A LEVEL PHYSICS 9702 · A LEVEL · TOPIC 18 · ~4 MIN READ

Electric fields

Electric field strength, uniform fields between parallel plates, the motion of charged particles in a uniform field, Coulomb's law for point charges, and electric potential and its link to field strength.

Electric field lines | Field strength E = F/q | Uniform field E = ΔV/Δd | Charged particles between plates | Coulomb's law | Field of a point charge | Electric potential | Potential energy

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Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Electric field strength E = F/q:** the force per unit positive charge. Its unit is N C^{-1} = V m^{-1}.
- **Uniform field between parallel plates:** E = ΔV/Δd. A charge in it feels a constant force, so it moves in a parabola (like a projectile).
- **Point charges:** $F = Qq/(4\pi\varepsilon_o r^2)$ and $E = Q/(4\pi\varepsilon_o r^2)$. Both follow an inverse-square law.
- **Electric potential $V = Q/(4\pi\varepsilon_o r)$:** work done per unit positive charge bringing it from infinity. Field strength is the negative potential gradient.

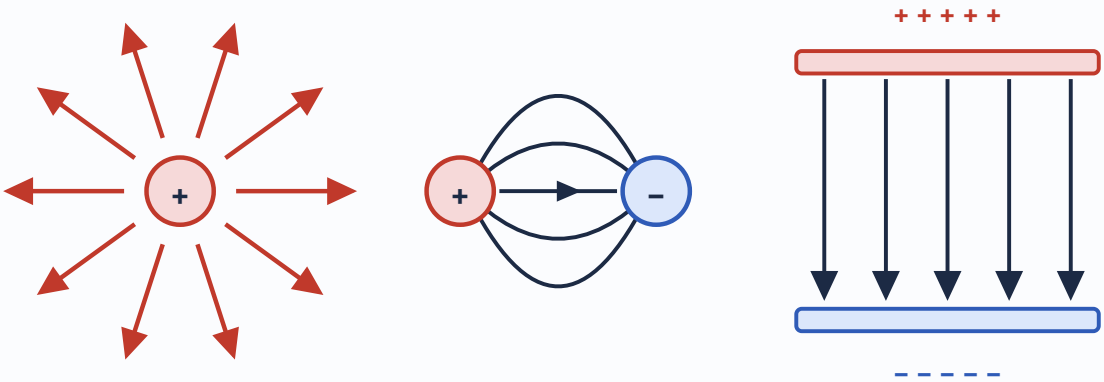
BY THE END YOU CAN

- Understand electric fields and field lines, and define E = F/q.
- Use E = ΔV/Δd for a uniform field and describe the motion of charged particles in it.
- Recall and use Coulomb's law and $E = Q/(4\pi\varepsilon_o r^2)$.
- Define and use electric potential $V = Q/(4\pi\varepsilon_o r)$ and electric potential energy.

1 Field strength

Definitions and uniform fields

Electric field strength — the force per unit positive charge acting on a stationary charge: E = F/q.

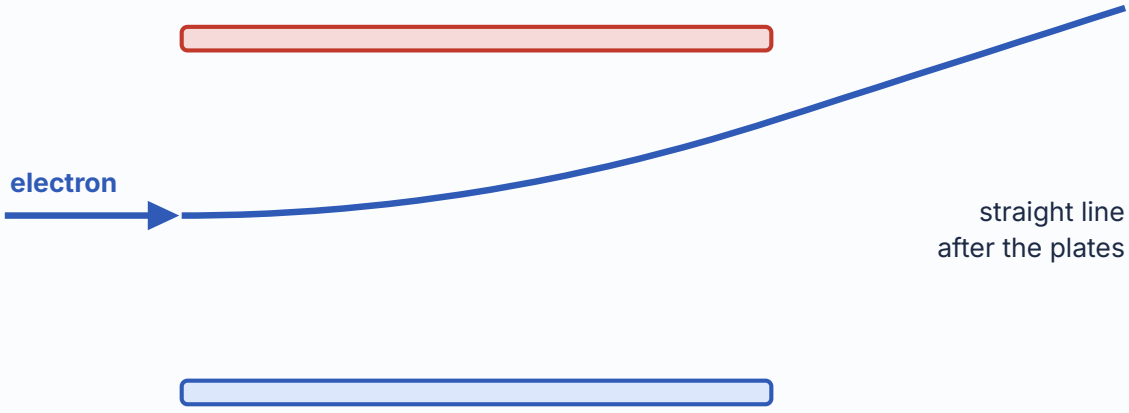


positive: lines outwards **dipole** **parallel plates: uniform**

Field lines go from + to −; closer lines mean a stronger field.

