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Introduction

Static Electricity

- Electric shock sensation occurs due to discharge of static electric charges through the body.
- Static electricity is generated by accumulation of electric charges on surfaces.
- Electrostatics studies forces, fields, and potentials from static charges.

Solved Examples

- **Ex 1:** Why do we feel a shock when touching a car door after sliding on a bus seat?
  Step 1: Sliding causes charge accumulation on body.
  Step 2: Touching metal door discharges static electricity.
  Step 3: Discharge causes shock sensation.

Practice Set

- **Q1:** What causes the sensation of electric shock when touching a metal object after sliding on a seat?
  A. Current flow
  B. Discharge of static electricity
  C. Magnetic field
  D. Heat generation
- **Q2:** Electrostatics primarily deals with:
  A. Moving charges
  B. Static charges
  C. Magnetic fields
  D. Electric currents
- **Q3:** Which of the following is NOT related to static electricity?
  A. Charge accumulation
  B. Electric discharge
  C. Electric current
  D. Electrostatic force

Answer Key

- **Q1:** B - Shock is due to discharge of static electric charges.
- **Q2:** B - Electrostatics studies static charges and their effects.
- **Q3:** C - Electric current involves moving charges, not static electricity.

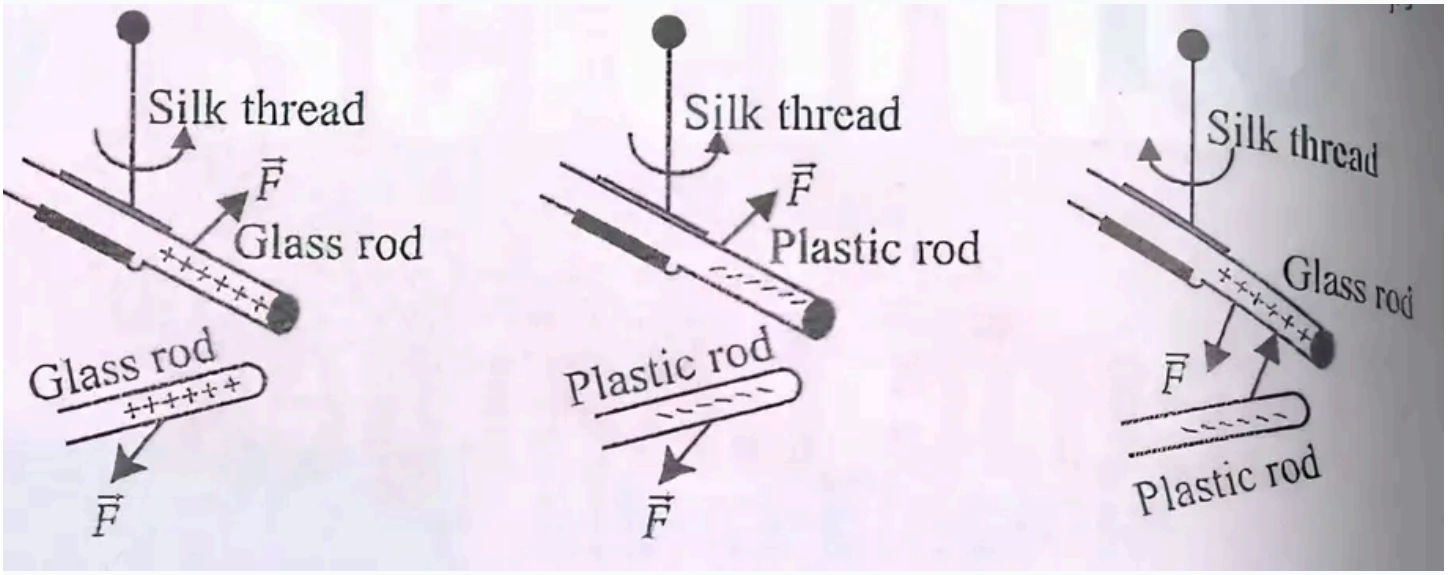
Memory Aids

- Static electricity = charges at rest.
- Shock = sudden discharge of static charge.
- Electrostatics = study of static charges and forces.

Electric Charge

Types and Properties

- Neutral body becomes charged by gaining or losing electrons.
- Two types of charges: positive (+) and negative (−).
- Losing electrons → positive charge; gaining electrons → negative charge.
- Like charges repel; unlike charges attract.
- Glass rod or cat's fur rubbed with silk → positive charge.
- Plastic rod or silk rubbed → negative charge.
- Charged object = electrified; no net charge = neutral.
- Gold-leaf electroscope detects presence and type of charge.



Solved Examples

- **Ex 1:** Identify charge types on rods:
  Step 1: Glass rod rubbed with silk → positive charge.
  Step 2: Plastic rod rubbed with silk → negative charge.
  Step 3: Like charges repel; unlike charges attract.

Practice Set

- **Q1:** What happens when a neutral object loses electrons?
  A. Becomes negatively charged
  B. Becomes positively charged
  C. Remains neutral
  D. Becomes magnetic
- **Q2:** Which pair of charges will repel each other?
  A. Positive and negative
  B. Positive and positive
  C. Negative and positive
  D. Neutral and positive
- **Q3:** What device is used to detect electric charge?
  A. Ammeter
  B. Voltmeter
  C. Gold-leaf electroscope
  D. Galvanometer

Answer Key

- **Q1:** B - Losing electrons makes object positively charged.
- **Q2:** B - Like charges (positive-positive) repel each other.
- **Q3:** C - Gold-leaf electroscope detects electric charge.

Memory Aids

- Positive charge = loss of electrons.
- Negative charge = gain of electrons.
- Like charges repel; unlike charges attract.
- Gold-leaf electroscope detects charge.

Conductors and Insulators

Properties of Conductors

- Allow electric current to pass easily due to free electrons.
- Examples: Metals (copper, aluminum), human and animal bodies, earth.
- Charge distributes uniformly over the surface when transferred.

Properties of Insulators

- Offer high resistance to electric current.
- Examples: Glass, porcelain, plastic, nylon, wood.
- Charge remains localized at the point of contact.

Electric Wiring in Houses

- Three wires: Live, Neutral, Earth.
- Live and Neutral carry current from power station.
- Earth wire connected to ground for safety.
- Metallic parts of appliances connected to earth wire to discharge extra charge safely.

Solved Examples

- **Ex 1:** Charge distribution on a conductor
  - Given charge Q on conductor.
  - Charge spreads uniformly on surface.
  - Surface charge density $\sigma = \frac{Q}{A}$, where A is surface area.
- **Ex 2:** Identifying conductor or insulator
  - Material allows current easily → Conductor.
  - Material resists current → Insulator.

Practice Set

- Q1: Which of the following is a good conductor?
  - A. Glass

    - B. Copper
    - C. Plastic
    - D. Wood
- Q2: What happens to charge on an insulator when charged?
    - A. Spreads over surface
    - B. Moves freely inside
    - C. Remains localized
    - D. Flows to earth
- Q3: In household wiring, the earth wire is used to:
    - A. Carry current to appliances
    - B. Connect live and neutral wires
    - C. Discharge extra charge safely to ground
    - D. Increase resistance

Answer Key

- Q1: B - Copper is a metal and a good conductor of electricity.
- Q2: C - Charge on insulators remains localized and does not spread.
- Q3: C - Earth wire safely discharges extra charge to the ground to prevent shocks.

Memory Aids

- Conductors: "Free electrons flow" → easy current flow.
- Insulators: "Charge stays put" → no free electron movement.
- Earth wire: "Safety path" for extra charge.

Basic Properties of Electric Charge

Addition of Charges

- Total charge in a system with discrete charges $q_1, q_2, q_3, \ldots, q_n$ is $q = q_1 + q_2 + q_3 + \ldots + q_n$.

Conservation of Charge

- Total charge in an isolated system remains constant.

- Charge can neither be created nor destroyed, only transferred.

Quantisation of Charge

- Charge is quantised: $Q = \pm ne$, where $n = 1, 2, 3, \ldots$ and $e = 1.6 \times 10^{-19}$ C (charge of one electron).
- 1 Coulomb charge contains approximately 6×10^{18} electrons.

Solved Examples

Ex 1: Find total charge if a system has charges 2×10^{-6} C, -3×10^{-6} C, and 5×10^{-6} C.

- Total charge $q = 2 \times 10^{-6} - 3 \times 10^{-6} + 5 \times 10^{-6} = 4 \times 10^{-6}$ C.

Ex 2: Calculate number of electrons in 3 C charge.

- Number of electrons $= \frac{3}{1.6 \times 10^{-19}} \approx 1.875 \times 10^{19}$.

Practice Set

Q1: What is the total charge of charges $1\mu C, -2\mu C, 3\mu C$?
A) $2\mu C$ B) $6\mu C$ C) $1\mu C$ D) \(0 \mu C\>

Q2: Which statement is true about charge conservation?
A) Charge can be created
B) Charge can be destroyed
C) Total charge in isolated system is constant
D) Charge is not quantised

Q3: If $Q = 4.8 \times 10^{-19}$ C, what is n in $Q = ne$?
A) 2 B) 3 C) 4 D) 5

Answer Key

Q1: A) $2\mu C$ - Sum of charges: $1 - 2 + 3 = 2\mu C$.

Q2: C) Total charge in isolated system is constant - Conservation law states charge is neither created nor destroyed.

Q3: B) 3 - $n = \frac{Q}{e} = \frac{4.8 \times 10^{-19}}{1.6 \times 10^{-19}} = 3$.

Memory Aids

- Charge addition: Sum all charges algebraically.
- Conservation: Charge constant in isolated system.
- Quantisation: Charge = integer × electron charge.

Coulomb's Law

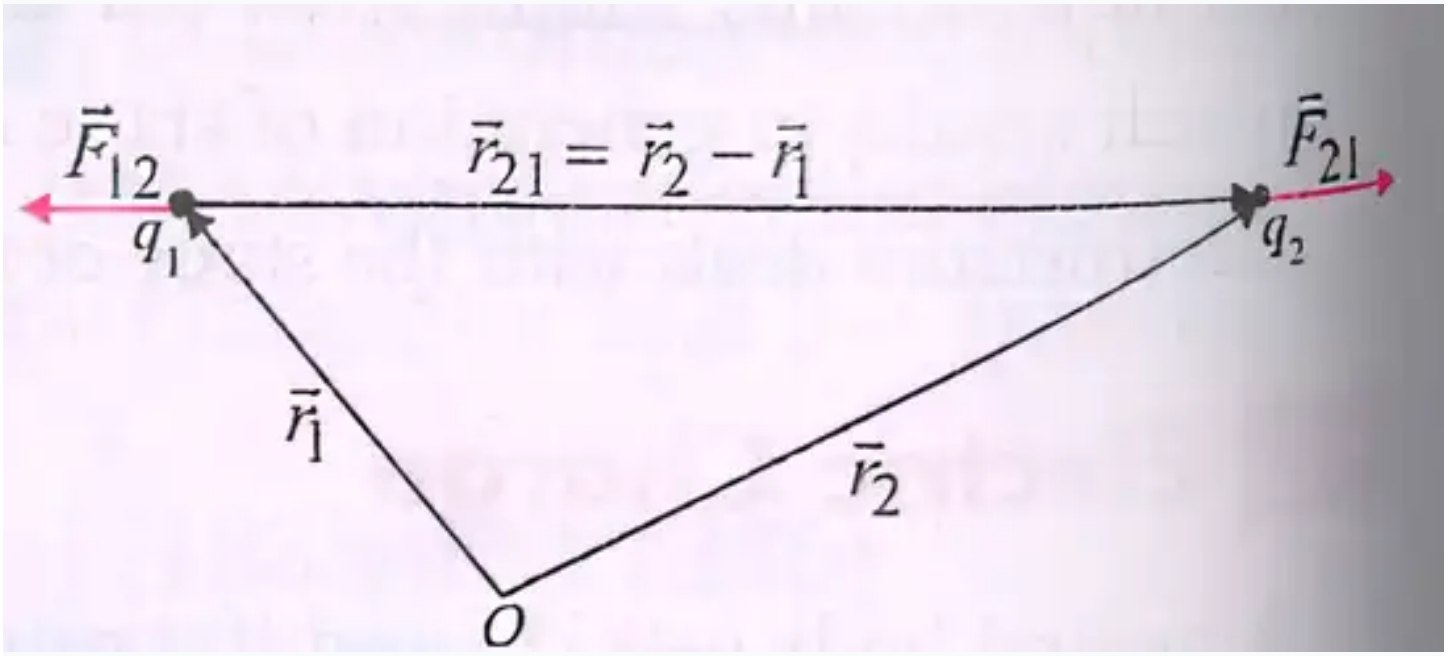
Fundamental Concept

- Force between two point charges q_1 and q_2 separated by distance r in vacuum:
- $$F = k\frac{|q_1 q_2|}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$$
- ϵ_0 = permittivity of free space = $8.854 \times 10^{-12}\ \mathrm{C^2N^{-1}m^{-2}}$
- $k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ \mathrm{Nm^2C^{-2}}$
- Force is attractive if charges are unlike, repulsive if like.

