King Saud University
College of Science
Physics & Astronomy Dept.

111 PHYS (GENERAL PHYSICS 2)
CHAPTER 25: Electric Potential
LECTURE NO. 5

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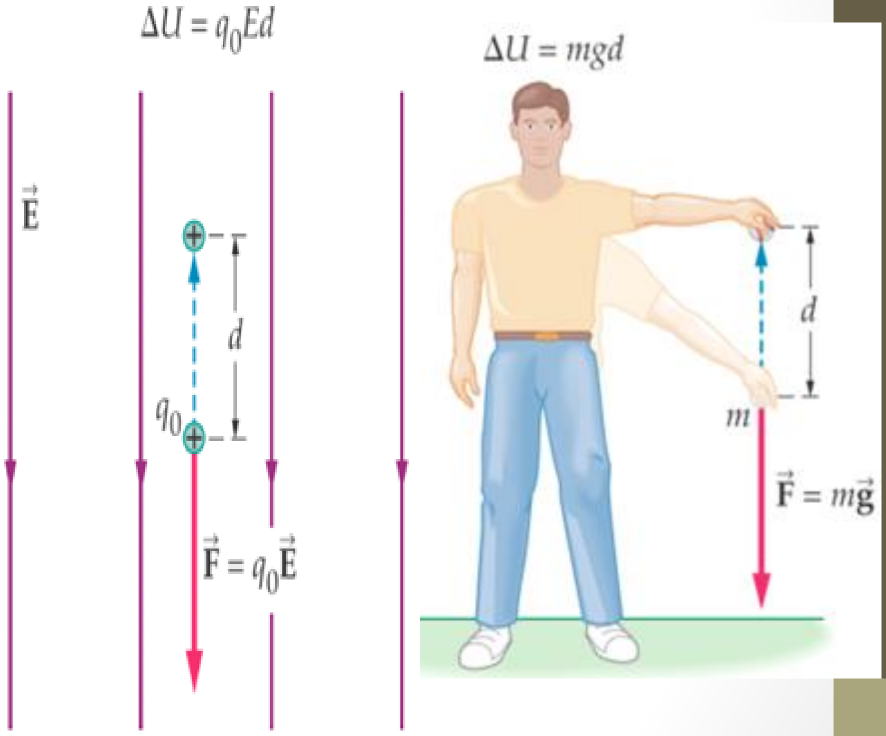
25.1 Electric Potential and Potential Difference

(a) A positive test charge $q_\circ$, experiences a downward force due to the electric field $\vec{E}$. 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.

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

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

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

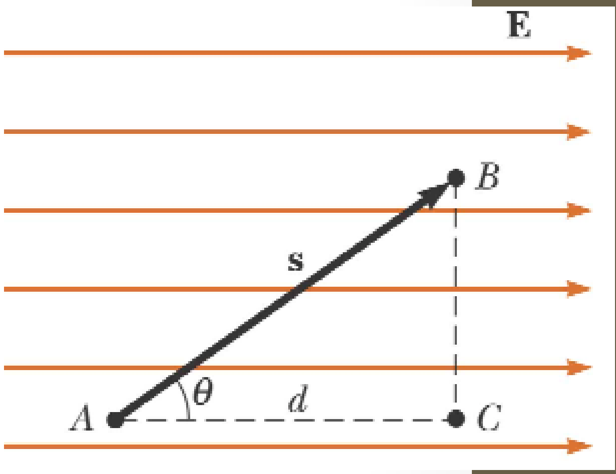
The work done to move a charge q from point A to point B

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

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 (Electric potential V) 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: .

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

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

25.1 Electric Potential and Potential Difference

Electron volt (eV)

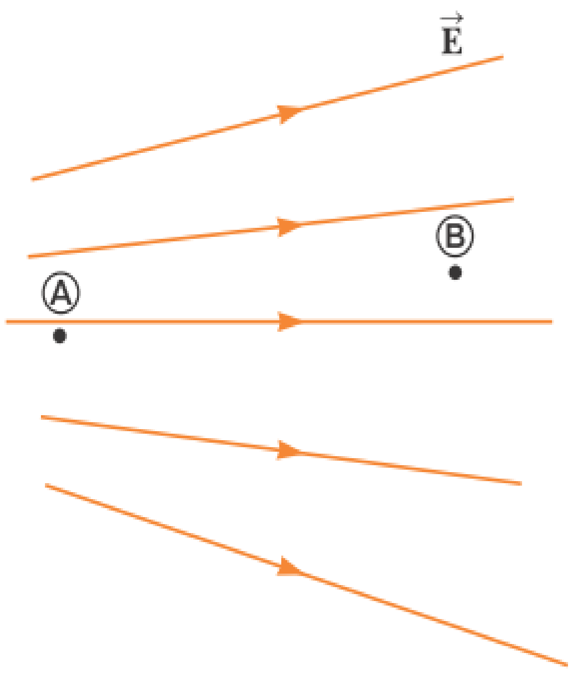
A unit of energy commonly used in atomic and nuclear physics.

