Chapter 25

1

Electric Potential

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Lecture 02

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Calculating The Potential From The Field

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Calculating the Potential from the Field

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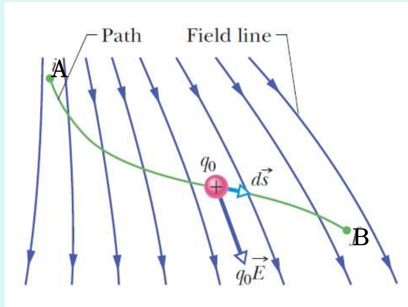
As a charged particle moves from (A) to (B) in an electric field, it will experience a change in electric potential.

$$\Delta V = \frac{\Delta U}{q_\circ}$$

$$\Delta V = V_B - V_A = -\int_A^B \vec{E}\cdot d\vec{s}$$



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Calculating the Potential from the Field, Uniform E

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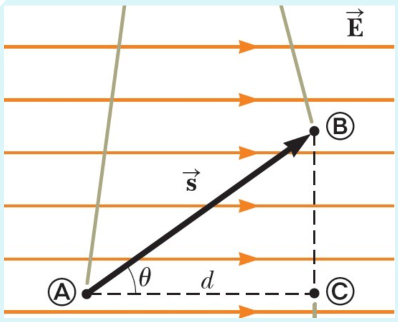
If the electric field is uniform, and the direction of motion between the two points (A) and (B) occurred along a displacement vector ($\vec{s}$) that makes an angle (θ) with the direction of the electric field, then:



$$\Delta V = V_B - V_A = -\int_A^B \vec{E}\cdot d\vec{s} = -\vec{E}\cdot\int_A^B d\vec{s}$$

$$\Delta V = V_B - V_A = -\vec{E}\cdot\vec{s} = -|\vec{E}||\vec{s}|\,cos\theta$$

Another SI unit of electric field is:

$$N/C = V/m$$

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Calculating the Potential from the Field, Uniform E

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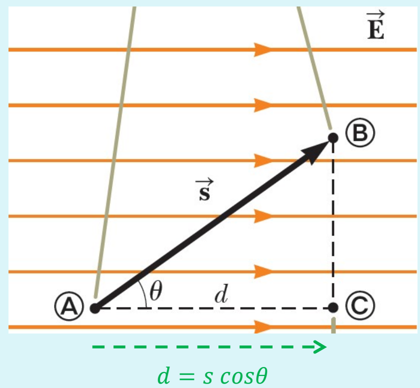
- Note that:

$$\cos\theta = \frac{d}{s}$$

$$d = s \cos\theta$$

- d: is the displacement from (A) to (C) and is parallel to the field lines.
- Therefore:

$$\Delta V = V_B - V_A$$
$$= -E\, s \cos\theta$$
$$= -E\, d$$
$$= V_C - V_A$$
$$\Longrightarrow \quad V_B = V_C$$



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Equipotential surfaces

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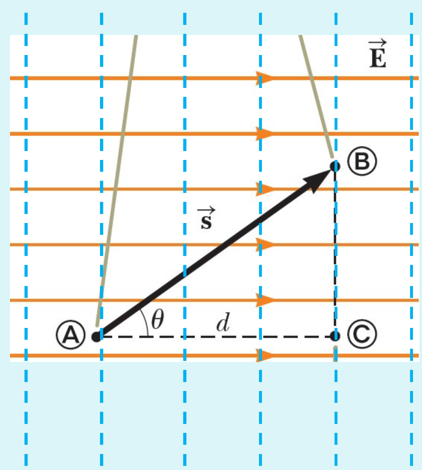
Note that:

$$V_B = V_C$$

Points (B) and (C) are at the same potential.

The name equipotential surface is given to **any surface consisting of a continuous distribution of points having the same electric potential:**

- **No** net work is done on a charged particle by an electric field when the particle moves between two points on the same equipotential surface.
- Equipotential surfaces are always **perpendicular** to electric field lines.



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Calculating the Potential from the Field, Uniform E

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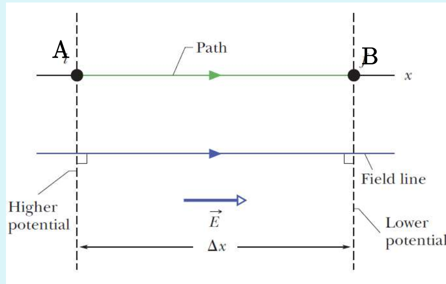
Note that:

The **negative sign** in:

$$V_B - V_A = -\vec{E} \cdot \vec{s} = -|\vec{E}||\vec{s}|\, cos\theta$$

indicates that the electric potential at point (B) is lower than at point (A).