Vector Form

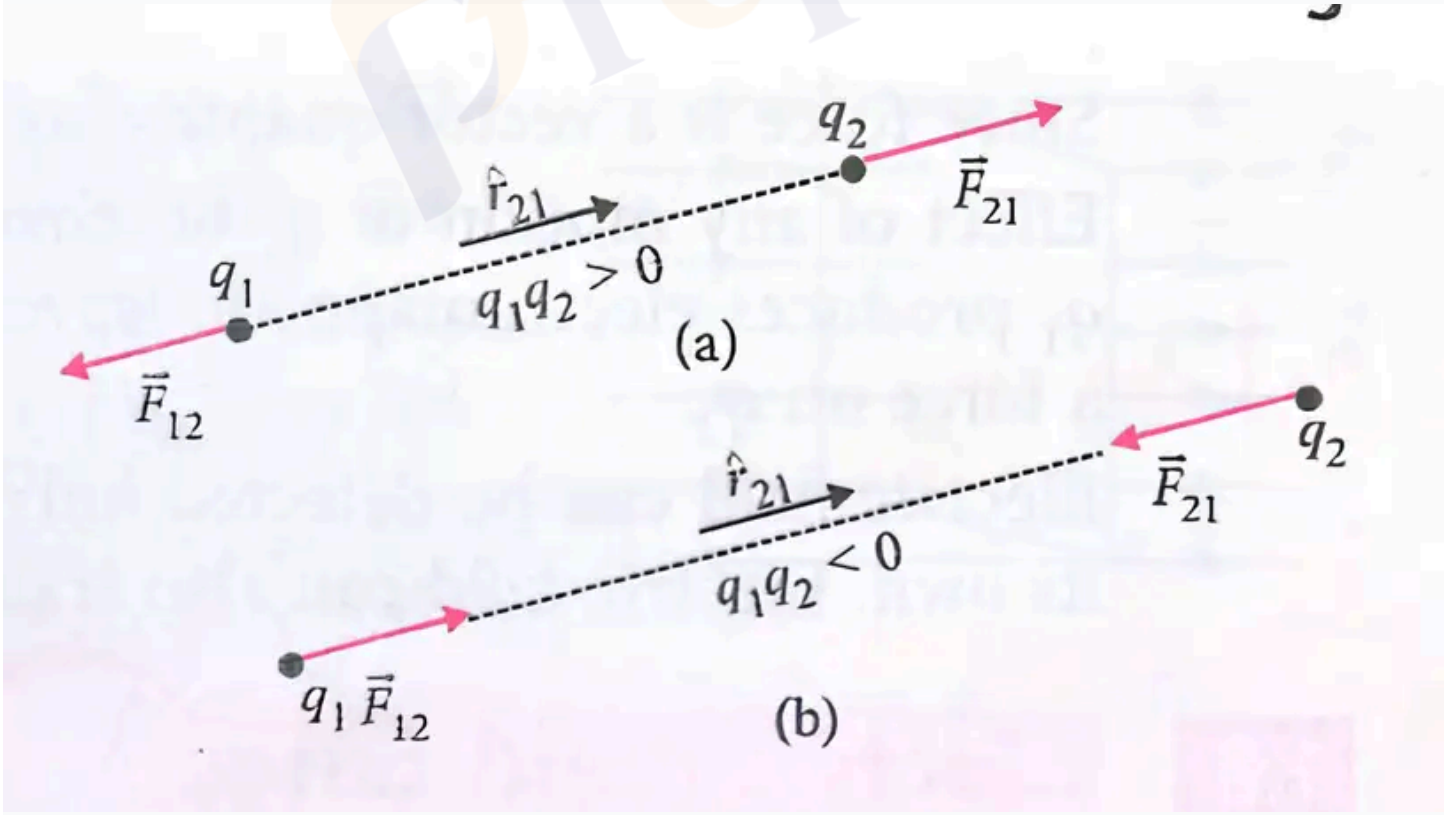
- Force on q_2 due to q_1:
- $$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}_2 - \vec{r}_1|^3}(\vec{r}_2 - \vec{r}_1) = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}_{21}|^2}\hat{r}_{21} = -\vec{F}_{12}$$
- Obeys Newton's third law: forces are equal in magnitude and opposite in direction.

- $\vec{r}_{21} = \vec{r}_2 - \vec{r}_1$ is the vector from q_1 to q_2.



Force Direction for Charges

- For like charges ($q_1 q_2 > 0$), force vectors point away (repulsion).
- For unlike charges ($q_1 q_2 < 0$), force vectors point towards each other (attraction).



Effect of Dielectric Medium

- In a medium with dielectric constant K, force reduces by factor K:
- $$F = \frac{F_0}{K} = \frac{1}{4\pi\epsilon_0 K}\frac{q_1 q_2}{r^2}$$
- F_0 is force in vacuum.

Solved Examples

- **Ex 1:** Calculate force between two charges $2\mu C$ and $3\mu C$ separated by 0.5 m in vacuum.
- Use $F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$
- $F = 9 \times 10^9 \times \frac{2\times10^{-6}\times3\times10^{-6}}{0.5^2} = 216\ \text{N}$

Practice Set

- Q1: Two charges $+1\mu C$ and $+2\mu C$ are 1 m apart. Force magnitude is?
  - A) 18 N
  - B) 9 N
  - C) 36 N
  - D) 0 N
- Q2: If distance between charges is doubled, force becomes?
  - A) Half
  - B) Quarter
  - C) Double
  - D) Four times
- Q3: Two charges $q_1 = 3\mu C$, $q_2 = -3\mu C$ separated by 0.3 m in dielectric medium $K = 3$. Force magnitude?
  - A) 90 N
  - B) 30 N
  - C) 10 N
  - D) 270 N

Answer Key

- Q1: A) 18 N - $F = 9 \times 10^9 \times \frac{1\times10^{-6}\times2\times10^{-6}}{1^2} = 18\ \text{N}$
- Q2: B) Quarter - Force varies as $1/r^2$, doubling r reduces force by 4.

- Q3: C) 10 N - Force in vacuum $= \frac{9\times10^{9}\times3\times10^{-6}\times3\times10^{-6}}{0.3^{2}} = 30\ \text{N}$, in medium $F = 30/3 = 10\ \text{N}$

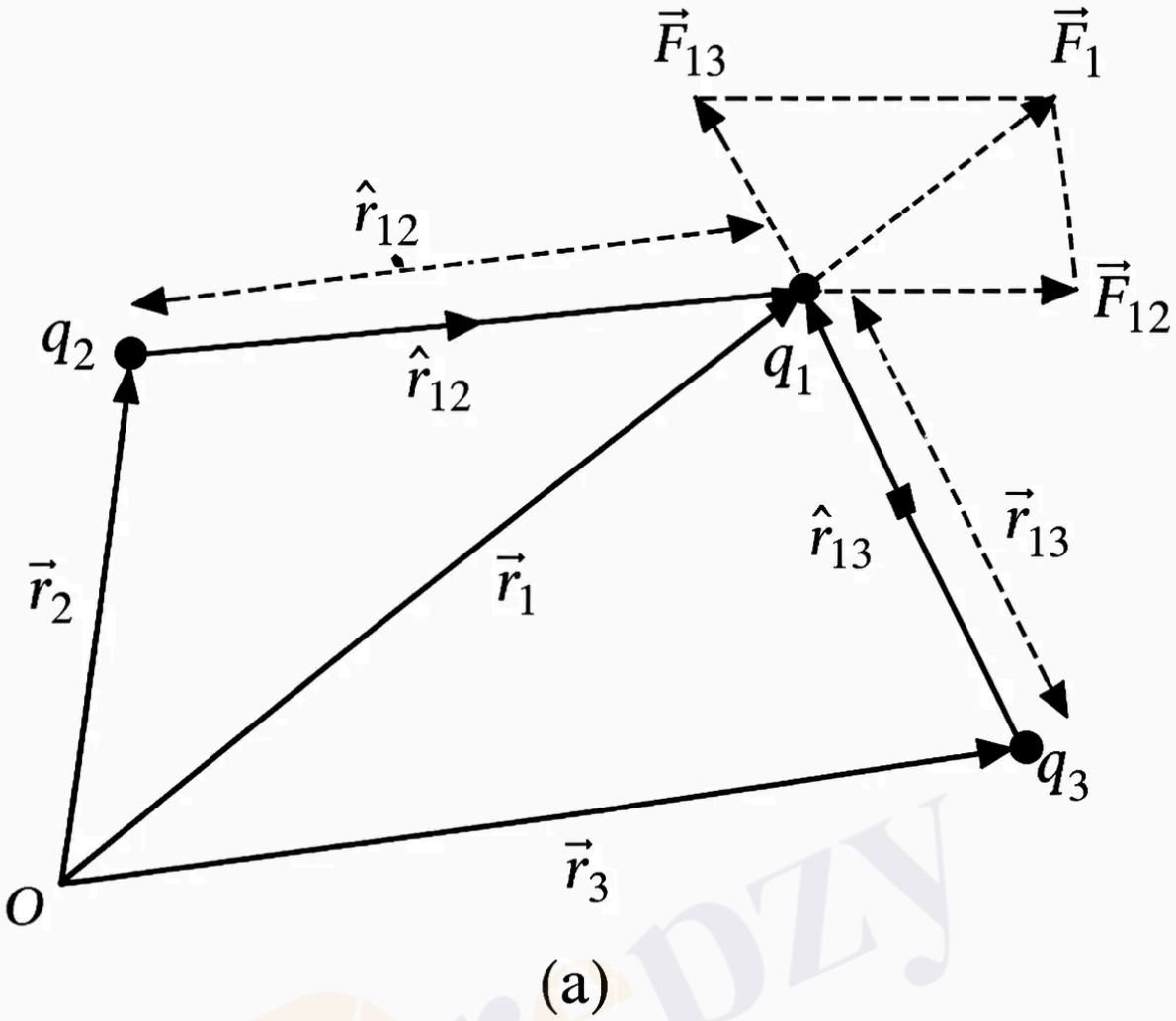
Memory Aids

- Force $F \propto \frac{|q_1 q_2|}{r^2}$
- Like charges repel, unlike attract
- Force in dielectric $= \frac{\text{Force in vacuum}}{K}$
- $k = 9 \times 10^9$, $\epsilon_0 = 8.854 \times 10^{-12}$

Forces between Multiple Charges

Principle of Superposition

- Force on a charge due to multiple charges is the vector sum of individual forces.
- Individual forces remain unaffected by other charges.
- Mathematically, $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \ldots + \vec{F}_{1n}$.
- Each force $\vec{F}_{1i}$ is calculated using Coulomb's law: $\vec{F}_{1i} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_i}{r_{1i}^2}\hat{r}_{1i}$.
- Unit vector $\hat{r}_{1i}$ points from charge q_1 to q_i.



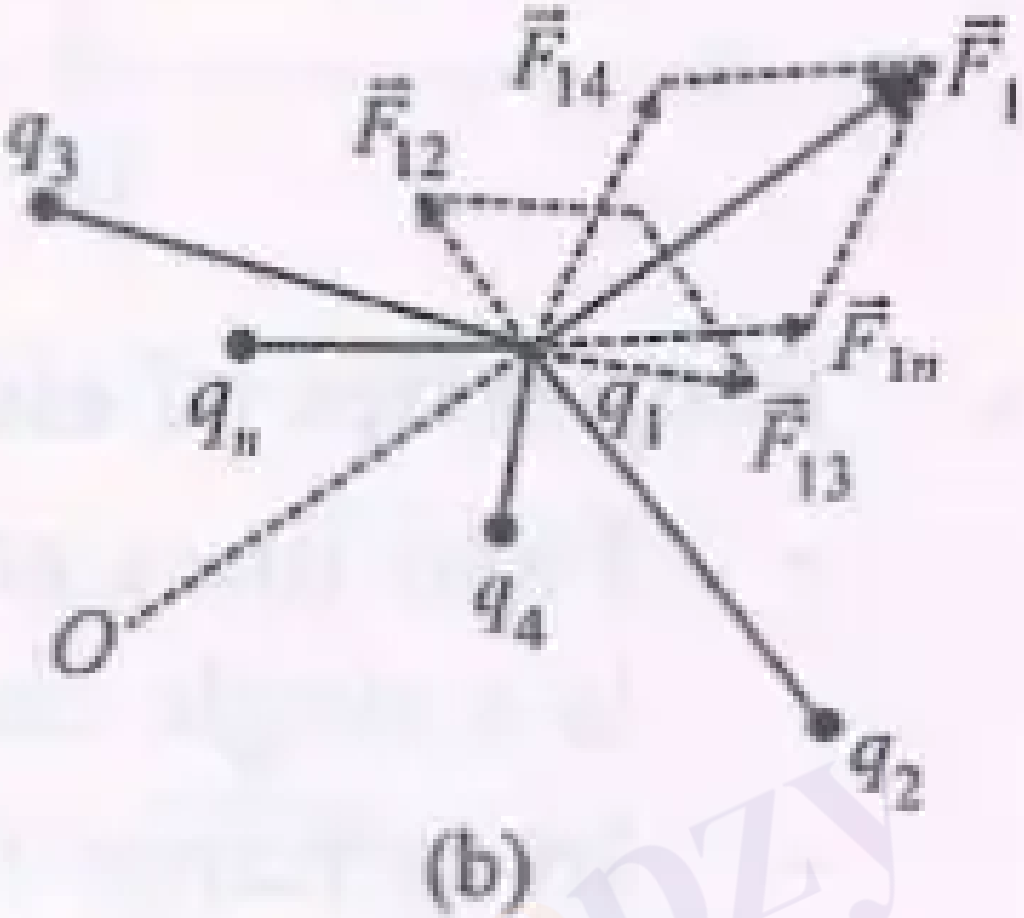
(a)

Vector Addition of Forces

- Charges q_1, q_2, q_3 have position vectors $\vec{r}_1, \vec{r}_2, \vec{r}_3$ from reference point O.
- Vectors $\vec{r}_{12} = \vec{r}_2 - \vec{r}_1$ and $\vec{r}_{13} = \vec{r}_3 - \vec{r}_1$ represent directions and distances.
- Forces $\vec{F}_{12}$ and $\vec{F}_{13}$ act on q_1 due to q_2 and q_3 respectively.
- Total force on q_1 is $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13}$.

Generalization for n Charges

- For n charges, net force on q_1 is sum of forces from all other charges.
- Formula: $\vec{F}_1 = \sum_{i=2}^{n} \vec{F}_{1i} = \frac{1}{4\pi\epsilon_0} \sum_{i=2}^{n} \frac{q_1 q_i}{r_{1i}^2} \hat{r}_{1i}$.
- Each force vector is calculated independently and then summed vectorially.



