Kuwait University Department of Physics

General Physics II for Biological Sciences (Phy 122)

Second Midterm Examination (Fall Semester 2024-2025)

November 23, 2024

Time: 2:00 PM to **3:30 PM**

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Solution

Fundamental Constants

$k = \dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$	Coulomb's constant
$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$	Permitivity of free space
$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$	Permeability of free space
$e = 1.6 \times 10^{-19}\ \mathrm{C}$	Elementary charge
$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$	Mass of an electron
$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$	Mass of a proton
$\mathrm{eV} = 1.6 \times 10^{-19}\ \mathrm{J}$	Conversion from eV to J
$N_A = 6.022 \times 10^{23}/\mathrm{mol}$	Avogadro's number

Prefixes of units

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

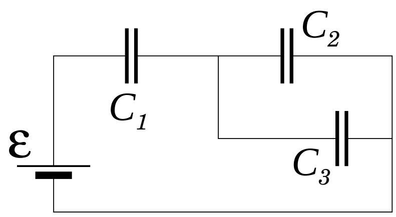
Instructions to the Students:

- All communication devices must be switched off and placed in your bag. Anyone found using a communication device will be disqualified.
- Programmable calculators, which can store equations, are not allowed.

1. Three capacitors are connected to a source of emf $\mathcal{E}$ as shown in the circuit. The capacitance $C_1 = C_2 = 9$ nF, but C_3 is unknown. The plate-charges on C_1 and C_3 are $Q_1 = 81$ nC and $Q_3 = 27$ nC respectively.

   (a) Find C_3. **3 points**

   (b) Find $\mathcal{E}$. **2 points**



Solution: We have

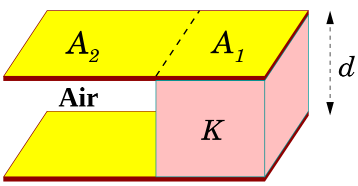
$$V_1 = \frac{Q_1}{C_1} = 9 \text{ V}$$

Then

$$\left.\begin{array}{l} C_2 \text{ and } C_3 \text{ are parallel} \\ C_1 \text{ and } C_{23} \text{ are in series} \end{array}\right\} \implies \left\{\begin{array}{l} Q_1 = Q_{23} \implies Q_1 = Q_2 + Q_3 \\ \\ Q_2 = Q_1 - Q_3 = 54 \text{ nC} \end{array}\right.$$

$$\implies V_2 = \frac{Q_2}{C_2} = 6 \text{ V}$$
$$\implies V_3 = V_2 = 6 \text{ V}$$
$$\implies C_3 = \frac{Q_3}{V_3} = 4.5 \text{ nF}$$
$$\implies \mathcal{E} = V_1 + V_{23} = V_1 + V_2 = 15 \text{ V}$$

2. A parallel-plate capacitor with thickness $d = 2.7$ mm is partially filled with a dielectric of dielectric constant K. The area of the plate above the dielectric is $A_1 = 3.0 \times 10^{-4}$ m^2 and the area above the empty space (air) between the plates is $A_2 = 4.0 \times 10^{-4}$ m^2. If the capacitance of this capacitor is $C = 4.26$ pF, find K. **4 points**



Solution: This capacitor can be considered as two capacitors C_1 (with the dielectric) and C_2 (with air) in **parallel**. Now

$$C_2 = \varepsilon_0 \frac{A_2}{d} = 1.31 \times 10^{-12} \text{ F}$$

$$C = C_1 + C_2 \implies C_1 = C - C_2 = 2.95 \times 10^{-12} \text{ F}$$

$$C_1 = K\varepsilon_0 \frac{A_1}{d} \implies 2.95 \times 10^{-12} = K\varepsilon_0 \frac{A_1}{d}$$

$$\implies K = 3$$

3. A heating coil is required to dissipate 1200 W of power when connected to a 240 V source. If the resistivity of the material of the coil is $\rho = 6.4 \times 10^{-6}$ Ω·m and the radius of the wire is 1.5 mm, find the length of the wire needed to make the coil. **4 points**

