Electric fields

Electric field strength and field lines, uniform fields between parallel plates and how charged particles move in them, Coulomb's law, the field of a point charge, electric potential and potential gradient, and electric potential energy.

18.1 Electric fields and field lines

An **electric field** is a field of force. The **electric field strength** at a point is the force per unit **positive** charge:

$$E = \frac{F}{q} \qquad F = qE$$

The unit is N/C, which equals V/m.

Field lines

Field lines show the direction of the force on a positive charge: away from positive charges and towards negative ones. Closer lines mean a stronger field, and lines never cross. They meet a conductor's surface at right angles.

18.2 Uniform electric fields

Between parallel plates with a p.d. ΔV and separation Δd, the field is uniform, except near the edges:

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

Charged particles in a uniform field

The force qE is constant and acts parallel to the field lines, so the acceleration is constant: $a = qE/m$. Positive charges accelerate along the field, and negative charges against it.

A particle entering at right angles to the field follows a **parabola**, just like a projectile: constant velocity along the plates and uniform acceleration across them.

> TRY IT
>
> **An electron enters a field of 2.0×10^4 V/m between plates. Find its acceleration.** $a = eE/m = (1.60 \times 10^{-19} \times 2.0 \times 10^4)/(9.11 \times 10^{-31}) = 3.5 \times 10^{15}$ m/s².

The weight of an electron or a proton is negligible compared with the electric force.

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18.3 Electric force between point charges

For a point outside a spherical conductor, the charge on it may be treated as a **point charge at its centre**.

Coulomb's law, for two point charges in free space:

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

where $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m is the permittivity of free space. Like charges repel and unlike charges attract. Air can be treated as free space.

18.4 Electric field of a point charge

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

The field points away from a positive charge and towards a negative one. It is a vector, so fields from several charges add as vectors.

TRY IT

Find the field 0.10 m from a charge of $+2.0 \times 10^{-9}$ C. $E = (2.0 \times 10^{-9})/(4\pi \times 8.85 \times 10^{-12} \times 0.10^2) = 1.8 \times 10^3$ N/C, directed away from the charge.

18.5 Electric potential

Definition

The **electric potential** at a point is the work done per unit positive charge in bringing a small test charge from infinity to the point.

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

The unit is the volt. It is positive near a positive charge, because you must do work to push a positive charge in, and negative near a negative charge. Potential is a scalar, so potentials from several charges simply add.

Potential gradient

The electric field strength at a point equals the negative of the potential gradient at that point: $E = -\frac{\Delta V}{\Delta x}$.

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On a graph of V against x, the steeper the slope, the stronger the field. The field points from high to low potential.

Electric potential energy

The potential energy of two point charges is:

$$E_P = \frac{Qq}{4\pi\varepsilon_0 r}$$

Unlike gravity, it can be positive (like charges) or negative (unlike charges).

> **TRY IT**
>
> **A proton is accelerated from rest through 2000 V. Find its kinetic energy and speed.** Work done $= qV = 1.60 \times 10^{-19} \times 2000 = 3.2 \times 10^{-16}$ J. Then $\frac{1}{2}mv^2 = 3.2 \times 10^{-16}$, so with $m = 1.67 \times 10^{-27}$ kg, $v = 6.2 \times 10^{5}$ m/s.

Comparing gravitational and electric fields

	Gravitational	Electric
Acts on	mass	charge
Force law	$F = Gm_1m_2/r^2$	$F = Q_1Q_2/(4\pi\varepsilon_0 r^2)$
Direction	attractive only	attractive or repulsive
Field strength	force per unit mass	force per unit positive charge
Potential	always negative	positive or negative

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