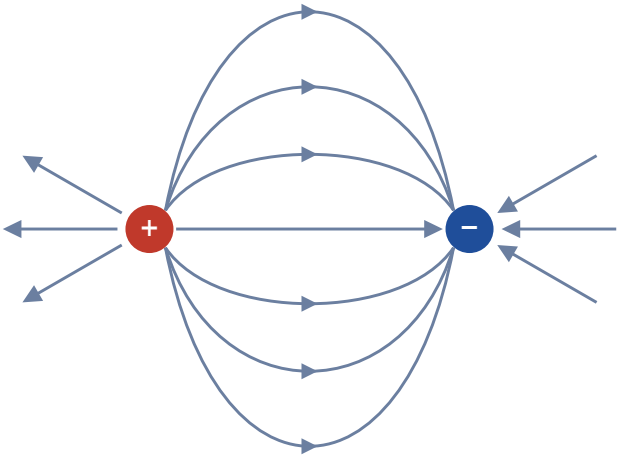
Electric Charges and Fields

NCERT Class 12 Physics · Chapter 1

Easy notes · Step-by-step derivations · Numericals · Questions



Electric dipole: lines start on +q and end on −q.

Board weightage: Unit 1 Electrostatics (Ch 1 + Ch 2) = 16 marks. From this chapter expect: 1 derivation (dipole field / torque / Gauss's law application), 1–2 numericals, MCQs on Coulomb's law and flux.

How to use this booklet:

- Day 1: Parts A–C (charge, Coulomb's law, field, field lines). Read each Note + Hinglish box.
- Day 2: Parts D–F (flux, dipole, Gauss's law). Copy every derivation **once in your notebook** – line by line, with the diagram.
- Day 3: Formula sheet + solved numericals (Parts G–H). Then cover answers in Parts I–J and recite.

Colour	Meaning
Yellow highlight	Must remember

Colour	Meaning
Blue card	A formula + a small Note
Green box	Hinglish mein samjho
Orange box	Values to remember (constants)
Purple box	A difficult idea explained
Cream box	Derivation – step by step, with 'Why'
Red box	Exam tip

Start Here · Difficult Words Made Easy

Word	Simple meaning	Symbol / unit
Electric charge	Property of matter due to which it feels electric force. Two kinds: positive and negative. **Hinglish:** Matter ki ek property jiski wajah se woh **electric force** feel karta hai. Do type: + aur −.	q, coulomb (C)
Quantisation	Charge always comes in whole-number multiples of e. **Hinglish:** Charge hamesha **e ke multiple** mein aata hai (q = ne). Aadha electron jaisa kuch nahi hota.	q = ne
Conservation of charge	Total charge of an isolated system never changes. Charge is only transferred. **Hinglish:** Charge na **banta** hai na **khatam** hota hai, sirf ek body se doosri mein **shift** hota hai.	–

Word	Simple meaning	Symbol / unit
Additivity	Total charge = algebraic sum of all charges (with signs). **Hinglish:** Total charge = sab charges ka **simple jod** (sign ke saath), jaise numbers jodte hain.	$q = q_1 + q_2 + \dots$
Conductor	Material in which charges (electrons) move freely. **Hinglish:** Jisme electrons **free** ghoomte hain (metals). Charge poore mein phail jaata hai.	Metals, human body
Insulator	Material in which charges cannot move freely. **Hinglish:** Jisme electrons **bandhe** hain (glass, rubber). Charge jahan diya wahin **ruka** rehta hai.	Glass, rubber, plastic
Earthing (grounding)	Connecting a body to the earth, which can give or take any amount of charge. **Hinglish:** Body ko zameen se jodna. Earth **bahut bada** hai, extra charge le leta hai ya de deta hai.	–
Point charge	Charged body whose size is very small compared to the distances involved. **Hinglish:** Charged body jiska size distance ke saamne **negligible** hai, bas ek point maan lo.	–
Permittivity (ε_0)	Tells how a medium allows electric force. ε_0 is for vacuum. **Hinglish:** Medium electric force ko kitna **allow** karta hai. Vacuum ka $\varepsilon_0 = 8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.	$8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

Word	Simple meaning	Symbol / unit
Dielectric constant (K)	$K = \varepsilon/\varepsilon_0$. Medium reduces force K times. Also called relative permittivity ε_r. **Hinglish:** $K = \varepsilon/\varepsilon_0$. Medium force ko **K guna kam** kar deta hai. Paani ka K ≈ 80.	No unit
Test charge (q_0)	Very small positive charge used to measure a field without disturbing it. **Hinglish:** Bahut **chhota** + charge jo field ko **naapta** hai, khud field ko disturb nahi karta.	q_0
Electric field (E)	Force per unit positive charge at a point. A vector. **Hinglish:** Charge ke aas-paas ka woh area jahan doosra charge **force feel** kare. $E = F/q_0$.	N C^{-1} or V m^{-1}
Field lines	Imaginary curves; tangent at any point gives direction of E. **Hinglish:** Imaginary lines jo batati hain + charge kis taraf **bhaagega**. Ghani lines = strong field.	–
Area vector	Vector of size = area, direction = perpendicular to the surface (outward for closed surface). **Hinglish:** Area ko vector banaya: size = area, direction = surface ke **perpendicular (bahar ki taraf)**.	ΔS
Electric flux (Φ)	Number of field lines crossing a surface. $\Phi = E \cdot \Delta S$. A scalar. **Hinglish:** Kisi surface se **kitni field lines guzarti** hain, uska naap. $\Phi = E \cdot \Delta S$.	N m^2 C^{-1}

Word	Simple meaning	Symbol / unit
Electric dipole	Pair of equal and opposite charges separated by a small distance 2a. **Hinglish:** Barabar aur ulte charges (+q, −q) jo **chhoti doori 2a** pe hain.	–
Dipole moment (p)	p = q × 2a, directed from −q to +q. **Hinglish:** p = q × 2a. Direction hamesha **−q se +q** ki taraf. Unit C m.	C m
Torque (τ)	Turning effect of a force = force × perpendicular distance. **Hinglish:** **Ghumaane wala** effect. Force × perpendicular distance.	N m
Gaussian surface	An imaginary closed surface chosen to apply Gauss's law. **Hinglish:** Ek **imaginary band surface** jo hum khud chunte hain taaki E nikaalna easy ho.	–
Charge density (λ, σ, ρ)	Charge per unit length / area / volume. **Hinglish:** Charge kitna **ghana** phaila hai: λ = per length, σ = per area, ρ = per volume.	C m^{-1}, C m^{-2}, C m^{-3}
Superposition principle	Net force (or field) = vector sum of forces (fields) due to each charge separately. **Hinglish:** Har charge apni force **alag se** lagata hai, doosre ki parwah kiye bina. Total = **vector sum**.	–
Uniform field	Field with the same magnitude and direction everywhere. **Hinglish:** Field jiska **size aur direction** har jagah same ho. Lines parallel aur barabar doori pe.	Parallel equidistant lines

