

Charges, coulomb's law and electric potential

Physics grades 11-12 (A Level · IB · Class 11-12) · Lesson

Quick answer: An electric field is the region around a charge where other charges feel a force, with strength is $E = F / q$ in N/C. Coulomb's law gives the force between point charges: $F = kQ_1Q_2 / r^2$. Between plates $E = V / d$ is uniform, and a charge moving through a potential difference ΔV gains energy $q\Delta V$.

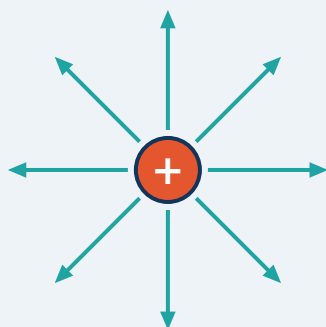
Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB D.2

What is an electric field?

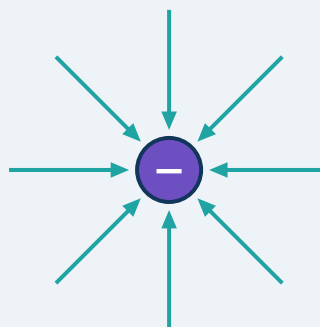
Every electric charge changes the space around it. Another charge placed there feels a force, and the map of that influence is the **electric field**. A rubbed balloon sticking to a wall and a lightning flash both come from such fields.

Definition

Electric field strength E at a point is the force per unit positive charge placed there: $E = F / q$. It is a vector and is measured in newtons per coulomb (N/C), which equals volts per metre (V/m).



positive point charge: field points away



negative point charge: field points in

Field lines show the direction of the force on a small positive test charge. They are closer together where the field is stronger.

How does Coulomb's law give the force between charges?

Two point charges attract if their signs differ and repel if they are the same. The force falls with the square of the distance, just as gravity does, but it is far stronger.

Formula

$F = kQ_1Q_2 / r^2$ and, for a point charge, $E = kQ / r^2$

F = force (N), E = field strength (N/C), Q = charge (C), r = distance between centres (m), $k = 1 / (4\pi\epsilon_0) = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$. The elementary charge is $e = 1.60 \times 10^{-19} \text{ C}$.

Worked example

A $+3.0 \text{ nC}$ charge and a -5.0 nC charge are 4.0 cm apart. Calculate the force between them.

$F = kQ_1Q_2 / r^2 = (8.99 \times 10^9 \times 3.0 \times 10^{-9} \times 5.0 \times 10^{-9}) / (0.040)^2 = 1.35 \times 10^{-7} / 1.6 \times 10^{-3} = \mathbf{8.4 \times 10^{-5} \text{ N}}$, and it is attractive because the signs differ.

Common mistake

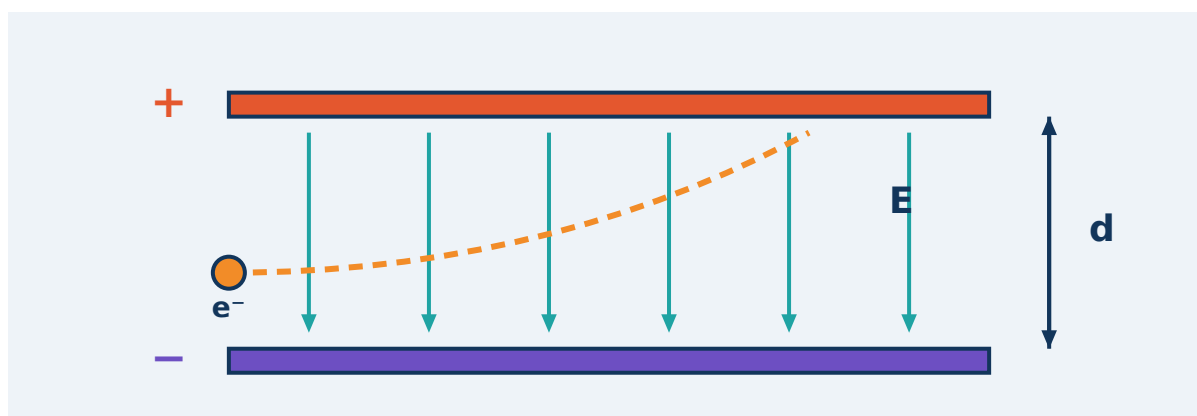
Put r in metres, not centimetres, and square it. Converting 4.0 cm to 0.040 m is the step most often forgotten, and it changes the answer by a factor of 10^4 .

What is the field between two charged plates?

Two parallel metal plates connected to a power supply create a **uniform field**. The field lines are parallel and equally spaced, so E has the same size and direction everywhere between the plates, except near their edges.

Key law

For plates separated by a distance d with potential difference V : $\mathbf{E} = \mathbf{V} / \mathbf{d}$. A charge q feels a constant force $\mathbf{F} = q\mathbf{E}$, so a free particle accelerates uniformly and follows a parabola if it enters at right angles to the field.



Uniform field between parallel plates: $E = V / d$. An electron is pulled towards the positive plate and follows a parabola.

