Kuwait University **Department of Physics**

General Physics II for Biological Sciences (Phy 122)
First Midterm Examination (Summer Semester 2024-2025)
July 8, 2025
Time: 6:30 PM to 8:00 PM

Instructor: Dr. S.S.A. Razee

Solution

Fundamental Constants

$k = 9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$	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:

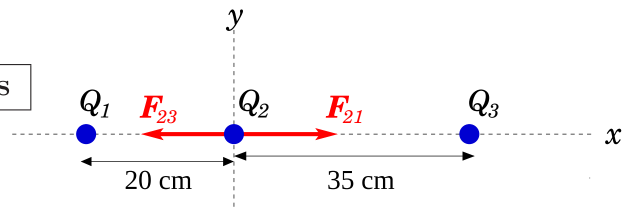
- All communication devices must be switched off and placed in your bag. Anyone found using a communication device will be disqualified.
- Programmable calculators, which can store equations, are not allowed.

For use by instructors only

Problems	#1	#2	#3	#4	#5	#6	#7	#8	Total
Max. Marks	**4**	**4**	**5**	**6**	**3**	**3**	**4**	**7**	**36**
Score									

1. Three point charges, $Q_1 = -4\ \mu$C, $Q_2 = -6\ \mu$C and $Q_3 = -9\ \mu$C are on the $x-$axis as shown.

   (a) Find the magnitude of the net electric force on charge Q_2. **3 points**



Solution: The forces $\vec{F}_{21}$ and $\vec{F}_{23}$ are shown in the figure (Note: Both the forces are repulsive). The $x-$components of the two forces are

$$F_{21,x} = +F_{21} = +\frac{k|Q_1 Q_2|}{0.2^2} = +5.4 \text{ N}$$

$$F_{23,x} = -F_{23} = +\frac{k|Q_2 Q_3|}{0.35^2} = -4.0 \text{ N}$$

So

$$F_{2,x} = F_{21,x} + F_{23,x} = +1.4 \text{ N}$$

   (b) The direction of the net force on Q_2 is: (Tick the correct answer) **1 point**

In the **Positive** $x-$direction ✓	In the **Negative** $x-$direction

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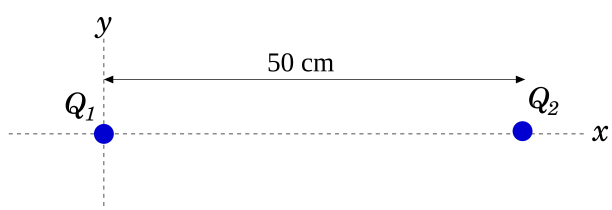
2. Two point charges, $Q_1 = +3\ \mu$C and $Q_2 = -9\ \mu$C are on the $x-$axis as shown. Find the $x-$coordinate of the point P where the net electric field $\vec{E} = 0$. **4 points**



__Solution:__ Since, Q_1 and Q_2 have opposite signs, and $|Q_1| < |Q_2|$, the point P at which the net electric field $\vec{E} = 0$, must be to the **left of** Q_1, *i.e.* $x < 0$. Let $d =$ distance of P from the origin (from Q_1). Then

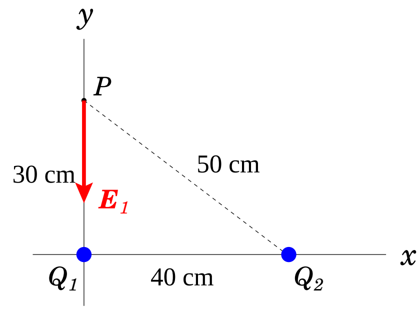
$$E_1 = E_2 \implies \frac{k|Q_1|}{d^2} = \frac{k|Q_2|}{(0.5+d)^2} \implies \frac{0.5+d}{d} = \sqrt{\frac{|Q_2|}{|Q_1|}} = 1.73$$

We chose the positive square root because on the left-hand-side all the terms are positive. Solving for d we get $d = 0.68$ m. Then the coordinate of P is $\boxed{x = -0.68 \text{ m}}$.

3. Two point charges, $Q_1 = -6$ nC and an unknown Q_2 are placed in the $xy-$plane as shown. The $y-$component of the net electric field at the point P is $E_y = -276$ N/C.

