UNIVERSITY OF FORT HARE

PHY113F

EXAMINATIONS

MAY / JUNE 2023

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Time: 3 HOURS

Subject: **ELECTROSTATICS AND MAGNETISM**

Marks: **100**

This paper consists of 5 pages, including the cover page.

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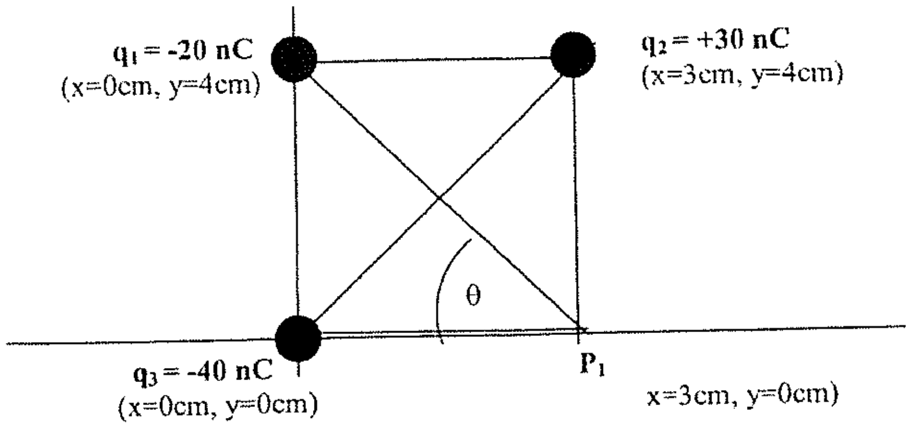
Instructions

- Answer all three (3) questions
- Read the question more than once and write down your data.
- On problem-solving, specify applicable definitions and draw clearly labeled diagrams.

Question1 **(Coulomb's law, Electric Field, Electric Potential, and Potential Energy)**

1.1.Two point charges are located in the xy plane as follows:



Charge q_1 **= -20 nC** is located at point ($x = 0\ cm, y = 4\ cm$), and a second charge, q_2 **= +30 nC,** is at the point ($x = 3\ cm, y = 4\ cm$). A third charge q_3 **= - 40 nC** is placed at the origin ($x = 0\ cm, y = 0\ cm$).

1.1.1. Calculate the Resultant Coulomb Force on charge q_2 **= +30 nC** due to the presence of q_1 and q_3 (both magnitude and direction). (10)

1.1.2. Draw a labeled vector diagram **(WITHOUT CALCULATIONS)** of the **Electric Field** at **point P_1.** (3)

1.1.3. Calculate the **Electric Field** at **point P_1.** (7)

1.1.4. **CALCULATE** the overall **Potential Energy (ΔU)** of the system of charges. (5)

1.1.5. **CALCULATE** the Electric **Potential (V)** at **point P_1.** (5)

1.2. The potential difference between the accelerating plates of a television set is about 25 kV. If the plates are separated by 1.5 cm, estimate the magnitude of the uniform electric field between the plates. (3)

1.3. An electron is shot from one large metal plate toward a parallel plate. If the electron's initial speed $6.0\times10^{6}\,m/s$ and its speed just before it hits the second plate is $4.0\times10^{6}\,m/s$.

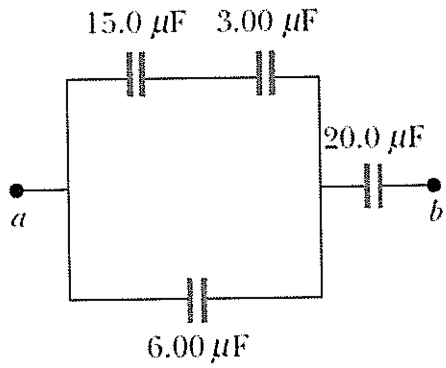
1.3.1. What is the potential difference between the plates? (5)

1.4 A particle of q1= +4q at the origin of an x-axis and a particle of q2= -q. The distance between the charges is L. At what point can a proton be placed so that it is in equilibrium? Please show the diagram. (10)

