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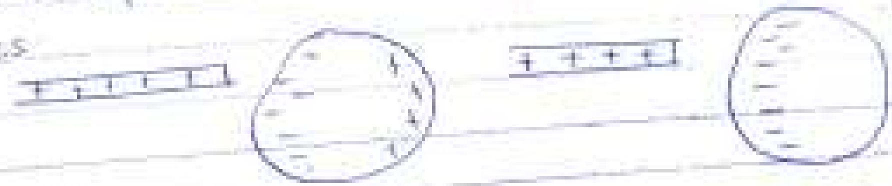
SECTION A 1 & 3

1a) Explain with the aid of a diagram, how you can produce a positively charged sphere by method of induction.

Answer: If a positively charged rod is brought near a neutral conducting sphere that is insulated so that there is no conducting path to ground, the repulsive force between the protons in the rod and those in the sphere causes a redistribution of charges on the sphere so that the protons move to the side of the sphere farthest from the rod. The region of the sphere nearest to the positively charged rod has an excess of negative charges because of migration of protons away from this location. If the sphere is grounded with a conducting wire, some of the protons leave the sphere and travel to the earth. If the wire is removed, the conducting sphere is left with an excess of induced negative charges



1b) $q_1 + q_2 = 5.0 \times 10^{-5} C$, $F = 1.0N$, $r = 2m$

$q_1 = ?$, $q_2 = ?$

Solution

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

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

$F = \frac{k q_1 q_2}{r^2}$

$1 = \frac{9 \times 10^9 \times q_1 (5.0 \times 10^{-5} - q_1)}{2^2}$

$4 \times 1 = 9 \times 10^9 (5.0 \times 10^{-5} q_1 - q_1^2)$

$4 = 4.5 \times 10^5 q_1 - 9 \times 10^9 q_1^2$

$9 \times 10^9 q_1^2 - 4.5 \times 10^5 q_1 + 4 = 0$

$a = 9{,}000{,}000{,}000$, $b = 450{,}000$, $c = 4$

Using, $q_1 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$q_1 = \frac{-450{,}000 \pm \sqrt{(450{,}000)^2 - 4(9{,}000{,}000{,}000 \times 4)}}{2(9{,}000{,}000{,}000)}$

$$q_1 = \frac{-450,000 \pm \sqrt{202500000000 - 4(36,000,000,000)}}{18,000,000,000}$$

$$q_1 = \frac{-450,000 \pm \sqrt{202,500,000,000 - 144,000,000,000}}{18,000,000,000}$$

$$q_1 = \frac{-450,000 \pm \sqrt{58,500,000,000}}{18,000,000,000}$$

$$q_1 = \frac{-450,000 \pm 241867.7324896}{18,000,000,000}$$

$$q_1 = \frac{-450,000 + 241867.7324896}{18,000,000,000} \quad \text{or} \quad q_1 = \frac{-450,000 - 241867.7324896}{18,000,000,000}$$

$$q_1 = \frac{-208,132.2675104}{18,000,000,000} \quad \text{or} \quad q_1 = \frac{-691867.7324896}{18,000,000,000}$$

$$q_1 = -1.16 \times 10^{-5}\,C \quad \text{or} \quad 3.84 \times 10^{-5}\,C$$

$$q_2 = 5.0 \times 10^{-5} - 3.84 \times 10^{-5}\,C$$

$$q_2 = 1.16 \times 10^{-5}\,C$$

c) $Q_1 = Q_2 = 9\,\mu C$, $d = 0.5m$, $q = ?$

To find r_1 and r_2 using pythagoras theorem

$r_1^2 = (2(0.5))^2 + 0.5^2$

$r_1^2 = 1^2 + 0.5^2$

$r_1^2 = 1 + 0.25$

$\sqrt{r_1^2} = \sqrt{1.25}$

$r_1 = r_2 = 1.12m$

To find E_1 : $E_1 = \frac{kq_1}{r_1^2} = \frac{9\times10^9 \times 8\times10^{-6}}{1.12^2} = 57397.96$

$E_1 = E_2 = 57397.96$ N/C

$E_q = \frac{\cancel{kq}}{\cancel{r}} = \frac{9\times10^9 q}{1^2} = 9\times10^9 q$

To find the angle E_1 and E_2 makes $= \tan\theta = \frac{1}{0.5}$

$\tan\theta = 2$; $\theta = \tan^{-1} 2$; $\theta = 63.4°$

Vector	Angle	X component	Y component
E_1	63.4°	$-57397.96\cos 63.4$	$57397.96\sin 63.4$
		$= -25{,}700.46$	$= 51{,}322.62$
E_2	63.4°	$+25{,}700.46$	$51{,}322.62$
E_q	90°	$9\times10^9 q \times \cos 90 = 0$	$9\times10^9 q \times \sin 90 = 9\times10^9 q$

$\sum E_x = 0$

$\sum E_y = 102645.24 + 9\times10^9 q$

$$E_p = \sqrt{\sum E_x^2 + \sum E_y^2}$$

$$E_p = \sqrt{0^2 + (102645.26 + 9\times10^9 q)^2}$$

$$E_p = \sqrt{(102645.26 + 9\times10^9 q)^2}$$

$$E_p = 102645.26 + 9\times10^9 q$$

but electric field at $P = 0$

$$0 = 102645.26 + 9\times10^9 q$$

$$\frac{-102645.26}{9\times10^9} = \frac{9\times10^9 q}{9\times10^9}$$

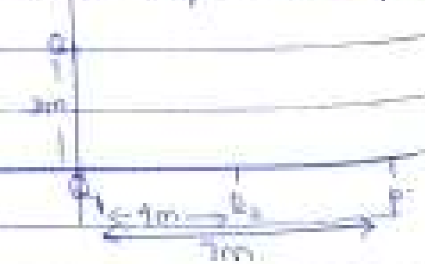
$$q = 1.14\times10^{-5}\ C$$

3) An electric field is the region of space where an electric charge will experience an electric force while electric field intensity can be defined as the strength of an electric field or force per unit charge.

