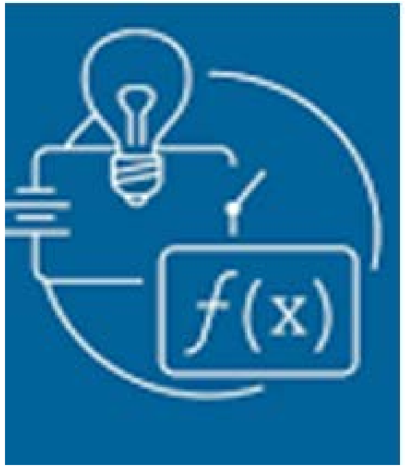
G12 ADV Physics :
Electricity and Magnetism

مؤسسة الإمارات للتعليم المدرسي
EMIRATES SCHOOLS ESTABLISHMENT

unit 3 | Electric Potential

1. Electric Potential energy



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Learning objectives:

Textbook Chapter	Ch 3 - Electric potential

Performance Indicators	*Electric Potential Energy*
	1- Identify that the electric force is conservative and thus has an associated potential energy which can be defined in analogy with the gravitational potential energy 2- Show that the work done on a charged particle moving from an initial point to a final point in an electric field is given in terms of the change of the electric potential energy of the system 1- Identify that the amount of work done by the electric force on a moving charged particle between two given points in an electric field is path independent 2- Find the work done by a constant electric field to move a charge through a known distance 3- Describe the electrostatic potential energy lost or gained in moving a charge between two points in a known electric field 4- Solve problems on electric potential energy

Conservative Force

Identify that the electric force is conservative and thus has an associated potential energy which can be defined in analogy with the gravitational potential energy

Conservative force: is a force with the property that the work done in moving a particle between two points is independent of the taken path.

ex: gravitational force, electric force, and spring force.

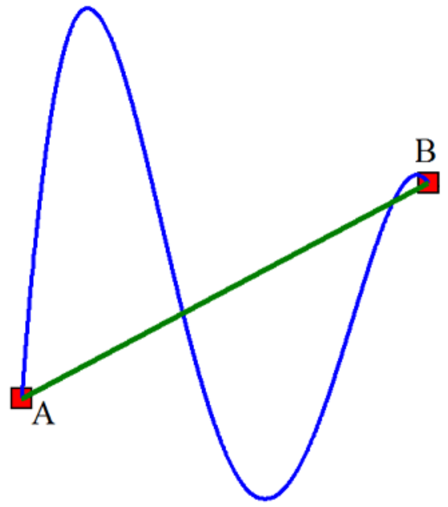
A conservative force depends only on the position of the object $\Longrightarrow$ path independent.

$$W = F.d = Fd\,cos\theta \qquad W = \int F.dr$$

The concept of potential energy is the stored energy in a system by applying internal work done from a conservative force.

ex: gravitational potential energy, electric potential energy, and elastic potential energy.

$$\Delta U = -W \qquad \Delta U = -F.d = -Fd\,cos\theta \qquad \Delta U = -\int F.dr$$



$$W_{AB} = W_{AB}$$

$$\Delta U = -K.E$$

conservative force
↓
conservative field
↓
potential energy
↓
conservative work
↓
path independent

Work Done by Electric Field

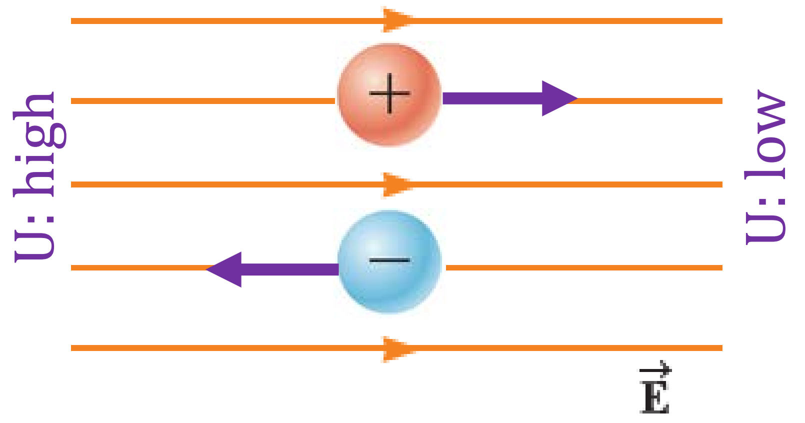
Show that the work done on a charged particle moving from an initial point to a final point in an electric field is given in terms of the change of the electric potential energy of the system

Assume there is a charge $(\pm)q$ is placed in an electric field E.

The electric field applies a conservative electric force $(F = qE)$ *on the charge.*

Positive charge: electric force in the same direction to the electric field, therefore the charge motion with electric field.