Question 2 **(GAUSS' LAW AND CAPACITENCE)**

2.1 Find the electric field outside and inside a hallow shell using Gauss law and show the diagram. (6)

2.2 Consider the combination of capacitors in the figure below.

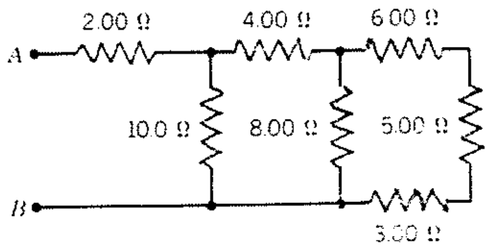


2.2.1 Calculate the equivalent (or total) capacitance of the group. (6)

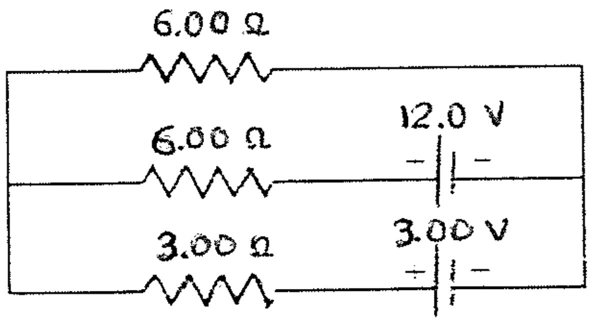
2.2.2 Calculate the charge on each capacitor if ΔVab =15.0 V. (10)

Question 3 **(Direct Current in Circuits)**

3.1. Find the equivalent resistance between points A and B in the drawing below. (10)



3.2. For the circuit shown in the drawing below, find the current in the 3.00 Ω resistor and specify the direction of the current. (10)



3.3 One end of an aluminium wire whose diameter is 2.5mm is welded to one end of a copper wire whose diameter is 1.8mm. The composite wire carries a steady current of 17mA. Determine the current density of both materials. (5)

3.4 A wire of length L= 2035 m and diameter d= 1.63 mm carries a current of 1.24A. The wire dissipates electrical energy at the rate P of 48.5 mW. Of what is the wire made of?(5)

Formulae Sheet (PHY 113F)

1. $\overline{F_{12}} = k_e \frac{q_1 q_2}{r^2}\hat{r}$, $\vec{E} \equiv \frac{\vec{F}}{q_0}$, $\overline{E} = k_e \frac{q}{r^2}\hat{r}$, $\overline{E} = k_e \sum_i \frac{q_i}{r_i^2}\hat{r_i}$

2. $\rho \equiv \frac{Q}{V}$, $\sigma \equiv \frac{Q}{A}$, $\lambda \equiv \frac{Q}{\ell}$, $dq = \rho dV$, $dq = \sigma dA$ and $dq = \lambda d\ell$, $\overline{E} = k_e \int \frac{dq}{r^2}\hat{r}$

3. $\vec{a} = \frac{q\overline{E}}{m}$, $v_y = a_y t = -\frac{eE}{m_e}t$, $y_i = \frac{1}{2}a_y t^2 = -\frac{1}{2}\frac{eE}{m_e}t^2$

4. $\Phi_E = EA\cos\theta$, $\Phi_E = \oint \overline{E}.d\overline{A} = \frac{q_{in}}{\varepsilon_0}$, $E_{ring} = \frac{k_e x}{(x^2+a^2)^{3/2}}Q$, $E_{rod} = \frac{k_e Q}{a(L+a)}$,

$E_{rod} = \frac{k_e Q}{x\sqrt{x^2+a^2}}$, $(E_x)_{disk} = 2\pi k_e \sigma\left[1 - \frac{x}{(R^2+x^2)^{\frac{1}{2}}}\right]$

5. $\Delta U = -q_0 \int_A^B \vec{E}d\vec{s}$, $\Delta V = \frac{\Delta U}{q_0} = -\int_A^B \vec{E}.d\vec{s}$, $\Delta V = -Ed$, $V = k_e \frac{q}{r}$, $U = k_e \frac{q_1 q_2}{r_{12}}$,

$E_x = -\frac{\partial V}{\partial x}$, $E_y = -\frac{\partial V}{\partial y}$, $E_z = -\frac{\partial V}{\partial z}$, $V = k_e \int \frac{dq}{r}$, $V_{ring} = k_e \frac{Q}{\sqrt{x^2+a^2}}$,

$V_{disc} = 2\pi k_e \sigma\left[(x^2+a^2)^{\frac{1}{2}} - x\right]$, $V_{sphere(r \geq R)} = k_e \frac{Q}{r}$, $V_{sphere(r<R)} = \frac{k_e Q}{2R}\left(3 - \frac{r^2}{R^2}\right)$,

$V_{conductingsphere(r<R)} = \frac{k_e Q}{2R}\left(3 - \frac{r^2}{R^2}\right)$, $V_{conductingsphere(r \geq R)} = k_e \frac{Q}{R}$,

6. $C_{sphere} = \frac{Q}{\Delta V} = \frac{Q}{k_e Q/R} = \frac{R}{k_e} = 4\pi\varepsilon_0 R$, $C_{\|plate} = \frac{Q}{\Delta V} = \frac{Q}{Ed} = \frac{Q}{Qd/\varepsilon_0 A} = \frac{\varepsilon_0 A}{d}$

7. $C_{cylinder} = \frac{\ell}{2k_e \ln\left(\frac{b}{a}\right)}$, $C_{(Sphere:innerr=a:outerr=b)} = -\frac{ab}{k_e(b-a)}$