Values to Remember · Particles and Constants

PARTICLES – charge and mass

Particle	Charge (q)	Mass (m)	Remember
Electron (e^-)	$q_e = -e = -1.6 \times 10^{-19}$ C	$m_e = 9.1 \times 10^{-31}$ kg (exact 9.109×10^{-31})	Lightest particle
Proton (p)	$q_p = +e = +1.6 \times 10^{-19}$ C	$m_p = 1.67 \times 10^{-27}$ kg (exact 1.673×10^{-27})	$m_p \approx 1836\, m_e$
Neutron (n)	$q_n = 0$ (no charge)	$m_n = 1.67 \times 10^{-27}$ kg (exact 1.675×10^{-27})	m_n slightly $> m_p$
Alpha particle (α (He nucleus))	$q_\alpha = +2e = +3.2 \times 10^{-19}$ C	$m_\alpha = 6.64 \times 10^{-27}$ kg $\approx 4\, m_p$	2 protons + 2 neutrons

CONSTANTS used in this chapter

Constant	Symbol	Value	Unit
Elementary charge Charge of 1 proton = −charge of 1 electron	e	1.6×10^{-19}	C
Permittivity of free space 8.85 – 'aath point aath paanch'	ε_0	8.854×10^{-12}	$C^2\ N^{-1}\ m^{-2}$
Coulomb constant $1/4\pi\varepsilon_0$ $k = 1/(4\pi\varepsilon_0) = 9 \times 10^9$	k	9×10^9	$N\ m^2\ C^{-2}$
Dielectric constant of water Force in water is 80 times smaller	K	≈ 80	no unit
Speed of light in vacuum $c = 1/\sqrt{(\mu_0 \varepsilon_0)}$	c	3×10^8	$m\ s^{-1}$
Gravitational constant Compare: electric force ≫ gravity	G	6.67×10^{-11}	$N\ m^2\ kg^{-2}$

PREFIXES – convert before you calculate

Prefix	Symbol	Value
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}

UNIT CONVERSIONS

Unit	In SI
1 cm	10^{-2} m
1 mm	10^{-3} m
1 Å (angstrom)	10^{-10} m
1 nm	10^{-9} m
1 cm^2	10^{-4} m^2
1 cm^3	10^{-6} m^3
1 μC	10^{-6} C
1 nC	10^{-9} C
1 eV	1.6×10^{-19} J
1 MeV	1.6×10^{-13} J
1 kWh	3.6×10^{6} J
1 atm	1.013×10^{5} Pa

HANDY FACTS

- $m_p / m_e \approx 1836$ – a proton is about 1836 times heavier than an electron.
- Number of electrons in 1 C = 1/e = 6.25×10^{18}.
- Electric force between two protons ≈ 10^{36} times their gravitational force.
- $4\pi\varepsilon_0 = 1/(9 \times 10^9) = 1.11 \times 10^{-10}$ C^2 N^{-1} m^{-2}.
- Charge is quantised: q = ne (n = whole number) – any charge must be a multiple of 1.6×10^{-19} C.

Hinglish mein samjho:
Roz ek baar yeh box padho. Sabse zaroori: **e = 1.6 × 10^{-19} C**, **k = 9 × 10^{9}**, **ε_0 = 8.85 × 10^{-12}**, electron mass **9.1 × 10^{-31} kg**, proton/neutron mass **1.67 × 10^{-27} kg**. Numerical se pehle units ko **SI** mein badlo (μC → 10^{-6} C).

Part A · Electric Charge

When you rub a glass rod with silk, electrons move from glass to silk. Glass becomes positive, silk becomes negative. Charge is not created – it is only transferred. Like charges repel, unlike charges attract.

1. Basic properties of charge

$$q = q_1 + q_2 + q_3 + \cdots$$

✎ **Note:** Additivity: charges add like ordinary numbers (scalars). E.g. +2, −5, +1 units → total −2 units.

Quantisation of charge

$$q = n\,e, \qquad n = 1, 2, 3, \ldots$$

$$e = 1.6 \times 10^{-19}\ \text{C}$$

✎ **Note:** Quantisation: charge comes in packets of e. We don't notice it in daily life because e is extremely small. Number of electrons: n = q/e.

Hinglish mein samjho:
Charge hamesha **e ke packet** mein. 1 C mein 6.25 × 10^{18} electrons. q = ne mein n hamesha **integer**.

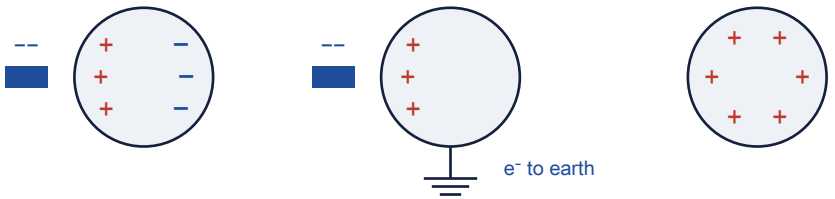
- Conservation: total charge of an isolated system stays constant (e.g. in rubbing, one body gains exactly what the other loses).
- SI unit of charge: coulomb (C). 1 μC = 10^{-6} C, 1 nC = 10^{-9} C.
- Charge of electron q_e = −e, of proton q_p = +e. A body becomes slightly heavier when it is negatively charged (it gains electrons of mass m_e

each).

Hinglish mein samjho:
Teen golden rules: (1) **Jodo** – total charge simple sum. (2) **Bachao** – charge banta/mitta nahi. (3) **Packet** – hamesha ne. Rubbing mein electrons **transfer** hote hain: glass ke electrons silk pe chale jaate hain, glass +, silk −.

2. Conductors, insulators and charging

- Conductors (metals) let charge flow – charge given to them spreads over the surface.
- Insulators (glass, plastic) hold charge where it is put – that's why we can charge them by rubbing.
- Three ways to charge: friction (rubbing), conduction (touching – same sign charge), induction (without touching – opposite sign).



1. Bring − rod near 2. Earth the sphere 3. Remove earth, then rod

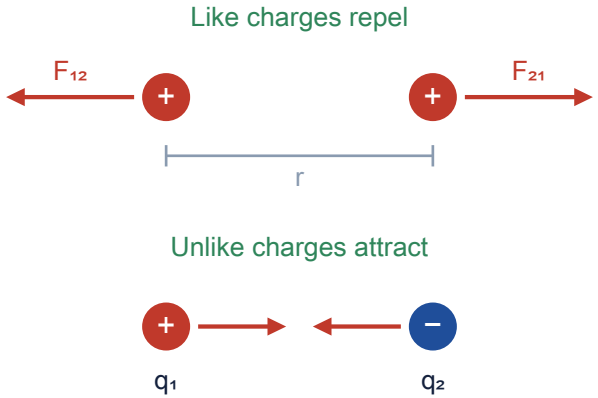
Charging by induction: the sphere gets a charge OPPOSITE to the rod, without touching it.

