1 Electric Charges and Fields

Fastrack Revision

- **Electric Charge:** It is a basic property of matter due to which it produces and experiences electric and magnetic effects.
  - It is a scalar quantity.
  - Its SI unit is Coulomb (C).
  - Like charges repel each other and unlike charges attract each other.
  - There are two types of charges: positive and negative.
  - Charge on glass rod or cat's fur is called positive/vitreous charge.
  - Charge on plastic rod or silk is called negative/resinous charge.
  - Charges have some properties which are additive, property, quantisation of charge and conservation of charge.
- **Additive Property:** Total charge on a body is equal to the algebraic sum of all the charges placed on different parts of the body.

  Consider a system which consists of three charges namely $q_1, -q_2$ and q_3. Hence, net charge will be:

  $$q = q_1 + (-q_2) + q_3$$

  For n charges, the net charge will be:

  $$q = q_1 + q_2 + q_3 + \dots\dots\dots + q_n$$
- **Quantisation of Charge:** It is the property by virtue of which all free charges exist in integer multiple of an elementary charge *i.e.*, electron.

  Mathematically, $q = \pm ne$ Where, n is an integer

  and $e = 1.6 \times 10^{-19}$C
- **Conservation of Charge:** The net charge on an isolated system remains constant. However, charge may be transferred from one part of the system to another.
- **Coulomb's Law:** It states that the force between two points like stationary charges (q_1 and q_2) is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

  $$F \propto \frac{q_1 q_2}{r^2}$$

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

  where, $k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ N-m}^2/\text{C}^2$

  and $\varepsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{N-m}^2$

  Here, k is the dielectric constant and ε_0 is called the permittivity of free space.
- **Relative Permittivity:** The ratio of the permittivity (ε) of the medium to the permittivity (ε_0) of the free space is called relative permittivity (ε_r) or dielectric constant (k).

  Thus, ε_r or $k = \frac{\varepsilon}{\varepsilon_0} = \frac{F_{vac}}{F_{med}}$
- **Principle of Superposition:** The net force on any charge due to number of other charges is the vector sum of all the forces exerted on the given charge by all other charges individually.

  Thus, net force on q_1 due to charges q_2, q_3, q_4, ... is given by

  $$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \dots$$
- **Electric Field:** The region or space around a charge in which an another charge q_0 experiences a force is called electric field.
  - It is a vector quantity.
  - Its SI unit is N/C.
  - Its dimensions are $[MLT^{-2}]/[AT]$ or $[MLT^{-3}A^{-1}]$.
  - Electric field does not exert any force on the charge which produces it.
  - Electric field exerts a force on any other charge placed in it.
  - The direction of a force on positive charge is the direction of electric field.
- **Electric Field Intensity:** Electric field intensity $(\vec{E})$ at a point is defined as the force $(\vec{F})$ experienced by a unit positive test charge (q_0) placed at that point.

  $$\vec{E} = \frac{\vec{F}}{q_0}$$
- **Electric Field due to a Point Charge *q***

  $$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$
- **Electric Field Lines:** Electric field lines are smooth curves such that a tangent drawn at any point on the curve gives the direction of electric field at that point.
- **Characteristics of Electric Field Lines**
  - Electric field lines originate at positive charge and terminate at negative charge. They do not form closed loop.
  - Electric field lines do not exist inside conductors *i.e.*, $E = 0$ inside a conductor.
  - Electric field lines do not cross each other. If they do, it means two directions of electric field at a single point which is absurd.
  - Electric field lines originate and terminate normally from the surface of a conductor.

- 'E' (electric field) is stronger where electric field lines are crowded and 'E' is weaker where they are farther apart.
- Number of electric field lines drawn are proportional to magnitude of the charge.

▶ **Electric Dipole:** A pair of equal and opposite charges separated by small distance constitutes a dipole.
e.g., NaCl, H_2O molecules etc.

▶ **Electric Dipole Moment (p):** Electric dipole moment is defined as the product of magnitude of either charge (q) and distance between the two charges ($2a$).

i.e., $$\vec{p} = q(2a)$$

- Its SI unit is Coulomb-metre (C-m).
- It is a vector quantity.
- Direction of p is from $-q$ to $+q$.

▶ **Torque on a Dipole in a Uniform Electric Field**
τ = One force × perpendicular distance between the forces
$\tau = qE \times 2a \sin\theta$ or $\tau = pE \sin\theta$ $[\because p = q(2a)]$
Torque rotates the dipole and aligns its axis in the direction of $\vec{E}$.

▶ **Electric Field of an Electric Dipole**
(i) For points on the axis:
$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{(r)^3}$$
(ii) For point on equatorial plane:
$$\text{Net electric field } E = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{(r^2 - a^2)^{3/2}}\hat{p}$$
If $r >>> a$, then $\vec{E} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3}$ $[\because \vec{p} = q \times 2a\hat{p}]$

▶ **Electric Flux (ϕ_E):** The number of electric field lines passing through any surface area held in the electric field is called electric flux (ϕ_E).

i.e., $$\phi_E = \oint E \cdot dS$$

- It is a scalar quantity.
- Its SI unit is $Nm^2 C^{-1}$ or V-m.

▶ **Continuous Charge Distribution:** The region in which charges are closely spaced in a continuous manner is said to have continuous distribution of charge.
The force on a charge due to continuous charge distribution is given by:
$$\vec{F} = \frac{q_0}{4\pi\varepsilon_0}\int\frac{dq}{r^2}\cdot\hat{r}$$

There are three types of continuous charge distribution:
- **Linear Charge Density:** It is the ratio of charge per unit length of a long wire.
$$\lambda = \frac{dq}{dl} \text{ (in C/m)}$$
- **Surface Charge Density:** It is the ratio of charge per unit area of a surface.
$$\sigma = \frac{dq}{dS} \text{ (in C/m}^2\text{)}$$
- **Volume Charge Density:** It is the ratio of charge per unit volume of a bulk material.
$$\rho = \frac{dq}{dV} \text{ (in C/m}^3\text{)}$$

▶ **Electric Field due to Charge Distribution**
(i) $\vec{E}_\lambda = \frac{1}{4\pi\varepsilon_0}\int_l \frac{\lambda dl}{r^2}\hat{r}$ (ii) $\vec{E}_\sigma = \frac{1}{4\pi\varepsilon_0}\int_S \frac{\sigma dS}{r^2}\hat{r}$
(iii) $\vec{E}_\rho = \frac{1}{4\pi\varepsilon_0}\int_V \frac{\rho dV}{r^2}\hat{r}$
where $\hat{r}$ is a unit vector.

▶ **Gauss's Theorem:** The total electric flux passing through a closed surface is $\frac{1}{\varepsilon_0}$ times the total charge enclosed in the surface.

i.e., $$\phi_E = \frac{q_{enclosed}}{\varepsilon_0}$$

▶ **Applications of Gauss's Law**
- Electric field (E) due to an infinitely long straight uniformly charged wire is given by:
$$E = \frac{\lambda}{2\pi r\varepsilon_0}$$
where, λ = linear charge density
r = perpendicular distance from the charged wire.
- Electric field (E) due to a uniformly charged infinite plane sheet is given by:
$$E = \frac{\sigma}{2\varepsilon_0}$$
where, σ = surface charge density
- Electric field due to a uniformly charged thin spherical shell is given by:
$$E = \frac{q}{4\pi\varepsilon_0 r^2} \quad \text{(outside the shell)}$$
$$E = 0 \quad \text{(inside the shell)}$$

Practice Exercise

Multiple Choice Questions

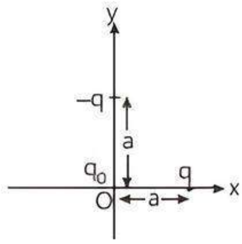
Q 1. Electricity produced on rubbing is:
a. static electricity b. electromagnetic
c. current electricity d. None of these

Q 2. When 10^{19} electrons are removed from a neutral plate, the electric charge on it is:
a. –1.6 C b. +1.6 C
c. 10^{19}C d. 10^{-19}C

Q 3. A negatively charge object X is repelled by another charged object Y. However an object Z is attracted to object Y. Which of the following is the most possibility for the object Z? *(CBSE 2021 Term-1)*
a. Positively charged
b. Negatively charged
c. Neutral or positively charged
d. Neutral or negatively charged

Q 4. Three charges q, $-q$ and q_0 are placed as shown in figure. The magnitude of the net force on the charge q_0 at point O is $\left[k = \frac{1}{4\pi\varepsilon_0}\right]$

(CBSE 2021 Term-1)



a. 0
b. $\frac{2kqq_0}{a^2}$
c. $\frac{\sqrt{2}kqq_0}{a^2}$
d. $\frac{1}{\sqrt{2}}\frac{kqq_0}{a^2}$

Q 5. An electron experiences a force $(1.6 \times 10^{-16}\ \text{N})\ \hat{i}$ in an electric field $\vec{E}$. The electric field $\vec{E}$ is:

(CBSE 2023)

a. $(1.0 \times 10^3 \text{N/C})\ \hat{i}$
b. $-(1.0 \times 10^3\ \text{N/C})\hat{i}$
c. $(1.0 \times 10^{-3}\ \text{N/C})\hat{i}$
d. $-(1.0 \times 10^{-3}\ \text{N/C})\hat{i}$

Q 6. Which one of the following is not a scalar quantity?

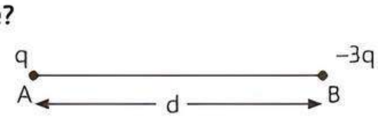
(CBSE 2023)

a. Electric field
b. Voltage
c. Resistivity
d. Power

Q 7. The force between two small charged sphere having charges of 1×10^{-7} C and 2×10^{-7} C placed 20 cm apart in air is:

a. 4.5×10^{-2} N
b. 4.5×10^{-3} N
c. 5.4×10^{-2} N
d. 5.4×10^{-3} N

Q 8. Two charges q and $-3q$ are fixed on X-axis separated by distance d. Where should a third charge $2q$ be placed from A such that it will not experience any force?

