Kuwait University Department of Physics

General Physics II for Biological Sciences (Phy 122)
First Midterm Examination (Summer Semester 2022-2023)
June 24, 2023
Time: 2:00 PM to 3:30 PM

Instructor: Dr. S.S.A. Razee

Solution

Fundamental Constants

$k = \dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$	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:

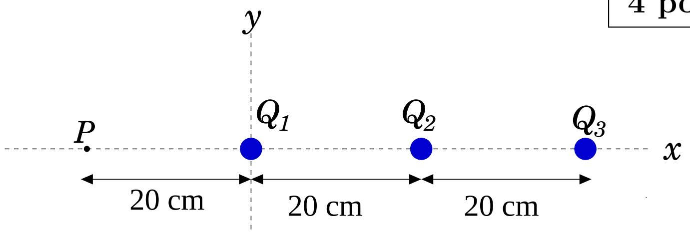
- All communication devices must be switched off and placed in your bag. Anyone found using a communication device will be disqualified.
- Programmable calculators, which can store equations, are not allowed.

For use by instructors only

Problems	#1	#2	#3	#4	#5	#6	#7	#8	Total
Max. Marks	**4**	**5**	**4**	**3**	**4**	**4**	**4**	**5**	**33**
Score									

1. Three point charges are on the $x-$axis as shown. The net electric field $\vec{E} = 0$ at the point P. If $Q_1 = +2$ nC and $Q_2 = -6$ nC, find Q_3.

4 points



Solution: There are no $y-$components. We see that, $E_{1x} < 0$ and $E_{2x} > 0$. Then

$$E_x = E_{1x} + E_{2x} + E_{3x}$$

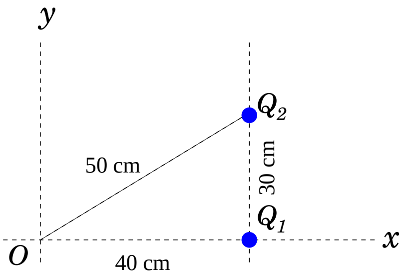
$$\Longrightarrow\ 0 = -\frac{k|Q_1|}{0.2^2} + \frac{k|Q_2|}{0.4^2} + E_{3x} \Longrightarrow\ 0 = -450.0 + 337.5 + E_{3x}$$

$$\Longrightarrow\ E_{3x} = +112.5 \text{ N/C} \Longrightarrow\ \boldsymbol{Q_3 < 0}$$

Now $$\frac{k|Q_3}{0.6^2} = 112.5 \Longrightarrow |Q_3| = 4.5\times 10^{-9}\text{ C} \Longrightarrow \boxed{\boldsymbol{Q_3 = -4.5\times 10^{-9}}\text{ C}}$$

2. Two point charges, $Q_1 = -4.0$ nC and $Q_2 = +9.0$ nC, are in the $xy-$-plane as shown. Find the $x-$component and the $y-$component of the net electric field $\vec{E}$ at O.

5 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

$$E_1 = \frac{k|Q_1|}{0.4^2} = 225.0 \text{ N/C} \Longrightarrow \begin{cases} E_{1x} = +225.0 \text{ N/C} \\ E_{1y} = 0 \text{ N/C} \end{cases}$$

$$E_2 = \frac{k|Q_2|}{0.5^2} = 324.0 \text{ N/C}; \Longrightarrow \begin{cases} E_{2x} = -E_2 \times \dfrac{0.4}{0.5} = -259.2 \text{ N/C} \\ E_{2y} = -E_2 \times \dfrac{0.3}{0.5} = -194.4 \text{ N/C} \end{cases}$$

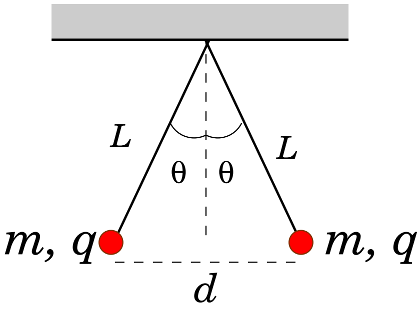
Then

$$E_x = E_{1x} + E_{2x} = -34.2 \text{ N/C} \qquad E_y = E_{1y} + E_{2y} = -194.4 \text{ N/C}$$

3. Two small metallic balls with equal positive charge q and equal mass $m = 3.0 \times 10^{-6}$ kg each hang from the ceiling by two insulating strings of equal length. When the balls are in equilibrium, the strings make an angle $\theta = 20^o$ with the vertical and the distance between them is $d = 4.0$ cm. Find the charge q (Take $g = 9.8$ m/s^2).

