Kuwait University **Department of Physics**

General Physics II for Biological Sciences (Phy 122)

Fall Semester 2024-2025

Final Examination

December 30, 2024
Time: 8:00 AM to 10:00 AM

Instructor: Dr. S.S.A. Razee

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 unit of charge
$m_e = 9.11 \times 10^{-31}\ \mathrm{kg} = 0.000549\ \mathrm{u}$	Mass of an electron
$m_p = 1.67 \times 10^{-27}\ \mathrm{kg} = 1.007276\ \mathrm{u}$	Mass of a proton
$m_n = 1.67 \times 10^{-27}\ \mathrm{kg} = 1.008665\ \mathrm{u}$	Mass of a neutron
$1\ \mathrm{u} = 1.6605 \times 10^{-27}\ \mathrm{kg} = 931.5\ \mathrm{MeV/c^2}$	Atomic mass unit
$1\ \mathrm{eV} = 1.6 \times 10^{-19}\ \mathrm{J}$	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.

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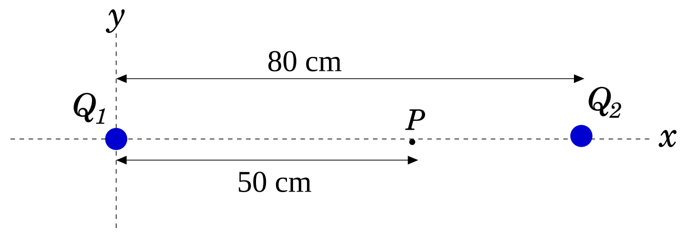
1. In the figure, Q_1 and Q_2 are point charges. It is given that the net electric potential at the point P is $V_P = 0$. If $Q_1 = -3.0$ nC, find the **magnitude** and the **direction** of the **net electric field $\vec{E}$** at the point P. **4 points**



Solution: The net electric potential at P is zero. So

$$\frac{kQ_1}{0.5} + \frac{kQ_2}{0.3} = 0 \implies Q_2 = -Q_1 \times \frac{0.3}{0.5} = +1.8 \times 10^{-9} \text{ C}$$

At P, both the electric fields, $\vec{E}_1$ and $\vec{E}_2$ are **to the left** (in $-x$ **direction**). Now,

$$E_1 = \frac{k|Q_1}{0.5^2} = 108 \text{ N/C} \qquad E_2 = \frac{k|Q_2}{0.3^2} = 180 \text{ N/C}$$

So the magnitude of the net electric field is

$$E = E_1 + E_2 = 288 \text{ N/C}$$

and the direction is **to the left** (in the $-x$ direction).

2. Two point charges, Q_1 and Q_2, of identical mass $m = 2.0 \times 10^{-12}$ kg were **released from rest** when they were 1.5 m from each other. They were found to travel with speed $v = 200$ m/s when the distance between them was 70 cm. The charge $Q_1 = +3.0$ nC.

   (a) Find Q_2. **3 points**

   (b) Find the magnitude of their acceleration when they were 70 cm apart. **2 points**

Solution: Then the work energy principle implies,

$$0 + \frac{kQ_1Q_2}{1.5} = 2 \times \frac{1}{2}mv^2 + \frac{kQ_1Q_2}{0.6}$$

$$\implies Q_2\left[\frac{kQ_1}{1.5} - \frac{kQ_1}{0.6}\right] = mv^2 \implies Q_2 \times (-20.57) = 8.0 \times 10^{-8}$$

$$\implies \boxed{Q_2 = -3.89 \times 10^{-9} \text{ C}}$$

The magnitude of the force between them when they are 60 cm apart is

$$F = \frac{k|Q_1Q_2|}{0.6^2} = 2.92 \times 10^{-7} \text{ N}$$

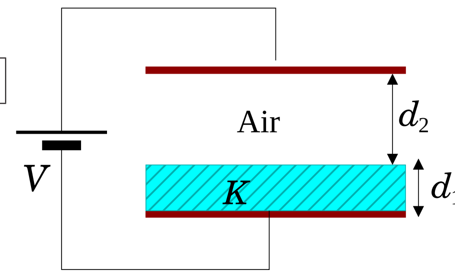
The magnitude of the acceleration is

$$a = \frac{F}{m} = 1.46 \times 10^5 \text{ m/s}^2$$

3. A parallel-plate capacitor of plate-area $A = 17\ \text{cm}^2$ has a slab of same area but thickness $d_1 = 2$ mm and dielectric constant $K = 1.2$ as shown in the figure. The thickness of air inside the capacitor is $d_2 = 5$ mm.