Electric Field from Multiple Charges

- Electric field at a point due to multiple charges is vector sum of fields from each charge.
- Electric field due to charge q_i at distance r_{1i} is $\vec{E}_{1i} = \frac{1}{4\pi\epsilon_0}\frac{q_i}{r_{1i}^2}\hat{r}_{1i}$.
- Total electric field: $\vec{E} = \sum_{i=1}^{n} \vec{E}_i$.
- Direction given by unit vectors $\hat{r}_{1i}$.

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1q_2}{r_{12}^2}\hat{r}_{12} + \frac{q_1q_3}{r_{13}^2}\hat{r}_{13} + \ldots\ldots + \frac{q_1q_n}{r_{1n}^2}\hat{r}_{1n}\right] = \frac{q_1}{4\pi\varepsilon_0}\sum_{i=2}^{n}\frac{q_i}{r_{1i}^2}\hat{r}_{1i}$$

Solved Examples

Ex 1

- Given charges $q_1 = 2\mu C, q_2 = 3\mu C$ at distance $r_{12} = 0.5m$.
- Calculate force $\vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_{12}^2}\hat{r}_{12}$.
- Use $k = 9 \times 10^9 Nm^2/C^2$, $F = 9 \times 10^9 \times \frac{2\times10^{-6}\times3\times10^{-6}}{0.5^2} = 0.216N$.
- Direction along $\hat{r}_{12}$.

Ex 2

- Three charges q_1, q_2, q_3 at known positions.
- Calculate $\vec{F}_{12}$ and $\vec{F}_{13}$ separately.
- Add vectors to find net force $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13}$.

Practice Set

- Q1: Two charges $+2\mu C$ and $+3\mu C$ are 1 m apart. Force magnitude is?
  - A) 5.4 N
  - B) 6.0 N
  - C) 10.8 N
  - D) 12.0 N
- Q2: If $q_1 = +1\mu C, q_2 = -1\mu C, r = 0.5m$, force is?
  - A) Attractive, 36 N
  - B) Repulsive, 36 N
  - C) Attractive, 18 N
  - D) Repulsive, 18 N
- Q3: Three charges $q_1 = 1\mu C, q_2 = 2\mu C, q_3 = -1\mu C$ at 1 m apart. Net force on q_1 is?
  - A) Zero
  - B) Directed towards q_3
  - C) Directed towards q_2
  - D) Directed away from both

Answer Key

- Q1: C) 10.8 N - Use Coulomb's law: $F = k\frac{q_1 q_2}{r^2} = 9 \times 10^9 \times \frac{2\times10^{-6}\times3\times10^{-6}}{1^2} = 10.8N$.

- Q2: A) Attractive, 36 N - Opposite charges attract; force magnitude calculated similarly.
- Q3: B) Directed towards q_3 - Negative charge q_3 attracts q_1 stronger than q_2 repels due to charge values.

Memory Aids

- Superposition: Add forces vectorially, independent of other charges.
- Coulomb's law: $F = k\frac{q_1 q_2}{r^2}$.
- Unit vector $\hat{r}$ shows force direction.
- Opposite charges attract, like charges repel.

Electric Field

Definition and Formula

- Electric field is the region around a charge where its force is felt by a unit positive test charge.
- Electric field $\vec{E}$ due to a point charge q at position $\vec{r}$:

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{|\vec{r}|^2}\hat{r} = \frac{\vec{F}}{q_0}$$

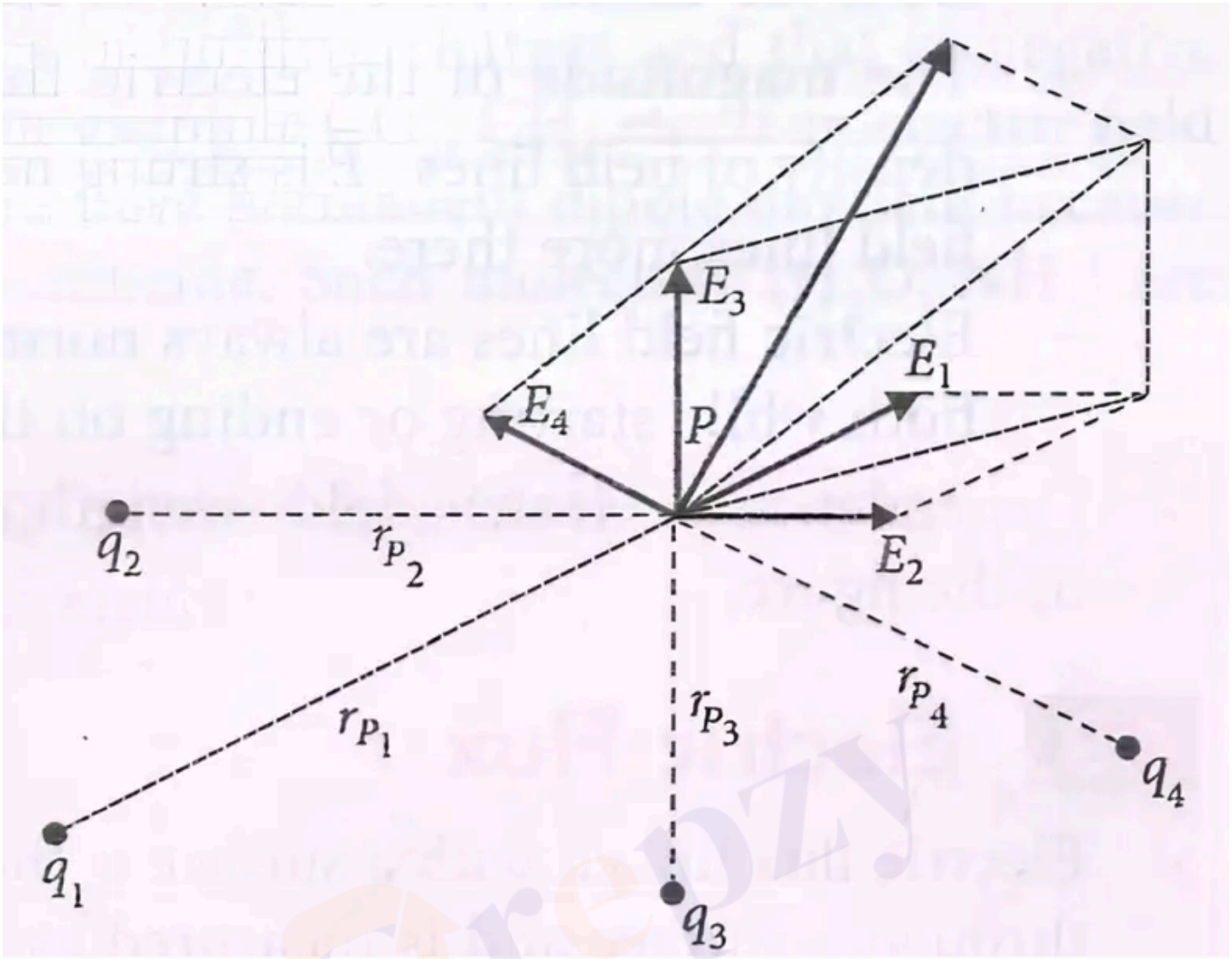
- q_0 is the positive test charge.

Electric Field from Multiple Charges

- Net force on test charge q_0 near charges $q_1, q_2, \ldots, q_n$:
  $\vec{F} = \vec{F}_1 + \vec{F}_2 + \ldots + \vec{F}_n$
- Net electric field at test charge:
  $\vec{E} = \frac{\vec{F}_1}{q_0} + \frac{\vec{F}_2}{q_0} + \ldots + \frac{\vec{F}_n}{q_0} = \vec{E}_1 + \vec{E}_2 + \ldots + \vec{E}_n$
- Formula:

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\epsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i^2}\hat{r}_{p_i}$$

- $\hat{r}_{p_i}$ points from the i^{th} charge to point P.



Physical Significance

- Electric field is a property of the charge system, independent of the test charge.
- Electric field is a vector quantity (like force).
- Changes in electric field propagate at the speed of light due to electromagnetic waves.
- Electric field is detected by forces on charges and can transport energy.

Solved Examples

- **Ex 1:** Calculate electric field at distance $r = 0.5\ \text{m}$ from a point charge $q = 2 \times 10^{-6}\ \text{C}$.
  Step 1: Use formula $E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$
  Step 2: Substitute $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ \text{Nm}^2/\text{C}^2$
  Step 3: $E = 9 \times 10^9 \times \frac{2\times10^{-6}}{(0.5)^2} = 7.2 \times 10^4\ \text{N/C}$

Practice Set

- **Q1:** Electric field due to a charge $+3\mu C$ at 2 m is:
  A) $6.75 \times 10^3\ \mathrm{N/C}$
  B) $2.25 \times 10^3\ \mathrm{N/C}$
  C) $1.5 \times 10^3\ \mathrm{N/C}$
  D) $9 \times 10^3\ \mathrm{N/C}$
- **Q2:** Net electric field at point P due to two charges $+q$ and $-q$ placed 4 m apart, P is midpoint. The field magnitude is:
  A) Zero
  B) $\frac{1}{4\pi\epsilon_0}\frac{2q}{(2)^2}$
  C) $\frac{1}{4\pi\epsilon_0}\frac{q}{4}$
  D) $\frac{1}{4\pi\epsilon_0}\frac{q}{2}$
- **Q3:** Four charges $q_1 = +1\mu C, q_2 = -1\mu C, q_3 = +2\mu C, q_4 = -2\mu C$ are placed at equal distances 1 m from point P. Net electric field at P is:
  A) Zero
  B) $9 \times 10^3\ \mathrm{N/C}$
  C) $18 \times 10^3\ \mathrm{N/C}$
  D) $36 \times 10^3\ \mathrm{N/C}$

Answer Key

- **Q1:** A
  Calculation: $E = 9 \times 10^9 \times \frac{3\times10^{-6}}{2^2} = 6.75 \times 10^3\ \mathrm{N/C}$
- **Q2:** A
  Fields due to equal and opposite charges at midpoint cancel out.
- **Q3:** A
  Equal positive and negative charges symmetrically placed produce zero net field.

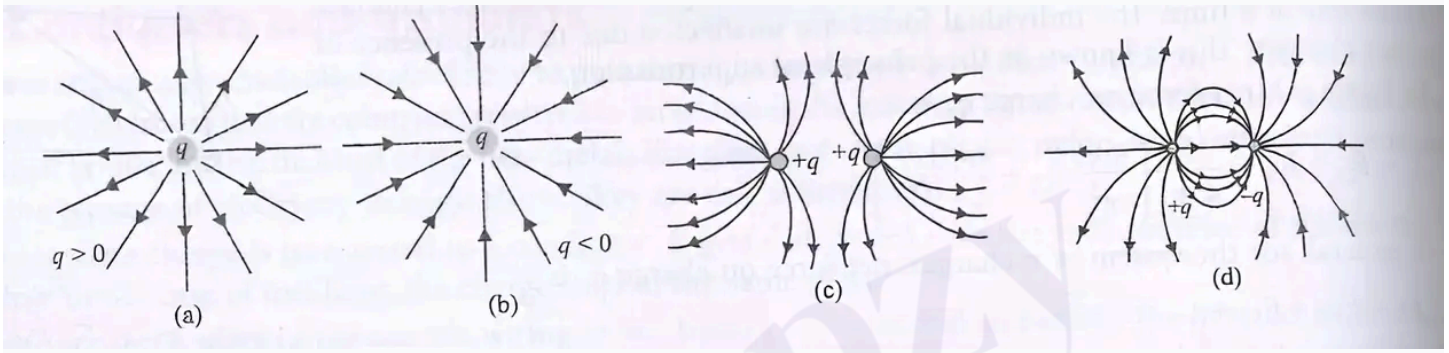
Memory Aids

- Electric field formula: $E = k\frac{q}{r^2}$, where $k = 9 \times 10^9\ \mathrm{Nm^2/C^2}$.
- Electric field vectors add like forces (vector sum).
- Field direction: away from positive, toward negative charges.

Electric Field Lines

Concept and Representation

- Electric field lines map the electric field around charges.
- Tangent to a field line at any point shows the direction of the net electric field.
- Field lines start from positive charges and end at negative charges or infinity.
- Field lines never intersect; intersection would imply multiple directions of the field.
- Field lines do not form closed loops due to the conservative nature of electrostatic fields.
- Density of field lines indicates field strength; closer lines mean stronger field.
- Field lines are normal (perpendicular) to conductor surfaces where they start or end.

