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DEPARTMENT: MEDICINE AND SURGERY

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SECTION A.

Explain with the aid of a diagram how you can produce a negatively charged sphere by method of 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 charge on the sphere so that some protons move to the side of the sphere farthest away from the rod in fig 1. The region of the sphere nearest to the positively charged rod has an excess of negative charge because of the migration of protons away from this location. If a grounded conducting wire is then connected to the sphere as in fig. 2, some of the protons will leave the sphere and travel to the earth. If the wire to ground is then removed as in

(2)

Fig 3, the conducting sphere is left with an excess of induced negative charge.

When the rubber rod is removed from the vicinity of the sphere in Fig 4, the induced negative charge remains on the ungrounded sphere and becomes uniformly distributed over the surface of the sphere.

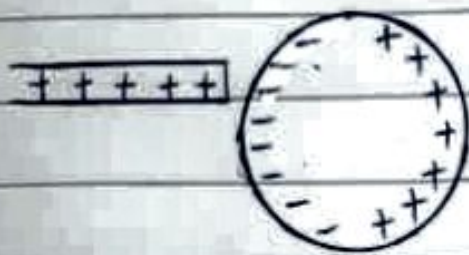


Figure 1

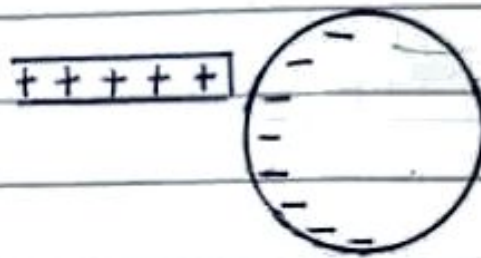


Figure 2.

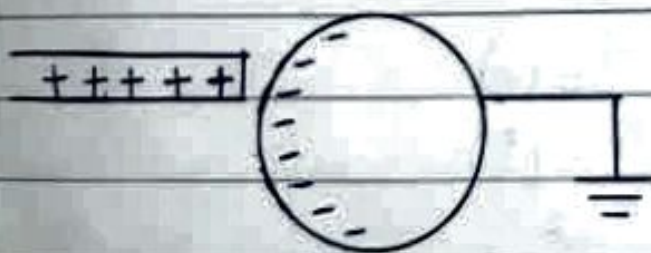


Figure 3



Figure 4

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

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Solution

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

$$q_1 = ? \quad q_2 = ?$$

$$F = 1.0 \text{ N} \quad r = 2.0 \text{ m}$$

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

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

Using the coulomb's law

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

$$\Rightarrow \frac{1.0}{1} = \frac{9 \times 10^9 \times (5 \times 10^{-5} - q_2) \times q_2}{(2.0)^2}$$

$$\Rightarrow \frac{1.0}{1} \times \frac{9 \times 10^9 \times q_2 \times (5 \times 10^{-5} - q_2)}{4.0}$$

$$\Rightarrow 4 = 9 \times 10^9 \times q_2 \times (5 \times 10^{-5} - q_2)$$

$$\Rightarrow 4 = 9 \times 10^9 q_2 (5 \times 10^{-5} - q_2)$$

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

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

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

where $a = 9 \times 10^9$; $b = -4.5 \times 10^5$; $c = 4$

$$q_2 = \frac{-(-4.5 \times 10^5) \pm \sqrt{(-4.5 \times 10^5)^2 - 4 \times 9 \times 10^9 \times 4}}{2 \times (9 \times 10^9)}$$

$$q_2 = \frac{4.5 \times 10^5 \pm \sqrt{2.025 \times 10^{11} - 1.44 \times 10^{11}}}{1.8 \times 10^{10}}$$

