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b) Charging by induction

Electric charges can be obtained on an object without touching it, by a process called electrostatic induction. Consider a negatively charged rubber rod brought near a neutral (uncharged) conducting sphere that is insulated so that there is no conducting path to ground as shown below. The repulsive force between the electrons in the rod and those in the sphere causes a redistribution of charges on the sphere so that some electrons move to the side of the sphere farthest away from the rod (fig 1.3a). The region of the sphere nearest the negatively charged rod has an excess of positive charge because of the migration of electrons away from this location. If a grounded conducting wire is then connected to the sphere, as in (fig 1.3b), some of the electrons leave the sphere and travel to the earth. If the wire to ground is then removed (fig 1.3c), the conducting sphere is left with an excess of induced positive charge.

Finally, when the rubber rod is removed from the vicinity of the sphere (fig 1.3d), the ~~uniformly~~ uniformly distributed over the surface of the sphere.

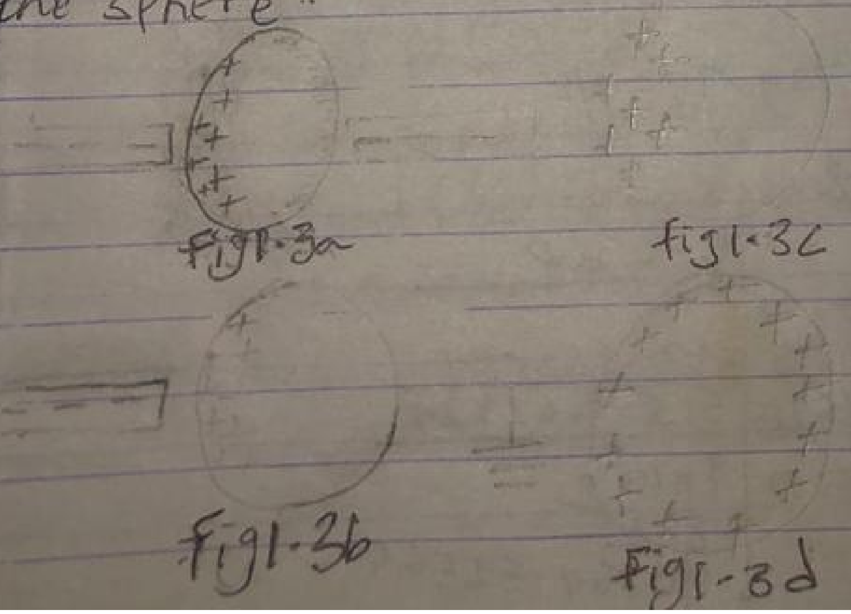


fig 1.3a fig 1.3c

fig 1.3b fig 1.3d

1b) $q_1 + q_2 = 5\times10^{-5}C$

$F = 1N$

$d = 2m$

Calculate the charge on each sphere.

Recall that

$k = 9\times10^9$

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

$L = \frac{9\times10^9(q_1 q_2 - 5\times10^{-5})}{2^2}$

$4 = 9\times10^9 \times 5\times10^{-5}q_1 + 9\times10^9 q_2$

$4 = 4.5\times10^5 q_1 + 9\times10^9 q_2$

It is a quadratic equation

$9\times10^9 q_2 - 4.5\times10^5 q + 4 = 0$

$q_1 = 0.0000111C$

$q_2 = 0.000038C$

$\therefore q_1 = 1.11\times10^{-5}C$

$\therefore q_2 = 3.8\times10^{-5}C$

1c) $Q_1 = Q_2 = 8\mu C$

$d = 0.5m$

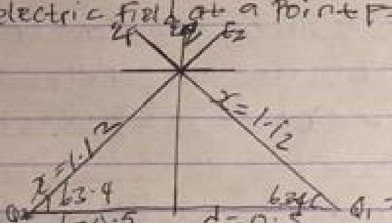
determine Q if electric field at a point P = zero

$\tan\theta = opp/adj$

$\tan\theta = 1/0.3 = 2$

$\theta = \tan^{-1}(2)$

$\theta = 6 = 63.4$




$x^2 = 1^2 + 0.5^2$

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

$x = \sqrt{1.25}$

$x = 1.12$

$E = \frac{kq_1}{r^2} = \frac{9\times10^9\times8\times10^{-6}}{(1.12)} = 5739.795918$

$E_1 = \frac{kq_1}{r^2} = \frac{9\times10^9\times8\times10^{-6}}{1.12^2} = 5739.795918$

$E_2 = \frac{kq}{r^2} = \frac{9\times10^9\times8\times10^{-6}}{1.12^2} = 5739.795918$

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

| vector | angle | x-comp | y-comp |
|---|---|---|---|
| $E_1 = 5739.795918$ | $63.4°$ | $E_1\times\cos\theta$ $= -2570.045785$ | $5132.262839$ |
| $E_2 = 5739.795918$ | $63.4°$ | $2570.045785$ | $5132.262839$ |
| $E_q = 9\times10^9 q$ | $90°$ | $E_1\cos\theta = 0$ $E_x = 0$ | $9\times10^9 q$ $E_y = 10264.52568$ |

magnitude $= \sqrt{(E_x)^2 + (E_y)^2}$

$E_q = \sqrt{(0)^2 + (10264.52568)^2}$

Since $E = 0$

$0 = 9\times10^9 q + 10264.52568$

Making q subject of the formula

$q = \frac{-10264.52568}{9\times10^9}$

$q = 1.140502853\times10^{-6}$

$\therefore q = 1.14\mu C$

3) Volume charge density,

$\rho = \frac{dQ}{dV} \rightarrow dQ = \rho dV$

ii) Surface charge density,

$\sigma = \frac{dQ}{dA} \rightarrow dQ = \sigma dA$

iii) Linear charge density,

$\lambda = \frac{dQ}{dL} \rightarrow dQ = \lambda dL$

3b) Electric potential difference

The electric potential difference between two points in an electric field can be defined as the work done per unit charge against electrical forces when a charge is transported from one point to the other. It is measured in volt (V) or Joules per coloumb (J/C). Electric potential difference is a scalar quantity.

