Electric Fields

Name _____ Date _____

By the end of this topic I can...

- define electric field strength and draw electric field lines
- use $E = V/d$ for a uniform field
- analyse a charge in equilibrium or deflected in a uniform field

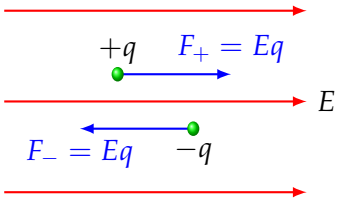
Electric forces and fields

- like charges repel ; opposite charges attract

An **electric field** is a region of space in which a charged object experiences a force .

Electric field strength is the force per unit positive charge :

$$E = \frac{F}{q} \qquad [E] = \mathrm{N\,C^{-1}} = \mathrm{V\,m^{-1}}$$



- E is a vector : its direction is that of the force on a positive test charge, so force on a charge is $F =$ Eq
- fields from several sources add as vectors

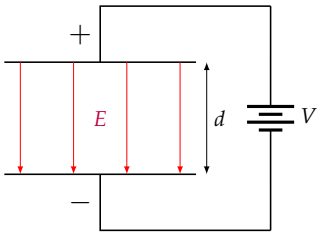
Example 13.1 An electron is at a point where the electric field strength is 1500 N C^{-1}, what is the electric force acting on the electron?

$$F = Eq = 1500 \times 1.60 \times 10^{-19} \quad \Rightarrow \quad F = 2.4 \times 10^{-16}\ \mathrm{N}$$

Field lines

- the tangent to a line gives the direction of E; closer lines mean a stronger field
- lines start on positive charge (or infinity) and end on negative charge (or infinity)
- lines never cross, and meet the surface of a conductor at right angles

Uniform electric fields



Two parallel plates with p.d. V and separation d produce a **uniform field** between them (parallel, equally spaced field lines):

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

- the field points from the higher to the lower potential

Example 13.2 Find the field strength between plates at potentials -50 V and $+30$ V separated by 10 cm.

$$E = \frac{V}{d} = \frac{30 - (-50)}{0.10} = 800\ \mathrm{N\,C^{-1}}.$$

Example 13.3 Two horizontal parallel plate conductors are separated by 1.5 cm in air. A potential difference of 36 V is applied across the plates. Compare the electric force and gravitational force acting on a proton between the plates.

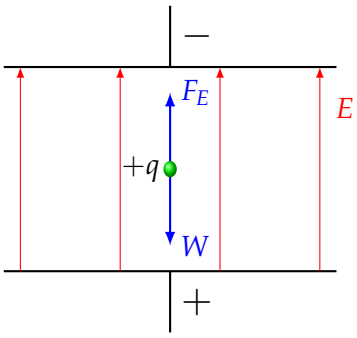
electric field strength: $E = \frac{V}{d} = \frac{36}{1.5\times10^{-2}} = 2400\ \text{N C}^{-1}$
electric force: $F_E = Eq = 2400 \times 1.60 \times 10^{-19} \approx 3.84 \times 10^{-16}$ N
weight of the proton: $W = mg = 1.67 \times 10^{-27} \times 9.81 \approx 1.64 \times 10^{-26}$ N
this shows electric force on proton are much stronger than gravitational forces
when dealing with motion of sub-atomic particles (e.g., protons, electrons, etc.) in an electric field, effects of gravity can therefore be ignored

Charge in equilibrium

- a charged particle is held stationary when $F_E = W$:

$$Eq = mg \qquad \text{with } E = \frac{V}{d}$$

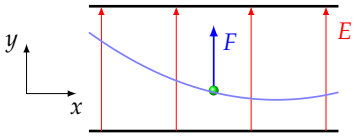
- the electric force must act upwards, so for a negative charge the field points downwards



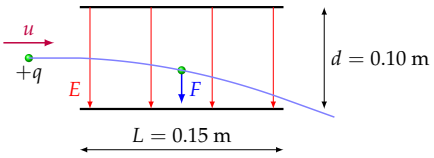
Example 13.4 An oil droplet of mass 0.040 g and charge −20 nC is at rest between plates 8.0 cm apart. (a) Find the strength and direction of the field. (b) What p.d. is needed? (c) What happens if the plate separation is reduced?

(a) $F_E = mg = 0.040 \times 10^{-3} \times 9.81 = 3.9 \times 10^{-4}$ N, so $E = \frac{F}{q} = \frac{3.9 \times 10^{-4}}{20 \times 10^{-9}} = 1.96 \times 10^4\ \text{N C}^{-1}$. The force must be up and the charge is negative, so the field points downwards.
(b) $V = Ed = 1.96 \times 10^4 \times 0.080 = 1.6 \times 10^3$ V.
(c) A smaller d gives a larger E, so $F_E > mg$ and the droplet accelerates upwards.

