Kuwait University Physics Department

جامعة الكويت
KUWAIT UNIVERSITY

Physics 102
Final Examination
Spring Semester 2023
May 13, 2023

Time: 17:00 – 19:00

Name: …… Student ID No: ……

Instructors: Drs. Afrousheh, Alfailakawi, Hadipour, Lajko, Sharma, & Vagenas

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Fundamental constants

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

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

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

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

Prob.	1	2	3	4	5	6	7	8	9	10	Total
Marks											

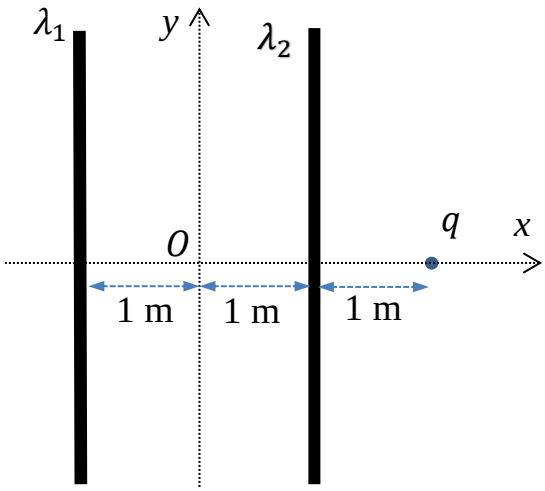
Ques.	1	2	3	4	5	6	7	8	Total
Marks									

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. Two long uniformly charged lines with charge densities $\lambda_1 = 9\ \text{nC/m}$ and $\lambda_2 = -6\ \text{nC/m}$ are placed perpendicular to the *x*-axis. Find the net electric force vector $\vec{F}$ acting on the point charge $q = 4\ \text{nC}$, shown in the figure. **[3 points]**



$$\vec{E}_{net,P} = \vec{E}_{1,P} + \vec{E}_{2,P} = \frac{\lambda_1}{2\pi\varepsilon_0 3m}\hat{\imath} + \frac{\lambda_2}{2\pi\varepsilon_0 1m}\hat{\imath}$$

$$\vec{E}_{net,P} = \left(-53.95\ \frac{\text{N}}{\text{C}}\right)\hat{\imath}$$

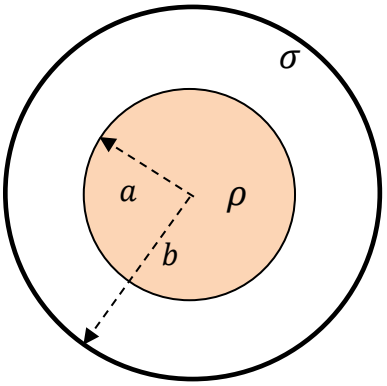
$$\vec{F}_{net} = q\,\vec{E}_{net,P} = (-2.16 \times 10^{-7}\ \text{N})\hat{\imath}$$

2. A sphere of radius $a = 30$ cm is concentric with a thin spherical shell of radius $b = 50$ cm. The sphere has a uniform volume charge density of $\rho = -180\ \text{nC/m}^3$ and the spherical shell has a uniform surface charge density of $\sigma = 15\ \text{nC/m}^2$. Find the magnitude and direction (in or out) of the net electric field at a radial distance $r = 60$ cm from the center. **[4 points]**

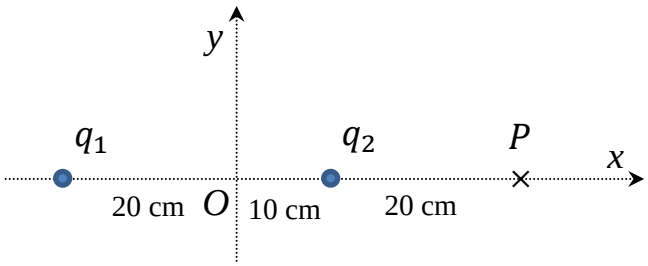
$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{sur} + Q_{vol}}{\varepsilon_0}$$