Difficult word → Charging by induction

Step 1: bring a negatively charged rod near a neutral metal sphere – positive charges gather near the rod, negative on the far side. Step 2: earth the sphere – the far negative charges flow to earth. Step 3: remove the earth, then the rod. The sphere is left with positive charge, spread uniformly.

Hinglish mein samjho:
Rod ko **touch kiye bina** charge karna. Rod ke paas opposite charge aate hain, door wale same charge earth mein chale jaate hain. Earth hatao, phir rod hatao. Sphere pe **rod ke ulta** charge bachta hai.

Part B · Coulomb's Law



Force acts along the line joining the charges; $F_{12} = -F_{21}$ (equal and opposite).

Coulomb's law

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

$$k = \frac{1}{4\pi\varepsilon_0} = 9\times10^{9}\ \mathrm{N\,m^2\,C^{-2}}$$

$$\varepsilon_0 = 8.854\times10^{-12}\ \mathrm{C^2\,N^{-1}\,m^{-2}}$$

✎ **Note:** Force is directly proportional to the product of charges and inversely proportional to the square of distance.

> **Hinglish mein samjho:**
> Force charges ke **product** ke saath badhti hai aur doori ke **square** ke saath ghatti hai. Doori double, force **1/4**.

Coulomb's law – vector form

$$\vec{F}_{21} = k\frac{q_1 q_2}{r^2}\hat{r}_{21}$$

$$\vec{F}_{12} = -\vec{F}_{21}$$

✎ **Note:** Vector form tells the direction: force acts along the line joining the charges; the two forces are equal and opposite.

> **Hinglish mein samjho:**
> F_{12} aur F_{21} **barabar aur ulte** (Newton ka 3rd law). Force hamesha dono charges ko jodne wali **line ke along**.

Force in a medium

$$F_{\text{medium}} = \frac{1}{4\pi\varepsilon_0 K}\frac{q_1 q_2}{r^2} = \frac{F_{\text{vacuum}}}{K}$$

✎ **Note:** In a medium of dielectric constant K the force becomes K times smaller. For water K ≈ 80.

Hinglish mein samjho:
Medium (jaise paani) beech mein aaye toh force **K guna kam**. Paani mein K = 80, force 80 guna kam.

Superposition principle

$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \cdots + \vec{F}_{1n}$$

✎ **Note:** Superposition principle: find the force due to each charge separately, then add them as vectors.

Hinglish mein samjho:
Teen charges hain? q_1 pe q_2 ki force aur q_3 ki force **alag-alag** nikaalo, phir **vector jod** do (direction dhyaan se!).

DERIVATION – Electric force vs gravity (two protons)

Step 1: Electric force between two protons (charge e each) at distance r:

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

Step 2: Gravitational force between them (mass m_p each):

$$F_g = G\frac{m_p^2}{r^2}$$

Step 3: Divide – r^2 cancels, so the answer is the same at every distance:

$$\frac{F_e}{F_g} = \frac{e^2}{4\pi\varepsilon_0 G m_p^2}$$

Why: both forces follow $1/r^2$, so their ratio does not depend on r.

Step 4: Put the values ($e = 1.6 \times 10^{-19}$ C, $m_p = 1.67 \times 10^{-27}$ kg, $G = 6.67 \times 10^{-11}$):

$$\frac{F_e}{F_g} = \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2} \approx 1.24 \times 10^{36}$$

Why: electric force is about 10^{36} times stronger. (For an electron and a proton use $m_e\, m_p$ in place of m_p^2 → about 2.3×10^{39}.)

Hinglish mein samjho:
Dono forces ka formula likho – dono mein **r^2 neeche** hai, isliye divide karte hi r **cancel**. Values daalo: electric force gravity se **10^{36} guna** zyada. Isliye atoms ke andar gravity ko ignore karte hain.

Hinglish mein samjho:
Dono inverse-square hain, par electric force **bahut zyada** strong hai (proton-proton mein ~10^{36} guna). Gravity sirf **kheenchti** hai; electric force kheench bhi sakti hai, **dhakel** bhi.

Exam tip: In numericals with 3 charges, draw a small diagram with arrows for each force first. Most mistakes are in the direction, not the formula.

Part C · Electric Field

Electric field – definition

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

$$\vec{F} = q\vec{E}$$

✎ **Note:** Electric field at a point = force per unit positive charge. It is a vector. SI unit: N C^{-1} (= V m^{-1}). Force on any charge q placed in the field: F = qE.

Hinglish mein samjho:
Field = **har 1 C** pe lagne wali force. Direction = + test charge jidhar bhaage. Unit **N/C** (ya V/m).

Difficult word → Why must a test charge be very small

A big test charge would push or pull the source charges and change the very field we want to measure. So $q_0 \to 0$.

Hinglish mein samjho:
Bada charge laoge toh woh source charges ko **khiska** dega, field hi badal jaayega. Chhota charge sirf **naapta** hai, chhedta nahi.

DERIVATION – Field of a point charge

Step 1: Place a small test charge q_0 at distance r from the charge q. By Coulomb's law the force on it is:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q\,q_0}{r^2}$$

Step 2: Field = force on each coulomb of test charge:

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

Step 3: Divide by q_0 – it cancels:

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

Why: the field depends only on the source charge q and the distance r – not on the test charge.

Hinglish mein samjho:
Ek chhota test charge q_0 rakho, Coulomb se force nikaalo, phir **q_0 se divide** karo. q_0 cancel ho jaata hai – field sirf **q aur r** pe depend karta hai: $E = kq/r^2$.

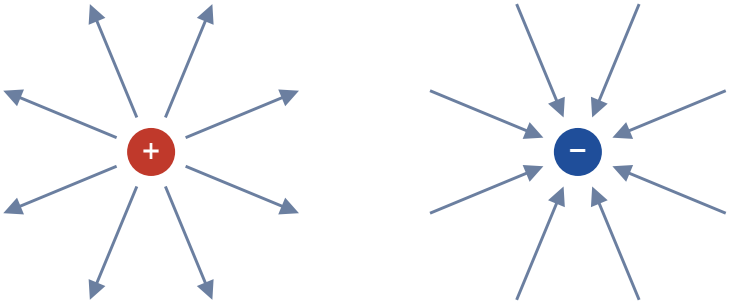
Field of a point charge

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

✎ **Note:** Field of a point charge falls as $1/r^2$ – double the distance, field becomes one-fourth. Radially outward for +q, inward for −q.

