Kuwait University | **Physics Department**

General Physics II | **PHY 102**

جامعة الكويت
KUWAIT UNIVERSITY

Second Midterm Examination
Spring Semester 2023 – 2024

May 4, 2024
Time: 12:00 – 1:30 PM

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

Section No: .... Serial No: ....

Instructors: Drs. Alfailakawi, Lajko, Sharma, Vagenas

Fundamental constants

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

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

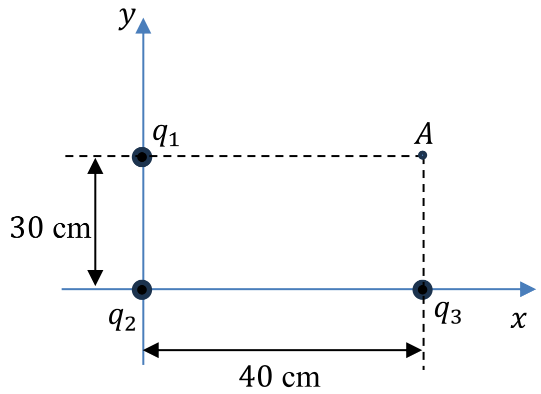
For use by Instructors only

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 $q_1 = 4$ nC, $q_2 = 5$ nC, and $q_3 = 4$ nC are placed on the x and y-axis as shown. Compute the work done by the external agent to move the electric charge $q = 3$ nC from infinity ($V_\infty = 0$ V) to point A, without changing its kinetic energy. **[4 points]**



$d = \sqrt{(0.40)^2 + (0.30)^2}$ m $\Longrightarrow d = 0.5$ m

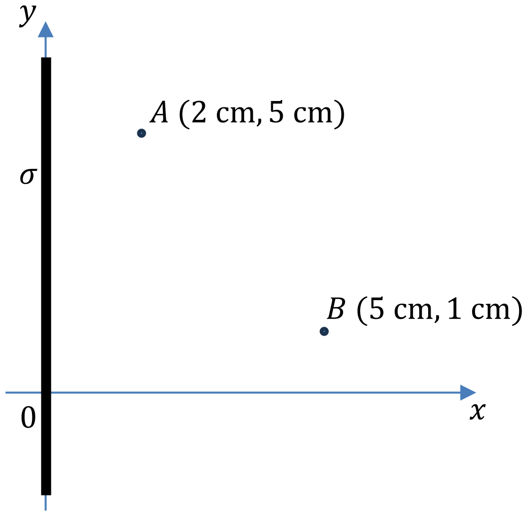
$W^{ext}_{\infty\rightarrow A} = -W^{el.field}_{\infty\rightarrow A} = -q(V_\infty - V_A) = qV_A$ [1]

$V_A = k\frac{q_1}{0.40} + k\frac{q_2}{0.50} + k\frac{q_3}{0.30}$ [1]

$V_A = 300$ V [1]

$W^{ext}_{\infty\rightarrow A} = qV_A \Longrightarrow W^{ext}_{\infty\rightarrow A} = 0.9$ μJ [1]

2. An infinite uniformly charged plane with surface charge density $\sigma = 35.4$ nC/m^2 is placed perpendicular to the x-axis as shown. Compute the potential difference $V_A - V_B$. **[4 points]**



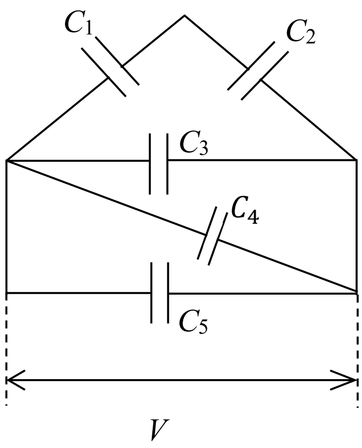
$V_A - V_B = \int_A^B \vec{E}\cdot d\vec{l}$ [1]

$\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{\imath} \qquad d\vec{l} = dx\hat{\imath} + dy\hat{\jmath}$ [1]

$V_A - V_B = \int_A^B \left[\frac{\sigma}{2\varepsilon_0}\hat{\imath}\right]\cdot(dx\hat{\imath} + dy\hat{\jmath}) = \frac{\sigma}{2\varepsilon_0}\int_{2cm}^{5cm} dx$ [1]

$V_A - V_B = \frac{\sigma}{2\varepsilon_0}(0.05 - 0.02) \Longrightarrow V_A - V_B = 60$ V [1]

