Kuwait University **Physics Department**

Physics 122

Final Exam, Fall Semester 2023
December 30, 2023

Time: 11:00 am – 1.00 p.m.

Name……………………… Student No.……………

Instructor: Prof. M.M. Sharma

(Fundamental Constants)

$k = \dfrac{1}{4\pi\varepsilon_o} = 9.0 \times 10^9 \,\mathrm{N\cdot m^2 / C^2}$ (Coulomb's constant)

$\varepsilon_o = 8.85 \times 10^{-12}\ \mathrm{C^2 / (N\cdot m^2)}$ (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)

$N_A = 6.022 \times 10^{23}$ (Avogadro's number)

$g = 9.8\ \mathrm{m/s^2}$ (Acceleration due to gravity)

$m_e = 9.1 \times 10^{-31}$ kg (Electron mass)

$m_p = 1.67 \times 10^{-27}$ kg (Proton mass)

Prefixes of units

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

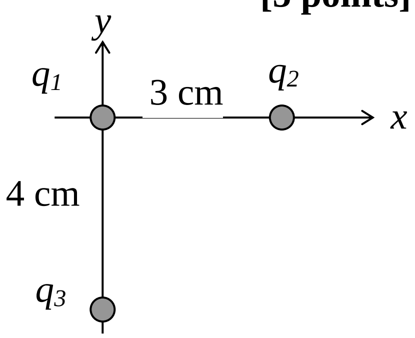
Important Instructions to the students:

1. Answer all the questions.
2. The solution should be given explicitly for each problem.
3. Mobiles or other electronic devices are **strictly prohibited** during the exam.
4. Programmable calculators, which can store equations, are not allowed.
5. Cheating incidents will be processed according to the university rules.

For use by the instructor only

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

1. Three charges q_1 = 10 µC, q_2 = 20 µC and q_3 = −30 µC are located in the *x*-*y* plane as shown in the figure. What is the magnitude of the resultant force on the charge q_2? **[5 points]**



$$F_{21} = k\frac{|q_2||q_1|}{r_{21}^2} = \frac{9\times10^9\times20\times10^{-6}\times10\times10^{-6}}{(0.03)^2}$$
$$= 2000\ \mathrm{N/C}$$

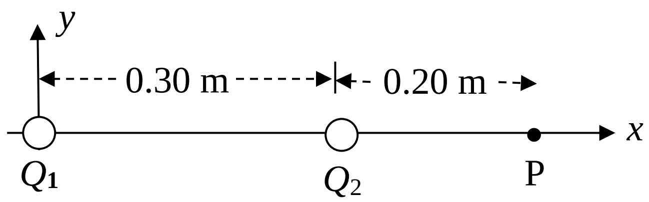
$$F_{23} = k\frac{|q_2||q_3|}{r_{23}^2} = \frac{9\times10^9\times20\times10^{-6}\times30\times10^{-6}}{(0.03^2+0.04^3)}$$
$$= 2160\ \mathrm{N/C}$$

$$F_x = F_{21} - F_{23}\,\mathbf{cos}\,\theta = 2000 - 2160\times\frac{0.03}{0.05} = 704\ \mathrm{N/C}$$

$$F_y = -F_{23}\sin\theta = -2160\times\frac{0.04}{0.05} = -1728\ \mathrm{N/C}$$

$$F_{net} = \sqrt{F_x^2+F_y^2} = 1866\ \mathrm{N}$$

2. Two charges Q_1 = 50 nC and Q_2 are located as shown in the figure. What should be the magnitude and sign of charge Q_2 so that the net electric field at the point P is E = 675 N/C directed along +*x*-axis? **[3 points]**



$$E_1 = k\frac{|Q_1|}{(0.30+0.20)^2} = 1800\ \mathrm{N\ along\ +x\ axis}$$

$$E_2 = k\frac{|Q_2|}{(0.20)^2}$$

$$E = E_1 + E_2$$

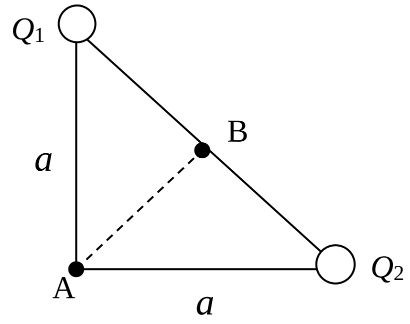
$$675 = 1800 + E_2$$

$$E_2 = 675 - 1800 = -1125\ \mathrm{N/C}\ \text{(must be along -x-axis)}$$

$$k\frac{|Q_2|}{(0.20)^2} = -1125 \rightarrow$$

$$Q_2 = -5\times10^{-9}\ \mathrm{C} = 5.0\ \mathrm{nC}$$

3. Two charges $Q_1 = 20$ μC and $Q_2 = -15$ μC are located at the corners of a right-angled triangle, with $a = 0.30$ m, as shown in the figure.
(a) What is the potential difference $V_B - V_A$? **[4 points]**
(b) How much work must be done to move charge $Q = 5$ μC from A to B? **[1 point]**