Solution: We have

$$P = \frac{V^2}{R} \implies R = \frac{V^2}{P} = 48\ \Omega$$

Then

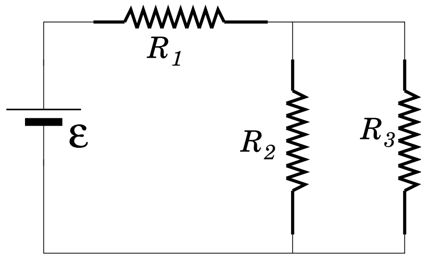
$$R = \rho\,\frac{L}{A} \implies L = \frac{RA}{\rho} = \frac{R\pi r^2}{\rho}$$

$$\implies L = 53\ \text{m}$$

4. In the circuit, $R_1 = 20\ \Omega$, $R_2 = 24\ \Omega$ and $R_3 = 40\ \Omega$. The current in is R_1 is $I_1 = 2.4$ A.

(a) Find the current I_2 in R_2. **3 points**

(b) Find $\mathcal{E}$. **2 points**



Solution: We have

$$V_1 = I_1 R_1 = 48\ \text{V}$$

Then

$$\left.\begin{array}{l} R_2 \text{ and } R_3 \text{ are parallel} \\ R_1 \text{ and } R_{23} \text{ are in series} \end{array}\right\} \implies \left\{ \begin{array}{l} R_{23} = \dfrac{R_2 R_3}{R_2 + R_3} = 15\ \Omega \\ \\ I_{23} = I_1 = 2.4\ \text{A} \end{array}\right.$$

$$\implies V_2 = V_{23} = I_{23} R_{23} = 36\ \text{V}$$

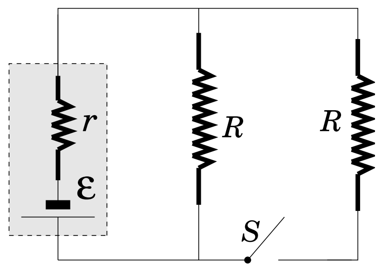
$$\implies I_2 = \frac{V_2}{R_2} = 1.5\ \text{A}$$

$$\implies \mathcal{E} = V_1 + V_{23} = 84\ \text{V}$$

5. In the circuit shown, $R = 12.0\ \Omega$, and the emf of the real battery $\mathcal{E} = 20.0$ V. When the **switch** S **is open** the terminal voltage of the battery is 19.2 V.

   (a) Find the internal resistance of the battery (r). **2 points**

   (b) Find the terminal voltage of the battery when the **switch** S **is closed**. **2 points**



Solution: We see that,

When the switch S is open

$$V_T = \varepsilon - Ir$$

$$\Longrightarrow\ Ir = \varepsilon - V_T = 0.8 \text{ V}$$

The equivalent resistance is

$$R_{eq} = R + r \implies I(R + r) = \varepsilon$$

$$IR + Ir = 20 \implies IR = 19.2 \text{ V}$$

$$\implies I = 1.6 \text{ A}$$

$$\implies r = \frac{0.8}{I} = 0.5\ \Omega$$

When the switch S is closed

The two resistors with $R = 12\ \Omega$ are parallel. So the equivalent resistance is

$$R_{eq} = \frac{12 \times 12}{12 + 12} + r = 6.5\ \Omega$$

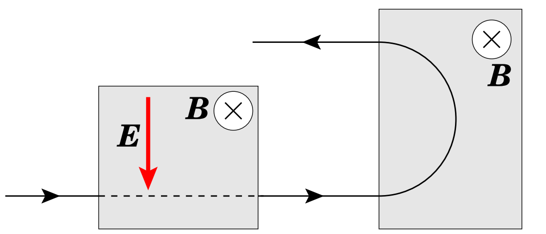
The current in the circuit is

$$I_1' = \frac{\varepsilon}{R_{eq}} = 3.08 \text{ A}$$

The terminal voltage is

$$V_T' = \varepsilon - I'r = 18.46 \text{ V}$$

6. A proton passes straight through a velocity selector and then enters the mass spectrometer where it moves in circular path of radius $R = 3.0$ mm. The magnetic fields in the mass spectrometer and the velocity selector are both into-the-plane and have equal magnitude B (see the figure). The magnitude of the electric field is $E = 3.5 \times 10^3$ N/C. Find the **speed** of the proton. **4 points**

