PHY132 Introduction to Physics II
Class 11 – **Outline:**

- Electric Potential Energy of:
  - Point Charges
  - Dipoles

- Electric Potential: V
- Voltage: ΔV

What is Potential Energy?

A. mgh

B. When an object has the ***potential*** to speed up.

C. Voltage

D. $\frac{1}{2} k(\Delta x)^2$

What is Potential Energy?

- An object has **potential energy** when it is in a situation in which, if it moves, the potential energy can drop as it gains kinetic energy.
- Gravitational potential energy is due to the gravity interaction between the earth and an object. It can be negative, and has an arbitrary zero point.
- Elastic potential energy (ch.10) is energy stored in a spring. It is always positive or zero, and is zero when the spring is in equilibrium ($\Delta x = 0$)

Energy

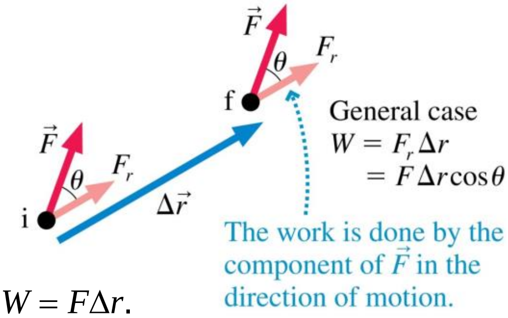
- The kinetic energy of a system, K, is the sum of the kinetic energies $K_i = 1/2m_iv_i^2$ of all the particles in the system.
- The potential energy of a system, U, is the *interaction energy* of the system.
- The change in potential energy, ΔU, is -1 times the work done by the interaction forces:

$$\Delta U = U_\mathrm{f} - U_\mathrm{i} = -W_\text{interaction forces}$$

- 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

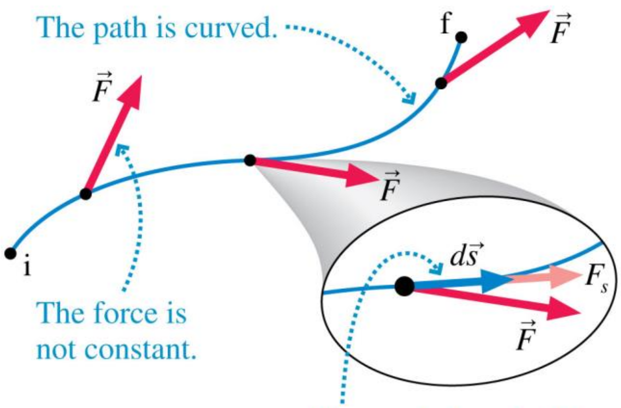
- Recall that the work done by a constant force depends on the angle θ between the force F and the displacement Δr.



- 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:

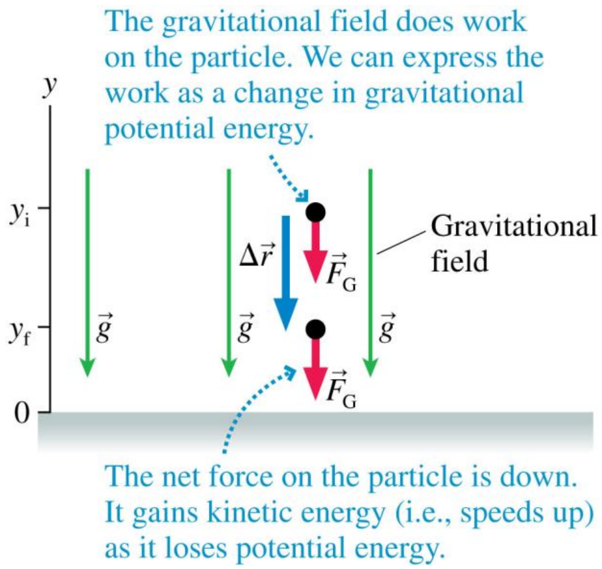
$$W_{\text{grav}} = mgy_{\text{i}} - mgy_{\text{f}}$$

- The change in gravitational potential energy is:

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

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:

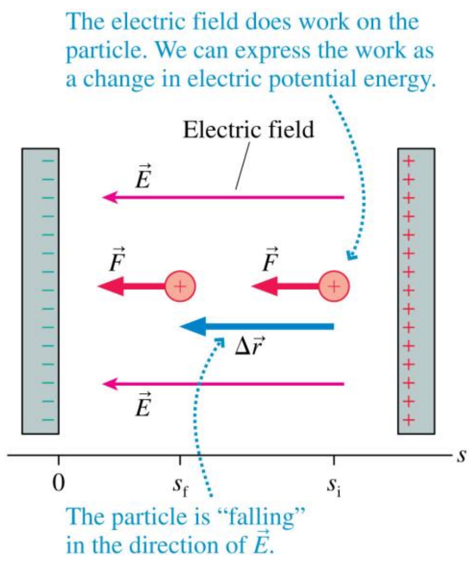
$$W_{\text{elec}} = qEs_{\text{i}} - qEs_{\text{f}}$$

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

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

where

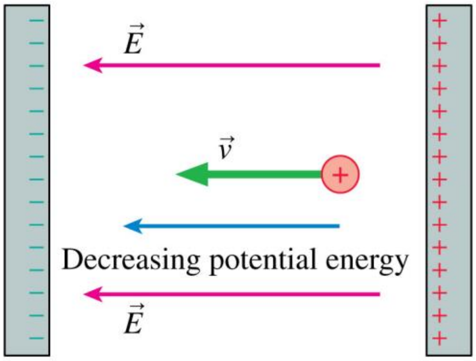
$$U_{\text{elec}} = U_0 + qEs$$



Electric Potential Energy in a Uniform Field

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

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

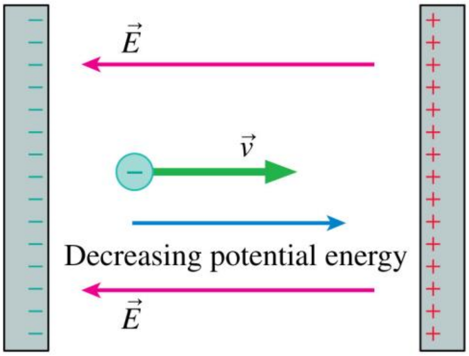


The potential energy of a positive charge decreases in the direction of $\vec{E}$. The charge gains kinetic energy as it moves toward the negative plate.

Electric Potential Energy in a Uniform Field

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

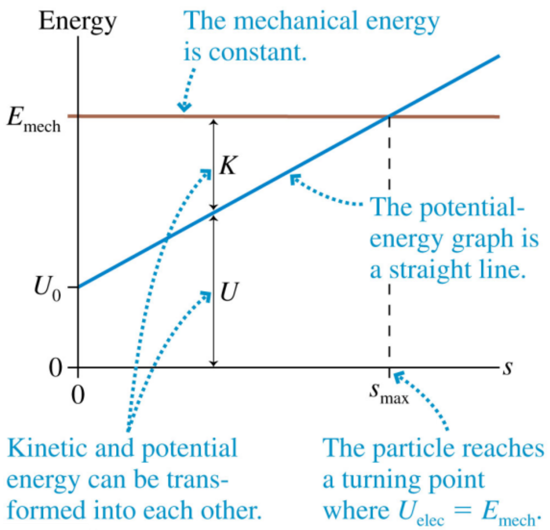
A negatively charged particle gains kinetic energy as it moves in the direction of decreasing potential energy.



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 figure shows the **energy diagram** for a positively charged particle in a uniform electric field.
- The potential energy increases linearly with distance, but the total mechanical energy E_{mech} is fixed.

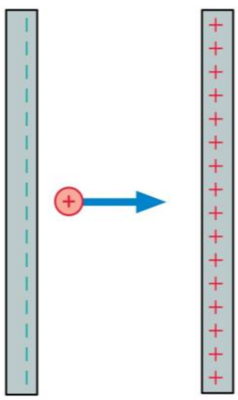


A positive charge moves as shown. Its kinetic energy

A. Increases.

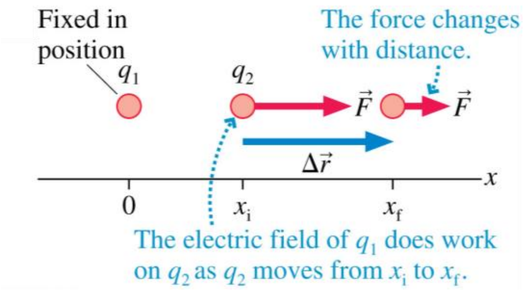
B. Remains constant.

