CHAPTER 1

ELECTRIC CHARGES AND FIELDS

1. What is meant by electrostatics?
Ans: Electrostatics is the branch of physics which deals with charges at rest.

2. Which are the three methods of charging a body?
Ans: The three methods are:
a) Rubbing (charging by friction)
b) Conduction
c) Induction

3. What is the method to charge an insulator?
Ans: Rubbing

4. What are the methods to charge a conductor?
Ans: Conduction and induction

5. What is frictional electricity? Give an example.
Ans: The charge obtained by a body on rubbing with another body is called frictional electricity.
Example: When a glass rod is rubbed with silk, the glass rod gets positively charged and silk gets negatively charged.

6. Give some examples for substances which get charge on rubbing.
Ans: The substances in column I when rubbed with substances in column II, acquire positive charge while substances in column II acquire negative charge.

Column I	Column II
Glass	Silk
Wool	Amber, ebonite, plastic
Ebonite	Polythene
Dry hair	Comb

7. How does a body get charged?
Ans: A body gets charged by the transfer of electrons. The body which loses electrons gets positively charged and the body which gains electrons gets negatively charged.

8. Is the mass of a body affected by charging?
Ans: Yes. A positively charged body loses electrons. Therefore, its mass decreases. A negatively charged body gains electrons. So its mass increases. (Electron has a definite mass of 9.1×10^{-31}Kg)

9. Distinguish between conductors and insulators. Give examples for both.
Ans: The materials which allow electricity to pass through them easily are called conductors.
Examples: Metals
The materials which offer a high resistance to the passage of electricity are called insulators.
Examples: Most of the non-metals like glass, porcelain, plastic, nylon, wood are insulators.

10. Conductors cannot be charged by rubbing but insulators can. Why?

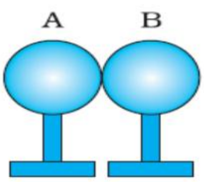
Ans: This is because, when some charge is transferred to a conductor, it readily gets distributed over the entire surface of the conductor. But if some charge is put on an insulator, it stays at the same place.

11. What is meant by charging by conduction?

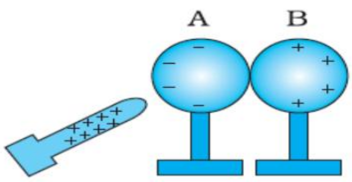
Ans: When a charged body is brought in to contact with an uncharged conductor, charge flows from the charged body to the uncharged body.

12. What is meant by charging by induction?

Ans: When a charged body is brought near to an uncharged conductor (without touching), that end of the uncharged conductor which is near to the charged body gets oppositely charged and the farther end is charged with the same type of charge.



(a)



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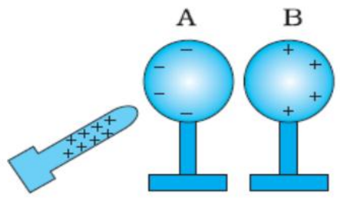

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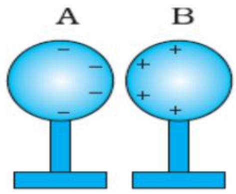

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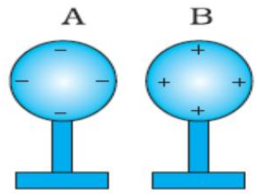


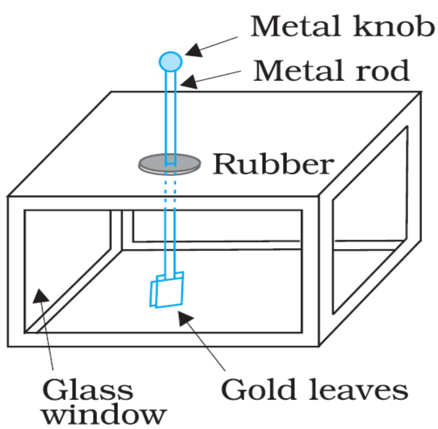
(e)

13. What is the use of an electroscope?

Ans: It is a device used to detect the charge on a body.

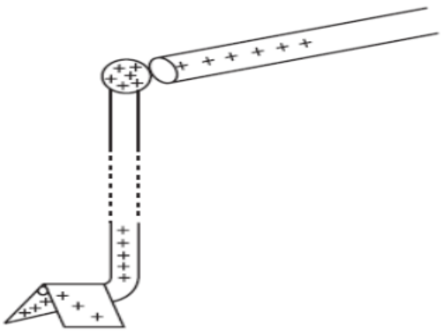
14. Briefly explain the working of a gold leaf electroscope.

Ans: A gold leaf electroscope consists of a vertical metal rod fixed in a box, with two thin gold leaves attached to its end.



When a charged object touches the metal knob at the top of the rod, charge flows on to the leaves. Since both the leaves are charged by the same type of charge, they diverge due to electrostatic repulsion.

The separation between the leaves gives a rough measure of the amount of charge.



15. State whether the following statement is true or false.

'During charging by induction, new charges are created in the body'

Ans: False. During induction only a rearrangement of charges takes place. No new charges are created in the body.

