Part –1: Introduction, Electric Charge and Basic Properties

1. Introduction

विद्युत (Electricity) आधुनिक विज्ञान एवं प्रौद्योगिकी का आधार है। पंखा, बल्ब, कम्प्यूटर, मोबाइल, टेलीविज़न, चिकित्सा उपकरण तथा उपग्रह—सभी का संचालन विद्युत सिद्धान्तों पर आधारित है।

Electrostatics, Physics की वह शाखा है जिसमें **स्थिर विद्युत आवेशों (Static Electric Charges)** तथा उनके द्वारा उत्पन्न बल एवं विद्युत क्षेत्र का अध्ययन किया जाता है।

यह अध्याय आगे आने वाले अध्यायों—**Electric Potential, Capacitance, Current Electricity तथा Electromagnetism**—की नींव है।

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2. Electric Charge

Definition

Electric Charge पदार्थ का वह मूलभूत गुण है जिसके कारण वह अन्य आवेशित वस्तुओं पर आकर्षण या प्रतिकर्षण बल लगाता है तथा उनसे बल अनुभव करता है।

Symbol: q या Q

SI Unit: Coulomb (C)

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3. Types of Electric Charges

दो प्रकार के विद्युत आवेश होते हैं:

(i) Positive Charge (+)

उदाहरण:

- Glass Rod को Silk से रगड़ने पर Glass Rod पर धनात्मक आवेश उत्पन्न होता है।

(ii) Negative Charge (−)

उदाहरण:

- Ebonite Rod को Fur से रगड़ने पर Ebonite Rod पर ऋणात्मक आवेश उत्पन्न होता है।

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4. Interaction Between Charges

- समान प्रकार के आवेश (Like Charges) एक-दूसरे को **प्रतिकर्षित (Repel)** करते हैं।
- विपरीत प्रकार के आवेश (Unlike Charges) एक-दूसरे को **आकर्षित (Attract)** करते हैं।

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5. Methods of Charging

किसी वस्तु को तीन प्रमुख विधियों से आवेशित किया जा सकता है:

(i) Charging by Friction

दो वस्तुओं को रगड़ने पर इलेक्ट्रॉनों का स्थानान्तरण होता है।

Examples:

- Glass Rod + Silk
- Ebonite Rod + Fur

(ii) Charging by Conduction

आवेशित वस्तु को दूसरी वस्तु से स्पर्श कराने पर आवेश का स्थानान्तरण होता है।

For example, body A has charge q and it is brought in contact with another charged body B of charge 2q, then after separation, body A will have charge 3q/2 and body B will also have charge 3q/2.
Similarly if body A has charge –q and is brought in contact with body B which is uncharged and has identical size with that of body A, then after separation, body A will have charge –q/2 and body B will also have charge –q/2.

Note:

If both bodies are not identical in sizes, charges after separation will be different. The charges will be shared proportionately according to their radii.
For two isolated conducting spheres of radii R_1 and R_2 after contact and separation, their final charges are proportional to their radii, because their potentials become equal during contact.

For example,

The body A has charge q_1 and radius R_1 and is brought in contact with body B of charge q_2 and radius R_2, then after separation, the charge distribution will be as: $q \propto R$, so, $\frac{q_1}{q_2} = \frac{R_1}{R_2}$.

After separation, body A will have charge

$$\boxed{{q_1}' = q_{net}\left(\frac{R_1}{R_1 + R_2}\right)}$$

And body B will have charge

$$\boxed{{q_2}' = q_{net}\left(\frac{R_2}{R_1 + R_2}\right)}$$

Where,

$$\boxed{q_{net} = q_1 + q_2}$$

(iii) Charging by Induction

बिना स्पर्श किए किसी चालक में आवेश उत्पन्न करना **Charging by Induction** कहलाता है।
महत्वपूर्ण तथ्य: इसमें प्रत्यक्ष संपर्क (Direct Contact) आवश्यक नहीं होता।

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6. Basic Properties of Electric Charge

(A) Additivity of Charge

किसी प्रणाली का कुल आवेश उसके सभी आवेशों का बीजगणितीय योग होता है।

$$Q = q_1 + q_2 + q_3 + \; - - - -$$

Example:

If q_1 = 3C, q_2 = −2C, then Q =1C

(B) Conservation of Charge

Statement

किसी पृथक (Isolated) प्रणाली में कुल विद्युत आवेश सदैव नियत रहता है। आवेश न तो उत्पन्न किया जा सकता है और न ही नष्ट किया जा सकता है; केवल एक वस्तु से दूसरी वस्तु में स्थानान्तरित किया जा सकता है।

Applications:

- Charging by Friction
- Charging by Conduction
- Charging by Induction

(C) Quantisation of Charge

किसी वस्तु पर उपस्थित कुल आवेश सदैव मूल आवेश e का पूर्णांक गुणज होता है।

$$q = \pm ne$$

Where,

- n=1, 2, 3, -----
- e $=1.6\times10^{-19}$ C

Example

If an object has charge Q = 4.8×10^{-19} C, then n = 3. That is, this object has charge equals to the magnitude of charge of 3 electrons.

Important Facts

 Charge of Proton = $+1.6\times10^{-19}$C
 Charge of Electron = -1.6×10^{-19} C
  No charge on Neutron

Summary

- Electric Charge पदार्थ का मूलभूत गुण है।
- दो प्रकार के आवेश होते हैं—धनात्मक एवं ऋणात्मक।
- समान आवेश प्रतिकर्षित तथा विपरीत आवेश आकर्षित करते हैं।
- आवेश उत्पन्न नहीं होता, केवल स्थानान्तरित होता है।
- कुल आवेश सदैव Q = ±ne के अनुसार होता है।

Part –2: Conductors, Insulators, Charging by Induction & Coulomb's Law

Learning Objectives

After studying this part, students will be able to:

- Distinguish between conductors and insulators.
- Explain charging by induction.
- State and apply Coulomb's Law.
- Understand the vector nature of electrostatic force.
- Apply the Principle of Superposition.
- Solve basic numerical problems based on Coulomb's Law.

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1. Conductors and Insulators

Conductors

A **conductor** is a material in which electric charges can move freely throughout the substance.

Examples

- Copper
- Silver
- Aluminium
- Gold
- Graphite
- Mercury

Characteristics

- Large number of free electrons
- Low electrical resistance
- Easily conducts electric current
- Charges redistribute themselves over the entire surface

Insulators

An **insulator** is a material in which electric charges cannot move freely.

Examples

- Glass
- Rubber
- Plastic
- Dry Wood
- Mica
- Porcelain

Characteristics

- Very few free electrons
- High electrical resistance
- Charges remain localized
- Poor conductor of electricity

Comparison

Property	Conductors	Insulators
Free Electrons	Present	Almost Absent
Charge Movement	Easy	Difficult
Electrical Conductivity	High	Very Low
Resistance	Low	High

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2. Charging by Induction

Charging by induction is the process of charging a conductor **without direct physical contact**.

Principle

A nearby charged body causes the free electrons inside a conductor to rearrange themselves. If grounding is provided and later removed appropriately, the conductor acquires a net charge opposite to that of the inducing body.

Steps of Charging by Induction

1. Bring a charged rod near a neutral conductor.
2. Charges inside the conductor redistribute.
3. Connect the conductor to the Earth.
4. Remove the Earth connection.
5. Remove the charged rod.

The conductor is left with a charge opposite to that of the inducing rod.

Important Features

- No direct contact is required.
- Based on redistribution of free electrons.
- Charge is produced due to induction.
- Widely used in electrostatic applications.

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3. Coulomb's Law

Statement

The electrostatic force between two stationary point charges is directly proportional to the product of their magnitude of charges and inversely proportional to the square of the distance between them.

