Kuwait University **Department of Physics**

General Physics II for Biological Sciences (Phy 122)

Summer Semester 2024-2025

Final Examination

August 2, 2025

Time: 12:00 PM to 2:00 PM

Instructor: Dr. S.S.A. Razee

Solution

Fundamental Constants

$k = \dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$	Coulomb's constant
$\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/(\text{N}\cdot\text{m}^2)$	Permitivity of free space
$\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$	Permeability of free space
$e = 1.6 \times 10^{-19}$ C	Elementary unit of charge
$m_e = 9.11 \times 10^{-31}$ kg $= 0.000549$ u	Mass of an electron
$m_p = 1.67 \times 10^{-27}$ kg $= 1.007276$ u	Mass of a proton
$m_n = 1.67 \times 10^{-27}$ kg $= 1.008665$ u	Mass of a neutron
1 u $= 1.6605 \times 10^{-27}$ kg $= 931.5 \text{ MeV/c}^2$	Atomic mass unit
1 eV $= 1.6 \times 10^{-19}$ J	Conversion from eV to J
$N_A = 6.022 \times 10^{23}$ /mol	Avogadro's number

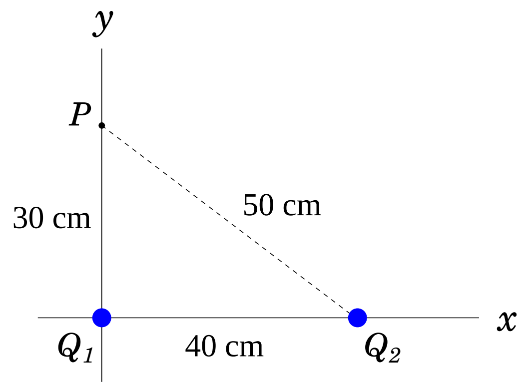
Prefixes of units

m $= 10^{-3}$ $\mu = 10^{-6}$ n $= 10^{-9}$ p $= 10^{-12}$ k $= 10^3$ 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. In the figure, Q_1 and Q_2 are point charges. It is given that the net electric potential at the point P is $V_P = 0$ and $Q_1 = +6.0$ nC.



(a) Find Q_2. **1 point**

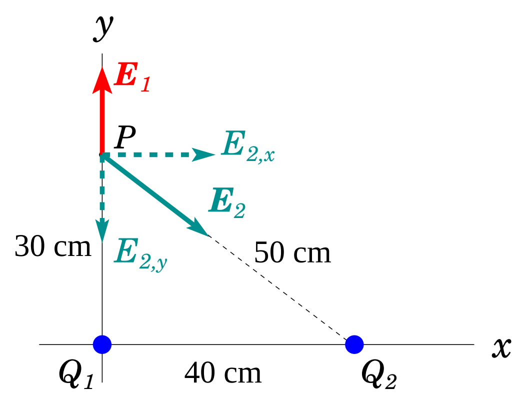
We have

$$\frac{kQ_1}{0.3} + \frac{kQ_2}{0.5} = 0$$

$$\implies Q_2 = -Q_1 \times \frac{0.5}{0.3} = -1.0 \times 10^{-8} \text{ C}$$

(b) Find E_x, the $x-$component of the **net electric field** $\vec{\boldsymbol{E}}$ at P. **2 points**

(c) Find E_y, the $y-$component of the **net electric field** $\vec{\boldsymbol{E}}$ at P. **2 points**



We draw the vectors $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ from the knowledge of Q_1 and Q_2.

Then,

$$E_1 = \frac{k|Q_1|}{0.3^2} = 600 \text{ N/C} \implies \begin{cases} E_{1,x} = 0 \\ E_{1,y} = +600 \text{ N/C} \end{cases}$$

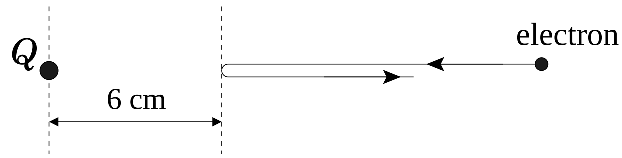
$$E_2 = \frac{k|Q_2|}{0.5^2} = 360 \text{ N/C} \implies \begin{cases} E_{2,x} = +E_2 \times \frac{0.4}{0.5} = +288 \text{ N/C} \\ E_{2,y} = -E_2 \times \frac{0.3}{0.5} = -216 \text{ N/C} \end{cases}$$

So

$$E_x = 288 \text{ N/C} \qquad E_y = 384 \text{ N/C}$$

2. An electron is moving **directly towards** a **fixed** point charge Q. When the electron is 40 cm from the charge its speed is $v = 2.0 \times 10^7$ m/s. The **distance of closest approach** between the charge Q and the electron is 6 cm.