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$$q_2 = \frac{4.5 \times 10^5 \pm \sqrt{5.85 \times 10^{10}}}{1.8 \times 10^{10}}$$

$$q_2 = \frac{4.5 \times 10^5 + \sqrt{5.85 \times 10^{10}}}{1.8 \times 10^{10}}$$

$$q_2 = \frac{4.5 \times 10^5 - \sqrt{5.85 \times 10^{10}}}{1.8 \times 10^{10}}$$

$$q_2 = \frac{4.5 \times 10^5 + 241867.7234}{1.8 \times 10^{10}}$$

$$q_2 = \frac{4.5 \times 10^5 - 241867.7234}{1.8 \times 10^{10}}$$

$$q_2 = \frac{691867.7324}{1.8 \times 10^{10}}$$

$$q_2 = \frac{208132.2766}{1.8 \times 10^{10}}$$

$$q_2 = 3.8437 \times 10^{-5} \approx 3.84 \times 10^{-5} \text{ C} \quad | \quad q_2 = 1.15629 \times 10^{-5} \text{ C} \approx 1.16 \times 10^{-5} \text{ C}$$

$$\therefore q_2 = 3.84 \times 10^{-5} \text{ C} \quad \& \quad 1.16 \times 10^{-5} \text{ C}$$

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

$$\text{when } q_2 = 3.84 \times 10^{-5} \text{ C}$$

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

$$q_1 = 1.16 \times 10^{-5} \text{ C}$$

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

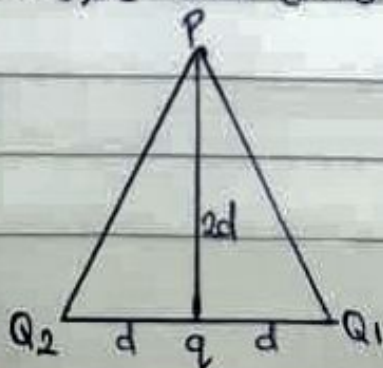
$$q_2 = 3.84 \times 10^{-5} \text{ C} \quad \& \quad 1.16 \times 10^{-5} \text{ C}$$

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

$$q_1 = 5 \times 10^{-5} - 1.16 \times 10^{-5} \text{ C}$$

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

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

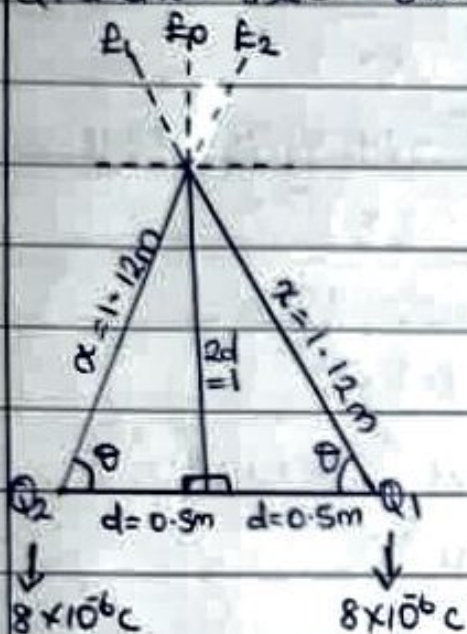


(5)

Solution

$$d = 0.5 \text{ m}$$

$$Q_1 = Q_2 = 8 \mu\text{C} = 8 \times 10^{-6} \text{ C}$$

find r using pythagoras theorem

$$r^2 = 2d^2 + d^2$$

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

$$r = \sqrt{1^2 + 0.5^2}$$

$$r = \sqrt{1 + 0.25}$$

$$r = \sqrt{1.25}$$

$$r = 1.12 \text{ m}$$

To find θ using SOHCAHTOA

$$\tan \theta = 1/0.5$$

$$\tan \theta = 2$$

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

$$\theta = 63.43^\circ$$

$$F = kq/r^2$$

$$Q_1 = Q_2$$

$$F_1 = F_2$$

$$F_1 = F_2 = \frac{9 \times 10^9 \text{ N/m}^2 \text{C}^2 \times 8 \times 10^{-6} \text{ C}}{(1.12 \text{ m})^2}$$

$$F_1 = F_2 = 7200/1.2544$$

⑥

$$E_1 = E_2 = 5739.795918 \text{ Nc}^{-1} \approx 5.74 \times 10^3 \text{ Nc}^{-1}$$

