Electric Charges and Fields

Chapter 1

1 ELECTRIC CHARGE

Positive and negative charges were named by Benjamin Franklin.

Charging can be done by

1. Friction 2. Induction 3. Conduction

Charging by friction

When glass rod is rubbed with silk, the rod acquires one type of charge and silk acquires other type of charge.

2 PROPERTIES OF CHARGES

- Two types of charges exist.
- Like charges repel unlike attract.
- A body is charged by loss or gain of electrons.
- In an isolated systems, total charge remains conserved.
- Charge exists in discrete nature. $q = \pm n \times e$
- Moving charge has magnetic effects along with electric effects.
- Accelerating charges emit radiations.
- Gold leaf electroscope detects charge on a body.
- Charge is scalar and additive in nature.

3 CONDUCTORS AND INSULATORS

- Some substances which readily allow passage of electricity through them are called conductors
- Metals, human body and earth are conductors.
- Materials which opposes flow of charge through them are insulators.
- Glass, porcelain, plastic, nylon, wood etc are insulators.

Earthing

A process of sharing charges with earth is called grounding or earthing

4 CHARGES INTERACTION

Coulomb's law is quantitative statement about force between two point charges.

- Force varies inversely as square of distance between the charges and directly proportional to product of magnitude to two charges and acts along the line joining two charges
- Two charges q_1 and q_2 separated by distance r in vacuum, the magnitude of force (F) between them

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

K depends on system of units and medium. In SI unit in vacuum $K = 9 \times 10^9$. Unit of charge is coulomb(C)

$$F = \frac{1}{4\pi\varepsilon_0}\frac{(q_1 q_2)}{r^2}, \quad \varepsilon_0 = 8.854 \times 10^{-12}\ C^2N^{-1}m^{-2}$$

5 FORCE BETWEEN MULTIPLE CHARGES

Force on any charge due to 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 by presence of other charges. This is termed as superposition principle of electrostatics. Vector sum of forces is obtained by parallelogram law of addition of vectors. Force on first charge due to other is given as $\vec{F}_1 = \frac{q_1}{4\pi\varepsilon_0}\sum_{i=2}^{n}\frac{q_i}{r_{1i}^2}\hat{r}_{1i}$

6 ELECTRIC FIELD OF GHARGES

- A charge placed at a point produces an electric field everywhere in the surrounding. When another charge is brought in field, field there acts on it and produces a force. Faraday introduced field concept.
- Electric field intensity produced by a charge Q at a point distance r is given by

$$E(r) = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\hat{r}$$

- SI unit of electric field is N/C. Field intensity at a point due to charge Q in space is defined as the force that a unit positive charge would experience if placed at that point.

$$\vec{E} = \lim_{q\to 0}\left(\frac{\vec{F}}{q}\right)$$

- Field vary from point to point and is a vector quantity. Field can transport energy.

Field Due to System of Charges

Electric field at a point P in space due to system of charges is defined as force experienced by a unit test charge placed at that point

$$\vec{E}(r) = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_{ip}^2}\hat{r}_{ip}$$

7 ELECTRIC DIPOLE

- An electric dipole is an arrangement of pair of equal and opposite point charges separated by a distance.
- Direction from $-q$ to $+q$ is direction of dipole moment.

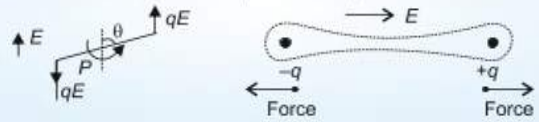
Electric fields due to dipole

On Axis of Dipole	On Equatorial Plane
$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}r}{(r^3 - a^2)^2} \approx \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$ (if $r >> a$)	$\vec{E} = \frac{-1}{4\pi\varepsilon_0}\frac{\vec{p}}{(r^2 + a^2)^{3/2}} \approx \frac{-1}{4\pi\varepsilon_0}\frac{\vec{p}}{(r^3)}$ (if $r >> a$)

- Polar molecule : H_2O have permanent electric dipole moment even in absence of electric field.
- Non polar molecule : CH_4, CO_2. The Dipole moment is zero.
- A dipole in external uniform electric field experience torque but no net force.

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

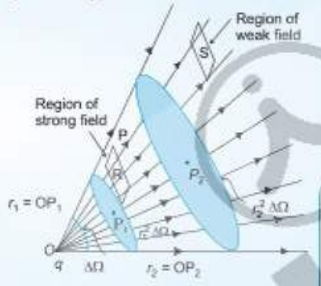
$|\tau| = PE \sin\theta$



8 ELECTRIC FIELD LINES

(Lines of force by Faraday)

Field lines carry information about direction of electric field at different points in space. Relative density of field lines at different points indicates relative strength of electric fields at these points. Faraday introduced non mathematical way of visualizing electric field around charge configuration.