   (a) Find the capacitance of this capacitor. **3 points**

   (b) This capacitor is connected to a battery of voltage $V = 6$ V, find the total electrostatic energy PE stored in the capacitor. **2 points**



Solution: The capacitor can be considered as two capacitors C_1 and C_2 in series, with

$$C_1 = K\varepsilon_0 \frac{A}{d_1} = 1.2 \times (8.85 \times 10^{-12}) \times \frac{17 \times 10^{-4}}{2.0 \times 10^{-3}} = 9.0 \times 10^{-12}\ \text{F}$$

$$C_2 = \varepsilon_0 \frac{A}{d_2} = (8.85 \times 10^{-12}) \times \frac{17 \times 10^{-4}}{5.0 \times 10^{-3}} = 3.0 \times 10^{-12}\ \text{F}$$

The capacitance is

$$C = \frac{C_1 C_2}{C_1 + C_2} = 2.25 \times 10^{-12}\ \text{F}$$

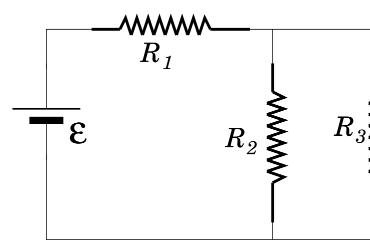
The energy in the capacitor is

$$\text{PE} = \frac{1}{2} C V^2 = 4.05 \times 10^{-11}\ \text{J}$$

4. In the circuit shown, $\varepsilon = 45$ V and $R_1 = 2\ \Omega$. The current in R_1 is $I_1 = 5$ A and the power dissipated by R_2 is $P_2 = 75$ W.

   (a) Find R_2. **3 points**

   (b) Find R_3. **3 points**



Solution: We can calculate

$$V_1 = I_1 R_1 = 10\ \text{V}$$

R_2 and R_3 are parallel and then R_{23} is in series with R_1 } $\Longrightarrow$ $V_1 + V_{23} = \varepsilon \Longrightarrow V_{23} = 35$ V

$$V_2 = V_3 = 35\ \text{V}$$

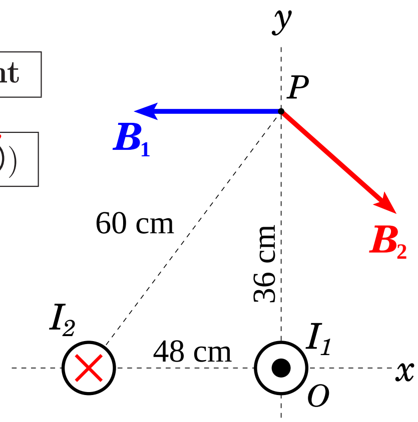
$$I_2 + I_3 = I_1 = 5\ \text{A}$$

$$\text{PE}_2 = \frac{V_2^2}{R_2} \Longrightarrow R_2 = \frac{V_2^2}{\text{PE}_2} = 16.3\ \Omega$$

$$I_3 = I_1 - I_2 = I_1 - \frac{V_2}{R_2} = 2.86\ \text{A}$$

$$R_3 = \frac{V_3}{I_3} = 12.25\ \Omega$$

5. Two long straight wires perpendicular to the $xy-$plane are shown. The wire carrying $I_1 = 9$ A passes through the origin and the wire with unknown current I_2 passes through the $x-$axis at -48 cm. The point P is on the $y-$axis at 36 cm. It is observed that the $x-$component of the net magnetic field $\boldsymbol{B_x = 0}$ at the point P.



(a) The current I_2 is (Tick the correct answer) **1 point**

out-of-the-plane (⊙) **into-the-plane** (⊗) ✓

We determined the direction of $\vec{\boldsymbol{B}}_1$ by the right-hand rule, and then determined the direction of $\vec{\boldsymbol{B}}_2$ such that the $x-$components cancel out. Then used the right-hand rule to find the direction of the current I_2.

(b) Find the value of the current I_2. **3 points**

$B_{1,x}$ and $B_{2,x}$ cancel out each other. So their magnitudes must be equal. Then

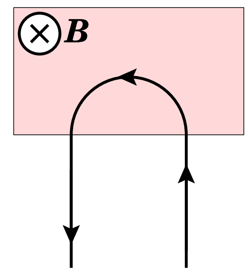
$$\frac{\mu_0 I_1}{2\pi(0.36)} = \frac{\mu_0 I_2}{2\pi(0.60)} \times \frac{0.36}{0.60}$$

$$\Longrightarrow\ I_2 = I_1 \times \frac{0.60^2}{0.36^2} \ \Longrightarrow\ I_2 = 25\ \text{A}$$

(c) Find the $y-$component (B_y) of the net magnetic field at P (your answer should reflect the direction of the net magnetic field). **2 points**

$$B_y = -B_2 \times \frac{0.48}{0.60} = -\frac{\mu_0 I_2}{2\pi(0.6)} \times \frac{0.48}{0.60} = -6.7 \times 10^{-6}\ \text{T}$$

6. A charge particle of mass $m = 1.17 \times 10^{-26}$ kg enters a region of uniform magnetic field of magnitude $B = 5.0 \times 10^{-3}$ T with its velocity perpendicular to the magnetic field, and exits the region after completing a semicircular path of radius $R = 4.0 \times 10^{-3}$ m as shown below. The magnitude of the charge on the particle is $|q| = 4.8 \times 10^{-19}$ C.