- **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?



Analysis Model: Particle in a Field (Electric)

Examples:

- an electron moves around the nucleus in the electric field established by the proton in a hydrogen atom as modeled by the Bohr theory (Chapter 42)
- a hole in a semiconducting material moves in response to the electric field established by applying a voltage to the material (Chapter 43)

Example 23.5 A Suspended Water Droplet

- A water droplet of mass 3.00×10^{-12} kg is located in the air near the ground during a stormy day. An atmospheric electric field of magnitude 6.00×10^{3} N/C points vertically downward in the vicinity of the water droplet. The droplet remains suspended at rest in the air. What is the electric charge on the droplet?

Write Newton's second law from the particle in equilibrium model in the vertical direction:

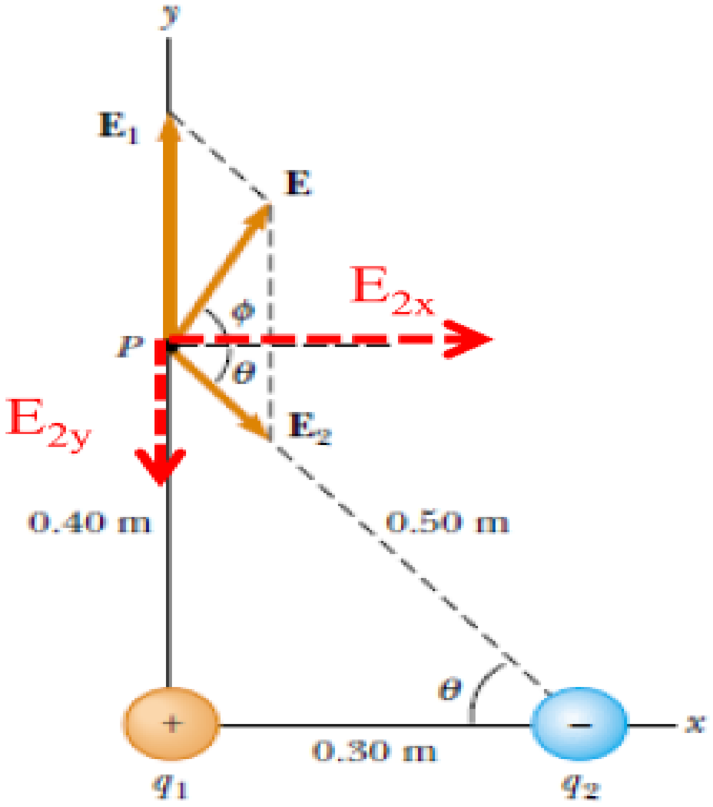
$$\sum F_y = 0 \rightarrow F_e - F_g = 0$$

$$q(-E) - mg = 0$$

$$q = -\frac{mg}{E} = -\frac{(3.00 \times 10^{-12}\,\text{kg})(9.80\,\text{m/s}^2)}{6.00 \times 10^{3}\,\text{N/C}} = -4.90 \times 10^{-15}\,\text{C}$$

Example: Electric Field Due to Tow Charges

A charge $q_1 = 7.0\ \mu C$ is located at the origin, and a second charge $q_2 = -5.0\ \mu C$ is located on the x axis, 0.30 m from the origin (Fig. 23.14). Find the electric field at the point P, which has coordinates (0, 0.40) m.



Solution

$$E_1 = k_e \frac{|q_1|}{r_1^2} = (8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)\frac{(7.0 \times 10^{-6}\text{ C})}{(0.40\text{ m})^2}$$
$$= 3.9 \times 10^5 \text{ N/C}$$

$$E_2 = k_e \frac{|q_2|}{r_2^2} = (8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)\frac{(5.0 \times 10^{-6}\text{ C})}{(0.50\text{ m})^2}$$
$$= 1.8 \times 10^5 \text{ N/C}$$

Vector E1 has only y component in the positive direction then : $\mathbf{E}_1 = 3.9 \times 10^5\hat{\mathbf{j}}$ N/C

While vector E2 has x component in the positive direction, and y component in the negative direction then: $\mathbf{E}_2 = (1.1 \times 10^5\hat{\mathbf{i}} - 1.4 \times 10^5\hat{\mathbf{j}})$ N/C

The resultant field **E** at *P* is the superposition of $\mathbf{E}_1$ and $\mathbf{E}_2$:

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 = (1.1 \times 10^5\hat{\mathbf{i}} + 2.5 \times 10^5\hat{\mathbf{j}}) \text{ N/C}$$

The magnitude of E 2.7×10^5 N/C. at angle ϕ = 66 ◦

Example 23.6 Electric Field Due to Two Charges

Charges q_1 and q_2 are located on the x axis, at distances a and b, respectively, from the origin as shown in Figure 23.12.

(A) Find the components of the net electric field at the point P, which is at position $(0, y)$.

