Kuwait University **Physics Department**

General Physics II **PHY 102**

جامعة الكويت
KUWAIT UNIVERSITY

Second Midterm Examination
Spring Semester 2022 – 2023

April 29, 2023
Time: 12:00 – 1:30 PM

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

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

Instructors: Drs. Alfrousheh, 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)

$\mu_0 = 4\pi \times 10^{-7}$ 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)

$g = 9.8\ \text{m/s}^2$ (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. An air-filled parallel plate capacitor C with a plate area 0.030 m^2 and a plate separation 1.0 mm is charged to a potential difference $V_0 = 20$ V. The battery is then disconnected. A dielectric slab with $K = 3.2$ is then inserted between the plates filling the space completely. What is the energy stored on the capacitor now? **[4 points]**

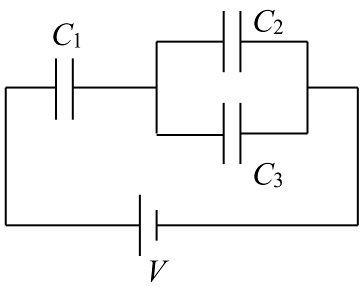
$$C_0 = \varepsilon_0 \frac{A}{d} = \frac{8.85\times10^{-12}\times0.03}{1.0\times10^{-3}}\text{ F} = 2.66\times10^{-10}\text{ F}$$

$$Q_0 = C_0V_0 = 2.66\times10^{-10}\text{ F}\times 20\text{ V} = 5.31\times10^{-9}\text{ C}$$

$$C = KC_0 = 8.51\times10^{-10}\text{ F}$$

$$U = \frac{Q_0^2}{2C} = \frac{(5.31\times10^{-9}\ C)^2}{2\times8.51\times10^{-10}\ F} = 1.66\times10^{-8}\text{ J}$$

2. If $C_1 = 12$ μF, $C_2 = 8$ μF, $C_3 = 16$ μF and $V = 15$ V, what is the charge stored on the capacitor C_3? **[5 points]**



$$C_{23} = C_2 + C_3 = 8\ \mu\text{F} + 16\ \mu\text{F} = 24\ \mu\text{F}$$

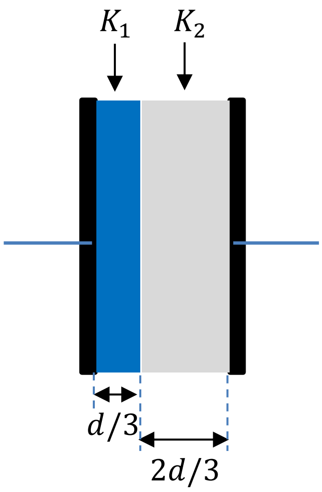
$$C_{eq} = \frac{C_1.C_{23}}{C_1+C_{23}} = \frac{12\ \mu\text{F}\times24\ \mu\text{F}}{(12+24)\ \mu\text{F}} = 8\ \mu\text{F}$$

$$Q = C_{eq}V = 8\ \mu\text{F}\times15\text{ V} = 120\ \mu\text{C}$$

$$V_{C_2} = V_{C_3} = \frac{Q}{C_{23}} = \frac{120\ \mu\text{C}}{24\ \mu\text{F}} = 5\text{ V}$$

$$Q_{C_3} = C_3V_{C_3} = 16\ \mu\text{F}\times5\text{ V} = 80\ \mu\text{C}$$

3. An air-filled parallel-plate capacitor with a surface area A and a plate separation d, has capacitance C_0. When the capacitor is filled with two dielectric materials with dielectric constants $K_1 = 2$ and $K_2 = 4$, as shown, the capacitance is 120 nF. Calculate the initial capacitance C_0. **[5 points]**



$$C_0 = \varepsilon_0 \frac{A}{d}$$

$$C_1 = K_1 \varepsilon_0 \frac{A}{d/3} = 3K_1 \varepsilon_0 \frac{A}{d} = 6C_0$$

$$C_2 = K_2 \varepsilon_0 \frac{A}{2d/3} = \frac{3}{2} K_2 \varepsilon_0 \frac{A}{d} = 6C_0$$

