



**Final Examination**  
**Spring Semester 2025 – 2026**

**May 13, 2026**  
**Time: 3:00 – 5:00 PM**

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

Sec. No: ..... Serial No: .....

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

**Fundamental constants**

$k = \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \text{ N}\cdot\text{m}^2 / \text{C}^2$	(Coulomb constant)
$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 / (\text{N} \cdot \text{m}^2)$	(Permittivity of free space)
$\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$	(Permeability of free space)
$e = 1.60 \times 10^{-19} \text{ C}$	(Elementary charge)
$N_A = 6.02 \times 10^{23}$	(Avogadro's number)
$g = 9.8 \text{ m/s}^2$	(Acceleration due to gravity)
$m_e = 9.11 \times 10^{-31} \text{ kg}$	(Electron mass)
$m_p = 1.67 \times 10^{-27} \text{ kg}$	(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**

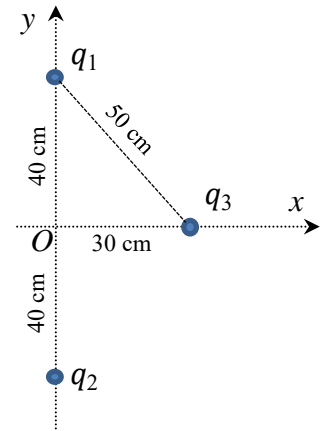
Problems	1	2	3	4	5	6	7	8	Questions	Total
Marks										

**Instructions to the Students:**

1. Mobile 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 point charges,  $q_1 = q_2 = q_3 = 4 \mu\text{C}$ , are placed on the  $xy$ -plane, as shown. Calculate the  $x$  and  $y$  components of the net electric force,  $\vec{F}_3$ , acting on  $q_3$ . **[4 points]**



$$F_{3,y} = F_{13,y} + F_{23,y} = k \frac{|q_1 q_3|}{r_{12}^2} \sin(\theta) - k \frac{|q_2 q_3|}{r_{23}^2} \sin(\theta) = 0.0 \text{ N}$$

$$F_{3,x} = F_{13,x} + F_{23,x} = k \frac{|q_1 q_3|}{r_{13}^2} \cos(\theta) + k \frac{|q_2 q_3|}{r_{23}^2} \cos(\theta) = 0.69 \text{ N}$$

2. A spherical shell of inner radius  $a = 3 \text{ cm}$  and outer radius  $b = 7 \text{ cm}$  has uniform volume charge density  $\rho = -300 \text{ nC/m}^3$ . Use Gauss's law and determine the magnitude and direction of the net electric field at  $r = 5 \text{ cm}$  distance from the center. **[4 points]**

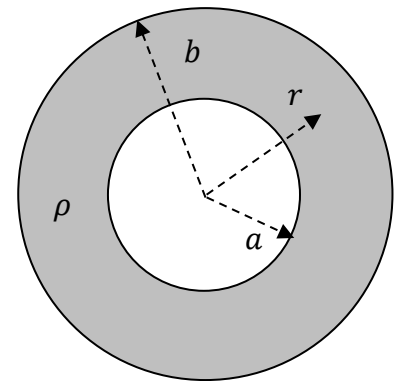
Gauss's Law:

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\epsilon_0}$$

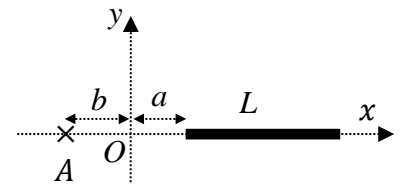
$$E(4\pi r^2) = \frac{Q_{enc}}{\epsilon_0}$$

$$Q_{encl} = \rho \left( \frac{4}{3} \pi (r^3 - a^3) \right)$$

$$E = \frac{Q_{enc}}{4\pi r^2 \epsilon_0} = -443.3 \text{ N/C, inward}$$



3. A rod of length  $L = 2.0$  m has charge  $Q = 80$  nC uniformly distributed along it and it is fixed on the  $x$ -axis, as shown. Derive a formula of the net electric field vector  $\vec{E}_A$  at point A and determine its magnitude and direction. Given  $a = 0.2$  m and  $b = 0.3$  m. **[5 points]**