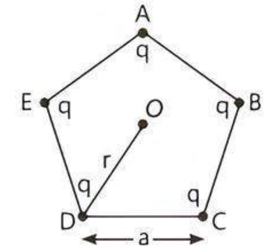


a. $\frac{d - \sqrt{3}d}{2}$
b. $\frac{d + \sqrt{3}d}{2}$
c. $\frac{d + 3d}{2}$
d. $\frac{d - 3d}{2}$

Q 9. A force of 2.25 N acts on a charge of 15×10^{-4} C. The intensity of electric field at that point is:

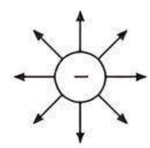
a. 150 NC^{-1}
b. 15 NC^{-1}
c. 1500 NC^{-1}
d. 1.5 NC^{-1}

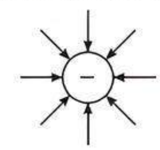
Q 10. Five equal charges each of value q are placed at the corners of a regular pentagon of side a. The electric field at the centre of the pentagon is:

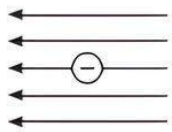


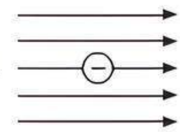
a. $\frac{q}{4\pi\varepsilon_0 r^2}$
b. $\frac{q^2}{4\pi\varepsilon_0 r^2}$
c. $\frac{2q}{4\pi\varepsilon_0 r^2}$
d. zero

Q 11. Which of the following figures represents the electric field lines due to a single negative charge?

a. 

b. 

c. 

d. 

Q 12. Two point charges $+8q$ and $-2q$ are located $x = 0$ and $x = L$ respectively. The point on X-axis at which net electric field is zero due to these charge is:

(CBSE SQP 2021-22 Term-1)

a. $8L$
b. $4L$
c. $2L$
d. L

Q 13. An electric dipole of moment p is placed parallel to the uniform electric field. The amount of work done in rotating the dipole by 90° is:

a. $2pE$
b. pE
c. $pE/2$
d. zero

Q 14. Two point charges placed in a medium of dielectric constant 5 are at a distance r between them, experience an electrostatic force F. The electrostatic force between them in vacuum at the same distance r will be:

a. $5F$
b. F
c. $F/2$
d. $F/5$

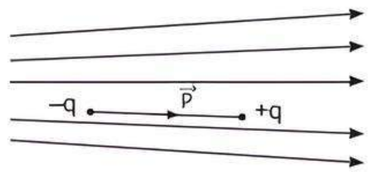
Q 15. According to Coulomb's law, which is the correct relation for the following figure? *(CBSE SQP 2022-23)*

a. $q_1 q_2 > 0$
b. $q_1 q_2 < 0$
c. $q_1 q_2 = 0$
d. $1 > q_1/q_2 > 0$

Q 16. Two parallel large thin metal sheets have equal surface densities 26.4×10^{-12} C/m^2 of opposite signs. The electric field between these sheets is:

a. 1.5 N/C
b. 1.5×10^{-16} N/C
c. 3×10^{-10} N/C
d. 3 N/C

Q 17. Figure shows electric field lines in which an electric dipole $\vec{p}$ is placed as shown. Which of the following statements is correct? *(NCERT EXEMPLAR)*



a. The dipole will not experience any force
b. The dipole will experience a force towards right
c. The dipole will experience a force towards left
d. The dipole will experience a force upwards

Q 18. An electric dipole placed in an electric field of intensity 2×10^5 N/C at an angle of 30° experiences a torque equal to 4 Nm. The charge on the dipole of dipole length 2 cm is: *(CBSE SQP 2023-24)*

a. 7 μC
b. 8 mC
c. 2 mC
d. 5 mC

Q 19. An electric dipole placed in a non-uniform electric field, can experience: *(CBSE 2020)*

a. a force but not a torque
b. a torque but not a force
c. always a force and a torque
d. Neither a force nor a torque

Q 20. If σ = surface charge density, ε = electric permittivity, then dimension of $\frac{\sigma}{\varepsilon}$ is same as:

a. electric force
b. electric field intensity
c. pressure
d. electric charge

Q 21. A cylinder of radius r and length l is placed in an uniform electric field parallel to the axis of the cylinder. The total flux for the surface of the cylinder is given by:

a. zero
b. πr^2
c. $E\pi r^2$
d. $2E\pi r^2$

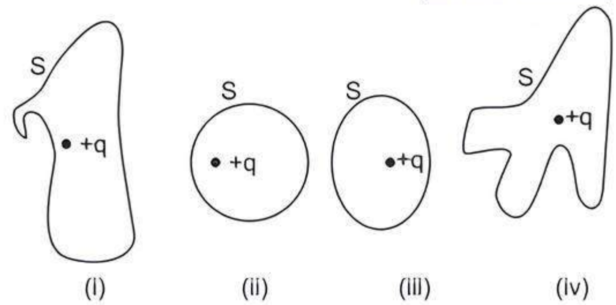
Q 22. The electric flux through a closed Gaussian surface depends upon: *(CBSE 2020)*

a. net charge enclosed and permittivity of the medium
b. net charge enclosed, permittivity of the medium and the size of the Gaussian surface
c. net charge enclosed only
d. permittivity of the medium only

Q 23. If the net electric flux through a closed surface is zero, then we can infer that: *(CBSE 2020)*

a. no net charge is enclosed by the surface
b. uniform electric field exists within the surface
c. electric potential varies from point to point inside the surface
d. charge is present inside the surface

Q 24. The electric flux through the surface: *(NCERT EXEMPLAR)*



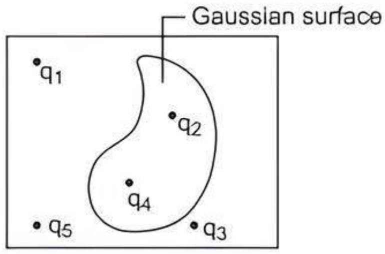
a. in figure (iv) is the largest
b. in figure (iii) is the least
c. in figure (ii) is same as in figure (iii) but is smaller than figure (iv)
d. is the same for all the figures

Q 25. Which statement is true for Gauss law?

a. All the charges whether inside or outside the Gaussian surface contribute to the electric flux.
b. Electric flux depends upon the geometry of the Gaussian surface.
c. Gauss theorem can be applied to non-uniform electric field.
d. The electric field over the Gaussian surface remains continuous and uniform at every point.

Q 26. Five charges q_1, q_2, q_3, q_4 and q_5 are fixed at their positions as shown in figure, S is a Gaussian surface.

The Gauss's law is given by $\oint_s \vec{E}.d\vec{S} = \frac{q}{\varepsilon_0}$



Which of the following statement is correct? *(NCERT EXEMPLAR)*

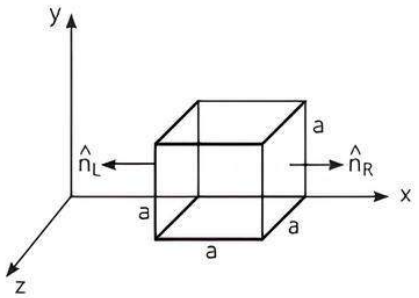
a. $\vec{E}$ on the LHS of the above equation will have a contribution from q_1, q_5 and q_3 while q on the RHS will have a contribution from q_1 and q_4 only.

b. $\vec{E}$ on the LHS of the above equation will have a contribution from all charges while q on the RHS will have a contribution from q_2 and q_4 only.

c. $\vec{E}$ on the LHS of the above equation will have a contribution from all charges while q on the RHS will have a contribution from q_1, q_3 and q_5 only.

d. Both $\vec{E}$ on the LHS and q on the RHS will have contribution from q_2 and q_4 only.

Q 27. The electric field components in the given figure are $E_x = \alpha x^{1/2}, E_y = E_z = 0$ in which $\alpha = 800 NC^{-1} m^{-1/2}$. The charge within the cube, if net flux through the cube is 1.05 Nm^2C^{-1}, is (Assume, $a = 0.1$ m):



a. 9.30×10^{-12} C
b. 9.27×10^{12} C
c. 6.97×10^{-12} C
d. 6.97×10^{12} C

Q 28. An infinitely long uniformly charged wire produces an electric field of 18×10^4 NC^{-1} at a distance of 1.0 cm. The linear charge density on the wire is: *(CBSE 2023)*

a. 1.12×10^{-14} Cm^{-1}
b. 3.08×10^{-15} Cm^{-1}
c. 1.0×10^{-9} Cm^{-1}
d. 1.0×10^{-7} Cm^{-1}

Q 29. A point charge $+q$, is placed at a distance d from an isolated conducting plane. The field at a point P on the other side of the plane is: *(NCERT EXEMPLAR)*

a. directed perpendicular to the plane and away from the plane
b. directed perpendicular to the plane but towards the plane
c. directed radially away from the point charge
d. directed radially towards the point charge

Assertion & Reason Type Questions

Directions (Q.Nos. 30-39): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 30. Assertion (A): When we rub a glass rod with silk, the rod gets positively charged and the silk gets negatively charged.

Reason (R): On rubbing, electrons from silk cloth moves to the glass rod.

Q 31. Assertion (A): A negative charge in an electric field moves along the direction of the electric field.

Reason (R): On a negative charge, a force acts in the direction of the electric field. *[CBSE 2021 Term-1]*

Q 32. Assertion (A): If there exists coulomb attraction between two bodies, both of them may not be charged.

Reason (R): In Coulomb attraction two bodies are oppositely charged.

Q 33. Assertion (A): The force with which two charges attract or repel each other are not affected by the presence of a third charge.

Reason (R): Force on any charge due to a number of other charges is the vector sum of all the forces on that charge due to other charges, taken one at a time.

Q 34. Assertion (A): Work done in moving a charge around a closed path, in an electric field is always zero.

Reason (R): Electrostatic force is a conservative force. *(CBSE 2023)*

Q 35. Assertion (A): Electric field is always normal to equipotential surfaces and along the direction of decreasing order of potential.

Reason (R): Negative gradient of electric potential is electric field.

Q 36. Assertion (A): As force is a vector quantity, hence electric field intensity is also a vector quantity.

Reason (R): The unit of electric field intensity is Newton per coulomb.

Q 37. Assertion (A): No two electric lines of force can intersect each other.

Reason (R): Tangent at any point of electric line of force gives the direction of electric field.

Q 38. Assertion (A): The surface charge densities of two spherical conductors of different radii are equal. Then the electric field intensities near their surface are also equal.

Reason (R): Surface charge density is equal to charge per unit area.

Q 39. Assertion (A): The electric flux emanating out and entering a closed surface are 8×10^3 and 2×10^3 Vm respectively. The charge enclosed by the surface is 0.053 μC.

Reason (R): Gauss's theorem in electrostatics may be applied to verify.

Fill in the Blanks Type Questions

Q 40. The expression $q = ne$ is due to .... of electric charge.

Q 41. A silk cloth rubbed with a glass rod has a charge $q = -1.6 \times 10^{-19}$ C, then the charge on the glass rod will be .... C.

Q 42. A charge Q is enclosed by a Gaussian spherical surface of radius R. If the radius is doubled, then the electric ....will remain same.

Q 43. An electric dipole is placed inside uniform electric field. When it is rotated from unstable equilibrium to stable equilibrium in a uniform electric field, its potential energy ....

Q 44. SI unit of electric field is ....

