PHY 102

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MECHATRONICS ENGINEERING
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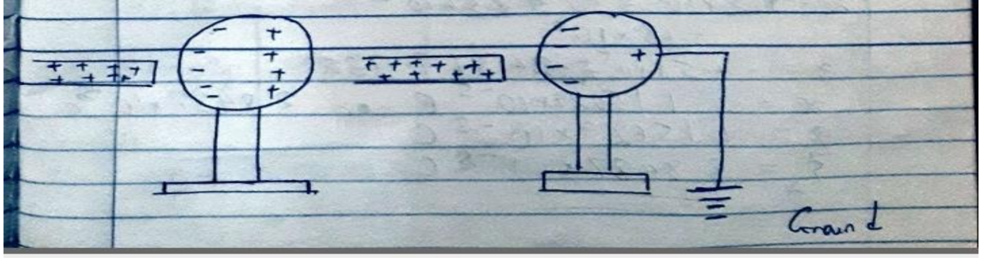
1a Explain with the aid of diagram how you can produce a negatively charged sphere by method of induction

Consider a positively charged rubber rod brought near a neutral (uncharged) 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 some protons move to the side of the sphere farthest away from the rod. The region of the sphere nearest the positively charged rod has an excess negative charge because of the migration of protons away from this location. If a grounded wire is connected to the sphere, some of the protons leave the sphere and travel to the earth. If the wire to ground is then removed the conducting sphere is left with an excess of induced negative charge.

Finally, when the rubber rod is removed from the vicinity of the sphere, the induced negative charge remains on the ungrounded sphere and becomes uniformly distributed



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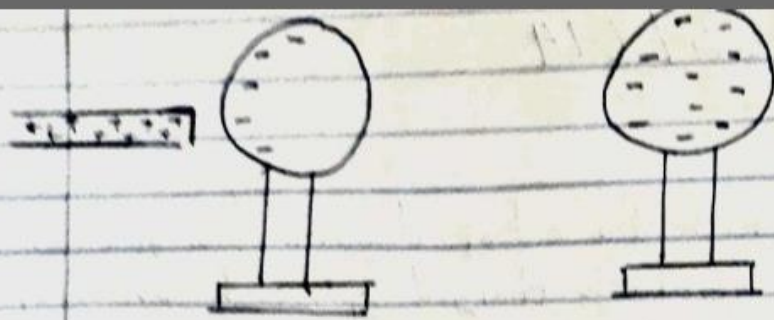


1b Each of two small spheres is ~~charged~~ charged positively, they combined charge being 5.0×10^{-5} C. If each sphere is repelled from the other by a force of 1.0N when the spheres are 2.0m apart, calculate the charge on each sphere.

$q_1 + q_2 = 5.0 \times 10^{-5}$ $f = 1N$ $r = 2m$

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

$f = \frac{k q_1 q_2}{r^2}$ $1 = \frac{9 \times 10^9 \times (5.0 \times 10^{-5} - q_2) q_2}{2^2}$

$4 = (4.5 \times 10^5 - 9 \times 10^9 q_2) q_2$

$4 = 4.5 \times 10^5 q_2 - 9 \times 10^9 q_2^2$

$-9 \times 10^9 q_2^2 + 4.5 \times 10^5 q_2 - 4 = 0$

Using quadratic formula $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$x = \frac{-4.5 \times 10^5 \pm \sqrt{(4.5 \times 10^5)^2 - 4(-9 \times 10^9)(-4)}}{2(-9 \times 10^9)}$

