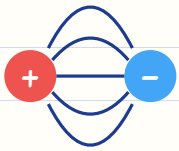
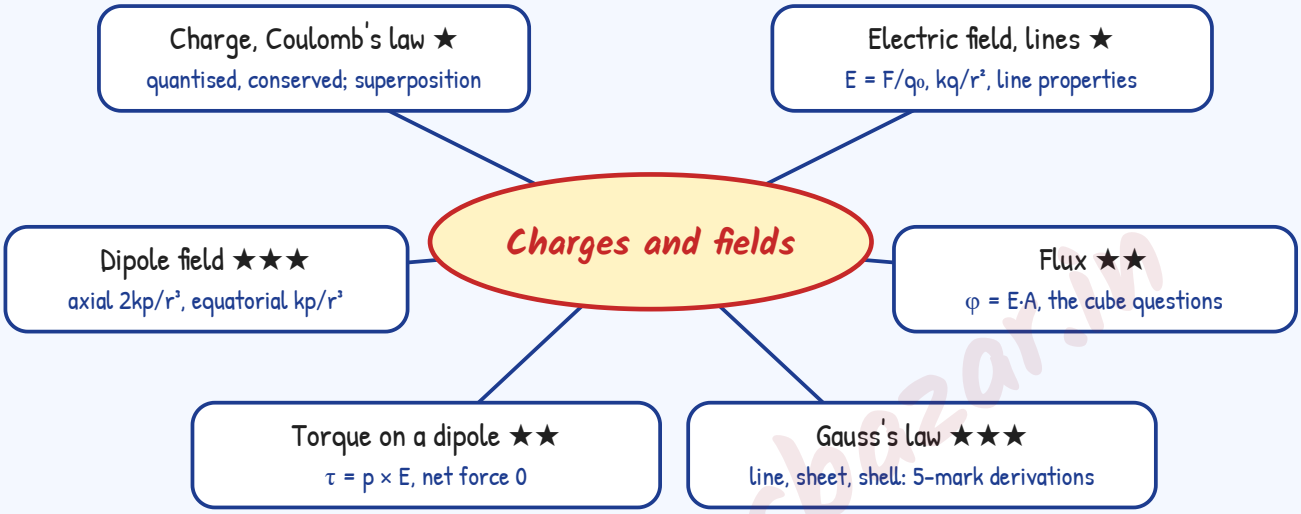
Class 12 · Physics · Unit I Electrostatics

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 (p. 2–3)
2. Electric field, field lines, flux (p. 4–5)
3. Dipole: field, torque; charge densities (p. 6–7)
4. Gauss's law and its three applications (p. 8–9)
5. Derivation checklist, don't-confuse table (p. 10)
6. NCERT Exercises 1.1–1.23, solved (p. 11–13)
7. CBSE board questions 2024–2026, solved (p. 14–16)
8. What the board asked · 3 case studies (p. 17)
9. Practice set A–G, 20 MCQs, 6 A–R, answers, summary (p. 18–21)

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.

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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.

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.

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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.

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

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

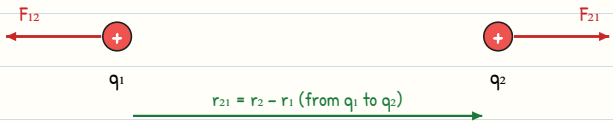
$\varepsilon_0 = 8.854 \times 10^{-12}$ C² N⁻¹ m⁻² is the **permittivity of free space**.

1 C is the charge that, placed 1 m from an equal charge in vacuum, repels it with 9×10^9 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).

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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 2.0×10^4 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: 7.2×10^4 **N/C** towards q_2. At B: 3.6×10^4 (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 3.2×10^4 **N/C**, to the left. At C (equidistant, 0.1 m from each): 9×10^3 **N/C**, parallel to $q_1 \to q_2$.

★ **Exam tip:** Board 1-markers love "**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).