$$E4\pi r^2 = \frac{\sigma 4\pi b^2 + \rho\frac{4\pi a^3}{3}}{\varepsilon_0} =$$

$$E = 669\ \frac{\text{N}}{\text{C}}. \qquad \text{out.}$$



3. Point charges $q_1 = q$ and $q_2 = -q$ are fixed along the *x*-axis as shown. When a third point charge $q_3 = q$ is at the origin O, its potential energy is $U(q_3) = -4$ nJ. What is the potential energy of q_3 if it is placed at point P? **[4 points]**



$$U(q_3) = k\frac{q^2}{0.2m} - k\frac{q^2}{0.1m} = kq^2\left(\frac{1}{0.2m} - \frac{1}{0.1m}\right) = -4 \text{ nJ}$$

$$\Rightarrow kq^2 = 0.8 \text{ nJ} \cdot \text{m}$$

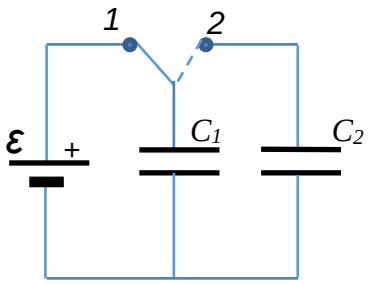
$$U(q_3) = kq^2\left(\frac{1}{0.5m} - \frac{1}{0.2m}\right) = -2.4 \text{ nJ}$$

4. A capacitor $C_1 = 8$ μF is charged by a battery of $\mathcal{E} = 6$ V. Then the switch is thrown to position 2 and capacitor C_1 is connected to an uncharged capacitor $C_2 = 16$ μF, as shown. Find the final energy stored in the capacitor C_2. **[4 points]**

$$Q_1 = C_1\mathcal{E}$$

$$V_{fin} = \frac{Q_1}{C_1+C_2} = \frac{C_1\mathcal{E}}{C_1+C_2} = 2\ V$$

$$U_2 = \frac{C_2V_{fin}^2}{2} = 32 \text{ μJ}$$



5. A cylindrical metallic wire of length $L = 50.0$ m has a potential difference $V = 50$ V. The wire has a concentration of free electrons $n = 8.5 \times 10^{28}$ m^{-3} and its resistivity is $\rho = 1.72 \times 10^{-8}\,\Omega \cdot$ m. Calculate the time the electrons take to move along the length of the wire. **[4 points]**

$J = n|e|v_d$ and $J = \frac{E}{\rho} = \frac{V}{\rho L}$

$t = \frac{L}{v_d} = \frac{L}{\frac{J}{nq}} = \frac{Lnq}{J} = \frac{Lnq}{\frac{V}{L\rho}} = \frac{L^2 nq\rho}{V} = 11696\ s$

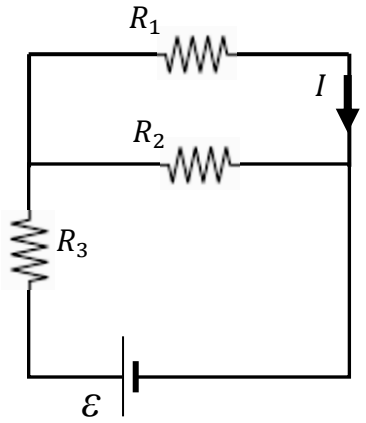
6. In the circuit shown, $\mathcal{E} = 24$ V and the three resistors have identical resistance $R_1 = R_2 = R_3 = 4\ \Omega$. Determine the value of current I through R_1. **[4 points]**

$R_{12} = \frac{R \cdot R}{R+R} = \frac{R}{2} = 2\ \Omega$

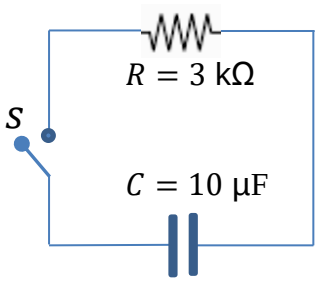
$R_{123} = R_{12} + R_3 = 6\ \Omega$

$I_{123} = \frac{\varepsilon}{R_{123}} = 4$ A

$I = \frac{I_{123}}{2} = 2$ A



7. In the RC circuit below, the initial charge of the capacitor C is $Q_0 = 40$ μC. At time $t = 0$ s, the switch S is closed. Find the time at which the energy stored in the capacitor is $\frac{1}{4}$ of its initial value. **[3 points]**



