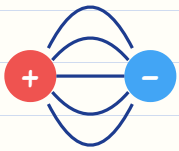
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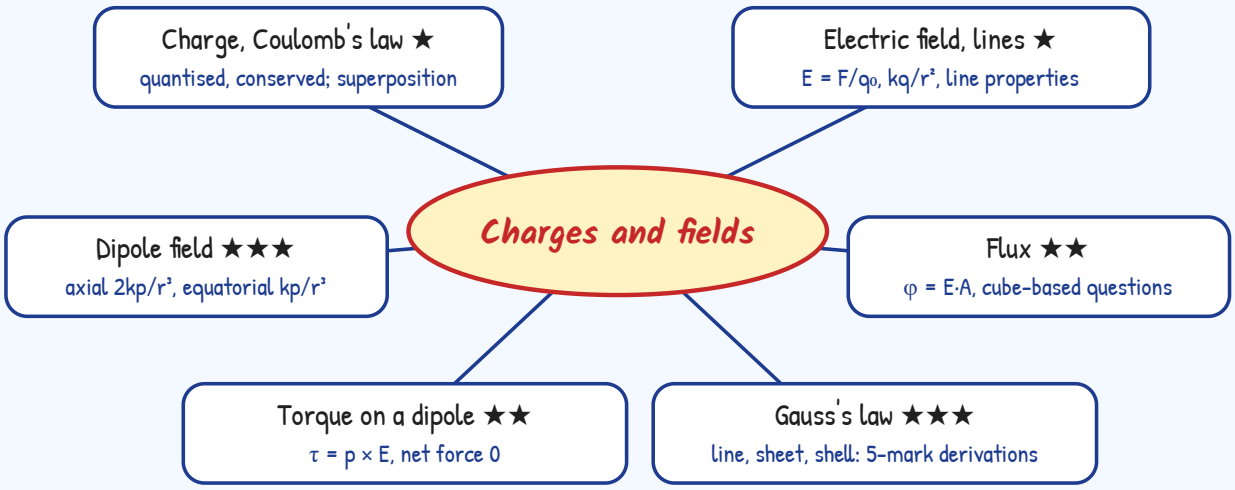


# Chapter 1
# Electric Charges and Fields




NCERT Physics Part I, Reprint 2026-27 · CBSE board 2027

## Chapter map (★ = asked again and again in CBSE 2024–2026)




## What is inside

1. Charge, Coulomb's law, superposition
2. Electric field, field lines, flux
3. Dipole: field, torque; charge densities
4. Gauss's law and its three applications
5. Derivation checklist, commonly confused points
6. NCERT Exercises 1.1–1.23, solved
7. CBSE board questions 2024–2026, solved
8. What the board asked · 3 case studies
9. Practice set A–G, 20 MCQs, 6 A–R, answers, summary

## Colour code used

red = key term  green = definition

purple = sub-heading  black = working

★ = high-frequency board topic

1 = mark the examiner gives for that step

★ **Exam tip:** I checked 16 CBSE Physics papers (2024: 55/1–5, 2025: 55/1, 2, 4–7, 2026: 55/1–5, set 1 of each). This chapter came in **at least 12 of them**. The 5-mark question is almost always a **dipole field derivation** or a **Gauss's law application** (sheet, line or shell) with a numerical.

Based on NCERT Physics Part I (2026-27), Chapter 1. Figures redrawn and all answers written by us. Board questions are quoted from the CBSE papers named in each tag; answers checked against the CBSE marking schemes where available.

# 1.1–1.3 Electric charge

**Definition** ✎ **Electrostatics** is the study of forces, fields and potentials due to charges **at rest**.

- Thales of Miletus (≈600 BC): amber rubbed with wool attracts light objects. The word **electricity** comes from the Greek *elektron* (amber).
- There are **two kinds** of charge, named **positive** and **negative** by Benjamin Franklin. **Like charges repel, unlike charges attract.** Glass rod rubbed with silk: glass +, silk −. Plastic rod rubbed with fur: rod −, fur +.
- On rubbing, **electrons are transferred** from one body to the other; no charge is created. The body that loses electrons becomes positive.
- A **gold-leaf electroscope** detects charge: the leaves diverge, and the divergence shows the amount.

## Conductors and insulators

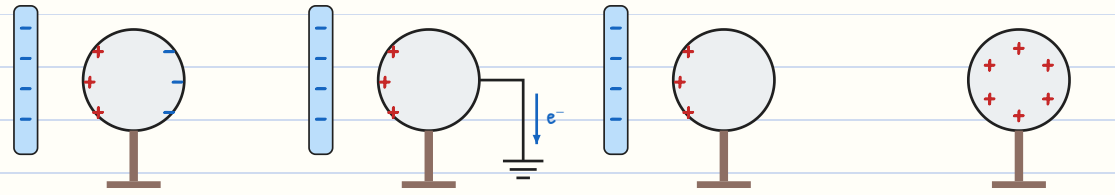
**Conductors** (metals, human body, earth) let charge move freely; charge given to a conductor spreads over its whole surface. **Insulators** (glass, plastic, nylon) hold charge where it is put.

**Earthing (grounding):** connecting a body to the earth through a conductor; the excess charge flows to the earth and the body becomes neutral. Appliances have a third **earth pin** for safety.

## Charging by induction ★

1. Bring a charged rod (say −) near an **uncharged, insulated** metal sphere: + is induced on the near side, − on the far side.
2. Connect the far side to the earth: the − charge flows away.
3. Remove the earth connection first, **then** the rod.
4. The sphere is left with a **+ charge** (opposite to the rod), spread uniformly.

A charged body attracts a neutral one because the induced unlike charge is nearer than the like charge.




(a) rod near: charges separate (b) far side earthed: $e^-$ flow away (c) earth removed, rod still near (d) rod removed: + spreads

*Charging by induction (−rod): the insulated sphere ends up with a + charge, opposite to the rod*

# 1.4 Basic properties of charge ★

| Property | What it means | Example |
|---|---|---|
| **Additivity** | Charge is a scalar: total charge = algebraic sum $q_1 + q_2 + \cdots + q_n$ | $+1, +2, -3, +4, -5$ units give $-1$ unit |
| **Conservation** | Total charge of an isolated system never changes; charge is only transferred | rubbing; in pair production, $\gamma \to e^- + e^+$ (net 0) |
| **Quantisation** | Every free charge is an integral multiple of $e$: $q = ne$, $n = 0, \pm1, \pm2, \ldots$ | $e = 1.602 \times 10^{-19}$ C (Millikan's oil drop) |

At the macroscopic level quantisation can be **ignored**: 1 μC holds about $10^{13}$ electronic charges, so adding or removing a few $e$ makes no visible difference and charge behaves as continuous. The SI unit of charge is the **coulomb** (C): the charge flowing in 1 s through a wire carrying 1 A. 1 μC = $10^{-6}$ C, 1 nC = $10^{-9}$ C.

*NCERT Example 1.1* If $10^9$ electrons move out of a body every second, how long will it take to collect 1 C on it?

> **Ans.** Charge per second $= 10^9 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-10}$ C. Time $= 1/1.6 \times 10^{-10} = 6.25 \times 10^9$ s $\approx$ **198 years**. So 1 C is a very large charge.

*NCERT Example 1.2* How much positive and negative charge is there in a cup of water (250 g)?

> **Ans.** Moles $= 250/18 = 13.9$; molecules $= 13.9 \times 6.02 \times 10^{23} = 8.36 \times 10^{24}$, each with 10 electrons. Charge $= 8.36 \times 10^{25} \times 1.6 \times 10^{-19} = 1.34 \times 10^7$ **C** of each sign.

## 1.5 Coulomb's law ★

> **Definition** ✎ The force between two **point charges** is directly proportional to the product of the charges and inversely proportional to the square of the distance between them, acting along the line joining them.

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

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

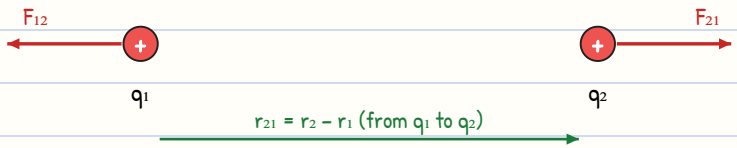
$\varepsilon_0 = 8.854 \times 10^{-12}$ C² N⁻¹ m⁻² is the **permittivity of free space**.

**1 C** is the charge that, placed 1 m from an equal charge in vacuum, repels it with $9 \times 10^9$ N.

**Vector form:** force on $q_2$ due to $q_1$:

$$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0}\,\frac{q_1 q_2}{r_{21}^2}\,\hat{r}_{21}$$

Works for both signs: $q_1 q_2 > 0$ gives repulsion, $q_1 q_2 < 0$ attraction. $\vec{F}_{12} = -\vec{F}_{21}$ (Newton's third law).




*Like charges: $F_{21}$ (on $q_2$) acts along $\hat{r}_{21}$; $F_{12} = -F_{21}$ (Newton's third law)*

In a medium of dielectric constant $K$: $F_{\text{medium}} = F_{\text{vacuum}}/K$.

| Coulomb force | Gravitational force |
|---|---|
| attractive or repulsive | always attractive |
| depends on the medium | independent of the medium |
| very strong: e-p ratio $\approx 2.4 \times 10^{39}$ | very weak |
| both: inverse-square, central, conservative, act at a distance | |

**✗ Don't do this:** Coulomb's law is for **point charges** (size ≪ distance). For two charged metal spheres placed close together, the charges redistribute and the simple formula is not exact.

## 1.6 Forces between multiple charges: superposition ★★

The force on a charge due to several charges is the **vector sum** of the forces due to each one, each calculated as if the others were absent:

$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \cdots + \vec{F}_{1n} = \frac{q_1}{4\pi\varepsilon_0}\sum_{i=2}^{n}\frac{q_i}{r_{1i}^2}\hat{r}_{1i}$$

*NCERT Example 1.5* Three charges $q$ each at the vertices of an equilateral triangle of side $l$. Force on a charge $Q$ (same sign) at the centroid?

> **Ans.** The three forces are equal ($kqQ/(l/\sqrt{3})^2$) and 120° apart, so their sum is **zero**. (Symmetry: rotating by 120° leaves the system unchanged.)

*NCERT Example 1.6* Charges $q, q, -q$ at the corners of an equilateral triangle of side $l$. Force on each?

> **Ans.** On each $+q$: $F = kq^2/l^2$ from the other $+q$ (repulsion) and $kq^2/l^2$ towards $-q$; at 120°, resultant $F$ along the bisector. On $-q$: two attractions of $F$ at 60°, resultant $\sqrt{3}F$. Total of all three forces $= 0$.