4 points

Solution: The free-body diagrams for the balls are shown. For any one ball, we find



$$\left.\begin{aligned} F_T\ \cos\theta &= mg \\ F_T\ \sin\theta &= F \end{aligned}\right\} \implies \tan\theta = \frac{F}{mg}$$

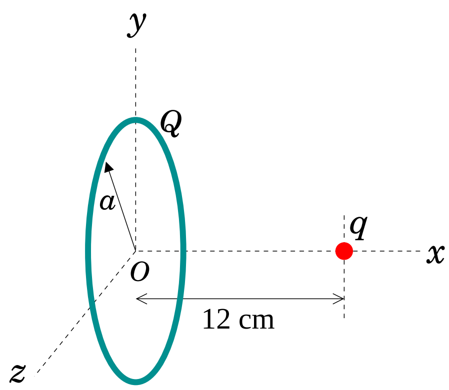
$$\implies F = mg\ \tan\theta = 1.07 \times 10^{-5}\text{ N}$$

Then

$$F = \frac{kq^2}{d^2} \implies q = \sqrt{\frac{Fd^2}{k}} = 1.38 \times 10^{-9}\text{ C}$$

4. A uniform ring of radius $a = 8$ cm and charge $Q = -4.0\ \mu$C is fixed in the $yz-$plane with its centre at the origin O. A point charge q is on the $x-$axis at $x = 12$ cm. The net electric potential $V = 0$ at O. Find the net electric field $\vec{\boldsymbol{E}}$ at O.

3 points



Solution: The net electric potential at O is

$$\frac{kQ}{a} + \frac{kq}{0.12} = 0$$

$$\implies q = -\frac{Q \times 0.12}{a} = +6.0 \times 10^{-6}\text{ C}$$

The electric field at O due to the ring is $E_{Ring} = 0$.

The electric field at O due to q is

$$E_q = \frac{k|q|}{(0.12)^2} = 3.75 \times 10^6\text{ N/C}, \quad \text{to the } \textbf{left}$$

So, the net electric field at O is

$$E = E_{Ring} + E_q = 3.75 \times 10^6\text{ N/C}, \quad \text{to the } \textbf{left}$$

5. Two charge particles of identical mass $m = 5.0 \times 10^{-14}$ kg are travelling directly towards each other. When the distance between them is 1.5 m, each particle is moving with speed $v = 3.0 \times 10^3$ m/s. If $q_1 = -2.0$ nC and the **distance of closest approach** between the particles is 20 cm, find q_2.

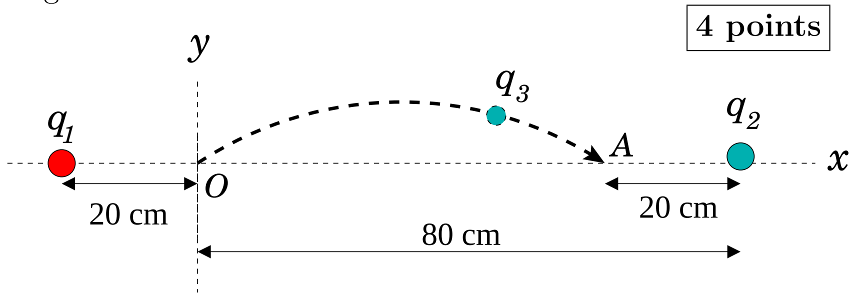
4 points

<u>Solution:</u> The speeds of the particles are zero at the distance of closest apparoach. The work-energy principle is

$$\text{KE}_i + \text{PE}_i = \text{KE}_f + \text{PE}_f$$
$$\implies 2 \times \left(\frac{1}{2}mv^2\right) + \frac{kq_1q_2}{1.5} = \frac{kq_1q_2}{0.2}$$
$$\implies mv^2 = q_2\left(\frac{kq_1}{0.2} - \frac{kq_1}{1.5}\right)$$
$$\implies 4.5 \times 10^{-7} = q_2 \times (-78.0)$$
$$\implies q_2 = -5.8 \times 10^{-9} \text{ C}$$