16. Repulsion is the sure test of electrification. Explain

Ans: A charged body can attract another oppositely charged body as well as an uncharged body. But a charged body can repel only similar charged bodies.

17. Can a body attract a similar charged body in any case?

Ans: Yes. If the charge on one body is much greater than the charge on the other body, it can induce opposite charges on the other body. Then the attraction can dominate the repulsion.

18. Explain the properties electric charges.

Ans: The basic properties electric charges are:

a) Additive property

If a system contains 'n' charges q_1, q_2, q_3, ------, q_n, then the total charge of the system is $q_1 + q_2 + q_3 + \text{-------} + q_n$.

b) Conservation Electric Charge

Charge can neither be created nor be destroyed but can be transferred from one body to another.

OR

The total charge of an isolated system is always conserved.

c) Quantization of electric charge

According to quantization of electric charge *"in the universe, charge of any body is an integer multiple of e"*

Q = ne, where n is an integer and $\mathbf{e = 1.6 \times 10^{-19} C}$

That is, charges like 1**e**, 2**e**, 3**e**, ------ are possible but a charge like 1.5**e** is not possible.

19[P]. 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?)

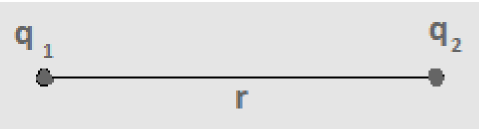
(b) Is there a transfer of mass from wool to polythene?

COULOMB'S LAW

20. State Coulomb's inverse square law in electrostatics.

Ans: **Coulomb's law states that "the electrostatic force between two stationary point**

charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them.”



$$F = \frac{1}{4\Pi\varepsilon}\frac{q_1q_2}{r^2}$$

ϵ is called the permittivity of the medium.

If the charges are placed in vacuum or air, $\epsilon = \epsilon_0$, where ϵ_0 is the permittivity of vacuum or air.

Then, $\boxed{\mathbf{F = \frac{1}{4\Pi\varepsilon_0}\frac{q_1q_2}{r^2}}}$

$\epsilon_0 = 8.854 \times 10^{-12}\ C^2/Nm^2$

$$\frac{1}{4\Pi\varepsilon_0} = 9\times10^9 Nm^2/C^2$$

For any other medium $\epsilon = \epsilon_0\epsilon_r$, where $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$ is called the relative permittivity (or dielectric constant)of the medium with respect to vacuum or air.

$$F_{med} = \frac{1}{4\Pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{r^2}$$

$$\boxed{\mathbf{F_{med}} = \frac{F_{air}}{\varepsilon_r}}$$

21. Define dielectric constant of a medium.

Ans: *Dielectric constant of a medium is the ratio of permittivity of the medium to the permittivity of vacuum.*

22. If the air medium between two charges is replaced by water, what change you expect in the electrostatic force and why?

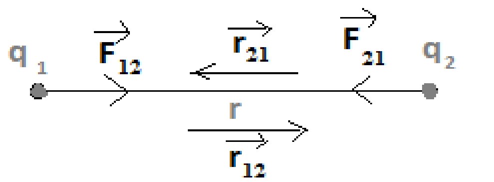
Ans:

$$\boxed{\mathbf{F_{med}} = \frac{F_{air}}{\varepsilon_r}}$$

The force decreases by ε_r times.

23. Write Coulomb’s law in vector form.

Ans: Case(i) When <u>the force is attractive</u>



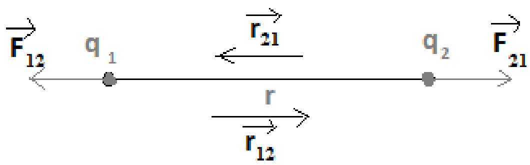
Force on q_1 due to q_2

$$\vec{F}_{12} = \frac{1}{4\Pi\varepsilon_0}\frac{q_1q_2}{r^2}\hat{r}_{12}$$

Force on q_2 due to q_1

$$\vec{F}_{21} = \frac{1}{4\Pi\varepsilon_0}\frac{q_1q_2}{r^2}\hat{r}_{21}$$

Case(ii) <u>When the force is repulsive</u>



Force on q_1 due to q_2

$$\vec{F}_{12} = \frac{1}{4\Pi\varepsilon_0}\frac{q_1q_2}{r^2}\hat{r}_{21}$$

Force on q_2 due to q_1

$$\vec{F}_{21} = \frac{1}{4\Pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{21}$$

24. Define one coulomb.

Ans: According to Coulomb's law,

$$\mathbf{F} = \frac{1}{4\Pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Put $q_1 = q_2 = 1C$ and $r = 1m$, then

$$\mathbf{F} = 9\times10^9\frac{1\times1}{1^2} = 9\times10^9 N$$

"One coulomb is defined as that charge which when placed in free space at a distance of 1m with an equal and similar charge, will repel with a force of $9\times10^9 N$ *."*

25[P]. Four point charges q_A=2μC, q_B=–5μC, q_C=2μC and q_D=⁻5μC are located at the corners of a square ABCD of side 10cm. What is the force on a charge of 1μC placed at the centre of the square?

26[P]. (a) Two insulated charged copper spheres A and B have their centres separated by a distance of 50cm. What is the mutual force of electrostatic repulsion if the charge on each is 6.5 x 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?

