Kuwait University — Department of Physics

جامعة الكويت
KUWAIT UNIVERSITY
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General Physics II for Biological Sciences (Phy 122)
First Midterm Examination (Summer Semester 2023-2024)
June 29, 2024
Time: 8:00 AM to 9:30 AM

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

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

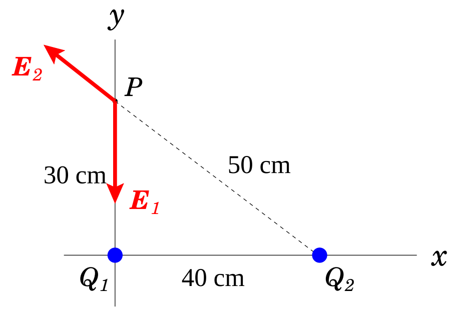
Instructions to the Students:

- 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.

For use by instructors only

Problems	#1	#2	#3	#4	#5	#6	#7	#8	Total
Max. Marks	**6**	**4**	**4**	**5**	**3**	**4**	**4**	**5**	**35**
Score									

1. Two point charges, $Q_1 = -6.0$ nC and $Q_2 = +8.0$ nC, are in the $xy-$-plane as shown. The point P is on the $y-$axis. Find the $x-$component and the $y-$component of the net electric field $\vec{\boldsymbol{E}}$ at P. **6 points**



Solution: Since $Q_1 < 0$ and $Q_2 > 0$, the directions of $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ are as shown. The magnitudes and components of $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ are

$$E_1 = \frac{k|Q_1|}{0.3^2} = 600.0 \text{ N/C} \Longrightarrow \begin{cases} E_{1x} = 0.0 \text{ N/C} \\ E_{1y} = -600.0 \text{ N/C} \end{cases}$$

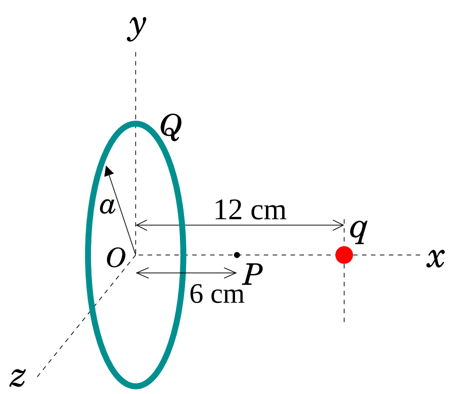
$$E_2 = \frac{k|Q_2|}{0.5^2} = 288.0 \text{ N/C}; \Longrightarrow \begin{cases} E_{2x} = -E_2 \times \dfrac{0.4}{0.5} = -230.4 \text{ N/C} \\ E_{2y} = +E_2 \times \dfrac{0.3}{0.5} = +172.8 \text{ N/C} \end{cases}$$

Then

$$E_x = E_{1x} + E_{2x} = -230.4 \text{ N/C} \qquad E_y = E_{1y} + E_{2y} = -427.2 \text{ N/C}$$

2. A uniform ring of radius $a = 8$ cm and charge $Q = -12.0$ μC is fixed in the $yz-$plane with its centre at the origin O. A point charge $q = +4.0$ μC is on the $x-$axis at 12 cm from the origin. Find the net electric field $\vec{\boldsymbol{E}}$ at the point P which is at a distance $x = 6.0$ cm from the origin. **4 points**

Solution: Both $\vec{\boldsymbol{E}}_{Ring}$ and $\vec{\boldsymbol{E}}_q$ are in the **negative** x-direction. The magnitudes are



$$E_{Ring} = \frac{k|Q|(0.06)}{(0.06^2 + 0.08^2)^{3/2}} = 6.5 \times 10^6 \text{ N/C}$$

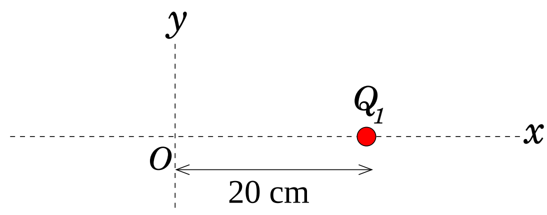
$$E_q = \frac{k|q|}{0.06^2} = 1.0 \times 10^7 \text{ N/C}$$

The magnitude of the net electric field is

$$E = E_{Ring} + E_q = 1.65 \times 10^7 \text{ N/C}$$

The direction: in the **negative** $x-$direction.

3. The point charge $Q_1 = -3.0\ \mu$C is on the $x-$axis at a distance of 20 cm from the origin as shown. Find the location of the point charge $Q_2 = +2.0\ \mu$C on the $x-$axis such that the net electric field $\vec{\boldsymbol{E}} = 0$ at the origin O. **4 points**



Solution: Since Q_1 and Q_2 have opposite signs, and $|Q_2| < |Q_1|$, the point at which $\vec{\boldsymbol{E}} = 0$ (in this case, it is the origin), must lie on the side of Q_2 and not in the middle. Therefore, Q_2 must be **between** O **and** Q_1. Let this distance be x. Then

$$\frac{k|Q_1|}{0.2^2} = \frac{k|Q_2|}{x^2} \implies x = 0.16 \text{ m}$$

4. Two charged particles of identical mass $m = 5.0 \times 10^{-6}$ 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 25 m/s? **5 points**

Solution: Let r be the distance between the particles when their speeds are 3.0×10^3 m/s. The work-energy principle gives