Mathematical Expression

Magnitude of electrostatic force of attraction or repulsion

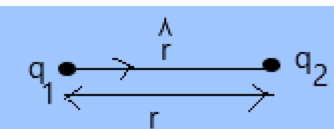

Figure-1: Two point charges separated by distance r

$$F \propto |q_1||q_2|$$

And,

$$F \propto \frac{1}{r^2}$$

Or,

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

(Coulomb's law in magnitude form)

Where,

- F = Electrostatic force (N)
- q_1, q_2 = Point charges (C)
- r = Distance between charges (m)
- k = Electrostatic constant

In S. I. unit, $k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9$ N-m^{2}C^{-2} (for air or free space)

Here, $\epsilon_0 = 8.85 \times 10^{-12}$ C^{2}N^{-1}m^{-2} [or C^2/N-m^2 or Farad/m (Fm^{-1})] = absolute permittivity of air or free space.

Here, k = 1 is taken CGS unit and $F = \frac{|q_1||q_2|}{r^2}$

Dimensional formula of permittivity of free space $(\boldsymbol{\epsilon_0})$:

$$[\epsilon_0] = [M^{-1}L^{-3}T^4A^2]$$

4. Nature of Electrostatic Force

- Like charges repel each other.
- Unlike charges attract each other.
- Electrostatic force acts along the line joining the two charges.
- It is a central force.
- It obeys Newton's Third Law.

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5. Vector Form of Coulomb's Law

The vector form gives both the **magnitude** and **direction** of the electrostatic force.

If $\hat{r}$ is the unit vector from q_1 to q_2 , then

$$\boxed{\vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\left(\frac{q_1 q_2}{r^2}\right)\breve{r}}$$

Direction of Force

The direction of force at a charge due to other charge is along the line joining the centre of two charges and directed either away from charge q_2 or towards charge q_2 depending upon both are like charges or unlike charges.

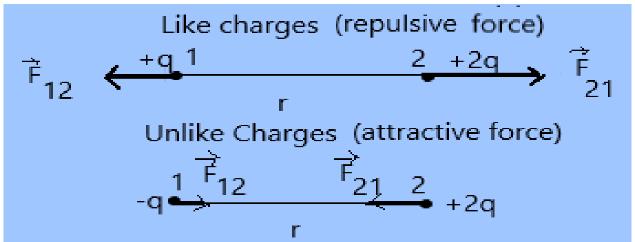

Figure-2: Direction of Force in like and Unlike Charges

In the Figure-2:

(a) For Like Charges (Repulsive Force)

$\vec{F}_{12}$= force on charge (charge +q) at point 1 due to charge (+2q) at point 2, acting away from point-1

And,

$\vec{F}_{21}$ = force on charge (charge + 2q) at point 2 due to charge (+q) at point 1, acting away from point-2.

(b) For Unlike Charges (Attractive Force)

$\vec{F}_{12}$ = force on charge (charge -q) at point 1 due to charge (+2q) at point 2, acting towards charge + 2q at point -2

$\vec{F}_{21}$ = force on charge (charge + 2q) at point 2 due to charge (+q) at point 1, acting towards charge –q at point-1

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6. Principle of Superposition

When more than two charges are present, the net electrostatic force on any charge is equal to the **vector sum** of the forces exerted by all other individual charges.
Mathematically,

$$\boxed{\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ----}$$

This principle is applicable because electrostatic forces obey vector addition.

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7. Limitations of Coulomb's Law

Coulomb's Law is valid when:

- Charges are point charges.
- Charges remain stationary.
- Medium is homogeneous and isotropic.
- Distance between point charges is much larger than their sizes.
- For extended charged bodies, Coulomb's point-charge expression can be used when their dimensions are small compared with separation.

Solved Example 1

Two charges of 2 μC and 3 μC are placed 0.50 m apart in air. Find the electrostatic force between them.

Given

$q_1 = 2\mu C$= $2 \times 10^{-6} C$, $q_2 = 3\mu C$= $3 \times 10^{-6} C$, r = 0.50 m

Formula

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

Solution

$$F = k\frac{|q_1||q_2|}{r^2} = (9 \times 10^9)\frac{2 \times 10^{-6} \times 3 \times 10^{-6}}{(0.50)^2} = 0.216\ N$$

Answer: 0.216 N (Repulsive)

Exam Tips

 Always convert μC into Coulomb.
 Always use SI units.
 Mention whether the force is **attractive** or **repulsive**.
 Draw a neat force diagram whenever possible.

Common Mistakes

□ Forgetting to convert μC into C.
□ Using centimetres instead of metres.
□ Forgetting to square the distance.
□ Writing only the magnitude without mentioning the nature of the force.

Quick Revision

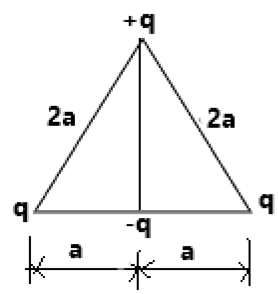
- Conductors contain free electrons.
- Insulators do not allow free movement of charge.
- Induction requires no physical contact.
- Coulomb's Law:

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

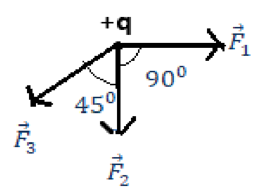
- Electrostatic force follows the inverse square law.
- Net force is obtained using the Principle of Superposition.

Try Yourself

1. Two spheres A and having charges Q and 3Q of (i) same radii and of same material and (ii) A has radius r and B has radius 2r, having same material also, are brought in contact and then separated. Find the net charge on A and On B in case of (i) and (ii).
2. As shown in the figure, find the net electric force on charge –q.



3. Two point and like charges of same magnitude experiences the force F when kept in air. What will be the new force between them placed at same distance but kept in vacuum?
4. Three forces $\vec{F}_1$, $\vec{F}_2$ and $\vec{F}_3$ are acting on a point charge q due to other charges in the given direction as shown. Given their magnitudes as: $F_1 = F_2 = F = \frac{Kq^2}{l^2} = 2F_3$. Show that arrangement of charges and find the net force and its direction at charg
By using methods as
   (a) Law of parallelogram method
   (b) Unit vector method
   (c) Vector method
   (d) Component of force method



Part –3: Electric Field, Electric Field Intensity & Electric Field Lines

Learning Objectives

After studying this part, students will be able to:

- Define an electric field.
- Explain electric field intensity.
- Calculate the electric field due to a point charge.
- Understand the principle of superposition of electric fields.
- Interpret electric field lines and their characteristics.
- Solve basic numerical problems related to electric fields.

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1. Electric Field

Definition

An **Electric Field** is the region around a charged body in which another charge experiences an electrostatic force.

In other words,

An electric field is the space surrounding a charge where its influence can be detected by another charge.

Concept

A charged body does not need to touch another charge to exert force on it. The force is transmitted through the electric field surrounding the source charge.

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2. Test Charge

A **Test Charge** is an imaginary, sufficiently small positive charge used to determine the electric field at a point without appreciably disturbing the existing charge distribution.

Characteristics

- Very small in magnitude.
- Positive by convention.
- Does not disturb the existing electric field.

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3. Electric Field Intensity

Definition

Electric Field Intensity at a point is the electrostatic force experienced by a **unit positive test charge** placed at that point.

Mathematically,

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

Where,

- E = Electric field intensity
- F = Electrostatic force
- q_0 = Positive test charge

SI Unit

$$\boxed{Newton\ per\ Coulomb\ (NC^{-1})}$$

Another commonly used unit is

$$\boxed{Volt\ per\ metre\ (Vm^{-1})}$$

Both units are equivalent.

Nature

Electric field intensity is a **vector quantity**.
Its direction is the same as the force acting on a positive test charge.

