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19/MHS01/272

MBBS PHY 102

Question Solutions.

Section A

1a. Method of induction involves getting an object charged without actually touching it.

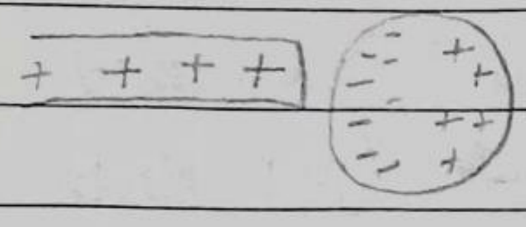


Fig. 1

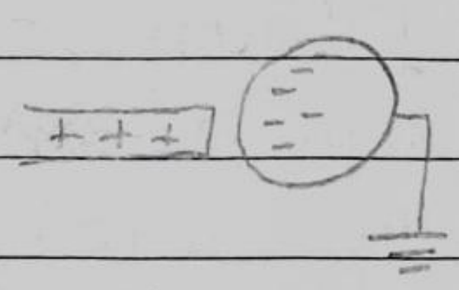


Fig. 2

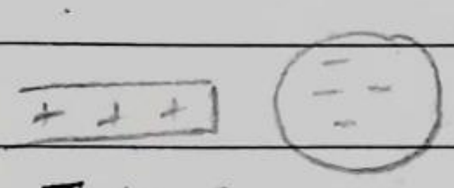


Fig 3

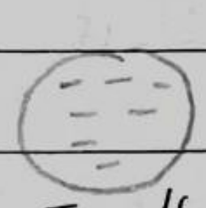


Fig 4

In the above diagrams, Fig 1 shows a neutral conducting sphere that is insulated with no conducting path used. After the charged rod is brought near, the charges separate. The sphere is then grounded as shown in Fig 2 which leaves only negative charges as shown in Fig 3. The rod is then removed, leaving the sphere negatively charged.