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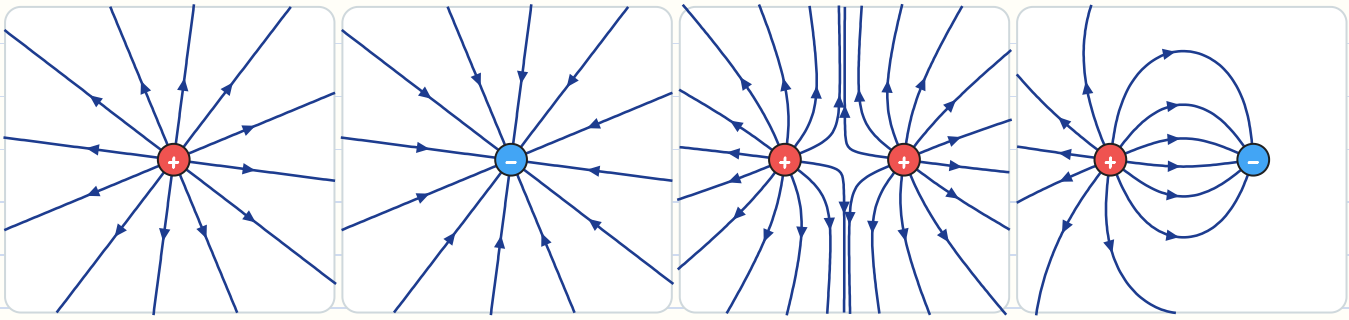
1.8 Electric field lines ★

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)

- θ = 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 with one corner at the origin, side along x from a to $2a$ (Fig. 1.24). Flux and charge?

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, p. 14.)

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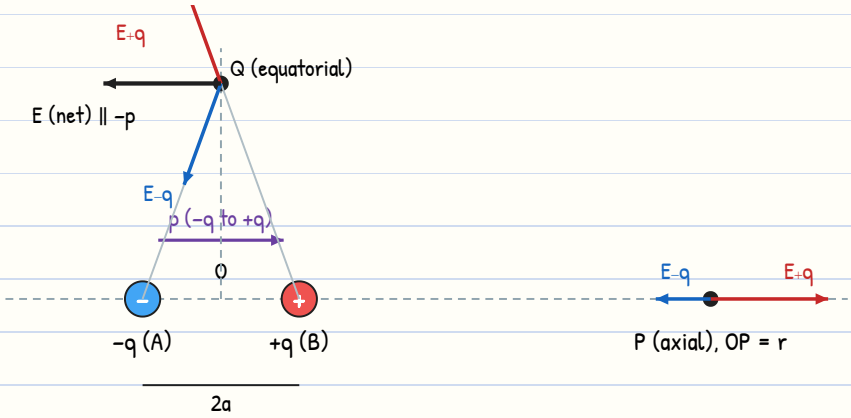
1.10 Electric dipole ★★★

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.

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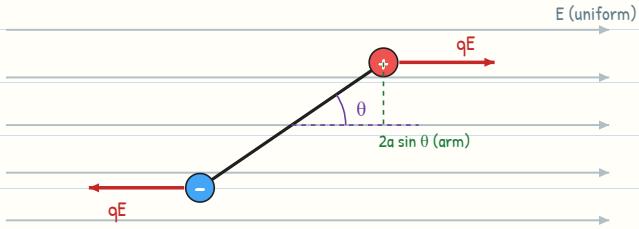
NCERT Example 1.9 Charges ± 10 μC are 5.0 mm apart. Find the field (a) at a point on the axis 15 cm from the centre on the side of $+q$, (b) on the equatorial line at 15 cm.

> **Ans.** $p = 10^{-5} \times 5 \times 10^{-3} = 5 \times 10^{-8}$ C m.
> (a) Using the exact charges: $E = 9 \times 10^9 \times 10^{-5}\left[\frac{1}{0.1475^2} - \frac{1}{0.1525^2}\right] = 2.6 \times 10^5$ 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 $\vec{E}$.
- τ is maximum (pE) at $\theta = 90^\circ$, zero at 0° (stable) and 180° (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 p. 15.

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: $\vec{E} = \frac{1}{4\pi\varepsilon_0}\int \frac{dq}{r^2}\hat{r}$. The elements are macroscopically small but contain very many electronic charges. **Ring with uniform** λ: 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).