$$q(t) = Q_0 e^{-\frac{t}{RC}} \Rightarrow U(t) = \frac{q^2(t)}{2C} = \frac{Q_0^2 e^{-\frac{2t}{RC}}}{2C} = U_0 e^{-\frac{2t}{RC}}$$

$$\frac{U_0}{4} = U_0 e^{-\frac{2t}{RC}} \Rightarrow \frac{1}{4} = e^{-\frac{2t}{RC}} \Rightarrow$$

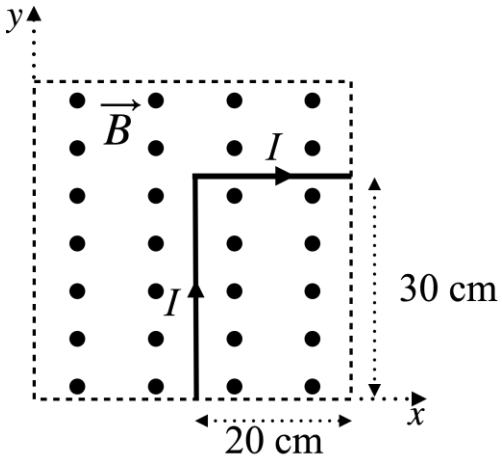
$$\ln\left(\frac{1}{4}\right) = -\frac{2t}{RC} \Rightarrow t = -\frac{RC}{2}\ln\left(\frac{1}{4}\right) = 20.8 \text{ ms}$$

8. An electron enters with a velocity $\vec{v} = (1.5 \times 10^5 \text{ m/s})\hat{\imath} + (2 \times 10^5 \text{ m/s})\hat{\jmath} + (3 \times 10^5 \text{ m/s})\hat{k}$ into a region of uniform magnetic field $\vec{B} = (2 \text{ T})\hat{\imath}$. Find the radius of the path of the electron. **[3 points]**

$$v_\perp = \sqrt{v_y^2 + v_z^2} = 3.6 \times 10^5 \frac{\text{m}}{\text{s}}.$$

$$R = \frac{m_e v_\perp}{eB} = 10.25 \times 10^{-7} \text{ m}.$$

9. A bent wire carries a current $I = 4.5$ A, as shown in the figure. Find the net magnetic force acting on the wire due to the uniform magnetic field $\vec{B} = (2\ T)\hat{k}$. **[3 points]**

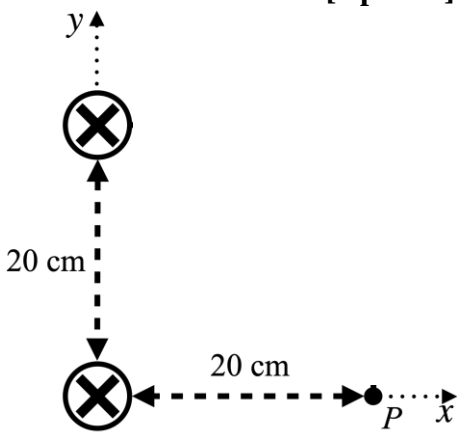


$\vec{F} = I\vec{L} \times \vec{B}$

$\vec{F} = 4.5\text{A}((0.2\ \text{m})\hat{\imath} + (0.3\ \text{m})\hat{\jmath}) \times (2\ \text{T})\hat{k}$

$\vec{F} = (2.7\ \text{N})\hat{\imath} + (-1.8\ \text{N})\hat{\jmath}$

10. Two long parallel wires carry identical current $I = 10$ A perpendicular to the plane as shown. Calculate the net magnetic field $\vec{B}$ at point *P*. **[4 points]**



$\vec{B}_P = \vec{B}_{1,P} + \vec{B}_{2,P}$

$\vec{B}_P = -\frac{\mu_0 I}{2\pi r}\hat{\jmath} - \frac{\mu_0 I}{2\pi r\sqrt{2}}(\cos(45^o)\,\hat{\imath} + \sin(45^o)\,\hat{\jmath})$

$\vec{B}_P = (-5\ \mu\text{T})\hat{\imath} + (-15\ \mu\text{T})\hat{\jmath}$

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

1. When two point charges q_1 and q_2 are at a distance r, the magnitude of electric force acting on q_2 is F. If both the charges and the distance are doubled, the magnitude of force on q_2 is

   a) F. ⟸

   b) $2F$.

   c) $F/2$.

   d) $F/4$.