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4. Electric Field Due to a Point Charge

Consider a point charge Q.
A test charge q_0 is placed at a distance r.
Using Coulomb's Law,

$$F = \left(\frac{1}{4\pi\epsilon_0}\right)\left(\frac{|Q||q_0|}{r^2}\right)$$

Since

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

Therefore,

$$E = \left(\frac{1}{4\pi\epsilon_0}\right)\left(\frac{|Q|}{r^2}\right)$$

Important Formula

$$\boxed{E = k\frac{|Q|}{r^2}}$$

Where
$k=9\times10^9\ Nm^2/C^2$

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5. Direction of Electric Field

Positive Charge

Electric field lines point **away** from the charge.

Negative Charge

Electric field lines point **towards** the charge.
Its direction is shown in the following figures.
(i) Due to a +ve point charge q placed at a point (say at point A) in free space or in air:
So, due to a positive point charge, the direction of electric field intensity at point (say P) is away from that point and along AP (that is, line joining point charge (+q) and the point P.). Its magnitude is $E_{PA} = \frac{1}{4\pi\epsilon_0}\left(\frac{|q|}{r^2}\right) = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{r^2}\right)$

(ii) Due to a –ve point charge placed at a point (say at point B) in free space or in air:

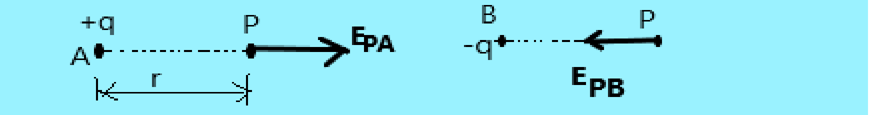

Figure-3 (i) Electric Field direction due to +ve Charge

Figure-3(ii) Electric Field direction due to -ve Charge

6. Principle of Superposition of Electric Fields

If several charges are present, the resultant electric field at any point is equal to the **vector sum** of the electric fields due to individual charges.

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + -----$$

This principle is widely used in solving multi-charge systems.

General Formula to find net electric field in vector form:

Electric field intensity at a point whose position is r due to other charges whose positions are r_1, r_2, r_3, -------can be expressed as- (Principle of Superposition for Electric field intensity)

$$\vec{E} = \frac{1}{4\pi\varepsilon}\sum_{i=1}^{n}\frac{q_i(\vec{r}-\vec{r_i})}{|\vec{r}-\vec{r_i}|^3}$$

7. Electric Field Lines

Definition

Electric field lines are **imaginary curves** drawn such that the tangent at any point gives the direction of the electric field.

They provide a convenient way to visualize electric fields.

Characteristics of Electric Field Lines

(i) Originate from Positive Charges

Field lines always begin on positive charges.

(ii) Terminate on Negative Charges

They end on negative charges or at infinity.

(iii) Never Intersect

Two electric field lines can never cross each other.

If they intersected, the electric field would have two directions at the same point, which is impossible.

(iv) Density Represents Strength

Closer field lines indicate a stronger electric field.

Widely spaced lines indicate a weaker field.

(v) Continuous Curves

Electric field lines are continuous and smooth.

(vi) Perpendicular to Conductors
At the surface of a charged conductor, field lines are always perpendicular to the surface.

(vii) Number of field lines proportional to charge
The number of field lines is directly proportional to magnitude of charge.

8. Electric Field Due to Multiple Charges
The electric field at any point is obtained by adding the individual field vectors.
Depending on the geometry,

- Parallel vector addition
- Opposite vector subtraction
- Component method

may be used.

Solved Example
A charge of Q = 5×10^{-6} C is placed in air. Find the electric field intensity at a point 0.20 m away.

Given

Q =5×10^{-6} C, r = 0.20m

Formula

$$E = \frac{kQ}{r^2}$$

Solution

$$E = \frac{kQ}{r^2} = \frac{9 \times 10^9 \times 5 \times 10^{-6}}{0.04} = 1.125 \times 10^6 N/C$$

Answer:

$$\boxed{1.125 \times 10^6 N/C}$$

Exam Tips
 Electric field always exists around a charged body.
 Electric field is independent of the test charge.
 Direction is always defined for a **positive** test charge.
 Never confuse **Electric Force** with **Electric Field**.

Common Mistakes
 Writing Electric Field as a scalar quantity.
 Forgetting that electric field direction is defined using a positive test charge.
 Drawing field lines intersecting each other.
 Ignoring vector addition while calculating the resultant electric field.

Nature of Electric Field
- Vector Quantity
- Acts along the line joining charges
- Follows the inverse square law

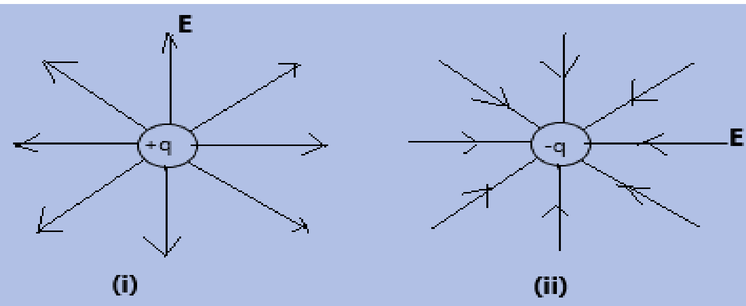

Figure-4 (i) and (ii): Electric field Lines due to isolated +ve and -ve point Charges

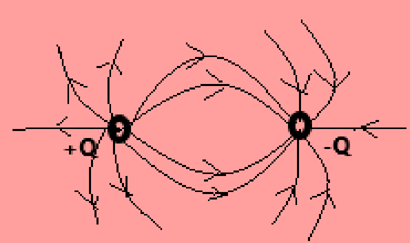

Figure-5(1): Electric Field Lines due to a Dipole

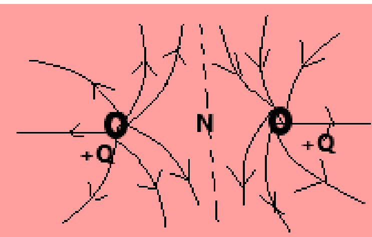

Figure-5(2): Electric Field Lines due to two like charges of equal magnitude

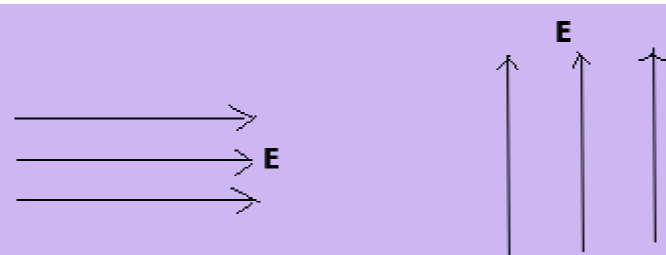

Figure-6(1) and (2): Uniform Electric Field Lines

Part – 4: Electric Dipole, Dipole Moment, Electric Field Due to a Dipole & Torque on a Dipole

Learning Objectives

After studying this part, students will be able to:

- Define an electric dipole.
- Explain electric dipole moment.
- Derive the electric field due to an electric dipole at axial and equatorial positions.
- Understand the torque acting on a dipole in a uniform electric field.
- Distinguish between stable and unstable equilibrium.
- Solve Board, NEET, and JEE Main level numerical problems.

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1. Electric Dipole

Definition

An **electric dipole** is a system consisting of **two equal and opposite point charges separated by a small fixed distance**.

If

- Positive charge = +q
- Negative charge = −q

and the separation between them is 2a, then the system is called an **electric dipole**.

Examples

- HCl molecule
- H_2O molecule, HCL, NH_3 (Polar molecule)
- NH_3 molecule

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2. Dipole Axis

The straight line joining the two charges of an electric dipole is called the **Dipole Axis**.
The midpoint of the dipole is called the **centre of the dipole** (O).

