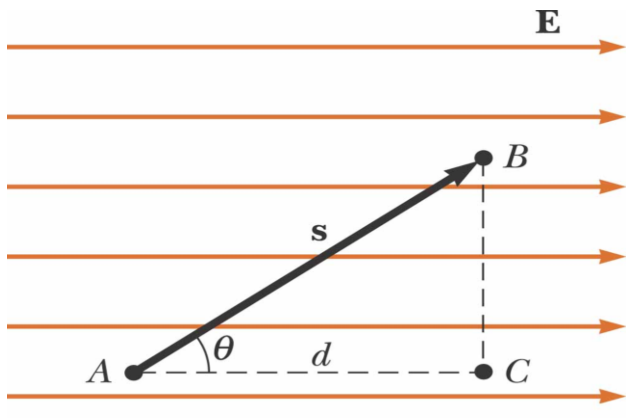
Chapter 25

Electrical Potential

25.1 Potential Difference and Electric Potential

- What is the electric potential?
- What is the electrical potential energy?
- What is the potential difference?



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Let's place a positive test charge in a uniform electric field.
What's the work done moving the charge from A to B?

dW= F *ds* cosθ

However, the total work done is given by*:*

$W = \int_A^B Fds\cos\theta$

Since F=Eq, one can rewrite W as:

$W = \int_A^B qEds\cos\theta$

But work is the negative of the change in potential energy,

$$\Delta U = U_f - U_i = -\int_A^B qEds\cos\theta = -q\int_A^B \vec{E}.\overrightarrow{ds}$$

This means that the potential energy is changed by an amount of $-q\vec{E}.\overrightarrow{ds}$

Electric potential is defined as potential energy per unit charge:

$$V = \frac{\Delta U}{q} = -\int_A^B \vec{E}.\overrightarrow{ds}$$

Electric potential is a scalar characteristic of an electric field, independent of any charges that may be placed in the field.

- **Unite of electric potential and potential difference:**

Because electric potential is a measure of potential energy per unit charge, the SI unit of both electric potential and potential difference is joules per coulomb, which is defined as a volt (V):

$$1\,V \equiv 1\,\mathrm{J/C}$$

A unit of energy commonly used in atomic and nuclear physics is the electron volt (eV), which is defined as the energy a charge–field system gains or loses when a charge of

$$\mathbf{1\ eV = (1.6x10^{-19}\ C)x(1\ V) = 1.6x10^{-19}J}$$

25.2 Potential difference in a Uniform electric field

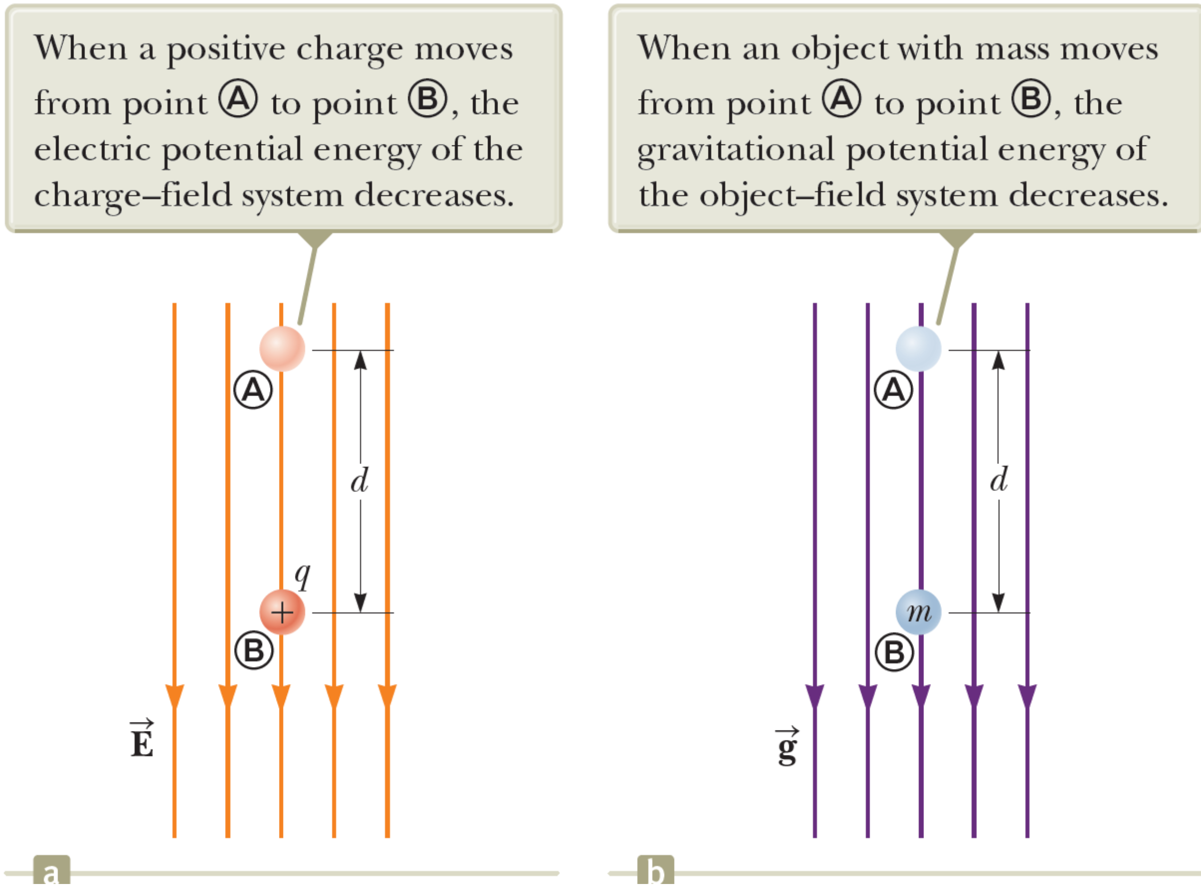
Often, what someone is interested in is the difference in potential between two specific points. In simple terms, a potential difference is the ratio of the work needed to move a charge from A to B, divided by the magnitude of that charge. charge