1b. $q_1 + q_2 = 5.0 \times 10^{-5} C$

$F = 1.0N$

$r = 2.0m$

$q_1 = ?, \; q_2 = ?$

$$F = \frac{kq_1q_2}{r^2}$$

$$k = 9 \times 10^9 \, Nm^2C^{-2}$$

$$q_1q_2 = \frac{Fr^2}{k}$$

$$q_1q_2 = \frac{1 \times 2 \times 2}{9 \times 10^9}$$

$$q_1q_2 = 4.44 \times 10^{-10}$$

$$q_1 = 5.0 \times 10^{-5} - q_2$$

$$q_2(5.0 \times 10^{-5} - q_2) = 4.44 \times 10^{-10}$$

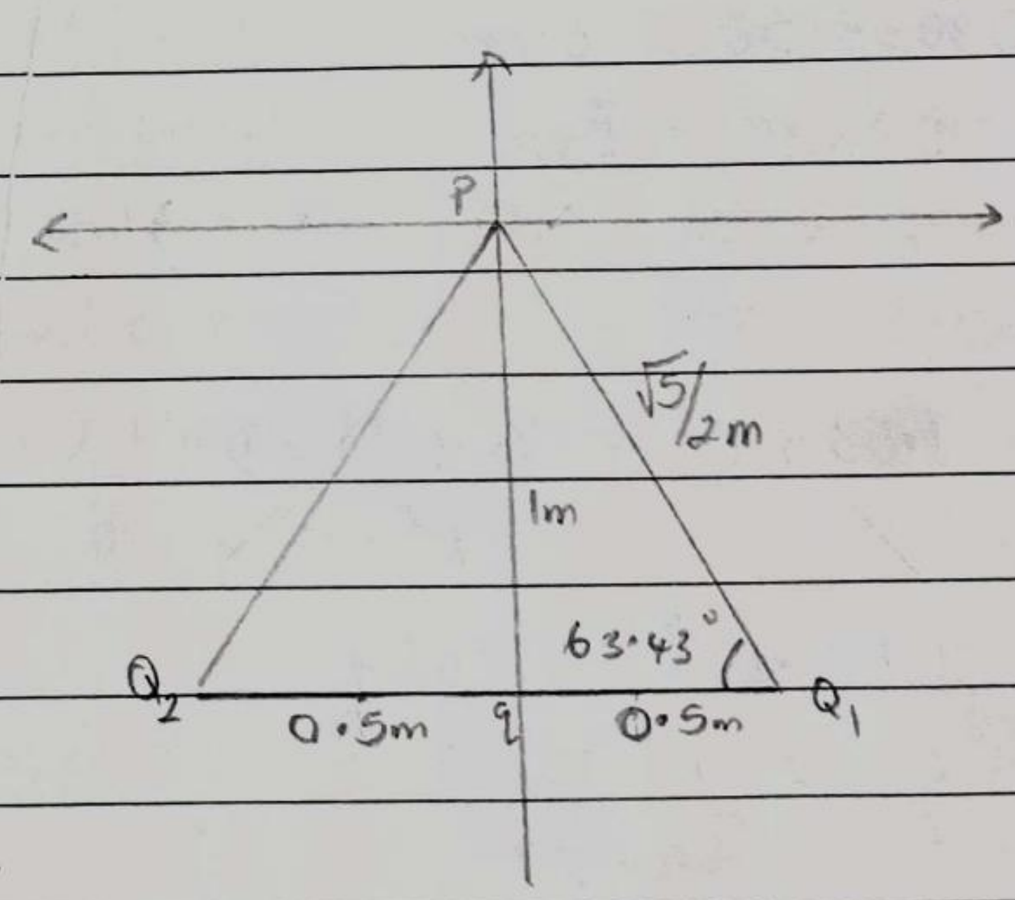
$$5.0 \times 10^{-5} q_2 - q_2^2 = 4.44 \times 10^{-10}$$

$$q_2^2 - 5.0 \times 10^{-5} q_2 + 4.44 \times 10^{-10} = 0$$

$$\therefore q_1 = 3.84 \times 10^{-5}$$

$$q_2 = 1.15 \times 10^{-5}$$

1c.



Given $Q_1 = Q_2 = 8\mu C = 8 \times 10^{-6}$, $d = 0.5m$

$$E = \frac{kq}{r^2}$$

$$E_{Q_2} = E_{Q_1} = \frac{(9 \times 10^{+9}) \times (8 \times 10^{-6})}{\left(\frac{\sqrt{5}}{2}\right)^2}$$

$$E_{Q_2} = E_{Q_1} = 5.76 \times 10^4 \, NC^{-1}$$

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$E_{Q_1x} = 5.76\times10^4 \times \cos 63.43$

$= 25763.95$

$E_{Q_1x} = 5.76\times10^4 \times \sin 63.43$

$= 51516.78$

$E_{Q_2x} = -25763.95$

$E_{Q_2Y} = 51516.78$

$\vec{E_x} = 25763.95 + (-25763.95)$

$= 0$

$\vec{E_Y} = E_{Q_1Y} + E_{Q_2Y} + E_{qp}$

$\vec{E_Y} = 51516.78 + 51516.78 + E_{qp}$

$\vec{E_Y} = 103033.56 + E_{qp}$

$0 = 103033.56 + E_{qp}$

$-103033.56 = E_{qp}$

$-1.03\times10^5 = E_{qp}$

$E = \frac{kq}{r^2}$

$1.03\times10^5 = \frac{(9\times10^9)\times q}{1^2}$

$1.03\times10^5 = 9\times10^9 q$

$q = \frac{1.03\times10^5}{9\times10^9}$

$q = 1.14\times10^{-5}$

$q = 11.\times10^{-6}C$

2a) Electric field - It is the region of space in which an electric charge will experience electric force.