$x = \frac{-4.5 \times 10^5 \pm \sqrt{5.85 \times 10^{10}}}{-18 \times 10^9}$

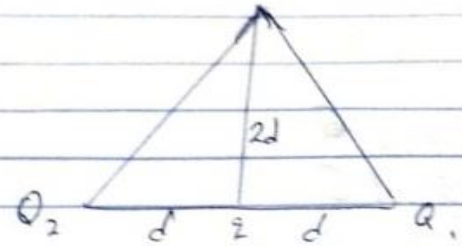
$x = -4.5 \times 10^5 \pm 241867.732$

$x = 1.15629 \times 10^{-5}$ C or 3.8437×10^{-5} C

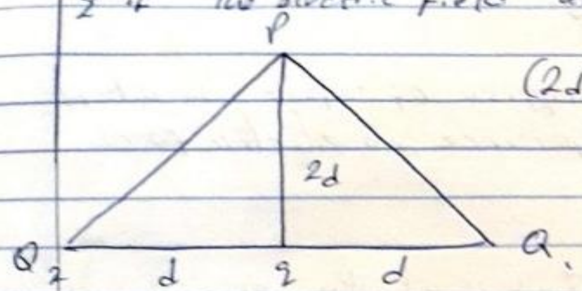
$q_1 = 1.15629 \times 10^{-5}$ C

$q_2 = 3.8437 \times 10^{-5}$ C

1c



Three charges were positioned as shown in the figure above. If $Q_1 = Q_2 = 8\,\mu C$ and $d = 0.5m$ determine q if the electric field at P is zero.



$(2d)^2 + d^2 = 5d^2$

$\sqrt{5d^2} = d\sqrt{5}$

$\sin\theta = \frac{2d}{d\sqrt{5}} = \frac{2}{\sqrt{5}}$

$\theta = \sin^{-1} 2/\sqrt{5} = 63.43^\circ$ $\quad d = 0.5m$

$E_1 = \frac{kQ_1}{r^2} = \frac{9\times10^9 \times 8\times10^{-6}}{(\sqrt{5}/2)^2} = 57600\,NC^{-1}$

$E_2 = \frac{kQ_2}{r^2} = \frac{9\times10^9 \times 8\times10^{-6}}{(\sqrt{5}/2)^2} = 57600\,NC^{-1}$

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

E	θ	$E_x = E\cos\theta$	$E_y = E\sin\theta$
57600	63.43°	-25763.953	51516.781
57600	63.43°	25763.953	51516.781
$9.0\times10^9 q$	90°	0	$9.0\times10^9 q$
		0	$103033.562 + 9\times10^9 q$

$E = \sqrt{(103033.562 + 9\times10^9 q)^2 + 0^2}$

$0 = 103033.562 + 9\times10^9 q$

$-9\times10^9 q = 103033.562$

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$$q = \frac{103033.56^2}{-9\times10^{-9}}$$

$$q = -11.448\times10^{-6}$$

$$q = \underline{\underline{-11.448\,\mu C}}$$

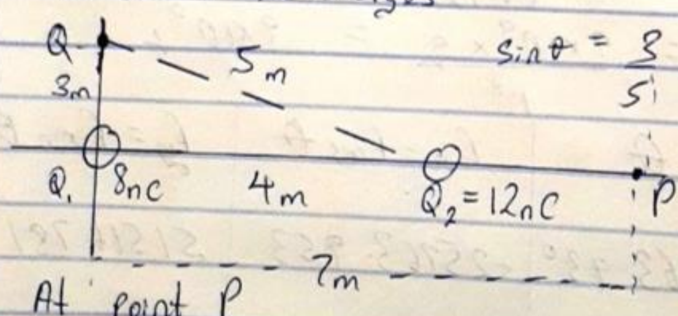
2a Distinguish between the terms electric field and electric field intensity.

Electric field is a region of space in which electric charge will experience an electric force.

2b A positive charge $Q_1 = 8nC$ is at the origin and a second positive charge $Q_2 = 12nC$ is on the x-axis at $x = 4m$. Find

i) The net electric field at point P on the x axis at $x = 7m$

ii) The electric field at a point Q on the y axis at $y = 3m$ due to the charges



$\sin\theta = \frac{3}{5}$ $\quad \theta = \sin^{-1}(3/5)$

$\theta = 36.87°$

At point P

$$E_1 = \frac{Kq_1}{r^2} = \frac{9\times10^9 \times 8\times10^{-9}}{7^2} = 1.46939\ NC^{-1}$$

$$E_2 = \frac{Kq_2}{r^2} = \frac{9\times10^9\times 12\times10^{-9}}{3^2} = 12\ NC^{-1}$$

$$E_{net} = E_1 + E_2 = 12 + 1.46939 = \underline{\underline{13.46939\ NC^{-1}}}$$