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



At the **distance of closest approach**, the **speed is zero**. So the work-energy principle implies

$$\frac{1}{2}mv^2 + \frac{kQ(-e)}{0.4} = 0 + \frac{kQ(-e)}{0.06}$$

$$\Longrightarrow \frac{1}{2}mv^2 = Q\left[\frac{ke}{0.4} - \frac{ke}{0.06}\right] \Longrightarrow 1.822 \times 10^{-16} = Q \times (-2.04 \times 10^{-8})$$

$$\Longrightarrow \boxed{Q = -8.93 \times 10^{-9} \text{ C}}$$

(b) Find the magnitude of the **maximum acceleration** of this electron. **1 point**

Maximum acceleration happens at the **minimum distance** between the charges, which in this case is 6 cm. So

$$a_{max} = \frac{F_{max}}{m} = \frac{1}{m} \times \frac{k|Qe|}{0.06^2} = 3.92 \times 10^{15} \text{ m/s}^2$$

(c) Find the **maximum speed** attained by this electron. **1 point**

In this case, the **PE is positive** because two charges have the same sign. **Maximum speed** happens when the **KE is maximum**, and so when the **PE is minimum**. In this case, $\text{PE}_{min} = 0$ (Although you do not need to use in this problem, but you should know that this happens when the distance between the charges is ∞). So using the work-energy principle,

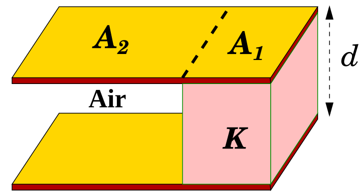
$$0 + \frac{kQ(-e)}{0.06} = \frac{1}{2}mv_{max}^2 + 0$$

$$\Longrightarrow v_{max} = 2.17 \times 10^7 \text{ m/s}$$

3. A parallel-plate capacitor of thickness $d = 3$ mm is partially filled by an unknown dielectric as shown. When this capacitor is connected to a battery of voltage $V = 9$ V, the plate-charge in the capacitor is $Q = 2.87 \times 10^{-12}$ C.

   (a) Find the capacitance of this capacitor. **1 points**

   (b) The crossection area of the dielectric is $A_1 = 0.2$ cm^2 and that of the empty space (air) in the capacitor is $A_2 = 0.5$ cm^2. Find the dielectric constant K of the dielectric. **3 points**



Solution: The plate-charge of the capacitor is

$$Q = CV \implies C = \frac{Q}{V} = 3.19 \times 10^{-13} \text{ F}$$

The capacitor can be considered as two capacitors C_1 and C_2 in parallel, with

$$C_1 = K\varepsilon_0 \frac{A_1}{d} = K \times \left(5.9 \times 10^{-14}\right) \qquad C_2 = \varepsilon_0 \frac{A_2}{d} = 1.48 \times 10^{-13} \text{ F}$$

Then

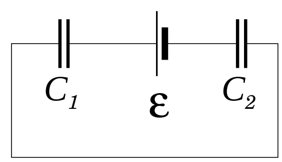
$$C = C_1 + C_2 \implies 3.19 \times 10^{-13} = K \times \left(5.9 \times 10^{-14}\right) + 1.48 \times 10^{-13}$$

$$\implies K = 2.9$$

4. In the circuit shown, $\varepsilon = 26$ V. The two capacitors are required to store electrostatic potential energies $\text{PE}_1 = 200$ nJ and $\text{PE}_2 = 320$ nJ respectively.

   (a) Find C_1. **3 points**

   (b) Find C_2. **1 point**



The total electrostatic energy in the series is

$$\text{PE} = \text{PE}_1 + \text{PE}_2 = 5.2 \times 10^{-7} \text{ J}$$

So the total charge in the capacitors can be obtained as

$$\text{PE} = \frac{1}{2} Q\varepsilon \implies Q = \frac{2 \times \text{PE}}{\varepsilon} = 4.0 \times 10^{-8} \text{ C}$$

The capacitors are in **series**, so $Q_1 = Q_2 = Q$. Then

$$\text{PE}_1 = \frac{Q^2}{2C_1} \implies C_1 = 4.0 \times 10^{-9} \text{ F}$$

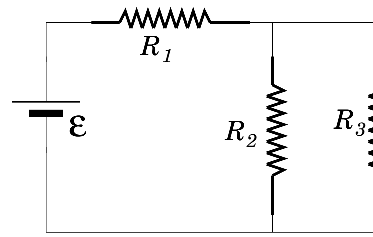
$$\text{PE}_2 = \frac{Q^2}{2C_2} \implies C_2 = 2.5 \times 10^{-9} \text{ F}$$

5. In the circuit shown, the two unknown resistors R_1 and R_2 dissipate equal power, $P_1 = P_2 = 90$ W, and $R_3 = 12\ \Omega$. The current through R_3 is $I_3 = 2.5$ A.