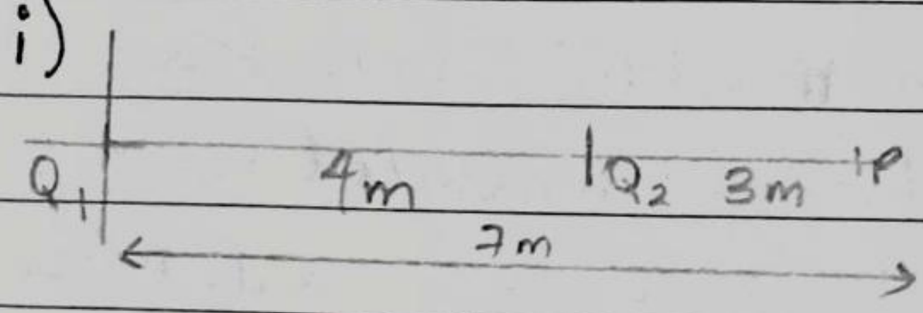
Electric field Intensity - It is the force experienced by a test object per unit charge.

Deduction - Electric field intensity is the force experienced by an object in an electric field. Therefore, electric field intensity cannot exist without an electric field.

2b. $Q_1 = 8nC = 8\times10^{-9}C$

$Q_2 = 12nC = 12\times10^{-9}C$

i)



$E_{P_1} = \frac{kQ_1}{r^2} = \frac{(9\times10^9)\times(8\times10^{-9})}{(7\times7)}$

$= 1.469 NC^{-1}$

$E_{P_2} = \frac{kQ_2}{r^2} = \frac{(9\times10^9)\times(12\times10^{-9})}{(3\times3)}$

$= 12NC^{-1}$

Vector	Angle	x-component	Y-comp.
1.469	0	1.47	0
12	0	12	0
		$\Sigma f_x = 13.47$	$\Sigma f_y = 0$

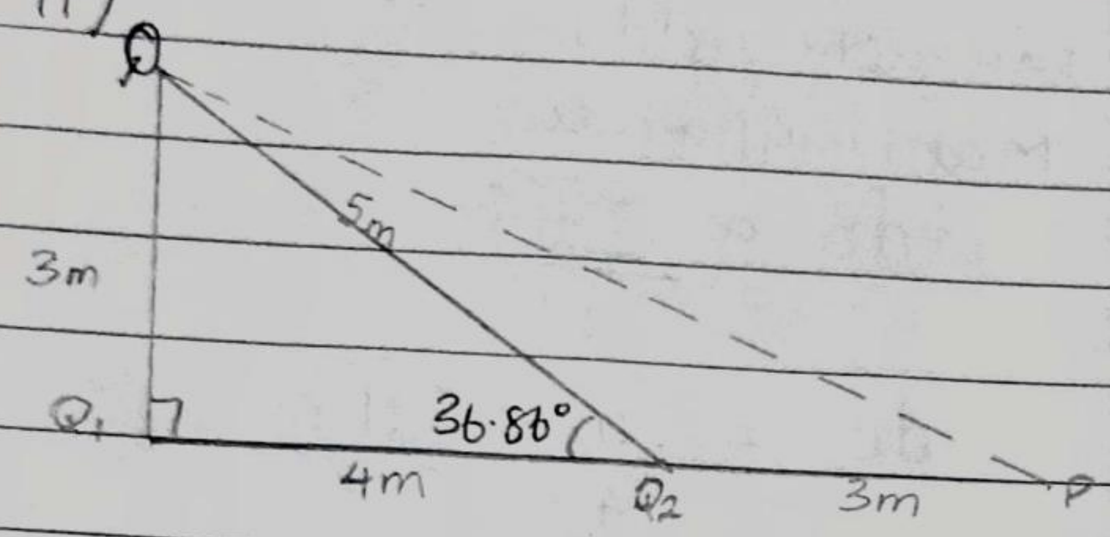
$E = \sqrt{\Sigma f_x^2 + \Sigma f_y^2} = \sqrt{(13.47)^2 + (0)^2}$