(B) Evaluate the electric field at point P in the special case that $|q_1| = |q_2|$ and $a = b$.

C) Find the electric field due to the electric dipole when point P is a distance $y >> a$ from the origin.

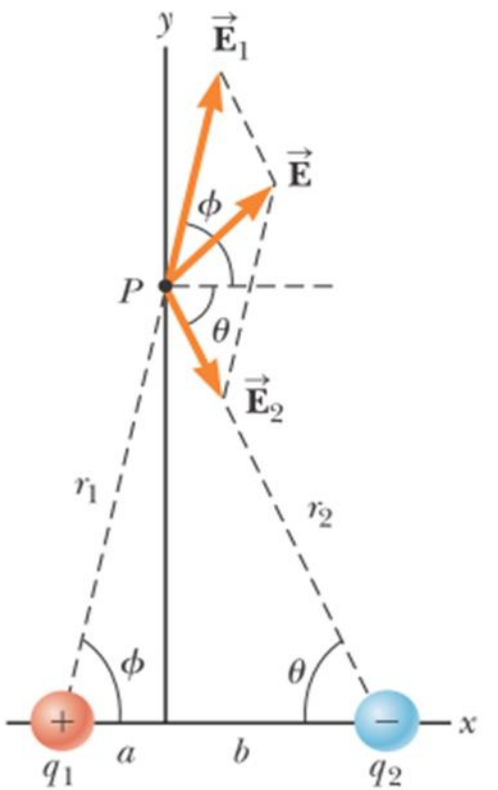
Solution 23.6 (A)

$$E_1 = k_e \frac{|q_1|}{r_1^2} = k_e \frac{|q_1|}{a^2 + y^2}$$

$$E_2 = k_e \frac{|q_2|}{r_2^2} = k_e \frac{|q_2|}{b^2 + y^2}$$

$$\vec{\mathbf{E}}_1 = k_e \frac{|q_1|}{a^2 + y^2} \cos\phi\,\hat{\mathbf{i}} + k_e \frac{|q_1|}{a^2 + y^2} \sin\phi\,\hat{\mathbf{j}}$$

$$\vec{\mathbf{E}}_2 = k_e \frac{|q_2|}{b^2 + y^2} \cos\theta\,\hat{\mathbf{i}} - k_e \frac{|q_2|}{b^2 + y^2} \sin\theta\,\hat{\mathbf{j}}$$



$$(1) \quad E_x = E_{1x} + E_{2x} = k_e \frac{|q_1|}{a^2 + y^2} \cos\phi + k_e \frac{|q_2|}{b^2 + y^2} \cos\theta$$

$$(2) \quad E_y = E_{1y} + E_{2y} = k_e \frac{|q_1|}{a^2 + y^2} \sin\phi - k_e \frac{|q_2|}{b^2 + y^2} \sin\theta$$

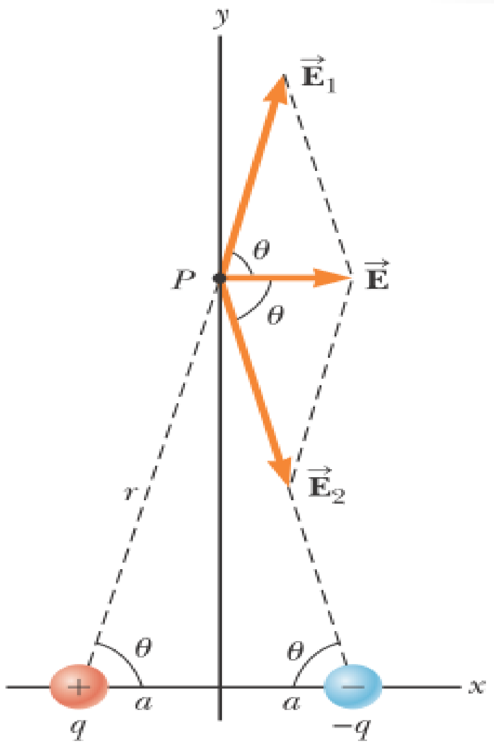
Solution 23.6 (B)

$$(3) \quad E_x = k_e \frac{q}{a^2 + y^2} \cos\theta + k_e \frac{q}{a^2 + y^2} \cos\theta = 2k_e \frac{q}{a^2 + y^2} \cos\theta$$

$$E_y = k_e \frac{q}{a^2 + y^2} \sin\theta - k_e \frac{q}{a^2 + y^2} \sin\theta = 0$$

$$(4) \quad \cos\theta = \frac{a}{r} = \frac{a}{(a^2 + y^2)^{1/2}}$$

$$E_x = 2k_e \frac{q}{a^2 + y^2} \left[\frac{a}{(a^2 + y^2)^{1/2}} \right] = k_e \frac{2aq}{(a^2 + y^2)^{3/2}}$$



Solution 23.6 (C)

$$(5) \quad E \approx k_e \frac{2aq}{y^3}$$