ELECTRIC CHARGES AND FIELDS

NCERT EXERCISE AND SOLUTIONS - PHYSICS

1.1 What is the force between two small, charged spheres having charges of 2×10^{-7}C and 3×10^{-7} C placed 30 cm apart in air?

SOLUTION:-

Given – 2 small, charged spheres $q_1 = 2 \times 10^{-7}$ C and $q_2 = 3 \times 10^{-7}$ C, distance between charged spheres (r) = 30 cm = 0.3 m

Need to find – Force (F) between charged spheres.

Electrostatic force between the charged spheres is given by,

$$F = \frac{1}{4\pi \in_0}\frac{q_1 q_2}{r^2} N \quad (\therefore \frac{1}{4\pi \in_0} = 9\times10^9 Nm^2C^2)$$

$$F = \frac{(9\times10^9 Nm^2/C^2)\times(2\times10^{-7}C)\times(3\times10^{-7}C)}{(0.3m)^2} = 6\times10^{-3}N$$

Hence, Electrostatic force between two charged spheres is 6×10^{-3}N and both the charges have the same nature, i.e., the force between them is repulsive in nature.

1.2 The electrostatic force on a small sphere of charge 0.4 μC due to another small sphere of charge – 0.8 μC in air is 0.2 N.
(a) What is the distance between the two spheres?
(b) What is the force on the second sphere due to the first?

SOLUTION:-

Given – 2 small, charged spheres q_1 = 0.4 μC = 4×10^{-7} C and q_2 = –0.8 μC = 8×10^{-7} μC,
Electrostatic force between charged spheres (F) = 0.2 N

(a) Electrostatic force between the charged spheres is,

$$F = \frac{1}{4\pi \in_0}\frac{q_1 q_2}{r^2} N$$

$$r^2 = \frac{1}{4\pi \in_0}\frac{q_1 q_2}{F} m^2 \qquad (\because \frac{1}{(4\pi\epsilon_0)} = 9\times10^9 Nm^2/C^2)$$

$$r^2 = \frac{(9\times10^9 Nm^2/C^2)\times(4\times10^{-7}C)\times(8\times10^{-7}C)}{0.2N} = 144\times10^{-4}m^2$$

$$r = \sqrt{144 \times 10^{-4}} = 0.12\text{m}$$

Hence, the distance between the two spheres is 0.12 m

(b) We know that the electrostatic force follows Newton's 3rd law, i.e., the force on the second sphere due to the first is also 0.2 N.

1.3 Check that the ratio ke^2/Gm_em_p is dimensionless. Look up a Table of Physical Constants and determine the value of this ratio. What does the ratio signify?

SOLUTION:-

Given – ratio $ke^2/G\, m_e m_p$

Where, $k = \frac{1}{(4\pi\epsilon_0)}$, e (electric charge) = 1.6×10^{-19} C, G (universal gravitational constant) = 6.67×10^{-11} Nm^2/Kg^2, $m_e = 9.1\times10^{-31}$ kg, $m_p = 1.66\times10^{-27}$ kg

Need to find – The value of this ratio and what does it signify.

The numerical value of the ratio is given by,

$$ke^2/G\, m_e m_p = \frac{\left(9\times10^9\, Nm^2/C^2\right)\times\left(1.6\times10^{-19}\,C\right)^2}{\left(6.67\times10^{-11}\, Nm^2/kg^2\right)\times\left(9.1\times10^{-31}\,kg\right)\times\left(1.67\times10^{-27}\,kg\right)} \approx 2.3\times10^{39}$$

This illustrates the ratio of the electric force to the gravitational force between a proton and an electron, with the distance between them remaining constant, where the electrostatic force is 10^{39} times stronger than the gravitational force.

Also, this ratio is dimensionless.

1.4 (a) Explain the meaning of the statement 'electric charge of a body is quantised'.

(b) Why can one ignore quantisation of electric charge when dealing with macroscopic i.e., large scale charges?

SOLUTION:-

(a) The electric charge of a body is quantized, meaning that only whole numbers (1, 2, ………,n) of electrons can be transferred between bodies. Charges cannot be transferred in fractional amounts. Consequently, a body can have a total charge that is only an integral multiple of the elementary electric charge.