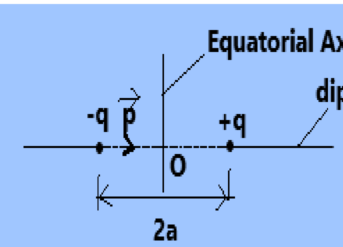

Figure-7: Electric Dipole and Dipole Moment Direction

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3. Electric Dipole Moment

Definition

The **Electric Dipole Moment** is defined as the product of the magnitude of either charge and the separation vector from the negative charge to the positive charge.
Mathematically,

$$\boxed{\vec{p} = q\vec{d}}$$

Where

- q = Magnitude of either charge

- d=2a Separation between the charges

Hence,

$$\boxed{p = q(2a)}$$

SI Unit: Coulomb metre (C m)

Direction

The direction of the dipole moment is **from the negative charge towards the positive charge**.

Properties of Dipole Moment

- It is a **vector quantity**.
- Its direction is from **−q to +q**.
- Larger charge or greater separation produces a larger dipole moment.

4. Electric Field Due to an Electric Dipole

The electric field produced by a dipole depends on the position of the observation point.
Two important positions are studied:

- Axial Position
- Equatorial Position

5. Electric Field at an Axial Position

Consider a point P on the axis of the dipole at a distance r from its centre.

Derivation-1: Derive the electric field at the axial position due to a short dipole

The electric field at P is the algebraic sum of the fields due to +q and −q.
For a **short dipole** (r ≫ l),

$$\boxed{E_{axial} = \frac{1}{4\pi\epsilon_0}\left(\frac{2p}{r^3}\right)}$$

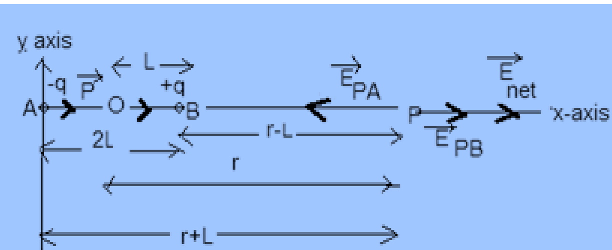


Figure-8: Electric Field at Axial Position due to a dipole

Let a dipole of charge $\pm q$ are separated by small distance 2 l and placed along x-axis.
Let P be the point where field intensity is being derived at distance r from the centre of dipole O as shown in the Figure-8.

.

The direction of electric dipole moment is from –q charge to +q charge as shown in the figure.

Now, magnitude of electric field intensity at point P due to charge +q at point B is

$$E_{PB} = \left|\vec{E}_{PB}\right| = \frac{1}{4\pi\epsilon_0}\left(\frac{|q|}{(r-l)^2}\right) = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{(r-l)^2}\right) - -(i), away\ from\ P\ along\ BP$$

Magnitude of electric field intensity at point P due to charge -q at point A is

$$E_{PA} = \left|\vec{E}_{PA}\right| = \frac{1}{4\pi\epsilon_0}\left(\frac{|-q|}{(r+l)^2}\right) = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{(r+l)^2}\right) - -(ii), towards - q\ along\ PA$$

Since,

$$E_{PB} > E_{PA}$$

As,

$$(r-l) < (r+l)$$

The net electric field intensity at point P due to both point charges –q and +q (making a dipole) is along AB and away from point P and its magnitude is given by,

$$E_{net} = E_{PB} - E_{PA} = \frac{1}{4\pi\epsilon_0}\left[\left(\frac{q}{(r-l)^2}\right) - \left(\frac{q}{(r+l)^2}\right)\right] = \frac{1}{4\pi\epsilon_0}\left[q\left\{\frac{(x+l)^2-(x-l)^2}{(r^2-l^2)^2}\right\}\right]$$

Or,

$$E_{net} = E_P = \frac{1}{4\pi\epsilon_0}\left[\frac{4qrl}{(r^2-l^2)^2}\right] = \frac{1}{4\pi\epsilon_0}\left[\frac{2pr}{(r^2-l^2)^2}\right] - - - -(iii)$$

Where, p = electric dipole moment. p = q (2l)

We also see that direction of net electric field intensity is along the direction of electric dipole moment (that is, the case of stable equilibrium).

If $r \gg l, then\ r^2 \gg l^2$, so, from equation (iii),

$$E_{net} = \frac{1}{4\pi\epsilon_0}\left[\frac{2pr}{r^4}\right] - - - (iv)$$

Or,

$$E_{net} = \frac{1}{4\pi\epsilon_0}\left(\frac{2p}{r^3}\right) - - - (v)$$

In vector form, the net electric field intensity at axial position at point P when $r \gg l$

$$\vec{E}_P = \frac{1}{4\pi\epsilon_0}\left(\frac{2p}{r^3}\right)(\hat{\imath})$$

Observation

- Electric field is directed **along the dipole axis**.
- Net electric field direction is parallel to dipole moment direction. $(\theta = 90^0)$-Stable equilibrium
- It decreases as

$$E \propto \frac{1}{r^3}$$

---

6. Electric Field at an Equatorial Position

Consider a point P on the perpendicular bisector of the dipole.

The electric fields due to the two charges combine to produce a resultant field opposite to the dipole moment.

For a **short dipole**,

$$\boxed{E = \frac{1}{4\pi\epsilon_0}\left(\frac{p}{r^3}\right)}$$

(Direction opposite to $\vec{p}$)

Observation

- Field is opposite to the dipole moment.
- Net electric field direction is antiparallel to the direction of dipole moment. ($\theta = 180^0$)- Unstable equilibrium position
- Again,

$$E \propto \frac{1}{r^3}$$

Derivation-2:

To derive the expression of electric field intensity due to a dipole of charge $\pm q$, separated by 2l distance at the equatorial position when r >> l when placed in free space.

In right angle triangle AOP,

$$AP = \sqrt{OA^2 + OP^2} = \sqrt{l^2 + r^2} = BP$$

As shown in the Figure-9, the magnitude of electric field intensity at point P due to charge –q at point A is

$$E_{PA} = \frac{1}{4\pi\epsilon_0}\left(\frac{|-q|}{r^2 + l^2}\right) = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{r^2 + l^2}\right) - - - -(i), towards - q\ charge$$

And the magnitude of electric field intensity at point P due to charge +q at point B is

$$E_{PB} = \frac{1}{4\pi\epsilon_0}\left(\frac{|+q|}{r^2+l^2}\right) = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{r^2+l^2}\right) - - - -(ii), away\ from\ P$$

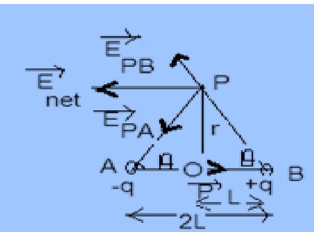


Figure-9: Electric Field at Equatorial Position due to a dipole

Here,

$$E_{PA} = E_{PB} = E\ (say) = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{r^2+l^2}\right) - - -\ (iii)$$

From the figure above shown,

$$\cos\theta = \frac{AO}{AP} = \frac{BO}{BP} = \frac{l}{\sqrt{r^2+l^2}} - - - -(iv)$$

Now, angle between $\vec{E}_{PA}$ and $\vec{E}_{PB}$ is 2 θ,

So, net electric field intensity at point P

$$E_P = \sqrt{{E_{PA}}^2 + {E_{PB}}^2 + 2(E_{PA})(E_{PB})\cos 2\theta}$$

Or,

$$E_P = \sqrt{E^2 + E^2 + 2E^2\cos 2\theta}$$

Or

$$E_P = \sqrt{2E^2 + 2E^2(2cos^2\theta - 1)}$$

Or

$$E_P = \sqrt{2E^2 + 4E^2cos^2\theta - 2E^2} = 2E\cos\theta - - - -(v)$$

Putting the value of E and cos θ from equations (iii) and (iv) into the equation (v), we get

$$E_P = \frac{1}{4\pi\epsilon_0}\left(\frac{2q}{r^2 + l^2}\right)\left(\frac{l}{\sqrt{r^2 + l^2}}\right)$$