   (a) Find the charge Q_2 (with correct sign). **2+1 points**

   (b) Find the $x-$component of the net electric field at the point P **2 points**

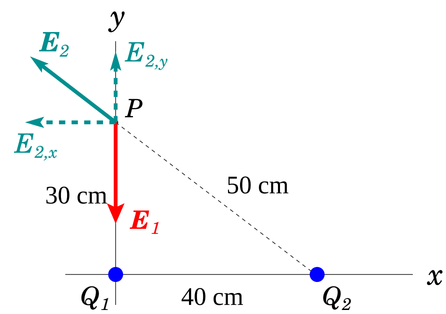


Solution: We know Q_1 (it is negative), so we can draw $\boldsymbol{E}_1$ at P.

The $y-$component of the net electric field is

$$E_y = E_{1,y} + E_{2,y} \implies -276 = -\frac{k|Q_1|}{0.3^2} + E_{2,y} \implies \boxed{E_{2,y} = +324 \text{ N/C}}$$

Since $E_{2,y}$ is positive, the only way $\boldsymbol{E}_2$ can be is as shown in the figure here. This makes $\boxed{Q_2 > 0}$.



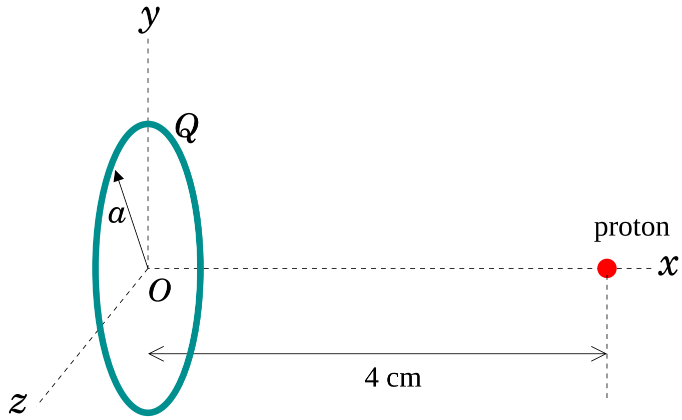
To get Q_2,

$$E_{2,y} = +\frac{k|Q_2|}{0.5^2} \times \frac{0.3}{0.5} = +324 \implies |Q_2| = 1.5 \times 10^{-8} \text{ C} \implies \boxed{Q_2 = +1.5 \times 10^{-8} \text{ C}}$$

Now

$$E_x = E_{2,x} = -\frac{k|Q_2|}{0.5^2} \times \frac{0.4}{0.5} \implies \boxed{E_x = -432 \text{ N/C}}$$

4. A uniformly charged ring of radius $a = 1.5$ cm is fixed in the $yz-$plane with its centre at the origin O. A proton is **released from rest** on the $x-$axis at $x = 4$ cm (see the figure). The proton **passes through** O with speed $v = 3.3 \times 10^6$ m/s. Find the charge Q on the ring. **6 points**



Solution: The work-energy principle is

$$\text{KE}_i + \text{PE}_i = \text{KE}_f + \text{PE}_f$$

$$0 + e \times V_{Ring}(x = 4\text{cm}) = \frac{1}{2} m_p v^2 + e \times V_{Ring}(x = 0)$$

$$\Longrightarrow e \times \frac{kQ}{(0.04^2 + 0.015^2)^{1/2}} = \frac{1}{2} m_p v^2 + e \times \frac{kQ}{0.015}$$

$$\Longrightarrow \left(3.37 \times 10^{-8}\right) Q = 9.09 \times 10^{-15} + \left(9.6 \times 10^{-8}\right)$$

$$\Longrightarrow -\left(6.23 \times 10^{-8}\right) Q = \left(9.6 \times 10^{-8}\right) \Longrightarrow \boxed{Q = -1.46 \times 10^{-7} \text{ C}}$$

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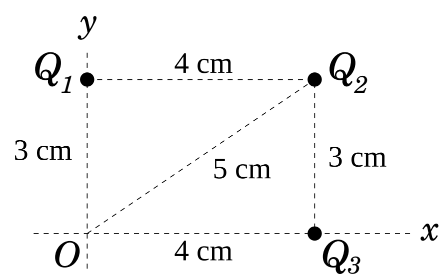
5. Three point charges, Q_1, Q_2 and Q_3 are in the $xy-$-plane as shown. If $Q_1 = +6.0$ nC, $Q_2 = +5.0$ nC and the **electric potential** $V = 0$ at the origin O, find the **electric potential energy** (PE_3) of the charge Q_3. **3 points**



Solution: At the origin O, $V = 0$,

$$\frac{kQ_1}{0.03} + \frac{kQ_2}{0.05} + \frac{kQ_3}{0.04} = 0 \Longrightarrow Q_3 = -12.0 \text{ nC}$$

