

Electric fields

A-Level Physics 9702 · Topic 18 revision notes · A2

Field strength and field lines, uniform fields between plates, Coulomb's law, the radial field of a point charge, and electric potential.

10 definitions to learn word for word, 12 equations in their own column, 10 diagrams and graphs. Read it, cover it, test yourself.

1. 18.1 Electric fields and field lines
2. 18.2 Uniform electric fields
3. 18.3 Electric force between point charges
4. 18.4 Electric field of a point charge
5. 18.5 Electric potential

Definitions (mark-scheme wording) Equations Exam traps

18.1 Electric fields and field lines

Definitions

Electric field: a region of space where a charge experiences a force.

Electric field strength (E): the force per unit positive charge acting on a small stationary charge placed at that point.

Field line: a line showing the direction of the force on a small positive test charge at each point.

Equations

$$E = F / q$$

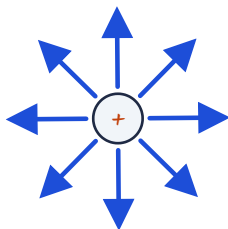
field strength = force per unit positive charge
 N C^{-1}

$$F = qE$$

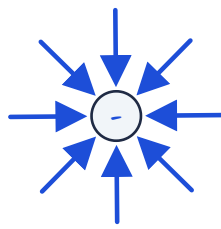
force on a charge q in a field E
 N

Key points

- ✓ E is a **vector**; its direction is that of the force on a **positive** charge.
- ✓ Field lines start on **positive** charges and end on **negative** charges.
- ✓ Closer lines mean a **stronger** field; field lines never cross.
- ✓ A negative charge feels a force **opposite** to the field direction.
- ✓ Unit of E : N C^{-1} , equivalent to V m^{-1} .

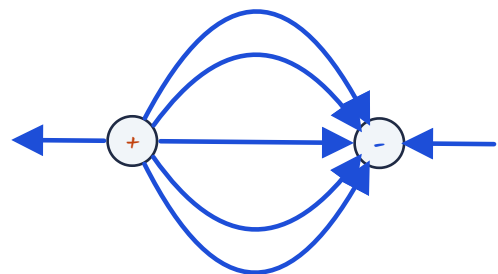


away from +



towards -

Radial fields: lines point away from a positive charge and towards a negative one.



Equal and opposite charges: lines curve from + to -; the field is strongest where the lines crowd together.

Watch out!

- ! Field lines show the force on a **positive** charge; an electron is pushed the other way.
- ! Define E as force per unit **positive** charge; omitting "positive" loses the mark.

18.2 Uniform electric fields

Definitions

Uniform field: a field in which the field strength is the same in magnitude and direction at every point.

Key points

- ✓ Between parallel plates the field is **uniform**: parallel, equally spaced lines from + to -.
- ✓ $E = \Delta V / \Delta d$: field strength equals the **potential gradient** (magnitude).
- ✓ The field **bulges** near the plate edges (non-uniform there).
- ✓ A charge in a uniform field feels a **constant force** qE , so constant acceleration qE/m .
- ✓ Charge entering at right angles to the field: constant velocity along the plates, uniform acceleration across them, so a **parabolic** path.
- ✓ Charge moving along the field lines: it speeds up or slows down in a straight line; energy gained = qV .

Equations

$$E = \Delta V / \Delta d$$

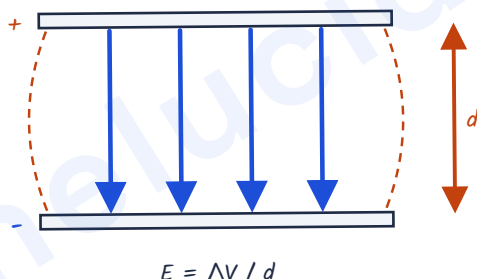
uniform field between parallel plates
 $V\ m^{-1}$

$$a = qE / m$$

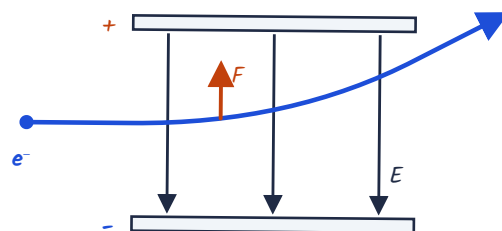
acceleration of a charge in the field
 $m\ s^{-2}$

$$W = qV$$

energy gained crossing a p.d. V
 J



Parallel plates: uniform field in the middle (equal spacing), bulging at the edges.