Worked example

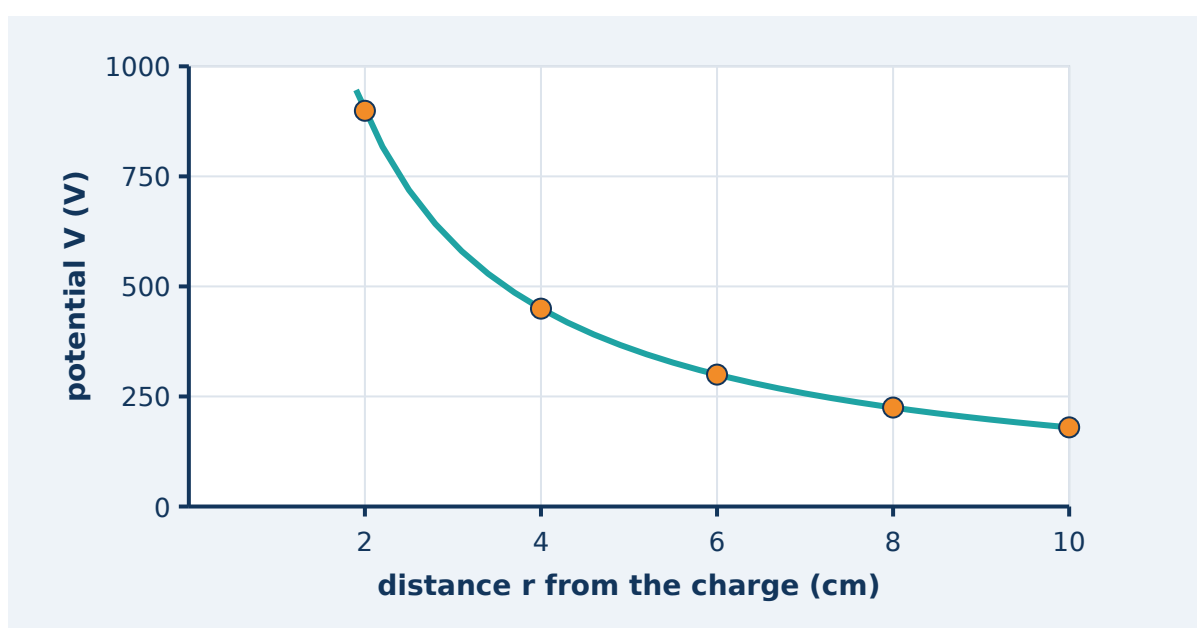
Plates 2.0 cm apart have a potential difference of 600 V . Calculate the field and the acceleration of an electron.

$E = V / d = 600 / 0.020 = \mathbf{3.0 \times 10^4 \text{ V/m}}$. $F = eE = 1.60 \times 10^{-19} \times 3.0 \times 10^4 = 4.8 \times 10^{-15} \text{ N}$. $a = F / m = 4.8 \times 10^{-15} / 9.11 \times 10^{-31} = \mathbf{5.3 \times 10^{15} \text{ m/s}^2}$.

How do potential and energy work in an electric field?

Electric potential V is the work done per unit positive charge in bringing a small test charge from infinity to a point. Around a point charge, $V = kQ / r$. Potential is a scalar, so contributions from several charges simply add with their signs.

Quantity	Point charge	Uniform field
Field strength	$E = kQ / r^2$ (falls as $1/r^2$)	$E = V / d$ (constant)
Potential	$V = kQ / r$ (falls as $1/r$)	V changes linearly with distance
Force on charge q	$F = qE$, radial	$F = qE$, constant
Link	$E = -\Delta V / \Delta r$	$E = -\Delta V / \Delta x$



Potential of a $+2.0 \text{ nC}$ point charge: $V = kQ / r$. Doubling r halves V , and the slope of the curve at any point equals $-E$.

When a charge q moves through a potential difference ΔV , the field does work $W = q\Delta V$. For an electron or proton the convenient unit is the **electronvolt**: $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$, the energy gained by a charge e crossing 1 V .

Worked example

An electron is accelerated from rest through 500 V . Calculate its speed.

Gain in kinetic energy $= eV = 500 \text{ eV} = 8.0 \times 10^{-17} \text{ J}$. From $\frac{1}{2}mv^2 = eV$, $v = \sqrt{(2eV / m)} = \sqrt{(2 \times 8.0 \times 10^{-17} / 9.11 \times 10^{-31})} = \mathbf{1.3 \times 10^7 \text{ m/s}}$.

Lina's tip

Sketch the field lines and mark the direction of the force on a positive charge first. For an electron, reverse the arrow. Most sign errors disappear after that sketch.

Key points to remember

- $E = F / q$, measured in N/C or V/m
- Coulomb's law: $F = kQ_1Q_2 / r^2$, with $k = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$
- Point charge: $E = kQ / r^2$ and $V = kQ / r$
- Uniform field between plates: $E = V / d$ and $F = qE$
- Energy gained by a charge crossing ΔV is $q\Delta V$; $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$

Charges, Coulomb's law and electric potential: frequently asked questions

What is the unit of electric field strength?

The unit is newton per coulomb (N/C), which is identical to volt per metre (V/m). Use N/C when you think about force and V/m when you think about potential difference across a gap.

How does the electric force change if the distance doubles?

The force falls to one quarter because Coulomb's law is an inverse square law. The same rule applies to the field strength of a point charge.

Why is the field between parallel plates uniform?

Charge spreads evenly over the large flat plates, so the field lines run parallel and equally spaced from one plate to the other. Only near the edges do the lines bulge outwards.

What is an electronvolt?

It is the energy transferred when one elementary charge moves through a potential difference of one volt. It equals $1.60 \times 10^{-19} \text{ J}$ and is used for particles such as electrons.

How do electric and gravitational fields differ?

Gravity always attracts, but electric forces can attract or repel because charge has two signs. The electric force between two protons is about 10^{36} times larger than their gravitational attraction.