The electric potential energy of Q_3 is

$$\text{PE}_3 = \frac{kQ_1Q_3}{0.05} + \frac{kQ_2Q_3}{0.03} = -3.1 \times 10^{-5} \text{ J}$$

6. A parallel-plate capacitor of plate-area $A = 4.0 \times 10^{-4}$ m^2 and thickness $d = 1.4$ mm is filled with paraffin (dielectric constant, $K = 3.4$). It is connected to a battery of voltage $V = 6$ V. How much **electric energy** is stored in the capacitor? **3 points**

Solution: The capacitance is

$$C = K\varepsilon_0 \frac{A}{d} = 8.6 \times 10^{-12} \text{ F}$$

$$\text{PE} = \frac{1}{2}CV^2 = 1.55 \times 10^{-10} \text{ J}$$

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7. A cellulose-filled parallel-plate capacitor has PE = 150 nJ of energy when it is connected to a battery. While it is still **connected to the battery**, the **cellulose slab is pulled out** and the **thickness is reduced** from $d = 4$ mm to $d' = 2$ mm. The dielectric constant of cellulose is K=1.5. How much energy is now stored in the capacitor? **4 points**

Solution: Let the old capacitor be C and the new capacitor be C'. Then

$$\frac{C'}{C} = \left(\frac{1}{K}\right)\left(\frac{A}{A}\right)\left(\frac{4 \times 10^{-3}}{2 \times 10^{-3}}\right) \implies \frac{C'}{C} = 1.333$$

In this case, the voltage V across the capacitor remains unchanged. So

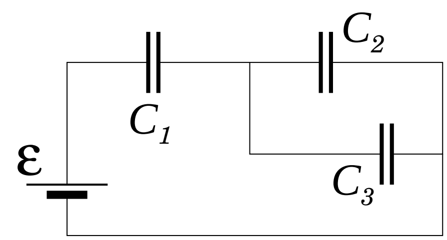
$$\left.\begin{aligned} \text{PE} &= \frac{1}{2}CV^2 \\ \text{PE}' &= \frac{1}{2}C'V^2 \end{aligned}\right\} \implies \frac{\text{PE}'}{\text{PE}} = \frac{C'}{C} = 1.33 \implies \text{PE}' = 1.333 \times \text{PE} = 200 \text{ nJ}$$

8. Three capacitors are connected to a battery of voltage $\mathcal{E} = 20$ V as shown. The capacitance $C_1 = 16$ nF. The energies stored in C_1 and C_2 are respectively $\text{PE}_1 = 200$ nJ and $\text{PE}_2 = 360$ nJ.

   (a) Find the energy PE_3 stored in the capacitor C_3. **3 points**

   (b) Find the capacitance C_2. **3 points**

   (c) Find the capacitance C_3. **1 point**



Solution: We have

$$\text{PE}_1 = \frac{Q_1^2}{2C_1} \implies Q_1 = \sqrt{2C_1 \times \text{PE}_1} = 8.0 \times 10^{-8} \text{ C}$$

$$\left.\begin{array}{r} C_2 \text{ and } C_3 \text{ are parallel} \\ C_1 \text{ and } C_{23} \text{ are in series} \end{array}\right\} \implies Q_{123} = Q_1 = 8.0 \times 10^{-8} \text{ C}$$

Total energy in the circuit is: $$\text{PE} = \frac{1}{2} Q_{123} \mathcal{E} = 8.0 \times 10^{-7} \text{ J}$$

So, energy in C_3 is: $$\text{PE}_3 = \text{PE} - \text{PE}_1 - \text{PE}_2 = 2.4 \times 10^{-7} \text{ J}$$

Voltage across C_1 is: $$V_1 = \frac{Q_1}{C_1} = 5 \text{ V}$$

$$\left.\begin{array}{r} C_2 \text{ and } C_3 \text{ are parallel} \\ C_1 \text{ and } C_{23} \text{ are in series} \end{array}\right\} \implies V_2 = V_3 = V_{23} = \mathcal{E} - V_1 = 15 \text{ V}$$

Then $$\text{PE}_2 = \frac{1}{2} C_2 V_2^2 \implies C_2 = \frac{2 \times \text{PE}_2}{V_2^2} = 3.2 \times 10^{-9} \text{ F}$$

And $$\text{PE}_3 = \frac{1}{2} C_3 V_3^2 \implies C_3 = \frac{2 \times \text{PE}_3}{V_3^2} = 2.1 \times 10^{-9} \text{ F}$$