Kuwait University **Department of Physics**

جامعة الكويت
KUWAIT UNIVERSITY

General Physics II for Biological Sciences (Phy 122)

First Midterm Examination (Summer Semester 2025-2026)

June 27, 2026
Time: 12:00 PM to 1:30 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

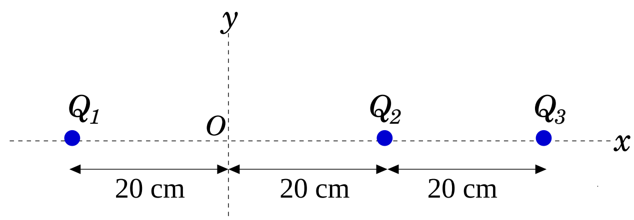
Prefixes of units

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

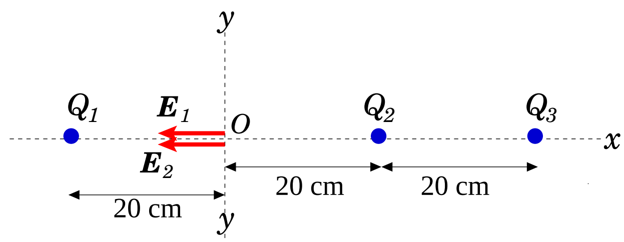
Instructions to the Students:

- 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.

1. Three point charges are on the $x-$axis as shown. If $Q_1 = -2$ nC, $Q_2 = +2$ nC and the net electric field $\vec{\boldsymbol{E}} = 0$ at the origin O, find Q_3. **4 points**



Solution We have drawn the electric fields $\vec{\boldsymbol{E}}_1$ and $\vec{\boldsymbol{E}}_2$. Given

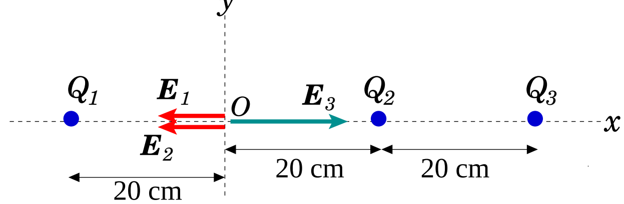


$$\vec{\boldsymbol{E}}_1 + \vec{\boldsymbol{E}}_2 + \vec{\boldsymbol{E}}_3 = 0$$

$$\Longrightarrow \; -E_1 - E_2 + E_{3x} = 0$$

$$\Longrightarrow E_{3x} = +900 \text{ N/C}$$

We can now draw $\vec{\boldsymbol{E}}_3$. This means Q_3 is **negataive**, and



$$\frac{k|Q_3|}{0.4^2} = 900 \implies |Q_3| = 1.6{\times}10^{-8} \text{ C}$$

$$\Longrightarrow Q_3 = -1.6 \times 10^{-8} \text{ C}$$

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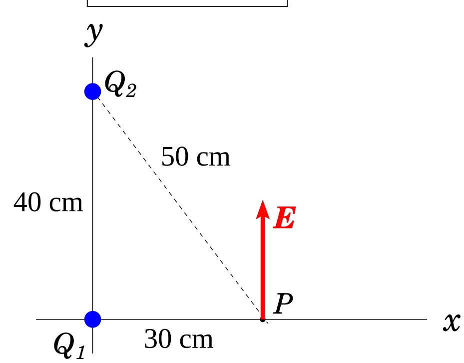
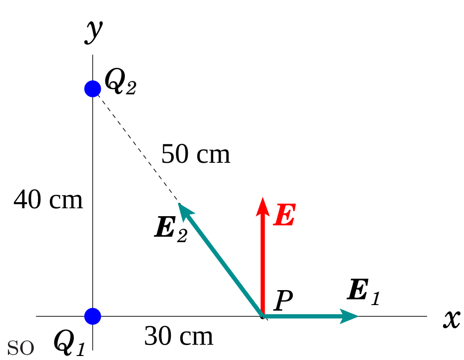
2. Two point charges, Q_1 and Q_2 lie in the $xy-$plane as shown. The net electric field at the point P has magnitude $E = 180$ N/C and points in the **positive** $y-$**direction** as shown (So, $E_x = 0$). Find the charges Q_1 and Q_2. **3+3 points**



<u>**Solution:**</u> For the given net electric field, $\vec{\boldsymbol{E}}_1$ and $\vec{\boldsymbol{E}}_2$ must be as drawn below. This implies that Q_1 is **positive** and Q_2 is **negative**.