   (a) Find R_2. **2 points**

   (b) Find R_1. **3 points**

   (c) Find ε. **1 point**



Solution: We can calculate

$$V_3 = I_3 R_3 = 30 \text{ V}$$

$$R_2 \text{ and } R_3 \text{ are parallel} \implies V_2 = V_{23} = V_3 = 30 \text{ V}$$

$$\text{PE}_2 = \frac{V_2^2}{R_2} \implies R_2 = \frac{V_2^2}{\text{PE}_2} = 10.0\ \Omega$$

$$\left.\begin{array}{l} R_2 \text{ and } R_3 \text{ are parallel and} \\ \text{then } R_{23} \text{ is in series with } R_1 \end{array}\right\} \implies I_1 = I_2 + I_3 = \frac{V_2}{R_2} + I_3 = 5.5 \text{ A}$$

$$\text{PE}_1 = I_1^2 R_1 \implies R_1 = \frac{\text{PE}_1}{I_1^2} = 3.0\ \Omega$$

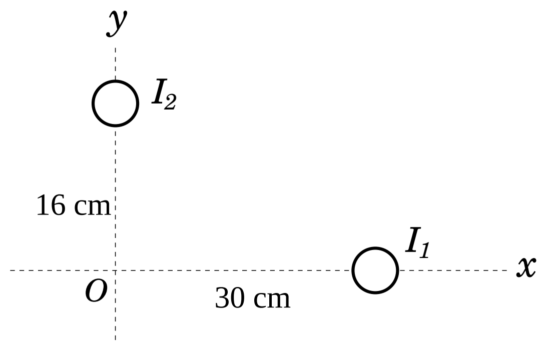
$$\left.\begin{array}{l} R_2 \text{ and } R_3 \text{ are parallel and} \\ \text{then } R_{23} \text{ is in series with } R_1 \end{array}\right\} \implies \varepsilon = V_1 + V_2 = I_1 R_1 + V_2 = 46.4 \text{ V}$$

6. Two long straight wires perpendicular to the $xy-$plane are shown. The $x-$component and the $y-$component of the **net magnetic field** at the **origin** O are given by

$$B_x = -5.0 \times 10^{-6} \text{ T}$$

and

$$B_y = -3.4 \times 10^{-6} \text{ T}$$



(a) What is the direction of current I_1? (Tick the correct answer) **1 point**

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

Because note that B_x is due to I_2 and B_y is due to I_1.

(b) What is the direction of current I_2? (Tick the correct answer) **1 point**

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

Because note that B_x is due to I_2 and B_y is due to I_1.

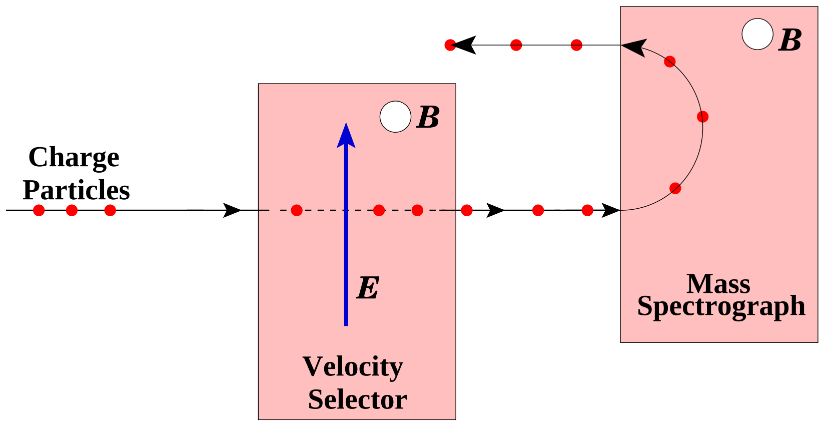
(c) Find the value of the current I_1. **2 points**

$$B_y = -B_1 \implies -3.4 \times 10^{-6} = -\frac{\mu_0 I_1}{2\pi(0.30)} \implies I_1 = 5.1 \text{ A}$$