**★ Exam tip:** Superposition questions: (1) draw every force with its direction, (2) use symmetry: equal charges at opposite corners of a square, or equal charges at the vertices of an equilateral triangle, cancel at the centre, (3) only then add components.

*Exam-style* Two identical conducting spheres touch: what happens to the charge?

> **Ans.** They share it **equally**: each gets $(q_1 + q_2)/2$. Touching one charged sphere to an identical neutral one halves its charge.

**Coulomb force on point charges in a line:** for a charge to be in equilibrium between two like charges $q_1$ and $q_2$ a distance $d$ apart, place it at $x = d\sqrt{q_1}/(\sqrt{q_1} + \sqrt{q_2})$ from $q_1$ (nearer the smaller charge).

## 1.7 Electric field ★

> **Definition** ✎ The **electric field** at a point is the force experienced by a **small positive test charge** placed there, per unit charge: $\vec{E} = \lim_{q_0 \to 0} \vec{F}/q_0$. SI unit N/C (= V/m). It is a **vector**.

**Field of a point charge** $Q$ at distance $r$:

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

- $Q > 0$: $\vec{E}$ points radially **outward**; $Q < 0$: inward.
- Same magnitude at every point of a sphere centred on $Q$ (spherical symmetry).
- Force on any charge $q$ placed in a field: $\vec{F} = q\vec{E}$ (opposite to $\vec{E}$ for $q < 0$).
- The test charge is taken very small so that it does not disturb the charges producing the field.

### 1.7.1 Field of a system of charges (superposition):

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

**1.7.2 Why the field matters:** the field exists at every point even with no charge placed there; it carries the effect of a charge to another charge, and for time-varying situations it travels at the speed of light. It is the physical agent (electromagnetic waves are fields that travel on their own).

*NCERT Example 1.7* An electron falls 1.5 cm in a uniform field of $2.0 \times 10^4$ N/C. The field is then reversed and a proton falls the same distance. Compare the times of fall.

> **Ans.** $a = eE/m, t = \sqrt{2h/a} = \sqrt{2hm/(eE)}$.
>
> Electron: $t_e = \sqrt{\dfrac{2 \times 0.015 \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 2 \times 10^4}} = 2.9 \times 10^{-9}$ s.
>
> Proton: $t_p = 1.3 \times 10^{-7}$ s. The heavier particle takes longer ($t \propto \sqrt{m}$). Gravity ($g$) is negligible compared with $eE/m$.

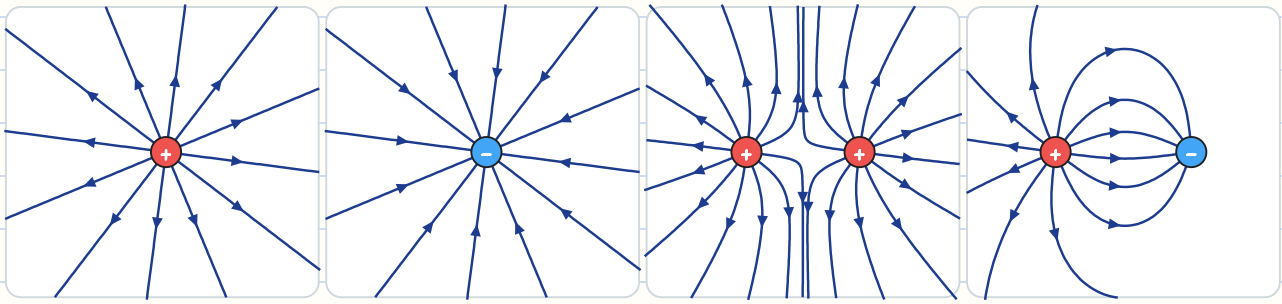
*NCERT Example 1.8* $q_1 = +10^{-8}$ C and $q_2 = -10^{-8}$ C are 0.1 m apart. Find the field at A (midpoint), B (0.05 m to the left of $q_1$) and C (0.1 m from both).

> **Ans.** Midpoint A: each charge gives $kq/r^2 = 9 \times 10^9 \times 10^{-8}/0.05^2 = 3.6 \times 10^4$ N/C, both towards $q_2$: $7.2 \times 10^4$ N/C towards $q_2$. At B: $3.6 \times 10^4$ (to the left, away from $q_1$) minus $9 \times 10^9 \times 10^{-8}/0.15^2 = 4 \times 10^3$ (to the right) gives $3.2 \times 10^4$ N/C, to the left. At C (equidistant, 0.1 m from each): $9 \times 10^3$ N/C, parallel to $q_1 \to q_2$.

★ **Exam tip:** Often asked as a 1-mark question: "**a charged particle released in a uniform field**": the force $qE$ is constant, so $a = qE/m$, and after a distance $x$ the kinetic energy is $qEx$ (asked in CBSE 2026, 55/3/1). Time to cover $x$ from rest: $t = \sqrt{2xm/(qE)} \propto \sqrt{m}$ for equal charges (CBSE 2024, 55/2/1).

## 1.8 Electric field lines ★

**Definition** ✎ A **field line** is a curve drawn so that the **tangent** at any point gives the direction of the net field there. Faraday called them "lines of force".



(a) +q: lines outwards (b) −q: lines inwards (c) +q, +q: neutral point (d) dipole +q, −q

*Field lines (traced from $E = \Sigma kq\,\hat{r}/r^2$): they start on +, end on −, never cross; denser = stronger field*

### Properties (write any four for 2 marks)

1. They start on positive charges and end on negative charges (or at infinity for a single charge).
2. In a charge-free region they are **continuous curves** without breaks.
3. Two field lines **never cross**: at the crossing point the field would have two directions.

4. Electrostatic field lines **do not form closed loops** (the field is conservative). (CBSE 2025, 55/2/1 asked exactly this.)
5. Where lines are **closer**, the field is **stronger**; parallel, equally spaced lines mean a uniform field.
6. They are normal to the surface of a conductor and do not exist inside it.

The number of lines is a matter of choice; what matters is their **relative density**. Through a solid angle the number of lines is fixed, so at distance $r$ the density falls as $1/r^2$, just like the field. For 2D drawings this is only a guide.

## 1.9 Electric flux ★★

**Definition** ✎ Electric flux through a small area $\Delta\vec{S}$ is $\Delta\phi = \vec{E}\cdot\Delta\vec{S} = E\,\Delta S\cos\theta$; it measures the **number of field lines** crossing the area.

$$\phi = \oint \vec{E}\cdot d\vec{S}$$ (scalar; unit N m² C⁻¹ or V m)

- $\theta$ = angle between $\vec{E}$ and the **normal** to the area (area vector). For a closed surface the normal points **outward**.
- Maximum ($ES$) when $\vec{E}$ is along the normal; **zero** when $\vec{E}$ lies in the plane of the area.
- Dimensions: $[\mathrm{M\,L^3T^{-3}A^{-1}}]$ (asked CBSE 2024, 55/5/1).

*NCERT Example 1.10* Field components $E_x = \alpha x^{1/2}$, $E_y = E_z = 0$, $\alpha = 800$ N C⁻¹ m⁻¹/². Cube of side $a = 0.1$ m placed as in Fig. 1.24: its faces normal to $x$ are at $x = a$ and $x = 2a$. Flux and charge?

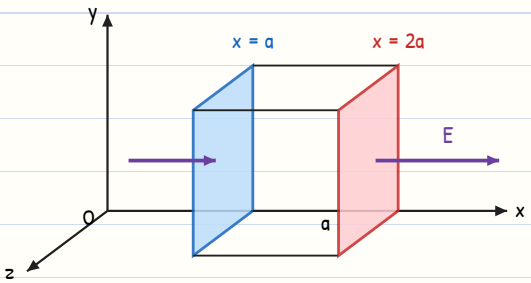
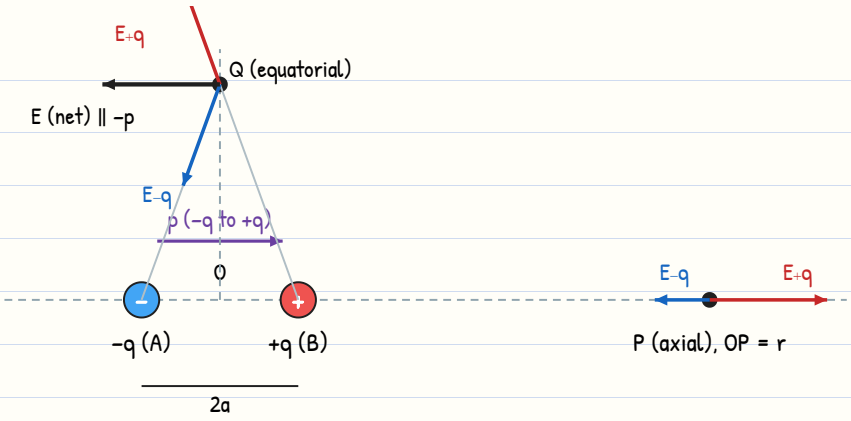



*Fig. 1.24: $E = \alpha\sqrt{x}\,\hat{i}$ enters at x = a and leaves, stronger, at x = 2a; the other four faces carry no flux*

**Ans.** Only the two faces normal to $x$ count. $\phi = E(2a)\,a^2 - E(a)\,a^2 = \alpha a^{5/2}(\sqrt{2}-1) = 800\times(0.1)^{5/2}\times 0.414 =$ **1.05 N m² C⁻¹**. $q = \varepsilon_0\phi = 9.27\times10^{-12}$ **C**. (Same method as the CBSE 2024 cube question, see 'Board questions: numericals inside the 5-markers'.)

## 1.10 Electric dipole ★★★

**Definition** ✎ An **electric dipole** is a pair of equal and opposite charges $+q$ and $-q$ separated by a small distance $2a$. **Dipole moment** $\vec{p} = q\times 2a\,\hat{p}$, directed from $-q$ to $+q$. SI unit C m. Total charge = 0, but the field is not zero.




*Axial point P: E along p. Equatorial point Q: the components along OQ cancel; E is opposite to p*

## (a) On the axis (point P, OP = r) S-mark

Field due to $-q$ (at distance $r+a$, towards $-q$) and $+q$ (at $r-a$, away from $+q$):

$$\vec{E}_{-q} = -\frac{q}{4\pi\varepsilon_0(r+a)^2}\hat{p}, \quad \vec{E}_{+q} = \frac{q}{4\pi\varepsilon_0(r-a)^2}\hat{p}$$

$$\vec{E} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]\hat{p} = \frac{q}{4\pi\varepsilon_0}\frac{4ar}{(r^2-a^2)^2}\hat{p}$$

For $r \gg a$:

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

## (b) On the equatorial plane (point Q, OQ = r) S-mark

Both charges are at distance $\sqrt{r^2+a^2}$; the magnitudes are equal:

$$E_{+q} = E_{-q} = \frac{q}{4\pi\varepsilon_0(r^2+a^2)}$$

The components along OQ cancel; the components parallel to the axis add, each $E\cos\theta$ with $\cos\theta = a/\sqrt{r^2+a^2}$, pointing opposite to $\vec{p}$:

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

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

For $r \gg a$:

$$\vec{E}_{\text{eq}} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3}$$

At the centre ($r=0$): $E = \dfrac{p}{4\pi\varepsilon_0 a^3} = \dfrac{2q}{4\pi\varepsilon_0 a^2}$ (CBSE 2025, 55/6/1).

