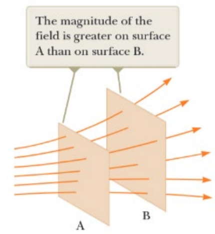
22.5 Electric Field Lines:

- **Concept of Electric Field Lines**:
  Electric field lines are imaginary lines that help visualize the electric field in space. They indicate *the direction and strength* of the electric field created by one or more charges.
- The electric field vector $\vec{E}$ is tangent to the electric field line at each point.
- **Strength Representation**:



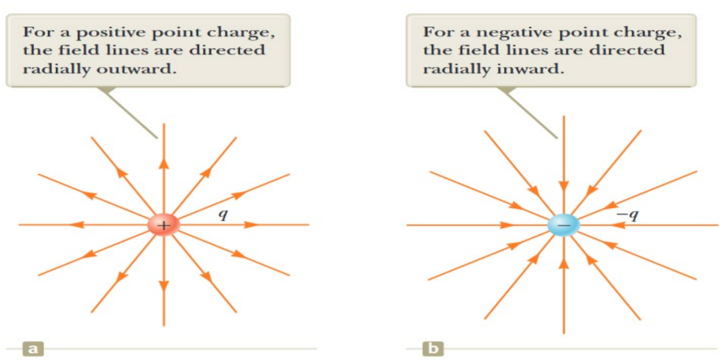
  - Where the lines are closer together, the electric field is stronger.
  - Where they are farther apart, the field is weaker.

- **Rules for Drawing Field Lines**:

  - The lines must begin on a positive charge and terminate on negative charges.
  - Lines never intersect because the electric field has a single direction at any point.
  - The number of lines drawn is proportional to the magnitude of the charge generating the field.

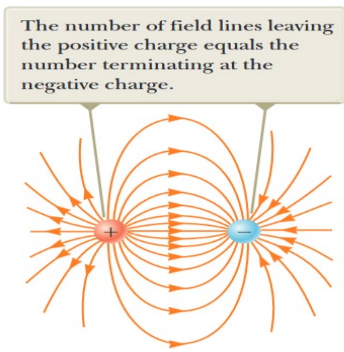
- **Examples**:

  - **Single Positive Charge**: Lines radiate outward symmetrically in all directions.
  - **Single Negative Charge**: Lines point inward toward the charge.
  - **Dipole (Positive and Negative Charge)**: Lines curve from the positive charge to the negative charge, forming a characteristic pattern.



Key Observations:

- The electric field is stronger near charges and weaker farther away.
- If there is no charge present, field lines do not exist in that region.



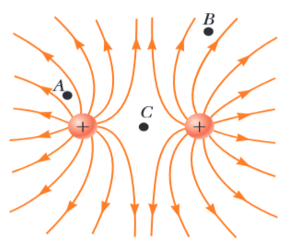


Figure 22.18 The electric field lines for two positive point charges. (The locations *A*, *B*, and *C* are discussed in Quick Quiz 22.5.)

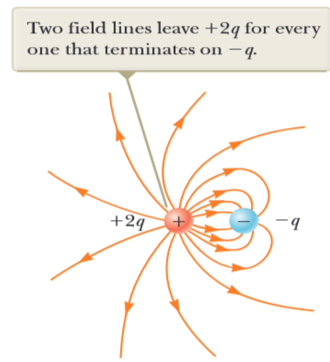


Figure 22.19 The electric field lines for a point charge $+2q$ and a second point charge $-q$.

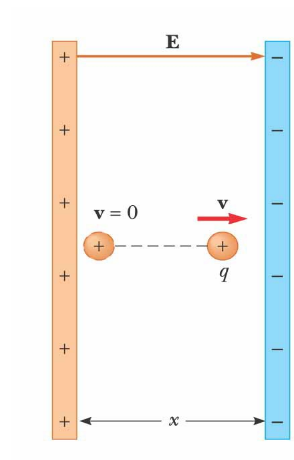
22.6 Motion of a Charged Particle in a Uniform Electric Field

When a particle of charge q and mass m is placed in an electric field **E**, the electric force exerted on the charge is q**E**. If this is the only force exerted on the particle, it must be the net force and so must cause the particle to accelerate. In this case, Newton's second law applied to the particle gives;

$$F_e = qE = ma$$

Then, the acceleration of the particle is

$$\vec{a} = \frac{q}{m}\vec{E}$$

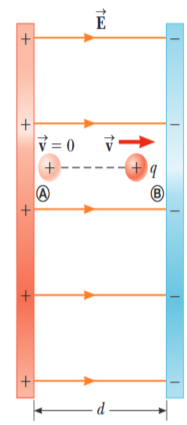


Please note that:

- If E is uniform (that is, **constant in magnitude and direction**), then the acceleration is constant.
- If the particle has a **positive** charge, then its acceleration is **in the direction of the electric field**.
- If the particle has a **negative** charge, then its acceleration is **in the direction opposite the electric field.**

Example-1:

A uniform electric field $\vec{E}$ is directed along the x-axis between parallel plates of charge separated by a distance d, as shown in the Figure. A positive point charge q of mass m is released from rest at a point Ⓐ next to the positive plate and accelerates to a point Ⓑ next to the negative plate.