9 ELECTRIC FIELD LINES PROPERTIES

- It is a way of pictorially mapping the electric field around a configuration of charges.
- A line is a curve drawn in such a way that tangent to it at each point is in the direction of net field at that point.
- A field line is a space curve (A curve in three dimension)
- Field lines of a single positive charge are radially outward.
- Field lines start from positive charges and end at negative charges.
- From a single charge, line can start from or end at infinity.
- In a charge free region, electric field lines can be taken to be continuous curves without any breaks.
- Two field lines can never cross each other.
- Electrostatic field lines don't form any closed loop. This follows from their conservative nature.

10 ELECTRIC FLUX

- Similar to fluid flow an analogous quantity exists in electrostatic called electric flux. There is no flow of observable quantity.
- The number of (field) lines crossing a unit area placed normal to field at a point is measure of strength of electric field at that point.
- Number of field lines crossing ΔS area is proportional to $E\Delta S\cos\theta$. This is called electric flux through area element ΔS.

$\Delta\phi = \vec{E} \cdot \Delta\vec{S} = E\Delta S \cos\theta$

θ = angle between $\vec{E}$ and outward drawn normal to area element $\Delta\vec{S}$.

- Units : $NC^{-1}m^2$
- Total flux $\phi \approx \Sigma \vec{E} \cdot \Delta\vec{S}$

Approximate sign is because electric field is taken uniform over area element.

If $\Delta S \to 0$ then, $\phi = \int \vec{E} \cdot d\vec{s}$

11 GAUSS'S LAW

- Total electric flux through closed surface $s = \frac{q}{\varepsilon_0}$, where q = Total charge enclosed by s
- Total flux is zero if closed surface encloses no charge.
- Gauss law is true for any surface, no matter what its shape or size is.
- q is total charge enclosed by surface, located anywhere inside.
- Gaussian surface should not pass through discrete charges.
- Any violation of Gauss's law will indicate departure of inverse square law.

Application of Gauss's law

- Electric field due to infinitely long wire

  $E = \frac{\lambda}{2\pi\varepsilon_0 r}$, at distance r from linearly charged rod.

- Field of Uniformly Charged Shell

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

  Directed out for $q > 0$, directed inwards for $q < 0$

  $E = 0$ $(r < R)$ field is zero inside shell.

- Electric field due to infinite plane sheet

  $\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$ is independent of distance from sheet.

Sharpen Your Understanding

1. The electrostatic force between two small charged spheres having charges of 2×10^{-6} C and 3×10^{-6} C placed 30 cm apart in air is [NCERT Pg. 46]

(1) 0.9 N (2) 0.6 N
(3) 1.2 N (4) 1.8 N

2. Four point charges $q_A = -2\ \mu C$, $q_B = -5\ \mu C$, $q_C = -2\ \mu C$ and $q_D = -5\ \mu C$ are located at the corners of a square of side 20 cm (In cyclic order). What is electric force on a charge of 1 μC placed at the centre of square? [NCERT Pg. 46]

(1) 0.9 N (2) Zero
(3) 0.6 N (4) 2.4 N

3. A system of two charges $q_A = 2.5 \times 10^{-7}$ C and $q_B = -2.5 \times 10^{-7}$ C are located at points A: (0, 0, – 15 cm) and B: (0, 0, 15 cm) respectively. The electric dipole moment of system is [NCERT Pg. 46]

(1) 2.5×10^{-7} C m (2) 5×10^{-7} C m
(3) 7.5×10^{-8} C m (4) Zero

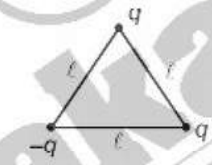
4. A polythene piece rubbed with wool is found to have negative charge of 3.2×10^{-6} C. The number of excess electrons on polythene is [NCERT Pg. 46]

(1) 2×10^{13} (2) 4×10^{12}
(3) 5.5×10^{9} (4) 6×10^{20}

5. An electron falls through distance of 2×10^{-2} m in uniform electric field from state of rest. The time of fall if $E = 6 \times 10^{4}$ NC^{-1} is [NCERT Pg. 21]

(1) 1.5×10^{-6} s
(2) 1.94×10^{-9} s
(3) 3.3×10^{-5} s
(4) 2.3×10^{-6} s

6. Consider charges q, $-q$ and q placed at vertices of an equilateral triangle as shown in figure. Calculate force on $-q$ charge due to other. [NCERT Pg. 17]