3. In the given network of capacitors with $C_1 = C_2 = C_3 = 10$ μF, and $C_4 = C_5 = 5$ μF, the capacitor C_2 has charge $Q_2 = 15$ μC. Find the stored energy in capacitor C_5. **[4 points]**



C_1 and C_2 are in series:

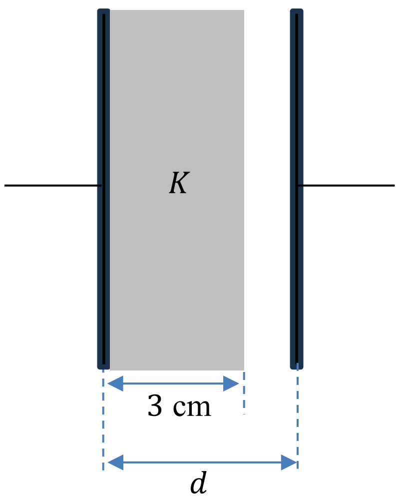
$C_{12} = \frac{C_1 C_2}{C_1 + C_2} = 5$ μF [1]

so, the total charge of C_{12} is $Q_{12} = Q_1 = Q_2$. [1]

$C_{12} = \frac{Q_{12}}{V} \Longrightarrow V = \frac{Q_{12}}{C_{12}} \Longrightarrow V = 3$ V [1]

$U_{C_5} = \frac{1}{2} C_5 V^2 \Longrightarrow U_{C_5} = 22.5$ μJ [1]

4. An air-filled parallel-plate capacitor with a plate area A and separation $d = 5$ cm, has capacitance $C_0 = 40$ μF. Then, the capacitor is partially filled with a dielectric with constant $K = 3$ as shown. Find the equivalent capacitance. **[4 points]**



$C_0 = \varepsilon_0 \frac{A}{d} \Longrightarrow \varepsilon_0 A = C_0 d$ [1]

$C_1 = K \varepsilon_0 \frac{A}{x} \Longrightarrow C_1 = K \frac{C_0 d}{0.03} \Longrightarrow C_1 = 200$ μF [1]

$C_2 = \varepsilon_0 \frac{A}{d - x} \Longrightarrow C_2 = \frac{C_0 d}{0.05 - 0.03} \Longrightarrow C_2 = 100$ μF [1]

C_1 and C_2 are in series:

$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} \Longrightarrow C_{eq} = 66.7$ μF [1]

5. In a metallic wire, the electric current is $I(t) = 12t + 3$ (t is in seconds and I is in amperes). Find the number of electrons that flow through a cross-sectional area of the metallic wire between the time $t_1 = 1$ ns and $t_2 = 3$ ns. **[4 points]**

$I = \frac{dQ}{dt} \Rightarrow Idt = dQ \Rightarrow Q = \int_{1\,ns}^{3\,ns} I(t)dt$ [1]

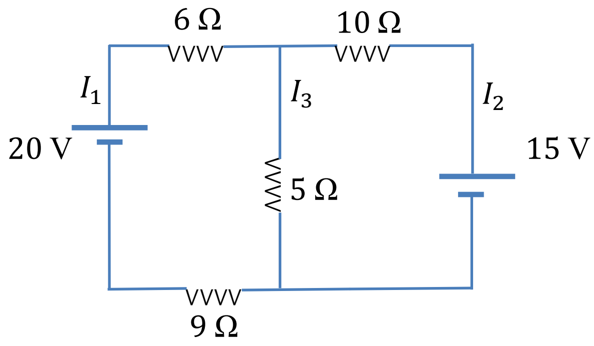
$Q = \int_{1\,ns}^{3\,ns}(12t+3)dt \Rightarrow Q = 12\left[\frac{t^2}{2}\right]_{1\,ns}^{3\,ns} + 3[t]_{1\,ns}^{3\,ns}$ [1]

$Q = 6$ nC [1]

Electric charge is quantized:

$Q = N\,|e| \Rightarrow N = \frac{Q}{|e|} \Rightarrow N = 3.75 \times 10^{10}$ electrons [1]

6. Find the electric currents in all branches of the given electric circuit. **[5 points]**



Junction rule:

$I_3 = I_1 + I_2$ [1]

Left loop:

$20 - 6I_1 - 5I_3 - 9I_1 = 0$

Substituting the first equation in the second one:

$20 - 20I_1 - 5I_2 = 0 \Rightarrow 4I_1 + I_2 = 4$ [1]

Right loop:

$15 - 10I_2 - 5I_3 = 0$

Substituting the first equation in the above:

$15 - 15I_2 - 5I_1 = 0 \Rightarrow I_1 + 3I_2 = 3$ [1]