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

$$C_{eq} = 3C_0 \Rightarrow C_0 = 40 \text{ nF}$$

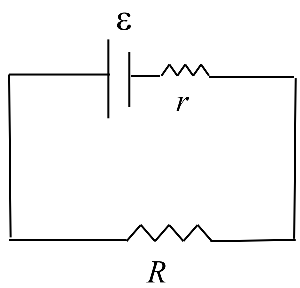
4. An electric field $E = 6.0$ V/m is applied across a conducting wire of radius 1.0 mm. If the resistivity of the conductor is 18.7×10^{-8} Ω.m, how much charge passes through the wire in 10 minutes? **[3 points]**

$$E = \rho J \Longrightarrow \quad J = \frac{E}{\rho} = \frac{6.0 \text{ V}}{18.7 \times 10^{-8} \ \Omega.\text{m}} = 3.2 \times 10^7 \text{ A/m}^2$$

$$I = J.A = 3.2 \times 10^7 \frac{\text{A}}{\text{m}^2} \times \pi \, (0.001 \text{ m})^2 = 100.8 \text{ A}$$

$$Q = I.t = 100.8 \text{ A} \times (10 \times 60 \text{ s}) = 6.05 \times 10^4 \text{ C}$$

5. A car battery with $\varepsilon = 12.0$ V shows a terminal voltage 11.3 V, when connected to a light bulb. The power dissipated in the bulb is 4.7 W. What is the internal resistance r of the battery? **[3 points]**

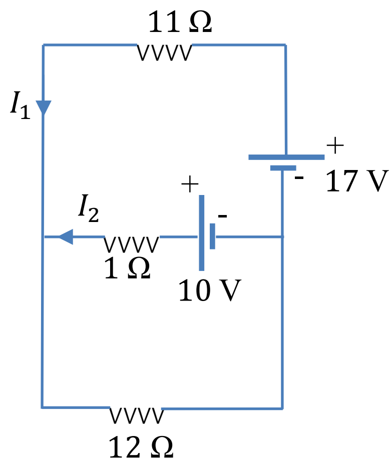


$$P = \frac{V^2}{R} \Longrightarrow \quad R = \frac{V^2}{P} = \frac{(11.3\text{ V})^2}{4.7\text{ W}} = 27.2\ \Omega$$

$$I = \frac{V}{R} = \frac{11.3\text{ V}}{27.2\ \Omega} = 0.415\text{ A}$$

$$\varepsilon = V + Ir \Longrightarrow \quad r = \frac{\varepsilon - V}{I} = \frac{(12.0-11.3)\text{ V}}{0.415\text{ A}} = 1.69\ \Omega$$

6. Find the electric currents I_1 and I_2. **[5 Points]**



Junction rule: $I_3 = I_1 + I_2$ (1)

Loop rule (upper):

$17 - 11I_1 + I_2 - 10 = 0$

$7 - 11I_1 + I_2 = 0$ (2)

Loop rule (big):

$17 - 11I_1 - 12I_3 = 0$

Substitute equation (1) in the above equation

$17 - 23I_1 - 12I_2 = 0$ (3)

Multiply equation (2) with (+12)

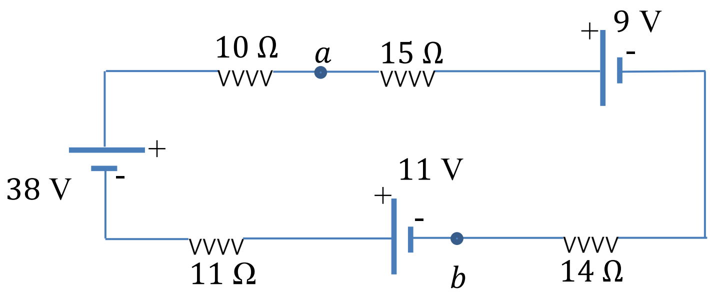
(2) $\Longrightarrow 84 - 132I_1 + 12I_2 = 0$ (4)

Add equations (3) and (4)

