Kuwait University Department of Physics

جامعة الكويت
KUWAIT UNIVERSITY

General Physics II for Biological Sciences (Phy 122)

First Midterm Examination (Fall Semester 2024-2025)

October 19, 2024

Time: 2:00 PM to 3:30 PM

Instructor: Dr. S.S.A. Razee

Solution

Fundamental Constants

$k = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$	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
$e = 1.6 \times 10^{-19} \text{ C}$	Elementary charge
$m_e = 9.11 \times 10^{-31} \text{ kg}$	Mass of an electron
$m_p = 1.67 \times 10^{-27} \text{ kg}$	Mass of a proton
$\text{eV} = 1.6 \times 10^{-19} \text{ J}$	Conversion from eV to J
$N_A = 6.022 \times 10^{23}/\text{mol}$	Avogadro's number

Prefixes of units

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

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. Two point charges, Q_1 and Q_2 are placed in the $xy-$plane as shown. The net electric field $\vec{\boldsymbol{E}}$ at the origin O is in the **positive** $y-$**direction** (see the figure) with **magnitude** $E_y = 120$ N/C.

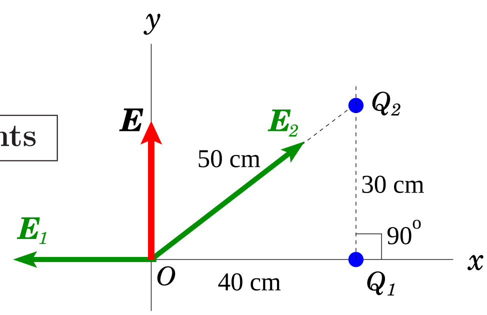
   (a) What is the **sign** of charge Q_1? (Tick the correct answer) **1 point**

   Positive ✓ **Negative**

   (b) What is the **sign** of charge Q_2? (Tick the correct answer) **1 point**

   Positive **Negative** ✓

   (c) Find the charges Q_1 and Q_2. **2+2 points**



Solution: For the given direction of the net electric field the directions of $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ are as shown by green arroes. Then $Q_1 > 0$ and $Q_2 < 0$.

The $y-$component comes entirely from $\boldsymbol{E}_2$. So

$$E_y = E_{2,y} = +E_2 \times \frac{0.3}{0.5} \Longrightarrow E_2 = E_y \times \frac{0.5}{0.3} = 200 \text{ N/C}$$

So

$$E_2 = \frac{k|Q_2|}{0.5^2} \Longrightarrow |Q_2| = \frac{E_2 \times (0.5)^2}{k} = 5.56 \times 10^{-9} \text{ C} \Longrightarrow Q_2 = -5.56 \times 10^{-9} \text{ C}$$

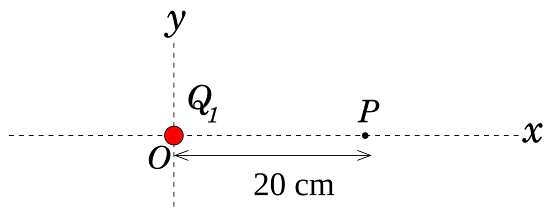
The $x-$component is zero. So

$$E_{1,x} + E_{2,x} = 0 \Longrightarrow E_{1,x} = -E_2 \times \frac{0.4}{0.5} = -160 \text{ N/C} \Longrightarrow E_1 = 160 \text{ N/C}$$

So

$$E_1 = \frac{k|Q_1|}{0.4^2} \Longrightarrow |Q_1| = \frac{E_1 \times (0.4)^2}{k} = 2.84 \times 10^{-9} \text{ C} \Longrightarrow Q_1 = +2.84 \times 10^{-9} \text{ C}$$

2. The point charge $Q_1 = +3.0\ \mu$C is at the origin and the point P is on the $x-$axis at a distance of 20 cm from the origin as shown. Find the location (coordinates) of the point charge $Q_2 = -5.0\ \mu$C such that the net electric field $\vec{\boldsymbol{E}} = 0$ at P. **5 points**



Solution: We have

$$E_1 = \frac{k|Q_1|}{0.2^2} = 6.75 \times 10^5 \text{ N/C} \qquad \textbf{to the right}$$

Since $\vec{\boldsymbol{E}} = 0$ at P, we must have

$$E_2 = 6.75 \times 10^5 \text{ N/C} \qquad \textbf{to the left}$$

$$\Longrightarrow \frac{k|Q_2|}{r^2} = 6.75 \times 10^5 \Longrightarrow r = 0.26 \text{ m}$$

Since $Q_2 < 0$, and $\vec{\boldsymbol{E}}_2$ is to the left, the charge Q_2 must be placed to the left of P. So the coordinate of the location of Q_2 is

$$-0.26 + 0.2 = -0.06 \text{ m}$$

3. A uniform ring of radius $a = 8$ cm and charge $Q = +12.0\ \mu$C is fixed in the $yz-$plane with its centre at the origin O. A point charge $q = -5.0\ \mu$C is on the $x-$axis at 6 cm from the origin.