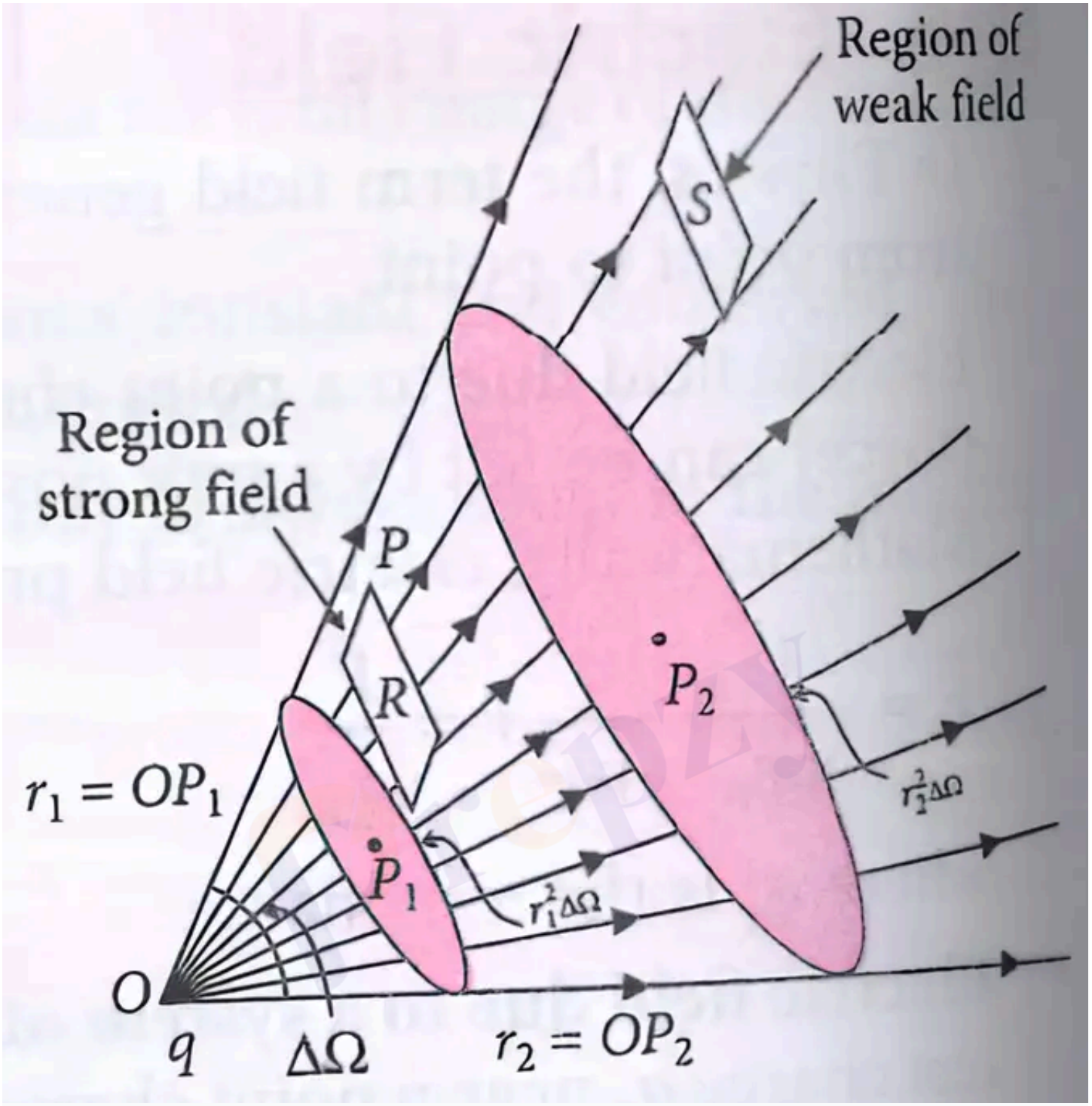


Properties of Electric Field Lines

- Continuous curves without breaks in charge-free regions.
- Start from positive charges, end at negative charges or infinity.
- Tangent at any point gives direction of electric field intensity.
- Two field lines never cross.
- Do not form closed loops.
- Field strength proportional to line density.
- Always perpendicular to conductor surfaces.

Dependence on Distance

- Electric field strength decreases with distance from the charge.
- Field lines spread out as distance increases, reducing density.
- Field strength at a point is inversely proportional to the square of the distance from the charge: $E \propto \frac{1}{r^2}$.



Solved Examples

Ex 1

- Find the relative strength of the electric field at points P_1 and P_2 located at distances r_1 and r_2 from a point charge q.
- Use formula: $E = \frac{k|q|}{r^2}$, where $k = 9 \times 10^9\ \mathrm{Nm^2/C^2}$.
- Calculate ratio: $\frac{E_1}{E_2} = \frac{r_2^2}{r_1^2}$.

Practice Set

Q1

What is the direction of electric field lines around a positive point charge?

- A. Toward the charge
- B. Away from the charge
- C. Circular around the charge
- D. Random directions

Q2

Which of the following is true about electric field lines?

- A. They can intersect
- B. They form closed loops
- C. They start from positive and end at negative charges
- D. They are parallel everywhere

Q3

At what distance from a point charge q is the electric field strength E reduced to one-fourth of its value at distance r?

- A. $2r$
- B. $\frac{r}{2}$
- C. $4r$
- D. $\frac{r}{4}$

Answer Key

- Q1: B - Field lines radiate outward from positive charges.

- Q2: C - Field lines start from positive and end at negative charges; they never intersect or form loops.
- Q3: A - Electric field $E \propto \frac{1}{r^2}$, so doubling distance reduces field to one-fourth.

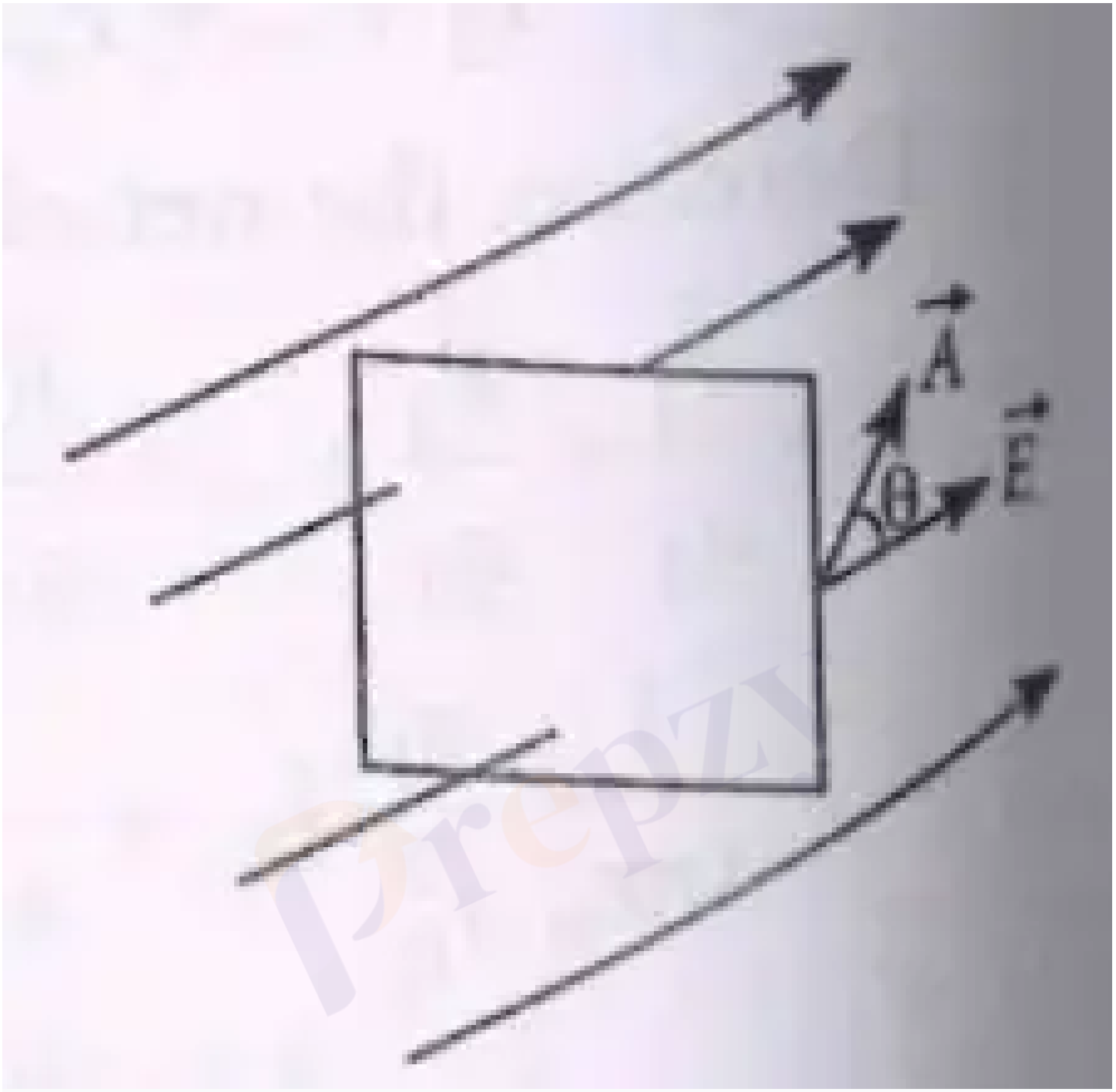
Memory Aids

- "Positive push out, negative pull in" for field line directions.
- Field strength $E \propto$ line density.
- Field lines never cross = unique field direction.
- Electric field $E \propto \frac{1}{r^2}$ for point charges.

Electric Flux

Concept and Formula

- Electric flux (Φ) is the number of electric field lines passing through a surface.
- Mathematically, $\Phi = \int_S \vec{E} \cdot d\vec{A}$.
- For uniform electric field, $\Phi = \vec{E} \cdot \vec{A} = EA\cos\theta$, where θ is the angle between $\vec{E}$ and the area vector $\vec{A}$.
- If $\theta = 90^\circ$, flux $\Phi = 0$ (field lines parallel to surface).
- If $\theta = 0^\circ$, flux is maximum $\Phi_{max} = EA$.
- Electric flux is a scalar quantity measured in volt-meter (V m) or newton meter squared per coulomb (N m^2 C^{-1}).
- Electric field can be non-zero even if flux is zero, but zero flux implies zero net field through the surface.



Solved Examples

Ex 1: Calculate electric flux through a flat surface of area 2 m^2 with uniform electric field 5 N/C at 30° to the normal.

- Use $\Phi = EA\cos\theta = 5 \times 2 \times \cos 30^\circ = 10 \times 0.866 = 8.66\ \mathrm{Nm^2/C}$.

Practice Set

Q1: Electric flux through a surface is zero when the angle between $\vec{E}$ and $\vec{A}$ is:

- A) 0°
- B) 45°
- C) 90°
- D) 180°

Q2: A uniform electric field of 10 N/C is perpendicular to a surface of area 3 m^2. What is the electric flux?

- A) 0 Nm^2/C
- B) 10 Nm^2/C
- C) 30 Nm^2/C
- D) 300 Nm^2/C

Q3: Electric flux through a surface of area 4 m^2 with electric field 6 N/C at an angle 60° is:

- A) 12 Nm^2/C
- B) 24 Nm^2/C
- C) 6 Nm^2/C
- D) 48 Nm^2/C

Answer Key

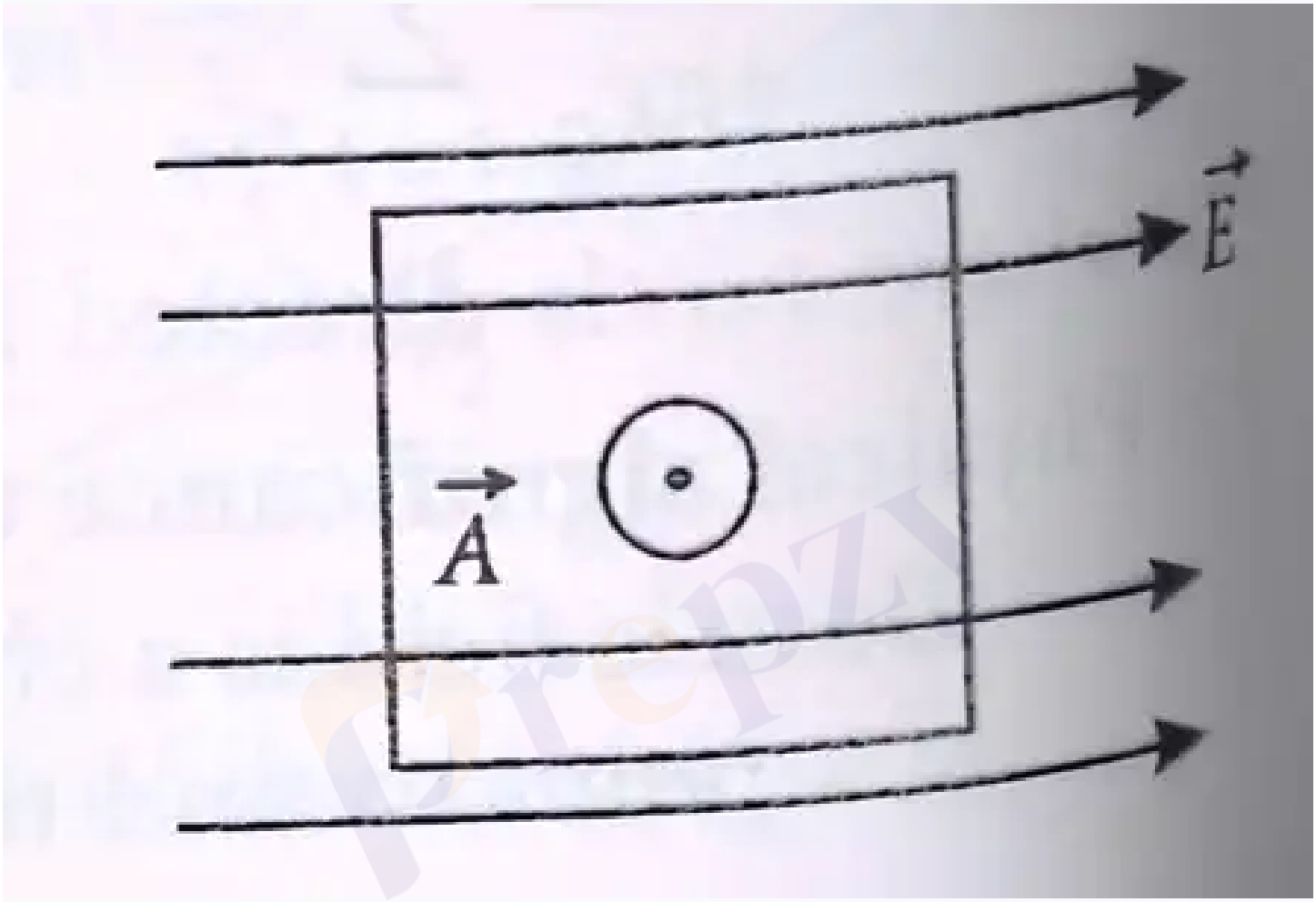
Q1: C) 90° - Flux is zero when field lines are parallel to surface.