Q 45. Two point charges are separated by some distance inside vacuum. When space between the charges is filled by some dielectric, the force between two point charges ....

Q 46. Net electrostatic field inside a positively charged conductor is ....

Q 47. Electric flux is a .... quantity.

Q 48. A point charge is placed at the centre of a hollow conducting sphere of internal radius 'r' and outer radius '$2r$'. The ratio of the surface charge density of the inner surface to that of the outer surface will be ....

Answers

1. (a) static electricity
2. (b) +1.6 C

Charge of one electron, $e = -1.6 \times 10^{-19}$ C

So, total charge removed from neutral plate, $q = ne$

$= 10^{19} \times (-1.6 \times 10^{-19}) = -1.6$ C

Since, charge on neutral plate is zero and -1.6 C charge is removed from it. *i.e.*, $q = 0 - (-1.6) = 1.6$ C.

Thus, it has +1.6 C charge.

3. (c) Neutral or positively charged
4. (c) $\dfrac{\sqrt{2}kqq_0}{a^2}$
5. (b) $-(1.0 \times 10^3 \text{ N/C})\hat{i}$

As we know, $\vec{F} = q\vec{E}$

$$\therefore \quad \vec{E} = \frac{\vec{F}}{q} = \frac{1.6 \times 10^{-16}}{-1.6 \times 10^{-19}} = -(1.0 \times 10^3 \text{ N/C})\ \hat{i}$$

6. (a) Electric field
7. (b) 4.5×10^{-3} N

Here, $q_1 = 1 \times 10^{-7}$ C, $q_2 = 2 \times 10^{-7}$ C,

$r = 20 \text{ cm} = 20 \times 10^{-2}$ m

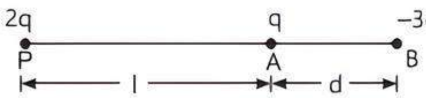
As $$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$$

$$= \frac{9 \times 10^9 \times 1 \times 10^{-7} \times 2 \times 10^{-7}}{(20 \times 10^{-2})^2}$$

$$\left[\because \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{N-m}^2/\text{C}^2\right]$$

$= 4.5 \times 10^{-3}$ N

8. (b) $\dfrac{d + \sqrt{3}d}{2}$



Let a charge $2q$ be placed at point P, at a distance l from A, where charge q is placed, as shown in figure.

The charge $2q$ will not experience any force, when force of repulsion on it due to q is balanced by force of attraction on it due to $-3q$ at B, where $AB = d$.

$$\therefore \quad \frac{(2q)(q)}{4\pi\varepsilon_0 l^2} = \frac{(2q)(3q)}{4\pi\varepsilon_0 (l+d)^2}$$

$$\Rightarrow \quad (l+d)^2 = 3l^2$$

$$\text{or} \quad 2l^2 - 2ld - d^2 = 0$$

$$\Rightarrow \quad l = \frac{2d \pm \sqrt{4d^2 + 8d^2}}{4} = \frac{d}{2} \pm \frac{\sqrt{3}d}{2}$$

$\because$ Negative sign shows charge $2q$ at P would lie between q and $-3q$ and hence it is unacceptable.

$\therefore \ l = \dfrac{d + \sqrt{3}d}{2}$ to the left of q.

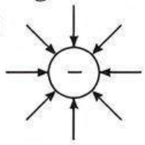
9. (c) 1500 NC^{-1}

Electric field, $E = \dfrac{F}{q} = \dfrac{2.25}{15 \times 10^{-4}\text{C}} = 1500 \text{ NC}^{-1}$

10. (d) zero

The centre of the pentagon is equidistant from all the charges at the end point of pentagon. Thus due to symmetry, the electric field at the centre of pentagon would be zero.

11. (b)



12. (c) $2L$

Let P is the observation point at a distance r from point charge $-2q$ and at a distance $(L + r)$ from point charge $+8q$. Given, net electric field intensity at point $P = 0$.

Let electric field intensity at point P due to $-2q = \vec{E}_1$

and electric field intensity at point P due to $+8q = \vec{E}_2$

According to the question,

$$\vec{E}_1 + \vec{E}_2 = 0 \quad \text{or} \quad \vec{E}_1 = -\vec{E}_2$$

$$\text{or} \quad |\vec{E}_1| = |\vec{E}_2|$$

$$\left|\frac{1}{4\pi\varepsilon_0}\frac{(-2q)}{r^2}\right| = \left|\frac{1}{4\pi\varepsilon_0}\frac{8q}{(L+r)^2}\right|$$

$$\frac{1}{r^2} = \frac{4}{(L+r)^2}$$

$4r^2 = (L+r)^2$

or $(2r)^2 = (L+r)^2$

or $2r = L + r$

or $r = L$

$\therefore$ p is at $x = L + L = 2L$ from origin.

13. (b) pE

Work, $W = pE(\cos\theta_1 - \cos\theta_2)$

$\because$ p is placed parallel to the uniform electric field.

$\therefore$ $\theta_1 = 0°$

and $\theta_2 = 90°$ (given)

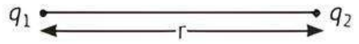
$W = pE(\cos 0° - \cos 90°)$

$= pE(1 - 0) = pE$

14. (a) $5F$

Force, $F = \dfrac{1}{4\pi\varepsilon_0 k}\dfrac{q_1 q_2}{r^2}$ ...(1)

Given, $k = 5$



The electrostatic force between the charges in vacuum is given by

$F' = \dfrac{1}{4\pi\varepsilon_0(1)}\dfrac{q_1 q_2}{r^2}$ ...(2)

$\because$ $k = 1$ for air or vacuum

$\therefore$ From eqs. (1) and (2),

$F' = Fk$

$F' = F \times 5 = 5F$

15. (b) $q_1 q_2 < 0$

According to Coulomb's law, $F_{12} = -F_{21}$.

In the given case, there is a force of attraction and the charge must be unlike charge.

We know that, $F = \dfrac{q_1 q_2}{4\pi\varepsilon_0 r^2}$

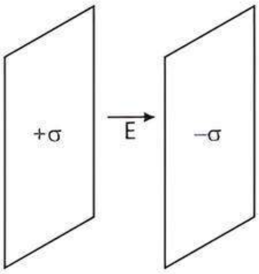
For attractive force, if $q_1 = +$ve, then $q_2 = -$ ve

$\therefore$ $q_1 q_2 < 0$

16. (d) 3 N/C

Surface charge density,

$\sigma = 26.4 \times 10^{-12}\ \dfrac{C}{m^2}$



Electric field, $E = \dfrac{\sigma}{2\varepsilon_0} + \dfrac{\sigma}{2\varepsilon_0}$

$= \dfrac{2\sigma}{2\varepsilon_0} = \dfrac{\sigma}{\varepsilon_0}$

$= \dfrac{26.4 \times 10^{-12}}{8.85 \times 10^{-12}}\dfrac{N}{C} = 3\ N/C$

17. (c) The dipole will experience a force towards left.

The spacing between electric lines of force increases from left to right. Therefore, E on left is greater than E on right. Force on $+q$ charge of dipole placed to the right is smaller than the force on $-q$ charge of dipole placed and to the left. Hence, the dipole will experience a force towards the left.

18. (c) 2 mC

We know,

$\tau = pE\sin\theta$

$\therefore$ $p = \dfrac{\tau}{E \cdot \sin\theta}$

$q \times 2l = \dfrac{4}{2 \times 10^5 \times 0.5}$ $(\because p = q \times 2l)$

$\therefore$ $q = \dfrac{4}{2 \times 10^5 \times 0.5 \times 0.02}$ $(\because 2l = 0.02\ m)$

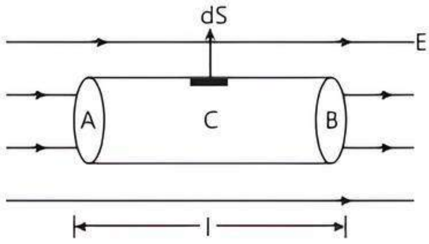
$= 2 \times 10^{-3}\ C$

$q = 2\ mC$

19. (c) always a force and a torque

20. (b) electric field intensity

21. (a) zero



Flux through surface A,

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

Flux through surface B,

$\phi_B = -E \times \pi r^2$

Flux through curved surface, $C = \int \vec{E} \cdot \vec{dS}$

$= \int E\,dS\cos 90° = 0$

$\therefore$ Total flux through cylinder $= \phi_A + \phi_B + \phi_C = 0$

$[\because \phi_A = -\phi_B]$

22. (a) net charge enclosed and permittivity of the medium

23. (a) no net charge is enclosed by the surface

24. (d) is the same for all the figures

As per Gauss's theorem in electrostatics, the electric flux through a surface depends only on the amount of charge enclosed by the surface. It does not depend on size and shape of the surface. Therefore, electric flux through the surface is the same for all figures.

25. (d) The electric field over the Gaussian surface remains continuous and uniform at every point.

26. (b) $\vec{E}$ on the LHS of the above equation will have a contribution from all charges while q on the RHS will have a contribution from q_2 and q_4 only.

When the point is on the diameter and away from the centre of hemisphere which is charged uniformly and positively, the component of electric field intensity parallel to the diameter cancel out. So, the electric field is perpendicular to the diameter.

27. (a) 9.30×10^{-12} C

By Gauss's law, $\phi = \dfrac{q}{\varepsilon_0}$

or $q = \phi\varepsilon_0 = 1.05 \times 8.854 \times 10^{-12}$ C
$= 9.30 \times 10^{-12}$ C

28. (d) 1.0×10^{-7} Cm^{-1}

Given that, $r = 1.0$ cm $= 1 \times 10^{-2}$ m

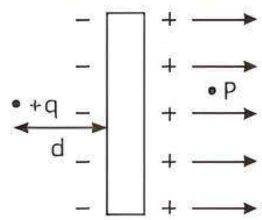
$\vec{E} = 18 \times 10^4$ NC^{-1}

$\therefore$ Linear charge density $= \dfrac{\vec{E} \cdot r}{2 \times k}$, where $k = \dfrac{1}{4\pi\varepsilon_0}$

$= \dfrac{18 \times 10^4 \times 1 \times 10^{-2}}{2 \times 9 \times 10^9}$

$= 1 \times 10^{-7}$ Cm^{-1}

29. (a) directed perpendicular to the plane and away from the plane



When a point charge $+q$ is placed at a distance of d from an isolated conducting plane, some negative charge develops on the surface of the plane towards the charge and an equal positive charge develops on opposite side of the plane. Hence, the field at a point P on the other side of the plane is directed perpendicular to the plane and away from the plane as shown in figure.

30. (c) When we rub a glass rod with silk cloth, electrons from the glass rod are transferred to the silk cloth. Thus, the rod gets positively charged and the silk gets negatively charged.

