Kuwait University **Physics Department**

جامعة الكويت
KUWAIT UNIVERSITY

Physics 102
Midterm-1 Examination

Spring Semester 2025
March 10, 2025

Time: 8:30 p.m. – 10:00 p.m.

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

Section: ………………………….............. Serial number: ………………………..

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

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									

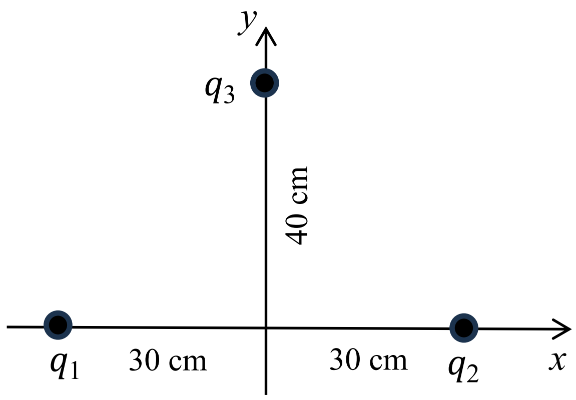
Ques.	1	2	3	4	5	6	7	8	Total
Marks									

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 $q_1 = 6.0\ \mu C$, $q_2 = -6.0\ \mu C$, and $q_3 = -5.0\ \mu C$ are placed on the *xy*-plane, as shown. What is the net force $\vec{F}$ on q_1? **[4 points]**



$$F_{12} = \frac{kq_1q_2}{r_{12}^2} = \frac{9\times10^9\times6\times10^{-6}\times6\times10^{-6}}{(0.60m)^2} = 0.90\text{ N}$$

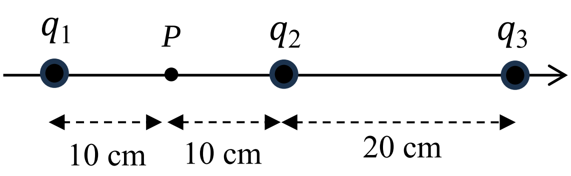
$$F_{13} = \frac{kq_1q_3}{r_{13}^2} = \frac{9\times10^9\times6\times10^{-6}\times5\times10^{-6}}{(0.50m)^2} = 1.08\text{ N}$$

$$F_x = F_{12} + F_{13}\cos\theta = 0.90\text{ N} + 1.08 \times \frac{0.3}{0.5}\text{ N}=1.55\text{ N}$$

$$F_y = F_{13}\sin\theta = 1.08 \times \frac{0.4}{0.5}\text{ N} = 0.86\text{ N}$$

$$\vec{F}_{net} = 1.55\text{ N}\,\hat{\imath} + 0.86\text{ N}\,\hat{\jmath}$$

2. Three charges $q_1 = 10.0$ nC, $q_2 = -10.0$ nC, and q_3 are located along the *x*-axis, as shown. What is the value of q_3 so that the net electric field at point *P* is zero? **[4 points]**



$$\vec{E}_1 = k\frac{|q_1|}{r^2}\hat{\imath} = \frac{9.0\times10^9\times10\times10^{-9}}{(0.10)^2}\text{N/C}\,\hat{\imath} = 9.00\times10^3\text{ N/C}\,\hat{\imath}$$

$$\vec{E}_2 = k\frac{|q_2|}{r^2}\hat{\imath} = \frac{9.0\times10^9\times10\times10^{-9}}{(0.10)^2}\text{N/C}\,\hat{\imath} = 9.00\times10^3\text{ N/C}\,\hat{\imath}$$

$$\vec{E}_1 + \vec{E}_2 + \vec{E}_3 = 0$$

$$\vec{E}_3 = -\vec{E}_1 - \vec{E}_2 = -9.00\times10^3\text{ N/C}\,\hat{\imath} - 9.00\times10^3\text{ N/C}\,\hat{\imath}$$