$C_{eq.\|} = C_1 + C_2 + C_3 + \ldots$, $\frac{1}{C_{eq,s}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$, $U = \frac{Q^2}{2C} = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2$,

$C = \kappa C_0$

8. $I_{avg} = \frac{\Delta Q}{\Delta t}$, $I \equiv \lim_{\Delta t \to 0}\frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$, $\Delta Q = (nAv_d\Delta t)q$, $J \equiv \frac{I}{A}$, $R \equiv \frac{\Delta V}{I}$, $R = \rho\frac{\ell}{A}$, $R = \frac{\ell}{\sigma A}$, V=AL

6. $\rho = \rho_o[1 + \alpha(T - T_0)]$, $R = R_o[1 + \alpha(T - T_0)]$, $P = I\Delta V = I^2 R = \frac{(\Delta V)^2}{R} = \frac{Q}{\Delta t}$

7. $R_{eq.s} = R_1 + R_2 + R_3 + \ldots$, $\frac{1}{R_{eq,\|}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$, $\sum I = 0$, $\sum \Delta V = 0$

TABLE 14.1

Densities of Some Common Substances at Standard Temperature (0°C) and Pressure (Atmospheric)

Substance	ρ (kg/m^3)	Substance	ρ (kg/m^3)
Air	1.29	Ice	0.917×10^3
Aluminum	2.70×10^3	Iron	7.86×10^3
Benzene	0.879×10^3	Lead	11.3×10^3
Copper	8.92×10^3	Mercury	13.6×10^3
Ethyl alcohol	0.806×10^3	Oak	0.710×10^3
Fresh water	1.00×10^3	Oxygen gas	1.43
Glycerin	1.26×10^3	Pine	0.373×10^3
Gold	19.3×10^3	Platinum	21.4×10^3
Helium gas	1.79×10^{-1}	Seawater	1.03×10^3
Hydrogen gas	8.99×10^{-2}	Silver	10.5×10^3

TABLE 1.4

Prefixes for Powers of Ten

Power	Prefix	Abbreviation	Power	Prefix	Abbreviation
10^{-24}	yocto	y	10^3	kilo	k
10^{-21}	zepto	z	10^6	mega	M
10^{-18}	atto	a	10^9	giga	G
10^{-15}	femto	f	10^{12}	tera	T
10^{-12}	pico	p	10^{15}	peta	P
10^{-9}	nano	n	10^{18}	exa	E
10^{-6}	micro	μ	10^{21}	zetta	Z
10^{-3}	milli	m	10^{24}	yotta	Y
10^{-2}	centi	c			
10^{-1}	deci	d			

TABLE 26.1

Approximate Dielectric Constants and Dielectric Strengths of Various Materials at Room Temperature

Material	Dielectric Constant κ	Dielectric Strength[a] (10^6 V/m)
Air (dry)	1.000 59	3
Bakelite	4.9	24
Fused quartz	3.78	8
Mylar	3.2	7
Neoprene rubber	6.7	12
Nylon	3.4	14
Paper	3.7	16
Paraffin-impregnated paper	3.5	11
Polystyrene	2.56	24
Polyvinyl chloride	3.4	40
Porcelain	6	12
Pyrex glass	5.6	14
Silicone oil	2.5	15
Strontium titanate	233	8
Teflon	2.1	60
Vacuum	1.000 00	—
Water	80	—

[a] The dielectric strength equals the maximum electric field that can exist in a dielectric without electrical breakdown. These values depend strongly on the presence of impurities and flaws in the materials.

TABLE 27.2

Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] ($\Omega \cdot$ m)	Temperature Coefficient[b] α[(°C)$^{-1}$]
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome[c]	1.50×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}
Silicon[d]	2.3×10^3	-75×10^{-3}
Glass	10^{10} to 10^{14}	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

[a] All values at 20°C. All elements in this table are assumed to be free of impurities.

[b] See Section 27.4.

[c] A nickel–chromium alloy commonly used in heating elements.

[d] The resistivity of silicon is very sensitive to purity. The value can be changed by several orders of magnitude when it is doped with other atoms.

Some useful quantities and relationships.

$$k_e = \frac{1}{4\pi\varepsilon_o} = 9 \times 10^9 \frac{N.m^2}{C^2}$$

$$\varepsilon_o = 8.85 \times 10^{-12} \frac{C^2}{N-m^2}$$

$N_A = 6.022 \times 10^{23}$ particles /mol

$m_e = 9.109 \times 10^{-31}$ kg

$m_p = 1.673 \times 10^{-27}$ kg

$|e| = 1.602 \times 10^{-19}$ C

$G = 6.67 \times 10^{-11}$ N.m^2/kg^2

$g = 9.8$ m/s^2