King Saud University
College of Science
Physics & Astronomy Dept.

PHYS 111 (GENERAL PHYSICS 2)
CHAPTER 25: Electric Potential
LECTURE NO. 4

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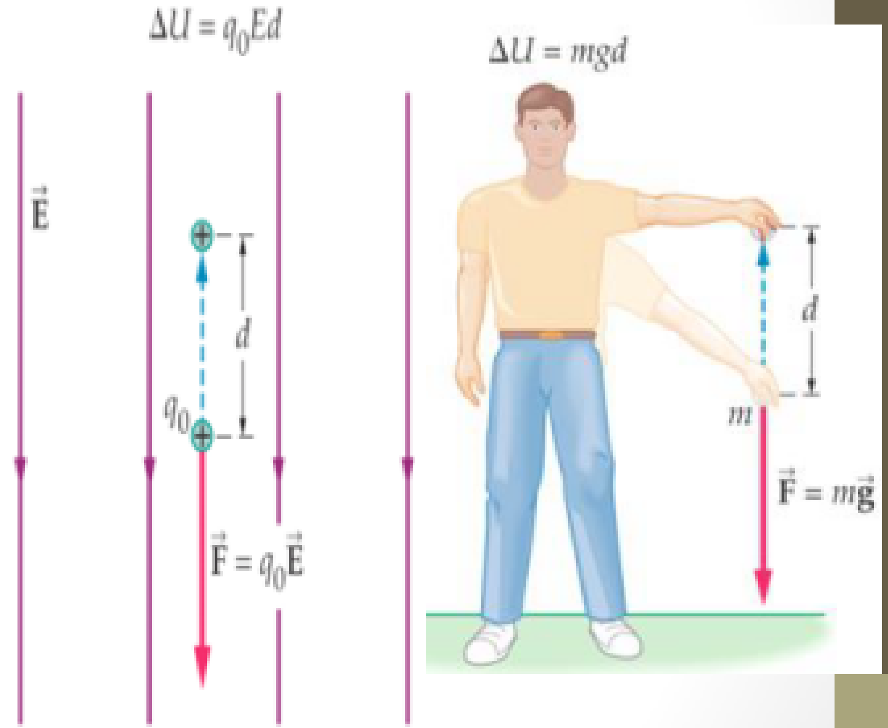
25.1 Electric Potential and Potential Difference

(a) A positive test charge $q_{\circ}$, experiences a downward force due to the electric field $E^{\rightarrow}$. If the charge is moved upward a distance d, the work done by the electric field -$q_{\circ}Ed$. At the same time the electric potential energy of the system increases by $q_{\circ}Ed$. The situation is analogous to that of an object in gravitational field. (b) If a ball is lifted against a force exerted By gravity, the gravitational potential Energy of the system increases.



25.1 Electric Potential and Potential Difference

When a charge q is placed in an electric field **E** created by some source charge distribution. Then there is an electric force q**E** acting on the charge. If the charge is free to move, it will response to the electric force. Therefore, the electric field will be doing work on the charge.

$$W_{\text{int}} = \vec{\mathbf{F}}_e \cdot d\vec{\mathbf{s}} = q\vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}.$$

✓Work is dot product of two vectors **E** and **ds**

$$\overline{E}.\overline{\boldsymbol{ds}} = E\, ds \cos\Theta$$

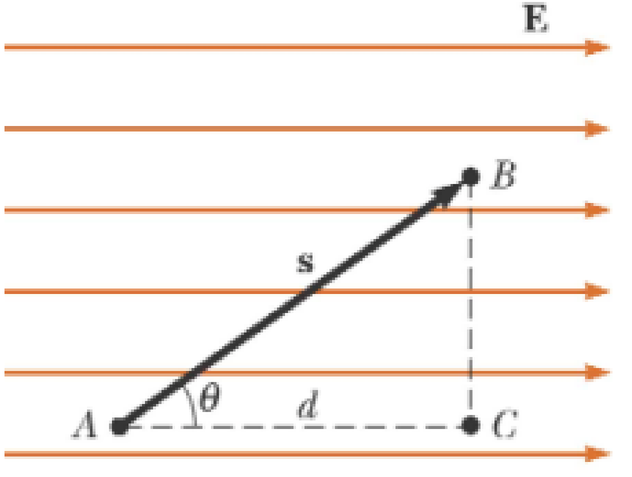
The work done to move a charge q from point A to point B

$$W_{int} = \int_A^B F\, ds \cos\theta \qquad W = \int_A^B Eq\, ds \cos\theta$$

25.1 Electric Potential and Potential Difference

The internal work W_{int} done in a system is equal to the negative of the change in the potential energy $-\Delta U$ of the system.

$$U = -\int_A^B E\, q\, ds \cos\theta \; = -q \int_A^B E\, ds \cos\theta$$



- The unit of work and energy is joule
- 1 joule = 1 N .1 m
- Potential energy is scalar quantity

because it is a dot product of two vector

25.1 Electric Potential and Potential Difference

- A charged object can have potential energy by virtue of its location in an electric field.
- Work is required to push a charged particle against the electric field of a charged body.
- When an electric field moves a positive charge toward the electric field, the electric potential energy of the positive charge decreases.
- When an electric field moves a negative charge against the electric field, the electric potential energy of the negative charge decreases.