★ **Exam tip:** At the same large distance, $E_{\text{axial}} = 2E_{\text{equatorial}}$, and the dipole field falls as $1/r^3$ (a point charge's falls as $1/r^2$). Remember the directions: axial along $\vec{p}$, equatorial opposite to $\vec{p}$. Examiners give 1 mark for the labelled diagram, so always draw it.

*NCERT Example 1.9* Charges $\pm 10$ μC are 5.0 mm apart. Find the field (a) at a point on the axis 15 cm from the centre on the side of $+q$, (b) on the equatorial line at 15 cm.

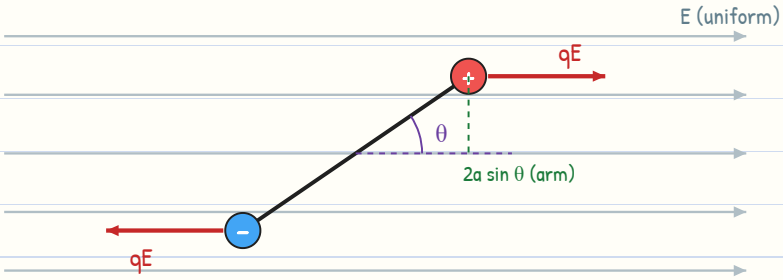
**Ans.** $p = 10^{-5} \times 5 \times 10^{-3} = 5 \times 10^{-8}$ C m.

(a) Using the exact charges: $E = 9 \times 10^9 \times 10^{-5}\left[\dfrac{1}{0.1475^2} - \dfrac{1}{0.1525^2}\right] = 2.6 \times 10^5$ N/C along $\vec{p}$ (the

short-dipole formula $2kp/r^3$ gives the same).
(b) $kp/r^3 = 9 \times 10^9 \times 5 \times 10^{-8}/0.15^3 = 1.33 \times 10^5$ N/C, opposite to $\vec{p}$.

**1.10.2 Where dipoles occur:** molecules like $H_2O$, HCl have a permanent dipole moment (**polar** molecules). $CO_2$, $CH_4$ have none (**non-polar**) but get an induced dipole moment in an external field.

## 1.11 Dipole in a uniform field ★★




*Net force = qE − qE = 0; the couple gives τ = qE × 2a sin θ = pE sin θ, i.e. τ = p × E*

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

- **Net force = 0** in a uniform field ($qE - qE$), but there is a **torque** that tries to align $\vec{p}$ with $\vec{E}$.
- $\tau$ is maximum ($pE$) at $\theta = 90^\circ$, zero at $0^\circ$ (stable) and $180^\circ$ (unstable).
- In a **non-uniform** field there is also a net force: towards increasing field when $\vec{p} \parallel \vec{E}$. That is why a charged comb attracts bits of paper (induced dipoles).

★ ***Exam tip:*** CBSE 2026 (55/1/1) gave a dipole lying **along** the x-axis in $\vec{E} = 2\hat{i}$ N/C and asked for $\vec{F}$ and $\vec{\tau}$: both are zero ($\vec{p} \parallel \vec{E}$, uniform field). CBSE 2024 (55/1/1) gave $\vec{p}$ from the positions of the charges and asked for $\vec{\tau} = \vec{p} \times \vec{E}$: see 'Board questions: numericals inside the 5-markers'.

## 1.12 Continuous charge distribution

| Charge spread over | Density | Unit | Charge in an element |
|---|---|---|---|
| a line (wire, ring) | linear $\lambda = \Delta Q/\Delta l$ | C/m | $dq = \lambda\, dl$ |
| a surface (sheet, shell) | surface $\sigma = \Delta Q/\Delta S$ | C/m² | $dq = \sigma\, dS$ |
| a volume (solid sphere) | volume $\rho = \Delta Q/\Delta V$ | C/m³ | $dq = \rho\, dV$ |

Field of a continuous distribution: $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\displaystyle\int \frac{dq}{r^2}\hat{r}$. The elements are macroscopically small but contain very many electronic charges. **Ring with uniform $\lambda$:** at the centre, every element's field is cancelled by the element opposite it, so $E = 0$ (CBSE 2024, 55/1/1). If the upper half is $+$ and the lower half $-$, the fields add and point from the + half to the − half (CBSE 2024, 55/5/1).

## 1.13 Gauss's law ★★★

**Definition ✎ Gauss's law:** the total electric flux through any closed surface is $1/\varepsilon_0$ times the total charge **enclosed** by the surface.

$$\oint_S \vec{E}\cdot d\vec{S} = \frac{q_{\text{enc}}}{\varepsilon_0}$$

### Proof for a point charge (consistent with Coulomb's law)

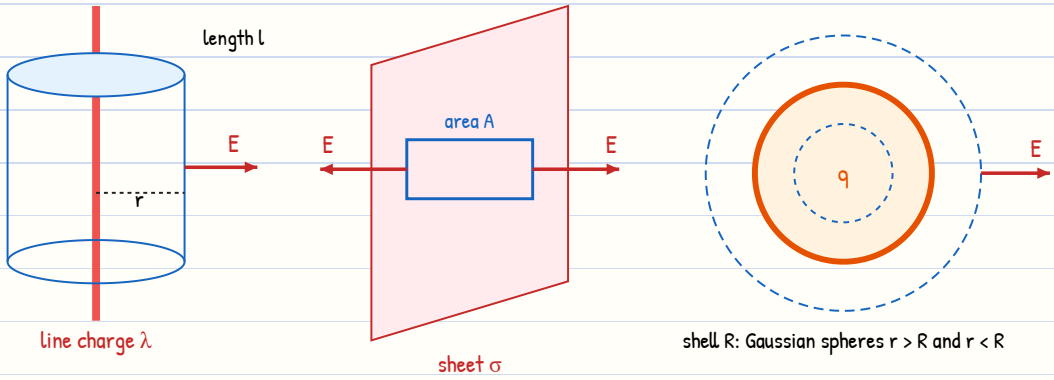
Take a sphere of radius $r$ centred on $q$. On it $\vec{E} = \frac{q}{4\pi\varepsilon_0 r^2}\hat{r}$ is along $d\vec{S}$ everywhere, so

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

The result is independent of $r$; with the solid-angle argument it holds for any shape of closed surface. (Asked as "show that Gauss's theorem is consistent with Coulomb's law" in CBSE 2025, 55/4/1.)

### Points to remember

- True for **any** closed surface (the **Gaussian surface**), any shape or size.
- $q_{\text{enc}}$ = algebraic sum of charges **inside**; charges outside give zero net flux.
- But $\vec{E}$ in the integral is the field due to **all** charges, inside and outside.
- Zero flux does not mean no charge inside, only zero **net** charge (NCERT Ex 1.16(b)).
- The surface must not pass through a discrete charge.
- Useful for finding $E$ when there is **symmetry**: line, plane, sphere.
- Charge $q$ at the centre of a cube: flux through each face = $q/6\varepsilon_0$.




*Choose the Gaussian surface by symmetry: cylinder (line), pill-box (sheet), concentric sphere (shell)*

## 1.14.1 Field of an infinitely long straight wire ★★★

Uniform linear density $\lambda$. By symmetry $\vec{E}$ is radial and has the same magnitude at all points distance $r$ from the wire.

Gaussian surface: a **coaxial cylinder** of radius $r$, length $l$. 1

Flux through the two flat ends = 0 ($\vec{E}$ parallel to them). Through the curved surface: $E \times 2\pi r l$. 1

Charge enclosed $= \lambda l$. Gauss: $E \times 2\pi r l = \lambda l/\varepsilon_0$ 1

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{n}$$ $\hat{n}$: radial unit vector

$E \propto 1/r$. Points away from the wire for $\lambda > 0$, towards it for $\lambda < 0$. Force per unit length between two parallel wires: $F/l = \lambda_2 E_1 = \frac{\lambda_1\lambda_2}{2\pi\varepsilon_0 r}$ (CBSE 2026, 55/3/1).

## 1.14.2 Infinite plane sheet ★★★

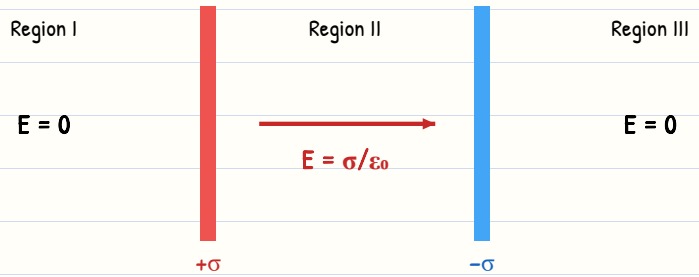
Uniform surface density $\sigma$. By symmetry $\vec{E}$ is normal to the sheet, equal in magnitude on both sides, pointing away for $\sigma > 0$. Gaussian surface: a **cylinder (pill-box)** of cross-section $A$ piercing the sheet. 1

Only the two flat faces have flux: $EA + EA = 2EA$; the curved surface has none ($\vec{E}$ parallel to it). 1

Charge enclosed $= \sigma A$. Gauss: $2EA = \sigma A/\varepsilon_0$ 1

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

$\hat{n}$ is the unit normal away from the sheet. For a **charged conducting plate** (charge on one face, field only outside): $E = \sigma/\varepsilon_0$, **twice** the sheet value (CBSE 2024, 55/3/1).




*Two large plates with +σ and −σ: fields add between the plates and cancel outside*

**Two large sheets (use superposition, each gives $\sigma/2\varepsilon_0$):** $+\sigma$ and $-\sigma$: $E = \sigma/\varepsilon_0$ between, 0 outside (NCERT Ex 1.23, a capacitor). Both $+\sigma$: $E = 0$ between, $\sigma/\varepsilon_0$ outside, pointing away (CBSE 2026, 55/1/1). $\sigma_1$ and $\sigma_2$ in general: between $(\sigma_1 - \sigma_2)/2\varepsilon_0$, outside $(\sigma_1 + \sigma_2)/2\varepsilon_0$.