Or

$$E_P = \frac{1}{4\pi\epsilon_0}\left(\frac{2ql}{(r^2 + l^2)^{\frac{3}{2}}}\right) - - - - (vi)$$

Since, magnitude of dipole moment is

$$p = 2ql - - - - - (vii)$$

When $r \gg l, then\ l^2$ can be neglected in comparison to r^2.
Therefore, using equations (vi) and (viii), we obtain,

$$\boxed{\boldsymbol{E_P = \frac{1}{4\pi\epsilon_0}\left(\frac{p}{r^3}\right)}}$$

(antiparallel to $\vec{p}$)
In vector form,

$$\boxed{\boldsymbol{\vec{E}_p = \frac{1}{4\pi\epsilon_0}\left(\frac{p}{r^3}\right)(-\hat{\imath})}}$$

7. Comparison of Axial and Equatorial Fields

Property	Axial Position	Equatorial Position
Direction	Along dipole moment	Opposite to dipole moment
Magnitude	$2kp/r^3$	kp/r^3
Relative Strength	Stronger	Weaker

Thus,

$$\boxed{\frac{E_{axial}}{E_{equatorial}} = 2:1}$$

for a short dipole at the same distance.

8. Dipole in a Uniform Electric Field

When an electric dipole is placed in a **uniform electric field**, the two charges experience equal and opposite forces.
The net force on the dipole is **zero**, but these forces form a **couple**, producing a torque that tends to rotate the dipole.

9. Torque on an Electric Dipole

If the dipole moment makes an angle θ with the electric field, the torque is given by:

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

Only the perpendicular component of force contributes to the torque.
Where

- τ = Torque
- p = Dipole moment
- E = Electric field

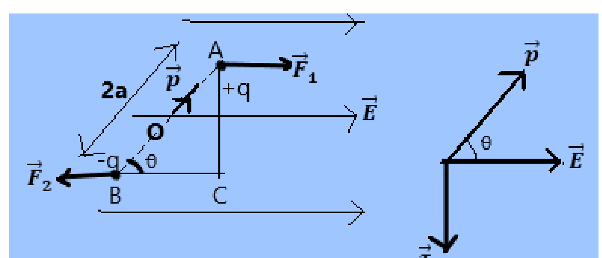


Figure-10: Torque on a dipole

- θ = Angle between $\vec{p}$ and $\vec{E}$

Derivation-3:

To derive torque acting due to a dipole of charge $\pm q$, separated by 2l distance and placed in a uniform electric field.

Let a dipole of charge $\pm q$ and length $2a$ is placed in the uniform electric field as shown in the Figure-10.

Torque acting on the dipole is

$$\tau = F \times r \perp ---(1)$$

Here,

$$r \perp = AC = 2a \sin\theta --- (2)$$

The force on each charge is of equal magnitude and in
Opposite direction as shown in the Figure-10.

Then,

$$F_1 = F_2 = F$$

Since,

$$F = qE ----(3)$$

From equation (1), (2) and (3), we get

$$\tau = qE(2a \sin\theta) --- (4)$$

The dipole moment is $\vec{p}$ and makes angle θ with $\vec{E}$, (from $\vec{p}$ to $\vec{E}$)

The magnitude of dipole moment is

$$p = q(2a) --- (5)$$

From equation (4) and (5), we obtain

$$\tau = pE \sin\theta --- (6)$$

Derived

In vector form,

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

Special Cases

(i) Maximum Torque

When θ = 90^0,

$$\boxed{\tau_{max} = pE}$$

(ii) Zero Torque

When θ = 0^0

$$\boxed{\tau = 0}$$

---

10. Stable and Unstable Equilibrium

Stable Equilibrium

The dipole is in **stable equilibrium** when its dipole moment is **parallel** to the electric field.

$$\theta = 0^0$$

A small displacement produces a restoring torque.

Unstable Equilibrium

The dipole is in **unstable equilibrium** when its dipole moment is **antiparallel** to the electric field.

$$\theta = 180^0$$

A small displacement causes the dipole to rotate further away from its original position.

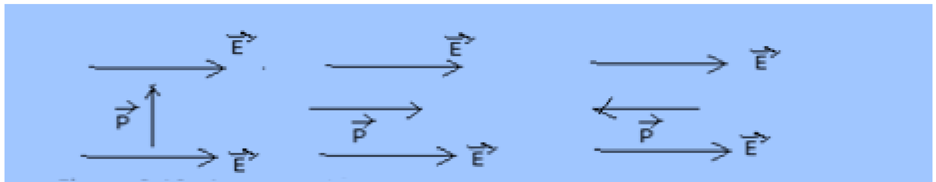


Figure-11(i) Figure-11(ii): Stable Equilibrium Figure-11(iii): Unstable Equilibrium

Solved Example

An electric dipole has a dipole moment p = 4×10^{-8} C m. It is placed in a uniform electric field of E = 5×10^{5} N/C at an angle of 30^0. Find the torque acting on the dipole.

Solution

Using

$$\tau = pE\sin\theta$$

Or

$$\tau = 4\times10^{-8}\times5\times10^{5}\times\sin 30^0 = 1\times10^{-2}Nm$$

Exam Tips

- Dipole moment is directed **from negative to positive charge**.
- For a short dipole, both axial and equatorial fields vary as 1/r31/r^3.
- At the same distance,

$$E_{axial} = 2E_{equatorial}$$

- Torque is maximum at 90^0 and zero at 0^0 and 180^0.

Common Mistakes

- Drawing the dipole moment from positive to negative.
- Using $1/r^2$ instead of $1/r^3$for the field of a short dipole.
- Confusing net force with torque in a uniform electric field.
- Forgetting the direction of the equatorial field.

Part –5: Electric Flux, Area Vector & Gauss's Law

Learning Objectives

After studying this part, students will be able to:

- Define electric flux.
- Understand the concept of an area vector.
- Calculate electric flux through a plane surface.
- State and explain Gauss's Law.
- Apply Gauss's Law to symmetric charge distributions.
- Solve Board, NEET, and JEE level numerical problems.

---

1. Electric Flux

Definition

Electric Flux through a surface is the measure of the electric field passing through that surface and it mathematically defined by the surface integral of electric field over the surface,
Field line diagram provides a qualitative visualization of electric flux.
It represents the number of electric field lines crossing a surface.
Flux is a **scalar quantity**.

---

2. Concept of Area Vector

For every plane surface, an **Area Vector** is defined.

Definition

The area vector is a vector whose:

- Magnitude = Area of the surface
- Direction = Normal (perpendicular) to the surface

Symbol:

$$\vec{A}$$

Magnitude:

$$A = |\vec{A}|$$

---

3. Electric Flux Through a Plane Surface

Consider

- Electric field = $\vec{E}$
- Area vector = $\vec{A}$
- Angle between them = θ

Electric Flux is given by

$$\boxed{\varphi = \vec{E} \cdot \vec{A}}$$

Or

$$\boxed{\varphi = EA\cos\theta}$$

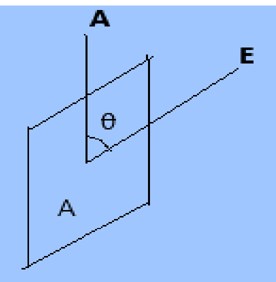


Figure-12: Electric Flux through a Plane Surface

SI Unit

$$\boxed{Nm^2C^{-1}}$$

Cases of Electric Flux

Case 1

Electric field perpendicular to the surface, $\theta = 0^0$

$$\varphi = \varphi_{max} = EA$$

Maximum flux.