Mathematically, $q = \pm ne$

Where, n = 1, 2, 3, ………., n and e = 1.6×10^{-19} C

(b) On a macroscopic scale, the charges involved are significantly larger compared to the magnitude of a single elementary charge. As a result, the quantization of electric charge becomes negligible and has no practical significance. Therefore, it is generally ignored, and electric charge is treated as if it is continuous.

1.5 When a glass rod is rubbed with a silk cloth, charges appear on both. A similar phenomenon is observed with many other pairs of bodies. Explain how this observation is consistent with the law of conservation of charge.

SOLUTION:-

When a glass rod is rubbed with a silk cloth, charges appear on both objects due to the transfer of electrons. The glass rod loses electrons and becomes positively charged, while the silk cloth gains those electrons and becomes negatively charged. This phenomenon is consistent with the law of conservation of charge because the total charge of the system (glass rod + silk cloth) remains the same before and after rubbing. This phenomenon is consistence with the law of conservation of energy. A similar phenomenon is observed with many other pairs of bodies.

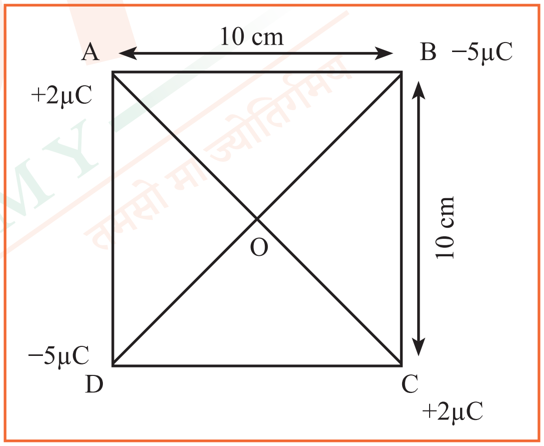
1.6 Four point charges $q_A = 2\ \mu C$, $q_B = -5\ \mu C$, $q_C = 2\ \mu C$, and $q_D = -5\ \mu C$ are located at the corners of a square ABCD of side 10 cm. What is the force on a charge of 1 C placed at the centre of the square?

SOLUTION:-

Given – Four point charges $q_A = 2\ \mu C$, $q_B = -5\ \mu C$, $q_C = 2\ \mu C$, and $q_D = -5\ \mu C$

Sides of square = 10 cm = 0.1 m

Need to find – Force on charge 1 μC at the centre O.



From figure, (sides) AB = BC = CD = DA = 0.1 m

(diagonal) AC = BD = $10\sqrt{2}$ cm = $0.1\sqrt{2}$ m

AO = OC = DO = OB = $5\sqrt{2}$ cm = $0.05\sqrt{2}$ m

From figure it clearly shows that all the charges at corners are equidistant from the centre O.

i.e. F_{AO} (Repulsive) = F_{CO} (Repulsive) (Equal in magnitude but opposite in direction)

Hence, they will cancel each other.

Similarly, F_{DO} (Attractive) = F_{BO} (Attractive) (Equal in magnitude but opposite in direction)

Hence, they will also cancel each other.

Therefore, the net force on the charge 1 μC at centre O is zero.

1.7 (a) An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not?

(b) Explain why two field lines never cross each other at any point?

SOLUTION

(a) An electrostatic field line is a continuous curve because a charge in an electrostatic field experiences a continuous force. Field lines cannot have sudden breaks because the motion of a charge is seamless and continuous, flowing smoothly without any abrupt jumps from one point to another.

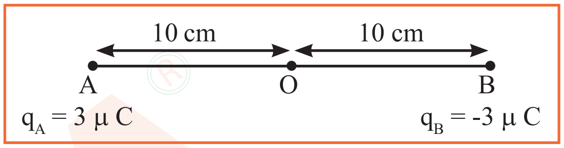
(b) If two field lines were to intersect at a point, the electric field intensity or electrostatic force at that point would have two different directions, which is impossible. Therefore, two field lines never cross each other.