25.1 Electric Potential and Potential Difference

- If we push a single charge against an electric field, we do a certain amount of work. If we push two charges against the same field, we do twice as much work.

- Two charges in the same location in an electric field will have twice the electrical potential energy as one; ten charges will have ten times the potential energy.

25.1 Electric Potential and Potential Difference

Electric potential (or the potential) V :

Electric potential is electrical potential energy per charge.

$$V = \frac{U}{q} = \frac{E\,q\,d}{q} = E\,d$$

$$V = kq/d$$

- ✓ At any location the potential energy per charge <u>(Electric potential V</u>) whatever the amount of charge will be the same.
- ✓ The unit of potential is volt (V)
- ❑ what is the equivalent unit for volt?
- ❑ the electric potential is a scalar of a vector quantity?

25.1 Electric Potential and Potential Difference

Potential difference ΔV :

The potential difference between two points A and B in an electric field is defined as the change in electric potential energy of the system when a charge q is moved between the points divided by the charge.

$$\Delta V = V_B - V_A = \frac{\Delta U}{q} = -\int_A^B E\, ds$$

When the distance between A and B is d and Θ=180°

$$\Delta V = V_B - V_A = E\, d$$

- ✓ **The electric field is a measure of the rate of change of the electric potential with respect to position.**

$$E = \Delta V / d$$

25.1 Electric Potential and Potential Difference

The relation between work done on the charge and the potential

If the agent moves the charge from A to B without changing the kinetic energy of the charge, the agent performs work that changes the potential energy of the system: .

$$\Delta \boldsymbol{U} = \mathbf{W}$$

$\because \mathrm{V} = \frac{U}{q} \quad \rightarrow \quad \mathrm{V} = \frac{W}{q}$ hence, W= V.q

25.1 Electric Potential and Potential Difference

Electron volt (eV)

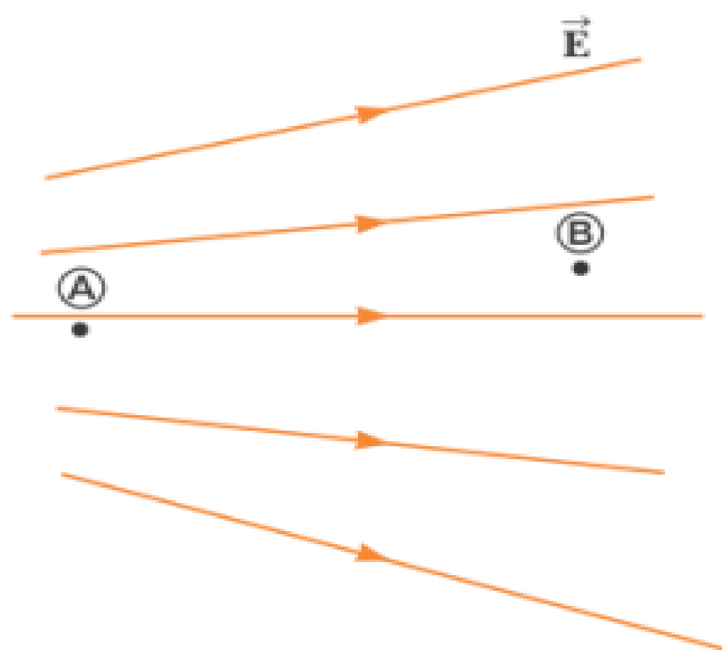
A unit of energy commonly used in atomic and nuclear physics.

- **is defined as the energy a charge–field system gains or loses when a charge of magnitude e (that is, an electron or a proton) is moved through a potential difference of 1 V.**

$$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{C} \cdot \text{V} = 1.60 \times 10^{-19}\ \text{J}$$

25.1 Electric Potential and Potential Difference

Quick Quiz 25.1 In Figure 25.1, two points Ⓐ and Ⓑ are located within a region in which there is an electric field. **(i)** How would you describe the potential difference $\Delta V = V_{Ⓑ} - V_{Ⓐ}$? (a) It is positive. (b) It is negative. (c) It is zero. **(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?



25.3 Electric Potential and Potential Energy Due to Point Charges

$$V_{Ⓑ} - V_{Ⓐ} = -\int_{Ⓐ}^{Ⓑ} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$$

$$V_{Ⓑ} - V_{Ⓐ} = -k_e q \int_{r_{Ⓐ}}^{r_{Ⓑ}} \frac{dr}{r^2} = k_e \frac{q}{r}\Big|_{r_{Ⓐ}}^{r_{Ⓑ}}$$

$$V_{Ⓑ} - V_{Ⓐ} = k_e q \left[\frac{1}{r_{Ⓑ}} - \frac{1}{r_{Ⓐ}}\right]$$

This tells us that the electric field of a fixed point charge q is conservative. Furthermore, Eqaution expresses the important result that the potential difference between any two points A and B in a field created by a point charge depends only on the radial coordinates r A and r B .