Consider the diagram above, suppose a test charge $q_0$ is moved from point A to B along an arbitary path inside an electric field. The electric field exerts a force on the charge as shown in fig 3-1. To move the test charge from A to B at constant velocity, an external force of must act on the charge. There fore, the elemental work done is given as: $dw = F \cdot dL$ — ①

But $F = -q \cdot E$ — ②

substituting equ ② and ① yields

$dw = -q_0 E dL$ — ③

The total work done in moving the charge from A to B is:

$W[A \rightarrow B]A_q = -q_0 \int_A^B E dL$ — ④

From the definition of electric potential diff. it follows that:

$V_B - V_A = \frac{W(A\rightarrow B)A_q}{q_0}$ — ⑤

Putting equ ④ in ⑤ yields

$V_B - V_A = -\int_A^B E dL$ — ⑥

3c)

$r_1 = 4+x$, $Q_1 = 10\times10^{-6}C$

$r_2 = x$, $Q_2 = -2\times10^{-6}C$

$V_P = K\left[\frac{Q_1}{r_1} + \frac{Q_2}{r_2}\right]$

$$0=9\times10^{9}\left[\frac{10\times10^{-6}x+(4+x)(-2\times10^{-6}x)}{x(4+x)}\right]$$

$$0=7.2\times10^{4}x-7.2\times10^{4}$$

$$\frac{\cancel{-7.2\times10^{4}}x}{\cancel{-7.2\times10^{4}}}=\frac{\cancel{-7.2\times10^{4}}}{\cancel{-7.2\times10^{4}}}$$

$F_2=x_1=1m$

$F_1=4+x=4+1$

$F_1=5$

Positions are 1m and 5m

## section B

4a) Magnetic Flux is defined as the strength of the magnetic field which can be represented by line of forces. It is represented by the symbol $\Phi$. Mathematically given as $\Phi=B\cdot dA$

4b) $m=9\times10^{-31}kg$

$V=1.4\times10^{-7}m$

$B=3.5\times10^{-1}$ weber/meter$^2$

Cycloton frequency = ang speed

$$W=\frac{V}{r}=\frac{qB}{m}=\frac{1.6\times10^{-19}\times3.5\times10^{-1}}{9\times10^{-31}}$$

$W=62222222222.2222T^{-1}$

4c) In the question we were given Paramiters such as

i) Mass of electron $=9.11\times10^{-31}kg$

ii) A radius of $1.4\times10^{-7}m$

iii) Magnetic Field of $3.5\times10^{-1}$ weber/meter square

and you are asked to find the cyclotron frequency which is equal or the same thing as angular speed. It is called cyclotron frequency becauses it is a frequency of an accelerator called cyclotron.

Recall that angular speed is given as $w = \frac{V}{r} = \frac{qB}{m}$

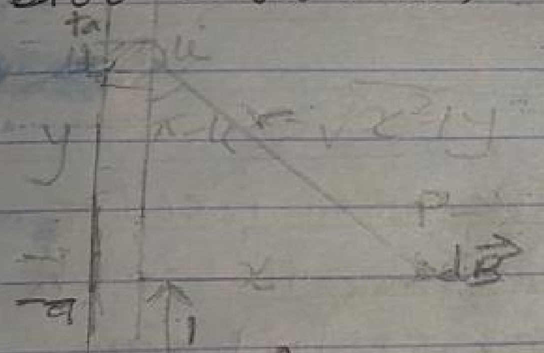
substituting we have $w = \frac{V}{r} = \frac{qB}{m} = \frac{1.6\times10^{-10}\times 3.5\times10^{-10}}{9.11\times10^{-31}}$

$$= 62222222222.22222\,T^{-1}$$

so since cyclotron frequency is equal to angular speed the cyclotron frequency is equal to $= 62222222.22222\,T^{-1}$, having a unit as $1/T$ which is equal to the unit of frequency dimensionally.

5b) magnetic field of a straight current carrying conductor.

Fig 1: A section of a straight carrying conductor applying the biot-Savart law, we use the magnitude of the field from diagram below




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

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

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

from diagram $r^2 = x^2+y^2$ (Pythagoras theorem)

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

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

substituting (2) into (1), we have

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

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

Recall $dl = dy$

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

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

using special integrals:

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

Equation (3) therefore becom[es]

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

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

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

When the length 2a of the conductor is very great in comparison to its distance x from point P, we consider it infinitely long. That is when a is much larger than x,

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

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

In a physical situation we have an axial symmetry above the y-axis. This at all point in a circle of radius (r) around the conductor, the magnitude of B is

$$B = \frac{\mu_0 I}{2\pi r} \quad \text{——— (4)}$$

Equation (4) defines the magnitude of the magnetic field of flux density B near a long, straight current carrying conductor

(c) Biot-Savart law states that the magnetic field is directly proportional to the product permeability of free space ($\mu_0$), the proportional to square of radius ($r^2$). It can be represented mathematically by

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

where $\mu_0$ a constant is called permeability of free space

$\mu_0 = 4\pi \times 10^{-7}\ T \cdot \frac{m}{A}$

The unit of B is weber/meter$^2$