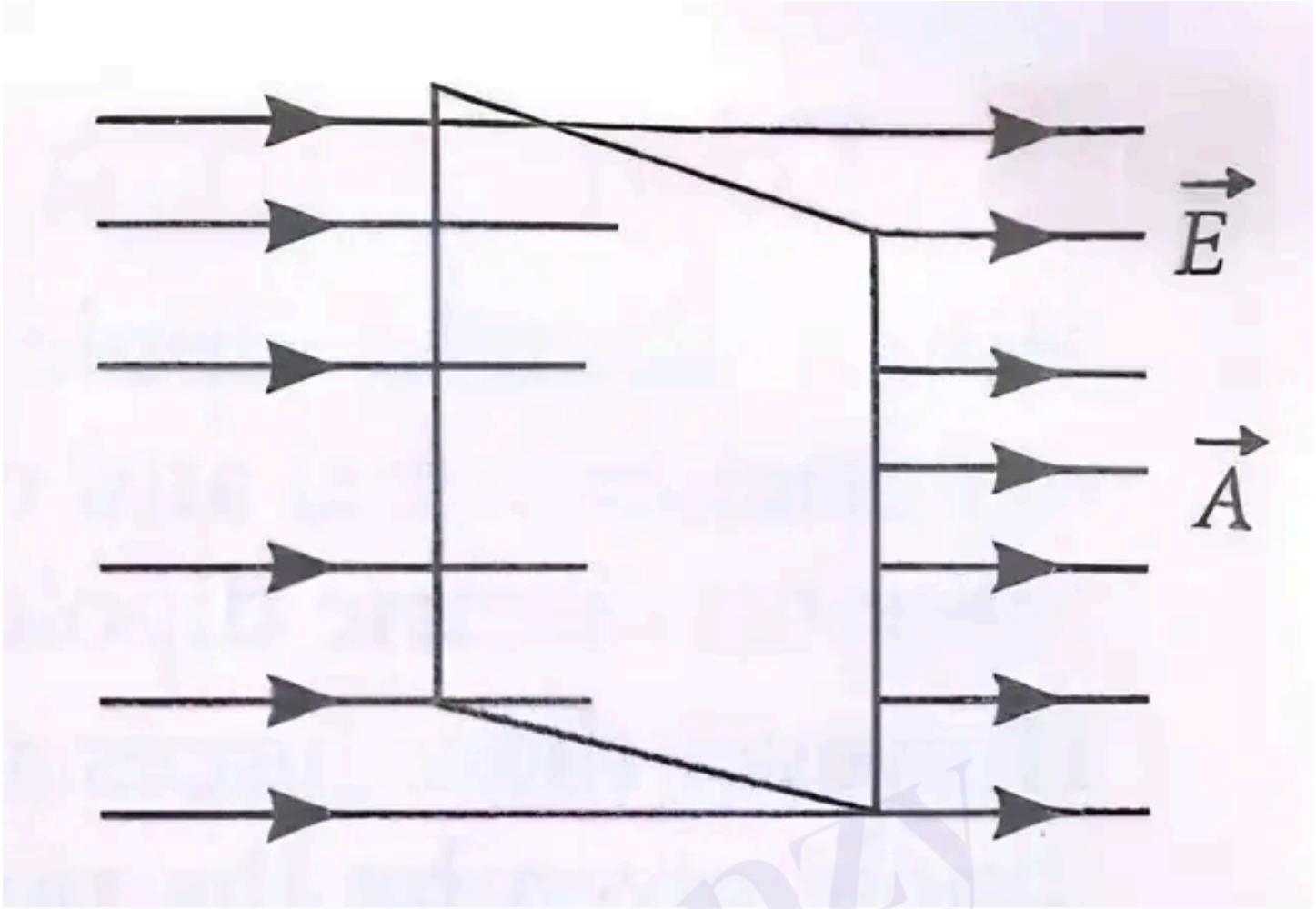
Q2: C) 30 Nm^2/C - $\Phi = EA\cos 0^\circ = 10 \times 3 = 30$.

Q3: A) 12 Nm^2/C - $\Phi = 6 \times 4 \times \cos 60^\circ = 24 \times 0.5 = 12$.

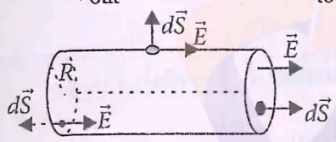
Memory Aids

- Flux $\Phi = EA\cos\theta$.
- $\theta = 0^\circ$ → max flux, $\theta = 90^\circ$ → zero flux.
- Flux is scalar, unit: V m or N m^2/C.

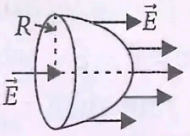




$\phi_{in} = -\pi R^2 E$ and $\phi_{out} = \pi R^2 E \implies \phi_{total} = 0$



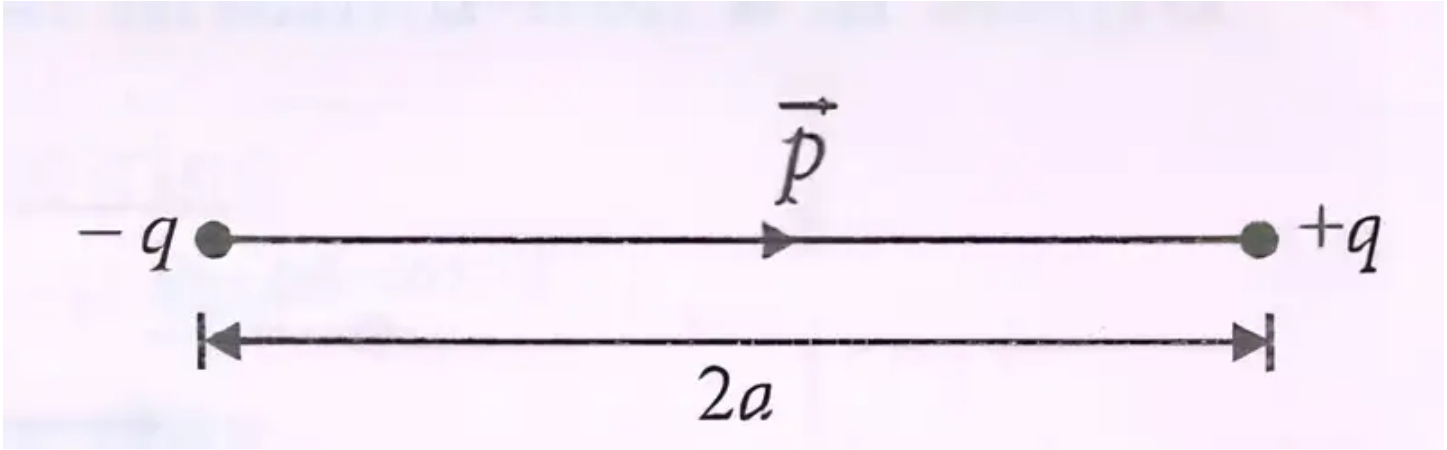
$\phi_{in} = \phi_{circular} = -\pi R^2 E$ and $\phi_{out} = \phi_{curved} = \pi R^2 E \implies \phi_{total} = 0$



Electric Dipole

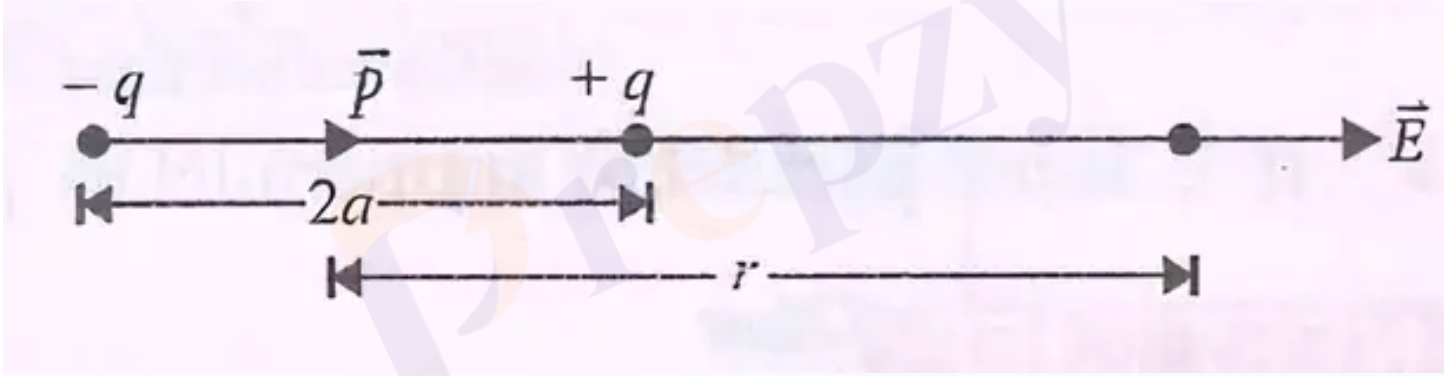
Definition and Dipole Moment

- Electric dipole: two equal and opposite charges separated by a small distance.
- Dipole moment $\vec{p} = q(2\vec{a})$, points from negative to positive charge.
- Distance between charges = $2a$.



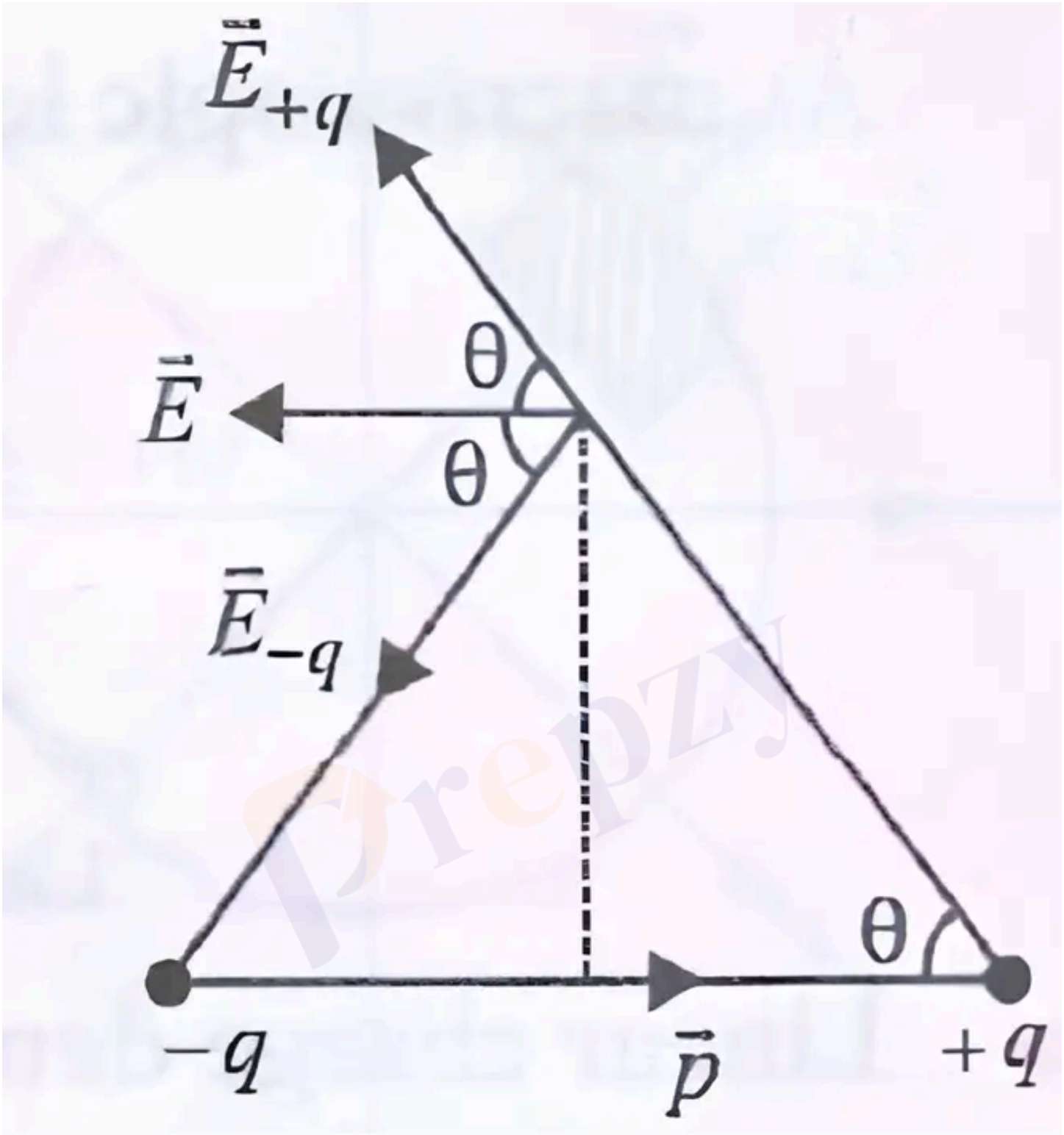
Electric Field on Axial Line (End-on Position)

- Electric field at point on axis: $\vec{E} = \vec{E}_{+q} + \vec{E}_{-q} = \frac{q\hat{p}}{4\pi\epsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]$
- Also, $\vec{E} = \frac{2\vec{p}r}{4\pi\epsilon_0(r^2-a^2)^2}$
- At large distance $(r \gg a)$, $\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{2\vec{p}}{r^3}$



Electric Field on Equatorial Line (Broadside-on Position)

- Electric field at equatorial point: $\vec{E} = -(\vec{E}_{+q} + \vec{E}_{-q})\cos\theta\hat{p} = \frac{1}{4\pi\epsilon_0}\frac{-\vec{p}}{(r^2+a^2)^{3/2}}$
- At large distance $(r \gg a)$, $\vec{E} = -\frac{\vec{p}}{4\pi\epsilon_0 r^3}$



Physical Significance

- Nonpolar molecules: centers of positive and negative charges coincide (e.g., CO_2, CH_4) → no permanent dipole moment.
- Polar molecules: centers do not coincide (e.g., H_2O, NH_3) → permanent dipole moment.
- External electric field can induce dipole moment in nonpolar molecules.

Solved Examples

Ex 1

- Calculate electric field at axial point $r = 10a$ for dipole moment p.
- Use formula: $E = \frac{1}{4\pi\epsilon_0}\frac{2p}{r^3}$.
- Substitute $r = 10a$, calculate E.