1.8 Two-point charges $q_A = 3\ \mu C$ and $q_B = -3\ \mu C$ are located 20 cm apart in vacuum.

(a) What is the electric field at the midpoint O of the line AB joining the two charges?

(b) If a negative test charge of magnitude 1.5×10^{-9} C is placed at this point, what is the force experienced by the test charge?

SOLUTION:



Given – Two point charges $q_A = 3\ \mu C$, $q_B = -3\ \mu C$

Distance between charges (AB) = 20 cm = 0.2 m

(a) From figure,

AB = 20 cm = 0.2 m, AO = OB = 10 cm = 0.1 m

Electric field at O due to charges q_A and q_B is same in magnitude and is same direction.

i.e. $E_{net} = (E_A + E_B)$ N/C

$E_{net} = 2E$ N/C $\quad (\because E_A = E_B = E)$

$E_{net} = 2\left(\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\right)$ N/C

Where, $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ Nm^2/C^2$, $q = 3\ \mu C = 3 \times 10^{-6}$ C, r = AO = OB = 0.1 m

$$E_{net} = 2\left[\left(9\times10^9\ Nm^2/C^2\right)\times\frac{\left(3\times10^{-6}C\right)}{(0.1m)^2}\right]$$

$$E_{net} = 5.4\times10^6\ N/C$$

Therefore, the electric field at mid-point O is 5.4×10^6 N/C and its direction is along OB.

(b) A negative test charge (1.5×10^{-9} C) is placed at midpoint O and force experience by the force is,

F = qE

$$F = \left(1.5\times10^{-9}C\right)\times\left(5.4\times10^6\ \frac{N}{c}\right)$$

$$F = 8.1\times10^{-3}\ N$$

Therefore, the net force acting on charge at mid-point O is and its direction is along OA.

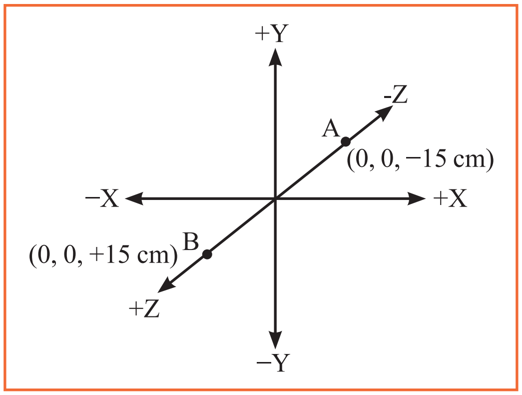
1.9 A system has two charges $q_A = 2.5 \times 10^{-7}$ C and $q_B = -2.5 \times 10^{-7}$ C located at points A: (0, 0, –15 cm) and B: (0, 0, +15 cm), respectively. What are the total charge and electric dipole moment of the system?

SOLUTION:

Given – Two charges $q_A = 2.5 \times 10^{-7}$ C and $q_B = -2.5 \times 10^{-7}$ C

Position coordinates of A and B: (0, 0, –15 cm) and (0, 0, +15 cm).

Need to find – Total charge and electric dipole moment of the system.



(i) Total charge of the system is,

$q_{net} = q_A + q_B$

$q_{net} = (2.5 \times 10^{-7}\ C) + (-2.5 \times 10^{-7}\ C)$

$q_{net} = 0$

(ii) Electric dipole moment of the system is,

$p = q\ (2a)$

where, $q = 2.5 \times 10^{-7}$ C and $2a = AB = 30$ cm $= 0.3$ m

Now, $p = (2.5 \times 10^{-7}\ C)\ (0.3\ m)$

$p = 7.5 \times 10^{-8}$ C m

Therefore, the electric dipole moment of the system is 7.5×10^{-8} C m along positive z-axis.

1.10 An electric dipole with dipole moment 4×10^{-9} Cm is aligned at 30° with the direction of a uniform electric field of magnitude $5 \times 10^4\ NC^{-1}$. Calculate the magnitude of the torque acting on the dipole.

SOLUTION:

Given – Dipole moment (p) = 4×10^{-9} C m, Uniform electric field (E) = $5 \times 10^4\ NC^{-1}$

Angle (θ) = 30.

