Today’s Topics

- Conductors in Electrostatic Equilibrium (Ch. 24.4)
- Electric Potential (Ch. 25-Part I)
  - Electric Potential Energy & Electric Potential
  - Electric Potential And Electric Field

 Expected from preview:
 Conductors
 Conservative force, electric energy, electric potential difference, voltage....
Conductors And Electrostatic Equilibrium

- Conductors: Total charge are initially balanced (=0) but negative charge (electrons) are able to move freely inside its body.
  ➞ capable of redistributing charges when subject to an external electric field.

- Charge redistribution ➔ eventually electrostatic equilibrium.

Initial ➔ transient, <10^{-16}s ➔ equilibrium (right after E applied)
Properties of Electrostatic Equilibrium

- Once in electrostatic equilibrium
  - The electric field is always zero inside the conductor
  - E field on the surface of conductor is always normal to the surface,
  - and has a magnitude of $\sigma/\varepsilon_0$ (Show using Gauss’s law)
  - All net charges reside on the surface of conductor (i.e. no net charge inside the body of a conductor).

  - The electric field is also zero inside any cavity within the conductor. (why?)
  - Electric potential is the same over the whole conductor (Ch. 25)

The above properties are valid regardless of the shape and the total charge of the conductors!
Potential Energy (Phy201 Review)

- Ch-8: path independent work $\rightarrow$ conservative force.
- e.g. Gravitational Force is a conservative force (Ch-13):

$$\vec{F}_{12} = -G \frac{m_1 m_2}{r^2} \hat{r}_{12} \quad \Rightarrow \quad W = \int_{\text{path}} \vec{F} \cdot ds = \frac{G m_1 m_2}{r_f} - \frac{G m_1 m_2}{r_i}$$

Gravitational Potential energy:

$$U = -\frac{G m_1 m_2}{r}$$

- Electric Force:

$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

Electric Potential Energy

$$U = \frac{k_e q_1 q_2}{r}$$
Electric Potential Energy

Electric energy between two point charges:
\[ U = U-U_\infty = K_e \frac{q_0 q}{r} \]
- \( U \) is a scalar quantity
- \( U=0 @ r=\infty \) (convenient convention)
- \( U \) can be positive or negative
  - +: between like-sign charges
  - -: between opposite charges
- SI unit: Joule (J)

Electric potential energy for system of multiple charges/charge distributions:
\[ U = \sum \text{of all combination of pairs.} \]
Integral if continuous distribution
Example: Three Charge system

- What is the work required to assemble the three charge system as shown? \((q_1=q_2=q_3=Q)\)
  Answer: \(k_e \frac{3Q^2}{a}\) (see board)

- Quiz: What if \(q_1=q_2=Q\) but \(q_3=-Q\) ?
  Answer: \(-k_e \frac{Q^2}{a}\)
Electric Potential Energy: Charge In An Electric Field

- Charge \( q \) is subject an electric force in electric field \( \mathbf{E} \)

\[
\mathbf{F} = q \mathbf{E}
\]

- Work done by electric force:

\[
W = \int_i^f \mathbf{F} \cdot d\mathbf{s} = q \int_i^f \mathbf{E} \cdot d\mathbf{s} = -\Delta U
\]

\[
\Delta U = U_f - U_i = -q \int_i^f \mathbf{E} \cdot d\mathbf{s}
\]

independent of \( q \)
Electric Potential Difference

Electric Potential Energy: $q$ In a Generic E. Field

$$\Delta U = U_B - U_A = -q \int_A^B \mathbf{E} \cdot ds = q \Delta V$$

Electric Potential Difference

$$\Delta V \equiv \frac{\Delta U}{q} = -\int_A^B \mathbf{E} \cdot ds = V_B - V_A$$
Properties of Electric Potential Difference

- It is defined upon the fact that the electric force is a conservative force.
- It is associated to the source field only and is independent of test charge.
- It has a unit: \( J/C \equiv \text{Volt (V)} \)
- It is commonly called as just Potential, but it is meaningful only as potential difference \( V_B - V_A \).
- Usually a convenient point (remote, earth..) is chosen as “ground” \( \Delta V = V - (V_A \equiv 0) = V \)
- It is a scalar quantity. (No vector operation necessary!)
- \( \Delta U = q \Delta V \)
Exercise 1: Potential In Uniform E. Field

- In the uniform electric field shown.
  - Find E. potential at points: B, C, D, G
  - If a charge +q is placed at B, what is the potential energy $U_B$? ($U_A=0$)
  - If a charge $-q$ is at B, what is $U_B$?

- If a negative charge $-q$ is initially at rest at G, will it move to A or B?

- What is the kinetic energy when it reaches A?
Exercise 2: E. Potential and Point Charges

In the configuration shown,
- Find the potential difference $V_B - V_A$

Answer:

$V_B - V_A = k_e \left( \frac{q}{r_B} - \frac{q}{r_A} \right)$

(Exercise with your TA)
Exercise 3: Cathode Ray Tube (CRT)

Electrons are emitted with almost zero velocity on plate C, what is the energy per electron when they reach plate A? (Do with your TA)

\[ V_A - V_C = 12000 \text{V} \]
Visualization of Electric Potential

Equipotential Lines

(a) Equipotential Lines

(b) Equipotential Lines around a Charge

(c) Equipotential Lines around a Dipole
Field lines always point towards lower electric potential
Field lines and equal-potential lines are always at a normal angle.

In an electric field:
- a +q is always subject a force in the same direction of field line. (i.e. towards lower V)
- a -q is always subject a force in the opposite direction of field line. (i.e. towards higher V)