$101 - 155I_1 = 0 \Longrightarrow I_1 = 0.65$ A

(2) $\Longrightarrow I_2 = 0.17$ A

7. Find the potential difference $V_a - V_b$. **[3 Points]**



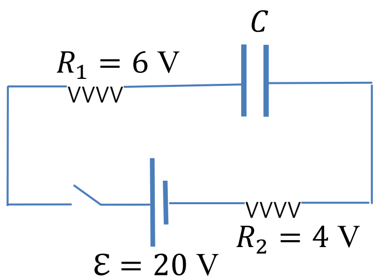
<u>Loop rule</u>

$38 - 10I - 15I - 9 - 14I + 11 - 11I = 0 \Longrightarrow I = 0.8\text{ A}$

$V_a + 10I - 38 + 11I - 11 = V_b \Longrightarrow V_{ab} - 49 + 21I = 0$

$V_{ab} = 49 - 21I \Longrightarrow V_{ab} = 32.2\text{ V}$

8. The capacitor is uncharged and at time $t = 0$ the switch is closed. At time t_1, the electric charge on the capacitor is $q(t_1) = 4\ \mu\text{C}$ and when the capacitor is fully charged the charge is $Q = 40\ \mu\text{C}$. Find the power dissipated in resistance R_1 at time t_1. **[4 Points]**



<u>Solution 1</u>

$R_{eq} = R_1 + R_2 \Longrightarrow R_{eq} = 10\ \Omega$

$I_0 = \frac{\mathcal{E}}{R_{eq}} \Longrightarrow I_0 = 2\text{ A}$

$q(t_1) = Q\left[1 - e^{-\frac{t_1}{R_{eq}C}}\right] \Rightarrow \frac{q(t_1)}{Q} = 1 - e^{-\frac{t_1}{R_{eq}C}} \Rightarrow e^{-\frac{t_1}{R_{eq}C}} = 1 - \frac{q(t_1)}{Q} \Rightarrow e^{-\frac{t_1}{R_{eq}C}} = 0.9$

$P_{R_1}(t_1) = i^2(t_1)R_1 = {I_0}^2 R_1\left(e^{-\frac{t_1}{R_{eq}C}}\right)^2 \Longrightarrow P_{R_1}(t_1) = 19.44\text{ W}$

<u>Solution 2</u>

$R_{eq} = R_1 + R_2 \Longrightarrow R_{eq} = 10\ \Omega$

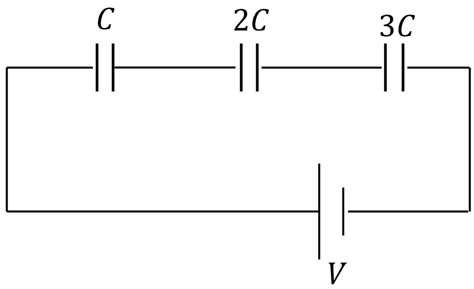
$C = \frac{Q}{\mathcal{E}} \Longrightarrow C = 2\ \mu\text{F}$

<u>Loop rule:</u> $\mathcal{E} - i(t_1)R_{eq} - \frac{q(t_1)}{C} = 0 \Rightarrow i(t_1) = 1.8\text{ A}.$

$P_{R_1}(t_1) = i^2(t_1)R_1 \Longrightarrow P_{R_1}(t_1) = 19.44\text{ W}$

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

1. A battery V is connected to three capacitors. The electric charge is

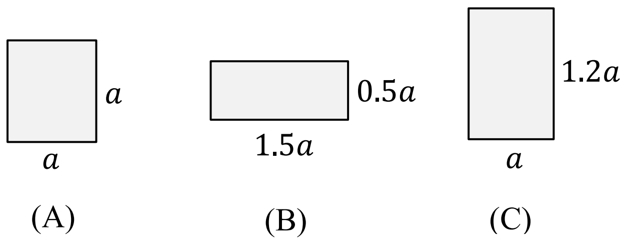


a) the greatest in capacitor C.
b) the greatest in capacitor $2C$.
c) the greatest in capacitor $3C$.
d) the same in all three capacitors. (ANSWER)

2. An air-filled capacitor C with plate separation d is charged to a potential difference V. The battery is disconnected and then the plate separation is increased to $2d$. Which statement is correct?

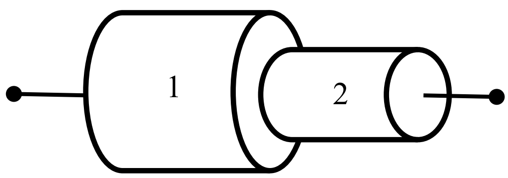
a) The energy stored on the capacitor becomes zero.
b) The energy stored on the capacitor becomes double. (ANSWER)
c) The energy stored on the capacitor becomes half.
d) The energy stored on the capacitor does not change.