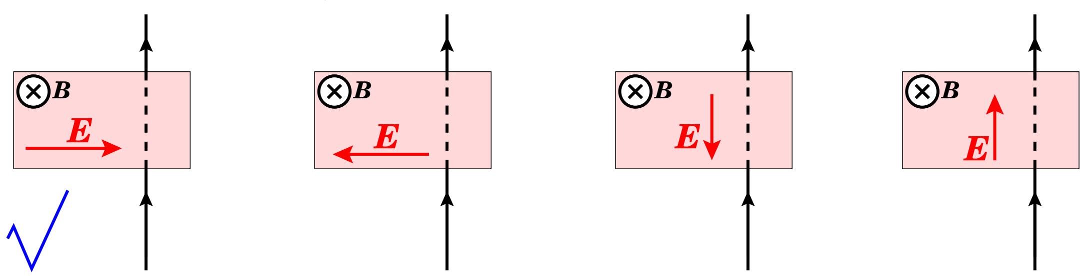
(a) What is the **sign** of the charge? **1 point**
(Tick the correct answer)

Positive ✓ **Negative**

(b) Find the **speed** of the charge particle. **2 points**

$$R = \frac{mv}{B|q|} \implies v = \frac{B|q|R}{m} = 820 \text{ m/s}$$

(c) If this particle is to **pass straight through the region**, an **electric field must also be applied**. In which direction it should be applied? **1 point**
(Tick the correct answer)



(d) What must be the **magnitude of the electric field**? **1 point**

$$E = vB = 4.1 \text{ N/C}$$

7. A 2.0 cm high object is placed 30 cm from a concave mirror of focal length 40 cm.

   (a) What is the image distance d_i? **3 points**

   Solution: We have

$$h_o = 2 \text{ cm}, \quad d_o = 30 \text{ cm}, \quad f = +40 \text{ cm}$$

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = -0.0083 \implies \boxed{d_i = -120 \text{ cm}}$$

   (b) Is the image real or virtual? (Tick the correct answer) **1 point**

   Real Image **Virtual Image** ✓

   (c) What is the height of the image? **1 point**

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o} = +4 \implies h_i = +4h_o = +8 \text{ cm}$$

8. A 4 cm high object is placed 20 cm from a lense. The image is **upright and 6 cm high**.

   (a) Find the focal length of the lense. **3 points**

   Solution: We have

$$h_o = 4 \text{ cm}, \quad h_i = +6 \text{ cm}, \quad d_o = 20 \text{ cm}$$

$$\frac{-d_i}{d_o} = \frac{h_i}{h_o} = +1.5 \implies d_i = -1.5 \times d_o = -30 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_o} = +0.0167 \implies \boxed{f = +60 \text{ cm}}$$

   (b) If we want to see an **inverted image of hight 6 cm**, at what distance from the lense the object should be placed? **2 points**

$$h_i = -6 \text{ cm}$$

$$\frac{-d_i}{d_o} = \frac{h_i}{h_o} = -1.5 \implies d_i = +1.5 \times d_o$$

$$\frac{1}{d_o} + \frac{1}{1.5 \times d_o} = \frac{1}{f} \implies \frac{1}{d_o} \times 1.6667 = \frac{1}{f} \implies \boxed{d_o = 100 \text{ cm}}$$

9. Consider the isotope $^{23}_{11}\text{Na}$. Find the binding energy of the **last neutron** in this isotope. Express your answer in MeV. **3 points**

The nuclear mass of some isotopes are given here:

$^{23}_{11}\text{Na}$: 22.983731 u	$^{22}_{11}\text{Na}$: 21.988398 u	$^{22}_{10}\text{Ne}$: 21.986742 u

The nuclear reaction equation is

$$^{23}_{11}\text{Na} \rightarrow {}^{22}_{11}\text{Na} + \text{n}$$

So the binding energy of the last neutron is

$$\text{BE} = \Big[21.988398 + 1.008665 - 22.983731\Big] \times 931.5 \text{ MeV} = 12.4 \text{ MeV}$$

10. The $^{68}_{32}\text{Ge}$ isotope is radioactive with a half-life of $T_{\frac{1}{2}} = 270$ days. A 5 μg sample of the isotope is kept in a container.

   (a) What is the **decay constant**? **1 point**

   The decay constant is

$$\lambda = \frac{0.693}{T_{\frac{1}{2}}} = \frac{0.693}{270 \times 24 \times 3600} = 2.97 \times 10^{-8} \text{ s}^{-1}$$

   (b) How many atoms of the sample are present initially? **1 point**

$$N_0 = \frac{N_A}{68} \times (5 \times 10^{-6}) = 4.43 \times 10^{16}$$

   (c) How many atoms of $^{68}_{32}\text{Ge}$ will remain in the sample after 3 years? **2 points**

$$t = 365 \times 3 \times 24 \times 3600 = 9.46 \times 10^{7} \text{ s}$$

$$N = N_0\, e^{-\lambda t} = 2.67 \times 10^{15}$$

   (d) What will be the **activity** of the sample after 3 years? **1 point**

$$R = \lambda N = 7.92 \times 10^{7} \text{ s}^{-1}$$