(1) $\frac{q^2}{2\pi\varepsilon_0\ell^2}$ (2) $\frac{q^2}{4\pi\varepsilon_0\ell^2}$
(3) $\frac{\sqrt{2}q^2}{\pi\varepsilon_0\ell^2}$ (4) $\frac{\sqrt{3}q^2}{4\pi\varepsilon_0\ell^2}$

7. Which among the given statements is incorrect statement? [NCERT Pg. 19]

(1) For every positive point charge, electric field lines will be directed radially outwards from charge.
(2) Magnitude of electric field E will depend on distance form point charge
(3) The electric field due to a point charge has spherical symmetry
(4) A test charge q experiences electric force $\vec{F}$ at a point then electric field intensity is defined as $\vec{E} = \frac{\vec{F}}{q^2}$

NCERT Based MCQs

8. A proton and an electron are released form rest in uniform electric field then the correct statement among the following is [NCERT Pg. 46]

(1) Time required to fall through certain distance is more for an electron
(2) The force experiences by proton will be more
(3) Magnitude of acceleration experienced by proton is more
(4) KE gained by both charges in moving through same distance are equal

9. Regarding electric lines of force, the correct statement is/are [NCERT Pg.24]

(1) Field lines carry information about direction of electric field
(2) Relative density of field lines at different points indicates relative strength of electric field at these points
(3) The field lines crowd where field is weak and spaced apart where field in strong
(4) Both (1) and (2) are correct

10. The incorrect statement among the following statements is [NCERT Pg. 25]

(1) Electric field lines can never cross each other

(2) Electrostatic field lines do not form any closed loop

(3) In charge free region, electric field lines can be taken to be continuous curve

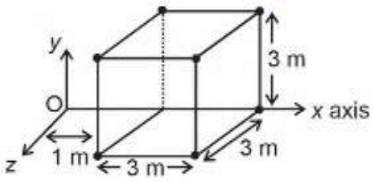
(4) Field lines around a system of two positive charges is straight and parallel lines pictorially

11. A dipole consist of two charges q and $-q$ separated by a distance $2a$. The electric field of this dipole at distance r from centre of dipole at a point A on axis is [NCERT Pg.28]

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

(3) $\frac{p}{4\pi\varepsilon_0 r^3}$ (4) $\frac{2pr}{4\pi\varepsilon_0 (r^2-a^2)^2}$

12. Electric field components are $E_x = 100\,x^{\frac{1}{2}}, E_y = E_z = 0$. Calculate net electric flux though the cube placed in electric field at shown position. [NCERT Pg. 35]



(1) 900 $Nm^2 C^{-1}$ (2) 1800 $Nm^2 C^{-1}$

(3) 600 $Nm^2 C^{-1}$ (4) 3600 $Nm^2 C^{-1}$

13. An infinite long straight wire has linear charge density $\lambda = 4 \times 10^5$ C m^{-1}. The electric force experienced by a proton at perpendicular distance of 10 mm from axis of wire is [NCERT Pg. 37]

(1) 1.25×10^{-4} N (2) 1.68×10^{-3} N

(3) 2.8×10^{-6} N (4) 1.15×10^{-1} N

14. Coulomb's law of electrostatic for the force between two point charges most closely resembles [NCERT Pg. 12]

(1) Law of conservation of charges

(2) Law of conservation of energy

(3) Newton's second law of motion

(4) Newton's law of gravitation

15. A point charge q of mass m is placed in front of a uniformly charged infinite sheet and released. The surface charge density of sheet is σ C m^{-2}. The kinetic energy of charge after t second is [NCERT Pg. 39]

(1) $\frac{q^2\sigma^2t^2}{4\varepsilon_0^2 m}$ (2) $\frac{q^2\sigma^2t^2}{\varepsilon_0^2 m}$

(3) $\frac{q^2\sigma^2t^2}{8\varepsilon_0^2 m}$ (4) $\frac{q^2\sigma^2t^2}{4\varepsilon_0^2 m^2}$

16. An electric dipole consists of two equal and opposite charges 0.02 μ C separated by 2 mm. The dipole is placed is uniform electric field of 10^7 N C^{-1}. Maximum torque exerted by field on dipole is [NCERT Pg. 31]

(1) 2×10^{-4} Nm (2) 4×10^{-4} Nm

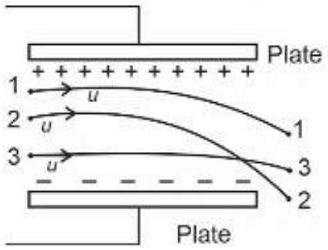
(3) 8×10^{-4} Nm (4) 2×10^{-6} Nm

17. A thin spherical shell is given a charge $q = 4$ μC, uniformly distributed over its surface. Consider a point P outside the shell at distance of 2 m from surface. If the radius of shell is 1 m, what is electric field at point P? [NCERT Pg. 39]