(d) Find the value of the current I_2. **2 points**

$$B_x = -B_2 \implies -5.0 \times 10^{-6} = -\frac{\mu_0 I_2}{2\pi(0.16)} \implies I_2 = 4.0 \text{ A}$$

7. Identical particles of mass $m = 1.25 \times 10^{-20}$ kg, kinetic energy KE $= 2.44 \times 10^{7}$ eV and charge q **pass straight through** the velocity selector in which the **electric field** is **upward** (↑) with magnitude $E = 500$ N/C. Then they complete a semicircular path of radius $R = 6$ mm inside the mass spectrograph (see the figure). The **magnetic fields** in the two regions have **same magnitude** and **same direction**.



(a) What is the direction of $\boldsymbol{B}$? (Tick the correct answer) **1 point**

out-of-the-plane ⊙ ✓ | **into-the-plane** ⊗

(b) Find the speed of the charge particles. **2 point**

$$\text{KE} = 2.44 \times 10^{7} \text{ eV} = 3.9 \times 10^{-12} \text{ J}$$

Then

$$\frac{1}{2}mv^2 = 3.9 \times 10^{-12} \implies v = 2.5 \times 10^{4} \text{ m/s}$$

(c) Find the charge q on the particles. **1 point** for **sign** + **2 points** for **value**

By the right-hand-rule, the charge is **negative**. Then

$$B = E/v = 0.02 \text{ T}$$

$$R = \frac{mv}{B|q|} \implies |q| = \frac{mv}{BR} = 2.6 \times 10^{-12} \implies q = -2.6 \times 10^{-12} \text{ C}$$

8. An object placed 20 cm from a lense produces a 5× **virtual** image. How far from the lense should the object be placed to get a 5× **real** image? **4 points**

First need to find the focal length. We have

$$\frac{-d_i}{d_o} = +5 \implies d_i = -5 \times 0.2 = -1.0 \text{ m}$$

Then

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \implies f = 0.25 \text{ m}$$

For a real image,

$$\frac{-d_i}{d_o} = -5 \implies d_i = 5d_o$$

Then

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \implies \frac{1}{d_o}\left[1 + \frac{1}{5}\right] = \frac{1}{f}$$
$$\implies d_o = 0.3 \text{ m}$$

9. A person with defective vision has his **near point** at 11 cm and **far point** at 20 cm. An optician suggested for him a lense of power −5.0 D for all purpose.

(a) Wearing this lense, can he read a book holding it at 25 cm from the eye? You must explain your answer. **2 points**

Wearing this lense, when the book is at 25 cm,

$$\frac{1}{0.25} + \frac{1}{d_i} = -5 \implies d_i = -0.11 \text{ m}$$

This is within his range of vision. So **yes**, he can read.

(b) Wearing this lense, can he see distant objects? You must explain your answer by calculating how far he can see properly? **2 points**

Wearing this lense, he can see those objects whose virtual images are formed at 20 cm. So

$$\frac{1}{d_o} + \frac{1}{-0.2} = -5 \implies d_o = \infty$$

So he can see **all** the objects at far distance.

10. The $^{59}_{26}$Fe isotope is radioactive. A sample of mass 9.20 μg of the isotope was kept in a container. After 100 days, the mass of the remaining $^{59}_{26}$Fe isotope was 1.94 μg.

(a) How many atoms of the sample were present initially? **1 point**

$$N_0 = \frac{N_A}{59} \times (9.20 \times 10^{-6}) = 9.39 \times 10^{16}$$

(b) How many atoms of the sample were present after 100 days? **1 point**

$$N = \frac{N_A}{59} \times (1.94 \times 10^{-6}) = 1.98 \times 10^{16}$$

(c) What is the **decay constant**? **2 points**

The time is

$$t = 100 \times 24 \times 3600 = 8.64 \times 10^6 \text{ s}$$

Then

$$N = N_0\, e^{-\lambda t} \implies -\lambda t = \ln\left(\frac{N}{N_0}\right) = -1.556 \implies \lambda = 1.8 \times 10^{-7} \text{ s}^{-1}$$

(d) What is the **half-life**? (express in **days**). **2 points**

The half-life is

$$T_{\frac{1}{2}} = \frac{0.693}{\lambda} = 3.85 \times 10^6 \text{ s} = 44.6 \text{ days}$$