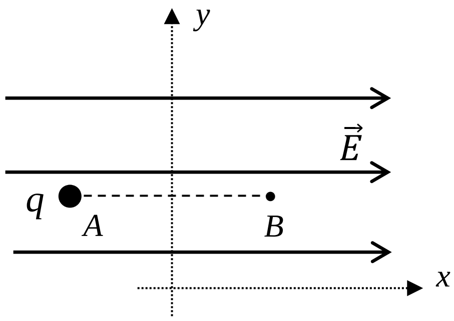
$$= -1.8\times10^4\text{ N/C}\,\hat{\imath}$$

$$E_3 = k\frac{|q_3|}{r^2} \rightarrow 1.8\times10^4 = \frac{9.0\times10^9\times q_3}{(0.30)^2} \rightarrow |q_3| = 1.8\times10^{-7}\text{ C}$$

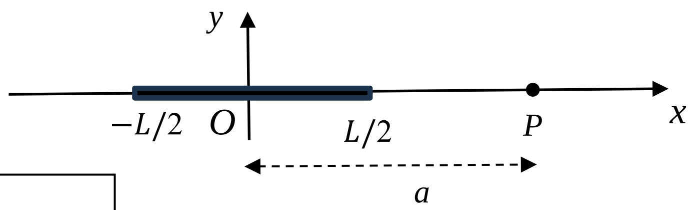
q_3 must be positive: $q_3 = +180$ nC

3. A charge $q = -10\ \mu C$ having mass $m = 1.2 \times 10^{-8}$ kg moves at point A in a region of uniform electric field $\vec{E}$, with speed $v_0 = 120$ m/s along $+x$-axis. It slows down to $v = 40$ m/s on reaching point B after 1.6 μs. What is the electric field vector $\vec{E}$? **[3 points]**

$$v = v_0 + at \rightarrow 40.0 = 120.0 + a \times 1.6 \times 10^{-6}$$
$$a = -5.0 \times 10^{7}\ \mathrm{m/s^2}$$
$$\vec{F} = q\vec{E} = m\vec{a}$$
$$-10 \times 10^{-6} \times \vec{E} = 1.2 \times 10^{-8} \times -5.0 \times 10^{7}\hat{\imath}$$
$$\vec{E} = \frac{1.2\times10^{-8}\times5.0\times10^{7}}{10.0\times10^{-6}}\hat{\imath} = 6.0 \times 10^{4}\ \mathrm{N/C}\ \hat{\imath}$$



4. A rod of length $L = 20$ cm has a charge $Q = 10.0$ nC distributed uniformly along its length, as shown. Derive the formula for the electric field at point P due to the rod. What is the electric field vector, $\vec{E}$, at point P if $a = 50.0$ cm? **[5 points]**



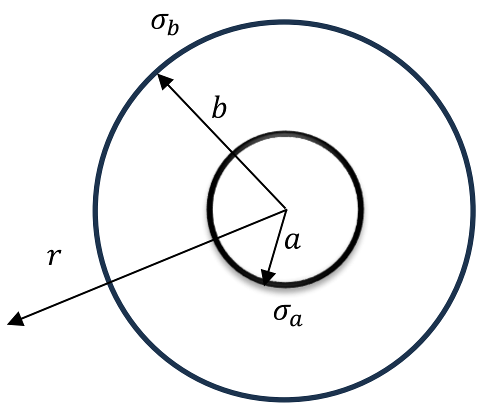
$$d\vec{E} = \frac{k|dQ|}{r^2}(\hat{\imath}) = \frac{k\lambda dx}{x^2}(\hat{\imath})$$
$$\vec{E} = \int_{-L/2}^{L/2} \frac{k|\lambda| dx}{(a-x)^2}(\hat{\imath}) \quad =$$
$$= k\lambda\left[\frac{1}{(a-x)}\right]_{-\frac{L}{2}}^{\frac{L}{2}} = k\lambda\left[\frac{1}{a-\frac{L}{2}} - \frac{1}{a+\frac{L}{2}}\right]$$
$$= k\frac{\lambda L}{a^2-L^2/4} = k\frac{Q}{a^2-L^2/4}(\hat{\imath})$$
$$\vec{E} = 375\ \mathrm{N/C}\ (\hat{\imath})$$