6. Two point charges $q_1 = -4.0\ \mu$C and $q_2 = +6.0\ \mu$C are fixed on the x-axis as shown. A third charged particle $q_3 = -2.0\ \mu$C is picked **from rest** at the origin O by an external agent and moved to point A. The kinetic energy of q_3 at A is $\text{KE}_A = 0.84$ J. How much work is done by the external agent?

4 points



Solution: The work-energy principle is

$$W_{ext} + \text{PE}_O + \text{KE}_O = \text{PE}_A + \text{KE}_A$$
$$\implies W_{ext} + \left(\frac{kq_1q_3}{0.2} + \frac{kq_2q_3}{0.8}\right) + 0.0 = \left(\frac{kq_1q_3}{0.8} + \frac{kq_2q_3}{0.2}\right) + \text{KE}_A$$
$$\implies W_{ext} + (0.36 - 0.135) + 0.0 = (0.09 - 0.54) + 0.84$$
$$\implies W_{ext} = +0.165 \text{ J}$$

7. A charged and isolated (**disconnected from the battery**) air-filled parallel-plate capacitor with thickness $d = 2.0$ mm has PE $= 4.8 \times 10^{-4}$ J of energy. If its thickness is increased to $d' = 5.0$ mm and a dielectric slab with $K = 3.4$ is inserted to fill the gap between the plates, find the energy now stored in this capacitor.

4 points

Solution: The new and old capacitances are related by

$$\frac{C'}{C} = \left(\frac{K}{1.0}\right)\left(\frac{A}{A}\right)\left(\frac{2.0 \times 10^{-3}}{5.0 \times 10^{-3}}\right) \implies \frac{C'}{C} = 1.36$$

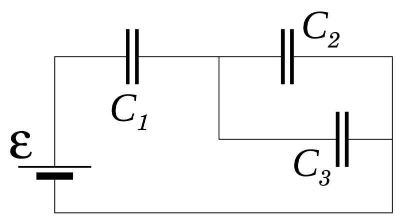
In this case, the charge Q in the capacitor remains unchanged. So

$$\left.\begin{aligned} \text{PE} &= \frac{Q^2}{2C} \\ \text{PE}' &= \frac{Q^2}{2C'} \end{aligned}\right\} \implies \frac{\text{PE}}{\text{PE}'} = \frac{C'}{C} = 1.36$$

$$\implies \text{PE}' = \frac{\text{PE}}{1.36} = 3.5 \times 10^{-4} \text{ J}$$

8. Three capacitors are connected to a source of emf $\varepsilon = 15.0$ V as shown in the circuit. The capacitance C_1 is unknown, but $C_2 = 12.0$ nF and $C_3 = 20.0$ nF. If the plate-charge on C_3 is $Q_3 = 60$ nC, find C_1.

5 points



Solution: We have

$$V_3 = \frac{Q_3}{C_3} = 3.0 \text{ V}$$

Then

$$C_2 \text{ and } C_3 \text{ are parallel} \implies \begin{aligned} C_{23} &= C_2 + C_3 = 32.0 \text{ nF} \\ V_{23} &= V_3 = 3.0 \text{ V} \\ Q_{23} &= C_{23}V_{23} = 96.0 \text{ nC} \end{aligned}$$

$$C_1 \text{ and } C_{23} \text{ are in series} \implies \begin{aligned} Q_1 &= Q_{23} = 96.0 \text{ nC} \\ V_1 &= \varepsilon - V_{23} = 12.0 \text{ V} \\ \implies C_1 &= \frac{Q_1}{V_1} = 8.0 \text{ nF} \end{aligned}$$