Topic D.2

ELECTRIC & MAGNETIC FIELDS

Every Formula, Trick & Trap on a Page
& IB-Style Quick Reference

Topics Covered

Coulomb's law & charge
Electric fields & field lines
Millikan's experiment
Magnetic fields & patterns
Electric potential (AHL)

Exam Relevance

P1 & P2 (SL + HL)
$E = V/d$ (plates)
$q = mgd/V$
Right-hand grip rule
$V = kQ/r$; eV

The Big Picture — How D.2 Fits Together

ELECTRIC & MAGNETIC FIELDS
charges make fields; fields store energy; magnets act on currents

- **Coulomb**: $F = \frac{kQq}{r^2}$ attract/repel
- **E field**: $E = \frac{F}{q} = \frac{kQ}{r^2}$ vector, V/d
- **Millikan**: $q = ne$ charge quantised
- **Magnetic**: B from currents wire, solenoid
- **Potential (AHL)**: $V = \frac{kQ}{r}$, $E = -\frac{\Delta V}{\Delta r}$

§1 — Electric Charge & Coulomb's Law D.2

Key Formulas

Coulomb's Law:

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

where $k = 8.99 \times 10^9\,\mathrm{N\,m^2/C^2}$, $\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2/(N\,m^2)}$.
Elementary charge: $e = 1.60 \times 10^{-19}\,\mathrm{C}$ (charge is quantised: $q = ne$).

TRICK Coulomb's law has the same form as Newton's law of gravitation. Replace $G \to k$, $m \to q$. But gravity is always attractive; electric force can attract or repel.

TRAP Always use **magnitudes** of charges in Coulomb's law and determine direction by inspection. A negative result does not mean "attractive" in exam-style mark schemes.

NOTE Charge is **conserved** (cannot be created or destroyed) and **quantised** (always $q = ne$).

§2 — Electric Fields D.2

Key Formulas

Electric field strength (force per unit positive test charge):

$$E = \frac{F}{q} \qquad [\mathrm{N/C}] = [\mathrm{V/m}]$$

Point charge field:

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

Uniform field between parallel plates:

$$E = \frac{V}{d}$$

Field Line Rules

- Away from $+$, toward $-$.
- Never cross.
- Density $\propto$ field strength.
- Perpendicular to conductor surfaces.
- Inside a conductor: $E = 0$.

TRICK The electric field is a **vector**. To find the net field due to multiple charges, you must resolve into components and add as vectors. Potential is a scalar — much easier to add.

TRICK **Two ways to see E:** $E = F/q$ (force per unit charge, how you measure it) $= E = kQ/r^2$ (set by the source Q). Between plates the geometry gives $E = V/d$ — same field, why N/C = V/m.

TRAP $E = V/d$ **only** applies to uniform fields (parallel plates). Do not use this for point charges!

FROM THE PHOTON QUESTION BANK
State field direction from the charge sign first, then add contributions as **vectors**. For a null point between like charges solve $kq_1/x^2 = kq_2/(L-x)^2$; between unlike charges the zero lies *outside*, beyond the smaller charge.

§3 — Millikan's Oil Drop Experiment D.2

Balance Condition

Drop stationary $\Rightarrow$ electric force $=$ weight (ignoring buoyancy):

$$qE = mg \quad \Rightarrow \quad q = \frac{mgd}{V}$$

Result: $q = ne$ always, proving charge quantisation.

TRICK To find n: calculate q, then $n = q/e$. Always round to nearest integer.

TRAP If the question asks you to include buoyancy: $qE = (\rho_{\text{oil}} - \rho_{\text{air}})Vg$ where V is volume. Don't confuse volume V with voltage V!

§4 — Magnetic Force & Fields D.2

Key Facts

- $\vec{B}$ field lines form **closed loops** (N $\to$ S outside, S $\to$ N inside).
- No magnetic monopoles exist.
- Magnetic force acts only on **moving** charges.
- Magnetic force is always $\perp$ to velocity $\Rightarrow$ does **no work**.

Field Patterns to Memorise

Configuration	Field Pattern
Straight wire	Concentric circles; right-hand grip r
Flat coil	Like a short bar magnet
Solenoid	Uniform inside; bar magnet shape outside
Bar magnet	N to S outside; closed loops

TRICK Right-hand grip: thumb = current direction, fingers curl = $\vec{B}$ direction (wire). For solenoid: fingers curl with current, thumb = N pole.