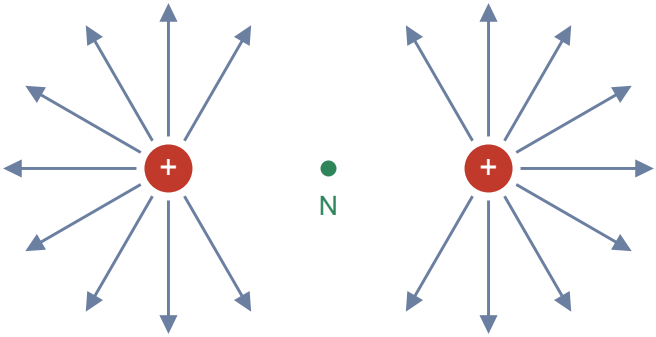
Hinglish mein samjho:
$E = kq/r^2$. Doori double, field **1/4**. + charge ka field **bahar**, − ka **andar** ki taraf.

Electric field lines



+q : lines go OUT −q : lines come IN

Field lines of single point charges (radial).



N = neutral point (E = 0)

Two equal positive charges: lines repel each other and never cross.

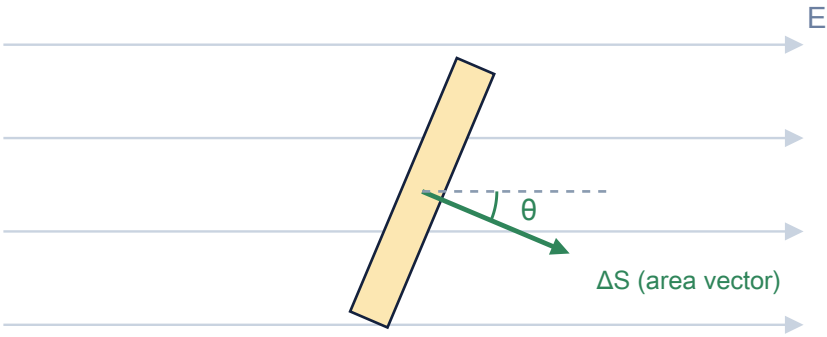
Properties of field lines (very important – 2/3 marks):

- Start from positive charge and end at negative charge (or at infinity).
- Two field lines never intersect – at the crossing point E would have two directions, which is impossible.
- They do not form closed loops (electrostatic field is conservative).
- Tangent at any point gives the direction of E.
- Closer lines = stronger field; far apart = weaker field.

- In a conductor at rest, lines meet the surface at 90° and there are no lines inside it.

Hinglish mein samjho:
Field lines + se **nikalti** hain, − mein **ghusti** hain. Kabhi **cross nahi** karti (ek point pe do direction nahi ho sakti). **Closed loop nahi** banati. Jahan lines ghani, wahan field strong.

Part D · Electric Flux



Flux ΔΦ = E ΔS cosθ. Area vector is perpendicular to the surface.

Electric flux

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

✎ **Note:** θ = angle between E and the area vector (normal). θ = 0° → maximum flux; θ = 90° → zero flux. Flux is a scalar. Unit: N m^2 C^{-1}.

Hinglish mein samjho:
Flux = kitni field lines surface ko **paar** karti hain. E aur area vector ke beech angle θ: Φ = EΔS cosθ. Scalar hai.

Difficult word → Area vector and cosθ

We make area a vector by giving it a direction – perpendicular to the surface. For a closed surface, it points outward. So flux out of a closed surface is positive, flux into it is negative.

Hinglish mein samjho:
Flux tab maximum jab field surface ko **seedha (90°)** chhed rahi ho, yaani area vector ke parallel (θ = 0). Surface field ke parallel ho toh **koi line paar nahi**, flux zero (θ = 90°).

Part E · Electric Dipole

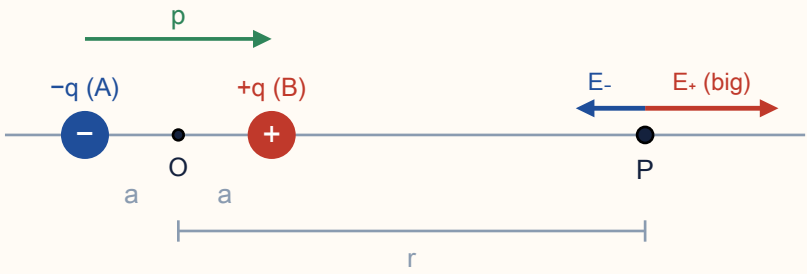
Electric dipole moment

$$p = q \times 2a$$

✎ **Note:** Two equal and opposite charges a small distance 2a apart. Total charge is zero, but the field is not zero because the charges are at different places. Direction of p: from −q to +q. Unit: C m. Polar molecules (H_2O) have a permanent dipole moment.

Hinglish mein samjho:
p = q × 2a. Direction **−q se +q** (yaad: minus se plus). Paani ka molecule ek **permanent dipole** hai.

DERIVATION – Field on the axial line



Axial point P: field due to +q (nearer) is bigger, so net E points along p.

Step 1: Point P is on the axis, at distance r from the centre O, on the side of +q. So P is (r − a) from +q and (r + a) from −q.

Step 2: Field of each charge at P (use $E = kq/r^2$):

$$E_{+q} = \frac{k\,q}{(r-a)^2} \quad (\text{along } \vec{p})$$

$$E_{-q} = \frac{k\,q}{(r+a)^2} \quad (\text{opposite to } \vec{p})$$

Step 3: They point in opposite directions, so subtract (the bigger one, from the nearer +q, wins):

$$E = k\,q\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]$$

Why: opposite vectors on a line → subtract.

Step 4: Take LCM. Use $(r + a)^2 - (r - a)^2 = 4ar$:

$$E = k\,q\,\frac{(r+a)^2-(r-a)^2}{(r^2-a^2)^2} = k\,q\,\frac{4ar}{(r^2-a^2)^2}$$

Step 5: Write q × 2a = p:

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

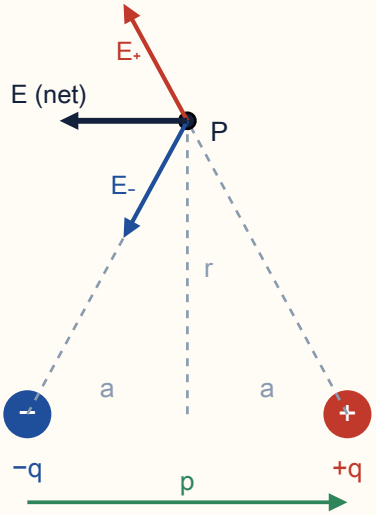
Step 6: Short dipole (r ≫ a): a^2 is tiny, drop it → $(r^2)^2 = r^4$:

$$E_{\text{axial}} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3} \qquad (\text{along } \vec{p})$$

Why: this boxed result is what the examiner wants.

