İzmir Kâtip Çelebi University
Department of Engineering Sciences
Phy102 Physics II
Midterm Examination
November 04, 2025 08:30 – 10:00
Good Luck!

NAME-SURNAME:

SIGNATURE:

ID:

DEPARTMENT:

INSTRUCTOR:

DURATION: 90 minutes

◇ **Answer all the questions.**
◇ **Write the solutions explicitly and clearly. Use the physical terminology.**
◇ **You are allowed to use Formulae Sheet.**
◇ **Calculator is allowed.**
◇ **You are not allowed to use any other electronic equipment in the exam.**

Question	Grade	Out of
1A		20
1B		15
2		20
3		20
4		10
5		15
TOTAL		100

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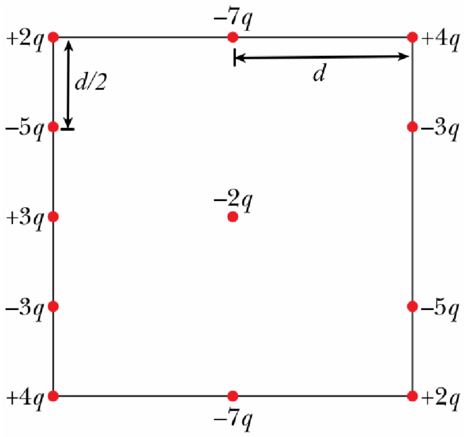
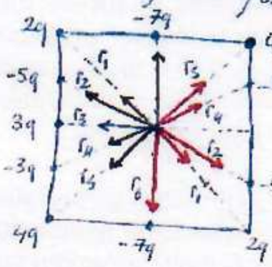
1. A) In the figure below, a central particle of charge $-2q$ is surrounded by a square array of charged particles, separated by either distance d or $d/2$ along the perimeter of the square.



i What are the magnitude and direction of the net electrostatic force on the central particle due to the other particles? (**Hint: Some forces on the central particle cancel each other!**)

ii What is the work you need to apply to bring central particle to its place from infinity?

i) Some of the forces cancel each other!



$$\vec{F} = k\frac{|q_1||q_2|}{r^2}\hat{r}, \quad \vec{F}_{net} = \sum_{i=1}^{11} \frac{k|-2q||q_i|}{r_i^2}\hat{r}_i \quad 3$$

$$\vec{F}_{net} = k|-2q|\left(\frac{|2q|}{r_1^2}\hat{r}_1 + \frac{|-5q|}{r_2^2}\hat{r}_2 + \frac{|3q|}{r_3^2}\hat{r}_3 + \frac{|-3q|}{r_4^2}\hat{r}_4 + \frac{|4q|}{r_5^2}\hat{r}_5 + \frac{|-7q|}{r_6^2}\hat{r}_6\right.$$

$$6 \quad \left. \frac{|2q|}{r_1^2}(-\hat{r}_1) + \frac{|-5q|}{r_2^2}(-\hat{r}_2) + \frac{|-3q|}{r_4^2}(-\hat{r}_4) + \frac{|4q|}{r_5^2}(-\hat{r}_5) + \frac{|-7q|}{r_6^2}(-\hat{r}_6)\right)$$

only survival force is due to $3q$.

$$\rightarrow \vec{F}_{net} = \frac{k|-2q||3q|}{r_3^2}\hat{r}_3 = k\frac{6q}{d^2}(-\hat{x}) = \boxed{\frac{1}{4\pi\varepsilon_0}\frac{6q^2}{d^2}(-\hat{x})} \quad 2$$

ii) To bring the central particle. First find the potential present at that central point. Potential is a scalar quantity. No cancellation as force vectors. $V = k\frac{q}{r}$

$$V_{net} = \sum_{i=1}^{11} V_i = k\left(\frac{-7q-7q+3q}{d} + \frac{+4q+4q+2q+2q}{d\sqrt{2}} + \frac{-5q-5q-3q-3q}{[d^2+(d/2)^2]^{1/2}}\right) \quad 2$$

$$2 \quad = \frac{q}{4\pi\varepsilon_0}\left(\frac{-11}{d} + \frac{12}{d\sqrt{2}} + \frac{-16}{d(\sqrt{5}/2)}\right) = \frac{q}{4\pi\varepsilon_0 d}\left(-11+6\sqrt{2}-32/\sqrt{5}\right) = \frac{q}{4\pi\varepsilon_0 d}(-16.8)$$

$$= \frac{-4.2q}{\pi\varepsilon_0 d} \quad 1$$

Now find the required potential energy (or work)

$$\underset{(qV)}{W = \Delta U} = (U_f - \underset{0 \text{ at infinity}}{U_i}) = U_f = (-2q)\left(\frac{-4.2q}{\pi\varepsilon_0 d}\right) = \boxed{\frac{8.4q}{\pi\varepsilon_0 d}} \quad 2$$

2

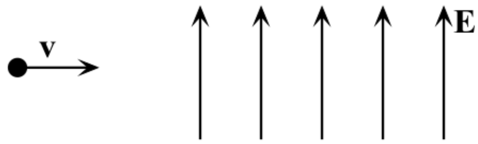
B) A proton moves at $4.50 \times 10^5\ m/s$ in the horizontal direction. It enters a uniform vertical electric field with a magnitude of $9.60 \times 10^3\ N/C$.