Deflection of a charged particle



- perpendicular to the field: constant velocity, $x = u_x t$
- along the field: constant acceleration $a = \dfrac{F}{m} = \dfrac{Eq}{m}$ (weight is negligible for sub-atomic particles), so $y = \frac{1}{2}at^2$
- the path is a parabola, like projectile motion



Example 13.5 A proton enters a uniform field of strength 1.0×10^4 N C^{-1} at an initial velocity of 5.0×10^5 m s^{-1}. The initial direction of motion is at right angles to the field. The dimensions of the field are shown in the diagram. (a) What is the time taken for the proton to pass through the field? (b) What is the deviation in the direction of the field during this time? (c) If an electron enters the field with the same initial velocity, describe how the deflection of the electron compares with that of the proton.

constant horizontal velocity, so time taken: $t = \frac{L}{u} = \frac{0.15}{5.0\times10^5} = 3.0 \times 10^{-7}$ s

constant acceleration in direction of field: $a = \frac{F}{m} = \frac{Eq}{m} = \frac{1.0\times10^4\times1.6\times10^{-19}}{1.67\times10^{-27}} \approx 9.58 \times 10^{11}$ m s^{-2}

displacement moved in this direction: $\Delta y = \frac{1}{2}at^2 = \frac{1}{2} \times 9.58 \times 10^{11} \times (3.0 \times 10^{-7})^2 \approx 0.043$ m

electron would experience a much greater deflection in the opposite direction

- electron has opposite charge to proton, so deflect in the opposite direction
- mass of electron is much smaller, so much greater acceleration

  time spent in the field is the same, so electron has much greater deflection

Practice questions

Question 13.1 A charge of $+2.0$ nC experiences a force of 6.0×10^{-5} N in a field. Find the field strength.

$E = \dfrac{F}{q} = \dfrac{6.0 \times 10^{-5}}{2.0 \times 10^{-9}} = 3.0 \times 10^{4}\ \mathrm{N\,C^{-1}}$.

Question 13.2 Two plates 2.0 cm apart have a p.d. of 500 V. Find (a) the field strength, (b) the force on an electron between them, (c) its acceleration.

(a) $E = \dfrac{V}{d} = \dfrac{500}{0.020} = 2.5 \times 10^{4}\ \mathrm{V\,m^{-1}}$.
(b) $F = Eq = 2.5 \times 10^{4} \times 1.60 \times 10^{-19} = 4.0 \times 10^{-15}$ N.
(c) $a = \dfrac{F}{m} = \dfrac{4.0 \times 10^{-15}}{9.11 \times 10^{-31}} = 4.4 \times 10^{15}\ \mathrm{m\,s^{-2}}$.

Question 13.3 An oil droplet of mass 1.0×10^{-14} kg is held at rest between plates 1.0 cm apart with a p.d. of 600 V. Find its charge and the number of excess electrons.

$E = \dfrac{600}{0.010} = 6.0 \times 10^{4}\ \mathrm{V\,m^{-1}}$. $Eq = mg \Rightarrow q = \dfrac{mg}{E} = \dfrac{1.0 \times 10^{-14} \times 9.81}{6.0 \times 10^{4}} = 1.6 \times 10^{-18}$ C.
$N = \dfrac{q}{e} = \dfrac{1.6 \times 10^{-18}}{1.60 \times 10^{-19}} \approx 10$ electrons.

Question 13.4 An electron enters a uniform field of strength $3.0 \times 10^{3}\ \mathrm{N\,C^{-1}}$ at $2.0 \times 10^{7}\ \mathrm{m\,s^{-1}}$ at right angles to the field. The field region is 5.0 cm long. Find (a) the time in the field, (b) the sideways deflection.

(a) $t = \dfrac{L}{u} = \dfrac{0.050}{2.0 \times 10^{7}} = 2.5 \times 10^{-9}$ s.
(b) $a = \dfrac{Eq}{m} = \dfrac{3.0 \times 10^{3} \times 1.60 \times 10^{-19}}{9.11 \times 10^{-31}} = 5.3 \times 10^{14}\ \mathrm{m\,s^{-2}}$, so $y = \frac{1}{2}at^2 = \frac{1}{2} \times 5.3 \times 10^{14} \times (2.5 \times 10^{-9})^2 = 1.6 \times 10^{-3}$ m.