5. Two concentric thin spherical surfaces have radii $a = 4$ cm and $b = 10$ cm, and uniform surface charge densities $\sigma_a = 10\ \mu\text{C/m}^2$ and $\sigma_b = -8\ \mu\text{C/m}^2$, as shown. What is the magnitude and direction of electric field at distance $r = 15$ cm from the center. **[3 points]**

$$\Phi = E.A_r = \frac{q_{enc}}{\epsilon_0}$$

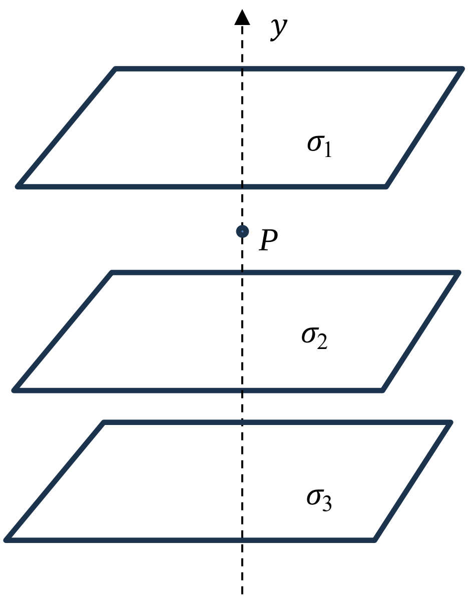
$$q_{enc} = \sigma_a A_a + \sigma_b A_b = -8.0 \times 10^{-7} C$$

$$E = \frac{q_{enc}}{A_r.\epsilon_0} = -3.2 \times 10^5 \frac{\text{N}}{\text{C}}$$, inward

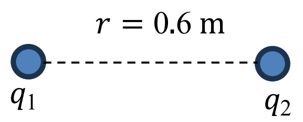


6. Three uniformly charged large sheets are perpendicular to the y-axis as shown. The surface charge density on sheet 1 is $\sigma_1 = 15\ \text{nC/m}^2$, and the surface charge density on sheet 3 is $\sigma_3 = 30\ \text{nC/m}^2$. If a charged particle at point P experiences *zero net force*, what is the surface charge density σ_2 on sheet 2? **[4 points]**

$$\vec{E}_1 = -\frac{\sigma_1}{2\epsilon_0}\hat{j} = -\frac{15}{2\epsilon_0} \times 10^{-9}\hat{j}\ \text{N/C}$$
$$\vec{E}_3 = \frac{\sigma_3}{2\epsilon_0}\hat{j} = \frac{30}{2\epsilon_0} \times 10^{-9}\hat{j}\ \text{N/C}$$
$$\vec{E}_{net} = 0 = \frac{30}{2\epsilon_0}\hat{j} - \frac{15}{2\epsilon_0}\hat{j} + \frac{\sigma_2}{2\epsilon_0}\hat{j} \rightarrow \sigma_2 = -15\ \text{nC/m}^2$$



7. Two charged particles $q_1 = 3$ μC and $q_2 = -4.5$ μC with identical masses are at rest at distance $r = 0.6$ m. Then, the two particles are released, and at distance $r = 0.2$ m both particles are moving with speed $v = 3 \times 10^5$ m/s toward each other. Find the mass of each particle. **[3 points]**