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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)

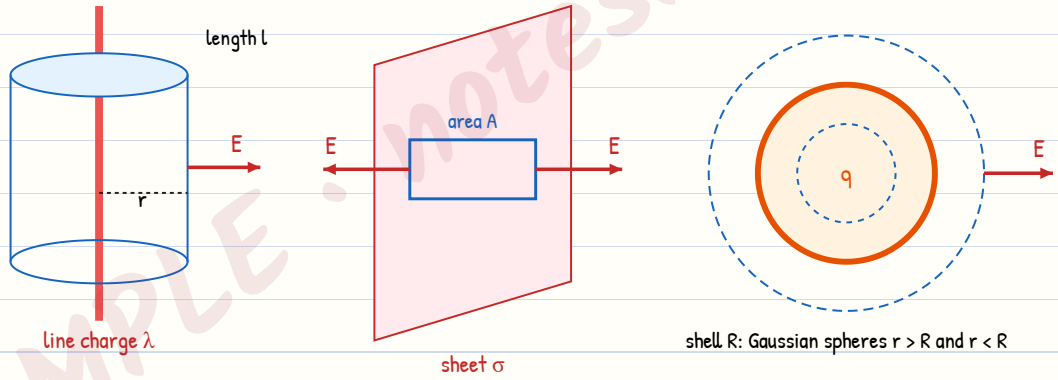
Take a sphere of radius r centred on q. On it $\vec{E} = \frac{q}{4\pi\varepsilon_0 r^2}\hat{r}$ is along $d\vec{S}$ everywhere, so

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

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_{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 λ. 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. I

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

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

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\,\hat{n}$$ $\hat{n}$: 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).

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1.14.2 Infinite plane sheet ★★★

Uniform surface density σ. By symmetry $\vec{E}$ is normal to the sheet, equal in magnitude on both sides, pointing away for $\sigma > 0$.

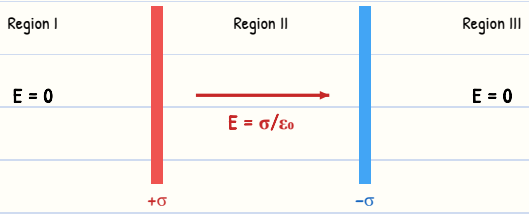
Gaussian surface: a **cylinder (pill-box)** of cross-section A piercing the sheet. 1

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, σ/ε_0 outside, pointing away (CBSE 2026, 55/1/1). σ_1 and σ_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 ★★★

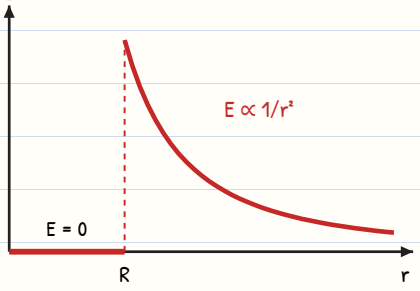
Shell of radius R, charge q ($\sigma = q/4\pi R^2$). By symmetry $\vec{E}$ is radial and depends only on r. Gaussian surface: a **concentric sphere** of radius r. 1

(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/R² just outside, then falls as 1/r²

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.

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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

Don't-confuse table

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 σ/ε_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 θ 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_{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.

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NCERT Exercises, solved

1.1 Force between charges 2×10^{-7} C and 3×10^{-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 $\approx 6 \times 10^{12}e$), 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 -1.5×10^{-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: 5.4×10^6 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 +).

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.

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1.11 Polythene rubbed with wool has -3×10^{-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 6.5×10^{-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?

> **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 8.0×10^3 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?

> **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.

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1.19 A point charge gives -1.0×10^3 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 -1.0×10^3 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 1.5×10^3 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 9×10^4 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: $\dfrac{4}{x^2} = \dfrac{1}{(0.3-x)^2}$, 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 $+q$: $\dfrac{q}{x^2} = \dfrac{4q}{(x+d)^2}$, $x + d = 2x$, $x = d$ (distance d beyond $+q$).

Exam-style An oil drop of mass 3.2×10^{-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.** $qE = mg$: $q = \dfrac{3.2 \times 10^{-15} \times 10}{10^5} = 3.2 \times 10^{-19}$ 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 $q/24\varepsilon_0$.