$$E_1 = E_2 = 5.74 \times 10^3 \text{ Nc}^{-1}$$

$$E_q = kq / r^2 = 9 \times 10^9 \text{ Nm}^2 \text{C}^{-2} \times q / 1^2 = 9 \times 10^9 q \text{ Nc}^{-1}$$

$$E_q = 9 \times 10^9 q \text{ Nc}^{-1}$$

Forces	Angles	x-component [$\pm \cos \theta$]	y-component [$\pm \sin \theta$]
$5.74 \times 10^4 \text{ Nc}^{-1}$	63.43°	$5.74 \times 10^4 \cos 63.43^\circ$ $= 2.57 \times 10^4$	$5.74 \times 10^4 \sin 63.43^\circ$ $= 5.13 \times 10^4$
$5.74 \times 10^4 \text{ Nc}^{-1}$	63.43°	$5.74 \times 10^4 \cos 63.43^\circ$ $= -2.57 \times 10^4$	$5.74 \times 10^4 \sin 63.43^\circ$ $= 5.13 \times 10^4$
$9 \times 10^9 q \text{ Nc}^{-1}$	90°	$9 \times 10^9 q \cos 90^\circ$ $= 0$	$9 \times 10^9 q \sin 90^\circ$ $= 9 \times 10^9 q$
		$\Sigma x = 0 \text{ Nc}^{-1}$	$\Sigma y = 1.026 \times 10^5 \text{ Nc}^{-1} + 9.0 \times 10^9 q$

$$\text{Magnitude} = \sqrt{(\Sigma x)^2 + (\Sigma y)^2}$$

$$E_q = \sqrt{\Sigma x^2 + \Sigma y^2}$$

$$E_q = \sqrt{(0)^2 + [(1.026 \times 10^5)^2 + (9.0 \times 10^9 q)^2]}$$

$$E_q = \sqrt{1.053 \times 10^{10} + (9.0 \times 10^9 q)^2}$$

$$\text{But } E_q = 0$$

$$\therefore 0 = \sqrt{1.053 \times 10^{10} + (9.0 \times 10^9 q)^2}$$

Square both sides.

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$$\Rightarrow 0^2 = \sqrt{1.053 \times 10^{10} + (9 \times 10^9 q)^2}^2$$

$$\Rightarrow 0 = 1.053 \times 10^{10} + (9 \times 10^9 q)^2$$

$$\Rightarrow (-9.0 \times 10^9 q)^2 = 1.053 \times 10^{10}$$

$$\therefore q^2 = \frac{1.053 \times 10^{10}}{(-9.0 \times 10^9)^2}$$

$$\Rightarrow q^2 = \frac{1.053 \times 10^{10}}{8.1 \times 10^{19}} = 1.3 \times 10^{10} \text{ C}$$

$$\Rightarrow q = \sqrt{1.3 \times 10^{10}}$$

$$\Rightarrow q = 1.14 \times 10^{-5} \text{ C}$$

$$q = 11.4 \mu\text{C}$$

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

Electric field is the region of space in which an electric charge will experience an electric force while electric field intensity also known as electric field strength is the force per unit charge, it is the magnitude of electric field.

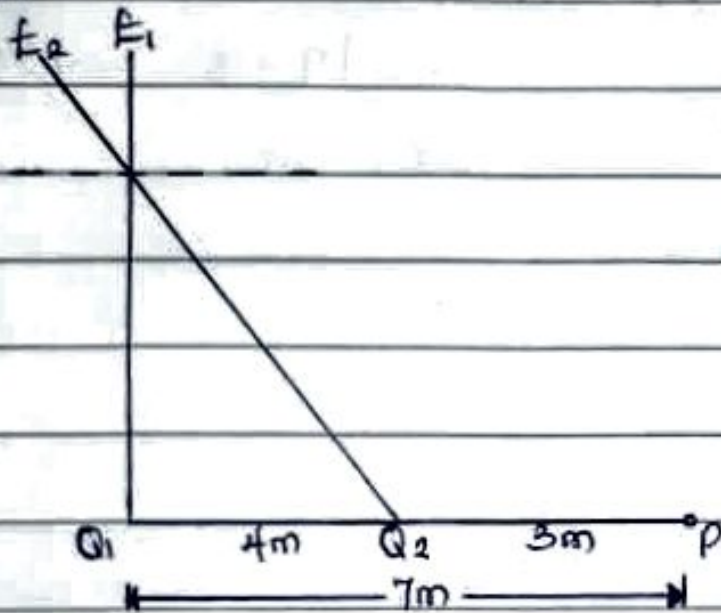
2b A positive charge $Q_1 = 8 \text{ nC}$ is at the origin and a second positive charge $Q_2 = 12 \text{ nC}$ is on the x axis at $x = 4 \text{ m}$. Find