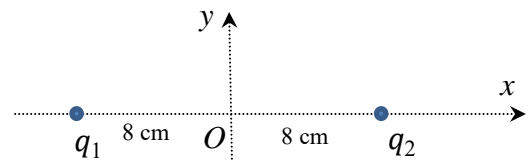


$$d\vec{E}_A = \frac{k dQ}{r^2} (-\hat{i}) = \frac{k \lambda dx}{(x+b)^2} (-\hat{i}); \quad \lambda = \frac{dQ}{dL} = \frac{Q}{L}$$

$$\vec{E}_A = \int d\vec{E}_A = - \int_a^{L+a} \frac{k \lambda dx}{(x+b)^2} \hat{i} = k \lambda \left[ \frac{1}{x+b} \right]_a^{L+a} \hat{i}$$

$$\vec{E}_A = -576 \frac{\text{N}}{\text{C}} \hat{i}$$

4. Two particles with charges,  $q_1 = q_2 = 6 \mu\text{C}$ , and masses  $m_1 = m_2 = 4 \times 10^{-6}$  kg, are fixed on the  $x$ -axis, as shown. Then these charges are simultaneously released from rest. Calculate the speed of  $q_1$  when it is infinitely far from  $q_2$ . **[3 points]**



Energy conservation:  $U^{in} = K^{fin}$

$$U^{in} = K^{fin} \Rightarrow \frac{kq^2}{r} = 2 \frac{m}{2} v^2$$

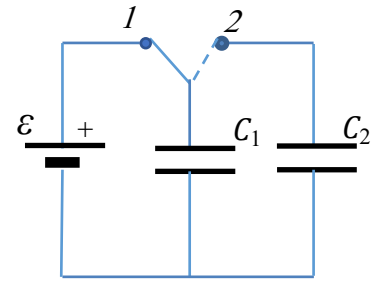
$$\Rightarrow v = 711.5 \text{ m/s}$$

5. A capacitor,  $C_1 = 30 \mu\text{F}$ , is charged by a battery  $\varepsilon = 12 \text{ V}$ , as shown. Then the switch is moved to position 2 so that the capacitor  $C_1$  is connected to uncharged capacitors  $C_2 = 10 \mu\text{F}$ . What is the final energy stored on  $C_2$ ? [3 points]

$$Q_0 = \varepsilon C_1 = 360 \mu\text{C}$$

$$V^{fin} = \frac{Q_0}{C_{eq}} = \frac{Q_0}{C_1 + C_2} = 9 \text{ V}$$

$$U_2^{fin} = \frac{C_2 (V^{fin})^2}{2} = 405 \mu\text{J}$$



6. In the circuit below, initially the capacitor is uncharged and the switch is closed at time  $t = 0 \text{ s}$ . Find the current in the circuit at time  $t_1$  when the charge on the capacitor is 90 % of its final value. [4 points]

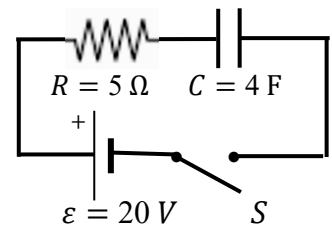
$$Q(t) = \varepsilon C \left[ 1 - e^{-\frac{t}{RC}} \right]$$

$$0.9 \varepsilon C = \varepsilon C \left[ 1 - e^{-\frac{t_1}{RC}} \right]$$

$$e^{-\frac{t_1}{RC}} = 0.1$$

$$I(t) = \frac{dQ(t)}{dt} = \frac{\varepsilon}{R} e^{-\frac{t}{RC}}$$

$$I(t_1) = \frac{\varepsilon}{R} 0.1 = 0.4 \text{ A}$$



7. A particle of charge  $q = +3 \text{ C}$  enters a region of uniform electric and magnetic fields with initial velocity  $\vec{v} = \left(4 \frac{\text{m}}{\text{s}}\right) \hat{i}$ . The magnetic field is  $\vec{B} = (2 \text{ T})\hat{j} + (3 \text{ T})\hat{k}$ . If the net initial force acting on the charged particle is  $\vec{F} = (24 \text{ N})\hat{j} + (15 \text{ N})\hat{k}$ , find the electric field vector  $\vec{E}$ . **[4 points]**