31. (d) Negative charge moves in the opposite direction to the electric field, as it experiences force in the direction opposite to electric field.

32. (b) Coulomb attraction exists even when one body is charged and the other is uncharged.

33. (b) Force on any charge due to a number of other charges is the vector sum of all the forces on that charge due to the other charges, taken one at a time. The individual forces are unaffected due to the presence of other charges. This is the principle of superposition of charges.

34. (a) We know that the work done by the conservative force around any closed path is zero, i.e., $\oint F \cdot dl = 0$.

35. (a) Because $\vec{E} = -\nabla \vec{V}$, so the electric field is always perpendicular to equipotential surface and the direction of electric field must be in the direction of decreasing of electric potential.

36. (b) The electric field intensity is equal to force experienced by unit positive test charge q_0 placed at that point i.e.,

$\vec{E} = \dfrac{\vec{F}}{q_0}$, thus $\vec{E}$ is also a vector quantity

And $E = \dfrac{F}{q} = \dfrac{\text{Newton}}{\text{Coulomb}}$

37. (a) If the two electric lines of force can intersect each other, then at the point of intersection, we can draw two tangents to the two lines of force. This would mean two directions of electric field intensity at the point of intersection, which is not possible.

38. (b) As, $\sigma_1 = \sigma_2$ (Given)

$\dfrac{q_1}{4\pi r_1^2} = \dfrac{q_2}{4\pi r_2^2}$ or $\dfrac{q_1}{q_2} = \dfrac{r_1^2}{r_2^2}$

Then ratio of electric field intensities,

$\dfrac{E_1}{E_2} = \dfrac{q_1}{4\pi\varepsilon_0 r_1^2} \times \dfrac{4\pi\varepsilon_0 r_2^2}{q_2}$

$= \dfrac{q_1}{q_2} \times \dfrac{r_2^2}{r_1^2} = \dfrac{q_1}{q_2} \times \dfrac{q_2}{q_1} = 1$

i.e., $E_1 = E_2$

39. (a) According to Gauss's theorem in electrostatics,

$\phi = \dfrac{q}{\varepsilon_0}$

$q = \varepsilon_0\phi = 8.85 \times 10^{-12} [8 \times 10^3 - 2 \times 10^3]$
$= 53.10 \times 10^{-9}$ C $= 0.053$ μC

40. quantisation **41.** $(+ 1.6 \times 10^{-19})$

42. flux **43.** decreases

44. N/C **45.** decreases

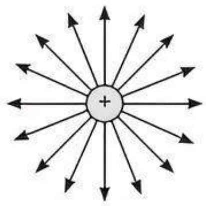
46. zero **47.** scalar

48. 4 : 1

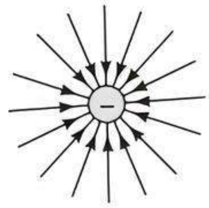
Case Study Based Questions

Case Study 1

A charge is a property associated with the matter due to which it experiences and produces an electric and magnetic fields. Charges are scalar in nature and they add up like real numbers. Also, the total charge of an isolated system is always conserved. When the objects rub against each other, charges acquired by them must be equal and opposite.



Electric field lines of a positive point charge



Electric field lines of a negative point charge

Read the given passage carefully and give the answer of the following questions:

Q 1. The cause of charging is:

a. the actual transfer of protons
b. the actual transfer of electrons
c. the actual transfer of neutrons
d. None of the above

Q 2. When a glass rod is rubbed with silk, then:

a. negative charge is produced on silk but no charge on glass rod
b. equal but opposite charges are produced on both
c. equal and similar charges are produced on both
d. positive charge is produced on glass rod but no charge on silk

Q 3. If an object is positively charged theoretically, the mass of the object:

a. remains the same
b. increases slightly by a factor of 9.11×10^{-31} kg
c. may increase or decrease
d. decreases slightly by a factor of 9.11×10^{-31} kg.

Q 4. We have two bodies with charges q_1 and q_2 on them, then $q_1 + q_2 = 0$ signify:

a. q_1 and q_2 are equal charges with opposite signs
b. q_1 and q_2 are equal charges with same signs
c. q_1 and q_2 are not equal charges
d. q_1 and q_2 are equal charges.

Q 5. The cause of quantisation of electric charges is:

a. transfer of an integral number of neutrons
b. transfer of an integral number of protons
c. transfer of an integral number of electrons
d. None of the above.

Answers

1. (b) the actual transfer of electrons
The cause of charging is the actual transfer of electrons from one body to the other.

2. (b) equal but opposite charges are produced on both
When glass rod is rubbed with silk, glass rod loses electrons and silk grabs them. So after rubbing, glass becomes positively charged and silk becomes negatively charged.
Thus, equal but opposite charges are produced on both.

3. (d) Decreases slightly by a factor of 9.11×10^{-31} kg.
When an object is positively charged, it loses some of its electrons. The mass of an electron is 9.11×10^{-31} kg, so the positively charged body loses electrons and its mass decreases by a factor of 9.11×10^{-31} kg.

4. (a) q_1 and q_2 are equal charges with opposite signs
$q_1 + q_2 = 0$, signifies that the net charge on the system is zero. This is possible only if q_1 and q_2 are equal but opposite in signs.

5. (c) transfer of an integral number of electrons.
The electric charges are said to be quantised when they exist in discrete amount rather than continuous value.

Case Study 2

Coulomb's law states that the electrostatic force of attraction or repulsion acting between two stationary points charges is given by

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

where F denotes the force between two charges q_1 and q_2 separated by a distance r in free space, ε_0 is a constant known as permittivity of free space. Free space is vacuum and may be taken to be air practically.

If free space is replaced by a medium, then ε_0 is replaced by $(\varepsilon_0 k)$ or $(\varepsilon_0 \varepsilon_r)$, where k is known as dielectric constant or relative permittivity.

Read the given passage carefully and give the answer of the following questions:

Q 1. In Coulomb's law, $F = k\frac{q_1 q_2}{r^2}$, then on which of the following factors does the proportionality constant k depends?

a. Electrostatic force acting between the two charges
b. Nature of the medium between the two charges
c. Magnitude of the two charges
d. Distance between the two charges

Q 2. Dimensional formula for the permittivity constant ε_0 of free space is:

a. $[ML^{-3}T^4A^2]$
b. $[M^{-1}L^3T^2A^2]$
c. $[M^{-1}L^{-3}T^4A^2]$
d. $[ML^{-3}T^4A^{-2}]$

Q 3. The force of repulsion between two charges of 1 C each, kept 1 m apart in vacuum is:

a. $\frac{1}{9 \times 10^9}$ N
b. 9×10^9 N
c. 9×10^7 N
d. $\frac{1}{9 \times 10^{12}}$ N

Q 4. Two identical charges repel each other with a force equal to 10 mg wt when they are 0.6 m apart in air. ($g = 10$ ms^{-2}). The value of each charge is:

a. 2 mC
b. 2×10^{-7} mC
c. 2 nC
d. 2 μC

Q 5. **Coulomb's law for the force between electric charges most closely resembles with:**
a. law of conservation of energy
b. Newton's law of gravitation
c. Newton's 2nd law of motion
d. law of conservation of charge

Answers

1. (b) Nature of the medium between the two charges.
2. (c) $[M^{-1}L^{-3}T^4A^2]$

As, we know that,

$$[\varepsilon_0] = \frac{1}{4\pi F} \cdot \frac{q_1 q_2}{r^2} = \frac{(AT)^2}{(MLT^{-2})(L^2)}$$
$$= [M^{-1}L^{-3}T^4A^2]$$

3. (b) 9×10^9 N
4. (d) 2 μC

Given that, $F = 10$ mg wt $= 10 \times 10^{-3} \times 10$ N

$\because$ $$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{d^2}$$

$\therefore$ $$(10 \times 10^{-3}) \times 10 = \frac{(9 \times 10^9) \times q^2}{(0.6)^2}$$

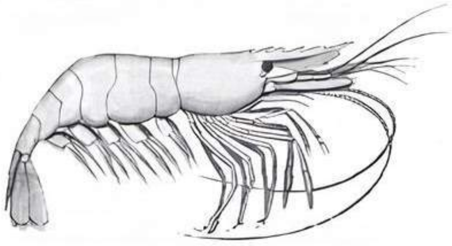
or $$q^2 = \frac{10^{-1} \times 0.36}{9 \times 10^9} = 4 \times 10^{-12}$$

or $$q = 2 \times 10^{-6} \text{ C} = 2\ \mu\text{C}$$

5. (b) Newton's law of gravitation.

Case Study 3

Animals emit low frequency electric fields due to a process known as osmoregulation. This process allows the concentration of ions (charged atoms or molecules) to flow between the inside of our bodies and the outside. In order for our cells to stay intact, the flow of ions needs to be balanced. But balanced doesn't necessarily mean equal. The concentration of ions within a shrimp's body is much lower than that of the sea water it swims in. Their voltage or potential difference generated between the two concentrations across 'leaky' surfaces, can then be measured.



Read the given passage carefully and give the answer of the following questions:

Q 1. **The Gaussian surface for ions in the body of animals:**
a. can pass through a continuous charge distribution
b. cannot pass through a continuous charge distribution
c. can pass through any system of discrete charges
d. can pass through a continuous charge distribution as well as any system of discrete charges

Q 2. **Gauss's law is valid for:**
a. any closed surface
b. only regular close surfaces
c. any open surface
d. only irregular open surfaces

Q 3. **The electric field inside a shrimp's body of uniform charge density is:**
a. zero
b. constant different from zero
c. proportional to the distance from the curve
d. None of the above

Q 4. **If a small piece of linear isotropic dielectric is swallowed by a shrimp and inside the body it is influenced by an electric field *E*, then the polarisation *P* is:**
a. independent of *E*
b. inversely proportional to *E*
c. directly proportional to $\sqrt{E}$
d. directly proportional to *E*

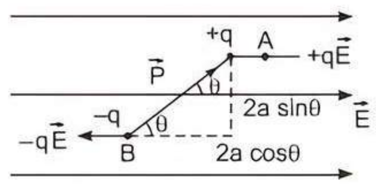
Q 5. **Field due to multiple charges/ions inside shrimp's body at a point is found by using:**
(i) superposition principle
(ii) Coulomb's law
(iii) law of conservation of charges
Choose the correct answer:
a. (i) and (ii)
b. (ii) and (iii)
c. (i) and (iii)
d. (i), (ii) and (iii)

Answers

1. (a) can pass through a continuous charge distribution
2. (a) any closed surface
3. (a) zero
4. (d) directly proportional to *E*
5. (a) (i) and (ii)

Case Study 4

When electric dipole is placed in uniform electric field, its two charges experience equal and opposites forces, which cancel each other and hence net force on electric dipole in uniform electric field is zero. However, these forces are not collinear, so they give rise to some torque on the dipole. Since, net force on electric dipole in uniform electric field is zero, so no work is done in moving the electric dipole in uniform electric field. However, some work is done in rotating the dipole against the torque acting on it.



