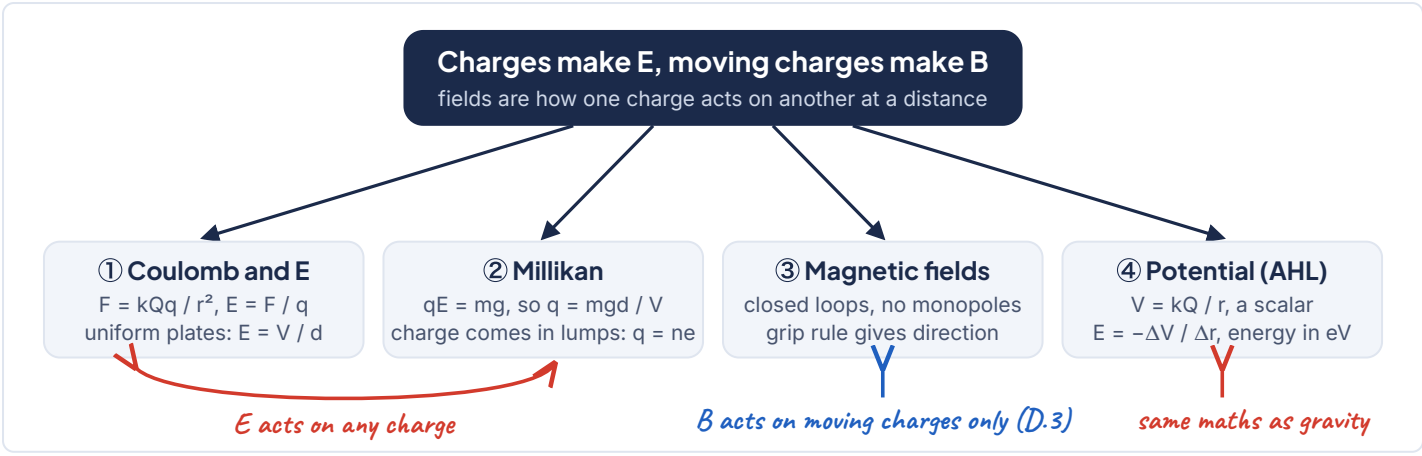
TOPIC D.2 · SL & AHL · THEME D FIELDS

Electric & magnetic fields cheatsheet

Charges make electric fields, moving charges make magnetic ones.
Every formula in D.2, with a picture and a worked example.

same shape as gravity, but charges have signs ↓

~14 minute read | Paper 1 & Paper 2 | AHL: electric potential, eV | 7 worked examples



1 Charge and Coulomb's law

gravity with two signs

SL/HL · P1 & P2

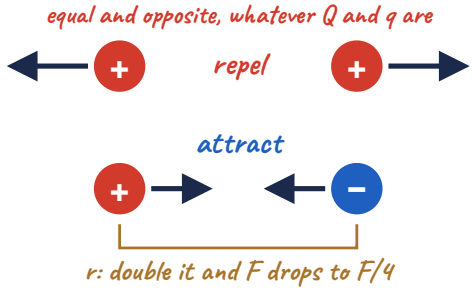
magnitudes in the formula, direction by eye

Two point charges push or pull on each other with a force that falls as 1/r². Like charges repel, unlike charges attract, and each feels the same size of force.

FORMULAS AND FACTS

Coulomb	$F = \frac{kq_1q_2}{r^2} = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}$	in booklet
constant	$k = 8.99 \times 10^9\ \text{N m}^2\ \text{C}^{-2}$	
constant	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2\ \text{N}^{-1}\ \text{m}^{-2}$	
quantised	$q = ne$	$e = 1.60 \times 10^{-19}\ \text{C}$

Charge is **conserved** (never created or destroyed) and **quantised** (a whole number of *e*). Same form as gravity with $G \to k$ and $m \to q$, but gravity only ever attracts.



Trap. Put the **sizes** of the charges in the formula and decide attract or repel by looking at the signs. A negative answer is not "attractive" in a mark scheme.

WORKED EXAMPLE · TWO CHARGES

A charge of +3.0 μC and one of −2.0 μC are 0.30 m apart. Find the force between them, and say what happens when they are moved to 0.60 m.