Case 2

Electric field parallel to the surface, $\theta = 90^0$,

$$\varphi = 0$$

No field lines cross the surface.

Case 3

Electric field opposite to the area vector, $\theta=180^0$,

$$\varphi = -EA$$

Flux is negative.

---

4. Closed Surface

A **closed surface** completely encloses a volume.

Examples:

- Sphere
- Cube
- Cylinder with both ends closed

The area vector of a closed surface is always directed **outward**.

---

5. Electric Flux Through a Closed Surface

For a closed surface,

$$\varphi_E = \oint \vec{E} \cdot d\vec{A}$$

The symbol

$$\oint$$

indicates integration over a **closed surface**.

---

6. Gauss's Law

Statement

The total electric flux through any closed surface is equal to $1/\epsilon_0$ times the total charge enclosed within that surface.

Mathematical Form

$$\boxed{\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0}}$$

Where

- $Q_{enclosed}$ = Net charge enclosed
- ϵ_0= Permittivity of free space

---

7. Significance of Gauss's Law

Gauss's Law enables the calculation of electric fields for highly symmetric charge distributions without directly applying Coulomb's Law.
It is especially useful for:

- Spherical symmetry
- Cylindrical symmetry
- Planar symmetry

---

8. Important Points

Charge Outside the Surface

A charge located outside a closed surface contributes **zero net electric flux** through that surface. Although its field lines may enter and leave the surface, the net flux remains zero.

Net Enclosed Charge

If the algebraic sum of charges inside a closed surface is zero,

$$Q_{enclosed} = 0$$

then

$$\varphi_E = 0$$

This does **not** necessarily mean that the electric field is zero everywhere on the surface.

---

9. Applications of Gauss's Law

Gauss's Law is used to determine the electric field due to:

- Infinitely long straight charged wire
- Infinite plane sheet of charge
- Uniformly charged spherical shell
- Uniformly charged solid sphere

These applications are discussed in the next part.

Solved Example 1

A uniform electric field of 200 NC^{-1} acts normally on a square plate of side 0.20 m. Find the electric flux.

Given

E=200 NC^{-1}, Side = 0.20 m, Area A A=$(0.20)^2$ = 0.04 m
Since

$$\theta = 0^0$$

Flux

$$\varphi = EA\cos\theta$$

Or

$$\varphi = 200 \times 0.04 \times \cos 0^0 = 8 \times 1 = 8\,Vm$$

Answer

$$\boxed{8\,Vm}$$

Solved Example 2

A closed surface encloses a charge of 6 μC. Find the total electric flux through the surface.

Given

$Q = 6\times10^{-6}C$

Using Gauss's Law,

$$\varphi = \frac{Q_{enclosed}}{\epsilon_0}$$

Or

$$\varphi = \frac{6\times 10}{8.854\times 10^{-12}} = 6.78\times 10^5 Nm^2C^{-1}$$

Exam Tips

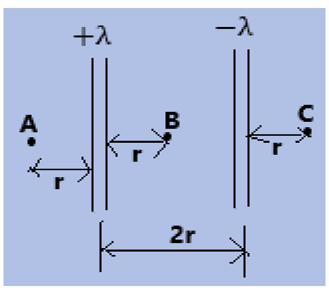
- Electric flux is a **scalar quantity**.
- Area vector is always perpendicular to the surface.
- For a closed surface, use the outward normal convention.
- Only the **enclosed charge** appears in Gauss's Law.

Common Mistakes

- Confusing electric field with electric flux.
- Using the total nearby charge instead of the enclosed charge.
- Taking the area vector parallel to the surface.
- Assuming zero flux implies zero electric field.

Try Yourself

2. Find the net electric field at point A, B and C of two - long line charge separated by distance 2 r and kept in air. The linear charge densities on line charge -1 and on line charge-2 are $+\lambda$ and $-\lambda$ respectively.



3. A square surface of side 10 cm placed in z-x plane. The electric field $\vec{E} = (3\hat{\imath} + 4\hat{\jmath})\times 10^3$ N/C exists in the region. Find the net flux passing through the square surface.
4. Two dipoles each p, are placed in x-direction and y-direction. The magnitude of electric field in x-direction is E. What is the torque acting on the dipole?

Part – 6: Applications of Gauss's Law

Learning Objectives

After studying this part, students will be able to:

- Apply Gauss's Law to highly symmetric charge distributions.
- Derive the electric field due to:
  - An infinitely long straight line charge
  - An infinite plane sheet of charge
  - A uniformly charged spherical shell
  - A uniformly charged solid sphere
- Solve Board, NEET, and JEE-level problems based on Gauss's Law.

---

1. Electric Field Due to an Infinitely Long Straight Line Charge

Principle

For an infinitely long uniformly charged wire, the electric field has **cylindrical symmetry**.
Choose a **cylindrical Gaussian surface** of radius r and length L.

Assumptions

- Uniform linear charge density = λ
- Infinite length
- Electric field is radial.
- Magnitude of electric field is constant over the curved surface.

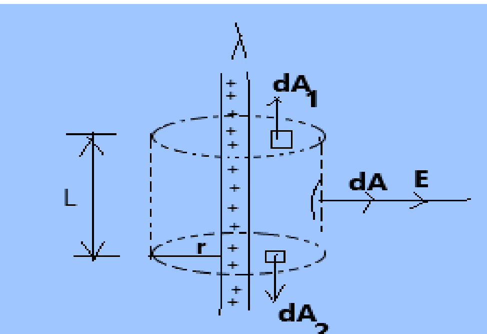


Figure -13: Cylindrical Gaussian Surface Around a Long Charged Wire

---

Derivation-4: To derive the electric field due to an infinite line charge at distance r from it Using Gauss's law.

Let length of Gaussian cylindrical surface is L. For the two flat end faces, the area vectors are perpendicular to the electric field, so the flux through them is zero. On the curved surfaces, it is parallel to the electric field.

The area vector $d\vec{A}_1$and $d\vec{A}_2$ makes 90^0 with the electric field, hence, flux is zero.

Charge enclosed,

$$Q = \lambda L - - - (1)$$

Curved surface area,
$A = 2\pi rL - - - (2)$
Using Gauss's Law,

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0} - - - (3)$$

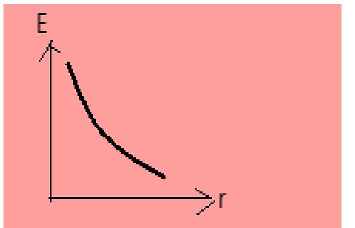


Figure-13(1): Graph between E and r for infinite line charge

Since the electric field is constant over the curved surface,
From equations (1), (2) and (3), we have

$$EA = \frac{\lambda L}{\epsilon_0} - - - - - - (4)$$

Therefore,

$$E = \frac{\lambda L}{2\pi\epsilon_0 rL} = \frac{\lambda}{2\pi\epsilon_0 r} - - - (5)$$

Final Result

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

Observation

- Electric field decreases as

$$E \propto \frac{1}{r}$$

Unlike a point charge, it does **not** follow the inverse square law.

---

2. Electric Field Due to an Infinite Plane Sheet of Charge

Principle

For an infinite plane sheet, the electric field is **uniform** and perpendicular to the sheet.
Choose a **cylindrical Gaussian pillbox**.