Read the given passage carefully and give the answer of the following questions:

Q 1. The dipole moment of a dipole in a uniform external field $\vec{E}$ is $\vec{P}$. What will be the torque $\vec{\tau}$ acting on the dipole?

Q 2. An electric dipole consists of two opposite charges, each of magnitude 1.0 μC separated by a distance of 2.0 cm. The dipole is placed in an external field of 10^5 NC^{-1}. What is the maximum torque on the dipole?

Q 3. Torque on a dipole in uniform electric field is minimum when θ is equal what angle?

Q 4. When an electric dipole is held at an angle in a uniform electric field, what are the net force F and torque τ on the dipole?

Q 5. What is the net force on electric dipole in uniform electric field?

Answers

1. As. τ = either force × perpendicular distance between the two forces

$$\tau = qE \times 2a \sin\theta \quad \text{or} \quad \tau = PE \sin\theta$$

or $$\vec{\tau} = \vec{P} \times \vec{E} \qquad (\because q(2a) = P)$$

2. The maximum torque on the dipole in an external electric field is given by

$$\tau = PE = q(2a) \times E$$

Here, $q = 1\,\mu C = 10^{-6}$ C, $2a = 2$ cm $= 2 \times 10^{-2}$m

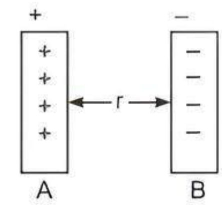
$$E = 10^5\ NC^{-1},\ \tau = ?$$

$$\therefore \quad \tau = 10^{-6} \times 2 \times 10^{-2} \times 10^5 = 2 \times 10^{-3} Nm$$

3. When θ is 0° or 180°, τ is minimum, which means the dipole moment should be parallel to the direction of the uniform electric field.
4. Net force is zero and torque acts on the dipole, trying to align p with E.
5. Zero.

Case Study 5

Surface charge density is defined as charge per unit surface area of surface charge distribution *i.e.*, $\sigma = \dfrac{dq}{dS}$. 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 having magnitude of 17.0×10^{-22} C/m^2 as shown. The intensity of electric field at a point is $E = \dfrac{\sigma}{\varepsilon_0}$, where ε_0 = permittivity of free space.



Read the given passage carefully and give the answer of the following questions:

Q 1. What is the value of E in the outer region of the first plate?

Q 2. What is the value of E in the outer region of the second plate?

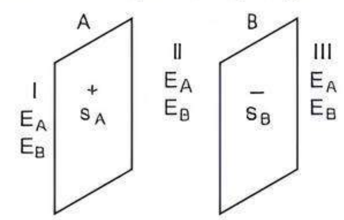
Q 3. What will be the value of E between the plates?

Q 4. What is the ratio of E from right side of B at distances of 2 cm and 4 cm, respectively?

Q 5. In order to estimate the electric field due to a thin finite plane metal plate, what is the shape of the Gaussian surface?

Answers

1. There are two plates A and B having surface charge densities, $\sigma_A = 17.0 \times 10^{-22}$ C/m^2 on A and $\sigma_B = -17.0 \times 10^{-22}$ C/m^2 on B, respectively.



According to Gauss's theorem, if the plates have same surface charge density but having opposite signs, then the electric field in region I is zero.

$$E_I = E_A + E_B = \frac{\sigma}{2\varepsilon_0} + \left(-\frac{\sigma}{2\varepsilon_0}\right) = 0$$

2. The electric field in region III is also zero.

$$E_{III} = E_A + E_B = \frac{\sigma}{2\varepsilon_0} + \left(-\frac{\sigma}{2\varepsilon_0}\right) = 0$$

3. In region II or between the plates, the electric field

$$E_{II} = E_A - E_B = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0}$$

$$= \frac{\sigma(\sigma_A \text{ or } \sigma_B)}{\varepsilon_0} = \frac{17.0 \times 10^{-22}}{8.85 \times 10^{-12}}$$

$$\therefore \quad E = 1.9 \times 10^{-10}\ NC^{-1}$$

4. Electric field due to an infinite plane sheet of charge does not depend on the distance of observation point from the plane sheet of charge.
So, ratio of E will be 1 : 1.
5. We take a cylindrical cross-sectional area A and length $2r$ as Gaussian surface.

Very Short Answer Type Questions

Q 1. A charge q is placed at the centre of a cube of side 1 cm. What is the electric flux passing through each face of the cube?

Sol. Electric flux through each face of the cube

$$= \frac{1}{6}\phi_E = \frac{1}{6}\frac{q}{\varepsilon_0} = \frac{q}{6\varepsilon_0}$$

Q 2. Define one coulomb.

Ans. Charge on a body is said to be of 1 coulomb if two charges experience a force of repulsion or attraction of 9×10^9 N when they are separated by a distance of 1 m.

Q 3. Two point charges having equal charges separated by 1 m distance experience a force of 8 N. What will be the force experienced by them, if they are held in water, at the same distance? (Given: $K_{water} = 80$)

Sol. $F_{water} = \frac{F_{air}}{K_{water}} = \frac{8}{80} = 0.1$ N

Q 4. Define electric flux. Write its SI unit. *(CBSE 2017, 15)*

Ans. Electric flux is defined as the total number of electric lines of force passing normally through a given surface. $\phi_E = \oint \vec{E} \cdot d\vec{S}$. Its SI unit is Nm^2/C.

Q 5. What is the electric flux through a cube of side 1 cm which encloses an electric dipole? *[CBSE 2015]*

Sol. In the given case, cube encloses an electric dipole.

$\therefore$ Net charge enclosed within the cube is zero, i.e., $q = 0$.

According to Gauss law of electrostatics, electric flux through any closed surface is given by

$$\phi_E = \oint \vec{E} \cdot d\vec{S} = q/\varepsilon_0$$

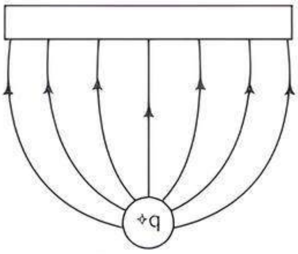
$$\therefore \quad \phi_E = 0 \qquad (\because q = 0)$$

TiP

The total charge of the electric dipole is zero.

Q 6. Draw the pattern of electric field lines when a point charge $+q$ is kept near an uncharged conducting plate.

Ans.



Q 7. What does $q_1 + q_2 =$ signify?

Ans. If $q_1 + q_2 = 0$, then $q_1 = -q_2$. Thus, both charges are equal in magnitude but of opposite is nature.

Q 8. Define electric field intensity. Give its SI unit.

Ans. The electric field intensity due to a static point charge is defined as the force experienced per unit positive test charge placed at that point without disturbing the static point charge.

$$\vec{E} = \frac{\vec{F}}{q_0}$$

It is a vector quantity and its SI unit is NC^{-1}.

Q 9. What is relative permittivity or dielectric constant of a medium?

Ans. Relative permittivity of a medium is defined as the ratio of electrostatic force between two points charges separated by a certain distance in air to the electrostatic force between the same two point charges separated by the same distance in a medium.

Q 10. What is force experienced by a charge q placed in a uniform electric field E?

Ans. Force experienced by a charge q is $F \; qE$.

Q 11. What would happen, if two identical bodies of opposite charge come in contact?

Ans. If two identical bodies of opposite charge come in contact, then charge is neutralised.

Q 12. What is the name of surface that considered for Gauss's law?

Ans. The surface considered for Gauss's law is Gaussian surface.

Short Answer Type-I Questions

Q 1. Write down any four properties of electrical field lines.

Ans.

TiP

Try to write the main body of the answer into points instead of paragraph.

The properties of electric field lines are as follows:

(i) The electric field lines are continuous curves.

(ii) The tangent to the electric field line of force at any point gives the direction of electric field intensity at that point.

(iii) Two electric field lines of force can never intersect each other.

(iv) The electric field lines contract longitudinally.

Q 2. What do you mean by an ideal dipole and what is the nature of symmetry of electric field of the dipole?

Ans. An electric dipole whose size is very small or negligible is called an ideal dipole. The nature of symmetry of electric field is cylindrical.

Q 3. 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 17.7×10^{-22} C/m^2. What is electric field intensity E:

(i) in the outer region of the first plate and

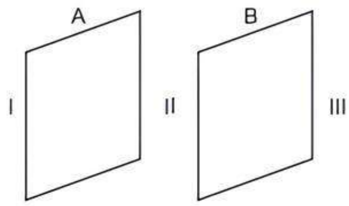
(ii) between the plates? *(CBSE SQP 2022-23)*

Sol. Given: Surface charge density of plate A

$= +17.7 \times 10^{-22}\ C/m^2$ (magnitude given)

Surface charge density of plate B

$= -17.7 \times 10^{-22}\ C/m^2$ (magnitude given)



(i) In the outer region of plate I, electric field intensity E is zero.

(ii) Electric field intensity E in between the plates is given by the relation,

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

where, ε_0 = permittivity of free space

$= 8.85 \times 10^{-12}\ N^{-1} C^2 m^{-2}$

$\therefore \quad E = \frac{17.7 \times 10^{-22}}{8.85 \times 10^{-12}} = 2.0 \times 10^{-10}$ N/C

Therefore, electric field between the plates is 2.0×10^{-10} N/C.

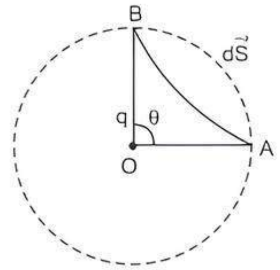
Q 4. State and prove Gauss's law. *(CBSE 2016)*

Ans. Gauss's law states that the total electric flux linked through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

Mathematically, $\phi = \frac{q_{enclosed}}{\varepsilon_0}$

Proof: Consider a small area element dS around a point 'O' on the surface.

Flux through area dS,



$$d\phi_E = \vec{E} \cdot \vec{dS} = E{\cdot}dS$$

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

Total flux $= \phi_E = \oint E \cdot dS$

$$= E\oint dS$$

$$= \frac{q}{4\pi\varepsilon_0 r^2}\oint dS = E{\cdot}A = \frac{q}{4\pi\varepsilon_0 r^2} \times 4\pi r^2$$

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

Q 5. Derive the expression for the torque acting on an electric dipole, when it is held in a uniform electric field. Identify the orientation of the dipole in the electric field, in which it attains a stable equilibrium.

Ans. Consider two charges $+q$ and $-q$ separated by a distance $2a$.

