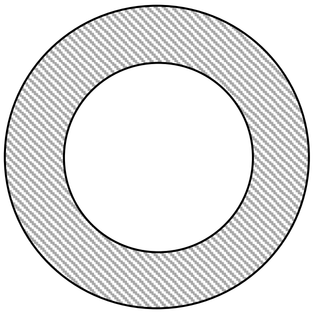
a) *A*.
b) *B*.
c) *C*.
d) *D*. (ans)

3. What is the direction of the net electric field at *the centre* of the square in the figure shown?



a) ↗
b) ↖ (ans)
c) ←
d) →

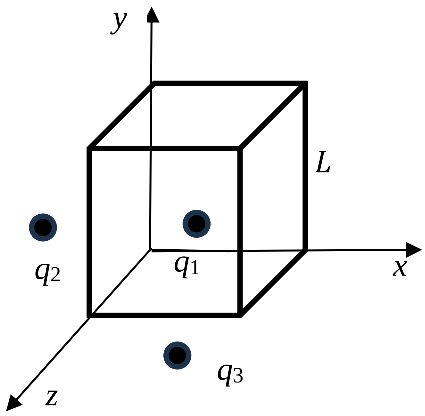
4. A metallic spherical shell has a total charge of +1.0 μC on its outer surface. A charge **+1.0** μC is then placed at the center of the shell. The charge on the outer surface now becomes:



a) zero.
b) –1.0 μC.
c) +1.0 μC.
d) +2.0 μC. (ans)

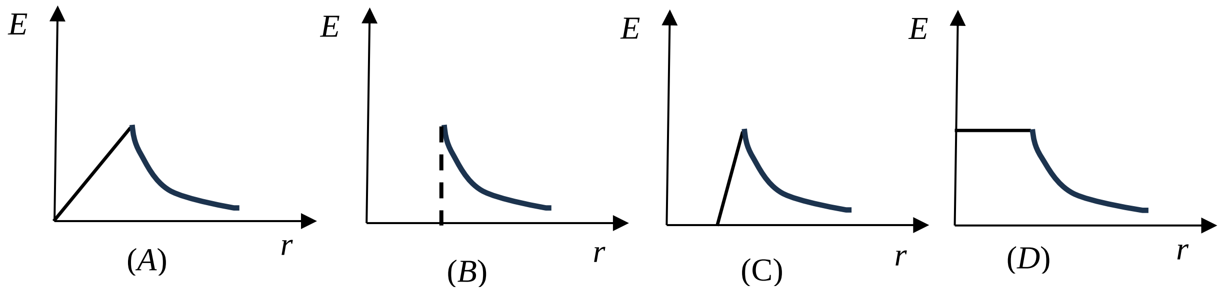
5. If $q_1 = +2q$, $q_2 = -2q$, and $q_3 = -3q$, the net flux through the cube of side L is:

a) zero.
b) $+q/\varepsilon_0$.
c) $+2q/\varepsilon_0$. (ans)
d) $-3q/\varepsilon_0$.



6. A *spherical shell* has a uniform charge density ρ. Which of the following diagrams represents the electric field of the shell as a function of distance r from the centre?

a) *A*.
b) *B*.
c) *C*. (ans)
d) *D*.



7. An electron moves in the direction opposite to an electric field $\vec{E}$. The potential energy U of the electron and the electric potential V are such that:

a) U increases and V decreases.

b) U decreases and V decreases.

c) U increases and V increases.

d) U decreases and V increases. (ans)

8. Two charges $q_1 = Q$, and q_2 are located on the x-axis as shown. If the electric potential at P is zero, relative to $V = 0$ at infinity, what is the value of q_2?

a) $q_2 = -Q$. (ans)
b) $q_2 = +Q$.
c) $q_2 = Q/2$.
d) $q_2 = 2Q$.