Hinglish mein samjho:
+q, P ke **paas** hai, isliye uska field bada. Dono fields ulte, toh **minus** karo: $kq/(r-a)^2 - kq/(r+a)^2$. Simplify karo, $2kpr/(r^2 - a^2)^2$. Door ho (r ≫ a), **$2kp/r^3$**, direction **p ke along**.

DERIVATION – Field on the equatorial line



Equatorial point P: vertical parts cancel, horizontal parts add → net E is opposite to p.

Step 1: Point P is on the perpendicular bisector, at distance r from O. Both charges are $\sqrt{(r^2 + a^2)}$ away from P, so both fields are equal:

$$|E_{+q}| = |E_{-q}| = \frac{k\,q}{r^2 + a^2}$$

Step 2: Split each field into two parts. The parts perpendicular to the dipole cancel; the parts parallel to it add:

$$E = 2\,E_{+q}\cos\theta$$

Why: equal fields, mirror-image directions → sideways parts cancel.

Step 3: From the right-angled triangle:

$$\cos\theta = \frac{a}{\sqrt{r^2 + a^2}}$$

Step 4: Substitute:

$$E = 2 \cdot \frac{k\,q}{r^2 + a^2} \cdot \frac{a}{\sqrt{r^2 + a^2}} = \frac{k\,(q \cdot 2a)}{(r^2 + a^2)^{3/2}}$$

Step 5: Write q × 2a = p:

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

Step 6: Short dipole (r ≫ a):

$$E_{\text{equatorial}} = \frac{1}{4\pi\varepsilon_0}\,\frac{p}{r^3} \qquad (\text{opposite to } \vec{p})$$

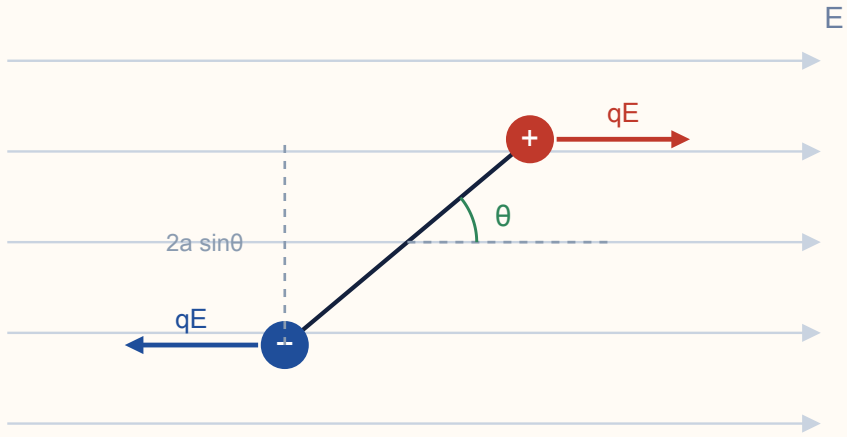
Why: compare with axial: $E_{axial} = 2 \times E_{equatorial}$ at the same distance.

Hinglish mein samjho:
Dono charges P se **barabar door**, toh dono fields ka size same.
Upar-neeche wale parts cancel, side wale jud jaate hain (2E cosθ). cosθ = a/√(r² + a²) daalo, kp/(r² + a²)^3/2. Door, **kp/r³**, direction **p ke ulta**.

Point	Field (short dipole)	Direction
Axial line	$(1/4\pi\varepsilon_0) \cdot 2p/r^3$	Along p
Equatorial line	$(1/4\pi\varepsilon_0) \cdot p/r^3$	Opposite to p
Result	$E_{axial} = 2 \times E_{equatorial}$	Dipole field $\propto 1/r^3$ (falls faster than a point charge, $1/r^2$)

Hinglish mein samjho:
Axial line pe field **$2kp/r^3$**, equatorial pe **kp/r^3**. Same doori pe axial = **2 × equatorial**. Dipole ka field $1/r^3$ se girta hai, point charge ka $1/r^2$ se, kyunki door se + aur − ek doosre ko **cancel** karne lagte hain.

DERIVATION – Torque on a dipole in uniform field



Equal and opposite forces (net force = 0) but they form a couple → torque τ = pE sinθ.

Step 1: Dipole at angle θ to a uniform field E. Forces on the two charges:

$$\vec{F}_{+q} = q\vec{E}, \qquad \vec{F}_{-q} = -q\vec{E}$$

Step 2: Add them – net force is zero, so the dipole does not move forward:

$$\vec{F}_{\text{net}} = q\vec{E} - q\vec{E} = 0$$

Step 3: But the two forces act at different points → they form a couple. Perpendicular distance between them (from the diagram):

$$d = 2a\sin\theta$$

Step 4: Torque = one force × perpendicular distance:

$$\tau = qE \times 2a\sin\theta = (q \cdot 2a)\,E\sin\theta$$

Step 5: Write q × 2a = p:

$$\tau = p\,E\sin\theta$$

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

Step 6: Special cases:

$$\theta = 90^\circ:\ \tau_{\max} = pE \qquad \theta = 0^\circ:\ \tau = 0\ \text{(stable)}$$

Why: at 0° the dipole is already along E, nothing turns it.

Hinglish mein samjho:
+q pe qE aage, −q pe qE peeche, barabar aur ulte, net force **zero**. Par alag points pe, toh **couple** banta hai. Torque = qE × 2a sinθ = **pE sinθ**. θ = 90° pe maximum, θ = 0° pe zero (stable).

Hinglish mein samjho:
Uniform field: dono charges pe force barabar-ulti, net force **zero**, sirf **ghoomta** hai. **Non-uniform**: forces barabar nahi, toh ghoomta bhi hai aur **khiskta** bhi.

Part F · Continuous Charges and Gauss's Law

Charge densities

$$\lambda = \frac{q}{L}\ (\mathrm{C\,m^{-1}}), \quad \sigma = \frac{q}{A}\ (\mathrm{C\,m^{-2}}), \quad \rho = \frac{q}{V}\ (\mathrm{C\,m^{-3}})$$

✎ **Note:** Linear, surface and volume charge density – used when charge is spread out on a wire, sheet or volume.

Hinglish mein samjho:
λ = charge per **metre** (wire), σ = per **m²** (sheet), ρ = per **m³** (volume). Units yaad rakho: C/m, C/m², C/m³.

Gauss's law

$$\Phi = \oint \vec{E} \cdot d\vec{S} = \frac{q_{\text{enclosed}}}{\varepsilon_0}$$

✎ **Note:** Gauss's law: total flux through any closed surface = (charge enclosed) / ε_0. Charges outside give zero net flux. Shape and size of the surface do not matter.