To solve this problem (and similar ones), we need to call on the kinematic equations introduced in Chapter 2.

$$\Delta x = x_f - x_i \quad ; \quad v_{x,ave.} = \frac{\Delta x}{\Delta t}$$

$$v_{xf} = v_{xi} + a_x t$$

$$v_{x,ave.} = \frac{v_{xi} + v_{xf}}{2}$$

$$x_f = x_i + \frac{1}{2}(v_{xi} + v_{xf})t$$

$$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$$

$$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$$

(A) Find the speed of the particle at Ⓑ by modeling it as a particle under constant acceleration.

$$v_f^2 = v_i^2 + 2a(x_f - x_i) = 0 + 2a(d - 0)$$

$$v_f^2 = 2ad$$

$$v_f = \sqrt{2ad}$$

$$a = \frac{qE}{m}$$

$$v_f = \sqrt{2(\frac{qE}{m})d} = \sqrt{\frac{2qEd}{m}}$$

(B) Find the speed of the particle at Ⓑ by modeling it as a non-isolated system in terms of energy.

$$W = F.\Delta x$$

$$W = \Delta K = F.\Delta x = K_f - K_i = \frac{1}{2}mv^2 - 0$$

$$F.\Delta x = \frac{1}{2}mv^2 \quad ; \quad F = qE$$

$$v = \sqrt{\frac{2F\Delta x}{m}} = \sqrt{\frac{2qEd}{m}}$$

Example-2:

An electron enters a uniform electric field region with v_o=3x10^6 m/s and E= 200 N/C. The horizontal length of the plates is *l* = 0.1 m.

(a) Find the acceleration of the electron while it is in the electric field.

(b) Assuming the electron enters the field at time t=0, find the time it leaves the field.

(c) Assuming the vertical position of the electron as it enters the field is $y_i = 0$, What is the vertical position when it leaves the field?

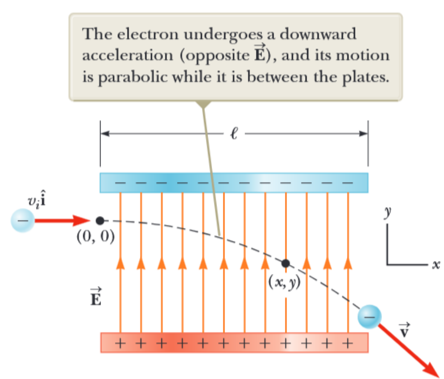


Figure 22.21 (Example 22.8) An electron is projected horizontally into a uniform electric field produced by two charged plates.

Solution:

Discussed during the lecture ….

Part (A) – Acceleration of the electron

The electric force on a charge q in a field is $F = qE$.
For an electron, $q = -e$, so the acceleration is
$a = F/m_e = (-eE)/m_e$.
Magnitude: $|a| = eE/m_e$.

With $E = 200$ N/C, $e = 1.60\times10^{-19}$ C, $m_e = 9.11\times10^{-31}$ kg:
$a \approx -3.51\times10^{13}$ m/s²
(negative sign indicates acceleration opposite the field direction).

Part (B) – Time inside the field

Horizontal motion has no acceleration (force is vertical), so $v_x = v_i$ is constant.
Time to cross the plate length ℓ:
$t = \ell / v_i$.

With $\ell = 0.100$ m and $v_i = 3.00\times10^6$ m/s:
$t = 0.100 / (3.00\times10^6) \approx 3.33\times10^{-8}$ s.

Part (C) – Vertical displacement while in the field

If the electron enters with initial vertical position $y_i = 0$ and initial vertical velocity $v\{y,i\} = 0$,
then the vertical displacement after time t is
$y_f = y_i + v\{y,i\}\ t + (1/2)\ a\ t^2 = (1/2)\ a\ t^2$.

Using $a \approx -3.51\times10^{13}$ m/s² and $t \approx 3.33\times10^{-8}$ s:
$y_f \approx (1/2)(-3.51\times10^{13})(3.33\times10^{-8})^2 \approx -1.95\times10^{-2}$ m $= -1.95$ cm.
The negative sign indicates deflection in the direction of the acceleration.