Need to find – Torque (τ) acting on the dipole.

Torque (τ) acting on the dipole is given by,

$\tau = pE\ Sin\theta$

$$\tau = \left(4\times10^{-9}\,Cm\right)\left(5\times10^{4}\,NC^{-1}\right)\sin 30^\circ$$

$$\tau = 2\times10^{-4}\times\frac{1}{2}\,Nm$$

$$\tau = 10^{-4}\,Nm$$

Therefore, the magnitude of the torque is 10^{-4} Nm.

1.11 A polythene piece rubbed with wool is found to have a negative charge of 3×10^{-7} C.

(a) Estimate the number of electrons transferred (from which to which?)

(b) Is there a transfer of mass from wool to polythene?

SOLUTION:

Given – Charge on polythene (q) = 3×10^{-7} C

(a) According to the question, the polythene piece rubbed with wool polythene gets a negative charge, i.e., electrons are transferred from wool to the polythene piece, and the number of electrons transferred is given by,

$$q = ne \qquad (\because e = -1.6 \times 10^{-19}\ C)$$

$$n = \frac{q}{e}$$

$$n = \frac{(-3\times10^{-7}\,C)}{\left(-1.6\times10^{-19}\,C\right)} = 1.87\times10^{12}$$

Therefore, the number of electrons transferred from wool to polythene is 1.87×10^{12}.

(b) yes.

Total mass transferred = (Mass of one electron) × (Number of electrons transferred)

$$M = \left(9.1\times10^{-31}\,Kg\right)\times\left(1.87\times10^{12}\right) = 1.701\times10^{-18}\,Kg$$

Therefore, the negligible amount of mass is transferred during this process.

1.12 **(a) Two insulated charged copper spheres A and B have their centres separated by a distance of 50 cm. What is the mutual force of electrostatic repulsion if the charge on each is 6.5×10^{-7} C? The radii of A and B are negligible compared to the distance of separation.**

(b) What is the force of repulsion if each sphere is charged double the above amount, and the distance between them is halved?

SOLUTION:

Given – distance between the centres of charged spheres (r) = 50 cm = 0.5 m

Charge on each sphere (q) = 6.5×10^{-7} C = $q_A = q_B$

(a) Force of repulsion between two spheres is,

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_A q_B}{r^2}\,N \qquad \left(\because \frac{1}{(4\pi\epsilon_0)} = 9\times10^9\ Nm^2/C^2\right)$$

$$F = \frac{\left(9\times10^9\,\frac{Nm^2}{C^2}\right)\left(6.5\times10^{-7}\,C\right)^2}{(0.5)^2}\,N$$

$$F = 1.52\times10^{-2}\,N$$

Therefore, the force between the two spheres is 1.52×10^{-2} N

(b) Now charge on each sphere (q') = 2q i.e. $q_A = q_B = q' = 13 \times 10^{-7}$ C

Distance between them (r') $= \frac{1}{2}r = \frac{1}{2}(0.5\ m) = 0.25$ m

Force of repulsion between two spheres is,

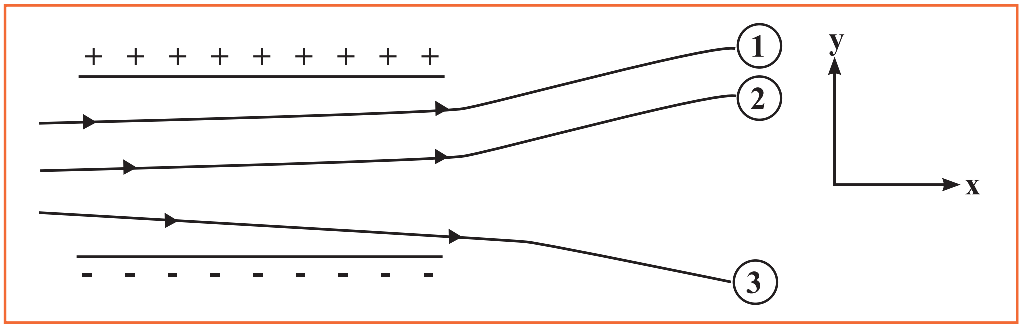
$$F = \frac{1}{4\pi\epsilon_0}\frac{q_A q_B}{r^2}\,N \qquad \left(\because \frac{1}{(4\pi\epsilon_0)} = 9\times10^9\ Nm^2/C^2\right)$$