1. Sizes only: $F = (8.99 \times 10^9)(3.0 \times 10^{-6})(2.0 \times 10^{-6}) / (0.30)^2 =$ **0.60 N**, **attractive** (unlike signs).
2. Double $r \to F / 4 =$ **0.15 N**. Each charge feels this same force, towards the other.

2 Electric fields *force per unit charge*

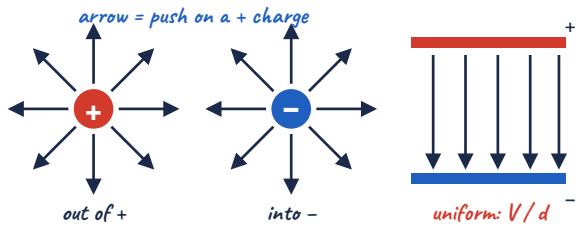
SL/HL · P1 & P2

The field strength E is the force each coulomb of **positive** test charge would feel. It is a vector; the line of the field is the path a positive charge would be pushed along.

THREE FORMS OF E

definition	$E = \frac{F}{q}$	N C^{-1} = V m^{-1}
point charge	$E = \frac{kQ}{r^2}$	*in booklet*
parallel plates	$E = \frac{V}{d}$	**uniform fields only**

- Lines go **away from +**, towards −, and never cross.
- Closer together means a stronger field.
- Lines meet a conductor at **90°**; inside a conductor $E = 0$.
- Several charges: **add the field vectors**, with components.



WORKED EXAMPLE · A NULL POINT

Charges +4.0 nC and +1.0 nC are 0.30 m apart. Where between them is the net field zero?

1. Fields cancel: $k(4.0)/x^2 = k(1.0)/(0.30 - x)^2$, with x from the 4.0 nC charge.
2. Square root: $x/(0.30 - x) = \sqrt{4} = 2 \rightarrow x = 2(0.30 - x)$.
3. $3x = 0.60 \rightarrow x =$ **0.20 m** from the 4.0 nC charge

like charges: null point between; unlike charges: outside, beyond the smaller one

WORKED EXAMPLE · ELECTRON BETWEEN PLATES

Plates 2.0 cm apart carry a potential difference of 500 V. Find E, and the force and acceleration of an electron.

1. $E = V/d = 500 / 0.020 =$ **2.5×10^4 V m^{-1}**
2. $F = eE = (1.60 \times 10^{-19})(2.5 \times 10^4) =$ **4.0×10^{-15} N**
3. $a = F/m = 4.0 \times 10^{-15} / 9.11 \times 10^{-31} =$ **4.4×10^{15} m s^{-2}**

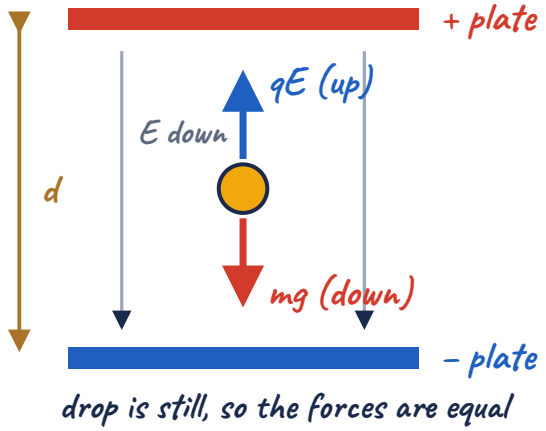
Trap. $E = V/d$ is for **uniform** fields between plates. For a point charge use kQ/r^2.

Two ways to see E

Measured as F/q, or set by the source kQ/r^2. Between plates the geometry gives V/d, so N C^{-1} and V m^{-1} are the same unit. → *one field, three formulas.*

3 Millikan's oil drop experiment *proof that charge is lumpy*

SL/HL · P1 & P2



drop is still, so the forces are equal

Adjust the voltage until a tiny charged oil drop hangs in the air. Then the electric force up exactly balances the weight.

BALANCE CONDITION

$$qE = mg \qquad q = \frac{mgd}{V}$$

Every q found was a whole number of e, so charge is **quantised**. To find n: $n = q/e$, then round to the nearest whole number.

WORKED EXAMPLE · HOW MANY ELECTRONS?

A drop of mass 1.00×10^{-15} kg hangs still between plates 1.0 cm apart at 307 V. Find its charge in terms of e.