   (a) What is the **direction of the force on** q? (Tick the correct answer) **1 point**

   ☐ In **positive** $x-$direction ☑ In **negative** $x-$direction

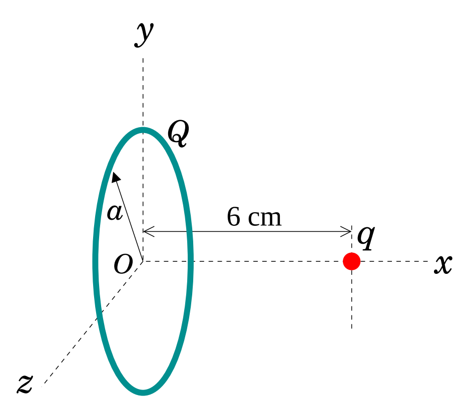
   (b) Find the magnitude of the **electric force** on the charge q by the ring. **3 points**

Solution: We have

$$E_{Ring} = \frac{k|Q|(0.06)}{(0.06^2 + 0.08^2)^{3/2}} = 6.48 \times 10^6 \text{ N/C}$$

The magnitude of the electric force on q is

$$F_q = |q|E_{Ring} = 32.4 \text{ N}$$



4. Two charged particles of identical mass $m = 5.0 \times 10^{-12}$ kg have charges $Q_1 = -3.0$ nC and $Q_2 = -2.0$ nC. They are released from rest when they were 40 cm from each other. Find the **distance between the particles** when the **speed of each particle** is $v = 140$ m/s? **5 points**

Solution: Let r be the distance between the particles when their speeds are 140 m/s. The work-energy principle gives

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

$$\implies 0 + \frac{kQ_1Q_2}{0.4} = 2 \times \frac{1}{2}mv^2 + \frac{kQ_1Q_2}{r}$$

$$\implies \frac{kQ_1Q_2}{r} = \frac{kQ_1Q_2}{0.4} - mv^2 = 3.7 \times 10^{-8}$$

$$\implies r = \frac{kQ_1Q_2}{3.7 \times 10^{-8}} = 1.46 \text{ m}$$

5. Three point charges, $Q_1 = -2$ nC, $Q_2 = +3$ nC and $Q_3 = +4$ nC are at the vertices of an **equilateral triangle** of side 8 cm. Find the **total electric potential energy** of the system. (Take PE = 0 when the charges are very far away from each other.) **4 points**

Solution: The total electrostatic potential energy is

$$\mathrm{PE} = \frac{kQ_1Q_2}{a} + \frac{kQ_2Q_3}{a} + \frac{kQ_1Q_3}{a} = -2.25 \times 10^{-7} \text{ J}$$

6. A parallel-plate capacitor of plate-area $A = 4.0 \times 10^{-4}$ m^2 and thickness $d = 1.5$ mm is filled with paraffin (dielectric constant, $K = 2.25$). If the **electric energy stored in the capacitor** is PE $= 2.4 \times 10^{-11}$ J, find the magnitude of the **electric field** between the plates. **4 points**

Solution: The capacitance is

$$C = K\varepsilon_0 \frac{A}{d} = 5.31 \times 10^{-12} \text{ F}$$

$$\text{PE} = \frac{1}{2}CV^2 \implies V = \sqrt{\frac{2 \times \text{PE}}{C}} = 9.0 \text{ V}$$

$$V = Ed \implies E = \frac{V}{d} = 6.03 \times 10^3 \text{ V/m}$$

7. An air-filled parallel-plate capacitor is charged to $V = 15$ V and the **battery is disconnected**. Then the thickness of the capacitor is changed from $d = 3$ mm to $d' = 4$ mm, and the space between the plates is filled with a dielectric of dielectric constant K. If the new voltage across the capacitor is $V' = 17$ V, find K. **4 points**

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

$$\frac{C'}{C} = \left(\frac{K}{1.0}\right)\left(\frac{A}{A}\right)\left(\frac{3.0 \times 10^{-3}}{4.0 \times 10^{-3}}\right) \implies \frac{C'}{C} = 0.75 \times K$$

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

$$CV = C'V' \implies \frac{V}{V'} = \frac{C'}{C} \implies \frac{V}{V'} = 0.75 \times K$$

$$\implies K = \frac{V}{V' \times 0.75} = 1.18$$