(a) $r_{1B} = r_{2B} = \frac{a\sqrt{2}}{2} = 0.21$ m

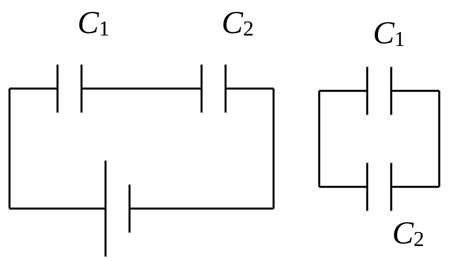
$V_A = V_{Q_1} + V_{Q_2} = k\frac{Q_1}{0.30} + k\frac{Q_2}{0.30} = 1.5 \times 10^5$ V

$V_B = V_{Q_1} + V_{Q_2} = k\frac{Q_1}{0.21} + k\frac{Q_2}{0.21} = 2.1 \times 10^5$ V

$V_B - V_A = 0.6 \times 10^5$ V

(b) $W_{ext} = Q\Delta V = Q(V_B - V_A) = 0.30$ J

4. Two capacitors $C_1 = 8$ μF and $C_2 = 12$ μF are connected in series across a 10 V battery, as shown. The battery is disconnected, and the capacitors are then connected in parallel with positive plates connected to each other and negative plates connected together. What is the charge across C_1 now? **[4 points]**



$$C_s = \frac{C_1C_2}{C_1 + C_2} = \frac{8\ \mu\text{F}.\ 12\ \mu\text{F}}{8\ \mu\text{F} + 12\ \mu\text{F}} = 4.8\ \mu\text{F}$$

Initial charge Q on C_1 and C_2:
$Q = C_{eq}V = 4.8\ \mu\text{F} \times 10\ \text{V} = 48\ \mu\text{C}$
When connected in parallel:
Voltage across C_1 and C_2:

$$V = \frac{Q_{total}}{C_{eq}} = \frac{48\ \mu\text{C} + 48\ \mu\text{C}}{(8\ \mu\text{F} + 12\ \mu\text{F})} = 4.8\ \text{V}$$

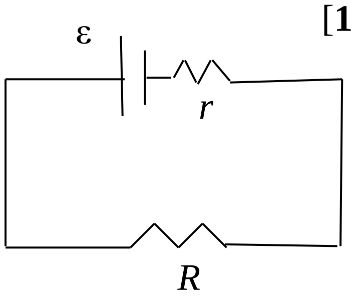
$q_1 = C_1V = 8\ \mu\text{F} \times 4.8\ \text{V} = 38.4\ \mu\text{C}$

5. A resistor R = 7.8 Ω is connected to a battery with an internal resistance r and the emf ε = 6 V. The energy dissipated in the resistor R in 5 minutes is 0.96 kJ.

(a) What is the rate of power dissipated in the resistor R? **[1 point]**

(b) What is the current in the circuit? **[1 point]**

(c) What is the internal resistance r? **[1 point]**



(a) $P = \frac{E}{t} = \frac{0.96\times10^{3}\text{J}}{5\times60\text{ s}} = 3.2\text{ W}$

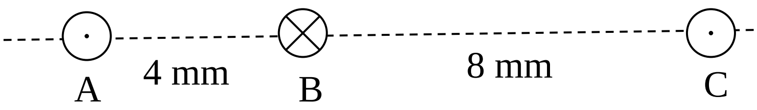
(b) $P = I^2R \rightarrow I = \sqrt{\frac{P}{R}} = 0.64\text{ A}$

(c) $I = \frac{\varepsilon}{R+r}$

$R + r = \frac{\varepsilon}{I} = 9.38\ \Omega$

$r = 9.38 - R = 1.58\ \Omega$

6. Three parallel wires are placed perpendicular to the page, each carrying a current of I = 12 A, as shown. The current in wires A and C is out of the page and in wire B it is into the page. What is the magnitude and direction of the resultant force on 2 m length of the wire C? **[3 points]**



$F_{CA} = \frac{\mu_0 I_C I_A L}{2\pi d} = 4.8\times10^{-3}\text{N}$ along -x axis

$F_{CB} = \frac{\mu_0 I_C I_A L}{2\pi d} = 7.2\times10^{-3}\text{N}$ along +x axis

$F_{net} = F_{CB} - F_{CA} = 2.4\times10^{-3}\text{N}$ along +x axis

7. Two long parallel conductors carry currents $I_1 = 8.0$ A and $I_2 = 20.0$ A in the directions shown. What is the x-component of the net magnetic field at point P? **[4 points]**