Hinglish mein samjho:
Kisi bhi **band surface** se total flux = andar ka charge / ε_0. Bahar ke charges ka net flux **zero**. Shape matter nahi karta.

- If net flux is zero, the net charge inside is zero (there may still be equal + and − charges).
- Gauss's law is most useful when there is symmetry – then E is constant on the chosen surface.

DERIVATION – Flux through a cube (charge at centre)

Step 1: By Gauss's law, total flux through the whole cube:

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

Step 2: The cube has 6 identical faces at the same distance from the charge, so each gets an equal share:

$$\Phi_{\text{one face}} = \frac{q}{6\,\varepsilon_0}$$

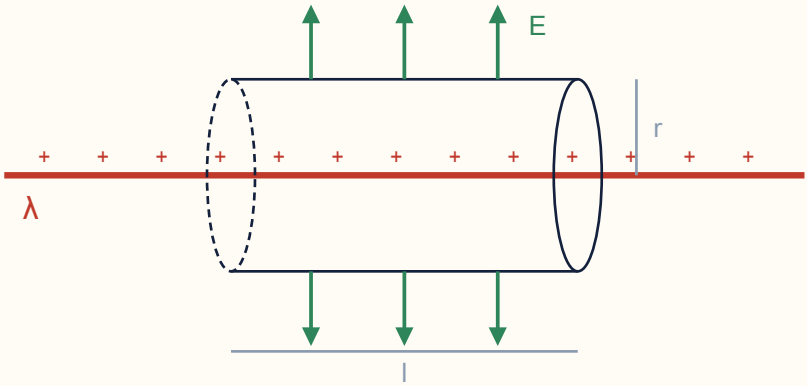
Step 3: If the charge is at a corner, 8 such cubes would surround it:

$$\Phi_{\text{cube}} = \frac{q}{8\,\varepsilon_0}$$

Hinglish mein samjho:
Gauss se total flux q/ε_0. Cube ke **6 barabar faces**, toh har face ko $q/6\varepsilon_0$. Charge corner pe ho toh **8 cubes** share karte hain: $q/8\varepsilon_0$.

Hinglish mein samjho:
Gauss law mein bas do cheezein dekho: surface ke **andar kitna charge** hai. Bahar wale charges flux mein **kuch add nahi** karte. Surface ka shape/size matter nahi karta. Symmetry ke hisaab se surface chuno: line = **cylinder**, sheet = **pill-box**, sphere = **sphere**.

DERIVATION – Field of an infinite line charge



Gaussian surface: cylinder of radius r and length l around the line charge.

Step 1: Choose a Gaussian cylinder of radius r and length l around the wire (charge per length λ).

Step 2: Flat ends: E is along the surface (E ⊥ area vector) → no flux. Curved surface: E is the same everywhere and along the area vector:

$$\Phi = E \times (2\pi r\, l)$$

Why: area of curved surface of a cylinder = 2πrl.

Step 3: Charge inside the cylinder:

$$q_{\text{enclosed}} = \lambda\, l$$

Step 4: Gauss's law – flux = charge / ε_0:

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

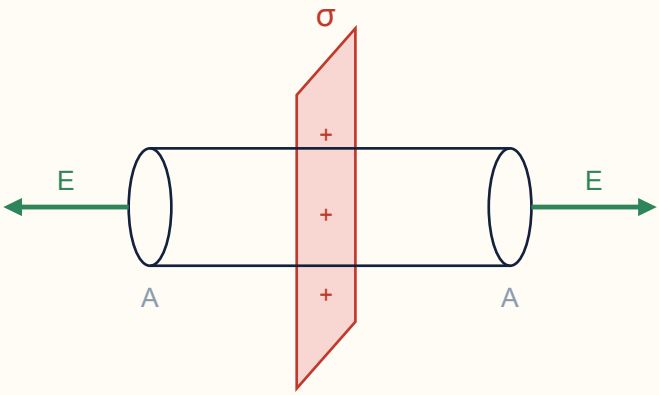
Step 5: Cancel l:

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

Why: field falls as 1/r and points radially outward (λ > 0).

Hinglish mein samjho:
Cylinder lo. Flat ends pe E surface ke **parallel**, flux zero. Curved surface pe E × 2πrl. Andar charge λl. Barabar rakho: **$E = \lambda/(2\pi\varepsilon_0 r)$**. Field 1/r se girta hai.

DERIVATION – Field of an infinite plane sheet



Gaussian surface: a small cylinder (pill-box) piercing the sheet; flux only through the two flat ends.

Step 1: Choose a small Gaussian cylinder (pill-box) of end area A that pierces the sheet (charge per area σ).

Step 2: E is perpendicular to the sheet on both sides. Curved surface: no flux. Two flat ends:

$$\Phi = EA + EA = 2EA$$

Step 3: Charge inside:

$$q_{\text{enclosed}} = \sigma A$$

Step 4: Gauss's law, then cancel A:

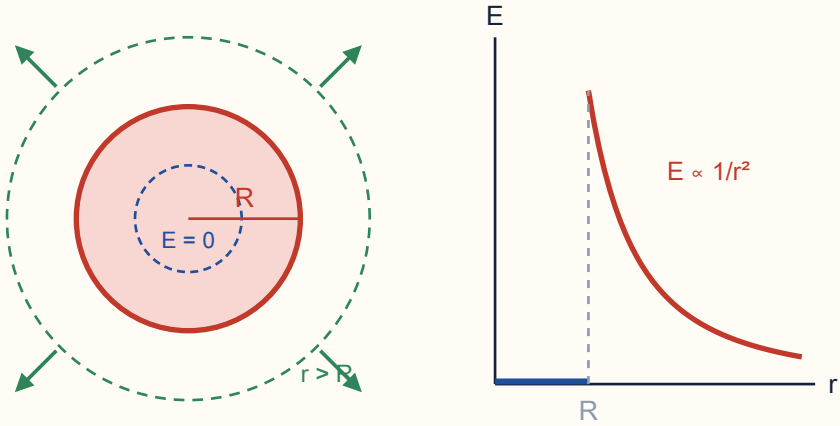
$$2EA = \frac{\sigma A}{\varepsilon_0}$$

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

Why: no r in the answer – the field is the same at every distance (uniform).

Hinglish mein samjho:
Pill-box lo. Flux sirf **do flat ends** se: 2EA. Andar charge σA. 2EA = σA/ε_0, **E = σ/2ε_0**. Mazedaar baat: field **doori pe depend nahi** karta!

DERIVATION – Field of a thin spherical shell



Thin spherical shell: E = 0 inside; outside it acts like a point charge at the centre (E ∝ 1/r²).

Step 1: Shell of radius R with charge q. Take a Gaussian sphere of radius r with the same centre.

Step 2: **Outside (r > R):** flux = E × area of sphere, and all of q is inside:

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

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

Why: same as a point charge q placed at the centre.