$$\Delta V_{AB} = -\int_A^B E ds \cos\theta = V_B - V_A$$

$$\Delta V_{AB} = -E\int_A^B ds \cos 0 = -Ed$$

Often the potential difference is taken with respect to ground potential (recall mgh for gravitational potential energy)
This expression rearranged gives the work required to move a charge:
$W = V_{ab}q$.

Note:
The Sign of ΔV: The negative sign is because we started at point Ⓐ and moved to a new point in the *same* direction as the electric field lines. If we started from Ⓑ and moved to Ⓐ, the potential difference would be 1*Ed*. In a uniform electric field, the magnitude of the potential difference is *Ed*, and the direction of travel can determine the sign.

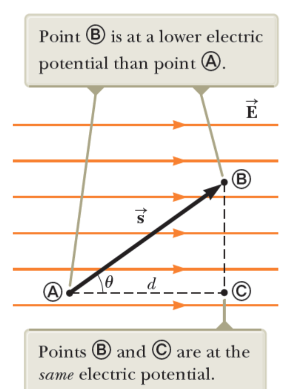


Electric potential is often compared to gravitational potential:

- A mass in a gravitational field has potential energy based on its height.
- Similarly, a charge in an electric field has an electric potential based on its position.

If we take point A at infinity, one can write the electric potential at any point B as:

$$V_B - V_A = -\int_{\infty}^{B} E ds \cos\theta = V_B$$

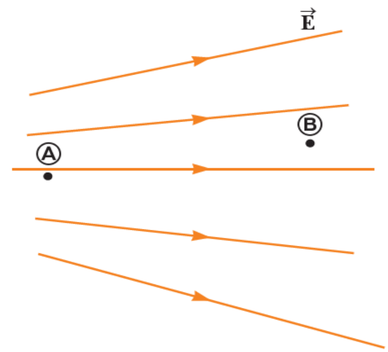


Prove that V_B=V_C.

Example-1: In the Figure, two points Ⓐ and Ⓑ are located within a region in which there is an electric field.

(i) How would you describe the potential difference $\Delta V = V_B - V_A$?

(a) It is positive. (b) It is negative. (c) It is zero.



Solution:

We know that:

$$V = -\int_{A}^{B} \vec{E}.\overrightarrow{ds}$$

- The electric field **E** points to the **right**.
- The path from **A → B** is also to the **right** (A is left of B on the same horizontal line).
- Therefore, E·ds > 0 along the path, so

$$\Delta V_{AB} is\ negative\ value$$

(ii) A negative charge is placed at Ⓐ and then moved to Ⓑ. How would you describe the change in potential energy of the charge–field system for this process? Choose from the same possibilities.

Solution:

Now the negative charge moved from A to B

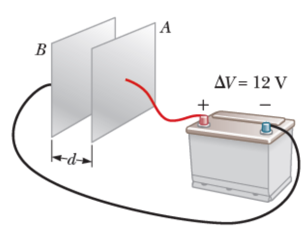
Potential-energy change:

ΔU=q ΔV.

Here q<0 and ΔV<0, so ΔU=(negative)(negative)=positive

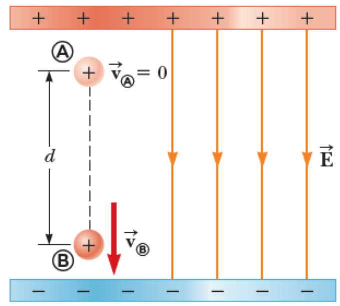
So the potential energy *increases* when the negative charge is moved from A to B.

Example-2: A battery has a specified potential difference ΔV between its terminals and establishes that potential difference between conductors attached to the terminals. A 12-V battery is connected between two parallel plates as shown in the Figure. The separation between the plates is d = 0.30 cm, and we assume the electric field between the plates to be uniform. (This assumption is reasonable if the plate separation is small relative to the plate dimensions and we do not consider locations near the plate edges.) Find the magnitude of the



electric field between the plates.

Example-3: A proton is released from rest at a point Ⓐ in a uniform electric field that has a magnitude of 8.0 x10^4 V/m (see the figure). The proton undergoes a displacement of magnitude d = 0.50 m to a point Ⓑ in the direction of $\vec{E}$. Find the speed of the proton after completing the displacement.



Exercise-4: An ion with charge +5|e| and 4.2x10^{-26} Kg is accelerated from rest through a potential difference ΔV. Its speed reaches 4x10^4 m/s. The potential difference ΔV in (V) unit is:

A. 12 B. 24 C. 42 D. 86