Negative charge: electric force in opposite direction to the electric field, therefore the charge motion opposite to electric field.



as the charge moves a distance d, The work is done by the electric field.

$$W = Fd\cos\theta$$

$$W_{\text{int}} = qEd\cos\theta$$

$$W_{\text{int}} = -\Delta U$$ work done by field

Internal forces decrease the potential energy of the system $(-\Delta U)$.

Natural process by internal force

In case you want to move the charge opposite to the direction of the electrical force with a constant speed it requires an external force equal in magnitude and opposite in direction to the electrical force

$$W = Fd\cos\theta$$

$$W_{\text{ext}} = qEd\cos\theta$$

$$W_{\text{ext}} = \Delta U$$ work done by force

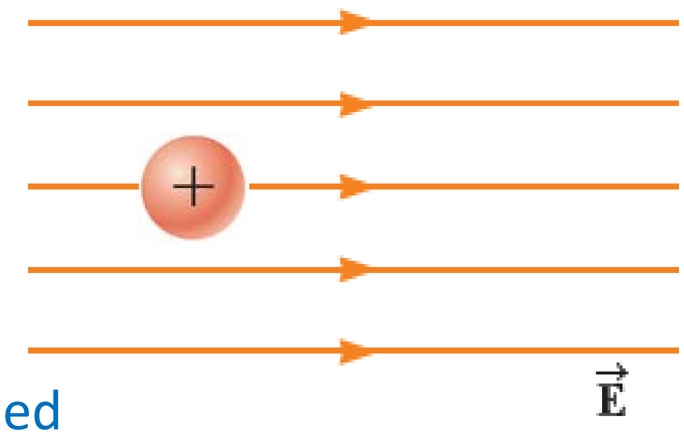
External forces increase the potential energy of the system $(+\Delta U)$.

requires external force

Conservation of Energy

Find the work done by a constant electric field to move a charge through a known distance

Suppose there is a charge-electric field system. As the charge is placed in the field, the internal work is done by the filed (force), so the electric potential energy is changed, kinetic energy is changed, or both.



$W_{\text{int}} = -\Delta U$ work done by electric force without changing speed

$0 = \Delta U + \Delta K.E$ work done by electric field with changing speed CoE

$$K.E = \frac{1}{2}mv^2$$

$W_{\text{ext}} = \Delta U$ work done by external agent without changing speed

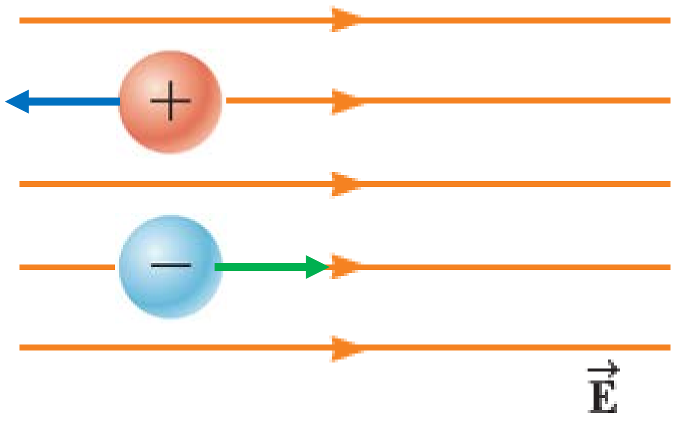
$W_{\text{ext}} = \Delta U + \Delta K.E$ work done by external agent but with changing speed

Charges signs are satisfied into scalar quantities such as potential, energy and work.

Find the work done by a constant electric field to move a charge through a known distance

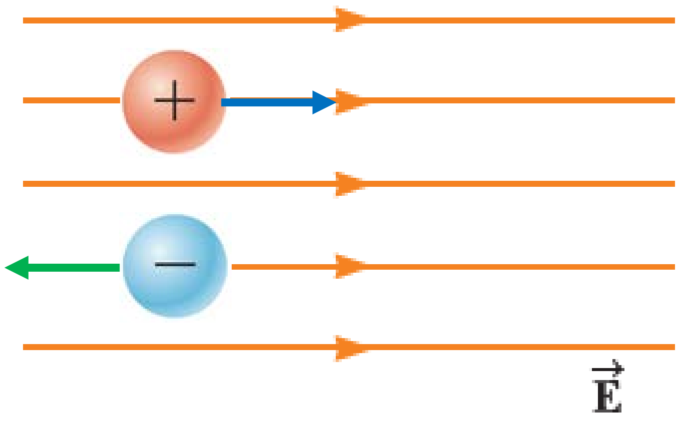
Positive work done means the charge-field system gains energy, so the potential and potential energy increases.
a positive charge is moved opposite to the field
a negative charge is moved with the field.