27[P]. Suppose the spheres A and B in the above problem have identical sizes. A third sphere of the same size but uncharged is bought in contact with the first, then brought in contact with the second, and finally removed from both. What is the new force of repulsion between A and B?

28[P]. Two point charges +16μC and -9μC are placed 8cm apart in air. You are asked to place a +10 μC charge at a third position such that the net force on +10 μC charge is zero. Where will you place the charge? Make necessary calculations.

29. State superposition principle.

Ans: If there are a number of charges q_1, q_2, - - - -q_n around a charge 'q', then according to super position principle "the total force acting on 'q' is the vector sum of the forces on 'q' due to individual charges".

Total force, $\vec{F} = \vec{F_1} + \vec{F_2} + \text{- - - -} + \vec{F_n}$

Where $\vec{F}_1 = \frac{1}{4\Pi\varepsilon_0}\frac{qq_1}{r_1^2}\hat{r}_1$,

$$\vec{F}_2 = \frac{1}{4\Pi\varepsilon_0}\frac{qq_2}{r_2^2}\hat{r}_2$$

$$\vec{F}_n = \frac{1}{4\Pi\varepsilon_0}\frac{qq_n}{r_n^2}\hat{r}_n$$

30. What is the use of superposition principle?

Ans: It is used to find the force on a charge due to more than two charges.

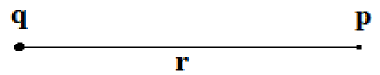
ELECTRIC FIELD

31. Define electric field.

Ans: It is the space around an electric charge, where an electrostatic force is experienced by another charge.

32. Define electric field intensity at a point?

Ans: *Electric field intensity at a point is defined as the force experienced by unit positive charge placed at that point.*



Let a small test charge '**δq**' is placed at P. Then the force experienced by this test charge is given by

$$\mathbf{F} = \frac{1}{4\Pi\varepsilon_0}\frac{q\delta q}{r^2}$$

Therefore, the force experienced by unit positive charge is $E = \lim\limits_{\delta q \to 0} \frac{F}{\delta q}$

$$\mathbf{E} = \frac{1}{4\Pi\varepsilon_0}\frac{q}{r^2}$$

33. Write the equations for electric field intensity.

Ans:

$$E = \lim_{q \to 0} \frac{F}{q}$$

$$E = \frac{1}{4\Pi\varepsilon_0}\frac{q}{r^2}$$

$$E = \frac{V}{d}$$

'V' is the voltage and 'd' is the distance

34. Electric field intensity at a point is defined as $\vec{E} = \lim\limits_{q \to o} \frac{\vec{F}}{q}$

here what does $\lim\limits_{q \to o}$ **imply?**

Ans: Here q is the test charge which is to be placed at the point where the field is to be determined.

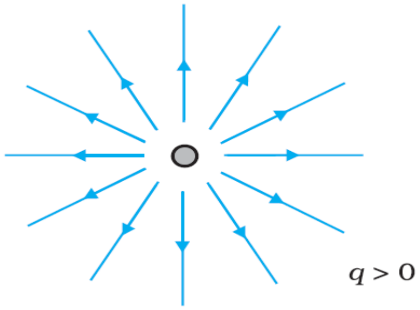
$\lim\limits_{q \to o}$ means that this test charge must be very small, otherwise it will produce its own field so that the field at that point will be changed.

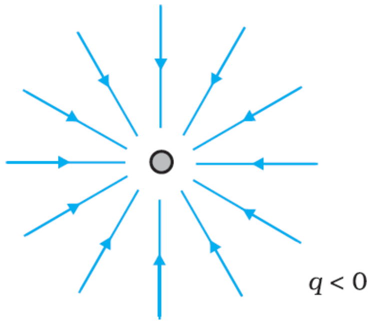
35. Define an electric line of force or electric field line.

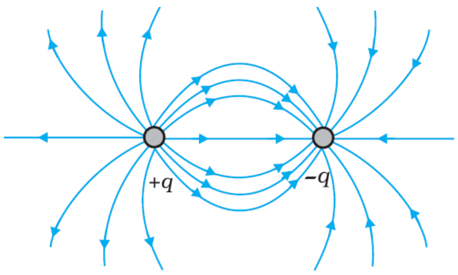
Ans: It is defined as "*the path along which a unit positive charge would move if it is free to do so.*"

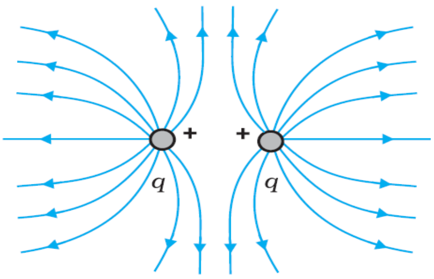
36. Draw the electric field lines due to (i) an isolated positive charge
(ii) an isolated negative charge
(iii) an electric dipole
(iv) Two positive charges

Ans:









37. Write the properties of electric field lines.

Ans: The properties of electric field lines are:

(i) *Electric field lines start at positive charge and end at negative charge. For an isolated single charge electric field lines start or end at infinity.*

