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COVID-19 Holiday Assignment

Section A

Charging by induction: Electric charges can be obtained on an object without touching it, by a process called electrostatic 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 as shown below. 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 furthest away from the rod (fig 1.3a). The region of the sphere nearest the positively charged rod has an excess of negative charges because of the migration of protons away from this location. If a grounded conducting wire is then connected to the sphere, as in (fig. 1.3b), some of the protons leave the sphere and travel to the earth. If the wire to the ground is then removed (fig. 1.3c), the conducting sphere is left with an excess of induced negative charges.

Finally, when the rubber rod is removed from the vicinity of the sphere (fig. 1.3d) the induced negatively charges remain on the ungrounded sphere and becomes uniformly distributed over the surface of the sphere.

Diagram:

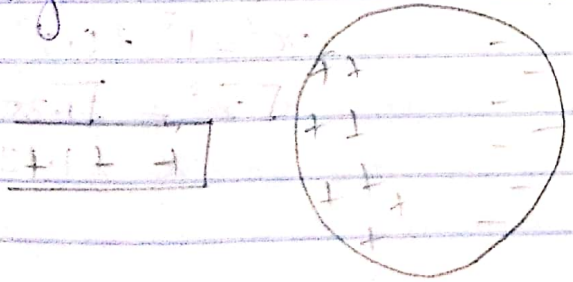


fig 1.3a

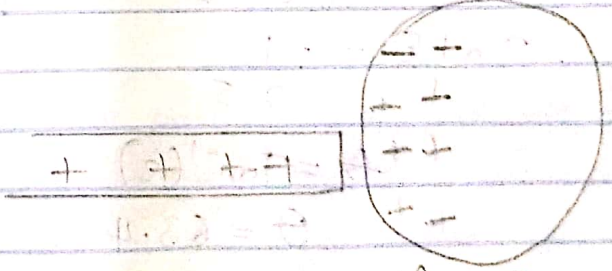


fig 1.3b

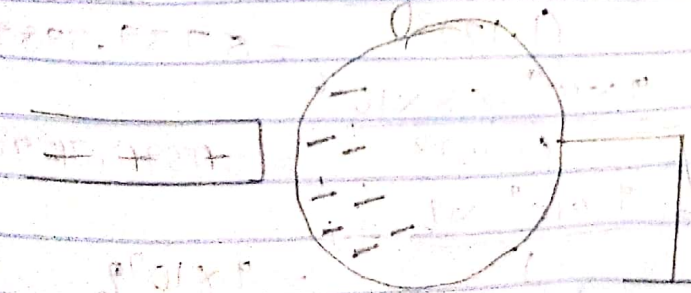


fig 1.3c

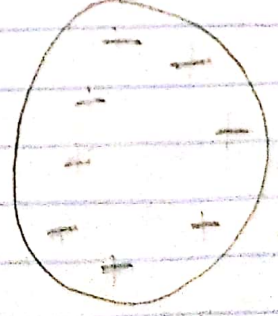


fig 1.3d

1b.