Electric field lines always point in the direction of decreasing electric potential.



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Conservation of Mechanical Energy

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Assume a charge moves in an electric field without any change in its kinetic energy. The work by the field is:

$$W = -\Delta U = -q\,\Delta V$$

If a charged particle moves through an electric field and the electric force is the only force acting on it, then the mechanical energy is conserved:

$$\Delta K = -\Delta U = -q\,\Delta V$$

$$\frac{1}{2}m(v_f^2 - v_i^2) = -q(V_f - V_i)$$

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Directions

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If a **positive** charge is released from rest in an electric field, it accelerates in the direction of the field; then:

- The kinetic energy (ΔK) increases.
- The electric potential energy (ΔU) decreases.
- The electric potential difference (ΔV) decreases.

If a **negative** charge is released from rest in an electric field, it accelerates in a direction opposite the direction of the field:

- The kinetic energy (ΔK) increases.
- The electric potential energy (ΔU) decreases.
- The electric potential difference (ΔV) increases.

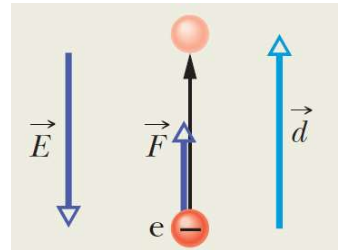
Work and potential energy in an electric field

Friday, 29 January, 2021 20:51

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

Near Earth's surface the electric field has the magnitude $E = 150\ N/C$ and is directed downward. What is the change in the electric potential energy of a released electron when the electrostatic force causes it to move vertically upward through a distance $\boldsymbol{d = 520\, m}$?



Solution

The change ΔU in the electric potential energy of the electron is related to the work W done on the electron by the electric field by the equation ($\Delta U = -W$).

The work done by a constant force $\vec{F}$ on a particle undergoing a displacement $\vec{d}$ is :

$$W = \vec{F} \cdot \vec{d}$$

The electrostatic force and the electric field are related by the force equation $\vec{F} = q\vec{E}$, where here q is the charge of an electron $(= -1.6 \times 10^{-19} C)$.

Substituting for $\vec{F}$ into $W = \vec{F} \cdot \vec{d}$ and taking the dot product yield:

$$W = q\vec{E} \cdot \vec{d} = qEd \cos\theta$$

where θ is the angle between the directions of $\vec{E}$ and $\vec{d}$.The field $\vec{E}$ is directed downward and the displacement $\vec{d}$ is directed upward; so $\theta = 180°$.

Substituting this and other data, we find:

$$W = (-1.6 \times 10^{-19} C)(150 N/C)(520 m) \cos 180° = 1.2 \times 10^{-14} J$$

Then:

$$\Delta U = -W = -1.2 \times 10^{-14} J.$$

This result tells us that during the 520 m ascent, the electric potential energy of the electron decreases by $1.2 \times 10^{-14} J$.

Motion of a Proton in a Uniform Electric Field

Friday, 29 January, 2021 20:52

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
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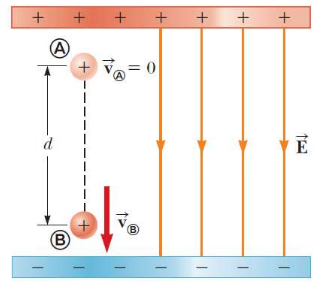
A proton is released from rest at point (A) in a uniform electric field that has a magnitude of $8 \times 10^4 \ V/m$ as shown. The proton undergoes a displacement of magnitude $d = 0.5\ m$ to point (B) in the direction of $\vec{E}$. Find the speed of the proton after completing the displacement.



Solution

The situation is analogous to an object falling through a gravitational field. The potential difference between points A and B is:

$$\Delta V = -Ed = -(8.0 \times 10^4 V/m)(0.50m) = -4.0 \times 10^4 V$$

Write the appropriate reduction of the conservation of energy equation for the isolated system of the charge and the electric field:

$$\Delta K + \Delta U = 0$$

Substitute the changes in energy for both terms:

$$\frac{1}{2}mv^2 - 0 + e\Delta V = 0$$

Solve for the final speed of the proton:

$$v = \sqrt{\frac{-2e\Delta V}{m}}$$

Substitute numerical values:

$$v = \sqrt{\frac{-2 \times 16 \times 10^{-19} C - 4.0 \times 10^4 V}{1.67 \times 10^{-27} kg}} = 2.8 \times 10^6 m/s$$

Because ΔV is negative for the field, ΔU is also negative for the proton–field system. The negative value of ΔU means the potential energy of the system decreases as the proton moves in the direction of the electric field. As the proton accelerates in the direction of the field, it gains kinetic energy while the electric potential energy of the system decreases at the same time.