PHYS 111

1^{ST} semester 1439-1440

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Lecture 7

25.1 Potential Difference and Electric Potential

- When a test charge q_0 is placed in an electric field **E** created by some source charge, the electric force acting on the test charge is $q_0\mathbf{E}$.
- The force $q_0\mathbf{E}$ is conservative because the force between charges described by Coulomb's law is conservative.
- When q_0 is moved in the field by some external agent, the work done by the field on the charge is equal to the negative of the work done by the external agent causing the displacement.
- For an infinitesimal displacement $d\mathbf{s}$ of a charge, the work done by the electric field on the charge is

$$W = \mathbf{F}.d\mathbf{s} = q_0\mathbf{E}.d\mathbf{s}.$$

- The **potential energy** of the charge–field system is changed by an amount $dU = - q_0\mathbf{E}.d\mathbf{s}$

25.1 Potential Difference and Electric Potential

- For a finite displacement of the charge from point *A* to point *B*, the change in potential energy of the system $\Delta U = U_B - U_A$ is

$$\Delta U = -q_0 \int_A^B \mathbf{E} \cdot d\mathbf{s}$$

- Because the force $q_0\mathbf{E}$ is conservative, **this line integral does not depend on the path taken from *A* to *B*.**

25.1 Potential Difference and Electric Potential

- The **potential difference** $\Delta V = V_B - V_A$ between two points *A* and *B* in an electric field is defined as the change in potential energy of the system when a test charge is moved between the points divided by the test charge q_0:

$$\Delta V \equiv \frac{\Delta U}{q_0} = -\int_A^B \mathbf{E} \cdot d\mathbf{s}$$

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

25.1 Potential Difference and Electric Potential

- Imagine an arbitrary charge *q* located in an electric field. the work done by an external agent in moving a charge *q* through an electric field at constant velocity is

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

- The SI unit of both electric potential and potential difference is joules per coulomb, which is defined as a **volt** (V)

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 magnitude *e* (that is, an electron or a proton) is moved through a potential difference of 1 V.** Because 1 V = 1 J/C and because the fundamental charge is 1.60×10^{-19} C, the electron volt is related to the joule as follows:

$$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{C}\cdot\text{V} = 1.60 \times 10^{-19}\ \text{J} \qquad (25.5)$$

25.1 Potential Difference and Electric Potential

Quick Quiz 25.1 In Figure 25.1, two points A and B are located within a region in which there is an electric field. The potential difference $\Delta V = V_B - V_A$ is (a) positive (b) negative (c) zero.

Quick Quiz 25.2 In Figure 25.1, a negative charge is placed at A and then moved to B. The change in potential energy of the charge–field system for this process is (a) positive (b) negative (c) zero.

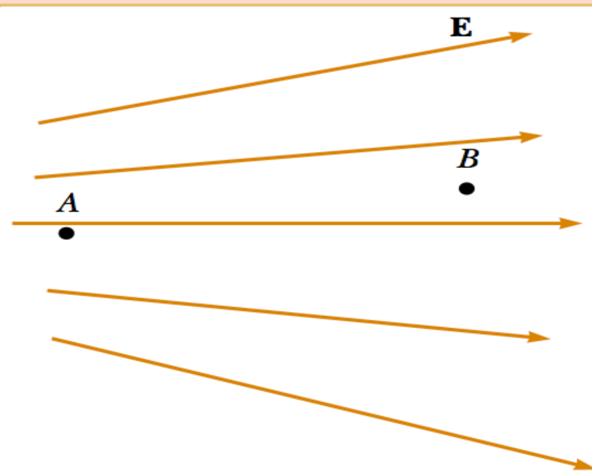
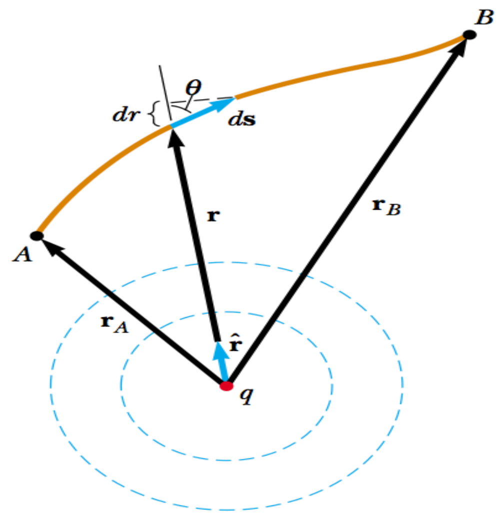


Figure 25.1 (Quick Quiz 25.1) Two points in an electric field.

25.3 Electric Potential and Potential Energy Due to Point Charges



- The electric potential at a point located a distance *r* from the charge, then the potential difference
-

$$V_B - V_A = -\int_A^B \mathbf{E} \cdot d\mathbf{s}$$

$$\mathbf{E} \cdot d\mathbf{s} = k_e \frac{q}{r^2} \hat{\mathbf{r}} \cdot d\mathbf{s}$$

Because the magnitude of $\hat{\mathbf{r}}$ is 1, the dot product $\hat{\mathbf{r}} \cdot d\mathbf{s} = ds \cos \theta$, where θ is the angle between $\hat{\mathbf{r}}$ and $d\mathbf{s}$. Furthermore, $ds \cos \theta$ is the projection of $d\mathbf{s}$ onto $\mathbf{r}$; thus, $ds \cos \theta = dr$. That is, any displacement $d\mathbf{s}$ along the path from point A to point B produces a change dr in the magnitude of $\mathbf{r}$, the position vector of the point relative to the charge creating the field. Making these substitutions, we find that $\mathbf{E} \cdot d\mathbf{s} = (k_e q / r^2)\, dr$; hence, the expression for the potential difference becomes

$$V_B - V_A = -k_e q \int_{r_A}^{r_B} \frac{dr}{r^2} = \frac{k_e q}{r} \Bigg]_{r_A}^{r_B}$$

$$V_B - V_A = k_e q \left[\frac{1}{r_B} - \frac{1}{r_A} \right]$$

25.3 Electric Potential and Potential Energy Due to Point Charges

- This equation shows us that the integral of **E**.*d***s** is *independent* of the path between points *A* and *B*.
- 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 created by a point charge at any distance *r* from the charge is

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