$$F = \frac{\left(9\times10^9\,\frac{Nm^2}{C^2}\right)\left(13\times10^{-7}\,C\right)^2}{(0.25)^2}\,N$$

$$F = 0.243N$$

Therefore, the force between the two spheres is 0.243 N

1.13 Figure shows track of three charged particles in a uniform electrostatic field. Give the signs of the three charges. Which particle has the highest charge to mass ratio?



SOLUTION:

We know that the same charges repel, and opposite charges attracts each other.

According to given figure,

The charge-to-mass ratio (e/m) is directly proportional to the displacement or deflection of a particle at a given velocity. Since particle 3 exhibits the maximum deflection, it has the highest charge-to-mass ratio.

1.14 Consider a uniform electric field E = 3 × 10³ î N/C.

(a) What is the flux of this field through a square of 10 cm on a side whose plane is parallel to the y-z plane?

(b) What is the flux through the same square if the normal to its plane makes a 60° angle with the x-axis?

SOLUTION:

Given – Uniform electric field (E) = 3×10^3 î N/C, side of square (a) = 10 cm = 0.1 m,

(a) Electric flux (ϕ_E) through the y-z plane is given by,

$$\phi_E = EACos\theta$$

The square lies parallel to the y-z plane. Therefore, the angle between the unit vector normal to the plane and the electric field is 0°.

Area (A) = $a^2 = (0.1)^2 = 0.01\ m^2$

$$\phi_E = \left(3\times10^3 N/C\right)\times\left(0.01m^2\right)\times\cos 0^\circ$$

$$\phi_E = 30Nm^2/C$$

(b) If θ then electric flux is,

$$\phi_E = \left(3\times10^3 N/C\right)\times\left(0.01m^2\right)\times\cos 60^\circ$$

$$\phi_E = 15Nm^2/C$$

1.15 What is the net flux of the uniform electric field of Exercise 1.14 through a cube of side 20 cm oriented so that its faces are parallel to the coordinate planes?

SOLUTION:

All faces of the cube are aligned parallel to the coordinate axes. Consequently, the number of field lines entering the cube equals the number of field lines exiting it. Therefore, the net flux through the cube is zero.

1.16 Careful measurement of the electric field at the surface of a black box indicates that the net outward flux through the surface of the box is 8.0 × 10^3 Nm^2/C.

(a) What is the net charge inside the box?

(b) If the net outward flux through the surface of the box were zero, could you conclude that there were no charges inside the box? Why or Why not?

SOLUTION:

Given – Flux passing through the surface (ϕ_E) = 8.0 × 10^3 Nm^2/C

(a) Net charge inside the body is given by, with the help of Gauss's law,

$$\phi E = \frac{q}{\epsilon_0} \qquad (\because \epsilon_0 = 8.854 \times 10^{-12} C^2/Nm^2)$$

$$q = \epsilon_0 \phi_E$$

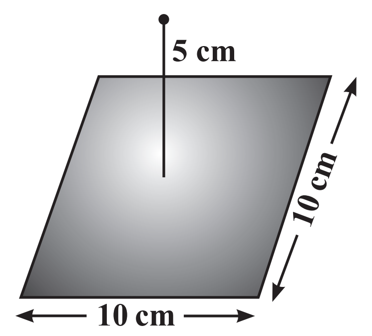
$$q = \left(8.854 \times 10^{-12} C^2 / Nm^2\right) \times \left(8.0 \times 10^3 Nm^2 / C\right)$$

$$q = 7.08 \times 10^{-8} C = 0.07 \mu C$$

Therefore, the net charge inside the body is 0.07 .

(b) No. The net flux passing through a body depends on the net charge enclosed within it. If the net flux is zero, it implies that the net charge inside the body is zero. This could mean the body contains an equal amount of positive and negative charges.