1. $q = mgd/V = (1.00 \times 10^{-15})(9.81)(0.010) / 307 =$ **3.2×10^{-19} C**
2. $n = q/e = 3.2 \times 10^{-19} / 1.60 \times 10^{-19} =$ **2** electrons.

pulled up to the + plate, so it is negative

Trap. With buoyancy: $qE = (\rho_{oil} - \rho_{air}) \cdot \text{Vol} \cdot g$. Do not mix up the drop's volume with voltage V.

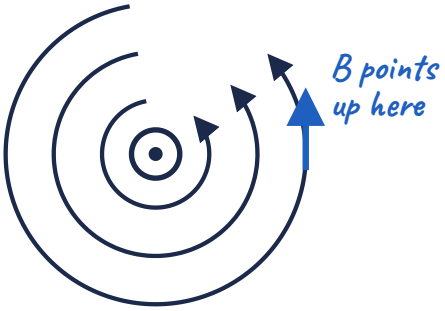
4 Magnetic fields and patterns *direction is the whole game*

SL/HL · P1 & P2

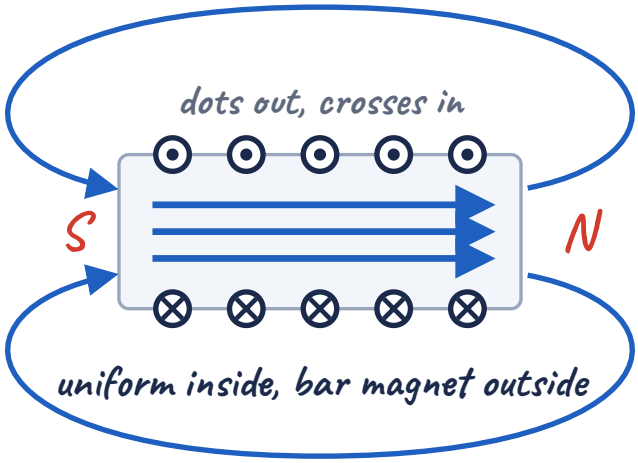
thumb = current, fingers = field

A magnetic field *B* is made by moving charges, so by currents and by magnets. The lines form **closed loops** (N to S outside a magnet) and **no isolated pole** has ever been found: cut a magnet in half and you get two magnets.

anticlockwise, closer = stronger



⊙ = current out of the page



Source	Field pattern
straight wire	concentric circles around it
flat coil	like a short bar magnet
solenoid	uniform inside, bar magnet outside
bar magnet	N to S outside, closed loops

Grip rule. Wire: thumb along the current, fingers curl the way *B* goes. Solenoid: fingers curl with the current, thumb points to the **N** end.

	Electric field E	Magnetic field B
source	charges	moving charges, currents
acts on	any charge	moving charges only
force direction	along E	⊥ to v and to B
does work?	yes	**no** (force ⊥ v)
isolated poles?	yes, + or −	no monopoles

WORKED EXAMPLE · WHICH WAY?

Electrons drift left to right along a wire. A compass sits just below it. Which way does the needle point?

1. Conventional current is opposite to electron flow: right to left.
2. Thumb left. Fingers curl **away** from you over the top and **towards you** under the wire.
3. Below the wire *B* points **towards you**, out of the page.

Earth is a bar magnet

Its magnetic **south** pole is near geographic north, which is why a compass N-pole points north. → *like poles repel, unlike attract.*

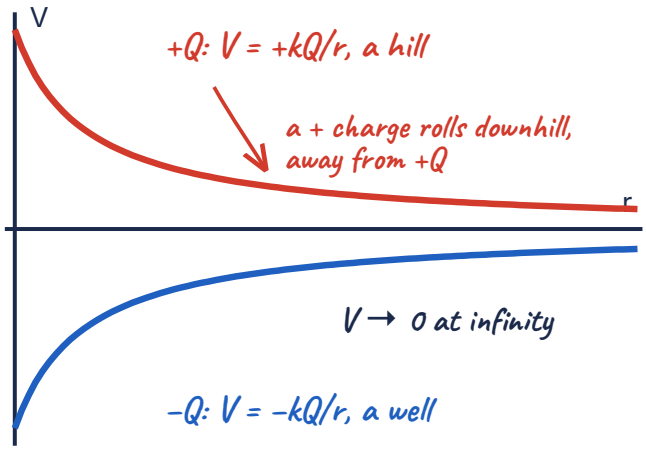
5 Electric potential and energy *a scalar: just add*

AHL · P1 & P2

Potential V is the work per unit **positive** charge to bring it from infinity to that point. Unlike gravity, V can be positive or negative, depending on the sign of Q.

