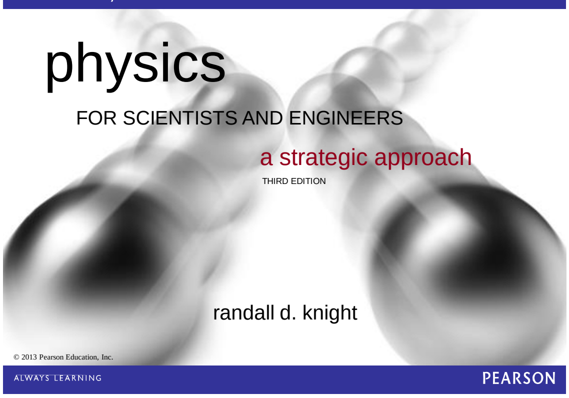
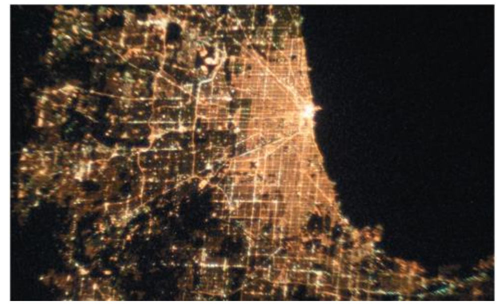
Class 11, Sections 28.1 – 28.3 Preclass Notes



ALWAYS LEARNING PEARSON

Chapter 28 The Electric Potential



Chapter Goal: To calculate and use the electric potential and electric potential energy.

Energy

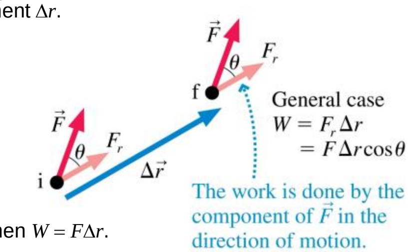
- The kinetic energy of a system, K, is the sum of the kinetic energies $K_i = 1/2 m_i v_i^2$ of all the particles in the system.
- The potential energy of a system, U, is the *interaction energy* of the system.
- The change in potential energy, ΔU, is -1 times the work done by the interaction forces:

$$\Delta U = U_f - U_i = -W_{\text{interaction forces}}$$

- If all of the forces involved are *conservative forces* (such as gravity or the electric force) then the total energy $K + U$ is *conserved*; it does not change with time.

Work Done by a Constant Force

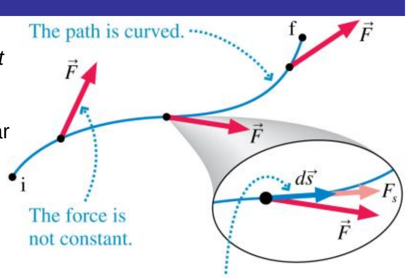
- Recall that the work done by a constant force depends on the angle θ between the force F and the displacement Δr.



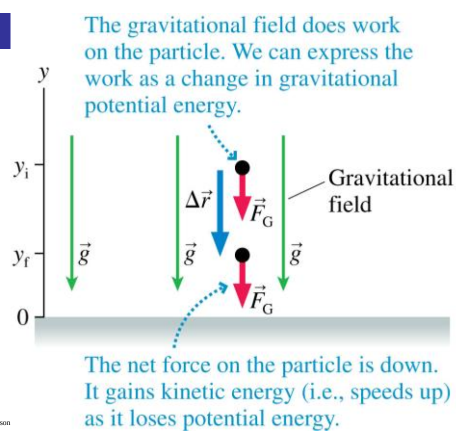
- If $\theta = 0°$, then $W = F\Delta r$.
- If $\theta = 90°$, then $W = 0$.
- If $\theta = 180°$, then $W = -F\Delta r$.