$$K = 9 \times 10^9$$

$$F = 1N$$

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

$$r = 2m$$

Recall that

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

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

$$1 = 4.5 \times 10^5 q_1 + 9 \times 10^7 q_2$$

$$9 \times 10^7 q_2 - 4.5 \times 10^5 q_1 + 4 = 0$$

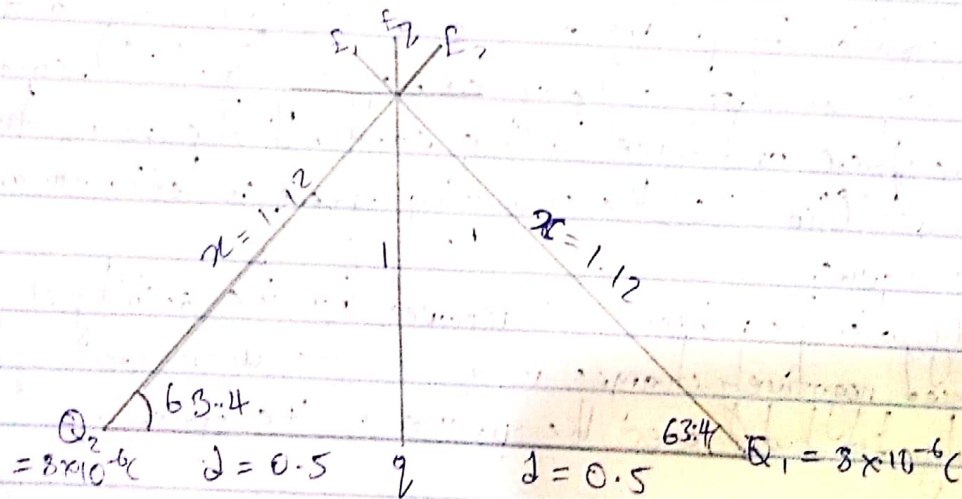
$$q_1 = 0.0000111 C = 1.11 \times 10^{-5} C$$

$$q_2 = 0.000038 C = 3.8 \times 10^{-5} C$$

1c.

$$Q_1 = Q_2 = 8 \mu C$$

$$d = 0.5m$$



$$\tan \theta = \frac{1}{0.5}$$

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

$$\theta = 63.4$$

$$r^2 = 1^2 + 0.5^2$$

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

$$r = 1.12$$

$$E_1 = \frac{K q_1}{r_1^2} = \frac{9 \times 10^9 \times 8 \times 10^{-6}}{(1.12)^2}$$

$$= 5739.795918$$

$$E_2 = \frac{K q_2}{r_2^2} = \frac{9 \times 10^9 \times 8 \times 10^{-6}}{(1.12)^2}$$

$$= 5739.795918$$

$$E_2 = \frac{K q}{r^2} = \frac{9 \times 10^9 \times 2}{1^2}$$

$$= 9 \times 10^9$$

Vector	angle	x - component	y - component
$E_1 = 5739.795918$	$63.4$	$E_1 \cos \theta$ $= 2570.0457846$	$E_1 \sin \theta$ $= 5132.26283867$
$E_2 = 5739.795918$	$63.4$	$E_2 \cos \theta$ $= 2570.0457546$	$E_2 \sin \theta$ $= 5132.26283267$
$E_3 = 9 \times 10^9 q$	$90^\circ$	$E_3 \cos \theta$ $= 0$	$E_3 \sin \theta$ $= 9 \times 10^9 q$
		$\Sigma x = 0$	$E_y = 10264.52568$

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

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

since  $E = 0$

$0 = 9 \times 10^9 q + 10264.52568$

$q = - \frac{10264.52568}{9 \times 10^9}$

$q = -1.140502853 \times 10^{-6}$

$q = -1.14 \mu C$

i. 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,  $\lambda = \frac{dQ}{dL} \rightarrow dQ = \lambda dL$

3. 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 Columb (J/C). Electric potential difference is a scalar quantity.

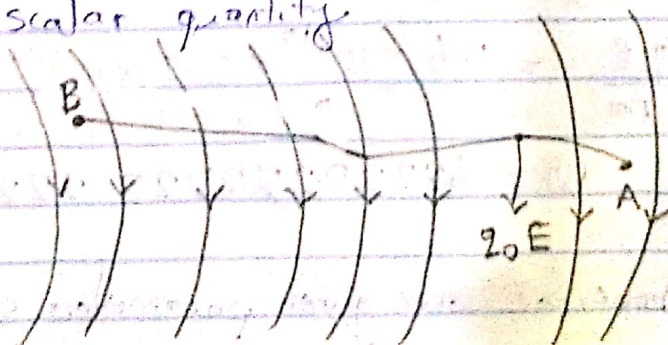


Fig 11.1.1.1

Consider the diagram above, suppose a test charge  $q_0$  is moved from point A to point B along an arbitrary path inside an electric field  $E$ . The electric field  $E$  exerts a force  $F = q_0 E$  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  $F = -q_0 E$  must act on the charge. Therefore, the elemental work done  $dW$  is given as:

$$dW = E dL \quad \text{--- (1)}$$

But  $F = -q_0 E$  --- (2)