i. the net electric field at a point P on the x axis at $x = 7 \text{ m}$.

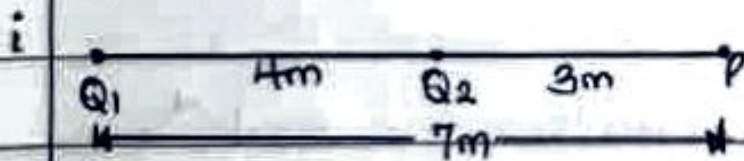
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ii the electric field at a point P on the y axis at $y = 3\text{m}$ due to the charges.

Solution



$$Q_1 = 8\text{nC}; Q_2 = 12\text{nC} \text{ i.e. } Q_1 = 8 \times 10^{-9}\text{C}; Q_2 = 12 \times 10^{-9}\text{C}$$

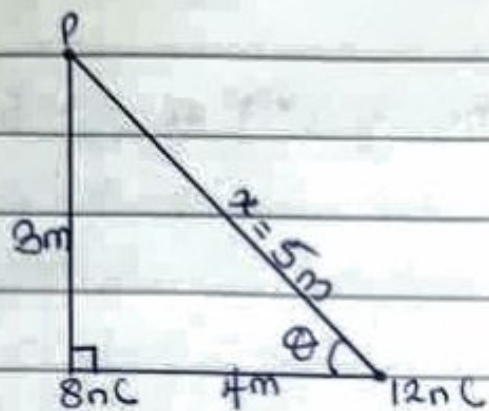


$$E_1 = kQ_1/r^2 = 9 \times 10^9 \text{Nm}^2\text{C}^{-2} \times 8 \times 10^{-9}\text{C} / 7^2 = 1.469 \text{Nc}^{-1}$$

$$E_2 = kQ_2/r^2 = 9 \times 10^9 \text{Nm}^2\text{C}^{-2} \times 12 \times 10^{-9}\text{C} / 3^2 = 12 \text{Nc}^{-1}$$

$$E_{\text{net}} = E_1 + E_2 = 1.469 \text{Nc}^{-1} + 12 \text{Nc}^{-1} = 13.469 \text{Nc}^{-1}$$

$$\therefore E_{\text{net}} \approx 13.5 \text{Nc}^{-1}$$



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Find x using Pythagoras theorem

$$x^2 = 3^2 + 4^2$$

$$x = \sqrt{\quad}$$

$$x = \sqrt{9 + 16} = \sqrt{25}$$

$$x = 5\text{m}$$

To find θ using SOHCAHTOA

$$\tan \theta = 3/4$$

$$\tan \theta = 0.75$$

$$\theta = \tan^{-1}(0.75)$$

$$\theta = 36.9^\circ$$

$$E_1 = kQ_1/r_1^2 = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2} \times 8 \times 10^{-9} \text{ C} / 3^2 = 8 \text{ N C}^{-1}$$

$$E_2 = kQ_2/r_2^2 = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2} \times 12 \times 10^{-9} \text{ C} / 5^2 = 4.32 \text{ N C}^{-1}$$

Vector	Angle	x component [cos θ]	y component [sin θ]
8 N C^{-1}	90°	$8 \text{ N C}^{-1} \cos 90^\circ = 0 \text{ N C}^{-1}$	$8 \sin 90^\circ = 8 \text{ N C}^{-1}$
4.32 N C^{-1}	36.9°	$4.32 \text{ N C}^{-1} \cos 36.9 = 3.45 \text{ N C}^{-1}$	$4.32 \sin 36.9 = 2.60 \text{ N C}^{-1}$