b) $Q_1 = 8\times10^{-9}C$, $Q_2 = 12\times10^{-9}C$, $x = 4m$

$E_p = ?$ at $x = 7m$, $E_q = ?$ at $q = 3m$

(i)



$E_1 = \frac{kq_1}{r_1^2} = \frac{9\times10^9 \times 8\times10^{-9}}{7^2} = \frac{9\times10^9\times8\times10^{-9}}{49} = 1.47 N/C$

$E_2 = \frac{kq_2}{r_2^2} = \frac{9\times10^9 \times 12\times10^{-9}}{3^2} = \frac{9\times10^9\times12\times10^{-9}}{9} = 12 N/C$

$E_{net} = (1.47 + 12) N/C$

$E_{net} = 13.47 N/C$

ii) For q at $y = 3m$,

$E_1 = \frac{kq_1}{r_1^2} = \frac{9\times10^9\times8\times10^{-9}}{3^2} = \frac{72}{9} = 8N/C$

To find r_2 using pythagoras theorem

$r_2^2 = 3^2 + 4^2$

$r_2^2 = 9+16$

$\sqrt{r_2^2} = \sqrt{25}$

$r_2 = 5$

$E_2 = \frac{kq_2}{r_2^2} = \frac{9\times10^9\times12\times10^{-9}}{5^2} = \frac{108}{25} = 4.32 N/C$

~~vector~~ To find the angle E_2 makes,

$\tan\theta = \frac{3}{4}$; $\tan\theta = 0.75$; $\theta = \tan^{-1} 0.75$

$\theta = 36.9°$

Vector	Angle	X component	Y component
$E_1 = 8N/C$	$90°$	$8\cos 90 = 0$	$8\sin 90 = 8$
$E_2 = 4.32N/C$	$36.9°$	$4.32\cos 36.9 = 3.45$	$4.32\sin 36.9 = 2.59$
		$\Sigma E_x = 3.45$	$\Sigma E_y = 10.59$

$E_q = \sqrt{\Sigma E_x^2 + \Sigma E_y^2}$

$E_q = \sqrt{10.59^2 + 3.45^2} = \sqrt{3.45^2 + 10.59^2}$

$E_q = \sqrt{112.1481 + 11.9025}$

$E_q = \sqrt{124.0506}$

$E_q = 11.14 N/C$

To find the direction of the electric field of q_1

$\tan\theta = \frac{\mathcal{E}_y}{\mathcal{E}_x}$

$\tan\theta = 3.0696$

$\theta = \tan^{-1} 3.0696$

$\theta = 71.96°$

SECTION B : 4 & 5 -

4a) Magnetic flux can be defined as the strength of the magnetic field represented by lines of force. It can also be defined as the number of magnetic field lines passing through a given closed surface area. It can also be defined as the product of the magnetic field, the perpendicular area and the angle between the plane area and the magnetic flux. It gives the measurement of the total magnetic field that passes through a given surface. The SI unit is Weber (Wb) and it is represented as Φ

$\Phi = BA\cos\theta$

b) $m = 9.11 \times 10^{-31} kg$, $r = 1.4 \times 10^{-7} m$, $B = 3.5 \times 10^{-1} Wbm^{-2}$

$q = -1.6 \times 10^{-19}$

$$\omega = \frac{qB}{m}$$

$$\omega = \frac{-1.6 \times 10^{-19} \times 3.5 \times 10^{-1}}{9.11 \times 10^{-31}}$$

$$\omega = -6.15 \times 10^{10} \text{ radsec}^{-1}$$

c) The cyclotron frequency is also referred to as angular speed (ω) because the charged particle circulates at this angular frequency or speed in the type of accelerator called CYCLOTRON. The cyclotron frequency or angular speed is -6.15×10^{10} radsec^{-1} (negative) because the charged particle is an electron.

5) Biot Savart's Law states that the magnitude of the magnetic field is directly proportional to the length element dl, current and unit vector $\hat{r}$ and is inversely proportional to the square of the distance between dl and P with the constant called permeability of free

space which is $4\pi \times 10^{-7}$ T-m/A.

b) Using Biot Savart's law to show that the magnitude of the magnetic field by a straight current carrying conductor is given as

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

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

$$\sin(\pi-\theta) = \sin\theta$$

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

From the diagram, $r^2 = x^2+y^2$ (Pythagoras theorem)

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

$$\text{But } \sin(\pi-\theta) = \frac{x}{\sqrt{x^2+y^2}} = \frac{x}{(x^2+y^2)^{1/2}} \quad (2)$$

Put (1) into (2)

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

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

Recall $dL = dy$ (3)

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

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

Equation (2) becomes

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

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

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

When the length of a conductor is very great in comparison to the distance x from point P, we consider it infinitely long. That is, when a is much larger than x:

$$(x^2+a^2)^{1/2} \simeq a, \text{ as } a \to \infty$$

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

In a physical situation, we have axial symmetry about the y axis. Thus, at all points in a circle of radius r, around the conductor, the magnitude of B is

$B = \frac{\mu_0 I}{2\pi r}$ and this defines the magnitude of the magnetic field flux density B near a long straight current carrying conductor.