## 1.14.3 Uniformly charged thin spherical shell ★★★

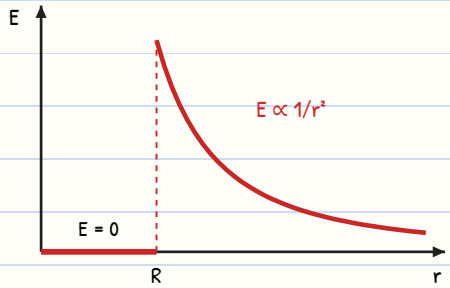
Shell of radius $R$, charge $q$ ($\sigma = q/4\pi R^2$). By symmetry $\vec{E}$ is radial and depends only on $r$. Gaussian surface: a **concentric sphere** of radius $r$. 1

**(i) Outside ($r > R$):** $E \times 4\pi r^2 = q/\varepsilon_0$ 1

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

as if all the charge were at the centre. **(ii) Inside ($r < R$):** $q_{\text{enc}} = 0$, so $E = 0$ everywhere inside. 1

Just outside the surface: $E = \sigma/\varepsilon_0$.




*Shell: E = 0 inside, $kq/R^2$ just outside, then falls as $1/r^2$*

Why $E = 0$ inside is not obvious from Coulomb's law alone: the nearer, smaller patch of charge and the farther, larger patch cancel exactly, thanks to the inverse-square law. This is the reason a person inside a car or a metal cage is safe from lightning (**electrostatic shielding**).

*NCERT Example 1.12* An early atom model: a point nucleus $+Ze$ surrounded by a uniform sphere of negative charge of radius $R$. Find $E$ at distance $r$ (inside and outside).

> **Ans.** Gaussian sphere of radius $r$. Outside ($r > R$): $q_{\text{enc}} = Ze - Ze = 0$, so $E = 0$. Inside: $\rho = -3Ze/4\pi R^3$; $q_{\text{enc}} = Ze(1 - r^3/R^3)$, so $E = \frac{Ze}{4\pi\varepsilon_0}\left(\frac{1}{r^2} - \frac{r}{R^3}\right)$, radially outward.

## The five derivations, in exam order

| Derivation | Diagram must show | Key steps | Result |
|---|---|---|---|
| Dipole, axial point ★★★ | $-q$, $+q$, $2a$, P at $r$, both fields | $E_+ - E_-$ along $\hat{p}$; simplify; $r \gg a$ | $\frac{2p}{4\pi\varepsilon_0 r^3}$ along $\vec{p}$ |
| Dipole, equatorial ★★★ | both fields, angle Θ, components | perpendicular parts cancel; $2E\cos\theta$ | $\frac{p}{4\pi\varepsilon_0(r^2+a^2)^{3/2}}$, opposite to $\vec{p}$ |
| Torque on dipole ★★ | forces $qE$, $-qE$, angle Θ, arm | force × perpendicular distance $2a\sin\theta$ | $\vec{\tau} = \vec{p} \times \vec{E}$; $\vec{F}_{\text{net}} = 0$ |
| Line charge (Gauss) ★★★ | coaxial cylinder $r$, $l$; E radial | end faces 0; curved $2\pi rlE$; $q = \lambda l$ | $\frac{\lambda}{2\pi\varepsilon_0 r}$ |
| Plane sheet (Gauss) ★★★ | pill-box, area A, E on both sides | $2EA$; curved 0; $q = \sigma A$ | $\frac{\sigma}{2\varepsilon_0}$ |
| Spherical shell (Gauss) ★★★ | shell R, spheres $r > R$ and $r < R$ | $4\pi r^2 E$; $q_{\text{enc}} = q$ or 0 | $\frac{q}{4\pi\varepsilon_0 r^2}$ outside; 0 inside |

## Commonly confused points

| Pair | Difference |
|---|---|
| Field of point charge vs dipole | $1/r^2$ vs $1/r^3$; a dipole has zero total charge |
| Field of sheet vs conducting plate | $\sigma/2\varepsilon_0$ (both sides) vs $\sigma/\varepsilon_0$ (outside only) |
| Field of line vs point charge | $\lambda/2\pi\varepsilon_0 r$ $(1/r)$ vs $q/4\pi\varepsilon_0 r^2$ $(1/r^2)$ |
| Flux vs field | flux is a scalar ($\vec{E}\cdot\vec{S}$), field a vector |
| Uniform vs non-uniform field on a dipole | torque only vs torque and net force |
| Charge inside a shell vs on a shell | field inside an empty charged shell is 0; a charge placed inside does produce a field there |
| Direction of $\vec{p}$ | from $-q$ to $+q$ (opposite to the field lines inside the dipole) |

✗ **Don't do this:** Writing "$E = 0$ inside a shell, so the potential is 0 inside". The potential is **constant** (= $kq/R$), not zero (Ch 2).

✗ **Don't do this:** Using $\theta$ as the angle between $\vec{E}$ and the **surface**. In $\phi = ES\cos\theta$, Θ is the angle with the **normal**.

✗ **Don't do this:** Taking $q_{\text{enc}}$ as all charges on the page. Only the charges **inside** the closed surface count.

✗ **Don't do this:** Forgetting units: N/C for E, N m²/C for flux, C m for p, C/m and C/m² for λ, σ.

★ **Exam tip:** Gauss derivations score 3 marks: **1** for the Gaussian surface with symmetry argument (diagram), **1** for the flux through each part, **1** for the result with direction.

## NCERT Exercises, solved

**1.1** Force between charges $2 \times 10^{-7}$ C and $3 \times 10^{-7}$ C, 30 cm apart in air?

> **Ans.** $F = \dfrac{9 \times 10^9 \times 2 \times 10^{-7} \times 3 \times 10^{-7}}{(0.3)^2} = 6 \times 10^{-3}$ N, repulsive.

**1.2** Force on 0.4 μC due to −0.8 μC is 0.2 N. (a) Distance? (b) Force on the second sphere?

> **Ans.** (a) $r^2 = \dfrac{9 \times 10^9 \times 0.4 \times 10^{-6} \times 0.8 \times 10^{-6}}{0.2} = 0.0144$, $r = 0.12$ m. (b) 0.2 N, attractive, towards the first sphere (third law).

**1.3** Check that $ke^2/Gm_em_p$ is dimensionless; find its value; meaning?

> **Ans.** $[ke^2/r^2] = [Gm_em_p/r^2]$ = force, so the ratio is dimensionless.
> $\dfrac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{6.67 \times 10^{-11} \times 9.1 \times 10^{-31} \times 1.67 \times 10^{-27}} \approx 2.3 \times 10^{39}$: the electric force between an electron and a proton is about $10^{39}$ times the gravitational force.

**1.4** (a) Meaning of "charge is quantised"? (b) Why ignore it for large charges?

> **Ans.** (a) Any charge is $q = ne$, an integral multiple of $e$; charge comes in packets of $e$, never $1.5e$.
> (b) Macroscopic charges contain huge numbers of $e$ (1 μC ≈ $6 \times 10^{12}e$), so the steps of $e$ are far too small to notice; charge looks continuous.

**1.5** Glass rubbed with silk: how is it consistent with conservation of charge?

> **Ans.** Electrons move from glass to silk. Glass becomes $+q$ and silk $-q$, equal and opposite: the total stays zero, as before rubbing. Charge is transferred, not created.

**1.6** $q_A = 2$ μC, $q_B = -5$ μC, $q_C = 2$ μC, $q_D = -5$ μC at the corners of a square ABCD of side 10 cm. Force on 1 μC at the centre?

> **Ans.** A and C (equal, opposite corners) push the centre charge equally in opposite directions; B and D pull it equally in opposite directions. Net force = zero.

**1.7** (a) Why can a field line have no sudden breaks? (b) Why do two lines never cross?

> **Ans.** (a) A field line traces the path of a free test charge, which moves continuously, so the line is continuous (the field exists at every point between). (b) At a crossing, the tangent would give two directions of $\vec{E}$ at one point, which is impossible.

**1.8** $q_A = 3$ μC and $q_B = -3$ μC are 20 cm apart. (a) Field at the midpoint O? (b) Force on a test charge of $-1.5 \times 10^{-9}$ C there?

> **Ans.** (a) Each gives $\dfrac{9 \times 10^9 \times 3 \times 10^{-6}}{(0.1)^2} = 2.7 \times 10^6$ N/C, both towards B: $5.4 \times 10^6$ N/C along OB. (b) $F = qE = 1.5 \times 10^{-9} \times 5.4 \times 10^6 = 8.1 \times 10^{-3}$ N, along OA (opposite to $\vec{E}$, since the charge is negative).

**1.9** $q_A = 2.5 \times 10^{-7}$ C at (0, 0, −15 cm), $q_B = -2.5 \times 10^{-7}$ C at (0, 0, +15 cm). Total charge and dipole moment?

> **Ans.** Total charge 0. $p = q \times 2a = 2.5 \times 10^{-7} \times 0.30 = 7.5 \times 10^{-8}$ C m, along −z (from $q_B$ to $q_A$, i.e. from − to +).

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**1.10** $p = 4 \times 10^{-9}$ C m at 30° to $E = 5 \times 10^{4}$ N/C. Torque?

> **Ans.** $\tau = pE \sin 30^\circ = 4 \times 10^{-9} \times 5 \times 10^{4} \times 0.5 = 10^{-4}$ **N m**.

**1.11** Polythene rubbed with wool has $-3 \times 10^{-7}$ C. (a) Number of electrons transferred, and which way? (b) Is mass transferred?

> **Ans.** (a) $n = q/e = 3 \times 10^{-7}/1.6 \times 10^{-19} = 1.9 \times 10^{12}$, from **wool to polythene**. (b) Yes, but tiny: $1.9 \times 10^{12} \times 9.1 \times 10^{-31} = 1.7 \times 10^{-18}$ **kg**, negligible.

**1.12** (a) Two copper spheres with $6.5 \times 10^{-7}$ C each, 50 cm apart. Force? (b) Charges doubled, distance halved?

> **Ans.** (a) $F = \dfrac{9 \times 10^{9} \times (6.5 \times 10^{-7})^2}{(0.5)^2} = 1.5 \times 10^{-2}$ **N**, repulsive. (b) $F' = F \times \dfrac{2 \times 2}{(1/2)^2} = 16F =$ **0.24 N**.

**1.13** Fig. 1.30 shows the tracks of three particles moving between a positive plate (top) and a negative plate (bottom). Signs of the charges? Which has the highest charge-to-mass ratio?