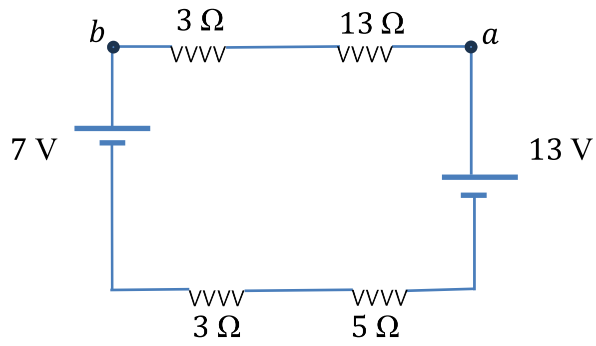
Multiplying the 3rd equation with (-3) and adding it to the above equation, one gets:

$-11I_1 = -9 \Rightarrow \boxed{I_1 = 0.82 \text{ A}}$ [1]

Substituting I_1 in the 2nd equation, one gets:

$4 \times 0.82 + I_2 = 4 \Rightarrow \boxed{I_2 = 0.73 \text{ A}}$ and so from the first equation: $\boxed{I_3 = 1.55 \text{ A}}$ [1]

7. Find the power dissipated between a and b. **[3 points]**



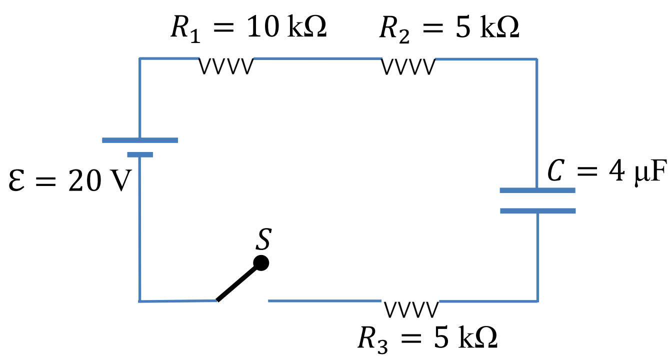
Loop rule:

$13 - 13I - 3I - 7 - 3I - 5I = 0 \Rightarrow 24I = 6 \Rightarrow I = 0.25$ A [1]

$V_a - 13I - 3I = V_b \Rightarrow V_a - V_b = 4\text{ V} \Rightarrow V_{ab} = 4\text{ V}$ [1]

$P = V_{ab}I \Rightarrow P = 1.0\text{ W}$ [1]

8. At $t = 0$ s, the switch S is closed. Find the electric charge stored in the capacitor at $t = 0.02$ s. **[4 Points]**



After infinite time, the capacitor is fully charged:

$Q = CV_C \Rightarrow Q = 80\ \mu\text{C}$ [1]

The capacitor will be charged through the three resistances.

$R_{eq} = R_1 + R_2 + R_3 = 20\text{ k}\Omega$ [1]

So, the time constant is: $\tau = R_{eq}C \Rightarrow \tau = 0.08$ s

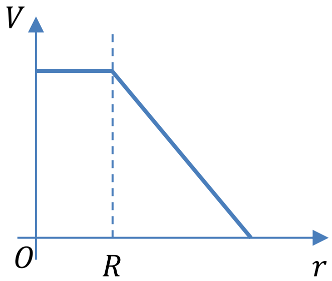
The electric charge stored in the capacitor at $t = 0.02$ s is:

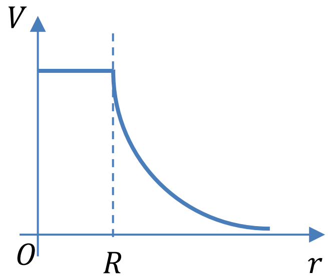
$q(t) = Q[1 - e^{-\frac{t}{\tau}}] \Rightarrow q(t) = 80[1 - e^{-\frac{0.02}{0.08}}]\ \mu\text{C}$ [1]

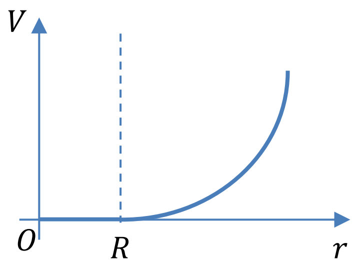
$q(t) = 17.7\ \mu\text{C}$ [1]

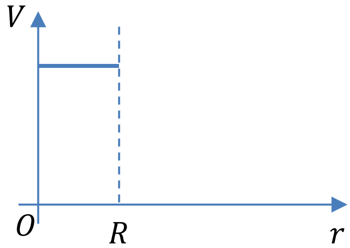
PART II: Conceptual Questions (each carries 1 point). Tick the best answer:

1. Which is the diagram that shows the electric potential of a charged conducting sphere of radius R as a function of distance r from the center of the conducting sphere?

a) 

b) 

c) 

d) 

2. An infinite conducting plane is uniformly charged. Its equipotential surfaces are:

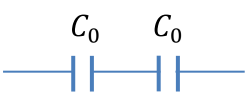
   a) Infinite inclined planes making an angle of 45^o with the conducting plane.
   b) infinite inclined planes making an angle of 60^o with the conducting plane.
   c) Infinite planes parallel to the conducting plane.
   d) Infinite planes perpendicular to the conducting plane.

3. An air-filled parallel-plate capacitor is charged by a battery. While the battery remains connected, the separation between the plates of the capacitor is increased. Which statement is correct?

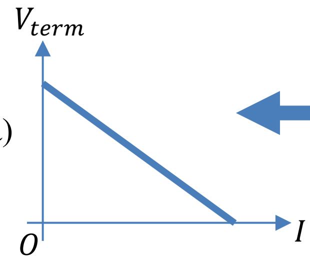
   a) The energy density of the capacitor will remain the same.
   b) The electric charge of the capacitor will increase.
   c) The electric energy of the capacitor will increase.
   d) The energy density of the capacitor will decrease.

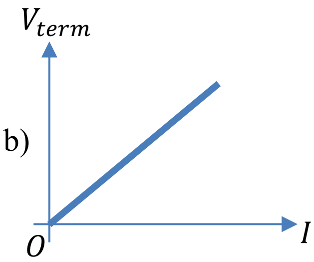
4. Two parallel-plate capacitors are connected as shown. Then, a dielectric is inserted in one of the capacitors and fully fills it. The equivalent capacitance of the two capacitors will

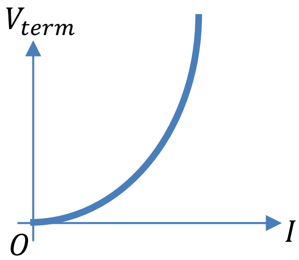
   a) increase.
   b) decrease.
   c) remain the same.
   d) become zero.

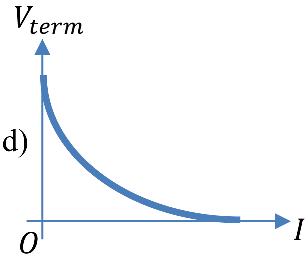


5. Which diagram gives the terminal voltage of a real source of emf as a function of the electric current?

a) 

b) 

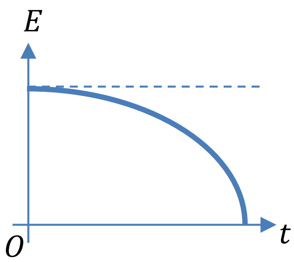
c) 

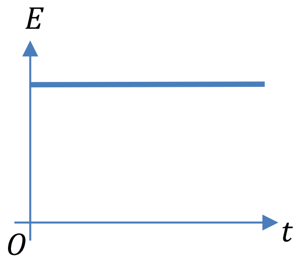
d) 

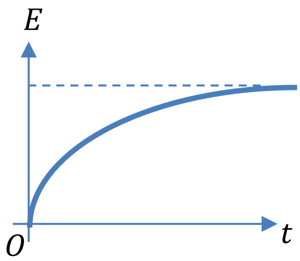
6. The power input to a real source of emf is:

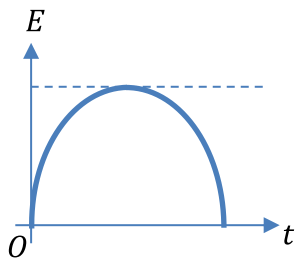
a) $P_{in} = \mathcal{E} - Ir$.
b) $P_{in} = \mathcal{E}I - I^2r$.
c) $P_{in} = \mathcal{E}I + I^2r$.
d) $P_{in} = \mathcal{E}I + I^2r^2$.

7. In an RC circuit, during the charging of the capacitor, the diagram of the magnitude of the electric field between the plates of the capacitor as a function of the time is:

a) 

b) 

c) 

d) 

8. In a charging RC circuit, the time constant is τ. If the switch is closed at $t = 0$, when the capacitor is uncharged, after how much time will the charge be the 63.2 % of its maximum value Q?

a) τ.
b) 2τ.
c) 5τ.
d) 10τ.