Practice Set

- Q1: Dipole moment $\vec{p}$ points from (A) positive to negative charge (B) negative to positive charge (C) both directions (D) none
- Q2: Electric field at large distance on axial line is proportional to (A) $1/r^2$ (B) $1/r^3$ (C) $1/r$ (D) r^2
- Q3: For a dipole with $p = 4 \times 10^{-29}$ C·m, distance $r = 0.1$ m, calculate approximate axial electric field E using $\epsilon_0 = 8.85 \times 10^{-12}$ F/m. (A) 7.2×10^3 N/C (B) 1.8×10^4 N/C (C) 3.6×10^3 N/C (D) 9.0×10^2 N/C

Answer Key

- Q1: B - Dipole moment vector points from negative to positive charge.
- Q2: B - Electric field on axial line at large distance varies as $1/r^3$.
- Q3: A - Using $E = \frac{1}{4\pi\epsilon_0}\frac{2p}{r^3}$, calculate $E \approx 7.2 \times 10^3$ N/C.

Memory Aids

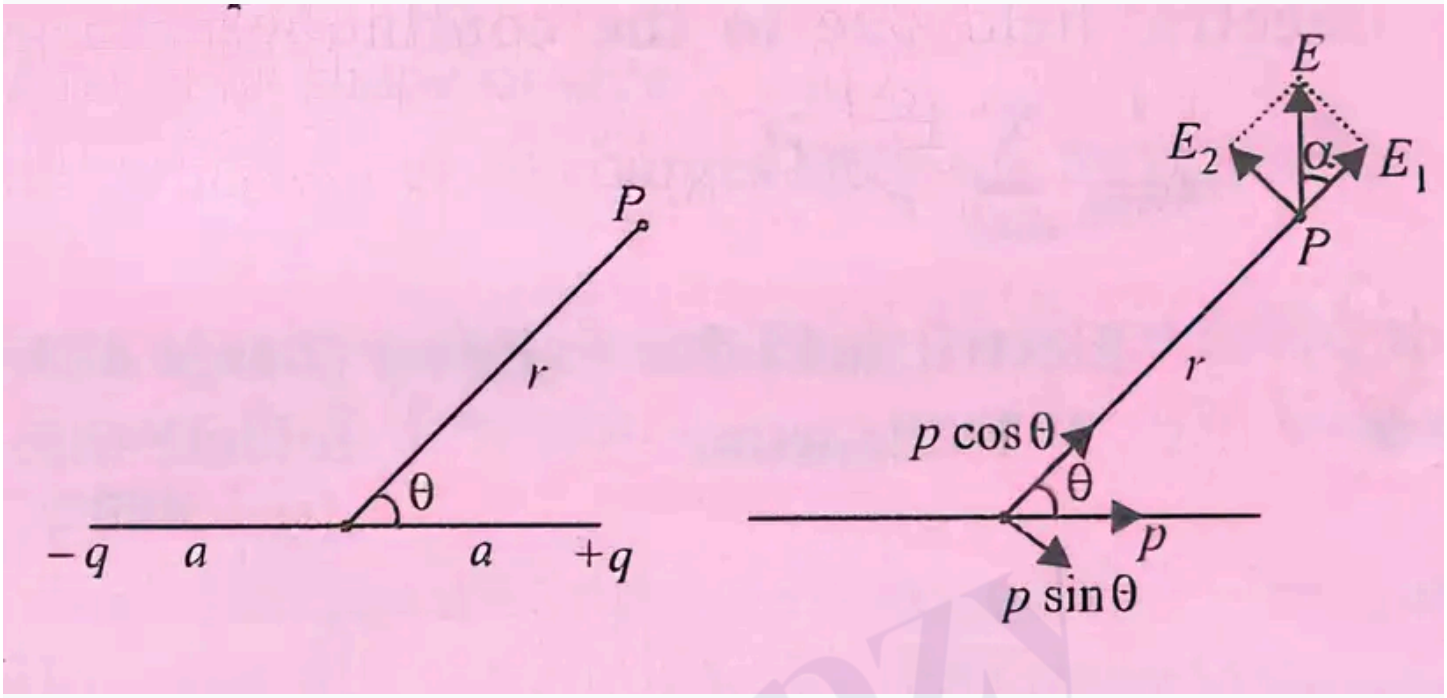
- Dipole moment $\vec{p} = q \times 2a$, points negative to positive.
- Axial field $\propto 2p/r^3$, equatorial field $\propto -p/r^3$.
- At large distances, axial field is twice equatorial field.

Electric Field at General Point

Field Components and Resultant

- Resolve dipole moment $\vec{p}$ into components: $p\cos\theta$ (axial), $p\sin\theta$ (equatorial).

- Electric field due to axial component: $E_1 = \frac{2kp\cos\theta}{r^3}$.
- Electric field due to equatorial component: $E_2 = \frac{kp\sin\theta}{r^3}$.
- Resultant field magnitude: $E = kp\frac{\sqrt{3\cos^2\theta+1}}{r^3}$.
- Angle α between $\vec{E}$ and $\vec{r}$: $\tan\alpha = \frac{\tan\theta}{2}$.



Solved Examples

Ex 1

- Find resultant electric field at point P where $\theta = 60^\circ$, $r = 0.2$ m, dipole moment $p = 5 \times 10^{-29}$ C·m.
- Calculate E_1, E_2 using formulas.
- Calculate resultant E and angle α.

Practice Set

- Q1: The angle α between resultant field and $\vec{r}$ is given by (A) $\tan^{-1}(\tan\theta)$ (B) $\tan^{-1}(\tan\theta/2)$ (C) $\tan^{-1}(2\tan\theta)$ (D) $\tan^{-1}(\sin\theta)$
- Q2: Resultant electric field magnitude varies as (A) $1/r^2$ (B) $1/r^3$ (C) $1/r$ (D) r^3
- Q3: For $\theta = 45^\circ$, $p = 3 \times 10^{-29}$ C·m, $r = 0.1$ m, calculate E_1 and E_2 (use $k = 9 \times 10^9$ Nm²/C²). (A) $E_1 = 3.8 \times 10^4, E_2 = 1.9 \times 10^4$ (B) $E_1 = 2.7 \times 10^4, E_2 = 2.7 \times 10^4$ (C) $E_1 = 1.9 \times 10^4, E_2 = 3.8 \times 10^4$ (D) $E_1 = 4.0 \times 10^4, E_2 = 2.0 \times 10^4$

Answer Key

- Q1: B - $\alpha = \tan^{-1}(\tan\theta/2)$ from formula.
- Q2: B - Electric field varies as inverse cube of distance $1/r^3$.
- Q3: A - Calculate using $E_1 = 2kp\cos\theta/r^3$, $E_2 = kp\sin\theta/r^3$.

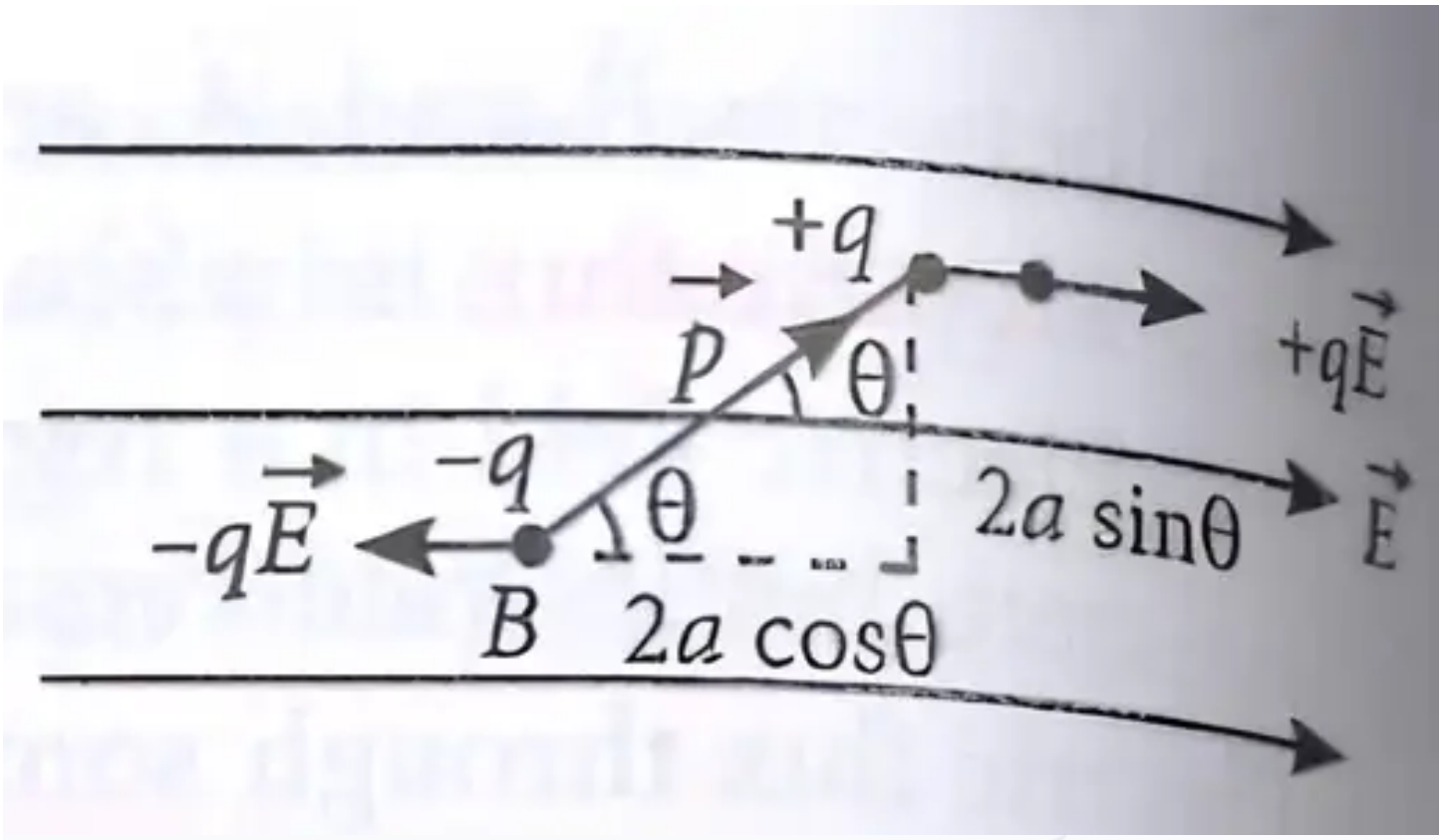
Memory Aids

- Resolve dipole moment into axial and equatorial components.
- Resultant field magnitude involves $\sqrt{3\cos^2\theta + 1}$.
- Angle α is half the tangent of θ in tangent form.

Dipole in a Uniform External Field

Concepts and Formulas

- An electric dipole consists of charges +q and -q separated by distance 2a.
- Placed in uniform electric field $\vec{E}$, forces on charges are equal and opposite, net force = 0.
- Forces are not collinear, causing torque $\tau = Fr_\perp = qE \times 2a\sin\theta = pE\sin\theta$, where $p = q \times 2a$.
- Vector form: $\vec{\tau} = \vec{p} \times \vec{E}$, θ is angle between $\vec{p}$ and $\vec{E}$.
- Torque extremes: $\tau_{min} = 0$ at $\theta = 0^\circ, 180^\circ$; $\tau_{max} = pE$ at $\theta = 90^\circ$.
- Torque aligns dipole along the electric field direction.



Solved Examples

- **Ex 1:** Calculate torque on dipole with $p = 4 \times 10^{-29}\ \text{C m}$, $E = 5 \times 10^{4}\ \text{N/C}$, $\theta = 60^\circ$.
  - Use $\tau = pE \sin\theta = 4 \times 10^{-29} \times 5 \times 10^{4} \times \sin 60^\circ$.
  - $\tau = 1.73 \times 10^{-24}\ \text{N m}$.

Practice Set

- Q1: What is the net force on an electric dipole in a uniform electric field?
  - A) Zero
  - B) qE
  - C) $2qE$
  - D) Depends on θ
- Q2: Torque on a dipole is maximum when θ is:
  - A) 0°
  - B) 45°
  - C) 90°
  - D) 180°
- Q3: A dipole with moment $2 \times 10^{-29}\ \text{C m}$ is in a field of $10^{5}\ \text{N/C}$ at 30°. Calculate torque.
  - A) $1 \times 10^{-24}\ \text{N m}$
  - B) $5 \times 10^{-25}\ \text{N m}$

- C) 1×10^{-25} N m
- D) 2×10^{-24} N m

Answer Key

- Q1: A - Forces on +q and -q cancel, net force is zero in uniform field.
- Q2: C - Torque $\tau = pE \sin\theta$ is max at 90°.
- Q3: B - $\tau = pE \sin 30^\circ = 2 \times 10^{-29} \times 10^5 \times 0.5 = 5 \times 10^{-25}$ N m.

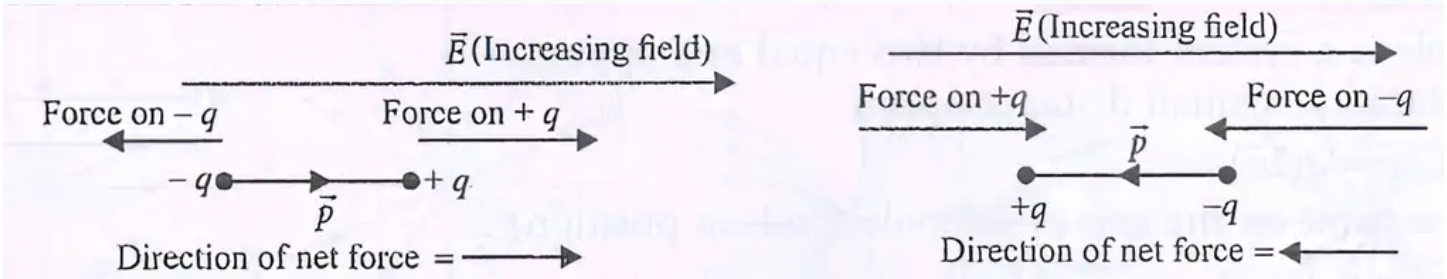
Memory Aids

- Torque $\tau = pE \sin\theta$ aligns dipole with field.
- Net force zero in uniform field.
- Max torque at 90°, zero at $0^\circ, 180^\circ$.