(ii) *In a charge free region electric field lines have no break or they are continuous.*

(iii) *Two electric field lines never intersect each other.*

(iv) *In a uniform electric field, electric field lines are parallel.*

(v) *The number density of electric field lines at a point gives the strength (intensity) of electric field at that point.*

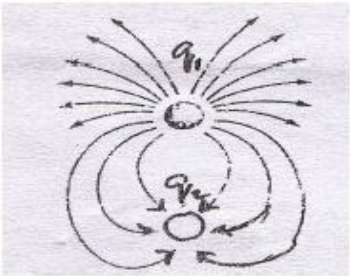
(vi) *The tangent drawn to the electric field line at a point gives the direction of the electric field at that point.*

(vii) *Electric field lines do not form closed loops.*

38. Two electric field lines never intersect. Why?

Ans: If two electric field lines intersect at a point, then there will be two directions for electric field at that point. But this is not possible. So two electric field lines never intersect each other.

39. Figure below shows the electric field lines for two point charges separated by a small distance.



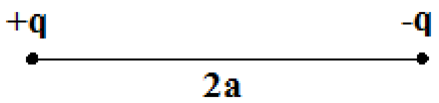
(a) Determine the ratio $\frac{q_1}{q_2}$

(b) What are the signs of q_1 and q_2?

ELECTRIC DIPOLE

40. What is an electric dipole?

Ans: Two equal and opposite charges separated by a small distance is called an electric dipole.



41. Define electric dipole moment.

Ans: *Electric dipole moment is defined as the product of magnitude of one of the charges and length of the dipole.*

Electric dipole moment $\vec{p} = q \times 2a\,p$

Electric dipole moment is a **vector quantity**.

42. What is the direction of electric dipole moment?

Ans: Electric dipole moment is directed from negative charge to the positive charge.

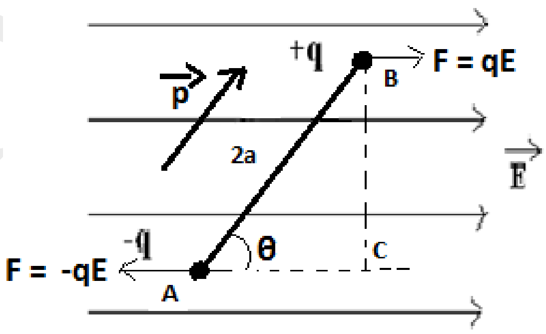
43. What is the SI unit of electric dipole moment?

Ans: coulomb- meter (Cm)

44[P]. 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,–15cm) and B (0,0,+15cm), respectively. What are the total charge and electric dipole moment of the system?

45. Derive the expression for the torque acting on an electric dipole placed in a uniform electric field.

Ans: Consider an electric dipole of dipole moment $\vec{p} = q \times 2ap$, placed in a uniform electric field.



Because of the two equal and opposite forces acting at the two ends of the dipole, a torque is experienced by the dipole. So the dipole will rotate till it becomes parallel to the electric field.

Torque,

$\tau = \text{Force} \times \perp^r \text{ distance}$

$= qE \times BC$

$= qE \times 2a \sin\theta$

$= (q \times 2a) E \sin\theta$

$= pE \sin\theta$

In vector form, $\vec{\tau} = \vec{p} \times \vec{E}$, The direction of this torque is given by right hand rule.

$$\boxed{\tau = pE\sin\theta}$$

46. What is the maximum value of torque acting on the dipole?

Ans:

When $\theta = 90^\circ$

torque, $\tau = pE\sin 90^\circ = pE \times 1 = pE$

This is the maximum value of torque.

47. At what orientations is the dipole placed in a uniform electric field in the (i) the stable equilibrium?

(ii) unstable equilibrium?

Ans: (i) stable equilibrium

When $\theta = 0^\circ$

torque, $\tau = pE\sin 0^\circ = pE \times 0 = 0$

This is the orientation of stable equilibrium.

(ii) unstable equilibrium

When $\theta = 180^\circ$

torque, $\tau = pE\sin 180^\circ = pE \times 0 = 0$

This is the orientation of unstable equilibrium.

48. What is the total charge of an electric dipole?

Ans: zero (q+ -q = 0)

49. What is the total force on an electric dipole placed in a uniform electric field?

Ans: Zero (qE + -qE =0)

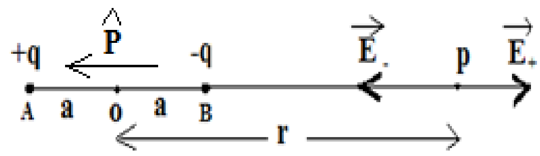
50. What happens when an electric dipole is placed in a non- uniform electric field?

Ans: The dipole will have both rotational and translational motion. The rotational motion will stop, when the dipole becomes parallel to the electric field.

51[P]. An electric dipole with dipole moment 4×10^{-9} C m is aligned at 30^0 with the direction of a uniform electric field of magnitude $5\times10^4 NC^{-1}$. Calculate the magnitude of the torque acting on the dipole.