$$\vec{F} = q \vec{E} + q(\vec{v} \times \vec{B}) \Rightarrow \vec{E} = \frac{\vec{F} - q(\vec{v} \times \vec{B})}{q}$$

$$\vec{E} = \frac{(24 \text{ N})\hat{j} + (15 \text{ N})\hat{k} - (-36 \text{ N})\hat{j} + (24 \text{ N})\hat{k}}{3 \text{ C}} = (20 \text{ N/C})\hat{j} - (3 \text{ N/C})\hat{k}$$

8. Three straight, very long, parallel wires are perpendicular to the  $xy$ -plane. Each wire carries a current of magnitude  $I = 8 \text{ A}$  in the direction as shown. Calculate the force per unit length vector  $\frac{\vec{F}_3}{L}$  acting on the wire of  $I_3$ . **[5 points]**

$$\frac{F_{13,x}}{L} = \frac{\mu_0 I_1 I_2}{2\pi 0.5 \text{ m}} \cos(\Theta) = +2.05 \times 10^{-5} \text{ N/m}$$

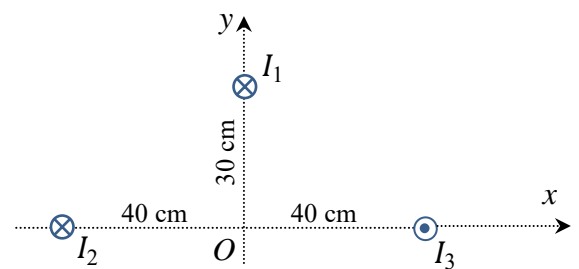
$$\frac{F_{13,y}}{L} = \frac{\mu_0 I_1 I_3}{2\pi 0.5 \text{ m}} \sin(\Theta) = -1.54 \times 10^{-5} \text{ N/m}$$

$$\frac{F_{23,x}}{L} = \frac{\mu_0 I_1 I_3}{2\pi 0.8 \text{ m}} = +1.6 \times 10^{-5} \text{ N/m}$$

$$\frac{F_{23,y}}{L} = 0$$

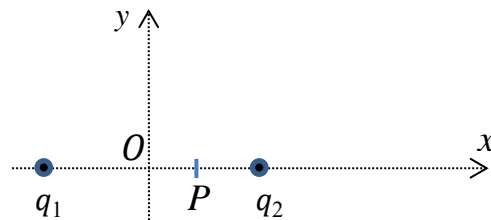
$$\frac{F_{3,x}}{L} = \frac{F_{23,x}}{L} + \frac{F_{13,x}}{L}; \quad \frac{F_{3,y}}{L} = \frac{F_{13,y}}{L}$$

$$\frac{\vec{F}_3}{L} = \left(3.65 \times 10^{-5} \frac{\text{N}}{\text{m}}\right) \hat{i} - \left(1.54 \times 10^{-5} \frac{\text{N}}{\text{m}}\right) \hat{j}$$



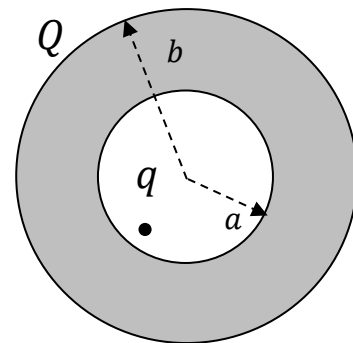
**PART II: Conceptual Questions (each carries 1 point). Tick the best answer:**

1. Two point charges  $q_1$ , and  $q_2$  are fixed on the  $x$ -axis at equal distance from the origin, as shown. If the net electric field is zero at point  $P$ , which statement can be correct for the charges?