Step 3: On the surface (r = R): use $q = \sigma \times 4\pi R^2$:

$$E = \frac{q}{4\pi\varepsilon_0 R^2} = \frac{\sigma}{\varepsilon_0}$$

Step 4: Inside (r < R): the Gaussian sphere encloses no charge:

$$E(4\pi r^2) = 0 \quad \Rightarrow \quad E = 0$$

Hinglish mein samjho:
Bahar (r > R): sphere Gaussian surface, poora q andar, E = kq/r^2, jaise saara charge **centre pe** ho. Andar (r < R): Gaussian surface ke andar charge **zero**, toh **E = 0**.

Exam tip: For every Gauss's law derivation write: (1) choice of Gaussian surface with a diagram, (2) flux through each part, (3) charge enclosed, (4) result. Each step has marks.

Part G · Formula Sheet (one page)

Quantity	Formula	Unit
Quantisation	$q = ne, \quad e = 1.6 \times 10^{-19}\ \text{C}$	C
Coulomb's law	$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$	N
In a medium	$F = \frac{1}{4\pi\varepsilon_0 K}\frac{q_1 q_2}{r^2}$	N
Electric field	$E = \frac{F}{q_0}$	N C^{-1}

Quantity	Formula	Unit
Point charge	$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$	N C^{-1}
Force on a charge	$F = qE$	N
Flux	$\Phi = E\,\Delta S\cos\theta$	N m^2 C^{-1}
Dipole moment	$p = q \times 2a$	C m
Axial field	$E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$	N C^{-1}
Equatorial field	$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$	N C^{-1}
Torque on dipole	$\tau = pE\sin\theta$	N m
Gauss's law	$\Phi = \frac{q_{\text{enc}}}{\varepsilon_0}$	N m^2 C^{-1}
Line charge	$E = \frac{\lambda}{2\pi\varepsilon_0 r}$	N C^{-1}
Plane sheet	$E = \frac{\sigma}{2\varepsilon_0}$	N C^{-1}
Shell: outside / inside	$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$; $E = 0$	N C^{-1}
Force ratio (protons)	$\frac{F_e}{F_g} = \frac{e^2}{4\pi\varepsilon_0 G m_p^2} \approx 10^{36}$	–

Part H · Solved Numericals

Hinglish mein samjho:
Numerical ke 4 step: (1) **Given** likho, SI units mein badlo (cm → m, μC → 10^{-6} C). (2) **Formula** likho. (3) Values daalo. (4) Answer **unit ke saath**. Har step pe marks milte hain!

QN1. How many electrons make up a charge of −1 C?

Ans. Given: q = 1 C, e = 1.6 × 10^{-19} C

Formula:

$$n = \frac{q}{e}$$

Solution:

$$n = \frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$$

Answer: n = 6.25 × 10^{18} electrons

QN2. Two charges 2 μC and 3 μC are 30 cm apart in air. Find the force.

Ans. Given: q_1 = 2 × 10^{-6} C, q_2 = 3 × 10^{-6} C, r = 0.3 m

Formula:

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

Solution:

$$F = \frac{9 \times 10^9 \times 2 \times 10^{-6} \times 3 \times 10^{-6}}{(0.3)^2} = \frac{54 \times 10^{-3}}{0.09}$$

Answer: F = 0.6 N (repulsive)

QN3. The same two charges (of N_2) are now placed in a medium of dielectric constant K = 6. Find the new force.

Ans. Given: F_{air} = 0.6 N, K = 6

Formula:

$$F_{\text{medium}} = \frac{F_{\text{air}}}{K}$$

Solution:

$$F = \frac{0.6}{6}$$

Answer: F = 0.1 N

QN4. Find the electric field 20 cm from a point charge of 4 nC.

Ans. Given: q = 4×10^{-9} C, r = 0.2 m

Formula:

$$E = k\frac{q}{r^2}$$

Solution:

$$E = \frac{9 \times 10^9 \times 4 \times 10^{-9}}{(0.2)^2} = \frac{36}{0.04}$$

Answer: E = 900 N C^{-1} (radially outward)

QN5. A dipole has charges ±10 μC separated by 5 mm. Find the field at 15 cm from its centre on (a) the axis (b) the equatorial line.

Ans. Given: q = 10^{-5} C, 2a = 5 × 10^{-3} m, r = 0.15 m (r ≫ a)

Formula:

$$p = q \times 2a; \quad E_{ax} = \frac{2kp}{r^3}; \quad E_{eq} = \frac{kp}{r^3}$$

Solution:

$$p = 10^{-5} \times 5 \times 10^{-3} = 5 \times 10^{-8}\ \text{C m}$$

$$E_{ax} = \frac{2 \times 9 \times 10^{9} \times 5 \times 10^{-8}}{(0.15)^3} = \frac{900}{3.375 \times 10^{-3}} = 2.67 \times 10^{5}\ \text{N C}^{-1}$$

$$E_{eq} = \frac{E_{ax}}{2} = 1.33 \times 10^{5}\ \text{N C}^{-1}$$

Answer: (a) 2.67 × 10^5 N/C along p (b) 1.33 × 10^5 N/C opposite to p

QN6. A dipole of moment 4 × 10^{-9} C m makes 30° with a uniform field of 5 × 10^4 N C^{-1}. Find the torque.

Ans. Given: p = 4 × 10^{-9} C m, E = 5 × 10^4 N C^{-1}, θ = 30°

Formula:

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

Solution:

$$\tau = 4 \times 10^{-9} \times 5 \times 10^{4} \times \sin 30^\circ = 2 \times 10^{-4} \times 0.5$$

Answer: τ = 1 × 10^{-4} N m

QN7. A square of side 10 cm is in a uniform field of 3×10^3 N C^{-1}. Its normal makes 60° with the field. Find the flux.

Ans. Given: $\Delta S = (0.1)^2 = 0.01$ m^2, $E = 3 \times 10^3$ N C^{-1}, $\theta = 60°$

Formula:

$$\Phi = E\,\Delta S \cos\theta$$

Solution:

$$\Phi = 3 \times 10^3 \times 0.01 \times \cos 60^\circ = 30 \times 0.5$$

Answer: Φ = 15 N m^2 C^{-1}

QN8. A charge of 8.85 μC is at the centre of a cube. Find the flux through the whole cube and through one face.

Ans. Given: $q = 8.85 \times 10^{-6}$ C, $\varepsilon_0 = 8.85 \times 10^{-12}$

Formula:

$$\Phi = \frac{q}{\varepsilon_0}; \qquad \Phi_{\text{face}} = \frac{\Phi}{6}$$

Solution:

$$\Phi = \frac{8.85 \times 10^{-6}}{8.85 \times 10^{-12}} = 10^6$$

$$\Phi_{\text{face}} = \frac{10^6}{6} = 1.67 \times 10^5$$

Answer: 10^6 N m^2 C^{-1} (total); 1.67×10^5 N m^2 C^{-1} (one face)

QN9. Find the field near an infinite sheet with σ = 8.85 × 10^{-8} C m^{-2}.