52. Derive an expression for the electric field at a point on the axial line of an electric dipole

Ans:



Consider an electric dipole of dipole moment $\vec{p} = q \times 2a\hat{p}$ .We have to find the electric field intensity at a point ‘P’ on the axial line of the dipole distant ‘r’ from the midpoint of the dipole.

Electric field at P due to the +q charge at A,

$$\vec{E_+} = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+a)^2} \ (\text{-p})$$

Similarly the electric field at P due to the –q charge at B,

$$\vec{E_-} = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2} \ (\text{p})$$

The resultant electric field at P,

$\vec{E} = \vec{E}_+ + \vec{E}_-$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+a)^2}(\text{-p}) + \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2}(\text{p})$$

$$= \frac{qp}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]$$

$$= \frac{qp}{4\pi\varepsilon_0}\left[\frac{(r+a)^2-(r-a)^2}{(r-a)^2(r+a)^2}\right]$$

$$= \frac{qp}{4\pi\varepsilon_0}\left[\frac{(r^2+2ra+a^2)-(r^2-2ra+a^2)}{[(r-a)(r+a)]^2}\right]$$

$$= \frac{qp}{4\pi\varepsilon_0}\left[\frac{4ra}{(r^2-a^2)^2}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{2(q\times 2a)rp}{(r^2-a^2)^2}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{2prp}{(r^2-a^2)^2}$$

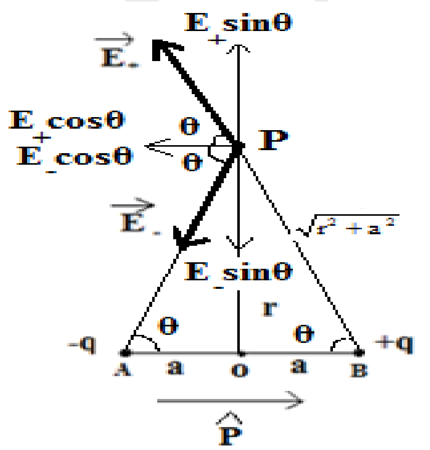
If $r^2 \gg a^2, a^2$ can be neglected,then

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}p$$

$$\boxed{\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}\hat{p}}$$

53. Derive an expression for the electric field at a point on the equatorial line of an electric dipole.

Ans:



Consider an electric dipole of dipole moment $\vec{p} = q\times 2a\hat{p}$ .We have to find the electric field intensity at a point 'P' on the equatorial line of the dipole distant 'r' from the midpoint of the dipole.

Electric field at P due to the +q charge at A,

$$E_+ = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+a^2}$$

Similarly the electric field at P due to the –q charge at B,

$$E_- = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+a^2}$$

E₊ can be split in to two components **E₊cosθ** and **E₊sinθ**. Similarly **E₋** can be split in to components **E₋cosθ** and **E₋sinθ**. The **E₊sinθ** and **E₋sinθ** components cancel each other being equal and opposite. The **E₊cosθ** and **E₋cosθ** components add together. Resultant electric field at P is given by,

$$\mathbf{E = E_+\cos\theta + E_-\cos\theta}$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+a^2}\cos\theta + \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+a^2}\cos\theta$$

From figure, $\cos\theta = \frac{a}{(r^2+a^2)^{\frac{1}{2}}}$

$$E = 2\times\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+a^2}\frac{a}{(r^2+a^2)^{1/2}}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q\times 2a}{(r^2+a^2)^{3/2}}$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2+a^2)^{3/2}}$$

If $r^2 \gg a^2, a^2$ can be neglected,then

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

In vector form,

$$\boxed{\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}(-\hat{p})}$$

54. Compare the electric fields on the axial and equatorial lines of an electric dipole .

Ans: (i) $E_{axial} = 2 \times E_{equatorial}$

(ii) Both the fields are inversely proportional to r^3

(iii) The direction of E_{axial} is parallel to electric dipole moment and that of $E_{equatorial}$ is antiparallel to electric dipole moment.

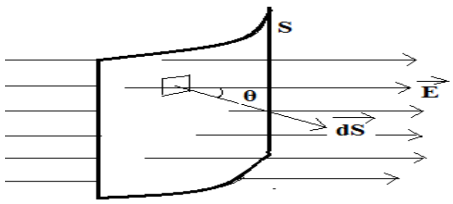
ELECTRIC FLUX

55. Define electric flux.

Ans: *Electric flux is defined as the total number of electric field lines passing normally through a surface.*

Electric flux through small area ds is defined as,

$$d\phi = \vec{E} \bullet \vec{dS}$$



The total electric flux through the surface **S** is given by

$$\phi = \oint \vec{E} \bullet \vec{dS}$$

If the surface S is a plane surface, then the total electric flux is

$$\phi = \vec{E} \bullet \vec{S}$$

$$= ES\cos\theta$$

56. Give the SI unit of electric flux.

Ans: Nm^2/C or Vm

57[P]. Consider a uniform electric field $E = 3 \times 10^3\, \hat{i}$ N/C. (a) what is the flux of this field through a square of 10cm on a side whose plane is parallel to the yz plane? (b) What is the flux through the same square if the normal to its plane makes a 60^0 angle with the x-axis?

58[P]. What is the net flux of the uniform electric field of above problem through a cube of side 20 cm oriented so that its faces are parallel to the coordinate planes?