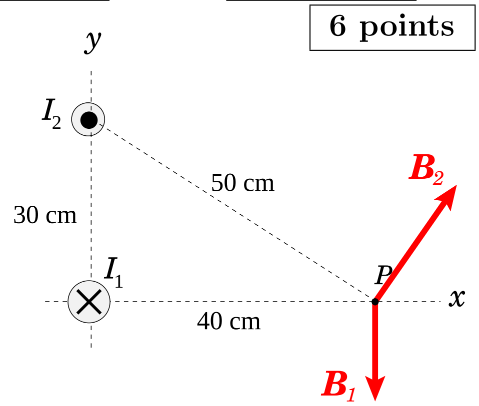


Solution: We have

$$E = vB \quad \text{and} \quad R = \frac{mv}{B|q|} \implies R = \frac{mv^2}{E|q|} \implies v^2 = \frac{E|q|R}{m}$$

$$\implies v = \sqrt{\frac{E|q|R}{m}} = 3.17 \times 10^4 \text{ m/s}$$

7. Two long straight wires carrying currents perpendicular to the $xy-$plane are shown. If $I_1 = 6$ A and $I_2 = 5$ A, find B_x and B_y (the $x-$component and the $y-$component of the **net magnetic field**) at the point P. **6 points**



Solution: We use the Right-Hand rule to draw the directions for $\vec{B}_1$ and $\vec{B}_2$. Then

$$B_1 = \frac{\mu_0 I_1}{2\pi(0.4)} = 3.0 \times 10^{-6}\ \text{T} \implies \begin{cases} B_{1,x} = 0.0\ \text{T} \\ B_{1,y} = -B_1 = -3.0 \times 10^{-6}\ \text{T} \end{cases}$$

$$B_2 = \frac{\mu_0 I_2}{2\pi(0.5)} = 2.00 \times 10^{-6}\ \text{T} \implies \begin{cases} B_{2,x} = +B_2 \times \dfrac{0.3}{0.5} = +1.2 \times 10^{-7}\ \text{T} \\ B_{2,y} = +B_2 \times \dfrac{0.4}{0.5} = +1.6 \times 10^{-6}\ \text{T} \end{cases}$$

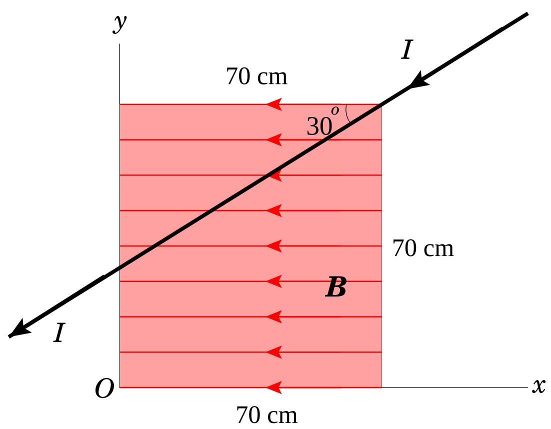
Then

$$B_x = B_{1,x} + B_{2,x} = +1.2 \times 10^{-6}\ \text{T} \qquad B_y = B_{1,y} + B_{2,y} = -1.4 \times 10^{-6}\ \text{T}$$

8. A uniform magnetic field of magnitude $B = 0.8$ T in the $-x$-direction is established in the square shaded area (see figure below). A wire carrying a current $I = 7$ A passes through this region as shown.

   (a) Find the magnitude of the magnetic force on the wire. **3 points**

   (b) Find the direction of the magnetic force on the wire. **1 point**



The part of the wire lying inside the region of magnetic field has length L such that

$$\frac{0.7}{L} = \cos 30^o \implies L = 0.81\ \text{m}$$

Then, the magnitude of the force is

$$F_B = ILB\ \sin 30^o = 2.26\ \text{N},$$

By the right-hand rule, the direction of the force is **into-the-plane**