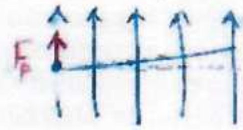
Ignoring any gravitational effects, find

i the time required for the proton to travel 5.00 cm horizontally,

ii the vertical displacement during that time,

iii the horizontal and vertical components of the velocity after the proton has traveled 5.00 cm horizontally.





$v = 4.5 \times 10^5\ m/s$ & $E = 9.6 \times 10^3\ N/C$ (uniform)

$v = v_x + v_y = 0$ } Constant $\vec{E} \rightsquigarrow$ constant

$a = a_y$ & $a_x = 0$ } acceleration $\leftarrow$ force

$qE = ma$

i) $v_x = v_{0x} = v = \frac{\Delta x}{\Delta t}$ (1) $\rightsquigarrow \Delta t = \frac{5 \times 10^{-2}\ m}{4.5 \times 10^5\ m/s} = 1.11 \times 10^{-7}\ s = \underline{111\ ns}$ (1) (1)

ii) $a_y m_p = q_p E$ (2) $\rightarrow a_y = \frac{q_p E}{m_p}$ (1) $= \frac{(1.6 \times 10^{-19}\ C)(9.6 \times 10^3\ N/C)}{(1.67 \times 10^{-27}\ kg)} = 9.21 \times 10^{11}\ m/s^2$ (1) (1)

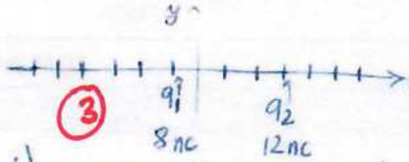
$y = y_0 + v_{0y} t + \frac{1}{2} a_y t^2$ (1) $\rightsquigarrow y - y_0 = h = \frac{1}{2} a_y t^2 = \frac{1}{2}(9.21 \times 10^{11}\ m/s^2)(1.11 \times 10^{-7}\ s)^2$ (1) (1)

$= 5.68 \times 10^{-3}\ m = \underline{5.68\ mm}$

iii) $v_x = v_{0x} = 4.5 \times 10^5\ m/s$ (1)

$v_y = v_{0y} + a_y t = a_y t = (9.21 \times 10^{11}\ m/s^2)(1.11 \times 10^{-7}\ s) = \underline{1.02 \times 10^5\ m/s}$ (1) (1) (1)

2. A positive point charge q_1=8 nC is on the x-axis at x_1= -1 m, a second positive point charge q_2=12 nC is on the x-axis at x_2=3 m. Find the net electric field (a) at point A on the x-axis at x=6 m, and (b) at point B on the x-axis at x=2 m.



i) $E(x=6m)=?$

ii) $E(x=2m)=?$

i) $\longrightarrow E_{q_1}$, $\longrightarrow E_{q_2}$

$$E(x=6m)=\sum_{i=1}^{2} E_{q_i}(x=6m) = E_{q_1}(x=6m) + E_2(x=6m)$$ 3

3

$$= k\frac{|q_1|}{(7m)^2} + k\frac{|q_2|}{(3m)^2} = \left(8.99\times10^{9}\frac{N}{C^2}m^2\right)\left(\frac{8\times10^{-9}C}{49m^2}+\frac{12\times10^{-9}C}{9m^2}\right)$$

$$= 13.45\ N/C \rightsquigarrow \boxed{\vec{E}(x=6m)=13.45\ N/C\ \hat{i}}$$ 3

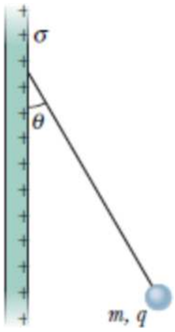
ii) $E(x=2m)=?$

$\longrightarrow E_{q_1}$, $\longleftarrow E_{q_2}$ 4

$$E(x=2m)=k\frac{|q_1|}{(9m^2)} - k\frac{|q_2|}{1m^2} = 8.99\times10^{9}\frac{N}{C^2}m^2\left(\frac{8\times10^{-9}C}{9m^2}-\frac{12\times10^{-9}C}{1m^2}\right)$$

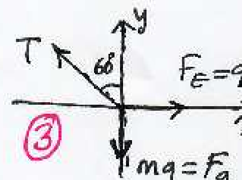
$$= -99.9\ N/C \rightarrow \boxed{\vec{E}(x=2m)=99.9\ N/C\,(-\hat{i})}$$ 4

3. A small, nonconducting ball of mass $m = 2 \times 10^{-6}\ kg$ and charge $q = 4.0 \times 10^{-8}\ C$ (distributed uniformly through its volume) hangs from an insulating thread that makes an angle $\theta = 30°$ with a vertical, uniformly charged **nonconducting sheet** (shown in cross section).



Considering the gravitational force on the ball and assuming the sheet extends far vertically and into and out of the page, **calculate the surface charge density** σ **of the sheet. Hint: The ball is in equilibrium (stationary)**.