Ans. Given: σ = 8.85 × 10^{-8} C m^{-2}

Formula:

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

Solution:

$$E = \frac{8.85 \times 10^{-8}}{2 \times 8.85 \times 10^{-12}} = \frac{10^4}{2}$$

Answer: E = 5 × 10^3 N C^{-1}

Part I · Conceptual "Why" Questions

Q1. Two electric field lines never intersect. Why? [2]

Ans. At the point of intersection there would be two tangents, i.e. two directions of E at one point – impossible. E has only one direction at a point.

Q2. Electrostatic field lines do not form closed loops. Why? [2]

Ans. They start on positive and end on negative charges. Also the electrostatic field is conservative – work done around a closed path is zero.

Q3. Why is a test charge taken to be very small? [2]

Ans. So that it does not disturb the source charges and hence does not change the field being measured.

Q4. When a glass rod is rubbed with silk, which one gains mass? [2]

Ans. Silk – electrons go from glass to silk. Silk becomes negative and its mass increases slightly ($n \times m_e$, $m_e = 9.1 \times 10^{-31}$ kg).

Q5. Why is quantisation of charge not noticed at the macroscopic level? [2]

Ans. $e = 1.6 \times 10^{-19}$ C is extremely small; ordinary charges contain billions of e, so charge seems continuous.

Q6. Force between two charges is less in water than in air. Why? [2]

Ans. Water has a high dielectric constant ($K \approx 80$) – force reduces K times.

Q7. A dipole is placed in a uniform field. Is there a net force? Torque? [2]

Ans. Net force = zero (equal and opposite forces). Torque = $pE \sin\theta$ – non-zero unless p is parallel/antiparallel to E.

Q8. What happens to a dipole in a non-uniform field? [2]

Ans. Forces on +q and −q are unequal → net force as well as torque. It moves (towards stronger field if p is along E) and rotates.

Q9. Net flux through a closed surface is zero. Does it mean there is no charge inside? [2]

Ans. No. It means the net charge inside is zero – there may be equal positive and negative charges.

Q10. Does flux through a closed surface depend on its shape or size? [2]

Ans. No. It depends only on the charge enclosed ($\Phi = q/\varepsilon_0$).

Q11. Why does the field of a dipole fall faster ($1/r^3$) than that of a point charge ($1/r^2$)? [2]

Ans. From far away, the + and − charges look almost at the same place and their fields nearly cancel.

Q12. Electric field inside a charged spherical shell is zero. Why? [2]

Ans. A Gaussian surface inside encloses no charge, so by Gauss's law the flux and hence E is zero.

Part J · Question Bank to Memorise

1-mark questions

Q1. SI unit of electric flux? [1]

Ans. N m^2 C^{-1} (or V m).

Q2. Value of $k = 1/4\pi\varepsilon_0$? [1]

Ans. 9×10^9 N m^2 C^{-2}.

Q3. Mass of electron and proton? [1]

Ans. $m_e = 9.1 \times 10^{-31}$ kg; $m_p = 1.67 \times 10^{-27}$ kg ($m_p \approx 1836\ m_e$).

Q4. Direction of dipole moment? [1]

Ans. From −q to +q.

Q5. If distance between two charges is doubled, force becomes? [1]

Ans. One-fourth ($F \propto 1/r^2$).

Q6. Electric field inside a uniformly charged thin spherical shell? [1]

Ans. Zero.

Q7. Charge q at the centre of a cube – flux through one face? [1]

Ans. $q/6\varepsilon_0$.

Q8. Field due to an infinite plane sheet? [1]

Ans. $\sigma/2\varepsilon_0$ – independent of distance.

Q9. Torque on a dipole is maximum when θ = ? [1]

Ans. 90°.

Q10. Can a body have charge 2.4×10^{-19} C? [1]

Ans. No – it is not an integer multiple of e (2.4/1.6 = 1.5).

Q11. Ratio of axial to equatorial field of a short dipole at equal distance? [1]

Ans. 2 : 1.

Assertion–Reason

A: both true, R explains A. B: both true, R doesn't explain A. C: A true, R false. D: A false, R true.

QAR1. A: Electric field lines never cross. R: At a point, the electric field has a unique direction. [1]

Ans. A

QAR2. A: A dipole in a uniform field experiences no net force. R: Forces on its two charges are equal and opposite. [1]

Ans. A

QAR3. A: Flux through a closed surface depends on charges outside it. R: Field lines from outside charges enter and leave the surface. [1]

Ans. D – A is false (outside charges give zero net flux); R is true.

QAR4. A: Field of an infinite sheet is independent of distance. R: Field lines of an infinite sheet are parallel (uniform). [1]

Ans. A

3-mark and 5-mark questions

QL1. Derive the expression for the electric field at a point on the axial line of a dipole. [3]

Ans. See Part E. Result:

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2 - a^2)^2} \quad \rightarrow \quad \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3} \; (r \gg a)$$

Direction: along p.

QL2. Derive the torque on a dipole in a uniform field. When is it in stable equilibrium? [3]

Ans. See Part E. Result:

$$\tau = pE\sin\theta, \qquad \vec{\tau} = \vec{p} \times \vec{E}$$

Stable at θ = 0° (p along E).

QL3. State Gauss's law. Use it to find the field due to an infinitely long straight charged wire. [3]

Ans. $\Phi = q/\varepsilon_0$. Gaussian cylinder (Part F):

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

QL4. Using Gauss's law find the field of a uniformly charged thin spherical shell at points (i) outside (ii) inside. Draw the E–r graph. [5]

Ans. Outside:

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

Inside: E = 0. Graph: zero up to R, then falls as $1/r^2$ (see Part F diagram).

QL5. State properties of electric field lines. Draw field lines for (i) a positive charge (ii) a dipole (iii) two equal positive charges. [5]

Ans. Six properties in Part C + three diagrams in Part C and on the cover.

Last-Minute Checklist

- I can write m_e, m_p, m_n, e, k and ε_0 with their values and units (orange box).
- I know 3 properties of charge and can explain charging by induction with a diagram.
- I can write Coulomb's law (scalar + vector form) and derive F_e/F_g for two protons.
- I can derive $E = kq/r^2$ from Coulomb's law.
- I can draw field lines for +q, −q, dipole and two like charges, and list 6 properties.
- I can derive: axial field, equatorial field, torque on dipole – line by line.
- I can derive with Gauss's law: line charge, plane sheet, spherical shell (+ E–r graph) and flux through a cube.
- I can solve all 9 numericals in Part H without looking.