An electron entering the field is pushed towards the + plate and follows a parabola, like a projectile.

Watch out!

- ! d is the **plate separation** in metres, not the plate length.
- ! In a uniform field the force is the **same everywhere** between the plates, unlike a radial field.

18.3 Electric force between point charges

Definitions

Coulomb's law: the electric force between two point charges is proportional to the product of the charges and inversely proportional to the square of their separation.

Point charge: a charge whose size is negligible compared with the distances involved; outside a charged conducting sphere, its charge acts as a point charge at the centre.

Equations

$$F = Q_1 Q_2 / (4\pi\epsilon_0 r^2)$$

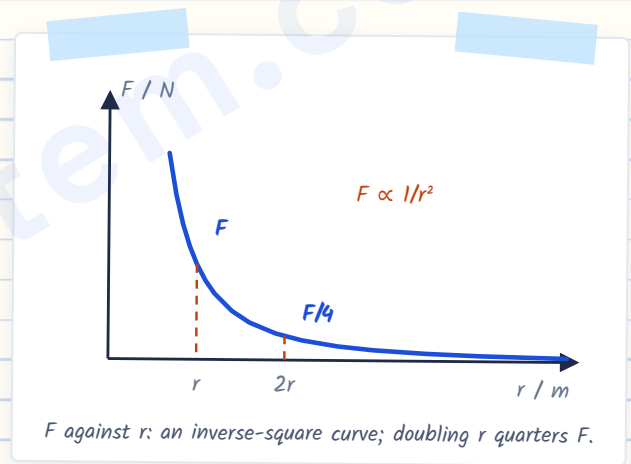
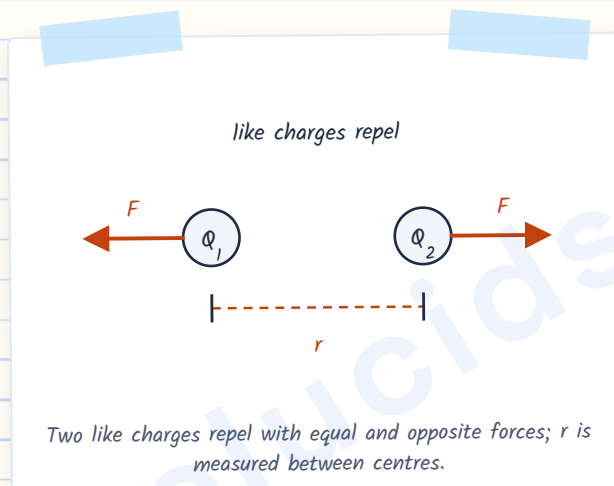
Coulomb's law; $\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
N

$$1 / (4\pi\epsilon_0) \approx 8.99 \times 10^9$$

Coulomb constant
N m² C⁻²

Key points

- ✓ Like charges **repel**, unlike charges **attract**; the forces on the two charges are equal and opposite (Newton's third law).
- ✓ Inverse-square law: doubling r gives **one quarter** of the force.
- ✓ For spheres, r is measured **centre to centre**.
- ✓ Same form as Newton's law of gravitation, but electric forces can repel and are far stronger.
- ✓ A positive F from the formula means repulsion; a negative F means attraction.



Watch out!

- ! Square the separation: $F \propto 1/r^2$, not $1/r$.
- ! Convert distances to metres and charges to coulombs ($1 \mu\text{C} = 10^{-6} \text{ C}$) before substituting.

18.4 Electric field of a point charge

Definitions

Radial field: a field whose lines spread out from (or converge on) a point, with strength decreasing with distance.