$m = 2\times10^{-6}\,kg$ (non-conducting)
$q = 4\times10^{-8}\,C$ uniform distribution
non-conducting sheet, $\sigma = ?$ (if hanged)
$E = \frac{\sigma}{2\varepsilon_0}$



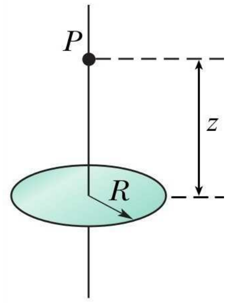
3

$F_E = qE$ 3 $T\cos 60° - mg = ma_y = 0$
3 $qE - T\sin 60° = ma_x = 0$
hangs ⇝ stationary
now, eliminate T

$\rightsquigarrow qE - \left(\frac{mg}{\cos 60°}\right)\sin 60° = 0$ 3 $\rightsquigarrow qE = mg\tan 60° \rightsquigarrow q\frac{\sigma}{2\varepsilon_0} = mg\tan 60° \rightsquigarrow \sigma = \frac{2mg\varepsilon_0\tan 60°}{q}$

$\rightsquigarrow \sigma = \frac{2mg\varepsilon_0\tan 60°}{q}$ 3 $= \frac{2(2\times10^{-6}kg)(9.8\,m/s^2)(8.85\times10^{-12}C^2/Nm^2)\tan 60°}{(4\times10^{-8}C)}$ 2 $= \boxed{15\times10^{-9}\,C/m^2}$ 2 1

4. The electric potential at any point on the central axis of a uniformly charged disk is



$$V = \frac{\sigma}{2\epsilon_0}\left(\sqrt{z^2+R^2} - z\right)$$

Starting with this expression, derive an expression for the electric field at any point on the axis of the disk.

Any point on the axis of disk → z-direction

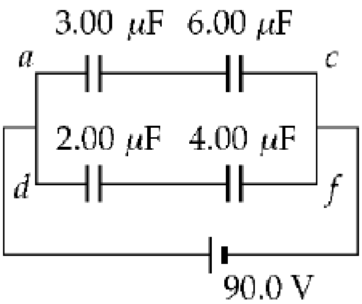
$$E = -\frac{\partial V}{\partial z} = -\frac{\partial}{\partial z}\left[\frac{\sigma}{2\varepsilon_0}\left((z^2+R^2)^{1/2} - z\right)\right]$$

4

$$= \frac{-\sigma}{2\varepsilon_0}\left[\frac{1}{2}(z^2+R^2)^{-1/2}2z - 1\right] \quad 3$$

$$\boxed{= \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{z}{\sqrt{z^2+R^2}}\right]} \quad 3$$

5. For the system of capacitors shown in Figure;



Find

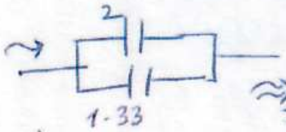
i the equivalent capacitance of the system,

ii the charge on each capacitor,

iii the potential across each capacitor.

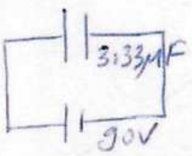
i) $C_{eqv} = ?$ $\quad \sim \frac{1}{C_{ac}} = \frac{1}{3\mu F} + \frac{1}{6\mu F} \Rightarrow C_{ac} = 2\mu F$

$\sim \frac{1}{C_{df}} = \frac{1}{2\mu F} + \frac{1}{4\mu F} \Rightarrow C_{df} = 1.33\mu F$ 2

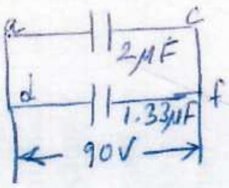


$\Rightarrow C_{eqv} = 3.33\,\mu F$ 2 1

ii)



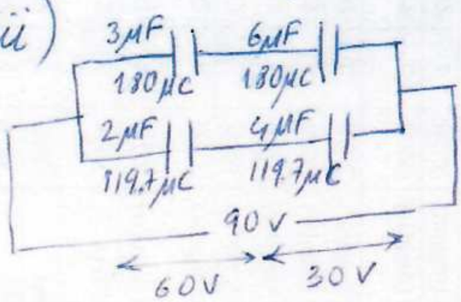
$C = \frac{Q}{V} \sim Q = C_{eqv} \times V = (3.33\times10^{-6}F)\,90V = 299.7\,\mu C$ 2 (total charge)



$Q_{ac} = (2\mu F)\,90V = 180\,\mu C = q_a = q_c$ 2

$Q_{df} = (1.33\mu F)\,90V = 119.7\,\mu C = q_d = q_f$ 2

iii)



$V_a = \frac{q_a}{C_a} = \frac{180\mu C}{3\mu F} = \boxed{60V}$ 1

$V_c = \frac{180\mu C}{6\mu F} = \boxed{30V}$ 1

$V_d = \frac{119.7\mu C}{2\mu F} \simeq \boxed{60V}$ 1

$V_f = \frac{119.7\mu C}{4\mu F} \simeq \boxed{30V}$ 1