Force on q is qE

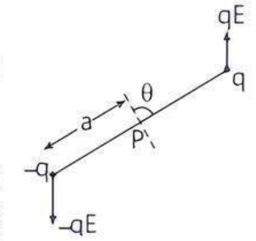
Force on $-q$ is $-qE$.

$\therefore$ torque (τ) = Force $\times$ Perpendicular distance

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

$= pE \sin\theta \qquad [\because p = 2aq]$

$\vec{\tau} = \vec{p} \times \vec{E}$



When the dipole is placed in an electric field in the direction of the field *i.e.*, when $\theta = 0°$, it attains a stable equilibrium.

Q 6. (i) Name any two basic properties of electric charge.

(ii) What does $q_1 + q_2 = 0$ signify in electrostatics?

Ans. (i) (a) Quantisation of electric charge

(b) Conservation of electric charge

(ii) It signifies that charges are algebraically additive and here q_1 and q_2 are equal and opposite in nature.

Q 7. Consider a uniform electric field $\vec{E} = 3 \times 10^3\ \hat{i}$ N/C. Calculate the flux of this field through a square surface of area 10 cm^2, when

(i) its plane is parallel to the Y-Z plane, and

(ii) the normal to the plane makes a 60° angle with the X-axis.

Sol. Given, $\vec{E} = 3 \times 10^3\ \hat{i}$ N/C

and $\vec{S} = 10\ cm^2 = 10 \times 10^{-4}\ m^2 = 10^{-3}\ m^2$

(i) Flux, $\phi_{E_1} = \vec{E} \times \vec{S} = 3 \times 10^3 \times 10^{-3} = 3\ Nm^2C^{-1}$

(ii) $\because \phi_E = E \cdot S \cos\theta$

Here, $\theta = 60°$

$\therefore$ Flux, $\phi_{E_2} = (3 \times 10^3) \times (10^{-3}) \times \cos 60°$

$= 3 \times \frac{1}{2} = 1.5\ Nm^2C^{-1}$

Q 8. An electric dipole when held at 30° with respect to a uniform electric field of 10^4 N/C experienced a torque of 9×10^{-25} Nm. Calculate dipole moment of the dipole.

Sol. Given, $\phi = 30°$, $\tau = 9 \times 10^{-25}$ Nm, $E = 10^4$ N/C

We know that, torque $\tau = pE \sin\theta$

$\therefore \qquad p = \frac{\tau}{E \sin\theta}$

$\Rightarrow \qquad p = \frac{9 \times 10^{-25}}{10^4 \times \sin 30°}$

$= \frac{9 \times 10^{-25} \times 10^{-4}}{1/2} = 18 \times 10^{-29}$ C-m

Q 9. Write any two limitations of Coulomb's law.

Ans. Two limitations of Coulomb's law are:

(i) It is applicable only for point charges at rest.

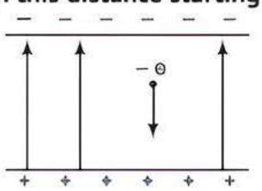
(ii) It is medium dependent law.

Q 10. An electric dipole is inside the Gaussian surface. What is electric flux through the Gaussian surface?

Ans. The electric flux through a closed or Gaussian surface is determined by the net charge within the surface. If the surface encloses a dipole, then net charge of electric dipole is zero, so flux through the Gaussian surface is zero.

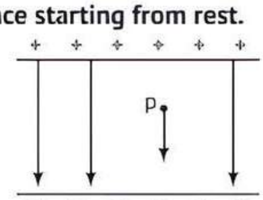
Short Answer Type-II Questions

Q 1. (i) An electron falls through a distance of 1.5 cm in a uniform electric field of magnitude 2.0×10^4 N/C (Fig. a). Calculate the time it takes to fall through this distance starting from rest.



(a)

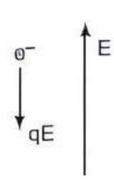
(ii) If the direction of the field is reversed (Fig. b) keeping its magnitude unchanged, calculate the time taken by a proton to fall through this distance starting from rest. *(CBSE 2018)*



(b)

Sol. (i) An electron falls through distance 1.5 cm, if electric field is 2×10^4 N/C.

So, net force on electron,



$$F = q_eE \qquad [\because F = ma]$$
$$m_e a = q_eE$$
$$a = \frac{q_eE}{m_e}$$

where, $q_e = 1.6 \times 10^{-19}$ C,

$m_e = 9.1 \times 10^{-31}$ kg

and $E = 2 \times 10^4$ N/C

$$a = \frac{1.6\times10^{-19}\times2\times10^4}{9.1\times10^{-31}}$$
$$= 3.5 \times 10^{15}\ \text{m/s}^2$$

As we know, $s = ut + \frac{1}{2}at^2$

$$\therefore\quad 1.5\times10^{-2} = 0\times t + \frac{1}{2}\times3.5\times10^{15}\times t^2$$

$$\Rightarrow\quad t = \sqrt{\frac{2\times1.5\times10^{-2}}{3.5\times10^{15}}}$$
$$= \sqrt{8.57\times10^{-9}} = 2.92\times10^{-9}$$
$$= 2.92\ \text{ns.}$$

(ii) Similarly, time of fall of proton if direction of field is reversed

$$t_p = \sqrt{\frac{2s}{a_p}} = \sqrt{\frac{2sm_p}{q_pE}} \qquad \left(\because a_p = \frac{q_pE}{m_p}\right)$$

where, $m_p = 1.6 \times 10^{-27}$ kg, $q_p = 1.6 \times 10^{-19}$ C

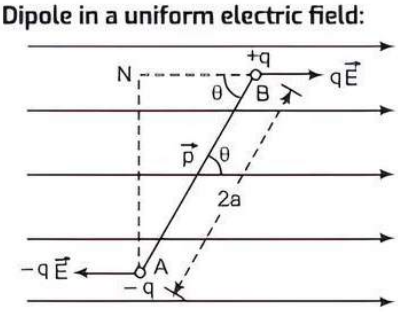
and $s = 1.5$ cm

$$t_p = \sqrt{\frac{2\times1.5\times10^{-2}\times1.6\times10^{-27}}{1.6\times10^{-19}\times2\times10^4}}$$
$$= \sqrt{1.5\times10^{-14}}$$
$$t_p = 1.22 \times 10^{-7}\ \text{s}$$

Q 2. (i) Obtain the expression for the torque τ experienced by an electric dipole of dipole moment $\vec{p}$ in a uniform electric field, $\vec{E}$.

(ii) What will happen, if the field were not uniform? *(CBSE 2017)*

Ans. (i) Dipole in a uniform electric field:



According to the figure, if we consider an electric dipole consisting of charges $-q$ and $+q$ and of length $2a$ placed in a uniform electric field $\vec{E}$ making an angle θ with electric field, then force exerted on charge $-q$ at $A = -q\vec{E}$ (opposite to $\vec{E}$).

Force exerted on charge $+q$ at $A = q\vec{E}$ (along $\vec{E}$).

Hence, the net translating force on a dipole in a uniform electric field is zero. But the two equal and opposite forces act at different points and form couple which exerts a torque τ.

τ = Force × Perpendicular distance between the two forces

$\Rightarrow\quad \tau = qE(AN) = qE(2a\sin\theta)$

$\Rightarrow\quad \tau = q(2a)E\sin\theta$

$\Rightarrow\quad \tau = pE\sin\theta$ or $\tau = \vec{p}\times\vec{E}$ $\quad(\because p = 2aq)$

(ii) When the dipole is placed in a non-uniform electric field, it experiences a net force and torque.

Q 3. Two large charged plane sheets of charge densities σ and -2σ C/m^2 are arranged vertically with a separation of d between them. Deduce expressions for the electric field at points:

(i) to the left of the first sheet,

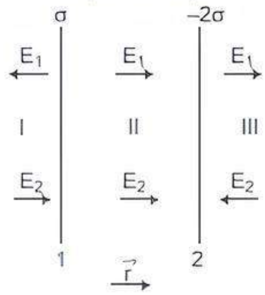
(ii) to the right of the second sheet and

(iii) between the two sheets. *(CBSE 2019)*

Ans. (i) Electric field to the left of plate 1 (region I)

$$E_I = E_1 + E_2 = \frac{2\sigma}{2\varepsilon_0}\vec{r} - \frac{\sigma}{2\varepsilon_0}\vec{r}$$

where $\vec{r}$ is the unit vector in the direction from plate 1 (+ ve plate) to plate 2 (– ve plate).



(ii) Electric field to the right of plate 2 (region III)

$$E_{III} = \frac{\sigma}{2\varepsilon_0}\vec{r} - \frac{2\sigma}{2\varepsilon_0}\vec{r}$$

(iii) Electric field between two plates (region II)

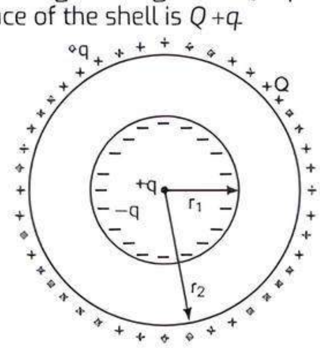
$$E_{II} = \frac{\sigma}{2\varepsilon_0}\vec{r} + \frac{2\sigma}{2\varepsilon_0}\vec{r}$$

Q 4. A spherical conducting shell of inner radius r_1 and outer radius r_2 has a charge Q.

(i) A charge q is placed at the centre of the shell. Find out the surface charge density on the inner and outer surfaces of the shell.

(ii) Is the electric field inside a cavity (with no charge) zero; independent of the fact whether the shell is spherical or not? Explain. *(CBSE 2019)*

Sol. (i) When a charge $+q$ is placed at the centre of spherical cavity, as shown in the figure, then, charge induced on the inner surface of a shell is $-q$ and charge induced on the outer surface of shell is $+q$. A charge of magnitude Q is placed on the outer surface of the shell is $Q+q$.



Therefore, outer surface charge density $= \dfrac{Q+q}{4\pi r_2^2}$

and inner surface charge density $= \dfrac{-q}{4\pi r_1^2}$

(ii) Yes, the electric field inside a cavity is zero irrespective of shape because the cavity has zero net charge.

Q 5. Consider two hollow concentric spheres, S_1 and S_2 enclosing charges $2Q$ and $4Q$ respectively as shown:

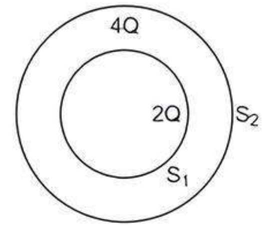
(i) Find out the ratio of the electric flux through them.

(ii) How will the electric flux through the sphere S_1 change, if a medium of dielectric constant ε_r is introduced in the space inside S_1 in place of air? Deduce the necessary expression.