$E = \sqrt{(13.47)^2} = 13.47$

$E = 13.47\,NC^{-1}$

$E \simeq 13.5\,NC^{-1}$

ii)



$\sin\theta = 3/5$, $\sin\theta = 0.6$

$\theta = \sin^{-1} 0.6 = 36.86°$

$E_{Q-Q_1} = \frac{kQ}{r^2} = \frac{(9\times10^9)\times(8\times10^{-9})}{3\times3}$

$= 8\,NC^{-1}$

$E_{Q-Q_2} = \frac{kQ}{r^2} = \frac{(9\times10^9)\times(12\times10^{-9})}{5\times5}$

$= 4.32\,NC^{-1}$

Vector	Angle	Y-comp. (× sinθ)	X-comp. (× cosθ)
8	0	0	8
4.32	36.86	2.59	3.46
		$\Sigma f_y = 2.59$	$\Sigma f_x = 11.46$

$E = \sqrt{\Sigma f_x^2 + \Sigma f_y^2}$

$E = \sqrt{(2.59)^2 + (11.46)^2}$

$E = \sqrt{138.0397}$

$E = 11.75\,NC^{-1}$

SECTION B

4a) Magnetic flux is a measurement of the total magnetic field which passes through a given area and it is represented by lines of force. Every field line passing through a magnetic field contributes some magnetic flux.

When calculating magnetic flux, we include only the component of the magnetic field vector which is normal to our test area. For example, if we choose a simple flat surface with area "A" as our test area and there is an angle θ between the normal to the surface and a magnetic field vector (magnitude B), then the magnetic flux is

$\Phi = BA\cos\theta$.

4b.) $m = 9.11\times10^{-31}\,kg$ $q = 1.6\times10^{-19}$

$r = 1.4\times10^{-7}\,m$

$B = 3.5\times10^{-1}$

$\theta = 90°$, $\sin 90 = 1$

$\omega = \frac{v}{r}$, $v = \frac{rqB}{m}$

$v = \frac{1.4\times10^{-7}\times1.6\times10^{-19}\times3.5\times10^{-1}}{9.11\times10^{-31}}$

$v = 8605.93$

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$$\omega = \frac{v}{r} = \frac{8605.93}{1.4\times10^{-7}}$$

$$\omega = \underline{6.15\times10^{10}} \text{ rads}^{-1}$$

4c) Cyclotron frequency is the same thing as angular speed "ω" which is measured in rads⁻¹. In finding the cyclotron frequency, the velocity of the electron needs to be found. The velocity is derived from the equation,

$$r = \frac{mv}{qB}, \text{ which gives}$$

$$v = \frac{rqB}{m}, \text{ which means}$$

that velocity is proportional to the product of the radius of the circular path, the charge on the particle and the magnetic field and inversely proportional to its mass. From this, we then find the cyclotron frequency which is given as,

$$\omega = \frac{v}{r}.$$

5a) The Biot-Savart law states that the magnetic field "$\vec{dB}$", is directly proportional to the product of the current, the length element of the wire "$\vec{dl}$" and the unit vector "$\hat{r}$" directed toward P (a point in the magnetic field) and inversely proportional to "r^2" the square of the distance from the length element and point P (a point on the magnetic field).