3. The figure shows cross-sections of three conductors of the same material, having the same length. When a potential difference V is applied separately across the length of these, the currents in them will be in the order:



a) $I_A < I_B < I_C$.
b) $I_B < I_A < I_C$. (ANSWER)
c) $I_B < I_C < I_A$.
d) $I_A < I_C < I_B$.

4. A potential difference is applied across the two ends of a conductor made of two cylinders of the same material with radii $r_1 = 2r_2$. The drift velocity in cylinder 1 is v_d. The drift velocity in cylindrical 2 will be:

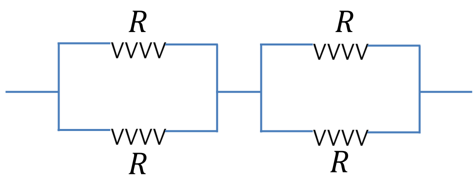


a) v_d.
b) $2v_d$.
c) $4v_d$. (ANSWER)
d) $v_d/4$.

5. In a metallic wire, electrons are moving in the $-x$ direction. Which statement is correct?

   a) The electric current density J has direction $-\hat{\imath}$ and the applied electric field $\vec{E}$ has $-\hat{\imath}$.
   b) The electric current density J has direction $-\hat{\imath}$ and the applied electric field $\vec{E}$ has $+\hat{\imath}$.
   c) The electric current density J has direction $+\hat{\imath}$ and the applied electric field $\vec{E}$ has $-\hat{\imath}$.
   d) The electric current density J has direction $+\hat{\imath}$ and the applied electric field $\vec{E}$ has $+\hat{\imath}$. (ANSWER)

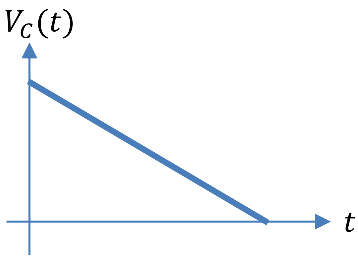
6. The equivalent resistance of the network is



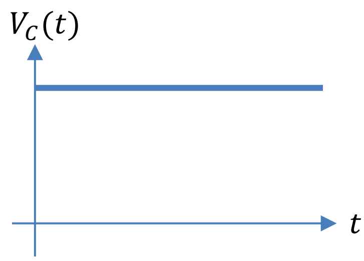
   a) $4R$.
   b) $2R$.
   c) R. (ANSWER)
   d) $R/2$.

7. During the discharging of a capacitor, the potential difference $V_C(t)$ across the capacitor versus the time t is described by the diagram

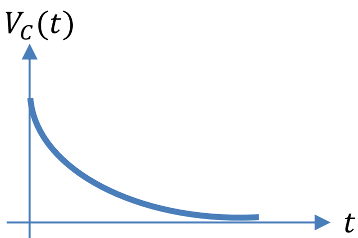
(a)



(b)

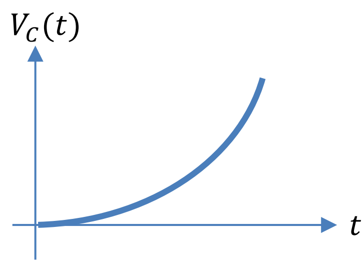


(c)

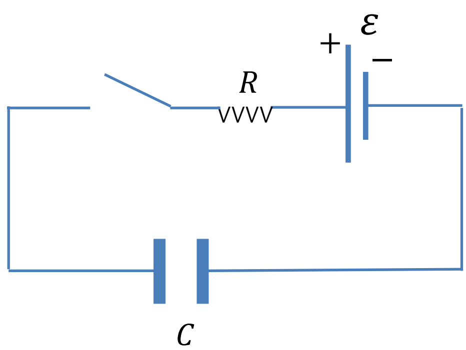


(ANSWER)

(d)



8. In the RC circuit below, the switch is closed at time $t = 0$. At time $t = 0$, the electric current is



   a) $I = 0$.
   b) $I = \frac{\varepsilon}{R}$. (ANSWER)
   c) $I = \varepsilon R$.
   d) $I = C\varepsilon$.