PHY-112
Principles of Physics-II

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Electric Potential Energy

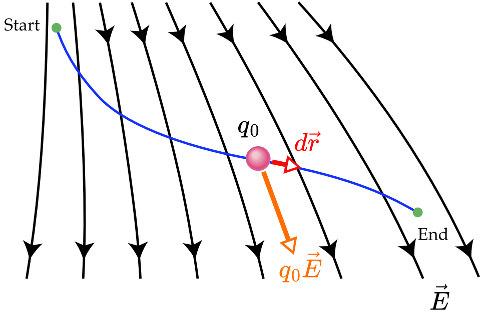
When a charge moves or is moved in the electric field, work is done by or against the Coulomb force to accelerate it, thus displacing it. This work is stored as potential energy in the system.

$$\begin{aligned} W &= \int dW \\ &= \int \vec{F} \cdot d\vec{r} \\ &= q_0 \int_{\text{start}}^{\text{final}} \vec{E} \cdot d\vec{r}. \end{aligned}$$

Types of Work Done due to Electrostatic Force

- Charges **moves** on its own due to Coulomb Force $\vec{F}_E \longrightarrow$ Positive Work (By the System)
- Charges are **moved** using external force $\vec{F}_{\text{ext}} \longrightarrow$ Negative Work (On the System)

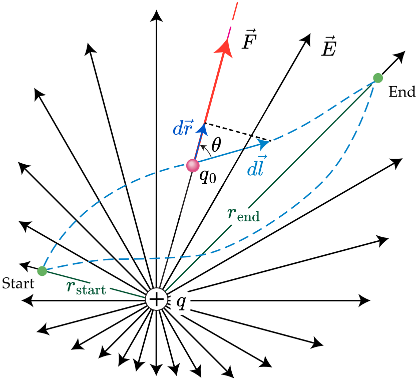
Defining Electrical Potential Energy



- Sheet Charges are good examples of sources with Uniform $\vec{E}$-fields
- The Potential Energy of a Charge in a Uniform Electric Field

$$\Delta U_{\text{elec}} = -W_{i\to f} = -q_0 \int_{\text{start}}^{\text{final}} \vec{E} \cdot d\vec{r}.$$

Defining Electrical Potential Energy



Defining Electrical Potential Energy

- Point Charges are good examples of sources with Non-Uniform $\vec{E}$-fields
- The Potential Energy of a Charge in a Non-Uniform Electric Field

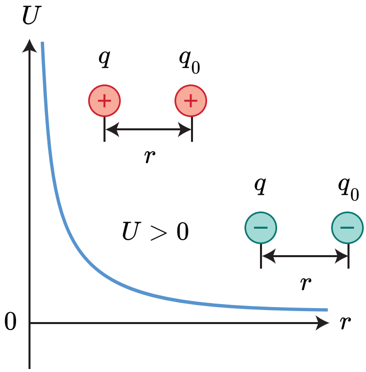
$$\Delta U_{\text{elec}} = -q_0 \int_{\text{start}}^{\text{final}} \vec{E} \cdot d\vec{r} = -\frac{q_0 q}{4\pi\epsilon_0} \left(\frac{1}{r_{\text{initial}}} - \frac{1}{r_{\text{final}}} \right)$$

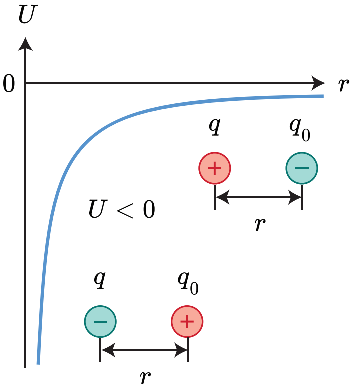
$$= U_{\text{final}} - U_{\text{initial}}$$

Physically, Electric potential energy is the work done to bring a charge from infinity (where the electric field is considered to be zero) **to a particular location in an electric field**.

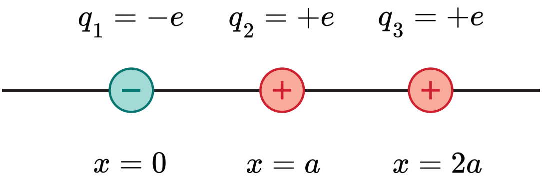
$$U_{\text{elec}} = -W_{\infty} = \frac{1}{4\pi\epsilon_0}\frac{qq_0}{r}$$

The Potential Energy of Point Charges



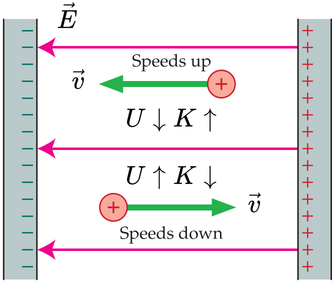


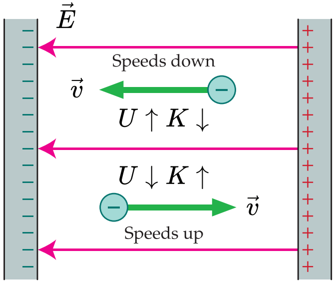
Q: Two point charges are at fixed positions on the x-axis, $q_1 = -e$ at $x = 0$ and $q_2 = +e$ at $x = a$. Take $a = 2\,\text{cm}$.



- Find the work that must be done by an external force to bring a third point charge $q_3 = +e$ from infinity to $x = 2a$.
- Find the total potential energy of the system of three charges.

Energy Exchange of a Charged Particle in $\vec{E}$-field





During Work Done by the system:

$$q_0 > 0 \longrightarrow \begin{cases} \Delta U < 0; \text{ Potential Energy is lost} \\ \Delta K > 0; \text{ Kinetic Energy is gained} \end{cases}$$

$$q_0 < 0 \longrightarrow \begin{cases} \Delta U < 0; \text{ Potential Energy is lost} \\ \Delta K > 0; \text{ Kinetic Energy is gained} \end{cases}$$

Energy Exchange of a Charged Particle in $\vec{E}$-field

During Work Done on the system:

$$q_0 > 0 \longrightarrow \begin{cases} \Delta U > 0; \text{ Potential Energy is gained} \\ \Delta K < 0; \text{ Kinetic Energy is lost} \end{cases}$$

$$q_0 < 0 \longrightarrow \begin{cases} \Delta U > 0; \text{ Potential Energy is gained} \\ \Delta K < 0; \text{ Kinetic Energy is lost} \end{cases}$$

Q: A 2.0 cm $\times$ 2.0 cm parallel-plate capacitor with a 2.0 mm spacing produces a uniform $\vec{E}$-field of intensity 2.85×10^5 N C^{-1}. First a proton and then an electron are released from rest midway between the capacitor plates. Assume the motion takes place in a vacuum.

- What is each particle's potential energy as it is released?
- What is each particle's speed as it reaches the plate?

Testing Concepts (2): Helping Diagram