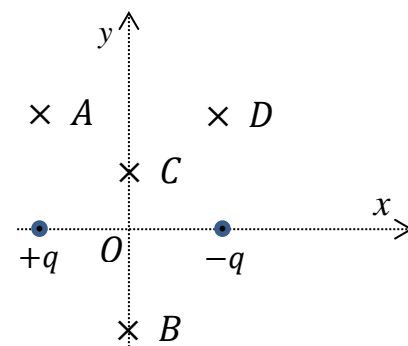
- a)  $q_1 = q_2$ .  
 b)  $|q_1| > |q_2|$ . ←  
 c)  $|q_1| < |q_2|$ .  
 d)  $|q_1| = |q_2|$ .

2. A conducting spherical shell has a net charge  $Q$  and a point charge  $q$  is fixed out of its center as shown. The surface charge density on the outer surface of the shell is



- a) non-uniform.  
 b)  $\frac{Q+q}{4\pi b^2}$ . ←  
 c)  $\frac{Q}{4\pi b^2}$ .  
 d)  $\frac{Q-q}{4\pi b^2}$ .

3. Two point charges  $+q > 0$  and  $-q$  are fixed on the  $x$ -axis at equal distance from the origin, as shown. Which statement can be correct for the electric potentials of these charges?



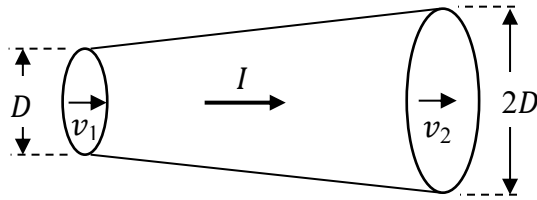
- a)  $V_A = V_B$ .  
 b)  $V_A < V_B$ .  
 c)  $V_B = V_C$ . ←  
 d)  $V_C < V_D$

4. An air-filled parallel-plate capacitor with separation  $d$  and surface area  $A$  has capacitance  $C$ . Then the separation between the plates is doubled and the surface area of the plates is halved, so its capacitance

- a) remains  $C$ .  
 b) increases to  $2C$ .  
 c) decreases to  $C/4$ . ←  
 d) decreases to  $C/2$ .

5. A wire with changing cross-section carries a steady current as shown. Which statement is correct for the drift velocities at the two ends of the wire?

- a)  $v_1 = v_2$ .
- b)  $v_1 = v_2/2$ .
- c)  $v_1 = 2v_2$ .
- d)  $v_1 = 4v_2$ . ←

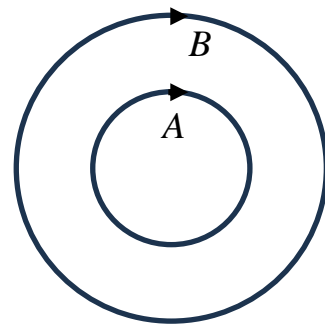


6. A resistor and a capacitor are connected in series in an RC circuit. If a second identical capacitor is connected parallel to the first capacitor, the time constant  $\tau$  for the circuit will

- a) decrease.
- b) become zero.
- c) not change.
- d) increase. ←

7. Two charged particles  $A$  and  $B$ , having the same mass, and the same speed, move on *circular* paths, as shown, due to a perpendicular uniform magnetic field. If the radii of the circles are related by  $R_B = 2R_A$ , their charges are related by:

- a)  $q_A = 2q_B$  ←
- b)  $q_A = q_B$ .
- c)  $q_B = 2q_A$ .
- d)  $q_A + q_B = 0$ .



8. A long wire carries current  $I$  along the  $x$ -axis, as shown. What is the direction of the magnetic field at points  $C$  and  $D$ ?

- a)  $\vec{B} = B\hat{k}$  at point  $C$ , and  $\vec{B} = B\hat{k}$  at point  $D$ .
- b)  $\vec{B} = -B\hat{k}$  at point  $C$ , and  $\vec{B} = B\hat{k}$  at point  $D$ .
- c)  $\vec{B} = B\hat{k}$  at point  $C$ , and  $\vec{B} = -B\hat{k}$  at point  $D$ . ←
- d)  $\vec{B} = -B\hat{k}$  at point  $C$ , and  $\vec{B} = -B\hat{k}$  at point  $D$ .