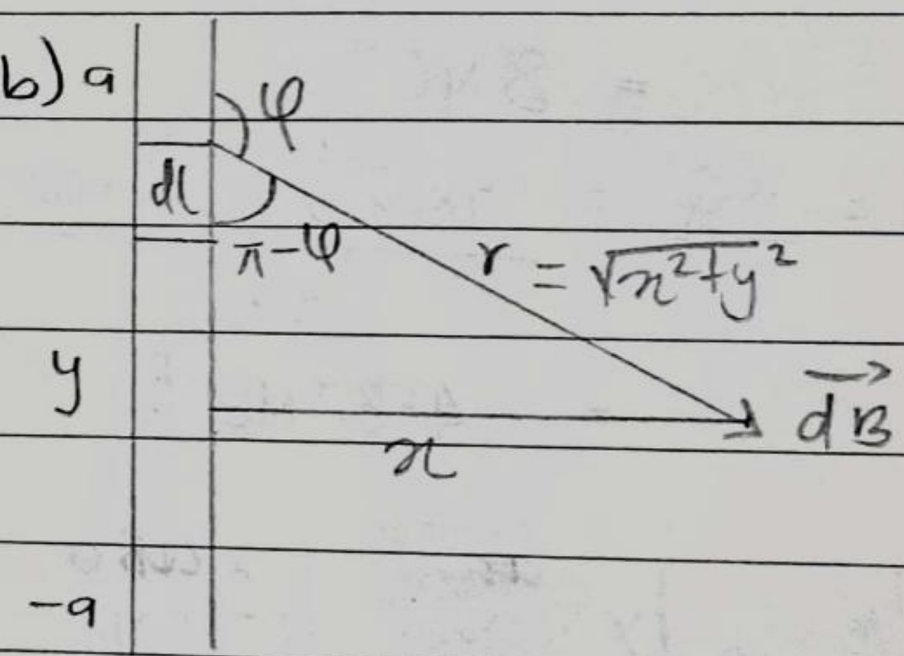
Mathematically,

$$\vec{dB} \propto \frac{I\vec{dl}\hat{r}}{r^2}$$

$$\vec{dB} = \frac{\mu_0}{4\pi} \times \frac{I\vec{dl}\hat{r}}{r^2}$$

where $\mu_0 = 4\pi\times10^{-7}$ and is the constant which is referred to as the "Permeability of free space".

5b) a



$$B = \frac{\mu_0 I}{4\pi}\int_{-a}^{a} \frac{dl\sin\varphi}{r^2}$$

$$\sin\theta = \sin(\pi-\varphi) - r\wedge\vec{dl}$$

$$B = \frac{\mu_0 I}{4\pi}\int_{-a}^{a} \frac{dl\sin\theta}{r^2}$$

$$B = \frac{\mu_0 I}{4\pi}\int_{-a}^{a} \frac{dl\sin(\pi-\varphi)}{x^2+y^2}$$

$$\sin(\pi-\varphi) = \frac{x}{\sqrt{x^2+y^2}}$$

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$$B = \frac{\mu_0 I}{4\pi}\int_{-a}^{a} dl \frac{x}{(x^2+y^2)(x^2+y^2)^{1/2}}$$

$$B = \frac{\mu_0 I}{4\pi}\int_{-a}^{a} dl \frac{x}{(x^2+y^2)^{3/2}}$$

$$dl = dy$$

$$B = \frac{\mu_0 I}{4\pi}\int_{-a}^{a} \frac{x}{(x^2+y^2)^{3/2}} dy$$

$$B = \frac{\mu_0 I x}{4\pi}\int_{-a}^{a} \frac{1}{(x^2+y^2)^{3/2}} dy$$

By using special integrals:

$$\int \frac{dy}{(x^2+y^2)^{3/2}} = \frac{1}{x^2} \times \frac{y}{(x^2+y^2)^{1/2}}$$

$$B = \frac{\mu_0 I}{4\pi x}\left(\frac{2a}{(x^2+a^2)^{1/2}}\right)$$

as $a \longrightarrow \infty$, $(x^2+a^2)^{1/2} \cong a$

$$B = \frac{\mu_0 I}{{}_2\cancel{4}\pi x}\left(\frac{\cancel{2}\cancel{a}}{\cancel{a}}\right)$$

$$B = \frac{\mu_0 I}{2\pi x}$$

when in a circle of radius r,

$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

QED