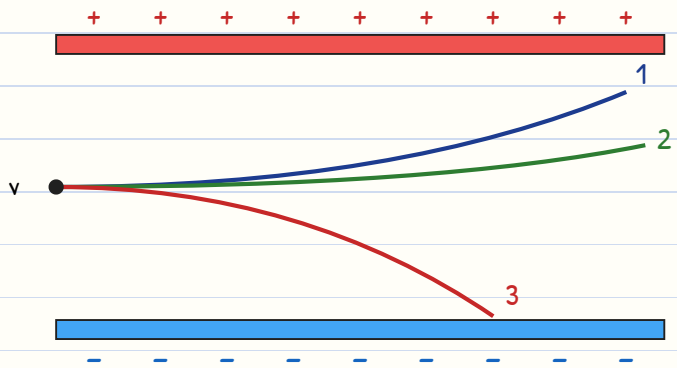



*Fig. 1.30: 1 and 2 bend towards the + plate; 3 bends most, towards the − plate*

> **Ans.** Particles **1 and 2** bend towards the positive plate, so they are **negative**; particle **3** bends towards the negative plate, so it is **positive**. Deflection $y = \dfrac{qEx^2}{2mv^2}$ grows with $q/m$; particle **3** is deflected most, so it has the highest $q/m$ (for equal speeds).

**1.14** $\vec{E} = 3 \times 10^{3}\,\hat{i}$ N/C. Flux through a 10 cm square (a) parallel to the yz plane, (b) with its normal at 60° to x?

> **Ans.** (a) Normal along x: $\phi = ES = 3 \times 10^{3} \times 0.01 =$ **30 N m²/C**. (b) $\phi = ES \cos 60^\circ =$ **15 N m²/C**.

**1.15** Net flux of the same field through a 20 cm cube with faces parallel to the coordinate planes?

> **Ans.** Uniform field: the flux in through one face equals the flux out through the opposite face. Net flux = **zero** (no charge inside).

**1.16** Net outward flux through a black box is $8.0 \times 10^{3}$ N m²/C. (a) Net charge inside? (b) If the flux were zero, would there be no charges inside?

> **Ans.** (a) $q = \varepsilon_0 \phi = 8.854 \times 10^{-12} \times 8 \times 10^{3} = 7.08 \times 10^{-8}$ **C** ≈ 0.07 μC. (b) **No**: zero flux only means the net charge is zero; there may be equal positive and negative charges inside.

**1.17** +10 μC is 5 cm directly above the centre of a 10 cm square (Fig. 1.31). Flux through the square?

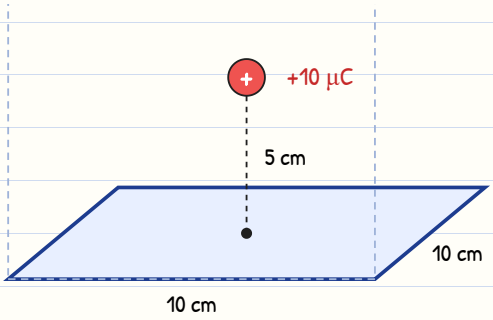



*Fig. 1.31: the square is one face of a 10 cm cube with the charge at its centre*

> **Ans.** The square is one face of a cube of edge 10 cm with the charge at its centre. By symmetry each face gets $1/6$ of the total: $\phi = \dfrac{q}{6\varepsilon_0} = \dfrac{10^{-5}}{6 \times 8.854 \times 10^{-12}} = 1.88 \times 10^{5}$ **N m²/C**.

**1.18** 2.0 μC at the centre of a cubic Gaussian surface of edge 9.0 cm. Net flux?

> **Ans.** $\phi = \dfrac{q}{\varepsilon_0} = \dfrac{2 \times 10^{-6}}{8.854 \times 10^{-12}} = 2.26 \times 10^{5}$ **N m²/C**. The size of the cube does not matter.

> ★ ***Exam tip:*** For "flux through one face" questions, imagine the closed box the face belongs to: a charge at the centre of a cube gives $q/6\varepsilon_0$ per face; at a corner of a cube, $q/8\varepsilon_0$ through the cube (8 such cubes surround the charge): $q/24\varepsilon_0$ through each of the three far faces and 0 through the three faces that meet at the charge.

**1.19** A point charge gives $-1.0 \times 10^{3}$ N m²/C through a Gaussian sphere of radius 10 cm centred on it. (a) Flux if the radius is doubled? (b) The charge?

> **Ans.** (a) Still $-1.0 \times 10^{3}$ **N m²/C**: the enclosed charge is the same. (b) $q = \varepsilon_0 \phi = 8.854 \times 10^{-12} \times (-10^{3}) = -8.85 \times 10^{-9}$ **C**.

**1.20** A conducting sphere of radius 10 cm: the field 20 cm from the centre is $1.5 \times 10^{3}$ N/C, radially **inward**. Net charge?

> **Ans.** Outside, $E = kq/r^2$: $q = \dfrac{Er^2}{k} = \dfrac{1.5 \times 10^{3} \times (0.2)^2}{9 \times 10^{9}} = 6.67 \times 10^{-9}$ C. Inward field, so the charge is negative: $q = -6.67$ **nC**.

**1.21** Conducting sphere of diameter 2.4 m with $\sigma = 80.0$ μC/m². (a) Charge? (b) Total flux leaving it?

> **Ans.** (a) $q = \sigma \times 4\pi R^2 = 80 \times 10^{-6} \times 4\pi \times (1.2)^2 = 1.45 \times 10^{-3}$ **C**. (b) $\phi = q/\varepsilon_0 = 1.64 \times 10^{8}$ **N m²/C**.

**1.22** An infinite line charge gives $9 \times 10^{4}$ N/C at 2 cm. Linear charge density?

> **Ans.** $E = \dfrac{2k\lambda}{r}$, so $\lambda = \dfrac{Er}{2k} = \dfrac{9 \times 10^{4} \times 0.02}{2 \times 9 \times 10^{9}} = 10^{-7}$ **C/m**.

**1.23** Two large thin metal plates, close and parallel, with $\pm 17.0 \times 10^{-22}$ C/m² on their inner faces. E (a) outside the first plate, (b) outside the second, (c) between them?

> **Ans.** (a) and (b): the two fields cancel outside: **E = 0**. (c) $E = \dfrac{\sigma}{\varepsilon_0} = \dfrac{17 \times 10^{-22}}{8.854 \times 10^{-12}} = 1.92 \times 10^{-10}$ **N/C**, from the + plate to the − plate.

## More NCERT-style worked problems

*Exam-style* Where between $+4$ µC and $+1$ µC, 30 cm apart, is the field zero?

> **Ans.** At $x$ from the 4 µC charge: $\frac{4}{x^2} = \frac{1}{(0.3-x)^2}$, so $2(0.3-x) = x$, $x = 0.2$ m (20 cm from 4 µC, 10 cm from 1 µC: nearer the smaller charge).

*Exam-style* Two point charges $+q$ and $-4q$ are $d$ apart. Where is the field zero?

> **Ans.** Unlike charges: outside the pair, beyond the **smaller** charge. At $x$ beyond $+q$: $\frac{q}{x^2} = \frac{4q}{(x+d)^2}$, $x + d = 2x$, $x = d$ (distance $d$ beyond $+q$).

*Exam-style* An oil drop of mass $3.2 \times 10^{-15}$ kg is held stationary between plates with $E = 10^5$ N/C. How many excess electrons does it carry? ($g = 10$ m/s²)

> **Ans.** $qE = mg$: $q = \frac{3.2 \times 10^{-15} \times 10}{10^5} = 3.2 \times 10^{-19}$ C $= 2e$: **2 electrons** (Millikan's idea of quantisation).

*Exam-style* A charge $q$ is at one corner of a cube. Flux through the cube?

> **Ans.** Eight such cubes surround the charge, so this cube gets $q/8\varepsilon_0$. The three faces touching the charge get none (E lies in them); each far face gets $q/24\varepsilon_0$.

## Board questions: 1, 2 and 3 marks

*CBSE 2024 · SS/1/1* A thin plastic rod bent into a ring of radius R is uniformly charged with linear density λ. The field at its centre is: (A) $\frac{\lambda}{2\varepsilon_0 R}$ (B) zero (C) $\frac{\lambda}{4\pi\varepsilon_0 R}$ (D) $\frac{\lambda}{4\varepsilon_0 R}$ [1]

> **Ans.** **(B) zero**: opposite elements cancel.

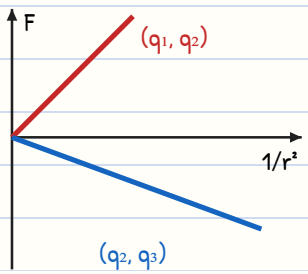
*CBSE 2024 · SS/2/1* Particles P and Q, same charge, masses $m_P$, $m_Q$, start from rest and travel equal distances in a uniform field in times $t_P$, $t_Q$. $t_P/t_Q$ = ? [1]

> **Ans.** $x = \frac{1}{2}\frac{qE}{m}t^2$ with $x$, $q$, $E$ equal: $t \propto \sqrt{m}$. $t_P/t_Q = \sqrt{m_P/m_Q}$.

*CBSE 2024 · SS/4/1* Identical balls $B_1$ ($-7$ pC) and $B_2$ ($+4$ pC) are brought into contact with a third identical ball $B_3$ and separated. Each now has $-2$ pC. Initial charge on $B_3$? [1]

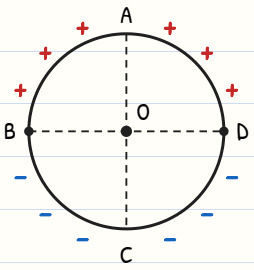
> **Ans.** Total conserved: $-7 + 4 + q_3 = 3 \times (-2)$, $q_3 = -3$ pC.

*CBSE 2025 · SS/1/1* Figure shows the variation of Coulomb force F acting between two point charges with 1/r², r being the separation between the two charges ($q_1$, $q_2$) and ($q_2$, $q_3$) (the ($q_1$, $q_2$) line rises steeply above the axis; the ($q_2$, $q_3$) line falls less steeply below it). If $q_2$ is positive and least in magnitude, then the magnitudes of $q_1$, $q_2$ and $q_3$ are such that: (A) $q_2 < q_3 < q_1$ (B) $q_3 < q_1 < q_2$ (C) $q_1 < q_2 < q_3$ (D) $q_2 < q_1 < q_3$ [1]




> **Ans.** Slope $= kq_iq_j$. $(q_1, q_2)$ repel: $q_1 > 0$; $(q_2, q_3)$ attract: $q_3 < 0$; steeper first line: $|q_1| > |q_3|$. **(A)** $q_2 < q_3 < q_1$ (magnitudes).