Sol. (i) $\phi_1 = \dfrac{2Q}{\varepsilon_0}$ and $\phi_2 = \dfrac{2Q+4Q}{\varepsilon_0} = \dfrac{6Q}{\varepsilon_0}$

∴ Ratio of electric flux,

$$\frac{\phi_1}{\phi_2} = \frac{2Q}{\varepsilon_0} \times \frac{\varepsilon_0}{6Q} = \frac{1}{3}$$



(ii) For sphere S_1, the electric flux, $\phi' = \dfrac{2Q}{\varepsilon_r}$

$$\frac{\phi'}{\phi_1} = \frac{\varepsilon_0}{\varepsilon_r}$$

$$\Rightarrow \quad \phi' = \phi_1 \times \frac{\varepsilon_0}{\varepsilon_r}$$

$\because \quad \varepsilon_r > \varepsilon_0$

$\therefore \quad \phi' < \phi_1$

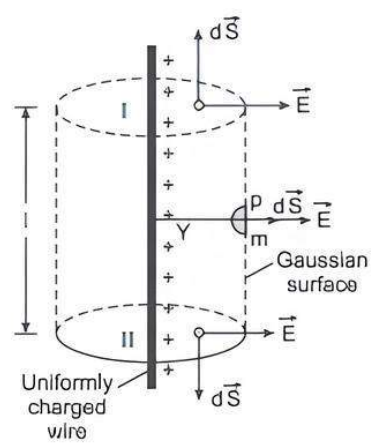
Therefore, the electric flux through the sphere S_1 decreases with the introduction of the dielectric inside it.

Q 6. Using Gauss's law, derive an expression for the electric field intensity due to an infinitely long, straight wire of linear charge density λC/m. *(CBSE 2018, 17)*

Sol. Charge enclosed by Gaussian surface, $q = \lambda l$.

At the part I and II of Gaussian surface, $\vec{E}$ and $\hat{n}$ are perpendicular (⊥), so flux through surfaces I and II is zero.

By Gauss's law, $\oint \vec{E} \cdot d\vec{S} = \dfrac{q}{\varepsilon_0}$



$$\Rightarrow \quad \oint E\, dS \cos 0° = \frac{q}{\varepsilon_0}$$

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

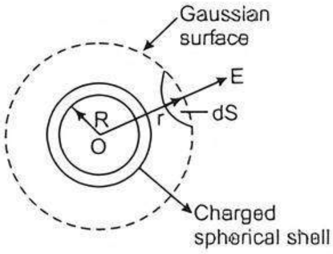
$$\Rightarrow \quad E(2\pi r l) = \frac{\lambda l}{\varepsilon_0}$$

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

Q 7. (i) Obtain the expression for the electric field intensity due to a uniformly charged spherical shell of radius *R* at a point distant *r* from the centre of the shell outside it.

(ii) Draw a graph showing the variation of electric field intensity *E* with *r*, for $r > R$ and $r < R$. *(CBSE SQP 2022-23)*

Sol. Electric field due to a uniformly charged thin spherical shell:



(i) Suppose that we have to calculate field at the point *P* at a distance *r* ($r > R$) from its centre. Draw Gaussian surface through point *P* so as to enclose the charged spherical shell. Gaussian surface is a spherical surface of radius *r* and centre *O*.

Let $\vec{E}$ be the electric field at point P, then the electric flux through area element of area $d\vec{S}$ is given by,

$$d\phi = \vec{E}\cdot d\vec{S}$$

Since, $d\vec{S}$ is along normal to the surface.

$$d\phi = E\cdot dS$$

$\therefore$ Total electric flux through the Gaussian surface is given by,

$$\phi = \oint E\cdot dS = E\oint dS$$

Now, $\oint dS = 4\pi r^2$ ...(1)

$\therefore \quad \phi = E \times 4\pi r^2$

Since, the charge enclosed by the Gaussian surface is *q*, so according to the Gauss's theorem,

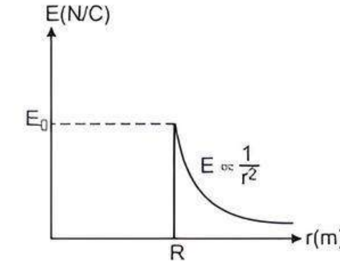
$$\phi = \frac{q}{\varepsilon_0} \quad ...(2)$$

From eqs. (1) and (2), we get

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

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2} \text{ (for } r > R\text{)}$$

(ii) A graph showing the variation of electric field as a function of *r* is shown below:



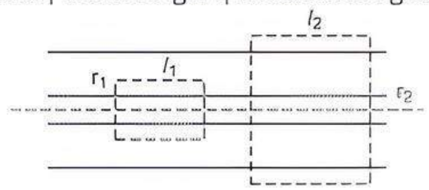
Q 8. A long charged cylinder of linear charge density $+\lambda_1$ is surrounded by a hollow co-axial conducting cylinder of linear charge density $-\lambda_2$. Use Gauss's law to obtain expressions for the electric field at a point (i) in the space between the cylinders and (ii) outside the larger cylinder. *(CBSE 2017)*

Sol. Gauss's law states that "total electrical flux through a closed surface equals the charge contained in the enclosed volume divided by ε_0. Here, ε_0 is the permittivity of free space enclosed by the surface.

Mathematically, $\oint E\,.\,dq = \dfrac{q}{\varepsilon_0}$ ...(1)

It is assumed the charged cylinders are infinitely long.

(i) To get electric field inside the charged co-axial cylinders, we consider an imaginary cylinder of radius r_1 and of length l_1 as shown in figure.



Due to infinite length, electric field is perpendicular to the curved surface of this imaginary cylinder and the field is uniform. Hence eq. (1) can be written for this imaginary cylinder as,

$$E_r \times 2\pi r_1 l_1 = \frac{\lambda_1 \times l_1}{\varepsilon_0}$$

or $$E_r = \frac{\lambda_1}{2\pi\varepsilon_0 r_1}$$

(subscript *r* indicates that field is in radial direction)

(ii) In the same way, electric field at a point outside the larger radius cylinder,

$$E_r = \frac{\lambda_1 - \lambda_2}{2\pi\varepsilon_0 r_2}$$

TiP

To obtain Coulomb's law, we use Gauss' theorem and find the expression for the intensity of electric field due to a point charge q at a distance of r.

Long Answer Type Questions

Q 1. (i) An electric dipole is held in a uniform electric field. Using suitable diagram, show that it does not undergo any translatory motion. Derive the expression for the torque acting on it.

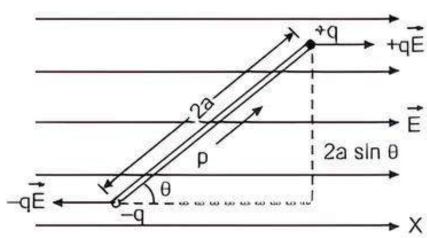
(ii) What would happen if the field is non-uniform?

(iii) What would happen if the external electric field E is increasing:

(a) parallel to $\vec{p}$ and (b) anti-parallel to $\vec{p}$?

(CBSE 2017, 16, 15)

Sol. (i) Let an electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$ as shown in figure.



Force: Force on $+q$, $F_1 = qE$

Force on $-q$, $\quad F_2 = -qE$

Hence, net force on the dipole, $F = qE - qE = 0$

Torque: Two equal and opposite forces $-qE$ and $+qE$ forms a couple which tries to rotate the dipole.

Torque due to this couple,

$\tau =$ either force × perpendicular distance

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

$\Rightarrow \quad \tau = pE\sin\theta = \vec{p} \times \vec{E} \qquad [\because 2aq = p]$

(ii) If the electric field is non-uniform, the net force on the dipole will not be zero, hence there will be the translatory motion of the dipole.

(iii) (a) Net force will be in the direction of increasing electric field.

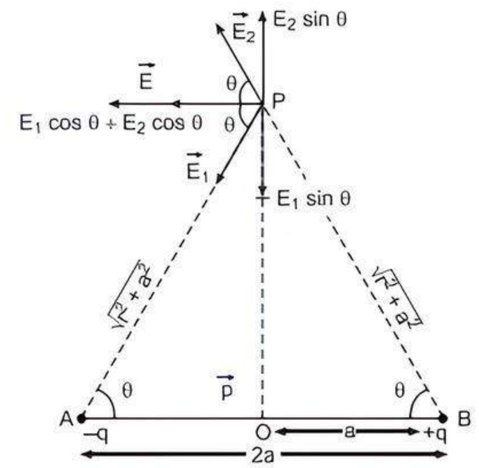
(b) Net force will be in the direction opposite to the increasing field.

Q 2. Derive an expression for the electric field intensity at a point on the equatorial line of an electric dipole moment $\vec{p}$ and length $2a$. What is the direction of this field? *(CBSE 2017, 15)*

Sol. Let, $\vec{E}_1$ and $\vec{E}_2$ be the electric field intensities at p due to $-q$ and $+q$ charges respectively, then

$$|\vec{E}_1| = |\vec{E}_2| = \frac{1}{4\pi\varepsilon_0}\frac{q}{(\sqrt{r^2+a^2})^2}$$

$$\Rightarrow \quad |\vec{E}_1| = |\vec{E}_2| = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2+a^2)}$$



On resolving $\vec{E}_1$ and $\vec{E}_2$ in horizontal and vertical components, resultant electric field intensity,

$$|\vec{E}| = E_1\cos\theta + E_1\cos\theta = 2E_1\cos\theta \quad [\because E_1 = E_2]$$

$$\Rightarrow \quad |\vec{E}| = 2\frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2+a^2)}\frac{a}{\sqrt{r^2+a^2}}$$

$$\left[\because \cos\theta = \frac{a}{\sqrt{r^2+a^2}}\right]$$

$$\Rightarrow \quad |\vec{E}| = \frac{1}{4\pi\varepsilon_0}\frac{2qa}{(r^2+a^2)^{3/2}}$$

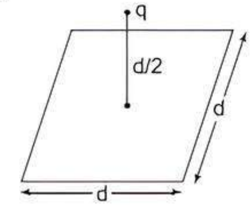
$$\Rightarrow \quad |\vec{E}| = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2+a^2)^{3/2}} \quad [\because p = 2qa]$$

Obviously, if $r >> a$, then $|\vec{E}| = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$

Direction of $\vec{E}$ is opposite to that of dipole moment $\vec{p}$.

Q 3. (i) Define electric flux. Is it a scalar or a vector quantity?

(ii) A point charge q is at a distance of $d/2$ directly above the centre of a square of side d, as shown in the figure. Use Gauss' law to obtain the expression for the electric flux through the square.