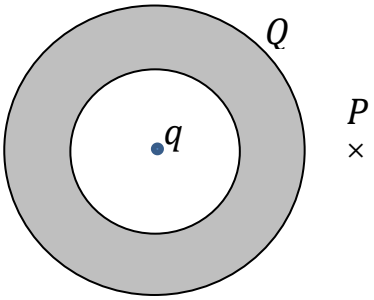
2. A conducting spherical shell has a net charge Q and a point charge q is at its center. If the electric field at point P has a direction pointing towards the center of the shell, which statement is correct for the charges?

   a) $|q| < -|Q|$.

   b) $q + Q > 0$.

   c) $|q + Q| < 0$.

   d) $q + Q < 0$. ⟸



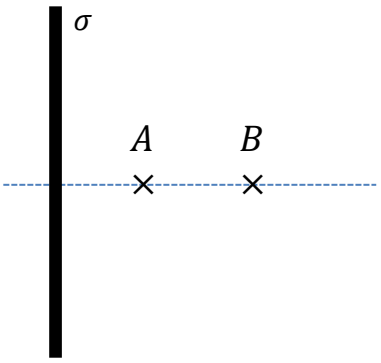
3. A uniformly charged large sheet has surface charge density $\sigma < 0$. Which statement is correct for the electric potential at point A and B?

   a) $V_A < V_B$. ⟸

   b) $V_A > V_B$.

   c) $V_A = V_B$.

   d) None of the above.



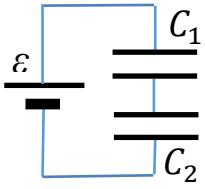
4. Capacitors C_1 and C_2 are connected to a battery in series and in parallel connections as shown. In which case is the stored energy larger?

   a) A.

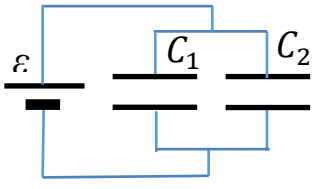
   b) B. ⟸

   c) The stored energy is the same in both cases.

   d) If $C_1 < C_2$, in case A, otherwise in case B.



(A)



(B)

5. Two cylindrical wires are made of identical material with identical cross-section. Wire 1 has twice the length of wire 2. If both wires are separately connected to the same potential difference, the currents have the relation

a) $I_1 = I_2$.

b) $I_1 = 2I_2$.

c) $I_1 = 4I_2$.

d) $I_1 = I_2/2$. ⟸

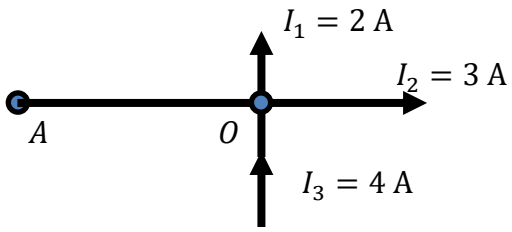
6. A junction point O is shown with four wires. Which statement is correct for the current between points A and O?

a) 1 A from O to A.

b) 1 A from A to O. ⟸

c) 2 A from O to A.

d) 2 A from A to O.



7. A circular loop of wire carries a constant current. If the loop is placed in a region of uniform magnetic field, the net magnetic force on the loop

a) is perpendicular to the plane of the loop, in a direction given by the right-hand rule.

b) is perpendicular to the plane of the loop, in a direction given by the left-hand rule.

c) is in the same plane as the loop.

d) is zero. ⟸

8. A bent wire carries a current I, as shown. What is the direction of the magnetic field $\vec{B}$ at point P due to this current?

a) to the right.

b) to the left.

c) out of the plane of the figure. ⟸

d) into the plane of the figure.