E vs B Fields Comparison

	Electric	Magnetic
Source	Charges	Moving charges/currents
Acts on	Any charge	Moving charges only
Force dir.	Parallel to $\vec{E}$	$\perp$ to $\vec{v}$ and $\vec{B}$
Does work?	Yes	No
Monopoles?	Yes	No

NOTE Earth acts like a bar magnet with a magnetic **south** pole near geographic North — that is why a compass N-pole points north. Cut a magnet in half and you still get N + S: **no isolated poles**.

FROM THE PHOTON QUESTION BANK

Grip rule: thumb = conventional current, fingers curl = $\vec{B}$. If given electron flow, reverse it. For two wires, find each $\vec{B}$ at the point separately then add as vectors; mark field into/out of page as $\otimes$/$\odot$.

§5 — Electric Potential Energy & Potential (AHL) D.2

Key Formulas

Electric potential (work per unit charge from ∞):

$$V = \frac{W}{q} = \frac{kQ}{r} \qquad \text{[V]}$$

V is a **scalar**: $V > 0$ near $+Q$, $V < 0$ near $-Q$, $V = 0$ at ∞.

Superposition: $V_{\text{total}} = \sum \frac{kQ_i}{r_i}$ (scalar addition — no vectors!).

Field from potential: $E = -\frac{\Delta V}{\Delta r}$ (negative gradient).

Conducting sphere:

- Outside ($r > R$): $V = kQ/r$
- Surface ($r = R$): $V = kQ/R$
- Inside ($r < R$): $V = kQ/R$ (constant)

TRICK Potential is scalar, field is vector. If a question asks for potential at a point, just add kQ_i/r_i with signs. No component resolution needed!

TRICK **Two ways E relates to V:** $E = -\Delta V/\Delta r$ is the slope of the potential; picture V as height on a contour map — the field points downhill, steepest where equipotentials crowd.

TRAP Inside a conducting sphere, $E = 0$ but $V \neq 0$. The potential equals the surface potential. Students often say $V = 0$ inside — this is wrong.

NOTE Equipotentials are $\perp$ to field lines. Closely spaced equipotentials = strong field.

FROM THE PHOTON QUESTION BANK

Add potentials *with sign* as scalars; for $V = 0$ set the terms to cancel. Work done by the field is $W = q\Delta V$ (mind the sign for a $-$ charge). Closest approach: $E_k = kQq/r_{\text{min}}$.

§6 — Gravitational & Electric Potentials Compared (AHL) D.2

Parallel Equations

	Gravitational	Electric
Force	$F = \frac{GMm}{r^2}$	$F = \frac{kQq}{r^2}$
Field	$g = \frac{GM}{r^2}$	$E = \frac{kQ}{r^2}$
Potential	$V_g = -\frac{GM}{r}$	$V_e = \frac{kQ}{r}$
PE	$E_p = -\frac{GMm}{r}$	$E_p = \frac{kQq}{r}$

TRICK Gravitational potential is **always negative** (mass attracts). Electric potential can be $+$ or $-$ depending on sign of Q.

Electronvolt

$1\,\text{eV} = 1.60 \times 10^{-19}\,\text{J}$

KE gained by electron through $1\,\text{V}$. Quick conversion: $E_k = qV$ gives energy in eV if q is in units of e and V in volts.

TRAP When converting to eV, divide joules by 1.60×10^{-19}. Students often multiply instead.

§7 — Key Differences Summary (AHL) D.2

Three Key Differences

1. **Sign of force:** Gravity always attracts; electric force can attract or repel.
2. **Sign of potential:** V_g always negative; V_e can be $+$ or $-$.
3. **Shielding:** Electric fields can be shielded (Faraday cage); gravitational fields cannot.

NOTE The mathematical **structure** is identical — inverse-square law, potential $\propto 1/r$, field $= -\mathrm{d}V/\mathrm{d}r$. Only the sign conventions differ because mass is always positive while charge can be $+$ or $-$.

D.2 Electric & Magnetic Fields

Student Self-Check Table

Ref	Topic	Formulas	Tricks	Confidence
§1	Coulomb's Law	☐	☐	☐☐☐☐☐
§2	Electric Fields & Field Lines	☐	☐	☐☐☐☐☐
§3	Millikan's Experiment	☐	☐	☐☐☐☐☐
§4	Magnetic Force & Fields	☐	☐	☐☐☐☐☐
§5	Electric Potential (AHL)	☐	☐	☐☐☐☐☐
§6	Grav vs Electric Comparison (AHL)	☐	☐	☐☐☐☐☐
§7	Field Comparison (AHL)	☐	☐	☐☐☐☐☐

Rate your confidence before the exam: fill each box for 1–5 (1 = need help, 5 = exam-ready)

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