agent



Negative work done means the charge-field system loses energy, so the potential and potential energy decreases.
a positive charge is moved with the field
a negative charge is moved opposite to the field.

natural

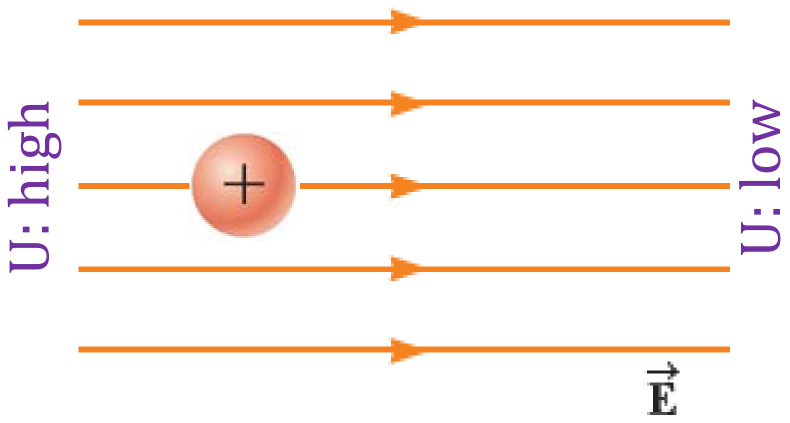


zero work done means the charge-field system's energy remains constant, so the potential and potential energy are constant too.
positive a negative charges are moved perpendicular to the field.

Find the work done by a constant electric field to move a charge through a known distance

Charge in a constant field:

Assume a test charge q_o is placed in a uniform electric field, the charge experiences electric force. The electric force does work which accelerates the charge with direction of the electric field.



In terms of potential energy, the charge moves naturally from high potential energy to low potential energy ($-\Delta U$).

All charges move in electric field in the direction which decreases their potential energy.

$$W_{\text{int}} = F.d = F_e d \cos\theta$$

$$W_{\text{int}} = q_o E d \cos\theta$$

$$W_{\text{int}} = -\Delta U$$

$$\Delta U = -q_o E d \cos\theta$$

change in potential energy for test charge in electric field

reference level: beginning of motion

internal force

$$U = q_o E d$$

potential energy for test charge in electric field

Work Done by Electric Field

Find the work done by a constant electric field to move a charge through a known distance

Ex: A positive charge of 3.0×10^{-8} C is placed in an upward directed uniform electric field of 4.0×10^{4} N/C. When the charge is moved 0.5 m upward, the work done by the electric force on the charge is:

(A) 6×10^{-4} J (B) 12×10^{-4} J (C) 2×10^{4} J (D) 8×10^{4} J (E) 12×10^{4} J

$$W_{\text{int}} = q_o E d \cos 0$$

$$W_{\text{int}} = (3 \times 10^{-8})(4 \times 10^{4})(0.5) \cos 0 = 6 \times 10^{-4} J$$

Find the work done by a constant electric field to move a charge through a known distance

Ex: Potential energy for test charge in electric field

A proton is released from rest in 300.0 N/C electric field pointing to positive x-direction. Calculate the change in electric potential energy if it moved 10.0 cm making an angle 60.0° with the electric field.