Work

If the force is *not* constant or the displacement is *not* along a linear path, we can calculate the work by dividing the path into many small segments.



$$W = \sum_j (F_s)_j \Delta s_j \rightarrow \int_{s_i}^{s_f} F_s \, ds = \int_i^f \vec{F} \cdot d\vec{s}$$



Gravitational Potential Energy

- Every conservative force is associated with a potential energy.
- In the case of gravity, the work done is:

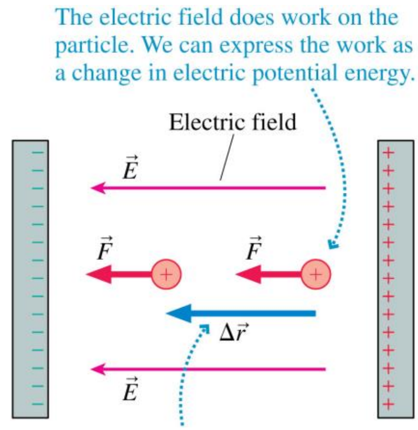
$$W_{grav} = mgy_i - mgy_f$$

- The change in gravitational potential energy is:

$$\Delta U_{grav} = -W_{grav}$$

where

$$U_{grav} = U_0 + mgy$$



Electric Potential Energy in a Uniform Field

- A positive charge q inside a capacitor speeds up as it "falls" toward the negative plate.
- There is a constant force $F = qE$ in the direction of the displacement.
- The work done is:

$$W_{elec} = qEs_i - qEs_f$$

- The change in **electric potential energy** is:

$$\Delta U_{elec} = -W_{elec}$$

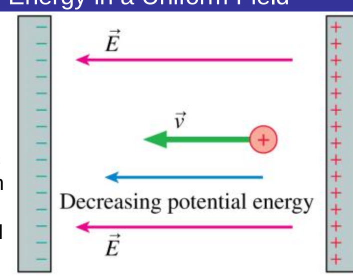
where

$$U_{elec} = U_0 + qEs$$

Electric Potential Energy in a Uniform Field

$$U_{elec} = U_0 + qEs$$

A positively charged particle **gains** kinetic energy as it moves in the direction of **decreasing** potential energy.

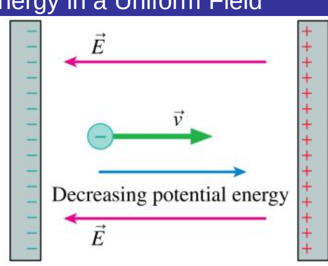


The potential energy of a positive charge decreases in the direction of $\vec{E}$. The charge gains kinetic energy as it moves toward the negative plate.

Electric Potential Energy in a Uniform Field

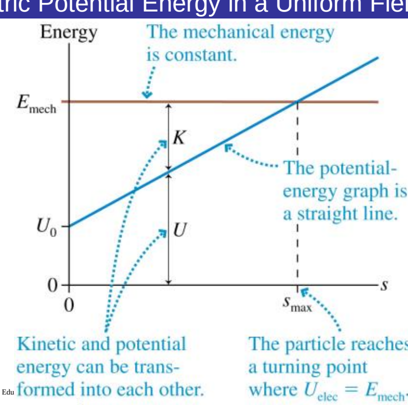
$$U_{elec} = U_0 + qEs$$

A negatively charged particle **gains** kinetic energy as it moves in the direction of **decreasing** potential energy.



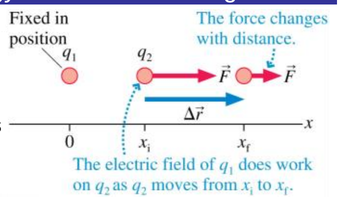
The potential energy of a negative charge decreases in the direction opposite to $\vec{E}$. The charge gains kinetic energy as it moves away from the negative plate.

Electric Potential Energy in a Uniform Field



The Potential Energy of Two Point Charges

- Consider two like charges q_1 and q_2.
- The electric field of q_1 *pushes* q_2 as it moves from x_i to x_f.
- The work done is:



$$W_{elec} = \int_{x_i}^{x_f} F_{1\text{ on }2}\,dx = \int_{x_i}^{x_f} \frac{Kq_1q_2}{x^2}\,dx = Kq_1q_2 \frac{-1}{x}\Bigg|_{x_i}^{x_f} = -\frac{Kq_1q_2}{x_f} + \frac{Kq_1q_2}{x_i}$$

- The change in electric potential energy of the system is $\Delta U_{elec} = -W_{elec}$ if:

$$U_{elec} = \frac{Kq_1q_2}{x}$$

The Potential Energy of Two Point Charges

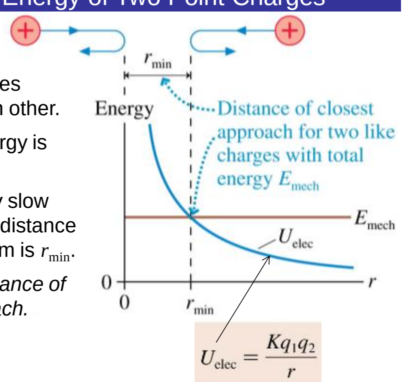
Consider two point charges, q_1 and q_2, separated by a distance r. The electric potential energy is

$$U_{elec} = \frac{Kq_1q_2}{r} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r} \qquad \text{(two point charges)}$$

This is explicitly the energy of *the system*, not the energy of just q_1 or q_2.
Note that the potential energy of two charged particles approaches zero as $r \to \infty$.