Dipole in a Non-Uniform Electric Field

Concepts and Formulas

- In non-uniform field, forces on +q and -q differ, causing net force and torque on dipole.
- Net force direction depends on dipole orientation relative to field gradient.
- If $\vec{E}$ not parallel or antiparallel to $\vec{p}$, dipole experiences both net force and torque.
- Time period of oscillating dipole in uniform field: $T = 2\pi\sqrt{\frac{I}{pE}}$, where I is moment of inertia.



Solved Examples

- **Ex 1:** Dipole in increasing field experiences net force. If force on +q is 2×10^{-6} N right and on -q is 1×10^{-6} N left, net force?

- Net force = $2 \times 10^{-6} - 1 \times 10^{-6} = 1 \times 10^{-6}$ N right.

Practice Set

- Q1: What happens to dipole in non-uniform field?
  - A) Only torque
  - B) Only net force
  - C) Both net force and torque
  - D) No force or torque
- Q2: If $\vec{E}$ is not parallel to $\vec{p}$, dipole experiences:
  - A) No force
  - B) Only torque
  - C) Only net force
  - D) Net force and torque
- Q3: Time period of oscillating dipole depends on:
  - A) $\sqrt{\frac{I}{pE}}$
  - B) $\sqrt{\frac{pE}{I}}$
  - C) $\frac{I}{pE}$
  - D) $\frac{pE}{I}$

Answer Key

- Q1: C - Non-uniform field causes both net force and torque.
- Q2: D - Non-parallel $\vec{E}$ and $\vec{p}$ cause net force and torque.
- Q3: A - $T = 2\pi\sqrt{\frac{I}{pE}}$ time period formula.

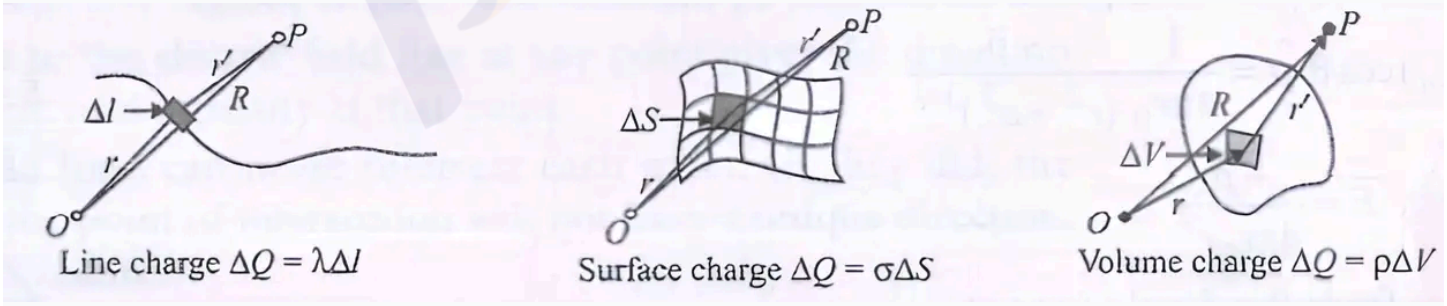
Memory Aids

- Non-uniform field: net force + torque.
- Oscillation period $T = 2\pi\sqrt{I/pE}$.
- Force direction depends on dipole orientation.

Continuous Charge Distribution

Charge Densities and Distribution

- Electric charge is treated as continuous at macroscopic scale due to dense electron concentration.
- Charge distributions:
  - **Line charge:** Charge spread along a line segment. Charge $\Delta Q = \lambda \Delta l$, where λ is linear charge density (C/m).
  - **Surface charge:** Charge spread over a surface area. Charge $\Delta Q = \sigma \Delta S$, where σ is surface charge density (C/m²).
  - **Volume charge:** Charge distributed in volume. Charge $\Delta Q = \rho \Delta V$, where ρ is volume charge density (C/m³).
- Charge densities:
  - Linear charge density: $\lambda = \frac{\Delta Q}{\Delta l}$ (C/m)
  - Surface charge density: $\sigma = \frac{\Delta Q}{\Delta S}$ (C/m²)
  - Volume charge density: $\rho = \frac{\Delta Q}{\Delta V}$ (C/m³)
- Electric field from continuous charge distributions:
  - $\vec{E}_\lambda = \frac{1}{4\pi\varepsilon_0} \sum \frac{\lambda \Delta l}{r'^2} \hat{r}'$ (line charge)
  - $\vec{E}_\sigma = \frac{1}{4\pi\varepsilon_0} \sum \frac{\sigma \Delta S}{r'^2} \hat{r}'$ (surface charge)
  - $\vec{E}_\rho = \frac{1}{4\pi\varepsilon_0} \sum \frac{\rho \Delta V}{r'^2} \hat{r}'$ (volume charge)



$$\vec{E}_\lambda = \frac{1}{4\pi\varepsilon_0} \sum_{\text{all}\Delta l} \frac{\lambda \Delta l}{r'^2} \hat{r}', \quad \vec{E}_\sigma = \frac{1}{4\pi\varepsilon_0} \sum_{\text{all}\Delta S} \frac{\sigma \Delta S}{r'^2} \hat{r}', \quad \vec{E}_\rho = \frac{1}{4\pi\varepsilon_0} \sum_{\text{all}\Delta V} \frac{\rho \Delta V}{r'^2} \hat{r}'$$

Solved Examples

- **Ex 1:** Calculate charge on 2 m length of wire with $\lambda = 3 \times 10^{-6}\ \text{C/m}$.
  - Use $Q = \lambda l = 3 \times 10^{-6} \times 2 = 6 \times 10^{-6}\ \text{C}$.
- **Ex 2:** Find surface charge on 0.5 m² with $\sigma = 4 \times 10^{-6}\ \text{C/m}^2$.

- Use $Q = \sigma S = 4 \times 10^{-6} \times 0.5 = 2 \times 10^{-6}\ \text{C}$.

Practice Set

- Q1: Linear charge density λ units are:
  - A) C/m
  - B) C/m²
  - C) C/m³
  - D) C
- Q2: Surface charge density σ is charge per unit:
  - A) Length
  - B) Area
  - C) Volume
  - D) Mass
- Q3: Volume charge density ρ units are:
  - A) C/m
  - B) C/m²
  - C) C/m³
  - D) C

Answer Key

- Q1: A) C/m — Linear charge density is charge per unit length.
- Q2: B) Area — Surface charge density is charge per unit area.
- Q3: C) C/m³ — Volume charge density is charge per unit volume.

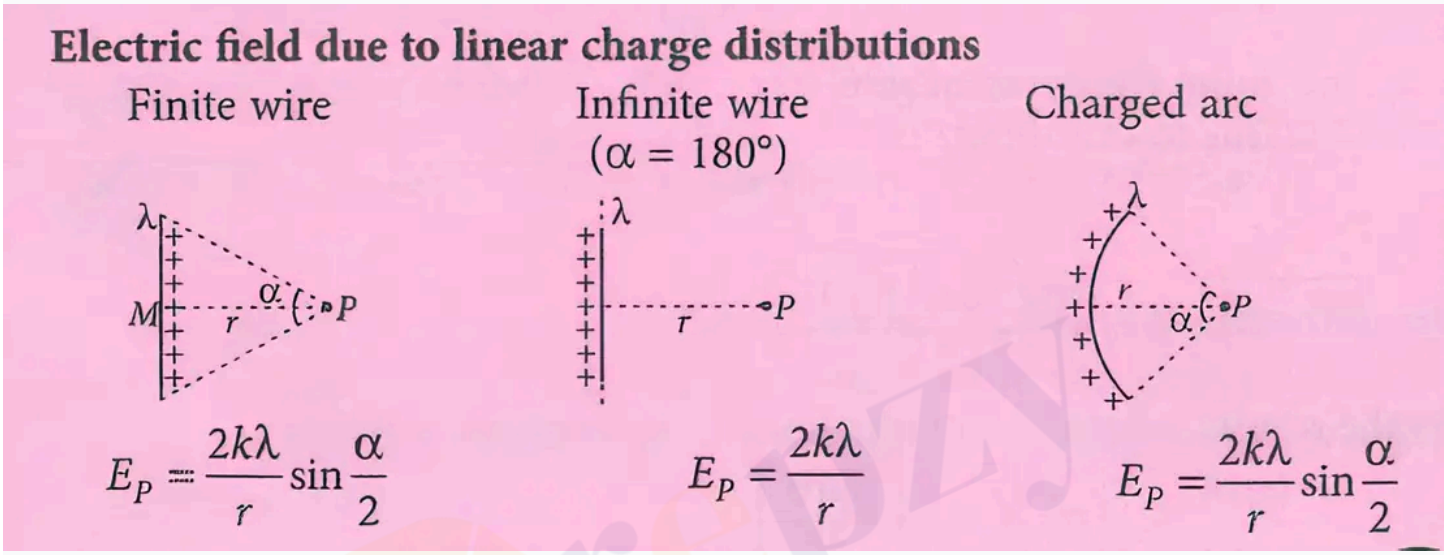
Memory Aids

- λ for line (length), units C/m.
- σ for surface (area), units C/m².
- ρ for volume, units C/m³.
- Electric field sums contributions from small charge elements.

Electric Field Linear Charge

Electric Field from Linear Charges

- Finite wire: $E_P = \frac{k\lambda}{r}\sin\alpha$, depends on wire angle α and distance r.
- Infinite wire: $E_P = \frac{2k\lambda}{r}$, depends on λ and r only.
- Charged arc: $E_P = \frac{k\lambda}{r}2\sin\alpha$, depends on arc angle α, λ, and r.
- $k = \frac{1}{4\pi\varepsilon_0}$ is Coulomb's constant.



Solved Examples

- **Ex 1:** Find electric field at P due to infinite wire with $\lambda = 5 \times 10^{-6}\ \mathrm{C/m}$ at $r = 0.1\ \mathrm{m}$.
  - Use $E_P = \frac{2k\lambda}{r} = \frac{2\times9\times10^9\times5\times10^{-6}}{0.1} = 9 \times 10^5\ \mathrm{N/C}$.
- **Ex 2:** Calculate E_P for charged arc with $\lambda = 4 \times 10^{-6}\ \mathrm{C/m}$, $\alpha = 30^\circ$, $r = 0.2\ \mathrm{m}$.
  - Use $E_P = \frac{k\lambda}{r}2\sin\alpha = \frac{9\times10^9\times4\times10^{-6}}{0.2} \times 2 \times 0.5 = 1.8 \times 10^5\ \mathrm{N/C}$.

Practice Set

- Q1: Electric field due to infinite wire varies as:
  - A) $1/r^2$
  - B) $1/r$
  - C) r
  - D) Constant
- Q2: For a finite wire, electric field depends on:
  - A) Wire length only

    - B) Angle subtended α and distance r
    - C) Charge only
    - D) None
- Q3: Electric field at P due to charged arc is proportional to:
    - A) $\sin \alpha$
    - B) $\cos \alpha$
    - C) $\tan \alpha$
    - D) α^2

Answer Key

- Q1: B) $1/r$ — Infinite wire field decreases inversely with distance.
- Q2: B) Angle α and distance r — Finite wire field depends on geometry.
- Q3: A) $\sin \alpha$ — Arc field proportional to sine of arc angle.

Memory Aids

- Infinite wire field $\propto 1/r$.
- Finite wire field depends on angle subtended.
- Arc field involves $2 \sin \alpha$ factor.

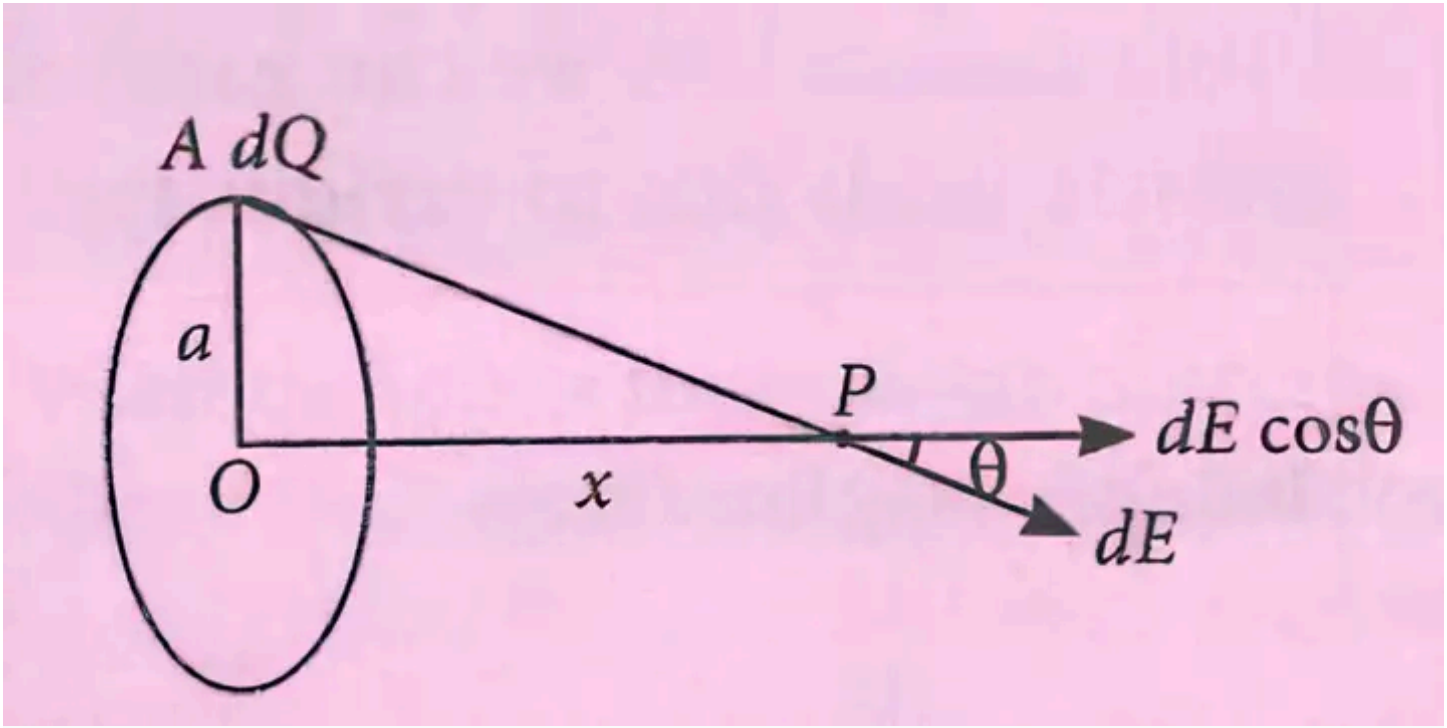
Electric Field Charged Ring

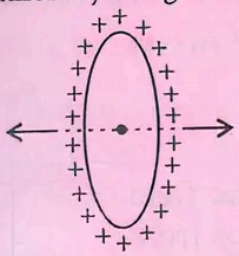
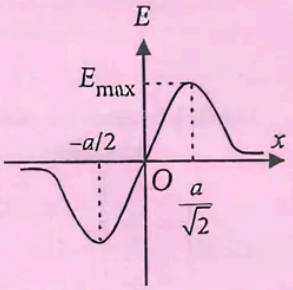
Electric Field on Ring Axis

- Consider ring radius a, total charge Q, point P on axis at distance x.
- Small charge element dQ produces field $dE = \frac{dQ}{4\pi\varepsilon_0 (AP)^2}$ at P.
- Field component along axis: $dE \cos\theta = \frac{x dQ}{4\pi\varepsilon_0 (a^2+x^2)^{3/2}}$.
- Net field at P:

$$E = \frac{xQ}{4\pi\varepsilon_0 (a^2 + x^2)^{3/2}}$$

- At ring center $x = 0$, $E = 0$ due to symmetry.
- Field points along ring axis; maximum at specific x.