25.3 Electric Potential and Potential Energy Due to Point Charges

It is customary to choose the reference of electric potential for a point charge to be $V = 0 \ \ at\ r_A = \infty$. With this reference choice, the electric potential due to a point charge at any distance r from the charge is

$$V = k_e \frac{q}{r}$$

For a group of point charges, we can write the total electric potential at P as

$$V = k_e \sum_i \frac{q_i}{r_i}$$

25.3 Electric Potential and Potential Energy Due to Point Charges

Now imagine that an external agent brings a charge q_2 from infinity to point P. The work that must be done to do this is given

$$W = q_2 \Delta V$$

This work represents a transfer of energy across the boundary of the two-charge system.

$$\Delta U = W = q_2 \Delta V \quad \rightarrow \quad U - 0 = q_2 \left(k_e \frac{q_1}{r_{12}} - 0 \right)$$

$$U = k_e \frac{q_1 q_2}{r_{12}}$$

25.3 Electric Potential and Potential Energy Due to Point Charges

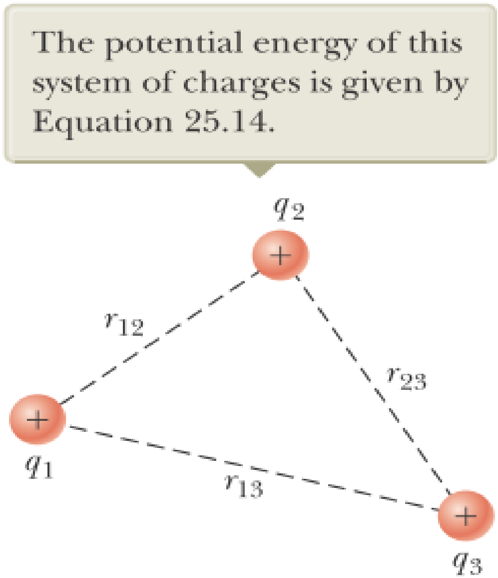
- If the charges are of the same sign, then U is positive. Positive work must be done by an external agent on the system to bring the two charges near each other (because charges of the same sign repel).

- If the charges are of opposite sign, then U is negative. Negative work is done by an external agent against the attractive force between the charges of opposite sign as they are brought near each other.

25.3 Electric Potential and Potential Energy Due to Point Charges

If the system consists of more than two charged particles, we can obtain the total potential energy of the system by calculating U for every *pair* of charges and summing the terms algebraically. For example, the total potential energy of the system of three charges shown in Figure 25.9 is

$$U = k_e\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right) \qquad \textbf{(25.14)}$$



25.3 Electric Potential and Potential Energy Due to Point Charges

- What is the electric potential at a point located at the middle between two charges equal but opposite?
- Tow charges $12 \times 10^{-6} C,$

$-12 \times 10^{-6} C, where\ the\ distance\ between\ them\ is\ 20\ cm.$

a) Find the potential at point a and b?

b) The electric potential energy for a positive charge $4 \times 10^{-19}\ C\ \ locates\ at\ point\ a\ and\ b$?

c) The potential difference between a and b?

Solution

a) $Va = k(12 \times 10^{-6}/6\times 10^{-2})+k(-12 \times 10^{-6}/4\times 10^{-2})$

$Va = k \{(2\times 10^{-4})-(3\times 10^{-4})\}$

$Va = 9\times 10^{9} \times 10^{-4}(-1) = -9\times 10^{5}$ V

$Vb= k(12 \times 10^{-6}/4\times 10^{-2})+k(-12 \times 10^{-6}/10 \times 10^{-2})$

$Vb= k \{(3\times 10^{-4})-(1.2 \times 10^{-4})\}$

$Vb = 9\times 10^{9} \times 10^{-4}(1.8) = 16.2 \times 10^{5}$ V

b) $Ua = k\,(4 \times 10^{-19})(-12 \times 10^{-6})/4 \times 10^{-2}) + k(-12 \times 10^{-6})(+12 \times 10^{-6})/10 \times 10^{-2}) + k\,(4 \times 10^{-19})(+12 \times 10^{-6})/\mathbf{6} \times 10^{-2}) = -13$ J

$Ub = k\,(4 \times 10^{-19})(12 \times 10^{-6})/4 \times 10^{-2}) + k(12 \times 10^{-6})(-12 \times 10^{-6})/10 \times 10^{-2}) + k\,(4 \times 10^{-19})(-12 \times 10^{-6})/\mathbf{1}4 \times 10^{-2}) = -13$ J

Solution

c) Δv = Vb-Va

$\Delta V = (16.2 \times 10^5)$ **- (**-9×10^5**) = 25**$\times 10^5$ **V**

Summary

- Electric Potential Energy
- Electric Potential Difference
- Electric Potential Difference
- The relation between work done on the charge and the potential
- Electron volt

The End