CBSE 2024 · 55/5/1 Assertion (A): Equal amount of positive and negative charges are distributed uniformly on two halves of a thin circular ring as shown in figure. The resultant electric field at the centre O of the ring is along OC. Reason (R): It is so because the net potential at O is not zero. [1]




> **Ans.** A is true (the fields of the two halves add). R is false: equal + and − charges at the same distance give V = 0. **(C).**

CBSE 2024 · 55/5/1 (a) 1 μC, −2 μC, 1 μC, −2 μC at the corners A, B, C, D of a square of side 30 cm. Net force on 4 μC at the centre? OR (b) Three charges of 1 pC each at the vertices of an equilateral triangle of side 10 cm: net field at the centroid? [2]

> **Ans.** (a) A and C (1 μC each) are opposite corners: equal opposite forces (0.8 N each). B and D likewise (1.6 N each). **Net force = 0.** (b) Three equal fields 120° apart: **E = 0.**

CBSE 2024 · 55/5/1 (a) Define electric flux; write its dimensions. (b) A square of side 1 cm is placed in $\vec{E} = 100\,\hat{i}$ N/C with unit normal $\hat{n} = 0.8\hat{i} + 0.6\hat{k}$. Flux? [3]

> **Ans.** (a) The number of field lines crossing a surface normally; $\phi = \oint \vec{E} \cdot d\vec{S}$. $[\mathrm{ML^3T^{-3}A^{-1}}]$. 1½
> (b) $\phi = \vec{E} \cdot \vec{A} = 100 \times 0.8 \times 10^{-4} = 8 \times 10^{-3}$ **N m²/C.** 1½

CBSE 2026 · 55/3/1 A particle of mass m and charge q starts from rest and moves in an electric field E = Eoî. After travelling a distance x in the field along x-axis, the kinetic energy of the particle will be: (A) qEox² (B) qEox (C) q²Eox (D) q²Eo²x [1]

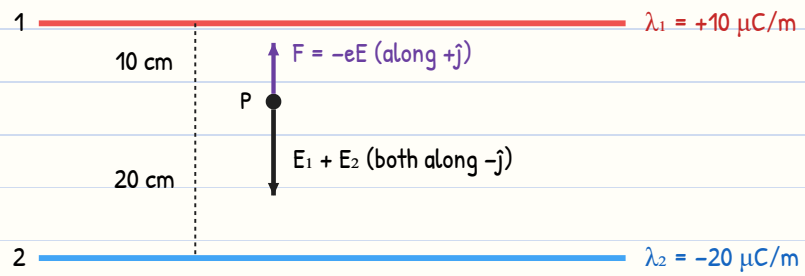
> **Ans.** Work-energy: KE = work done = force × distance = $qE_0x$ (B).

CBSE 2025 · 55/2/1 Which one of the following statements is correct? Electric field due to static charges is: (A) conservative and field lines do not form closed loops (B) conservative and field lines form closed loops (C) non-conservative and field lines do not form closed loops (D) non-conservative and field lines form closed loops [1]

> **Ans.** **Conservative, and its field lines do not form closed loops** (A).

## Board questions: numericals inside the 5-markers

CBSE 2024 · 55/2/1 (b)(i) State Gauss's law; obtain E near a uniformly charged infinite plane sheet. (ii) Wires 1 and 2 (figure) have $\lambda_1 = 10$ μC/m and $\lambda_2 = -20$ μC/m. P is 10 cm from wire 1 and 20 cm from wire 2 (they are 30 cm apart). Net force on an electron at P? [5]

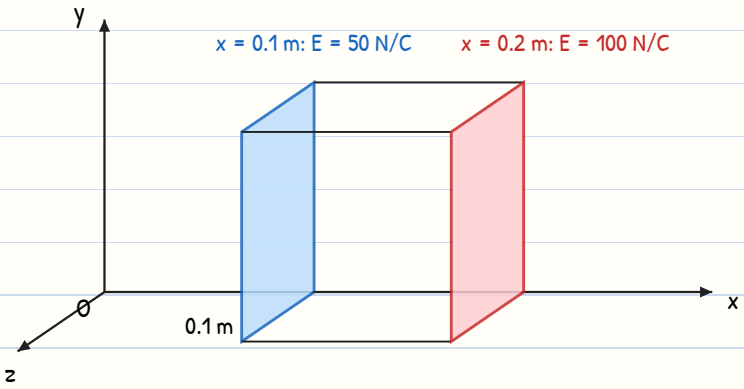



*CBSE 2024 (55/2/1): E₁ points away from wire 1 (+), E₂ towards wire 2 (−): both along −ĵ*

> **Ans.** (i) See '1.14.2 Infinite plane sheet': $E = \sigma/2\varepsilon_0$. 3
> (ii) $E_1 = \dfrac{2k\lambda_1}{r_1} = \dfrac{2 \times 9 \times 10^9 \times 10^{-5}}{0.1} = 1.8 \times 10^6$ N/C, away from wire 1 $(-\hat{j})$. $E_2 =$

$\frac{2\times9\times10^{9}\times2\times10^{-5}}{0.2}=1.8\times10^{6}$ N/C, towards wire 2 ($-\hat{j}$). $\vec{E}=-3.6\times10^{6}\hat{j}$ N/C. $\vec{F}=-e\vec{E}=5.76\times10^{-13}\,\hat{j}$ N (towards wire 1). 2

CBSE 2024 · 55/1/1 A cube of side 0.1 m (one face at x = 0.1 m, as in the figure) is in $\vec{E}=500x\,\hat{i}$ N/C. Find (a) the flux through the cube, (b) the charge inside. [3]




CBSE 2024 (55/1/1): only the two faces normal to x carry flux; the other four are parallel to E

**Ans.** (a) Left face (x = 0.1): $\phi_L=-500\times0.1\times0.01=-0.5$; right face (x = 0.2): $\phi_R=+500\times0.2\times0.01=+1.0$; other faces 0. **Net 0.5 N m²/C.** 2
(b) $q=\varepsilon_0\phi=8.85\times10^{-12}\times0.5=4.4\times10^{-12}$ **C.** 1

CBSE 2025 · 55/5/1 $q_1=16$ μC at $\vec{r}_1=(3\text{ m})\hat{i}$ and $q_2=1$ μC at $\vec{r}_2=(4\text{ m})\hat{j}$. Net field at $\vec{r}=(3\text{ m})\hat{i}+(4\text{ m})\hat{j}$? [2]

**Ans.** From $q_1$ to the point: $4\hat{j}$ m (4 m). $\vec{E}_1=\frac{9\times10^{9}\times16\times10^{-6}}{16}\hat{j}=9000\,\hat{j}$. From $q_2$: $3\hat{i}$ m. $\vec{E}_2=\frac{9\times10^{9}\times10^{-6}}{9}\hat{i}=1000\,\hat{i}$. $\vec{E}=(1000\,\hat{i}+9000\,\hat{j})$ **N/C**, magnitude $\approx9.06\times10^{3}$ N/C.

CBSE 2025 · 55/5/1 Two infinitely long wires 1 and 2, distance d apart, have uniform charge densities λ and −λ/2. Find the position of the point (from wire 1) where the net field is zero and the region (A left of 1, B between, C right of 2) it lies in. [3]

**Ans.** Between the wires both fields point the same way (towards 2), so E ≠ 0 there. The zero must be outside, nearer the **weaker** wire 2: region **C**. At distance $x$ from wire 1: $\frac{\lambda}{2\pi\varepsilon_0 x}=\frac{\lambda/2}{2\pi\varepsilon_0(x-d)}$, so $2(x-d)=x$, $x=2d$.

CBSE 2026 · 55/3/1 Two infinitely long straight wires with linear densities $-\lambda$ and $3\lambda$ are held parallel, distance r apart. Nature and magnitude of the force per unit length? [2]

**Ans.** Field of wire 1 at wire 2: $\frac{\lambda}{2\pi\varepsilon_0 r}$. Force per length on wire 2: $3\lambda\times\frac{\lambda}{2\pi\varepsilon_0 r}=\frac{3\lambda^2}{2\pi\varepsilon_0 r}$, **attractive** (unlike charges).

CBSE 2025 · 55/6/1 $\vec{E}=(10x+5)\,\hat{i}$ N/C; a cube of side L has one face in the yz plane (x = 0) and the opposite face at x = L. Net flux? [2]

**Ans.** Face at x = 0: $-5L^2$; face at x = L: $(10L+5)L^2$; others 0. $\phi=10L^3$ **N m²/C**, so $q=10\varepsilon_0L^3$.

CBSE 2024 · SS/1/1 A dipole: −1.0 pC at (0, 0) and +1.0 pC at (3 mm, 4 mm) in the x-y plane. $\vec{E} = 1000\,\hat{i}$ V/m is switched on. Torque on the dipole? [2]

> **Ans.** $\vec{p} = q\vec{d} = 10^{-12}(3\hat{i} + 4\hat{j}) \times 10^{-3} = (3\hat{i} + 4\hat{j}) \times 10^{-15}$ C m. $\vec{\tau} = \vec{p} \times \vec{E} = (3\hat{i} + 4\hat{j}) \times 10^{-15} \times 1000\,\hat{i} = 4 \times 10^{-12}(\hat{j} \times \hat{i}) = -4 \times 10^{-12}\,\hat{k}$ N m, magnitude $4 \times 10^{-12}$ N m.

## Board questions: the derivations they ask

CBSE 2026 · SS/1/1 (a) A dipole: charges q and −q, 2a apart. Derive E at a point r from the centre on the equatorial plane; write E for r ≫ a. (b) q at x = a and −q at x = b; $\vec{E} = 2\hat{i}$ N/C. Find $\vec{F}$ and $\vec{\tau}$. [5]

> **Ans.** (a) Point P on the perpendicular bisector, distance r from the centre. Distance of P from each charge = $\sqrt{r^2 + a^2}$, so the fields of +q and −q have equal magnitude $E_{+q} = E_{-q} = \dfrac{q}{4\pi\varepsilon_0(r^2 + a^2)}$ (1). Their components along the bisector cancel; the components parallel to the dipole axis (pointing from +q towards −q) add: $E = 2E_{+q}\cos\theta$ with $\cos\theta = \dfrac{a}{\sqrt{r^2 + a^2}}$ (1). So $E = \dfrac{2qa}{4\pi\varepsilon_0(r^2 + a^2)^{3/2}}$, and with $p = 2qa$, $\vec{E} = -\dfrac{\vec{p}}{4\pi\varepsilon_0(r^2 + a^2)^{3/2}}$ (opposite to $\vec{p}$). For $r \gg a$: $\vec{E} = -\dfrac{\vec{p}}{4\pi\varepsilon_0 r^3}$ (1).
>
> (b) Uniform field: $\vec{F} = q\vec{E} - q\vec{E} = 0$. The dipole lies along the x-axis, so $\vec{p} \parallel \vec{E}$ (or antiparallel): $\vec{\tau} = \vec{p} \times \vec{E} = 0$. (2)

CBSE 2025 · SS/4/1 (a)(i) $+q$ at (a, 0) and $-q$ at (−a, 0). Net field at (0, y); hence at y ≫ a. [3]

> **Ans.** Equatorial point: the y-components cancel, the x-components add. $\vec{E} = -\dfrac{2qa}{4\pi\varepsilon_0(y^2 + a^2)^{3/2}}\hat{i}$ (opposite to $\vec{p} = 2qa\,\hat{i}$). For $y \gg a$: $\vec{E} = -\dfrac{\vec{p}}{4\pi\varepsilon_0 y^3}$.