Uniformly charged ring			
	$E = \frac{kQx}{(a^2 + x^2)^{3/2}}$ $E_{centre} = 0$	– Q is total charge of the ring – x is distance of point on the axis from centre of the ring. – Electric field is always along the axis.	

Solved Examples

- **Ex 1:** Calculate electric field at $x = 0.1$ m on axis of ring with $Q = 5 \times 10^{-6}$ C, $a = 0.05$ m.
  - Use $E = \frac{kQx}{(a^2+x^2)^{3/2}} = \frac{9\times10^9\times5\times10^{-6}\times0.1}{(0.05^2+0.1^2)^{3/2}}$.
  - Calculate denominator and evaluate E.

Practice Set

- Q1: Electric field at center of charged ring is:
  - A) Maximum
  - B) Zero
  - C) Depends on charge
  - D) Infinite
- Q2: Electric field on axis of ring depends on:
  - A) Distance from center x
  - B) Ring radius a

    - C) Total charge Q
    - D) All above
- Q3: Formula for electric field on axis of ring is:
    - A) $\frac{kQ}{x^2}$
    - B) $\frac{kQx}{(a^2+x^2)^{3/2}}$
    - C) $\frac{kQa}{(a^2+x^2)^{3/2}}$
    - D) $\frac{kQx}{(a^2+x^2)^2}$

Answer Key

- Q1: B) Zero — Field cancels at ring center by symmetry.
- Q2: D) All above — Field depends on x, a, and Q.
- Q3: B) $\frac{kQx}{(a^2+x^2)^{3/2}}$ — Standard formula for ring axis field.

Memory Aids

- Field zero at ring center.
- Field max at some distance on axis.
- Formula involves x and a in denominator power 3/2.

Gauss's Law

Explanation

- Gauss's law states total electric flux Φ over a closed surface S in vacuum is $\frac{1}{\varepsilon_0}$ times the total charge enclosed q_{enclosed}:
  $\Phi = \oint_S \vec{E} \cdot d\vec{S} = \frac{q_{\text{enclosed}}}{\varepsilon_0}$
- Electric field E due to point charge Q at distance R is:
  $E = \frac{1}{4\pi\varepsilon_0} \frac{Q}{R^2}$
- For a spherical Gaussian surface of radius R, flux:
  $\Phi = E \times 4\pi R^2 = \frac{Q}{\varepsilon_0}$
- Gauss's law holds for any closed surface, regardless of shape or size.
- q_{enclosed} is the sum of all charges inside the surface.
- Electric field includes contributions from charges inside and outside, but Gauss's law relates only to enclosed charges.

- Gaussian surface must not pass through discrete charges but can pass through continuous charge distributions.
- Useful for calculating electrostatic fields in symmetric charge distributions.
- Based on inverse square law; violation indicates deviation from Coulomb's law.

Solved Examples

- **Ex 1:** Calculate electric flux through a spherical surface of radius 0.5 m enclosing charge 2 μC.
  Step 1: Use $\Phi = \frac{q}{\varepsilon_0}$
  Step 2: $q = 2 \times 10^{-6} C, \varepsilon_0 = 8.85 \times 10^{-12} C^2/Nm^2$
  Step 3: $\Phi = \frac{2 \times 10^{-6}}{8.85 \times 10^{-12}} = 2.26 \times 10^5 \ \mathrm{Nm^2/C}$
- **Ex 2:** Find electric field on surface of sphere radius 0.1 m with enclosed charge 5 μC.
  Step 1: Use $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R^2}$
  Step 2: $Q = 5 \times 10^{-6} C, R = 0.1 m$
  Step 3: $E = \frac{9 \times 10^9 \times 5 \times 10^{-6}}{(0.1)^2} = 4.5 \times 10^6 \ \mathrm{N/C}$

Practice Set

- Q1: Gauss's law relates electric flux to:
  A) Total charge outside surface
  B) Total charge inside surface
  C) Electric field only
  D) Surface area only
- Q2: Electric flux through a spherical surface of radius 0.2 m enclosing charge 3 μC is:
  A) $3.39 \times 10^5 \ \mathrm{Nm^2/C}$
  B) $2.5 \times 10^5 \ \mathrm{Nm^2/C}$
  C) $1.5 \times 10^5 \ \mathrm{Nm^2/C}$
  D) $4.0 \times 10^5 \ \mathrm{Nm^2/C}$
- Q3: Electric field at 0.3 m from a point charge 6 μC is:
  A) $2 \times 10^6 \ \mathrm{N/C}$
  B) $6 \times 10^6 \ \mathrm{N/C}$
  C) $1.8 \times 10^6 \ \mathrm{N/C}$
  D) $3 \times 10^6 \ \mathrm{N/C}$

Answer Key

- Q1: B - Gauss's law relates flux to total charge enclosed inside the surface.

- Q2: A - $\Phi = \frac{q}{\varepsilon_0} = \frac{3\times10^{-6}}{8.85\times10^{-12}} = 3.39 \times 10^5\ \mathrm{Nm^2/C}$
- Q3: C - $E = \frac{9\times10^9\times6\times10^{-6}}{(0.3)^2} = 1.8 \times 10^6\ \mathrm{N/C}$

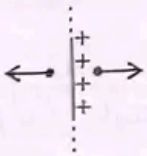
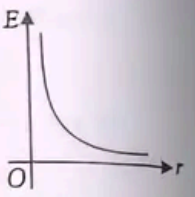
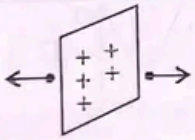
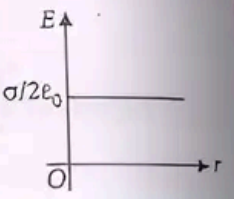
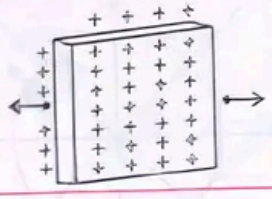
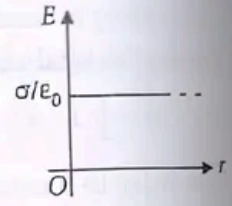
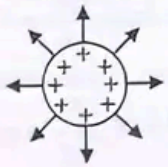
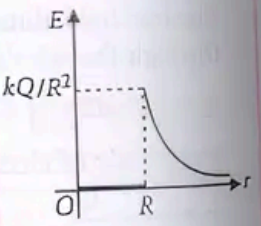
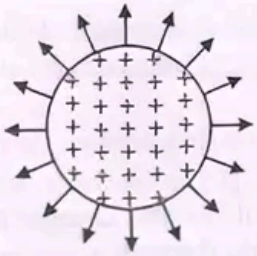
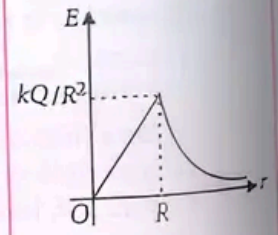
Memory Aids

- Flux $\Phi = \frac{q_{\text{enclosed}}}{\varepsilon_0}$
- Electric field $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R^2}$
- Gaussian surface: closed surface enclosing charge
- Gauss's law confirms inverse square law

Applications of Gauss's Law

Electric Fields from Charge Distributions

- Gauss's law helps find electric fields $\vec{E}$ for symmetric charge setups.
- Key charge distributions: line charge, thin sheet (non-conducting and conducting), spherical shell, solid sphere.
- Electric field formulas depend on geometry and charge arrangement.

Infinitely long line charge 	$\vec{E}=\frac{\lambda}{2\pi\varepsilon_0 r}\hat{r}=\frac{2k\lambda\hat{r}}{r}$	– λ is linear charge density (assumed uniform). – r is perpendicular distance of point from line charge. – $\hat{r}$ is radial unit vector drawn from the charge to test point.	
Infinitely large non-conducting thin sheet 	$\vec{E}=\frac{\sigma}{2\varepsilon_0}\hat{n}$	– σ is surface charge density (assumed uniform). – $\hat{n}$ is unit normal vector. – The magnitude of electric field is independent of distance from sheet.	
Infinitely large charged conducting sheet 	$\vec{E}=\frac{\sigma}{\varepsilon_0}\hat{n}$	– σ is the surface charge density (assumed uniform). – $\hat{n}$ is the unit vector perpendicular to the surface.	
Uniformly charged spherical shell / solid conducting sphere 	(i) For $r \geq R$, $\vec{E}=\frac{kQ}{\lvert\vec{r}\rvert^2}\hat{r}$ (ii) For $r < R$, $E=0$	– R is radius of the sheet. – $\vec{r}$ is vector drawn from centre of sphere to the point. – Sphere acts like a point charge placed at centre for points outside the sphere. – $\vec{E}$ is always along radial direction. – Q is the total charge ($=\sigma 4\pi R^2$) (σ = surface charge density)	
Uniformly charged solid non-conducting sphere (insulating material) 	(i) For $r \geq R$, $\vec{E}=\frac{kQ}{\lvert\vec{r}\rvert^2}\hat{r}$ (ii) For $r < R$, $\vec{E}=\frac{kQ}{R^3}\vec{r}$	– $\vec{r}$ is vector drawn from centre of sphere to the point. – Sphere acts like a point charge placed at the centre for points outside the sphere. – $\vec{E}$ is always along radial direction. – Q is total charge $\left(\rho\frac{4}{3}\pi R^3\right)$ (ρ = volume charge density) – Inside the sphere, $E \propto r$ – Outside the sphere, $E \propto \frac{1}{r^2}$	

Charge Distribution Details

- **Infinitely long line charge:** $E = \frac{\lambda}{2\pi\epsilon_0 r}$, field $\propto 1/r$, radial direction.
- **Infinitely large non-conducting thin sheet:** $E = \frac{\sigma}{2\epsilon_0}$, uniform field, perpendicular to sheet.

- **Infinitely large charged conducting sheet:** $E = \frac{\sigma}{\epsilon_0}$, uniform field, perpendicular to surface.
- **Uniformly charged spherical shell or conducting sphere:** Outside: $E = \frac{kQ}{r^2}$, Inside: $E = 0$.
- **Uniformly charged solid non-conducting sphere:** Outside: $E = \frac{kQ}{r^2}$, Inside: $E = \frac{kQr}{R^3}$, linear increase with r.

Solved Examples

- **Ex 1:** Find E at $r = 0.1\,m$ from a line charge with $\lambda = 5 \times 10^{-6}\,C/m$.
  - Use $E = \frac{\lambda}{2\pi\epsilon_0 r}$.
  - Calculate $E = \frac{5\times10^{-6}}{2\pi\times8.85\times10^{-12}\times0.1} \approx 8.99 \times 10^4\,N/C$.
- **Ex 2:** Electric field near a charged conducting sheet with surface charge density $\sigma = 1 \times 10^{-6}\,C/m^2$.
  - Use $E = \frac{\sigma}{\epsilon_0} = \frac{1\times10^{-6}}{8.85\times10^{-12}} \approx 1.13 \times 10^5\,N/C$.

Practice Set

- Q1: Electric field due to an infinite line charge varies as?
  - A) $1/r^2$
  - B) $1/r$
  - C) Constant
  - D) r
- Q2: Electric field inside a uniformly charged spherical shell is?
  - A) kQ/r^2
  - B) Zero
  - C) kQr/R^3
  - D) Constant non-zero
- Q3: For a uniformly charged solid sphere, electric field inside at distance r is?
  - A) kQ/r^2
  - B) Zero
  - C) kQr/R^3
  - D) $\sigma/2\epsilon_0$

Answer Key

- Q1: B) $1/r$ - Field from line charge decreases inversely with distance.
- Q2: B) Zero - Inside spherical shell, electric field is zero by Gauss's law.
- Q3: C) kQr/R^3 - Inside solid sphere, field increases linearly with r.

Memory Aids

- Line charge: $E \propto 1/r$.
- Sheet charge: uniform E, independent of r.
- Spherical shell: zero inside, $\propto 1/r^2$ outside.
- Solid sphere: linear E inside, $1/r^2$ outside.