Goal of this chapter is to teach you what is Electric Potential and how to use it to calculate Electric field

- Electric potential energy change: defined as $\Delta U = -W$, where $W$ is the work done by conservative force (here, electric force).
  - In an uniform field

  $$\vec{F} = q \vec{E}$$

  The work done by this electric field when the charge $q$ moves from $a$ to $b$ is:
  $$W_{ab} = \int_a^b \vec{F} \cdot \vec{d} = q |\vec{E}| (y_b - y_a)$$

  So, the electric potential energy change is defined as:
  $$\Delta U = -W_{ab} = q |\vec{E}| y_b - q |\vec{E}| y_a = U_b - U_a$$

  Thus, the electric potential energy:
  $$U = q |\vec{E}| y$$

- Electric potential energy of two point charge:

  - Electric force between the two charges:
  $$\vec{F} = \frac{1}{4\pi \epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}$$

  The work done by this electric field when their separation changes from $r_a$ to $r_b$ is:
  $$W_{ab} = \int_a^b \vec{F} \cdot \vec{d} = \frac{q_1 q_2}{4\pi \epsilon_0} \left( \frac{1}{r_a} - \frac{1}{r_b} \right)$$

  So, the electric potential energy change is defined as:
  $$\Delta U = -W_{ab} = \frac{q_1 q_2}{4\pi \epsilon_0} \left( \frac{1}{r_b} - \frac{1}{r_a} \right) = U_b - U_a$$

  Thus, the electric potential energy:
  $$U = \frac{1}{4\pi \epsilon_0} \frac{q_1 q_2}{r}$$
This is very similar to the same procedure to define gravitational potential energy: \( U = - \frac{G m_1 m_2}{r} \)

DO Example 23.2 (page 760)

- Electric potential energy with several point charges.
  - Since \( U \) is a scalar, you can just add all contribution together.

\[
U = \frac{1}{4 \pi \epsilon_0} \left( \frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_1 q_4}{r_{14}} + \frac{q_2 q_3}{r_{23}} + \frac{q_2 q_4}{r_{24}} + \frac{q_3 q_4}{r_{34}} \right) = \frac{1}{4 \pi \epsilon_0} \sum_{i<j} \frac{q_i q_j}{r_{ij}}
\]

- Again, in many cases, we want to know when we put one testing charge \( q \) in a system, what will that charge acts/feels. Similar to the reason we defined the electric field, now we define Electric Potential as: \textit{the potential energy per unit charge}.

\[
V = \frac{U}{q_0}
\]

- The unit of the electric potential is volt. 
  \( 1 \text{ V} = 1 \text{ volt} = 1 \text{ J} / \text{C} = 1 \text{ joule/coulomb} \)

- Electric potential for various situations (remember that you are using a testing charge \( q_0 \) to figure out the electric potential.):
  - Electric potential due to a point charge:
    \[
    V = \frac{1}{4 \pi \epsilon_0} \frac{q}{r}
    \]
  - Electric potential due to a collection of point charges:
    \[
    V = \frac{1}{4 \pi \epsilon_0} \sum_i \frac{q_i}{r_i}
    \]
  - Electric potential due to a continuous distribution of charges:
    \[
    V = \frac{1}{4 \pi \epsilon_0} \int \frac{dq}{r}
    \]
What is the relationship among $\vec{F}$, $\vec{E}$, $U$, and $V$?

**IMPORTANT:** Charge $q$ could be either positive or negative. (1) The electric force is: $\vec{F}=q \vec{E}$. Then the electric force, $\vec{F}$, and the electric field, $\vec{E}$, will be the **same** (opposite) direction if $q$ is **positive** (negative). (2) Same idea for the electric potential energy: $U_e=qV$. The electric potential energy, $U_e$, and the electric potential, $V$, will be the **same** (opposite) sign if $q$ is **positive** (negative).

**IMPORTANT #2:** The absolute number of the potential energy is not important, instead, the **difference** of the potential energy. Same for electric potential energy as well as electric potential.

New unit for **energy**: electron volt (eV)

1 eV = the electric potential energy gained by one electron with change of 1 V electric potential = ($1.602 \times 10^{-19}$ C) (1 V) = $1.602 \times 10^{-19}$ J

- Note: $CV = J$
- Note #2: eV is an unit of **energy**; while V is an unit of **electric potential**.

**Practice:**

**DO Example 23.8 (page 768)**

**DO Example 23.10 (page 769)**

Think: For charges on conductors, what determines them (the charges) to reach the equilibrium condition (all the charges stop moving, after the repelling from each other)?

- The whole surface (even the whole volume) of the conductor reach the same electric potential.

Electric field could be calculated from the electric potential (the derivation could be found on page 774 in the text book):

$$\vec{E}=-\nabla V=-(i \frac{\partial V}{\partial x} + j \frac{\partial V}{\partial y} + k \frac{\partial V}{\partial z})$$
Math Preview for Chapter 24:
- Nothing really special in Ch. 24

Question to think:
- Could we use the electric potential to move opposite signed charges to two different conductors, and use them later?