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

$$E_{\text{net}} = \sqrt{3.45^2 + 10.60^2}$$

$$E_{\text{net}} = \sqrt{124.2625}$$

$$E_{\text{net}} = 11.147 \text{ N C}^{-1} \approx 11.15 \text{ N C}^{-1}$$

$$E_{\text{net}} = 11.15 \text{ N C}^{-1}$$

(10)

SECTION B

Ha What is Magnetic flux?

Magnetic flux refers to the number of magnetic lines of force passing through a given closed surface which is the magnetic field. It is what generates the field around a magnetic material. Its SI unit is Weber [Wb]. It is also the strength of a magnetic field when represented by lines of force and usually denoted by the symbol ϕ .

b 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} Wb/m², perpendicular to the speed with which electron moves.

Find the cyclotron frequency of the moving electron.

$$m = 9.11 \times 10^{-31} \text{ kg}$$

$$\theta = 90^\circ$$

$$B = 3.5 \times 10^{-1} \text{ Wb/m}^2$$

$$r = 1.4 \times 10^{-7} \text{ m}$$

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

$$\text{Cyclotron frequency} \Rightarrow \omega = \frac{qB}{m} = \frac{v}{r}$$

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

$$\omega = \frac{5.6 \times 10^{-20}}{9.11 \times 10^{-31}}$$

$$\omega = 6.147 \times 10^{10} \approx 6.15 \times 10^{10}$$

$$\omega = 6.15 \times 10^{10} \text{ rad/s}$$

c. Discuss your answer in 4b above

The cyclotron frequency is the inverse of the period which is the time taken for the accelerated electron to complete a cycle in the magnetic field.

The cyclotron frequency is also known as the angular speed of the particle.

5. State the Biot-Savart Law.

Biot-Savart law states that the magnetic field is directly proportional to the product permeability of free space (μ_0), the current (I), the change in length, the radius and inversely proportional to the square of radius (r^2). It can be mathematically expressed as;

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

where μ_0 is a constant called permeability of free space

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

The unit of \vec{B} is Weber/meter square [Wb/m^2].

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b Using the Biot-Savart law, show that the magnitude of the magnetic field of a straight current-carrying conductor is given as $B = \frac{\mu_0 I}{2\pi r}$

Solution

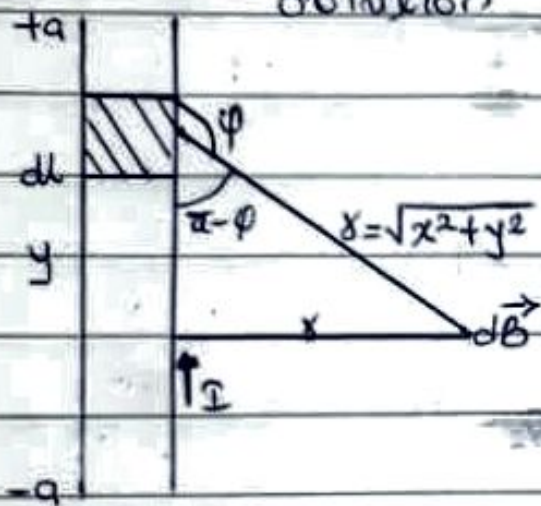


Diagram of a section of a straight current-carrying conductor. To find the magnitude of the field \vec{dB} by applying the Biot-Savart law

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

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

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

From the diagram, $r^2 = x^2 + y^2$ [Pythagoras theorem].

$$B = \frac{\mu_0 I}{4\pi} \int \frac{dl \sin(\pi - \phi)}{x^2 + y^2} \quad \text{----- ①}$$

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

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That is, when a is much longer 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. Thus at all points in a circle of radius x , around the conductor, the magnitude of B is $\Rightarrow B = \frac{\mu_0 I}{2\pi x}$ ----- (A)

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