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



$$E_y = E_{2,y} \implies 180 = +\frac{k|Q_2|}{0.5^2} \times \frac{0.4}{0.5}$$

$$\Longrightarrow |Q_2| = 6.25 \times 10^{-9} \text{ C}$$

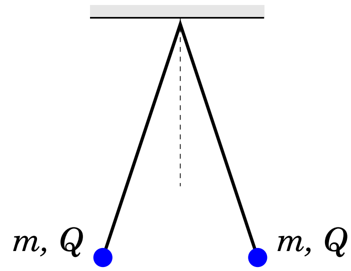
$$\Longrightarrow \boxed{Q_2 = -6.25 \times 10^{-9} \text{ C}}$$

The $x-$component of the net electric field is zero, so

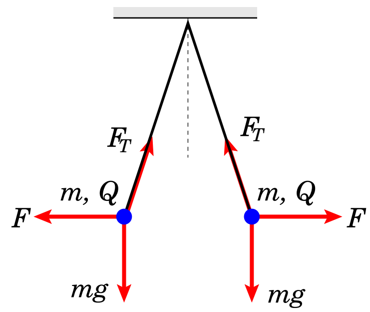
$$E_1 = |E_{2,x}| \implies \frac{k|Q_1|}{0.3^2} = \frac{k|Q_2|}{0.5^2} \times \frac{0.3}{0.5}$$

$$\Longrightarrow |Q_1| = 1.35 \times 10^{-9} \text{ C} \implies \boxed{Q_1 = +1.35 \times 10^{-9} \text{ C}}$$

3. Two identical tiny balls of mass $m = 2.0 \times 10^{-6}$ kg each hang from the ceiling by insulating cords of equal length. When each ball was given a charge of $Q = 8.0$ nC, the balls get into equilibrium as shown. If the distance between the balls is $r = 22$ cm, find the tension F_T in the cords. **3 points**



Solution: The free-body diagram is shown.



$$F_{T,x} = F = \frac{kQ^2}{r^2} = 1.19 \times 10^{-5} \text{ N}$$

$$F_{T,y} = mg = 1.96 \times 10^{-5} \text{ N}$$

$$F_T = \sqrt{F_{T,x}^2 + F_{T,y}^2} = 2.29 \times 10^{-5} \text{ N}$$

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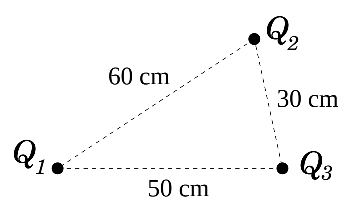
4. Three point charges, Q_1, Q_2 and Q_3 are placed as shown. Given that $Q_1 = +3.0$ nC, $Q_2 = -3.0$ nC and the **electric potential energy** of the system PE $= 0$. Find the **electric potential energy** PE_2 of the charge Q_2. **4 points**



Solution: The electric potential energy of the **system** is

$$\text{PE} = \frac{kQ_1Q_2}{0.6} + \frac{kQ_2Q_3}{0.3} + \frac{kQ_1Q_3}{0.5}$$

$$\implies \frac{kQ_1Q_2}{0.6} + Q_3\left(\frac{kQ_2}{0.3} + \frac{kQ_1}{0.5}\right) = 0$$

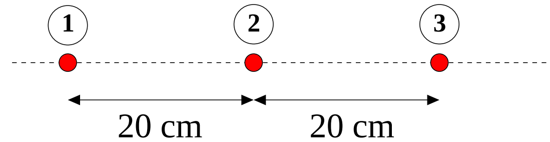
$$\implies -1.35 \times 10^{-7} + Q_3\left(-90 + 54\right) = 0$$

$$\implies Q_3 = -3.75 \times 10^{-9} \text{ C}$$

The electric potential energy of Q_2 is

$$\text{PE}_2 = \frac{kQ_1Q_2}{0.6} + \frac{kQ_2Q_3}{0.3} = +2.025 \times 10^{-7} \text{ J}$$

5. Three identical balls of mass $m = 1.5 \times 10^{-8}$ kg are initially placed on a straight line as shown. Each ball is charged to $q = -2$ nC. They are released from rest at their locations. Find the **maximum speed** attained by the ball marked ①. **4 points**



Solution: The net force on the ball marked ② is zero. So the ball marked ② will not move al=t all, *i.e* $v_2 = 0$.