Assumptions

Surface charge density, σ

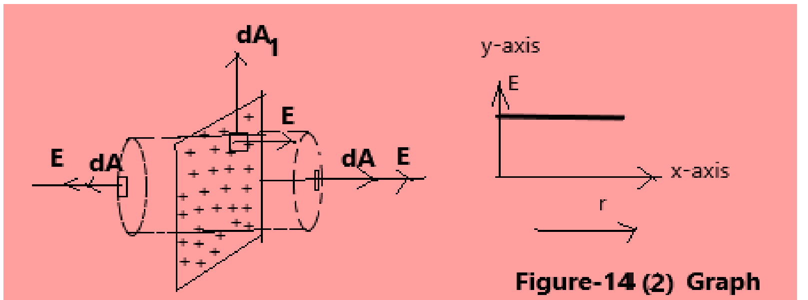


Figure-14 (1) Gaussian Pillbox Through a Infinite Plane Sheet

Figure-14 (2) Graph between E and r

Derivation-5

Charge enclosed,

$$Q = \sigma A$$

Using Gauss's law

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0} --- (1)$$

Flux passes through both flat faces

Hence,

$$2EA = \frac{\sigma A}{\epsilon_0} ----(2)$$

Or

$$E = \frac{\sigma}{2\epsilon_0} --- (3)$$

Final Result

$$\boxed{E = \frac{\sigma}{2\epsilon_0}}$$

Observation

The electric field is **independent of distance** from the sheet.

---

3. Electric Field Due to a Uniformly Charged Spherical Shell

Let radius of shell = R

Charge enclosed = Q

Gaussian surface area A = $4\pi r^2$

(A) Outside the Shell

Choose a spherical Gaussian surface of radius r > R

Using Gauss's Law,

$$EA = \frac{Q_{enclosed}}{\epsilon_0} --- (1)$$

Or

$$E = \frac{Q}{4\pi\epsilon_0 r^2} --- (2)$$

Hence,

$$\boxed{E_{outside} = \frac{1}{4\pi\epsilon_0}\left(\frac{Q}{r^2}\right)}$$

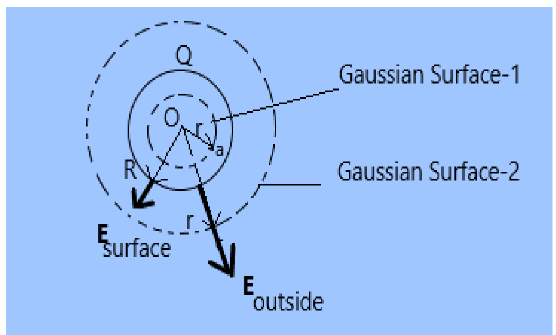


Figure-15(1) Electric Field due to a Spherical shell

The shell behaves exactly like a point charge placed at its centre.

(B) On the Surface

At r = R

From equation (1)

$$\boxed{E_{surface} = \frac{1}{4\pi\epsilon_0}\left(\frac{Q}{R^2}\right)}$$

Maximum electric field

(C) Inside the Shell

For r < R, at point a.
Enclosed charge

$$Q = 0$$

Therefore,

$$E = 0$$

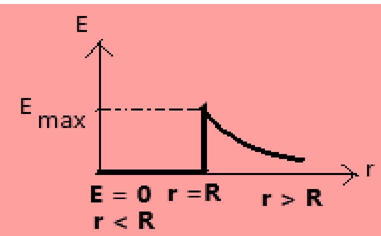


Figure-15(2): Graph between E and r in spherical shell

Important Result

Inside a charged spherical shell,

$$\boxed{E_{inside} = 0}$$

This is one of the most important Board and NEET questions.

---

4. Electric Field Due to a Uniformly Charged Solid Sphere (Extra/Competitive Exam Enrichment-Not required for CBSE Board 2026-27)

Radius = R
Total charge = Q

(A) Outside the Sphere

Exactly the same as a point charge.

$$E_{outside} = \frac{1}{4\pi\epsilon_0}\left(\frac{Q}{r^2}\right)$$

(B) Inside the Sphere

Suppose r < R
Charge enclosed,

$$Q_r = Q\frac{r^3}{R^3}$$

Using Gauss's Law,

$$E(4\pi r^2) = \frac{Q_r}{\epsilon_0} = Q\frac{r^3}{\epsilon_0 R^3}$$

Hence,

$$\boxed{E_{inside} = \frac{1}{4\pi\epsilon_0}\left(\frac{rQ}{R^3}\right)}$$

Observation

Inside a uniformly charged solid sphere,

$$E \propto r$$

The electric field increases linearly from the centre to the surface.

Comparison Table

Charge Distribution	Electric Field
Point Charge	$E \propto 1/r^2$
Dipole	$E \propto 1/r^3$
Quadrupole	$E \propto 1/r^4$
Infinite Line Charge	$E \propto 1/r$
Infinite Plane Sheet	Constant
Spherical Shell (Inside)	Zero
Solid Sphere (Inside)	$E \propto r$

Solved Example

A uniformly charged spherical shell has radius 0.20 m and charge 8×10^{-6} C. Find the electric field:

(i) At the centre

(ii) On the surface

Solution

At centre,

$$E = 0$$

On surface,

$$E = \frac{kQ}{r^2}$$

Or

$$E = 9 \times 10^9 \times \frac{8 \times 10^{-6}}{0.04} = 1.8 \times 10^5\ N/C$$

Exam Tips

- Always choose the Gaussian surface according to the symmetry.
- Write the enclosed charge first.
- Mention why the electric field is constant over the chosen Gaussian surface.
- Learn all four final formulae thoroughly.

Common Mistakes

- Using Coulomb's Law instead of Gauss's Law in highly symmetric problems.
- Forgetting that E = 0 inside a charged spherical shell.
- Confusing the results for a spherical shell and a solid sphere.
- Choosing an incorrect Gaussian surface.

Appendix – A

1. Important SI Units

Quantity	SI Unit
Charge	Coulomb (C)
Electric Field	N C^{-1} or Vm^{-1}
Electric Flux	N m^2 C^{-1} or Vm
Dipole Moment	C m
Surface Charge Density	C m^{-2}
Linear Charge Density	C m^{-1}

2. Frequently Asked Board Questions

1. State Coulomb's Law and write its mathematical expression.
2. Define electric field intensity.
3. What is an electric dipole?
4. Define electric dipole moment.
5. Derive the electric field at the axial position of a short dipole.
6. Derive the electric field at the equatorial position of a short dipole.
7. State and explain Gauss's Law.
8. Derive the electric field due to an infinite line charge.
9. Derive the electric field due to an infinite plane sheet of charge.
10. Explain why the electric field inside a uniformly charged spherical shell is zero.

3. Quick Memory Tips

- Like charges **Repel**; unlike charges **Attract**.
- Electric field points **away** from positive charges and **towards** negative charges.
- Dipole moment points from **negative** to **positive**.
- Eaxial=2Eequatorial
- Inside a charged spherical shell, **Electric Field = 0**.
- For an infinite plane sheet, the electric field is **independent of distance**.
- Always choose the Gaussian surface according to the symmetry of the problem.

4. Last-Minute Revision Checklist

☐ Properties of electric charge
☐ Coulomb's Law
☐ Electric field and field lines
☐ Electric dipole and dipole moment
☐ Axial and equatorial field derivations
☐ Torque on a dipole
☐ Electric flux
☐ Gauss's Law
☐ Applications of Gauss's Law
☐ Important formulae and SI units

Challenge Question (HOTS)

A Gaussian surface encloses three charges: +3 μC, −5 μC, and +4 μC. What is the total electric flux through the surface?
Hint: Use the net enclosed charge in Gauss's law.

Appendix – B: Assertion–Reason, Case Study & Competency-Based Questions

Section A : Assertion–Reason Questions

Directions

Choose the correct option:
A. Both Assertion (A) and Reason (R) are true, and R is the correct explanation of A.
B. Both A and R are true, but R is not the correct explanation of A.
C. A is true, but R is false.
D. A is false, but R is true.

Q1

Assertion (A):
Electric field lines never intersect each other.
Reason (R):
The electric field at a point has a unique direction.