substituting eq. (2) in (1) yields

$$dW = -q_0 E dL \quad \text{--- (3)}$$

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

$$W(A \rightarrow B)_{\text{ag}} = -q_0 \int_A^B E dL \quad \text{--- (4)}$$

from the definition of electric potential difference, it follows that:

$$V_B - V_A = \frac{W(A \rightarrow B)_{\text{ag}}}{q_0} \quad \text{--- (5)}$$

Putting eq. (4) in (5) yields

$$V_B - V_A = - \int_A^B E dL \quad \text{--- (6)}$$

### 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)  $m = 9 \times 10^{-31} \text{ Kg}$        $B = 3.5 \times 10^{-7} \text{ weber/meter}^2$   
 $r = 1.4 \times 10^{-7} \text{ m}$

Cyclotron frequency = angular speed:

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

$$\omega = \frac{qB}{m} = \frac{1.6 \times 10^{-19} \times 3.5 \times 10^{-7}}{9 \times 10^{-31}}$$

$$\omega = 62222222222.22222 \text{ T}^{-1}$$

4c) In the question 4b above, we were given parameters such as

- i mass of electron =  $9.1 \times 10^{-31}$  Kg
- ii A radius of  $1.4 \times 10^{-7}$  m
- iii magnetic field of  $3.5 \times 10^{-1}$  weber/meter square.

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

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

substituting the parameters, we have  $\omega = \frac{1.6 \times 10^{-19} \times 3.5 \times 10^{-10}}{9.1 \times 10^{-31}}$

So since cyclotron frequency is equal to angular speed the cyclotron frequency is equal to 6222222222.2222, having a unit of  $\text{K}$  which is equal to the unit of frequency dimensionally.

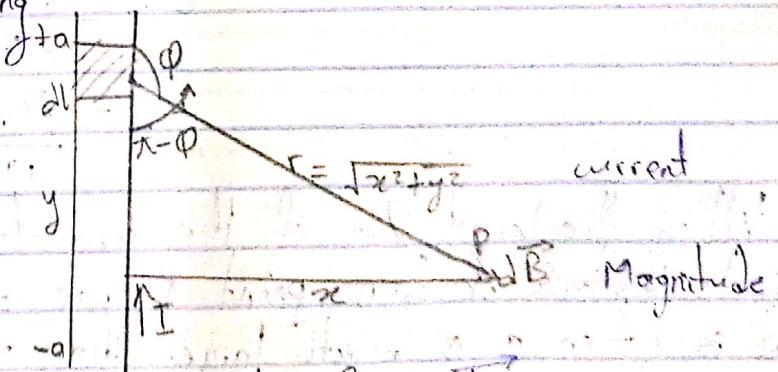
5b) Biot-Savart law states that the magnetic field is directly proportional to the product permeability of free space ( $\mu_0$ ), the current ( $I$ ), the change in length, the radius and inversely proportional to square of radius ( $r^2$ ). It can be represented mathematically by

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

where  $\mu_0$  is a constant called permeability of free space =  $4\pi \times 10^{-7} \frac{T \cdot m}{A}$   
 The unit of  $B$  is weber/meter square.

5c) Magnetic field of a straight current carrying conductor

fig 1. A section of straight carrying conductor



Applying Biot-Savart law, we find the field  $\vec{dB}$

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

we know that  $\sin(\alpha - \phi) = \sin \theta$

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

from the diagram above,  $r^2 = x^2 + y^2$  (Pythagoras Theorem).

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

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

Substituting (\*\*\*) into (\*), we have.

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

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

Recall  $dl = dy$

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

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

Using special integrals

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

Eq. (\*\*\*) therefore 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  $2a$  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  $x$ ,

$$(x^2 + a^2)^{1/2} \approx a, \text{ as } a \rightarrow \infty.$$

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

In a physical situation, we have axial symmetry about the  $y$ -axis.

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19/MH501/085

Thus, at all points in a circle of radius  $r$ , around the conductor, the magnitude of  $B$  is

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

Equ (#) defines the magnitude of the magnetic field of flux density  $B$  near a long, straight current carrying conductor.