CBSE 2025 · SS/6/1 Obtain E due to a dipole at a point on its equatorial plane and its direction. Find E (I) at the centre r = 0, (II) at r ≫ a. [3]

> **Ans.** (I) $E = \dfrac{p}{4\pi\varepsilon_0 a^3} = \dfrac{2q}{4\pi\varepsilon_0 a^2}$, from +q to −q. (II) $E = \dfrac{p}{4\pi\varepsilon_0 r^3}$, opposite to $\vec{p}$.

CBSE 2026 · SS/1/1 (a) Using Gauss's law deduce E due to a uniformly charged infinite plane thin sheet. (b) Two large thin sheets, each with surface density σ, are parallel and close. Net field (i) between, (ii) outside? [3]

> **Ans.** (a) Pill-box: $2EA = \sigma A/\varepsilon_0$, $E = \sigma/2\varepsilon_0$. (2) (b) (i) The two fields are opposite between the sheets: E = 0. (ii) They add outside: $E = \sigma/\varepsilon_0$, away from the sheets. (1)

CBSE 2024 · SS/3/1 (b)(i) A charge +Q is on a thin conducting spherical shell of radius R. Use Gauss's law to find E (i) inside, (ii) outside. (ii) Show that for the same σ the field of a conducting plate is twice that of a non-conducting sheet. [5]

> **Ans.** (i) By symmetry $\vec{E}$ is radial and has the same magnitude at all points at distance r from the centre, so take a concentric spherical Gaussian surface of radius r (1). Outside (r > R): it encloses Q, so $E \cdot 4\pi r^2 = Q/\varepsilon_0$, $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$ (as if Q were at the centre) (1). Inside (r < R): it encloses no charge (all of Q is on the shell), so $E \cdot 4\pi r^2 = 0$, E = 0 (1).
>
> (ii) Sheet: pill-box with flux through both faces, $2EA = \sigma A/\varepsilon_0$, $E = \sigma/2\varepsilon_0$. Conducting plate: E = 0 inside the metal, so only the outer face has flux, $EA = \sigma A/\varepsilon_0$, $E = \sigma/\varepsilon_0$: twice. (2)

CBSE 2025 · 55/4/1 Show that Gauss's theorem is consistent with Coulomb's law; derive E for a uniformly charged thin shell of radius r at distance y from the centre, (I) y > r, (II) y < r. [3]

> **Ans.** **Consistency**: put a sphere of radius r round a point charge q. By symmetry E is radial and the same everywhere on it, so Gauss's law gives $\oint \vec{E} \cdot d\vec{S} = E \cdot 4\pi r^2 = q/\varepsilon_0$, i.e. $E = \dfrac{q}{4\pi\varepsilon_0 r^2}$. The force on a charge $q_0$ there is $F = q_0 E = \dfrac{qq_0}{4\pi\varepsilon_0 r^2}$: Coulomb's law ½.
>
> **Shell** (charge q, radius r): Gaussian sphere of radius y, concentric. (I) y > r: encloses q, $E \cdot 4\pi y^2 = q/\varepsilon_0 \Rightarrow E = \dfrac{q}{4\pi\varepsilon_0 y^2}$ ½. (II) y < r: encloses no charge ⇒ **E = 0** ½.

★ ***Exam tip:*** Pattern of the last three years: the 5-mark question pairs **one derivation** (dipole equatorial/axial, sheet, line or shell) with a **2-mark numerical** (wires, dipole torque, field of two charges, flux through a cube). Practise both halves together.

## What the board asked (16 papers, 2024–2026)

| Topic | Papers that asked it | Marks |
|---|---|---|
| Dipole field (equatorial/axial) derivation | 2025 55/4/1, 2025 55/6/1, 2026 55/1/1 | 3 (inside a 5) |
| Gauss's law: sheet, plates, shell | 2024 55/2/1, 2024 55/3/1, 2025 55/4/1, 2026 55/1/1 | 3–5 |
| Line charges: field, force, zero point | 2024 55/2/1, 2025 55/5/1, 2026 55/3/1 | 2–3 |
| Flux: definition, cube, tilted area | 2024 55/1/1, 2024 55/5/1, 2025 55/6/1 | 2–3 |
| Torque/force on a dipole | 2024 55/1/1, 2026 55/1/1 | 2 |
| Superposition: square, triangle, two charges | 2024 55/5/1, 2025 55/5/1 | 2 |
| 1-mark MCQ / A–R (ring, charge sharing, F–1/r² graph, KE, field lines) | 2024 55/1, 2, 4, 5; 2025 55/1, 2; 2026 55/3 | 1 |

## Case-based practice *Exam-style*

**Case study 1: the ink-jet printer.** Ink drops of mass $1.5 \times 10^{-10}$ kg carry a charge of $-1.5 \times 10^{-13}$ C. They move horizontally at 20 m/s between deflecting plates 1.6 cm long, where the field is $1.4 \times 10^{6}$ N/C, directed downwards.

(i) Direction of the force on a drop? **Upwards (the charge is negative).** [1]

(ii) Acceleration of a drop? $a = qE/m = 1.4 \times 10^{3}$ **m/s².** [1]

(iii) Time between the plates? $t = 0.016/20 = 8 \times 10^{-4}$ **s.** [1]

(iv) Vertical deflection at the end of the plates? $y = \frac{1}{2}at^2 = 0.45$ **mm** (gravity negligible). [1]

**Case study 2: a water molecule in a field.** $H_2O$ is a polar molecule with $p = 6.2 \times 10^{-30}$ C m. It is placed in a uniform field of $1.5 \times 10^{4}$ N/C.

(i) The net force on it is: **zero (uniform field).** [1]

(ii) Maximum torque: $pE = 9.3 \times 10^{-26}$ **N m**, at **θ = 90°**. [1]

(iii) Position of stable equilibrium: $\vec{p}$ **along** $\vec{E}$ **(θ = 0°).** [1]

(iv) In a non-uniform field increasing to the right, with $\vec{p}$ along the field, the molecule: **is pulled to the right (towards the stronger field).** [1]

**Case study 3: Gauss's law in a box.** A closed box contains charges $+3$ μC, $-5$ μC and $+4$ μC. A charge of $+6$ μC sits just outside it.

(i) Net flux through the box: $q_{\text{enc}}/\varepsilon_0 = 2 \times 10^{-6}/8.85 \times 10^{-12} = 2.26 \times 10^{5}$ **N m²/C.** [1]

(ii) Effect of the outside charge on the net flux: **none.** [1]

(iii) Does it change E on the box's surface? **Yes: E is due to all charges.** [1]

(iv) The box is replaced by a sphere enclosing the same charges; the flux: **stays the same.** [1]

## Practice set: test yourself *Exam-style*

Try every question before looking at the answers at the end of the chapter. 64 or more out of 80 means you are ready for the board.

### A. Fill in the blanks (1 mark each)

1. The SI unit of electric charge is the _____.
2. The charge on an electron is _____ C.
3. $\dfrac{1}{4\pi\varepsilon_0}$ = _____ N m² C⁻².
4. The SI unit of electric dipole moment is _____.
5. Electric flux is a _____ quantity.
6. Field inside a uniformly charged thin spherical shell = _____.
7. Field of an infinite line charge varies as _____.
8. The direction of $\vec{p}$ is from _____ to _____.

### B. True or false? (1 mark each)

1. Charge can be created by rubbing.
2. A charge of $2.4 \times 10^{-19}$ C is possible on a body.
3. Two field lines can cross in a strong field.
4. Net force on a dipole in a uniform field is zero.
5. Gauss's law holds only for spherical surfaces.
6. Coulomb force between two charges decreases in a medium.
7. The field of a dipole falls as $1/r^2$.
8. The field of an infinite sheet does not depend on distance.

### C. Very short answer (1 mark each)

1. What is the net charge of an electric dipole?
2. Name the experiment that showed charge is quantised.
3. Flux through a closed surface with $+q$ and $-q$ inside?
4. Why is $\vec{E}$ normal to a charged conductor's surface?
5. Two charges attract with force F. If each charge and the distance are doubled, the force is?
6. Write the dimensional formula of $\varepsilon_0$.
7. At what angle between $\vec{p}$ and $\vec{E}$ is the torque maximum?

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8. Field at the centre of a uniformly charged ring?
9. Ratio of axial to equatorial field of a short dipole at the same distance?
10. How many electrons make $-1$ C?

## D. Short answer I (2 marks each)

1. State and explain the principle of superposition of electric forces.
2. Write four properties of electric field lines.
3. Draw the field lines of (a) two equal positive charges, (b) a dipole.
4. A charge $q$ is at the centre of a cube. Find the flux through (a) the whole cube, (b) one face.
5. Two charges $+9$ μC and $+1$ μC are 40 cm apart. Where is the field zero?
6. Derive the torque on a dipole in a uniform field. When is it zero?
7. Explain charging by induction with diagrams.
8. Find the force on $-2$ μC at 3 cm from an infinite line charge of $\lambda = 3$ μC/m.

## E. Short answer II (3 marks each)

1. Use Gauss's law to find the field due to an infinitely long straight wire with linear charge density λ.
2. Four charges $+q, +q, -q, -q$ are at the corners of a square of side $a$ (like charges adjacent). Find the field at the centre.
3. $\vec{E} = 200x\,\hat{i}$ N/C. Find the flux through a cube of side 0.2 m whose faces are at x = 0.2 m and x = 0.4 m, and the charge inside.
4. Show that the electric field of a charged conducting plate is twice that of a charged non-conducting sheet of the same σ.
5. Three charges $q$, $q$ and $-2q$ are at the corners of an equilateral triangle of side $l$. Find the dipole moment of the system.
6. A proton enters a uniform field of $3 \times 10^4$ N/C at right angles with speed $2 \times 10^6$ m/s. Find its deflection after 10 cm. ($m_p = 1.67 \times 10^{-27}$ kg)

## F. Long answer (5 marks each)

1. Derive the field of a dipole at a point on its axis. Show that for $r \gg a$ it is $2kp/r^3$. Find the field on the axis 20 cm from the centre of a dipole of $p = 2 \times 10^{-8}$ C m.
2. State Gauss's law. Use it to find E due to a uniformly charged thin shell outside and inside. Draw the E–r graph.
3. Derive the field on the equatorial line of a dipole. A dipole of charges ±2 μC, 2 cm apart, is placed at 30° to a field of $5 \times 10^5$ N/C: find the torque.
4. (a) Derive E due to an infinite plane sheet. (b) Two parallel sheets carry +2σ and −σ. Find E in the three regions.