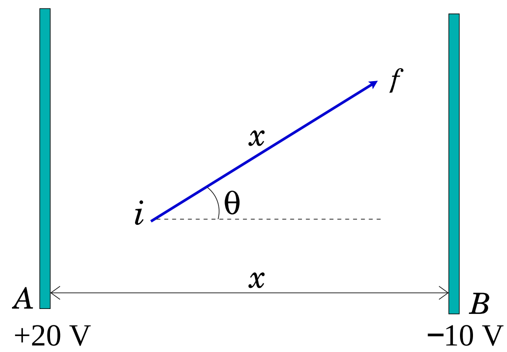
$$\text{KE}_f - \text{KE}_i + \text{PE}_f - \text{PE}_i = 0$$

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

$$\implies \frac{kQ_1Q_2}{r} = \frac{kQ_1Q_2}{0.4} - mv^2 = 0.132$$

$$\implies r = 0.41 \text{ m}$$

5. Two very large parallel flat sheets, A and B, are held at electric potentials $V_A = +20$ V and $V_B = -10$ V respectively as shown in the figure. The separation between the plates is $x = 8$ cm. The points i and f shown in the figure are also at a distance of x from each other and the angle $\theta = 40^o$. Find the potential difference $(V_i - V_f)$. **3 points**



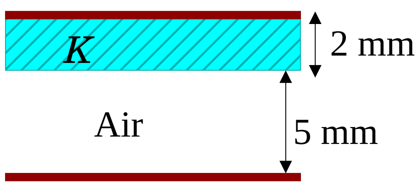
Solution: The electric field is **uniform**, so

$$V_A - V_B = Ex \implies E = \frac{V_A - V_B}{x} = 375 \text{ N/C}, \quad \text{and so, to the } \textbf{right}$$

The

$$V_i - V_f = Ex\ \cos 40^o = 23 \text{ V}$$

6. A parallel-plate capacitor with plate-area $A = 2.0 \times 10^{-4}$ m^2 is partially filled with a dielectric of dielectric constant $K = 3$ and thickness 2 mm. The thickness of empty space (air) between the plates is 5 mm (see the figure). Find the capacitance of this capacitor. **4 points**



Solution: This capacitor can be considered as two capacitors C_1 (with the dielectric) and C_2 (with air) in **series**. Now

$$C_1 = K\varepsilon_0 \frac{2.0 \times 10^{-4}}{0.002} = 2.66 \times 10^{-12} \text{ F}$$

$$C_2 = \varepsilon_0 \frac{2.0 \times 10^{-4}}{0.005} = 3.54 \times 10^{-13} \text{ F}$$

The capacitance of the given capacitor is

$$C = \frac{C_1 C_2}{C_1 + C_2} = 3.13 \times 10^{-13} \text{ F}$$

7. A parallel-plate capacitor filled with a dielectric of dielectric constant $K = 4.3$ has a thickness $d = 4.0$ mm. The energy in the capacitor is $\text{PE} = 4.8 \times 10^{-6}$ J when it is connected to a battery. While it is still **connected to the battery**, the **dielectric is pulled out** and its **thickness is decreased** to $d' = 3.0$ mm. Find the energy now stored in this capacitor. **4 points**

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

$$\frac{C'}{C} = \left(\frac{1.0}{K}\right)\left(\frac{A}{A}\right)\left(\frac{4.0 \times 10^{-3}}{3.0 \times 10^{-3}}\right) \implies \frac{C'}{C} = 0.31$$

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

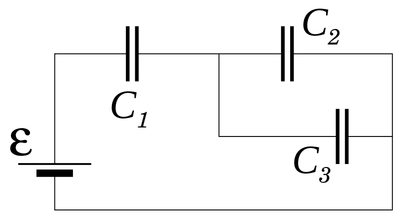
$$\left.\begin{aligned} \text{PE} &= \frac{CV^2}{2} \\ \text{PE}' &= \frac{C'V^2}{2} \end{aligned}\right\} \implies \frac{\text{PE}'}{\text{PE}} = \frac{C'}{C} = 0.31$$

$$\implies \text{PE}' = (0.31) \times \text{PE} = 1.5 \times 10^{-6} \text{ J}$$

8. Three capacitors are connected to an unknown source of emf $\mathcal{E}$ as shown in the circuit. The capacitance $C_1 = 6$ nF, $C_2 = 9$ nF, but C_3 is unknown. The plate-charges on C_1 and C_3 are respectively $Q_1 = 54$ nC and $Q_3 = 36$ nC.

   (a) Find C_3. **3 points**

   (b) Find $\mathcal{E}$. **2 points**



Solution: We have

$$V_1 = \frac{Q_1}{C_1} = 9 \text{ V}$$

Then

$$\left.\begin{array}{l} C_2 \text{ and } C_3 \text{ are parallel} \\ C_1 \text{ and } C_{23} \text{ are in series} \end{array}\right\} \implies \left\{\begin{array}{l} Q_1 = Q_{23} \implies Q_1 = Q_2 + Q_3 \\ Q_2 = Q_1 - Q_3 = 18 \text{ nC} \end{array}\right.$$

$$\implies V_2 = \frac{Q_2}{C_2} = 2 \text{ V}$$

$$\implies V_3 = V_2 = 2 \text{ V}$$

$$\implies C_3 = \frac{Q_3}{V_3} = 18 \text{ nF}$$

$$\implies \mathcal{E} = V_1 + V_{23} = V_1 + V_2 = 11 \text{ V}$$