59. Define the three charge densities.

Ans: The three different charge densities are:

(i) <u>Linear charge density(λ)</u>

It is the charge per unit length. $\lambda = \dfrac{q}{\ell}$

SI unit is C/m

(ii) <u>Surface charge density(σ)</u>

It is the charge per unit area

$$\sigma = \frac{q}{A}$$

SI unit is C/m^2

(iii) <u>Volume charge density(ρ)</u>

It is the charge per unit volume. $\rho = \dfrac{q}{V}$

SI unit is C/m^3

60. A spherical conducting shell of inner radius r_1 and outer radius r_2 has

a charge ‘Q’. A charge ‘q’ is placed at the centre of the shell.

(a) What is the surface charge density on the (i) inner surface, (ii) outer surface of the shell?

(b) Write the expression for the electric field at a point $x>r_2$ from the centre of the shell.

GAUSS’S THEOREM

61. State Gauss’s theorem in electrostatics.

Ans: Gauss’s theorem states that “ **the total electric flux over a closed surface enclosing a charge is equal to 1/ε₀ times the net charge enclosed**.”

Mathematically Gauss’s theorem can be stated as

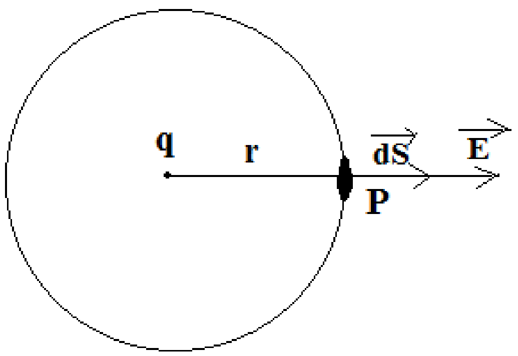
$$\phi = \frac{1}{\varepsilon_0} q$$

$$\Rightarrow \oint \vec{E} \bullet \vec{dS} = \frac{q}{\varepsilon_0}$$

62. Prove Gauss’s theorem.

Ans: Consider a point charge q placed at a point. Imagine a sphere of radius r with q as the centre.

The total electric flux through the sphere,



$$\oint \vec{E} \bullet \vec{dS}$$

$$= \oint EdS\cos 0 \quad (\because \ \vec{E} \parallel \vec{dS})$$

$$= \oint EdS$$

$$= E\oint dS$$

$$= E \times 4\pi r^2$$

At the surface of the sphere,

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

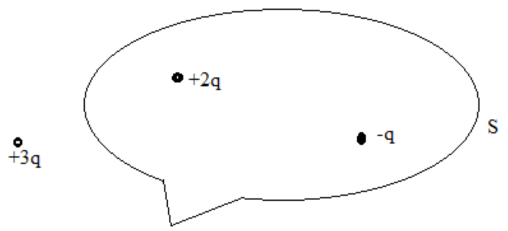
$$\therefore \oint \vec{E} \bullet \vec{dS} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} \times 4\pi r^2$$

$$= \frac{q}{\varepsilon_0}$$

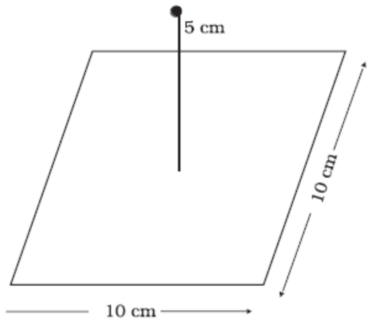
63. What is a Gaussian surface?

Ans: An imaginary surface enclosing a charge is called a Gaussian surface. A Gaussian surface can be a surface of any shape.

64. Figure shows three point charges, $+2q$, $-q$ and $+3q$. Two charges $+2q$ and $-q$ are enclosed in a surface ‘S’. What is the electric flux due to this configuration through the surface ‘S’?



65[P]. A point charge $+10\mu C$ is at a distance 5 cm directly above the centre of a square of side 10 cm, as shown in Fig. 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)



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

67[P]. A point charge causes an electric flux of -1.0×10^3 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?

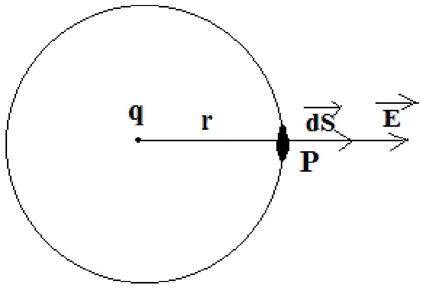
(b) What is the value of the point charge?

68[P]. A uniformly charged conducting sphere of 2.4 m diameter has a surface charge density of 80.0 $\mu C/m^2$. (a) Find the charge on the sphere. (b) What is the total electric flux leaving the surface of the sphere?

69. Derive Coulomb's law from Gauss's theorem.

Ans: By Gauss's theorem,

$$\oint \vec{E} \bullet \vec{dS} = \frac{q}{\varepsilon_0}$$



$$\oint EdS\cos 0 = \frac{q}{\varepsilon_0} \quad (\because\ \vec{E} \parallel \vec{dS})$$

$$\Rightarrow \oint EdS = \frac{q}{\varepsilon_0}$$

$$\Rightarrow E\oint dS = \frac{q}{\varepsilon_0}$$

$$\Rightarrow E \times 4\pi r^2 = \frac{q}{\varepsilon_0}$$

$$\therefore E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

this is the electric field at the surface of the sphere.