The magnitudes of the accelerations of the balls marked ① and ③ are identically equal. So when they move, $v_1 = v_3 = v$. The speed becomes maximum when the PE becomes minimum which is at very large distance. So $\text{PE}_f = 0$.

The work-energy principle is

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

$$0 + \frac{kq^2}{0.2} + \frac{kq^2}{0.4} + \frac{kq^2}{0.2} = \frac{1}{2}mv^2 + \frac{1}{2}mv^2 + 0 + 0 + 0$$

$$\implies 4.5 \times 10^{-7} = mv^2$$

$$\implies \boxed{v = 5.48 \text{ m/s}}$$

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6. A parallel-plate capacitor of plate-area $A = 5.0 \times 10^{-5}$ m^2 filled with cellulose (dielectric constant $K = 2.0$) has plate-charge $Q = 6.0$ pC when connected to a 1.5 V battery.

   (a) Find the thickness d of the capacitor. **2 points**

   (b) Find the magnitude of the electric field E between the plates. **1 point**

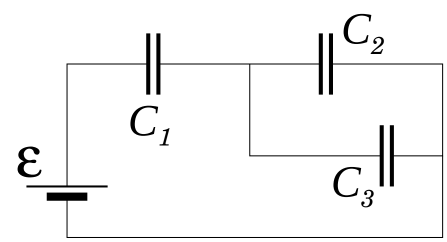
Solution: The capacitance is

$$C = \frac{Q}{V} = 4.0 \times 10^{-12} \text{ F}$$

$$C = K\varepsilon_0 \frac{A}{d} \implies d = K\varepsilon_0 \frac{A}{C} = 2.21 \times 10^{-4} \text{ m}$$

$$E = \frac{V}{d} = 6.78 \times 10^3 \text{ V/m}$$

7. Three capacitors are connected to a battery of voltage $\varepsilon = 18$ V as shown. The capacitance $C_1 = 15$ nF. The plate-charges on C_2 and C_3 are respectively $Q_2 = 50$ nC and $Q_3 = 70$ nC. Find the capacitance C_2. $\boxed{\textbf{4 points}}$



Solution: We have

$$\left.\begin{array}{l} C_2 \text{ and } C_3 \text{ are parallel} \\ C_1 \text{ and } C_{23} \text{ are in series} \end{array}\right\} \implies Q_1 = Q_{123} = Q_{23} = Q_2 + Q_3 = 1.2 \times 10^{-7} \text{ C}$$

Voltage across C_1 is: $$V_1 = \frac{Q_1}{C_1} = 8.0 \text{ V}$$

$$V_2 = V_3 = V_{23} = \mathcal{E} - V_1 = 10.0 \text{ V}$$

Then: $$C_2 = \frac{Q_2}{V_2} = 5.0 \times 10^{-9} \text{ F}$$

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8. A charged air-filled parallel-plate capacitor of thickness $d = 1$ mm has PE $= 90$ nJ of electrostatic energy. After **disconnecting the battery**, the thickness of the capacitor is reduced to $d' = 0.4$ mm and the space between the plates is filled by paper (dielectric constant $K = 2$). How much energy is now stored in the capacitor? $\boxed{\textbf{4 points}}$

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

$$\frac{C'}{C} = \left(\frac{K}{1}\right)\left(\frac{A}{A}\right)\left(\frac{d}{d'}\right) \implies \frac{C'}{C} = 5$$

In this case, the plate-charge Q remains unchanged. So

$$\left.\begin{array}{l} \text{PE} = \dfrac{Q^2}{2C} \\[2ex] \text{PE}' = \dfrac{Q^2}{2C'} \end{array}\right\} \implies \frac{\text{PE}'}{\text{PE}} = \frac{C}{C'} = \frac{1}{5} = 0.2 \implies \text{PE}' = 0.2 \times \text{PE} = 18 \text{ nJ}$$