1.17 A point charge +10 μC is a distance 5 cm directly above the centre of a square of side 10 cm, as shown in Fig. 1.31. What is the magnitude of the electric flux through the square? (*Hint:* Think of the square as one face of a cube with edge 10 cm.)



SOLUTION:

Given – Charge (q) = +10 μC, side of cube (a) = 10 cm, distance of charge from face of cube (r) = 5 cm.

Need to find – Electric flux (ϕ_E) passing through the square.

The square can be treated as one face of a cube with an edge length of 10 cm, having its centre where a charge q is placed.

According to Gauss's theorem, the total electric flux is distributed equally across all six faces of the cube.

$$\phi_{Total} = \frac{q}{\epsilon_0} \qquad (\because \in 0 = 8.854 \times 10^{-12} C^2/Nm^2)$$

Electric flux through one face of the cube is,

$$\phi_E = \frac{\phi_{Total}}{6} = \frac{q}{6\epsilon_0}$$

$$\phi_E = \frac{1}{6} \times \frac{10 \times 10^{-6}}{8.854 \times 10^{-12}} = 1.88 \times 10^5 Nm^2 / C$$

Therefore, electric flux passing through the square is 1.88 × 10^5 Nm^2/C.

1.18 A point charge of 2.0 μC is at the centre of a cubic Gaussian surface 9.0 cm on edge. What is the net electric flux through the surface?

SOLUTION:

Given – charge (q) = 2.0 μC, side of cube (a) = 9.0 cm = 0.09 m

Need to find – Net electric flux (ϕ_E) passing through the surface.

Net electric flux (ϕ_E) passing through the surface is given by,

$$\phi\text{Total} = \frac{q}{\epsilon_0} \qquad (\because \epsilon_0 = 8.854 \times 10^{-12}\ C^2/Nm^2)$$

$$\phi_{Net} = \frac{2\times10^{-6}}{8.854\times10^{-12}} = 2.26\times10^5\ Nm^2/C$$

Therefore, net electric flux passing through the surface is $2.26 \times 10^5\ Nm^2/C$.

1.19 A point charge causes an electric flux of $-1.0 \times 10^3\ Nm^2/C$ to pass through a spherical Gaussian surface of 10.0 cm radius centred on the charge.

(a) If the radius of the Gaussian surface were doubled, how much flux would pass through the surface?

(b) What is the value of the point charge?

SOLUTION:

Given – Electric flux (ϕ_E) = $-1.0 \times 10^3\ Nm^2/C$, radius of spherical surface (r) = 10 cm = 0.1 m

(a) The electric flux passing through a surface depends on the net charge enclosed within the body and is independent of the size of the surface. If the radius of the Gaussian surface is doubled, the flux through the surface remains unchanged at $-1.0 \times 10^3\ Nm^2/C$.

(b) With the help of Gauss's law the point charge is given by,

$$q = \epsilon_0\phi_E \qquad (\because \epsilon_0 = 8.854 \times 10^{-12}\ C^2/Nm^2)$$

$$q = \left(-1.0\times10^3\ Nm^2/C\right)\times\left(8.854\times10^{-12}\ C^2/Nm^2\right)$$

$$q = -8.854\times10^{-9}\ C = -8.854\,nC$$

Therefore, the value of point charge is −8.854nC.

1.20 A conducting sphere of radius 10 cm has an unknown charge. If the electric field 20 cm from the centre of the sphere is 1.5×10^3 N/C and points radially inward, what is the net charge on the sphere?

SOLUTION:

Given – radius of sphere (r) = 10 cm = 0.1 m, Electric field (E) = 1.5×10^3 N/C (radially inward),

Distance from the centre (d) = 20 cm = 0.2 m

Need to find – Net charge on the sphere.

The electric field E at a distance d from the centre of a sphere containing a net charge q is given by,

$$E = \frac{1}{4\pi\epsilon_0}\frac{q}{d^2} \qquad \left(\because \frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ Nm^2/C^2\right)$$

$$q = E(4\pi\epsilon_0)d^2$$

$$q = \frac{(1.5\times10^3)\times(0.2)^2}{9\times10^9} = 6.67\times10^9 C,$$

$$q = 6.67nC$$

Therefore, the net charge on the sphere is 6.67 nC.