2bii At point Q

$E_1 = \frac{kq_1}{r^2} = \frac{9\times10^{9} \times 8\times10^{-9}}{3^2} = 8\ NC^{-1}$

$E_2 = \frac{kq_2}{r^2} = \frac{9\times10^{9} \times 12\times10^{-9}}{5^2} = 4.32\ NC^{-1}$

E	θ	$E_x = E\cos\theta$	$E_y = E\sin\theta$
8	90	0	+8
4.32	36.87	3.456	2.592
		$3.456\ NC^{-1}$	$10.592\ NC^{-1}$

$E_{net} = \sqrt{E_x^2 + E_y^2}$

$E_{net} = \sqrt{(3.456)^2 + (10.592)^2}$

$E_{net} = \underline{11.14156\ NC^{-1}}$

SECTION B

4a What is Magnetic flux?

Magnetic flux is defined as the strength of magnetic field represented by lines of force. It is usually represented by the symbol Φ.

4b An electron with a rest mass of 9.11×10^{-31} kg moves in a circular orbit of radius 1.4×10^{-7} m in a uniform magnetic field of 3.5×10^{-1} Weber/m^2, perpendicular to the speed with which electron moves. Find the cyclotron frequency on the moving electron.

$\frac{mv^2}{r} = qvB \qquad \omega = v/r$

$mv\omega = qvB$

$m\omega = qB$

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

$$\omega = \frac{1.6\times10^{-19} \times 3.5\times10^{-1}}{9.11\times10^{-31}}$$

$$\omega = \underline{\underline{6.14709\times10^{10}}} \text{ rads}^{-1}$$

4c Discuss your answer in 4b above

This states that an ~~electron~~ electron mass 9.11×10^{-31} Kg and charge 1.6×10^{-19} C in motion in a magnetic field of 3.5×10^{-1} Tesla perpendicular with the field will have an angular frequency of 6.14709×10^{10} rads^{-1}

5a State Biot-Savart law

1 The vector $\vec{dB}$ is perpendicular both to $\vec{dl}$ (which points in the direction of the current) and to the unit vector $\hat{r}$ directed from $\vec{dl}$ toward P.

2 The magnitude of $\vec{dB}$ is inversely proportional to r^2 where r is the distance from $\vec{dl}$ to P

3 The magnitude of $\vec{dB}$ is proportional to the current I and to the magnitude of the length element $\vec{dl}$

4 The magnitude of $\vec{dB}$ is proportional to $n\theta$, where θ is the angle between $\hat{r}$ and $\vec{dl}$.

These observations are summarized in the mathematical expression known as Biot-savart Law.

~~5b Using the Bio~~ $$\vec{dB} = \frac{\mu_0 I}{4\pi} \cdot \frac{\vec{dl} \times \hat{r}}{r^2}$$

where $\vec{dB}$ = Magnetic field vector in Tesla
I = current

5b. Using the Biot-Savart Law, show [that the] magnitude of the magnetic field of a straight current carrying conductor is given as

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

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

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

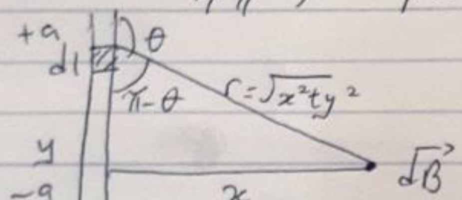
$$B = \frac{\mu_0 I}{4\pi} \int \frac{\vec{dl} \times \hat{r}}{r^2}$$

$\vec{dl} \times \hat{r} = dl\, r \sin\theta$

r = unit vector $= 1$

$dl\, \sin\theta$

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



$r = \sqrt{x^2 + y^2}$

$r^2 = x^2 + y^2$

$\theta = \pi - \theta$

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

$\sin(\pi - \theta) = x/r$

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

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

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

$dl \cong dy$

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

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

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

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

$$(x^2+a^2)^{1/2} \cong a$$

$a >> x$

$$B = \frac{\mu_0 I}{4\pi x} \cdot \frac{2a}{a}$$

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

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

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