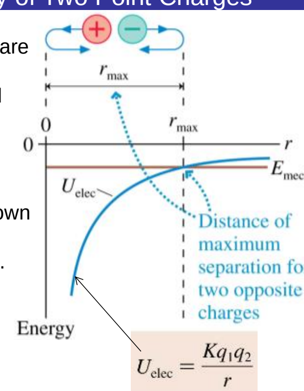
The Potential Energy of Two Point Charges

- Two like charges approach each other.
- Their total energy is $E_{mech} > 0$.
- They gradually slow down until the distance separating them is r_{min}.
- This is the *distance of closest approach.*

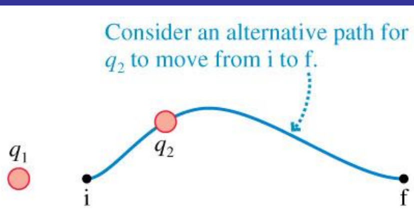


The Potential Energy of Two Point Charges

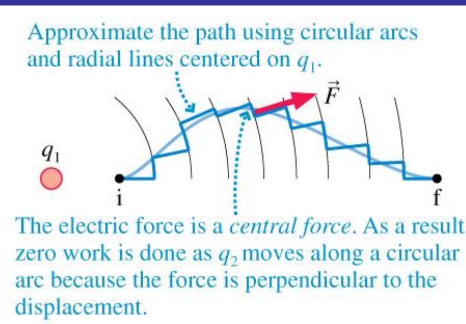
- Two opposite charges are shot apart from one another with equal and opposite momenta.
- Their total energy is $E_{mech} < 0$.
- They gradually slow down until the distance separating them is r_{max}.
- This is their *maximum separation.*



The Electric Force Is a Conservative Force



The Electric Force Is a Conservative Force



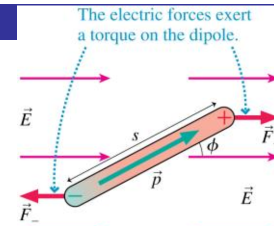
The work done by the electric force depends only on initial and final position, not the path followed.

The Potential Energy of Multiple Point Charges

Consider more than two point charges, the potential energy is the sum of the potential energies due to all pairs of charges:

$$U_{\text{elec}} = \sum_{i<j} \frac{Kq_iq_j}{r_{ij}}$$

where r_{ij} is the distance between q_i and q_j.
The summation contains the $i < j$ restriction to ensure that each pair of charges is counted only once.



- Consider a dipole in a uniform electric field.
- The forces F_+ and F_- exert a torque on the dipole.
- The work done is:

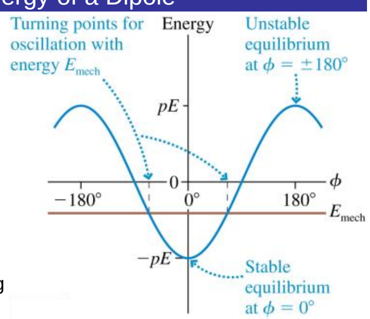
$$W_{\text{elec}} = -pE\int_{\phi_i}^{\phi_f} \sin\phi \, d\phi = pE\cos\phi_f - pE\cos\phi_i$$

- The change in electric potential energy of the system is $\Delta U_{\text{elec}} = -W_{\text{elec}}$ if:

$$U_{\text{dipole}} = -pE\cos\phi = -\vec{p}\cdot\vec{E}$$

The Potential Energy of a Dipole

- The potential energy of a dipole is $\phi = 0°$ minimum at where the dipole is aligned with the electric field.
- A frictionless dipole with mechanical energy E_{mech} will oscillate back and forth between turning points on either side of $\phi = 0°$.



$$U_{\text{dipole}} = -pE\cos\phi = -\vec{p}\cdot\vec{E}$$