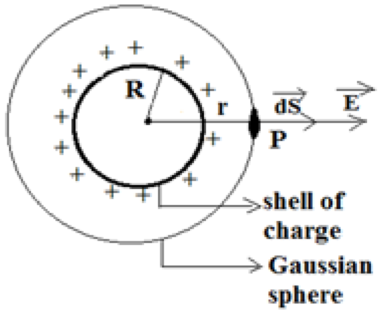
If we place another charge δq on the surface of the sphere, then force acting on it is

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q\delta q}{r^2} \text{ This is Coulomb's law.}$$

70. By applying Gauss's theorem deduce the expression for electric field due to a spherical shell of charge (hollow sphere) density σ.

Ans: Consider a shell of radius R and charge density σ. We have to find the electric field at a point distant r from the centre of this shell. For this we imagine a Gaussian sphere of radius r, concentric with the given shell of charge and passing through P.

Case(i): E.F.Outside the shell



The total Electric flux through the Gaussian sphere,

$$\oint \vec{E} \bullet \vec{dS}$$

$$= \oint EdS\cos 0 \quad (\because \ \vec{E} \parallel \vec{dS})$$

$$= \oint EdS$$

$$= E\oint dS$$

$$= E \times 4\pi r^2$$

The charge enclosed by the Gaussian sphere, $q = A\sigma = 4\pi R^2\sigma$

Applying Gauss's theorem,

$$\oint \vec{E} \bullet \vec{dS} = \frac{q}{\varepsilon_0}$$

$$E \times 4\pi r^2 = 4\pi R^2\sigma$$

$$E = \frac{R^2\sigma}{\varepsilon_0 r^2}$$

$$\boxed{E = \frac{R^2\sigma}{\varepsilon_0 r^2}}$$

Case(ii): E.F. on the shell

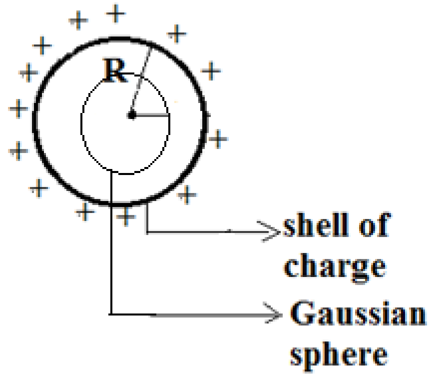
Put r=R

$$E = \frac{R^2\sigma}{\varepsilon_0 R^2} = \frac{\sigma}{\varepsilon_0}$$

$$E = \frac{\sigma}{\varepsilon_0}$$

$$\boxed{E = \frac{\sigma}{\varepsilon_0}}$$

Case(iii) E.F.inside the shell



In this case the charge enclosed by the Gaussian sphere, q=0

$\therefore$ Substituting in Gauss's theorem

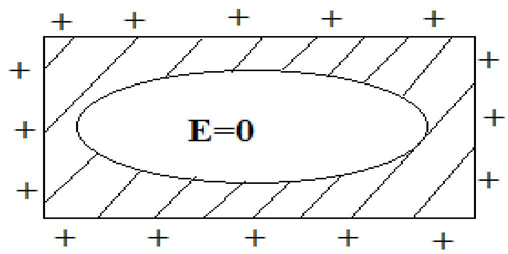
$$E \times 4\pi r^2 = \frac{0}{\varepsilon_0}$$

$\Rightarrow E = 0$.The electric field inside a sperical shell of charge is zero.

71. What is meant by electrostatic shielding?

Ans:

Electric field inside the cavity of a conductor of any shape is zero. This is called electrostatic shielding.



72[Q]. Draw the variation of electric field intensity of a shell of radius R with distance r .

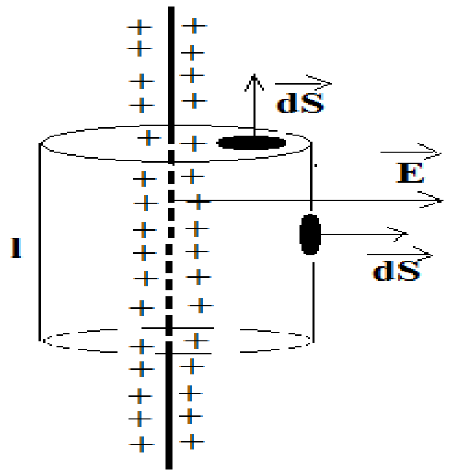
73. During lightning, a person inside a car is safer than outside. Why?

Ans: This is due to electrostatic shielding. Due to electrostatic shielding, electric field inside the car is zero.

73. By applying Gauss's theorem, derive an expression for the electric field due to a straight infinitely long charged wire (line charge) of charge density λ.

Ans:

Consider an infinitely long straight wire of charge density λ. We have to find the electric field at a point P distant 'r' from this line charge. For this imagine a Gaussian cylinder of radius 'r' and length 'l' with the line charge as the axis.