$q_p = +1.6 \times 10^{-19} C$

$E = 300\ N/C$

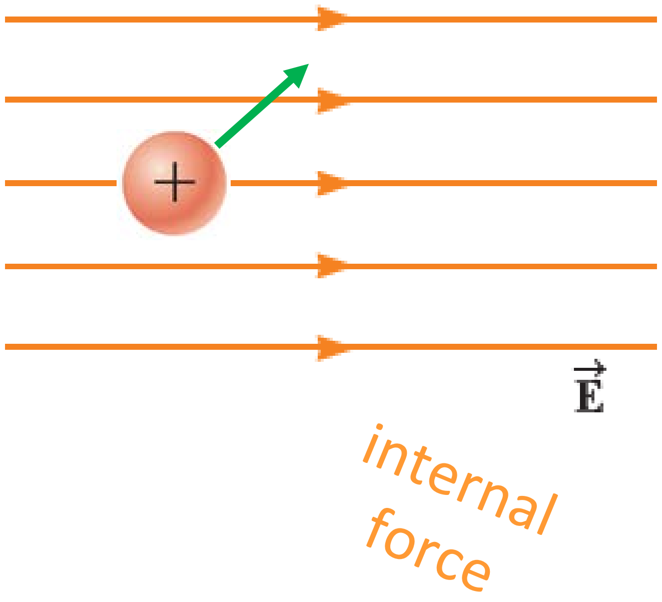
$d = 10 \times 10^{-2}\ m$

$\theta = 60°$

$\Delta U = -q_o E d \cos\theta$

$\Delta U = -(1.6 \times 10^{-19})(300)(10 \times 10^{-2}) \cos 60$

$\Delta U = -2.40 \times 10^{-18}$ J



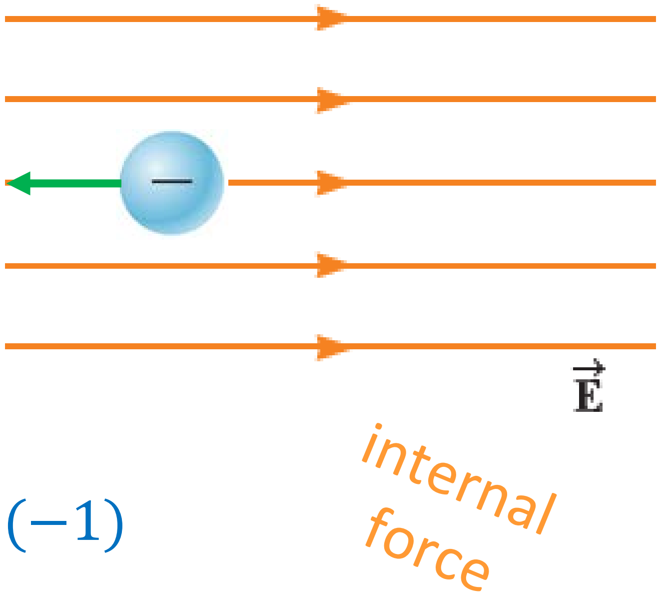
Internal force decreases the potential energy
Proton moves with direction of electric field

Charges signs are satisfied into scalar quantities such as flux, potential, energy and work.

Find the work done by a constant electric field to move a charge through a known distance

Ex: Potential energy for test charge in electric field

An electron is released from rest at x = 22.0 cm in 1.50 kN/C electric field pointing to positive x direction. Calculate the change in electric potential energy when it reaches x = 5.00 cm.



$$q_e = -1.6 \times 10^{-19} C$$

$$E = 1.5 \times 10^{3} N/C$$

$$d = (5 - 22) \times 10^{-2} m$$

$$\theta = 0$$

$$\Delta U = -q_o E d \cos 180$$

$$\Delta U = -(-1.6 \times 10^{-19})(1.5 \times 10^{3})(-17 \times 10^{-2})(-1)$$

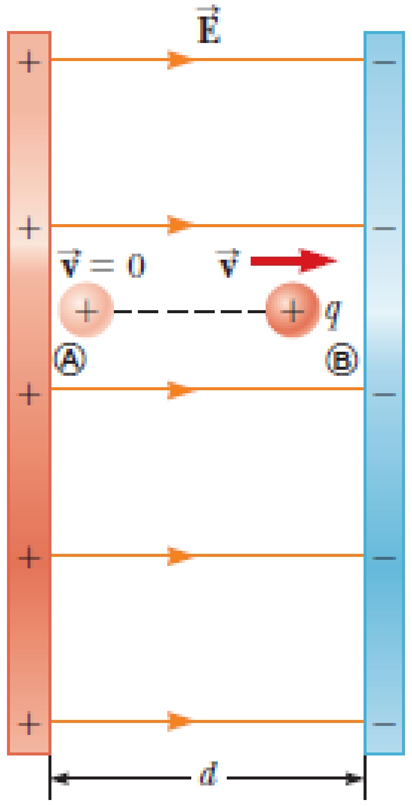
$$\Delta U = 4.08 \times 10^{-17}\ \text{J}$$

Internal force decreases the potential energy

Electron moves opposite to electric field

Charges signs are satisfied into scalar quantities such as flux, potential, energy and work.

Ex: A uniform electric field ($E = 2 \times 10^6 N/C$) is directed along the x axis between parallel plates of charge separated by a distance ($d = 2\ cm$). A positive point charge ($q = 8 \times 10^{-6} C$) of mass ($m = 4 \times 10^{-2}$) is released from rest at a point A and accelerates to a point B. Find the speed of the particle at B.



$$|\Delta U| = |-W| = |-\Delta K.E|$$

$$(qE)\ d\ cos\theta = (\frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2)$$

$\theta = 0 \quad ---\rightarrow \quad cos\theta = 1$

$v_i = 0$

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

$$v_f = \sqrt{\frac{2(qE)\ d}{m}} = \sqrt{\frac{2(8 \times 10^{-6})(2 \times 10^6)(2 \times 10^{-2})}{(4 \times 10^{-2})}} = 4\ m/s$$

Practice question