C. Decreases.



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

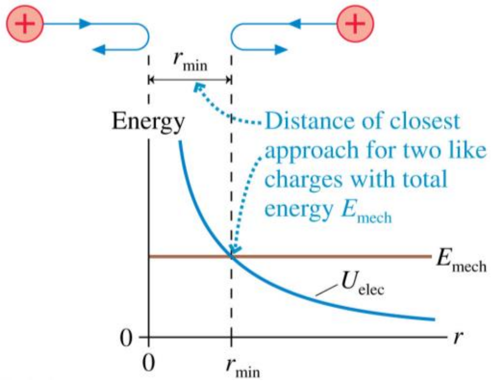
Consider two point charges, q_1 and q_2, separated by a distance r. The electric potential energy is

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

- 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

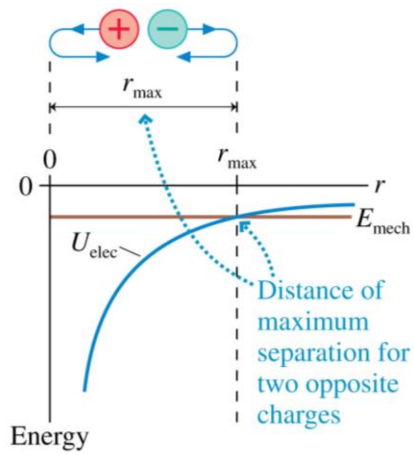
- Two like charges approach each other.
- Their total energy is $E_{mech} > 0$.
- They gradually slow down until the distance separating them is r_{min}.
- This is the *distance of closest approach.*



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

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.*



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

The Potential Energy of Multiple Point Charges

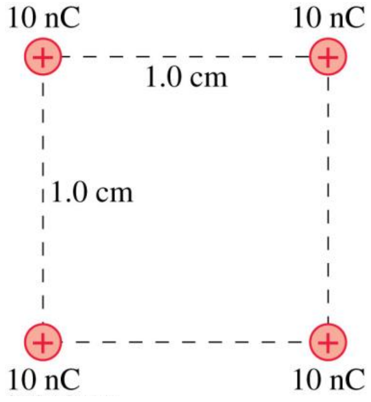
Consider more than two point charges, the potential energy is the sum of the potential energies due to all pairs of charges:

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

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.

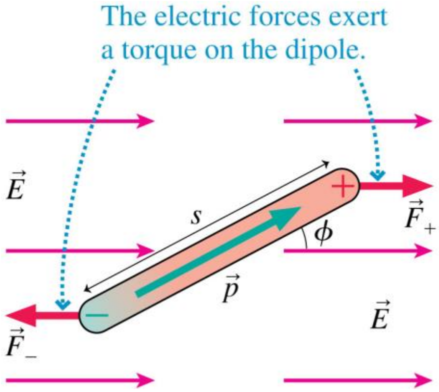
Problem 28.37

The four 1.0 g spheres shown in the figure are released simultaneously and allowed to move away from each other. What is the speed of each sphere when they are very far apart?



The Potential Energy of a Dipole

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



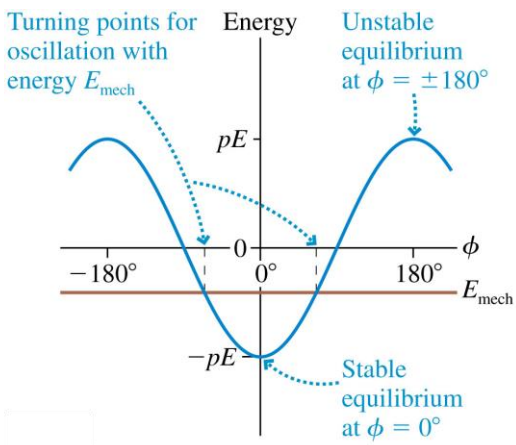
$$W_{\text{elec}} = -pE\int_{\phi_i}^{\phi_f} \sin\phi \, d\phi = pE\cos\phi_f - pE\cos\phi_i$$

- 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 $\phi = 0°$.