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Board questions: 1, 2 and 3 marks

CBSE 2024 · 55/1/1 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 · 55/2/1 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 · 55/4/1 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 · 55/1/1 Graph of Coulomb force F against $1/r^2$ for pairs (q_1, q_2) (steeper line, positive slope) and (q_2, q_3) (less steep, negative slope). q_2 is positive and least in magnitude. Then: [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 2026 · 55/3/1 A particle (mass m, charge q) starts from rest in $\vec{E} = E_0\hat{i}$. Its kinetic energy after a distance x: [1]

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

CBSE 2025 · 55/2/1 The electrostatic field is (MCQ on its nature). [1]

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

CBSE 2024 · 55/5/1 A: Equal + and − charges are spread uniformly on the two halves of a thin ring; the field at the centre O is along OC (from the + half towards the − half). R: 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).

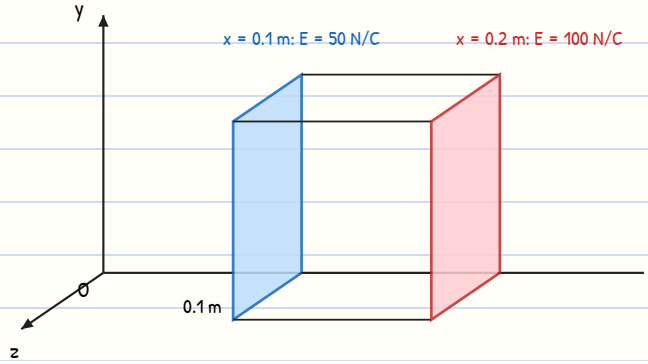
CBSE 2024 · 55/5/1 (a) 1 μC, −2 μC, 1 μC, −2 μC at the corners A, B, C, D of a square of side 30 cm. Net force on 4 μC at the centre? OR (b) Three charges of 1 pC each at the vertices of an equilateral triangle of side 10 cm: net field at the centroid? [2]

> **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 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): $\phi_L = -500 \times 0.1 \times 0.01 = -0.5$; right face (x = 0.2): $\phi_R = +500 \times 0.2 \times 0.01 = +1.0$; other faces 0. Net 0.5 N m²/C. 2
> (b) $q = \varepsilon_0\phi = 8.85 \times 10^{-12} \times 0.5 = 4.4 \times 10^{-12}$ C. 1

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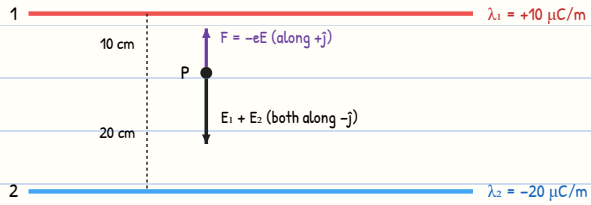
Board questions: numericals inside the 5-markers

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): E_1 points away from wire 1 (+), E_2 towards wire 2 (−): both along $-\hat{j}$

Ans. (i) See p. 9: $E = \sigma/2\varepsilon_0$. 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 ($-\hat{j}$). $E_2 = \dfrac{2 \times 9 \times 10^9 \times 2 \times 10^{-5}}{0.2} = 1.8 \times 10^6$ N/C, towards wire 2 ($-\hat{j}$). $\vec{E} = -3.6 \times 10^6 \hat{j}$ N/C. $\vec{F} = -e\vec{E} = 5.76 \times 10^{-13}\,\hat{j}$ N (towards wire 1). 2

CBSE 2024 · 55/11/1 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 4×10^{-12} N m.

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). $\vec{E}_1 = \dfrac{9 \times 10^9 \times 16 \times 10^{-6}}{16}\hat{j} = 9000\,\hat{j}$. From q_2: $3\hat{i}$ m. $\vec{E}_2 = \dfrac{9 \times 10^9 \times 10^{-6}}{9}\hat{i} = 1000\,\hat{i}$. $\vec{E} = (1000\,\hat{i} + 9000\,\hat{j})$ N/C, magnitude $\approx 9.06 \times 10^3$ 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: $\dfrac{\lambda}{2\pi\varepsilon_0 x} = \dfrac{\lambda/2}{2\pi\varepsilon_0(x-d)}$, so $2(x-d) = x$, $x = 2d$.