## G. HOTS (higher-order thinking)

1. A charge $q$ is at the centre of the open face of a hemisphere-shaped bowl. What is the flux through the curved surface?
2. Why is it safer to sit inside a car than under a tree during lightning?

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3. A small charged ball hangs on a silk thread. A charged rod is brought near and the ball is attracted. Can you conclude the ball and rod have opposite charges? Explain.
4. The field just outside a charged conductor is $\sigma/\varepsilon_0$, yet the field of a sheet is $\sigma/2\varepsilon_0$. Explain the factor of 2 using superposition.

**Case study 4 (practice): Millikan's oil drop.** A drop of radius $10^{-6}$ m and density 900 kg/m³ is held stationary between plates 1 cm apart when 770 V is applied ($g = 9.8$ m/s²).
(i) Field between the plates? (ii) Weight of the drop? (iii) Charge on the drop? (iv) How many electrons does this correspond to?

## 20 MCQs

1. The minimum charge a body can have is
   (a) 1 C (b) $3.2 \times 10^{-19}$ C (c) $1.6 \times 10^{-19}$ C (d) $0.8 \times 10^{-19}$ C

2. If the distance between two charges is halved, the force becomes
   (a) 4F (b) 2F (c) F/2 (d) F/4

3. The SI unit of electric field is
   (a) N C (b) N m²/C (c) C/N (d) N/C

4. Field lines of an isolated positive charge are
   (a) radially inward (b) radially outward (c) circles (d) parallel lines

5. The flux through a closed surface enclosing a dipole is
   (a) $q/\varepsilon_0$ (b) zero (c) $2q/\varepsilon_0$ (d) $q/2\varepsilon_0$

6. The field of a short dipole at a distance r varies as
   (a) $1/r$ (b) $1/r^2$ (c) $1/r^4$ (d) $1/r^3$

7. Torque on a dipole is maximum when θ is
   (a) 90° (b) 0° (c) 180° (d) 45°

8. Field of an infinite line charge at distance r is
   (a) $\lambda/2\varepsilon_0$ (b) $\lambda/4\pi\varepsilon_0 r^2$ (c) $\lambda/2\pi\varepsilon_0 r$ (d) zero

9. Field near an infinite plane sheet of charge is
   (a) $\sigma/\varepsilon_0$ (b) $2\sigma/\varepsilon_0$ (c) $\sigma/4\varepsilon_0$ (d) $\sigma/2\varepsilon_0$

10. Field inside a charged thin spherical shell is
    (a) maximum (b) zero (c) $kq/R^2$ (d) $kq/r^2$

11. A charge q at the centre of a cube: flux through one face is
    (a) $q/\varepsilon_0$ (b) $q/4\varepsilon_0$ (c) $q/6\varepsilon_0$ (d) $q/8\varepsilon_0$

12. Rubbing glass with silk, the glass
    (a) loses electrons (b) gains electrons (c) gains protons (d) loses protons

13. A dipole in a non-uniform field experiences
    (a) only a torque (b) a force and possibly a torque (c) neither (d) only a force, never torque

14. The unit of electric flux is
    (a) N/C (b) N C m (c) N m²/C (d) C/m²

15. The force between two charges in water (K = 80) compared with air is
    (a) 80 times (b) 1/√80 times (c) the same (d) 1/80 times

16. At a far point, $E_{\text{axial}}/E_{\text{equatorial}}$ of a dipole is
    (a) 2 (b) 1/2 (c) 4 (d) 1

17. Two plates with +σ and −σ: field between them is
    (a) $\sigma/\varepsilon_0$ (b) $\sigma/2\varepsilon_0$ (c) zero (d) $2\sigma/\varepsilon_0$

18. Dimensions of $\varepsilon_0$
    (a) $[\mathrm{M^{-1}L^3T^4A}]$ (b) $[\mathrm{ML^3T^{-3}A^{-1}}]$ (c) $[\mathrm{MLT^{-2}}]$ (d) $[\mathrm{M^{-1}L^{-3}T^4A^2}]$

19. A proton and an electron in the same field have accelerations in the ratio $a_p/a_e$
    (a) 1 (b) $m_e/m_p$ (c) $m_p/m_e$ (d) $\sqrt{m_e/m_p}$

20. Number of electrons in $-3.2\ \mu C$

(a) $2 \times 10^{12}$ (b) $5 \times 10^{12}$ (c) $2 \times 10^{13}$ (d) $3.2 \times 10^{13}$

*1 (c) · 2 (a) · 3 (d) · 4 (b) · 5 (b) · 6 (d) · 7 (a) · 8 (c) · 9 (d) · 10 (b) · 11 (c) · 12 (a) · 13 (b) · 14 (c) · 15 (d) · 16 (a) · 17 (a) · 18 (d) · 19 (b) · 20 (c)*

## Assertion–Reason (6)

(a) Both true, R explains A. (b) Both true, R does not explain A. (c) A true, R false. (d) A false, R true.

1. A: Two field lines never intersect. R: At a point the field has a unique direction.
2. A: The net flux through a closed surface with a charge outside it is zero. R: Field lines from an outside charge that enter the surface also leave it.
3. A: A dipole in a uniform field has zero net force. R: A dipole in a uniform field has zero torque at all angles.
4. A: The field inside a uniformly charged thin shell is zero. R: A Gaussian sphere drawn inside the shell encloses no charge.
5. A: Charge is quantised. R: The total charge of an isolated system is conserved.
6. A: The field of an infinite sheet varies as $1/r$. R: The field lines of an infinite sheet are parallel.

*Key: 1 (a) · 2 (a) · 3 (c) · 4 (a) · 5 (b) · 6 (d)*

## Answers to the practice set

**A.** 1. coulomb 2. $-1.6 \times 10^{-19}$ 3. $9 \times 10^{9}$ 4. C m 5. scalar 6. zero 7. $1/r$ 8. −q, +q

**B.** 1. F (transferred) 2. F (not a multiple of e) 3. F 4. T 5. F (any closed surface) 6. T 7. F ($1/r^3$) 8. T

**C.** 1. zero 2. Millikan's oil drop 3. zero 4. a tangential component would move charges along the surface 5. F (unchanged) 6. $[M^{-1}L^{-3}T^{4}A^{2}]$ 7. 90° 8. zero 9. 2 : 1 10. $6.25 \times 10^{18}$

**D.** 1. see '1.5 Coulomb's law' 2. see '1.8 Electric field lines' 3. see '1.8 Electric field lines' figure (c), (d) 4. (a) $q/\varepsilon_0$ (b) $q/6\varepsilon_0$ 5. $\frac{9}{x^2} = \frac{1}{(0.4-x)^2}$: 30 cm from 9 μC 6. $\tau = pE\sin\theta$; zero at 0° and 180° 7. see '1.1–1.3 Electric charge' 8. $E = 2k\lambda/r = 1.8 \times 10^{6}$ N/C; $F = qE = 3.6$ N, towards the wire

**E.** 1. see '1.13 Gauss's law' 2. each pair of like charges on one side gives a field towards the − side: $E = 4\sqrt{2}\,kq/a^2$, from the + side to the − side, perpendicular to it 3. $\phi = (200 \times 0.4 - 200 \times 0.2) \times 0.04 = 1.6$ N m²/C; $q = 1.4 \times 10^{-11}$ C 4. see 'Board questions: the derivations they ask' 5. treat as two dipoles $ql$ at 60°: $p = \sqrt{3}\,ql$, along the bisector, towards the $q$, $q$ side 6. $t = x/v = 5 \times 10^{-8}$ s, $a = eE/m = 2.9 \times 10^{12}$ m/s², $y = \frac{1}{2}at^2 = 3.6 \times 10^{-3}$ m = 3.6 mm (or $y = qEx^2/2mv^2$)

**F.** 1. see '1.10 Electric dipole'; $E = 2kp/r^3 = 2 \times 9 \times 10^{9} \times 2 \times 10^{-8}/0.008 = 4.5 \times 10^{4}$ N/C 2. see '1.14.2 Infinite plane sheet' 3. see '1.10 Electric dipole'; $p = 4 \times 10^{-8}$ C m, $\tau = pE\sin 30^\circ = 10^{-2}$ N m 4. see '1.14.2 Infinite plane sheet'; left of +2σ: $\sigma/2\varepsilon_0$ to the left; between: $3\sigma/2\varepsilon_0$ towards −σ; right of −σ: $\sigma/2\varepsilon_0$ to the right

**G.** 1. a closed sphere would get $q/\varepsilon_0$; the hemisphere is half of it: $q/2\varepsilon_0$ (the flat face has none, E lies in it) 2. the metal body acts as a shell: E = 0 inside (shielding) 3. no: a neutral ball is also attracted (induction); only repulsion proves like charges 4. near the conductor the field is due to the local patch ($\sigma/2\varepsilon_0$) plus the rest of the charge ($\sigma/2\varepsilon_0$), which add outside and cancel inside

**Case 4.** (i) $E = V/d = 770/0.01 = 7.7 \times 10^{4}$ N/C (ii) $mg = \frac{4}{3}\pi r^3 \rho g = 3.7 \times 10^{-14}$ N (iii) $q = mg/E = 4.8 \times 10^{-19}$ C (iv) $q/e = 3$ electrons

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## Last-night summary

- Charge: two kinds, additive, conserved, quantised ($q = ne$, $e = 1.6 \times 10^{-19}$ C). Charging by friction, conduction, induction.
- Coulomb: $F = kq_1q_2/r^2$, $k = 9 \times 10^9$; in a medium $F/K$. Superposition: add the vectors.
- Field $\vec{E} = \vec{F}/q_0$; point charge $kq/r^2$. Lines: + to −, never cross, no closed loops, dense = strong.
- Flux $\phi = \vec{E} \cdot \vec{S} = ES\cos\theta$ (θ with the normal). Gauss: $\oint \vec{E} \cdot d\vec{S} = q_{\text{enc}}/\varepsilon_0$.
- Dipole $p = 2qa$ (− to +): axial $2kp/r^3$ along $\vec{p}$; equatorial $kp/r^3$ opposite; $\vec{\tau} = \vec{p} \times \vec{E}$, $F = 0$ in a uniform field.
- Line $\lambda/2\pi\varepsilon_0 r$; sheet $\sigma/2\varepsilon_0$; conductor plate $\sigma/\varepsilon_0$; shell: $kq/r^2$ outside, 0 inside.