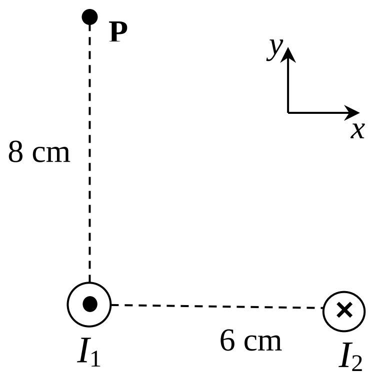
$B_1 = \frac{\mu_0 I_1}{2\pi r_1} = \frac{4\pi\times10^{-7}\times8.0}{2\pi\times0.08} = 2.0\times10^{-5}$ T along -x axis

$B_2 = \frac{\mu_0 I_2}{2\pi r_2} = \frac{4\pi\times10^{-7}\times20.0}{2\pi\times\sqrt{0.08^2+0.06^2}} = 4.0\times10^{-5}$ T

at angle θ above x-axis

$B_x = -B_1 + B_2\cos\theta = -2.0\times10^{-5}\text{ T} + 4.0\times10^{-5}\text{ T}\times\frac{0.08}{0.10}$

$= 1.2\times10^{-5}$ T



8. An object of height 5.0 cm is placed 10.0 cm from a lens with a power of +5.00 D.

(a) What is the focal length of the lens? **[1 point]**

(b) What will be the location of the image? **[1 points]**

(c) Will the image be inverted or upright? **[1 point]**

(d) What will be the height of the image? **[1 point]**

(e) Is the image real or imaginary? **[1 point]**

(a) $f = \frac{1}{P} = \frac{1}{5.00\ m^{-1}} = 0.20$ m $=$ 20 cm

(b) $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_0} = \frac{1}{20\ cm} - \frac{1}{10\ cm} = -0.05\ cm^{-1}$

$d_1 = -20.0$ cm on the same side as object

(c) $m = -\frac{d_i}{d_0} = -\frac{-20.0\ cm}{10.0\ cm} = 2.0$ the image is upright and magnified.

(d) $h_i = mh_o = 2.0\times5.0$ cm $=$ 10.0 cm

(e) The image is imaginary.

9. The binding energy of the last neutron in a nucleus of ^{15}N is 10.83 MeV.
Given $M(^{14}N)$ = 14.003074 u, $M(n)$ = 1.008665 u, and $M(^{1}H)$ = 1.007825 u.
(a) What is the mass of ^{15}N? **[2 points]**
(b) What is the binding energy per nucleon of ^{15}N? **[2 points]**

(a) Binding energy of the last neutron in ^{15}N:

$^{15}N = {}^{14}N + n$
$BE_n = (M(^{14}N) + M(n) - M(^{15}N))c^2$
10.83 MeV = (14.003074 u + 1.008665 u − $M(^{15}N)$)× 931.5 MeV
$M(^{15}N)$ = 15.000113 u

(b) $^{15}N = 7(^{1}H) + 8n$

BE (^{15}N) = (7× $M(^{1}H)$ +8× $M(n)$ − $M(^{15}N)$)c²
= (7×1.007825 u +8×1.008665 u − 15.000113 u) ×931.5 MeV
= 115.49 MeV

$$\frac{BE}{A} = \frac{115.49\ \text{MeV}}{15} = 7.699\ \text{MeV/nucleon}$$

10. For the isotope ^{18}F (half-life = 110 min.) given to a patient in the Positron Emission Tomography (PET), the decay rate becomes 180 per second after 30 hours.
(a) What was the decay rate initially? **[2 points]**
(b) How many ^{18}F nuclei were present in the beginning? **[1 point]**
(c) How much amount of ^{18}F (in gram) was present initially? **[1 point]**

(a) $\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{110\times 60\ \text{s}} = 1.05 \times 10^{-4}\ \text{s}^{-1}$

$R = R_0 e^{-\lambda t}$

$R_0 = Re^{\lambda t} = 180\ \text{s}^{-1} \times e^{1.05\times 10^{-4}\ \text{s}^{-1} \times (30\times 60\times 60\ \text{s})}$

$= 1.51\times 10^{7}\ \text{s}^{-1}$

(b) $R_0 = \lambda N_0$

$$N_0 = \frac{R_0}{\lambda} = \frac{1.51 \times 10^{7}\ \text{s}^{-1}}{1.05 \times 10^{-4}\ \text{s}^{-1}} = 1.44 \times 10^{11}\ \text{nuclei}$$

(c) $N = \frac{N_A}{Mol\ (\text{gram})} \times m(\text{gram})$

$m(\text{gram}) = \frac{N \times Mol\ (gram)}{N_A}$

$= \frac{1.44\times 10^{11}\times 15}{6.02\times 10^{23}} = 3.59 \times 10^{-12}$ gram