Equations

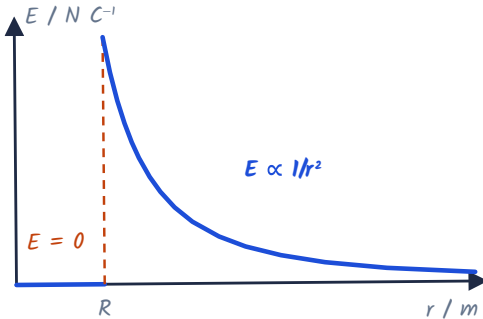
$$E = Q / (4\pi\epsilon_0 r^2)$$

field strength of a point charge
N C⁻¹

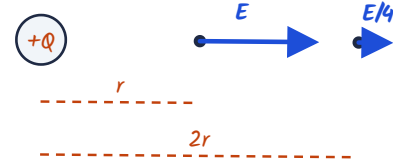
Key points

- ✓ Field of an isolated point charge is **radial** and obeys an **inverse-square law**.
- ✓ Mirrors gravity ($g = GM/r^2$) but can point outwards ($+Q$) or inwards ($-Q$).

- ✓ Charged conducting sphere: $E = 0$ **inside**; outside, it acts as a point charge at its centre.
- ✓ Field from several charges: add the individual field strengths as **vectors**.
- ✓ Neutral point: where the fields of two charges cancel (between like charges, closer to the smaller one).



Charged conducting sphere of radius R : zero field inside, $E \propto 1/r^2$ outside.



Moving from r to $2r$ from a point charge, the field strength falls to one quarter.

Watch out!

- ! $E \propto 1/r^2$ but $V \propto 1/r$: doubling r quarters E but only halves V .
- ! Adding fields from two charges: take account of **direction**, not just magnitude.

18.5 Electric potential

Definitions

Electric potential (V): the work done per unit positive charge in bringing a small test charge from infinity to that point.

Electric potential energy: the work done in bringing a charge from infinity to that point.

Equipotential: a surface on which every point has the same potential; no work is done moving a charge along it.

Key points

- ✓ Potential is zero at **infinity**; V is a **scalar**, so potentials from several charges simply add.
- ✓ Near a positive charge V is **positive**; near a negative charge V is **negative**.
- ✓ Field strength = **negative potential gradient**: $E = -dV/dr$ (field points towards falling potential).
- ✓ On a V - r graph, E at a point = **minus the gradient** of the tangent.
- ✓ Equipotentials are always **perpendicular** to field lines; for a point charge they are concentric spheres.
- ✓ Work done moving charge q through a potential difference ΔV is $W = q\Delta V$.

Equations

$$V = Q / (4\pi\epsilon_0 r)$$

potential of a point charge (zero at infinity)

V

$$E_p = Qq / (4\pi\epsilon_0 r)$$

electric potential energy of two point charges

J

$$E = -dV/dr$$

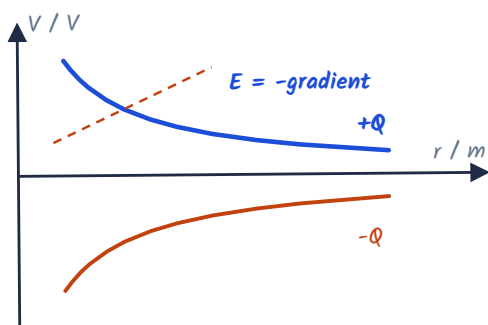
field strength = negative potential gradient

$V \text{ m}^{-1}$

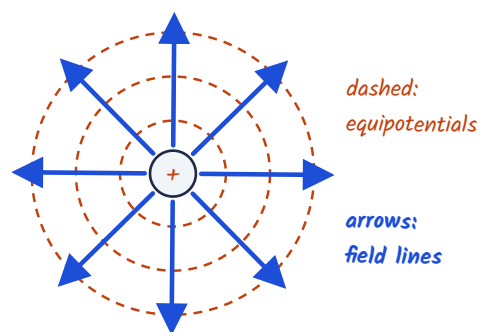
$$W = q\Delta V$$

work done moving charge q through ΔV

J



V against r : positive for $+Q$, negative for $-Q$, both tending to zero at infinity; $E = \text{minus the tangent gradient}$.



Equipotentials (dashed circles) around a point charge are perpendicular to the radial field lines.

Watch out!

- ! Electric potential can be **positive or negative** (gravitational potential is always negative): keep the sign of Q .
- ! Potential is a scalar: add potentials from several charges **algebraically**, not as vectors.