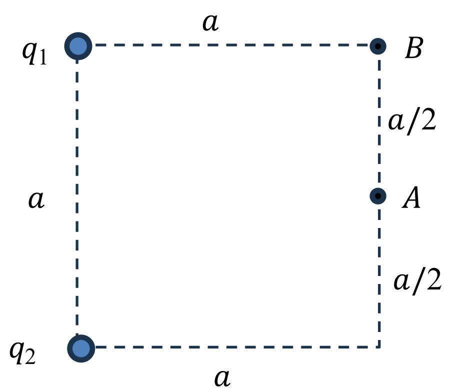


$K_1 + U_1 = K_2 + U_2$

$$\frac{q_1 q_2}{4\pi\epsilon_0 r_1} + 0 = \frac{q_1 q_2}{4\pi\epsilon_0 r_2} + 2\frac{mv^2}{2}$$

$$m = \frac{\frac{q_1 q_2}{4\pi\epsilon_0 r_1} - \frac{q_1 q_2}{4\pi\epsilon_0 r_2}}{v^2} = 4.5 \times 10^{-12} \text{ kg}$$

8. Two charged particles $q_1 = 5$ μC and $q_2 = -5$ μC are placed at the corners of a square of side $a = 10$ cm, as shown. Calculate the work done by an external force to move a third charge $q_3 = 4$ μC from point A to point B. **[4 points]**



$W_{ext} = \Delta U = U_B - U_A$

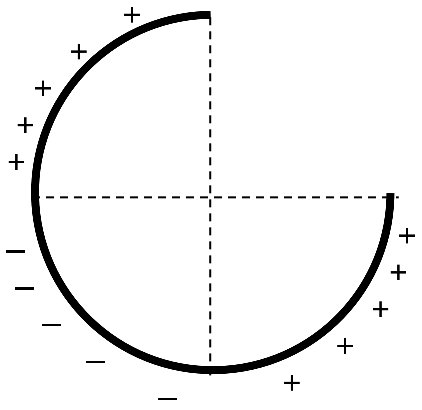
$U_A = 0$

$$U_B = \frac{q_1 q_3}{4\pi\epsilon_0 a} + \frac{q_2 q_3}{4\pi\epsilon_0 \sqrt{2}\, a}$$

$W = U_B = 0.53$ J

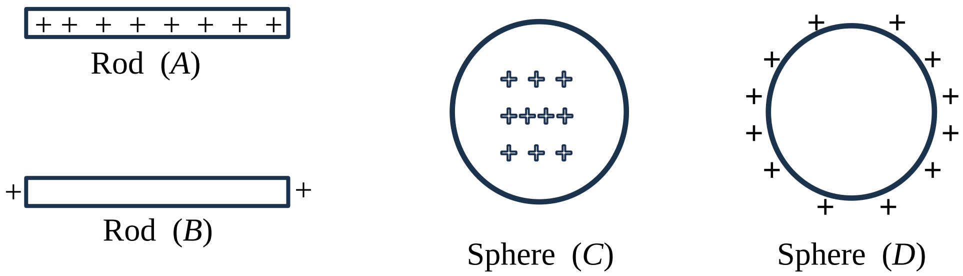
PART II : Conceptual Questions (each carries 1 point). Tick the best answer.

1. Three quarter-circular arcs have equal magnitude of uniform linear charge density with different signs, as shown. What is the direction of the net electric field at the center?



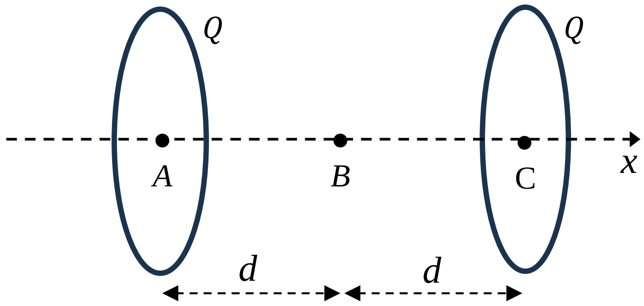
a) ↗
b) ↙ (ans)
c) ↘
d) ↖

2. Which object(s) can be conductor(s)?



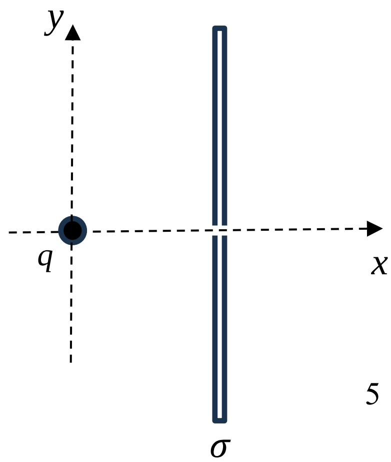
a) *A*.
b) *B* & *C*.
c) *B* & *D*. (ans)
d) *C*.