(1) 4 kN C^{-1} (2) 2 kN C^{-1}

(3) 9 kN C^{-1} (4) 36 kN C^{-1}

18. Figure shows track of three positive charged particles through uniform electric field E. All charges are equal in value. Which charge particle has more initial kinetic energy on entering horizontally between the plate? [NCERT Pg. 47]



(1) Particle 1

(2) Particle 2

(3) Particle 3

(4) Both 1 and 2 have equal initial KE

19. A uniformly charged conducting sphere of 3 m diameter has a surface charge density of 90 $\mu C/m^2$. What is total electric flux leaving the surface of sphere? [NCERT Pg.48]

(1) 1.76×10^8 N m^2 C^{-1}

(2) 2.87×10^8 N m^2 C^{-1}

(3) 5.2×10^8 N m^2 C^{-1}

(4) 4.52×10^6 N m^2 C^{-1}

20. Incorrect statement among the following is [NCERT Pg.48]

(1) Gauss's law is useful in calculating electric field when system has some symmetry

(2) Gaussian surface can pass through a continuous charge distribution

(3) Gauss's law is based on inverse square dependence of electric field on distance

(4) In situation when surface is so chosen that some charges are outside and some inside, electric field (whose flux appears on left side of Gauss's equation) is only due to the charges inside the closed surface

Thinking in Context

1. When a charge is put on an insulator, it stays at same place, when some charge is transferred to conductor it gets distributed over _____ surface of conductor. [NCERT Pg. 5]
2. A body is positively charged by ____ electrons and negatively charged by ____ electrons. [NCERT Pg. 4]
3. A simple apparatus to detect charge on a body is ____. [NCERT Pg. 3]
4. When electrified rods are brought near light objects. The rod induces opposite charges on near surface of the objects and similar type of charges move to farther side of objects, this method is called _____. [NCERT Pg. 6]
5. Experimentally, it is established that all free charges are integral multiple of basic unit of charge. This discrete nature of charge is called _____ of change. [NCERT Pg. 08]
6. SI units of absolute permittivity of free space is _____. [NCERT Pg. 11]
7. Coulomb's law of electrostatic agrees with the Newton's _____ law. [NCERT Pg. 12]
8. The ratio of electrostatic force between two protons to gravitational force at same separation in vacuum is _____. [NCERT Pg. 13]
9. Experimentally it is verified that force on any charge due to number of other charges is the vector sum of all the forces on that charge due to other charges. This is termed as _____. [NCERT Pg. 15]
10. Away from a point charge, the field gets weaker and density of field lines is less, resulting in well separated field line away from charge. This statement is [NCERT Pg. 23]

(1) True (2) False

11. Electrostatic field lines do not form any closed loops. This follows from the conservative nature of electric field. The statement is [NCERT Pg. 25]

(1) True (2) False

12. Total charge of electric dipole is _____. The electric field at distance much larger than dipole length of a dipole, on a plane perpendicular to dipole axis varies as ____. NCERT Pg. 27]
13. Total electric flux through a closed surface is equal to $\frac{q}{\varepsilon_0}$, here q is _____. [NCERT Pg. 34]
14. In a situation when surface is so chosen that there are some charges inside and some outside. The electric field whose flux appears on left side of Gauss's equation is due to all charges ____ the surface. [NCERT Pg. 34]

15. The shape of graph between electric field intensity and distance from axis of uniformly charged wire is _____. [NCERT Pg. 38]

16. Electric field due to uniformly charged large planar sheet from the surface of planar sheet is _____ distance from sheet. [NCERT Pg. 39]

17. Electric field inside uniformly charged thin spherical shell is ___and for points outside the shell, entire charge of the shell is assumed to be concentrated at ____. [NCERT Pg. 39]

18. **Statement A:** Coulomb's force and gravitational force follow the same inverse law.

Statement B: Gravitation force has one sign (Only attractive) and Coulomb force can give both signs (attractive and repulsive). Both statements are [NCERT Pg. 45]

(1) True

(2) False

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19. The electric field due to a discrete charge configuration is not defined at the location of the discrete charges. The statement is [NCERT Pg. 45]

(1) True (2) False

20. The electric field due to charge configuration with total charge zero is not zero, but for distance large compared to the configuration, its field falls of faster than $\frac{1}{r^2}$, typical of field due to single charge. This statement is [NCERT Pg. 46]

(1) True (2) False