1.21 A uniformly charged conducting sphere of 2.4 m diameter has a surface charge density of 80.0 C/m^2.

(a) Find the charge on the sphere.

(b) What is the total electric flux leaving the surface of the sphere?

SOLUTION:

Given – diameter of sphere (d) = 2.4 m, surface charge density (σ) = 80.0 C/m^2 = 80 × 10^{-6} C/m^2

(a) Electric charge on the sphere is given by,

$$q = \text{Charge density} \times \text{Surface area}$$

$$= \sigma\times(4\pi r^2)$$

$$= 80\times10^{-6}\times4\times3.14\times(1.2)^2$$

$$= 1.447\times10^{-3} C$$

Therefore, the charge on the sphere is 1.447 × 10^{-3} C.

(b) Total electric flux (ϕ_{Total}) leaving the surface is given by,

$$\phi_{Total} = \frac{q}{\epsilon_0} \qquad (\because \epsilon_0 = 8.854\times10^{-12}\ C^2/Nm^2)$$

$$\phi_{Total} = \frac{1.44\times10^{-3}}{8.854\times10^{-12}} = 1.63\times10^8\ Nm^2/C$$

Therefore, the total electric flux leaving the surface of the sphere is 1.63 × 10^8 Nm^2/C.

1.22 An infinite line charge produces a field of 9 × 10^4 N/C at a distance of 2 cm. Calculate the linear charge density.

SOLUTION:

Given – Electric field produced by line charge (E) = 9 × 10^4 N/C, Distance from line charge (r) = 2 cm = 0.02 m

Need to find – Linear charge density (λ).

Electric field due to infinite line charge at distance r is given by,

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

$$\lambda = (2\pi\epsilon_0 r)E$$

$$\therefore 4\pi\epsilon_0 = \frac{1}{9\times10^9} \Rightarrow 2\pi\epsilon_0 = \frac{4\pi\epsilon_0}{2} = \frac{1}{18\times10^9} \text{ then,}$$

$$\lambda = \frac{0.02\times9\times10^4}{18\times10^9} = 10\mu C/m$$

Therefore, the linear charge density is 10μC/m.

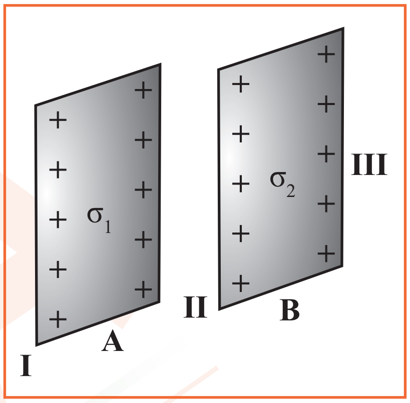
1.23 Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude 17.0×10^{-22} C/m². What is E:
(a) in the outer region of the first plate,
(b) in the outer region of the second plate, and
(c) between the plates?

SOLUTION:

Given – Surface charge density for plates A and B (σ) = 17.0×10^{-22} C/m²

Need to find – Electric field (E).

From the figure, plates A and B are two parallel plates positioned close to each other. The space surrounding the outer surface of plate A is labelled as region I, the space surrounding the outer surface of plate B is labelled as region III, and the space between plates A and B is labelled as region II.



(a) In the outer region of the first plate (region I), the electric field is zero because no net charge is enclosed by that region of the plate.

(b) In the outer region of the second plate (region III), the electric field is also zero because no net charge is enclosed in that region.

(c) In the region II, electric field is given by,

$$E = \frac{\sigma}{\epsilon_0} \qquad (\because \epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2/\text{Nm}^2)$$

$$E = \frac{17.0 \times 10^{-22}}{8.854 \times 10^{-12}} = 1.92 \times 10^{-10} \text{ N/C}$$

Therefore, the electric fiend between the plates is 1.92×10^{-10} N/C.