Q2

Assertion (A):
The electric field inside a uniformly charged spherical shell is zero.
Reason (R):
The net enclosed charge inside any Gaussian surface drawn within the shell is zero.

Q3

Assertion (A):
The electric field due to an infinite plane sheet of charge is independent of distance.
Reason (R):
The electric field due to an infinite plane sheet follows the inverse square law.

Q4

Assertion (A):
The electric dipole moment is directed from the negative charge to the positive charge.
Reason (R):
The dipole moment is a vector quantity.

Q5

Assertion (A):
The torque on an electric dipole is zero when it is parallel to a uniform electric field.
Reason (R):
The angle between the dipole moment and the electric field is 0^0, making $\sin\theta = 0$.

Section B: Case Study Questions

Case Study – 1 : Electric Dipole

Two equal and opposite charges are separated by a small fixed distance, forming an electric dipole. The dipole is placed in a uniform electric field.

Answer the following questions:

(i) What is the direction of the electric dipole moment?
A. Positive to Negative
B. Negative to Positive
C. Perpendicular to the dipole axis
D. Towards the centre

(ii) The net force on the dipole in a uniform electric field is:
A. Maximum
B. Zero
C. Infinite
D. Equal to pE

(iii) The torque on the dipole is maximum when:
A. 0^0
B. 30^0
C. 60^0
D. 90^0

Case Study – 2: Gaussian Surface

A closed spherical Gaussian surface encloses three charges:
+2 μC, $-5\mu C$ and +6 μC
Another positive charge is placed outside the surface.

Answer the following:

(i) The enclosed charge is:
A. 1 μC
B. 2 μC
C. 3 μC
D. 5 μC

(ii) The outside charge contributes to the net electric flux through the closed surface:
A. Completely
B. Partially
C. Not at all
D. Depends on the distance

(iii) Which law is directly used to calculate the electric flux?
A. Ohm's Law
B. Faraday's Law
C. Gauss's Law
D. Newton's Law

Section C: Competency-Based Questions

Q1

Why is a Gaussian surface chosen according to the symmetry of the charge distribution rather than its physical shape?

Q2
Why is the electric field inside a uniformly charged spherical shell zero, even though charges are present on the shell?

Q3
A student states that electric flux becomes zero whenever the electric field is zero. Is this statement always true? Justify your answer with an example.

Q4
Two equal positive charges are brought closer together. How does the electrostatic force between them change? Explain using Coulomb's law.

Q5
Why is the electric field inside a conductor in electrostatic equilibrium equal to zero?

Section D: HOTS (Higher Order Thinking Skills)

Q1
Two Gaussian surfaces of different shapes enclose the same point charge.
Will the electric flux through both surfaces be the same? Explain.

Q2
Can the electric field be zero at a point where the electric potential is not zero? Explain with an example.

Q3
An electric dipole is placed in a uniform electric field.
Why does it rotate but not translate?

Q4
Why does the electric field due to an infinite line charge vary as $1/r$, whereas the field due to a point charge varies as $1/r^2$?

Q5
Explain why electric field lines are always perpendicular to the surface of a charged conductor in electrostatic equilibrium.

Answer Key

Assertion–Reason

Question	Answer
1	A
2	A
3	C
4	B
5	A

Case Study – 1

(i) **B**
(ii) **B**
(iii) **D**

Case Study – 2

(i) **C** (+2−5+6=+3 μC
(ii) **C**
(iii) **C**

Teacher's Tip

Students should remember the following concepts very clearly:

- **Electric Field** → Vector quantity
- **Electric Flux** → Scalar quantity
- **Electric Dipole Moment** → From negative to positive
- **Only enclosed charge contributes to electric flux**
- **Net force on a dipole in a uniform electric field is zero, but torque may act**
- **Inside a charged spherical shell, the electric field is zero**
- **Inside a conductor in electrostatic equilibrium, the electric field is zero**

Appendix – C: Numerical Problems (Basic to Advanced)

Instructions

- Use:
  - $k = 9\times10^{9}$ N m^{2} C^{-2}
  - $\varepsilon_0 = 8.854\times10{-}12$ C^{2} N^{-1} m^{2}
- Answers are provided at the end.
- Difficulty Level:
  - ★ Basic
  - ★★ Moderate
  - ★★★ Advanced

Section A : Basic Numerical (Board Level)

Q1. ★

Two point charges of +2 μC and +4 μC are placed 0.30 m apart. Calculate the electrostatic force between them.

Q2. ★

Find the electric field intensity at a point 0.50 m from a point charge of 5 μC..

Q3. ★

An electric dipole has charges ±3 μC separated by 8 cm. Calculate its electric dipole moment.

Q4. ★

A uniform electric field of 400 N C^{-1} acts normally on a square plate of side 20 cm. Calculate the electric flux through the plate.

Q5. ★★

A closed surface encloses a charge of 8 μC. Find the total electric flux through the surface.

Section B : Intermediate Numerical (NEET Level)

Q6. ★★

A short electric dipole has a dipole moment of 6×10^{-8} C m. Find the electric field at an axial point 0.20 m from its centre.

Q7. ★★

Find the electric field at an equatorial point 0.20 m from the centre of the dipole in Question 6.

Q8. ★★

An electric dipole of moment 5×10^{-8} C m is placed in a uniform electric field of 2×10^{5} N C^{-1} at an angle of 60^{0}. Calculate the torque acting on it.

Q9. ★★
A uniformly charged spherical shell has a radius of 15 cm and a total charge of 4 μC. Calculate the electric field:
(a) At the centre
(b) On the surface

Q10. ★★★
A line charge has a linear charge density of 4×10^{-6} C m^{-1}. Calculate the electric field at a distance of 10 cm.

Section C : Advanced Numerical (JEE Main Level)

Q11. ★★★
An infinite plane sheet has a surface charge density of 5×10^{-6} C m^{-2}. Calculate the electric field near the sheet.

Q12. ★★★
A uniformly charged solid sphere has radius 0.20 m and total charge 8 μC. Find the electric field at a point 0.10 m from its centre.

Q13. ★★★
Two equal positive charges of 4 μC are fixed 40 cm apart. Determine the electric field at the midpoint.

Q14. ★★★
Three charges +2 μC, −3 μC, and +5 μC are enclosed within a Gaussian surface. Calculate the total electric flux through the surface.

Q15. ★★★
An electric dipole is placed perpendicular to a uniform electric field of 8×10^{4} NC^{-1}. If the dipole moment is 2×10^{-7} C m^{2}, calculate the maximum torque.

Answer Key

Q. No.	Answer
1	0.8 N
2	1.8×10^{5} N C^{-1}
3	2.4×10^{-7} C m^{2}
4	16 N m^{2} C^{-1}
5	9.04×10^{5} N m^{2} C^{-1}
6	1.35×10^{5} N C^{-1}
7	6.75×10^{4} N C^{-1}
8	8.66×10^{-3} N m
9(a)	0

Q. No.	Answer
9(b)	1.6×10^{6} N C^{-1}
10	7.2×10^{5} N C^{-1}
11	2.82×10^{5} N C^{-1}
12	4.5×10^{5} N C^{-1}
13	0
14	4.52×10^{5} N m2 C^{-1}
15	1.6×10^{-2} N m

Exam Tips

- Always convert **μC to C** and **cm to m** before calculation.
- Write the formula first, then substitute values with proper SI units.
- Keep **3 significant figures** unless instructed otherwise.
- In Board examinations, include the **SI unit** in the final answer to obtain full marks.

For CBSE Board/ Other Boards/NEET/IIT exam Point of View,

Solve Also Numerical based on

a) Electric Flux in Cube and Cylinder
b) Electric Field and Electric Force
c) Charging by Conduction method
d) Dipole, and
e) Gauss's law