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

The Electric Potential

- We define the electric potential V (or, for brevity, just the potential) as

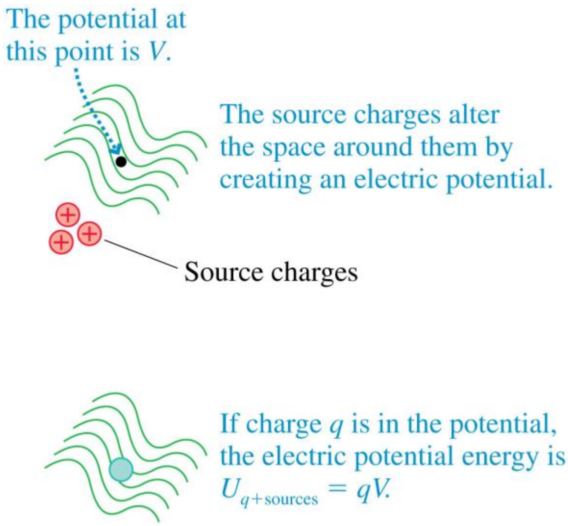
$$V \equiv \frac{U_{q+\mathrm{sources}}}{q}$$

- This is NOT the same as electric potential energy. (different units, for one thing).
- The unit of electric potential is the joule per coulomb, which is called the volt V:

$$1 \text{ volt} = 1\text{ V} \equiv 1\text{ J/C}$$

The Electric Potential

- Test charge q is used as a probe to determine the electric potential, but the value of V is *independent of* q.
- **The electric potential, like the electric field, is a property of the source charges.**

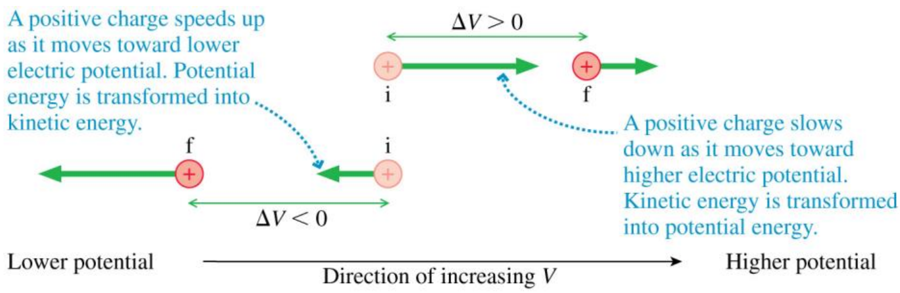


Using the Electric Potential

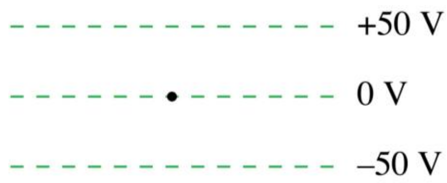
As a charged particle moves through a changing electric potential, energy is conserved:

$$K_f + qV_f = K_i + qV_i$$

	Electric potential	
	Increasing ($\Delta V > 0$)	Decreasing ($\Delta V < 0$)
+ charge	Slows down	Speeds up
− charge	Speeds up	Slows down



A proton is released from rest at the dot. Afterward, the proton



A. Remains at the dot.
B. Moves upward with steady speed.
C. Moves upward with an increasing speed.
D. Moves downward with a steady speed.
E. Moves downward with an increasing speed.

Before Class 12 on Wednesday (my last class…) 

- Please finish reading Knight Ch. 28
- Please do the short pre-class quiz on MasteringPhysics by tomorrow night.
- Something to think about. A battery is designed to supply a steady amount of which of the following quantities? 

  - Energy
  - Power
  - Electric potential difference
  - Electric current

(**Hint:** only *one* of these is correct!)