3. Two identical conducting rings, each with charge *Q*, are located perpendicular to *x*-axis. At which point is $\vec{E} = 0$?



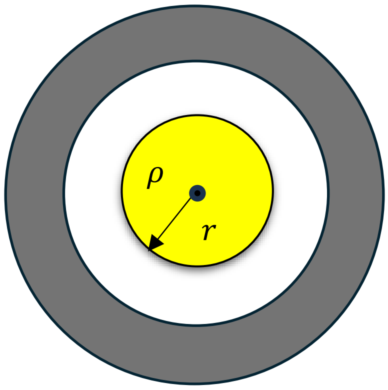
a) *A*.
b) *B*. (ans)
c) *C*.
d) At all points.

4. A large uniformly charged sheet, $\sigma > 0$, with a hole in the middle is perpendicular to the *x*-axis. Initially, a negative charge *q* is at rest to the left of the sheet, as shown. Then, charge *q* is allowed to move. What will happen to the charge?



a) It will travel large distances toward +*x*-axis and disappear.
b) It will travel toward −*x*-axis and disappear.
c) It will oscillate about the sheet. (ans)
d) It will travel along the *y*-axis.

5. A *non-conducting sphere* with radius r and uniform volume charge density ρ is within a *conducting shell* with *zero* net charge. What is the charge on the outer surface of the conductor?



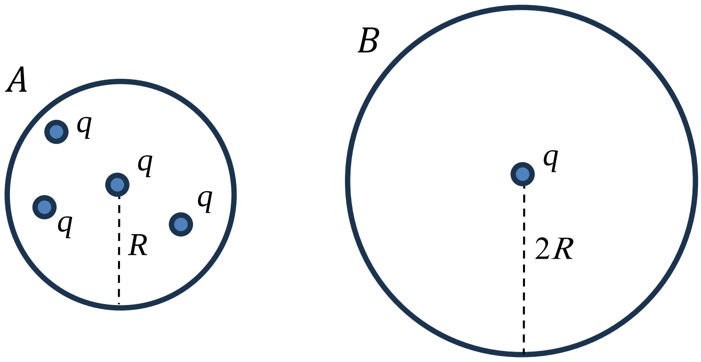
a) $\frac{4}{3}\pi r^3\rho$ (ans)

b) $-\frac{4}{3}\pi r^3\rho$

c) 0

d) $4\pi r^2\rho$

6. What is the electric flux through sphere A compared to sphere B?



a) $\Phi_A = \Phi_B$.

b) $\Phi_A = 4\Phi_B$. (ans)

c) $\Phi_A = \frac{1}{4}\Phi_B$.

d) $\Phi_A = \frac{1}{8}\Phi_B$.

7. An *uncharged* particle is accelerating in the *same* direction of a uniform electric field. The work *done by* the electric field is

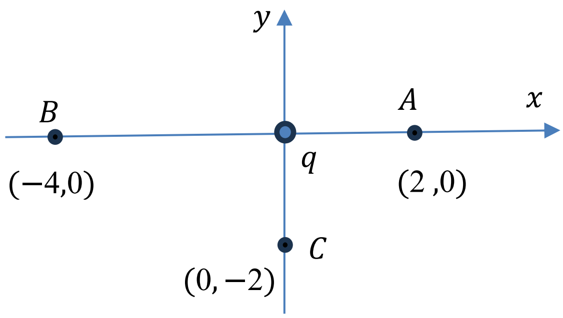
a) positive.

b) negative.

c) zero. (ans)

d) undetermined.

8. A positive charge q is located at the origin. Which point(s) have the largest electric potential?



a) A.

b) B.

c) A & B.

d) A & C. (ans)