(iii) If the point charge is now moved to a distance d from the centre of the square and the side of the square is doubled. Explain how the electric flux will be affected? *(CBSE 2018)*

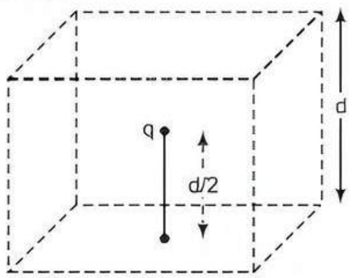
Ans. (i) **Electric flux:** It is defined as the total number of electric field lines that are normally pass through that surface.

Total electric flux ϕ over the whole surface S due to an electric field $\vec{E}$ is given as

$$\phi = \oint_S \vec{E} \cdot d\vec{S} = \oint E dS \cos\theta$$

It is a scalar quantity.

(ii) From the given problem, q is the point charge at a distance of $d/2$ directly above the centre of the square side.



Now, construct a Gaussian surface in the form of a cube of side d to evaluate the amount of electric flux.

We can calculate the amount of electric flux for six surfaces by using Gauss's law.

$$\phi_E = \int_S \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$$

For one surface of the cube, amount of electric flux is given as $\phi_{E'} = \dfrac{q}{6\varepsilon_0}$

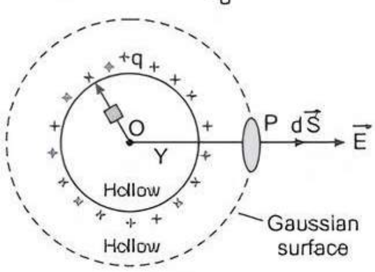
(iii) If the point charge is moved to a distance d from the centre of the square and side of the square is doubled, but amount of charge enclosed into the Gaussian surface does not change.

Hence, the amount of electric flux remains same.

Q 4. Using Gauss's law, deduce the expression for the electric field due to uniformly charged spherical conducting shell of radius R at a point (i) outside and (ii) inside the shell. *(CBSE 2020, 17, 15)*

Ans. (i) Outside the shell ($r > R$)

Let us consider the Gaussian surface as shown by Gauss's law, $\oint \vec{E} \cdot d\vec{S} = \dfrac{q}{\varepsilon_0}$



$$\Rightarrow \quad \oint E dS \cos 0^\circ = \frac{q}{\varepsilon_0} \quad \Rightarrow \quad E \oint dS = \frac{q}{\varepsilon_0}$$

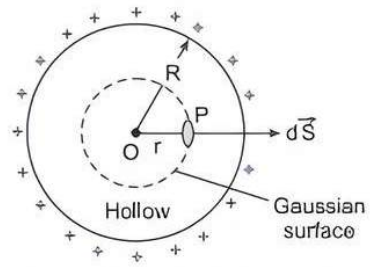
$$\Rightarrow E(4\pi r^2) = \frac{q}{\varepsilon_0}$$

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

(ii) Inside the shell ($r < R$)

Let us consider the Gaussian surface as shown below by Gauss's law

$$\oint \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$$



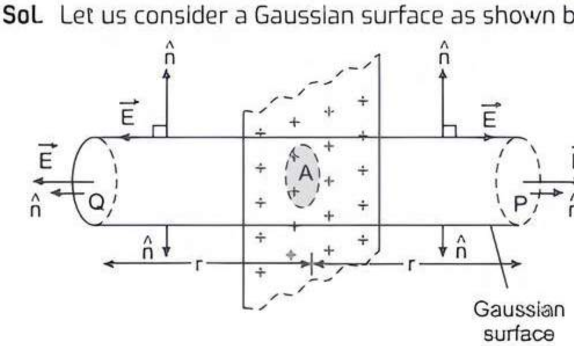
But, charge inside the spherical shell, *i.e.*, $q = 0$

$$\Rightarrow \quad \oint E dS \cos 0^\circ = 0$$

$$\Rightarrow \quad E = 0$$

Q 5. Using Gauss's law, obtain the expression for electric field intensity at a point due to an infinitely large plane sheet of charge of charge density σ C/m^2. How is the field directed if the sheet is (i) positively charged and (ii) negatively charged? *(CBSE 2015)*

Sol. Let us consider a Gaussian surface as shown below:



At the curved part of Gaussian surface $\vec{E}$ and $\hat{n}$ are perpendicular, so flux through curved surface is zero.

By Gauss's law, $\oint \vec{E} . d\vec{S} = \dfrac{q}{\varepsilon_0}$

$$\Rightarrow \quad \oint E dS \cos 0^\circ = \frac{q}{\varepsilon_0}$$

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

$$\Rightarrow \quad E(2A) = \frac{q}{\varepsilon_0}$$

$$\Rightarrow \quad E = \frac{q}{2A\varepsilon_0} = \frac{\sigma}{2\varepsilon_0}$$

Direction of field:

(i) If the sheet is positively charged, the field is directly away from it.

(ii) If sheet is negatively charged, the field is directly towards it.

Chapter Test

Multiple Choice Questions

Q 1. What is the SI unit of permittivity of free space?

a. Wb b. F
c. $C^2N^{-1}m^{-2}$ d. $C^2N^1m^2$

Q 2. The magnitude of the electric field due to a point charge object at a distance of 4.0 m is 9 N/C. From the same charged objects, the electric field of magnitude, 16 N/C will be at a distance of:

(CBSE 2023)

a. 1 m b. 2 m c. 3 m d. 6 m

Assertion and Reason Type Questions

Directions (Q.Nos. 3-4): *In the following questions, statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 3. Assertion (A): Electrostatic field lines start at positive charges and end at negative charges.
Reason (R): Field lines are continuous curves without any breaks and they form closed loop.

Q 4. Assertion (A): Total flux through a closed surface is zero, if net charge enclosed by the surface is zero.
Reason (R): Gauss law is true for any closed surface, no matter what its shape or size is.

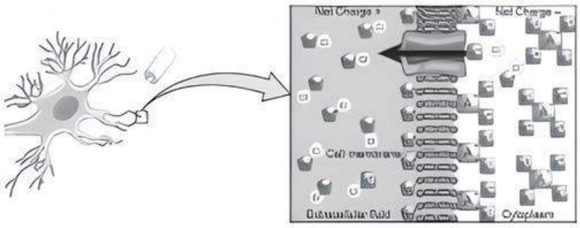
Fill in the Blanks

Q 5. The region or space around a charge in which an another charge experiences a force is called ....

Q 6. For a dipole, ... are dense at the point located at one of the charges.

Case Study Based Question

Q 7. Neurons maintain different concentrations of certain ions across their cell membranes. Imagine the case of a boat with a small leak below the water line. In order to keep the boat afloat, the small amount of water entering through the leak has to be pumped out, which maintains a lower water level relative to the open sea. Neurons do the same thing, but they pump out positively charged sodium ions. In addition, they pump in positively charged potassium ions. Thus, there is a high concentration of sodium ions present outside the neuron and a high concentration of potassium ions inside. Thus, sodium channels allow sodium ions through the membrane while potassium channels allow potassium ions through the membrane.



Read the given passage carefully and give the answer of the following questions:

(i) When neuron pump out and pump in are the positive sodium and positive potassium ions respectively, which property of charge is to be followed?

a. Quantisation of charge
b. Additivity of charges
c. Conservation of charges
d. Associativity of charges

(ii) Coulomb's law is true for:

a. atomic distances ($= 10^{-11}$ m)
b. nuclear distances ($= 10^{-15}$ m)
c. charged as well as uncharged particles
d. all the distances

(iii) Electric lines of force about a positive sodium or potassium ions are:

a. circular anticlockwise
b. circular clockwise
c. radial, inwards
d. radial, outwards

(iv) Electric flux produced by positive potassium ions indicates that electric lines are directed:

a. outwards b. inwards
c. either a or b. d. None of these

(v) Electric flux over a surface of neuron in an electric field may be:

a. positive b. negative
c. zero d. All of these

Very Short Answer Type Questions

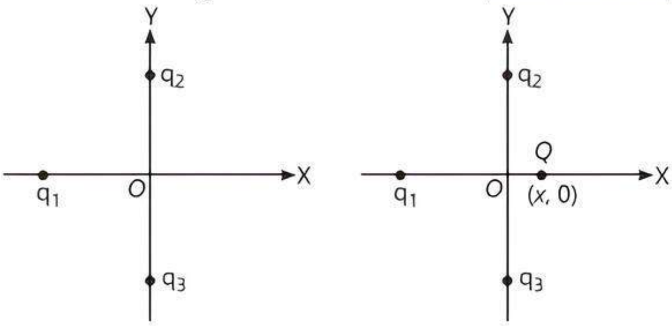
Q 8. What is the flux coming out from a unit positive charge enclosed in air?

Q 9. Charges ±20 nC are separated by 5 mm distance. What will be the magnitude of dipole moment?

Q 10. What is the value of the angle between the vectors $\vec{p}$ and $\vec{E}$ for which the potential energy of an electric dipole of dipole moment $\vec{p}$, kept in an external electric field $\vec{E}$, has maximum value?

Short Answer Type-I Questions

Q 11. In figure, two positive charges, q_2 and q_3 fixed along the Y-axis, exert a net electric force in the $+x$ direction on a charge q_1 fixed along the X-axis. If a positive charge Q is added at $(x, 0)$, what will be the force on q_1? *(NCERT EXEMPLAR)*



Q 12. The electrostatic attracting force on a small sphere of charge $0.2\mu C$ due to another small sphere of charge $-0.4\mu C$ in air is 0.4 N. What will be the distance between the two spheres?

Short Answer Type-II Questions

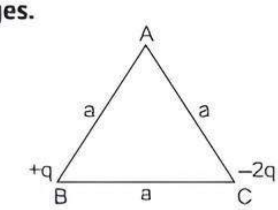
Q 13. Two point charges placed at a certain distance r in air exert a force F on each other. Then, what will be the distance r' at which these charges will exert the same force in a medium of dielectric constant K?

Q 14. Two charged conducting spheres of radii a and b are connected to each other by a wire. Find the ratio of the electric fields at their surface.

(CBSE 2023)

Long Answer Type Questions

Q 15. Two point charges $+q$ and $-2q$ are placed at the vertices 'B' and 'C' of an equilateral triangle ABC of side 'a' as given in the figure. Obtain the expression for (i) the magnitude and (ii) the direction of the resultant electric field at the vertex A due to these two charges.



Q 16. (i) Use Gauss's law to obtain an expression for the electric field due to an infinitely long thin straight wire with uniform linear charge density λ.

(ii) An infinitely long positively charged straight wire has a linear charge density λ. An electron is revolving in a circle with a constant speed v such that the wire passes through the centre and is perpendicular to the plane of the circle. Find the kinetic energy of the electron in terms of magnitudes of its charge and linear charge density λ on the wire.

(iii) Draw a graph of kinetic energy as a function of linear charge density λ. *(CBSE 2023)*