The total electric flux,

$$\oint \vec{E} \bullet \vec{dS}$$

$$= \int_{\substack{\text{curved}\\\text{surface}}} \vec{E} \bullet \vec{dS} + \int_{\substack{\text{end}\\\text{faces}}} \vec{E} \bullet \vec{dS}$$

$$= \int_{\substack{\text{cerved}\\\text{surface}}} EdS\cos 0^\circ + \int_{\substack{\text{end}\\\text{faces}}} EdS\cos 90^\circ$$

$$= \int_{\substack{\text{curved}\\\text{surface}}} EdS + \int_{\substack{\text{end}\\\text{faces}}} EdS \times 0$$

$$= E \int_{\substack{\text{curved}\\\text{surface}}} dS$$

$$= E \times 2\pi r\ell$$

The charge enclosed by the Gaussian cylinder, $q = \ell\lambda$

Applying Gauss's theorem,

$$\oint \vec{E} \bullet \vec{dS} = \frac{q}{\varepsilon_0}$$

$$E \times 2\pi r\ell = \frac{\ell\lambda}{\varepsilon_0}$$

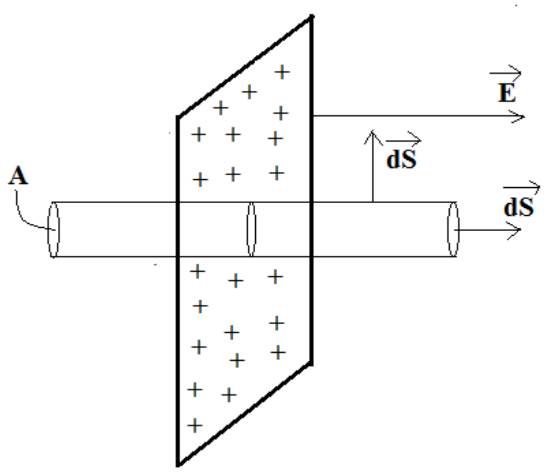
$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

$$\boxed{E = \frac{\lambda}{2\pi\varepsilon_0 r}}$$

74[P]. **An infinite line charge produces a field of** 9 x10^4 N/C **at a distance of** 2 cm. **Calculate the linear charge density.**

75. Applying Gauss's theorem find an expression for the electric field due to an infinitely large plane sheet of charge density 'σ'

Ans: Consider an infinitely large plane sheet of charge density λ. We have to find the electric field at a point P distant 'r' from this plane sheet of charge. For this imagine a Gaussian cylinder of small area of cross section with one end passing through the point P, penetrating the sheet and extending to both sides equally.



The total electric flux through the Gaussian cylinder,

$$\oint_s \vec{E} \bullet \vec{dS}$$

$$= \int_{\substack{\text{curved}\\ \text{surface}}} \vec{E} \bullet \vec{dS} + \int_{\substack{\text{end}\\ \text{faces}}} \vec{E} \bullet \vec{dS}$$

$$= \int_{\substack{\text{curved}\\ \text{surface}}} EdS\cos 90^\circ + \int_{\substack{\text{end}\\ \text{faces}}} EdS\cos 0^\circ$$

$$= \int_{\substack{\text{curved}\\ \text{surface}}} EdS \times 0 + \int_{\substack{\text{end}\\ \text{faces}}} EdS \times 1$$

$$= E \int_{\substack{\text{end}\\ \text{faces}}} dS$$

$$= E \times 2A$$

The charge enclosed by the Gaussian cylinder, $q = A\sigma$

Applying Gauss's theorem,

$$\oint \vec{E} \bullet \vec{dS} = \frac{q}{\varepsilon_0}$$

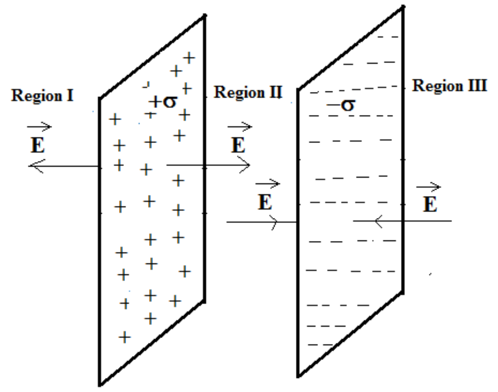
$$E \times 2A = \frac{A\sigma}{\varepsilon_0}$$

$$E = \frac{\sigma}{2\varepsilon_0}$$

$$\boxed{E = \frac{\sigma}{2\varepsilon_0}}$$

76. Find the expressions for the electric field due to two infinitely large parallel plane sheets of equal and opposite charge densities.

Ans: Consider two infinitely large plane parallel sheets having charge densities $+\sigma$ and $-\sigma$.



Electric field due to a single sheet,

$$E = \frac{\sigma}{2\varepsilon_0}$$

In Region I

$$E_I = -E + E = 0$$

In Region II

$$E_{II} = E + E$$

$$= \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = 2\frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$

In Region III

$$E_{III} = E + (-E) = 0$$

77[P]. Two charge, 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/m^2. 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?