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

Ans. Field of wire 1 at wire 2: $\dfrac{\lambda}{2\pi\varepsilon_0 r}$. Force per length on wire 2: $3\lambda \times \dfrac{\lambda}{2\pi\varepsilon_0 r} = \dfrac{3\lambda^2}{2\pi\varepsilon_0 r}$, 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 $q = 10\varepsilon_0 L^3$.

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Board questions: the derivations they ask

CBSE 2026 · 55/1/1 (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) p. 6: $\vec{E} = -\frac{\vec{p}}{4\pi\varepsilon_0(r^2+a^2)^{3/2}}$; for $r \gg a$, $-\frac{\vec{p}}{4\pi\varepsilon_0 r^3}$. 3
> (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 · 55/4/1 (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. $\vec{E} = -\frac{2qa}{4\pi\varepsilon_0(y^2+a^2)^{3/2}}\hat{i}$ (opposite to $\vec{p} = 2qa\,\hat{i}$). For $y \gg a$: $\vec{E} = -\frac{\vec{p}}{4\pi\varepsilon_0 y^3}$.

CBSE 2025 · 55/6/1 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) $E = \frac{p}{4\pi\varepsilon_0 a^3} = \frac{2q}{4\pi\varepsilon_0 a^2}$, from +q to −q.
> (II) $E = \frac{p}{4\pi\varepsilon_0 r^3}$, opposite to $\vec{p}$.

CBSE 2026 · 55/1/1 (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 · 55/3/1 (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) p. 9: inside $E = 0$; outside $E = \frac{Q}{4\pi\varepsilon_0 r^2}$. 3
> (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.** Sphere round a point charge gives $\phi = q/\varepsilon_0$ (p. 8); conversely, Gauss on that sphere gives $E = q/4\pi\varepsilon_0 r^2$, Coulomb's law. Shell: (I) $E = \frac{q}{4\pi\varepsilon_0 y^2}$; (II) $E = 0$.

★ **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.

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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 1.5×10^{-10} kg carry a charge of -1.5×10^{-13} C. They move horizontally at 20 m/s between deflecting plates 1.6 cm long, where the field is 1.4×10^{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 1.5×10^{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]

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Practice set: test yourself *Exam-style*

Try every question before looking at the answers on page 21. 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. $\frac{1}{4\pi\varepsilon_0}$ = _____ 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 2.4×10^{-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 ε_0.
7. At what angle between $\vec{p}$ and $\vec{E}$ is the torque maximum?
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.

My score (fill in after checking the answers)

Section	A /8	B /8	C /10	D /16	E /18	F /20	G (bonus)	Total /80
My marks								

Rough work

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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 3×10^4 N/C at right angles with speed 2×10^6 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 5×10^5 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?
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 σ/ε_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?

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20 MCQs

1. The minimum charge a body can have is
   (a) 1 C (b) 3.2×10^{-19} C (c) 1.6×10^{-19} C (d) 0.8×10^{-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/ε_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) σ/ε_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/ε_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) σ/ε_0 (b) $\sigma/2\varepsilon_0$ (c) zero (d) $2\sigma/\varepsilon_0$

18. Dimensions of ε_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 μC
    (a) 2×10^{12} (b) 5×10^{12} (c) 2×10^{13} (d) 3.2×10^{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)

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Answers to the practice set

A. 1. coulomb 2. -1.6×10^{-19} 3. 9×10^{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. $[\mathrm{M^{-1}L^{-3}T^{4}A^{2}}]$ 7. 90° 8. zero 9. 2 : 1 10. 6.25×10^{18}

D. 1. p. 3 2. p. 5 3. p. 5 figure (c), (d) 4. (a) q/ε_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. p. 2 8. $E = 2k\lambda/r = 1.8 \times 10^{6}$ N/C; $F = qE = 3.6$ N, towards the wire

E. 1. p. 8 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. p. 16 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. p. 6; $E = 2kp/r^3 = 2 \times 9 \times 10^{9} \times 2 \times 10^{-8}/0.008 = 4.5 \times 10^{4}$ N/C 2. p. 9 3. p. 6; $p = 4 \times 10^{-8}$ C m, $\tau = pE\sin 30^\circ = 10^{-2}$ N m 4. p. 9; 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/ε_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

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 σ/ε_0; shell: kq/r^2 outside, 0 inside.

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