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

uniform field between parallel plates



constant force upwards (towards +): parabola, like a projectile

Between parallel plates the field is uniform: equally spaced parallel lines.

WORKED EXAMPLE

Two parallel plates 2.0 cm apart have a p.d. of 500 V. Find the field strength and the force and acceleration of an electron between them.

1. $E = 500/0.020 = \mathbf{2.5 \times 10^{4}\ V\ m^{-1}}$ A1
2. $F = eE = 1.60 \times 10^{-19} \times 2.5 \times 10^{4} = \mathbf{4.0 \times 10^{-15}\ N}$ A1
3. $\mathbf{a = F/m = 4.0 \times 10^{-15}/9.11 \times 10^{-31} = 4.4 \times 10^{15}\ m\ s^{-2}}$ A1

Deflecting a beam

- **Horizontal:** no force, constant velocity, so t = L/v. **Vertical:** constant acceleration a = eE/m, so y = ½at².

WORKED EXAMPLE

An electron enters the field between plates of length 5.0 cm at 2.0×10^7 m s^{-1}, parallel to them. The field is 1.0×10^4 V m^{-1}. Find its vertical deflection on leaving.

1. $t = 0.050/2.0 \times 10^7 = 2.5 \times 10^{-9}$ s C1
2. $a = eE/m = 1.76 \times 10^{15}$ m s^{-2} C1
3. **$y = \frac{1}{2}at^2 = 5.5$ mm** A1

COMMON MISTAKE

Assuming the electron accelerates along the plates. The force is only perpendicular to the plates; its horizontal velocity is unchanged.

2 Point charges

Coulomb's law

$$F = Qq/(4\pi\varepsilon_0 r^2) \; ; \; E = Q/(4\pi\varepsilon_0 r^2) \; ; \; V = Q/(4\pi\varepsilon_0 r)$$ DATA & FORMULAE

$$1/(4\pi\varepsilon_o) = 8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

Electric potential — the work done per unit positive charge in bringing a small test charge from infinity to the point.

WORKED EXAMPLE

Find the field strength and potential 0.10 m from a point charge of +4.0 nC.

1. $E = 8.99 \times 10^9 \times 4.0 \times 10^{-9}/0.10^2 =$ **3.6×10^3 N C^{-1}** A1
2. **$V = 8.99 \times 10^9 \times 4.0 \times 10^{-9}/0.10 = 360$ V** A1

- **Potential energy** of charge q at potential V is $qV = Qq/(4\pi\varepsilon_o r)$. Unlike gravity, it can be positive (repulsion) or negative (attraction).
- **Field strength = −potential gradient:** $E = -dV/dr$. Equipotentials are perpendicular to field lines.

COMMON MISTAKE

Squaring r in the potential, or using the diameter instead of the radius of a charged sphere.

LINKING QUESTION

The same inverse-square ideas for masses are in Gravitational fields; storing charge is in Capacitance; and current and charge are in Electricity.

Test yourself — cover the answers first

QUICK CHECK

1. Define electric field strength.
2. Give two units for E.
3. How does E vary with distance from a point charge?

4. What shape path does an electron follow between parallel plates?
5. Define electric potential.

EXAM-STYLE

6. Two point charges of +2.0 μC are 0.30 m apart. Find the force between them.
7. An oil drop of mass 3.2×10^{-15} kg is held stationary between plates 1.0 cm apart at 980 V. Find its charge.
8. Find the work done moving +3.0 μC from a point at 200 V to a point at 50 V.

Show answers

1. force per unit positive charge
2. N C^{-1} and V m^{-1}
3. $E \propto 1/r^2$
4. a parabola
5. work done per unit positive charge bringing it from infinity
6. $8.99 \times 10^9 \times (2.0 \times 10^{-6})^2/0.09 = 0.40$ N (repulsive)
7. $qV/d = mg \Rightarrow q = 3.2 \times 10^{-15} \times 9.81 \times 0.010/980 = 3.2 \times 10^{-19}$ C (2e)
8. $W = q\Delta V = 3.0 \times 10^{-6} \times (-150) = -4.5 \times 10^{-4}$ J (the field does work)

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