FORMULAS

potential	$V = \frac{kQ}{r}$	*in booklet*
energy	$E_p = qV = \frac{kQq}{r}$	
work done	$W = q\,\Delta V$	by the field
field	$E = -\frac{\Delta V}{\Delta r}$	minus the slope
many charges	$V = \sum \frac{kQ_i}{r_i}$	signed sum
electronvolt	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$	



Trap. Joules to eV means **divide** by 1.60×10^{-19}. Inside a charged conducting sphere $E = 0$ but $V \neq 0$: it equals the surface value kQ/R.

WORKED EXAMPLE · POTENTIAL OF TWO CHARGES

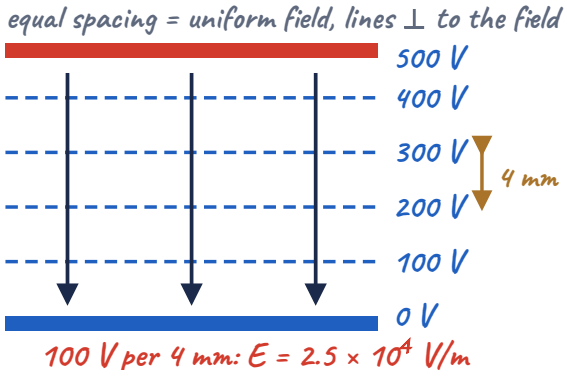
Point P is 0.30 m from a +6.0 nC charge and 0.20 m from a −2.0 nC charge. Find V at P.

1. From +6.0 nC: $(8.99 \times 10^9)(6.0 \times 10^{-9})/0.30 = +180$ V
2. From −2.0 nC: $(8.99 \times 10^9)(-2.0 \times 10^{-9})/0.20 = -90$ V
3. Add the numbers: $V =$ **+90 V** *no components needed*

WORKED EXAMPLE · CLOSEST APPROACH

An alpha particle (charge +2e) with 5.0 MeV is fired head-on at a gold nucleus (+79e). How close does it get?

1. $E_k = 5.0 \times 10^6 \times 1.60 \times 10^{-19} = 8.0 \times 10^{-13}$ J
2. All becomes E_p at the turning point: $E_k = kQq/r$
3. $r = (8.99 \times 10^9)(79 \times 1.60 \times 10^{-19})(2 \times 1.60 \times 10^{-19}) / 8.0 \times 10^{-13} =$ **4.5×10^{-14} m**



Think contour map

V is height. The field points **downhill**, and is steepest where equipotentials crowd together. → *moving along one costs no work.*

Work done by the field is $q\Delta V$. A negative charge goes uphill in V and still gains kinetic energy!

6 Gravitational against electric *same maths, three differences*

AHL · P1 & P2

	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	$V_g = -\frac{GM}{r}$	$V_e = \frac{kQ}{r}$
energy	$E_p = -\frac{GMm}{r}$	$E_p = \frac{kQq}{r}$

THREE KEY DIFFERENCES

1. **Force:** gravity only attracts. Electric force can attract or repel.
2. **Sign of V:** V_g is always negative. V_e can be + or −.
3. **Shielding:** electric fields can be screened (Faraday cage). Gravity cannot.

The electric force between a proton and an electron is about 10^{39} times the gravitational one. Atoms are all electric.

Same structure. Inverse square, potential $\propto 1/r$, field = −slope of V. If you know D.1, you know this: swap G, M, m for k, Q, q and watch the signs.

Before you move on from an electric or magnetic field question

- ✓ Coulomb's law: sizes of charges only, direction from the signs.
- ✓ Units: μC → 10^{-6}, nC → 10^{-9}, cm → m.
- ✓ More than one charge: field = vectors, potential = signed numbers.
- ✓ $E = V/d$ used only between parallel plates?
- ✓ Millikan: weight = electric force, then $n = q/e$, rounded.
- ✓ Magnetic direction: current is **conventional**. Reverse electron flow first.
- ✓ Energy in eV: divide joules by 1.60×10^{-19}.
- ✓ Did I say field lines are ⊥ to equipotentials and conductors?