Chapter 20
Electric Potential and Electric potential Energy

Outline

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20-1 Electric Potential Energy and the Electric Potential

Figure 20-1
Change in Electric Potential Energy

Electric field

(a)

\[ \Delta U = q_0 E d \]

\[ \vec{F} = q_0 \vec{E} \]

Gravitation field

(b)

\[ \Delta U = m g d \]

\[ \vec{F} = m \vec{g} \]
In figure 20-1, a positive charge $q_0$ is placed in the field. If the charge moves upward a distance $d$, the work done by the electric force is negative

$$W = -Fd = -q_0Ed$$

The change of the potential energy is

$$\Delta U = -W = q_0Ed \quad (20-1)$$
Definition of Electric potential, V

\[ \Delta V = \frac{\Delta U}{q_0} = \frac{-W}{q_0} \quad \text{(20-2)} \]

SI Unit: joule/Coulomb = volt, V

Note:
1) \( \Delta U = q_0 \Delta V \)
2) 1 V = 1 J/C
3) Electron volt (eV): potential energy
   \[ 1 \text{ eV} = 1.6 \times 10^{-19} \text{ J} \]
A computer monitor accelerates electrons and directs them to create image. If the accelerating plates are 1.05 cm apart, and have a potential difference of 25,500 V, find the change in electric potential energy for an electron that moves from one accelerating plate to the other in the computer monitor.

Solution:

\[
\Delta U = q_0 \Delta V = (-e)(25,500 \text{ V}) = \boxed{-25,500 \text{ eV}}
\]

\[
= -25,500 \text{ eV} \times 1.60 \times 10^{-19} \text{ J/eV} = 4.08 \times 10^{-15} \text{ J}
\]
There is a relationship between electric field and electric potential. In Figure 20-2, the work done by the electric field is

\[ W = F \times \Delta S = q_0 E \times \Delta S \]

Therefore, the change in electric potential is

\[ \Delta V = \frac{-W}{q_0} = -\frac{(q_0 E \Delta s)}{q_0} = -E \Delta s \]
Electric field and electric potential

\[ E = -\frac{\Delta V}{\Delta s} \quad \text{(20 – 4)} \]

SI unit: volts/meter, V/m

Note:

1) 1 N/C = 1 V/m since \( E \) has the unit of N/C

2) The electric field \( E \) depends \textit{the rate of the change of the electric potential with position};

3) The electric potential decreases as one moves in the direction of the electric field.

4) \( \Delta s \) is along the electric field direction.
A uniform electric field of magnitude $4.1 \times 10^{-5}$ N/C points in the positive x direction. Find the change in electric potential energy of a 4.5 $\mu$C charge as it moves from the origin to the points:

(a) (0, 6.0m); (b) (6.0, 0); and (c) (6.0m, 6.0m).
CONCEPTUAL CHECKPOINT 20–1

In a certain region of space the electric potential $V$ is known to be constant. Is the electric field in this region (a) positive, (b) zero, or (c) negative?
20-2 Energy Conservation

If there is no other resistant force (such as air resistance, friction), for a charged object in an electric field, the total energy must be conservative: The sum of its kinetic and electric potential energies must be the same at any two points (A and B):

\[ K_A + U_A = K_B + U_B \]

Expressed the kinetic energy as \( \frac{1}{2}mv^2 \), we have

\[ \frac{1}{2}mv_A^2 + U_A = \frac{1}{2}mv_B^2 + U_B \]

The express applies to any conservation force:

- For Gravitational field: \( U=mg\cdot y \)
- For electric potential energy: \( U=qV \)
Energy conversation can also be finally expressed as

\[
\frac{1}{2} m v_A^2 + q(V_A - V_B) = \frac{1}{2} m v_B^2
\]
CONCEPTUAL CHECKPOINT 20–2

An electron, with a charge of $-1.60 \times 10^{-19}$ C, accelerates from rest through a potential difference $V$. A proton, with a charge of $+1.60 \times 10^{-19}$ C, accelerates from rest through a potential difference $-V$. Is the final speed of the electron (a) more than, (b) less than, or (c) the same as the final speed of the proton?

Hint: electron has less mass than the proton.
A particle with a mass of 3.5 g and a charge of +0.045 μC is located in an electric field of 1200 N/C. If it is released from rest at point A in the following figure.

(a) In which direction will this charge move?

(b) What speed will it have after moving through a distance of 5.0 m?
Summary

20-1 Electric potential energy and the electric potential

1) The Change of electric potential energy, $\Delta U$

$$\Delta U = -W = -(-F_d) = (q_0E)d$$

2) Electric potential, $V$

$$\Delta V = \frac{\Delta U}{q_0}$$

3) Electric field and electric potential

$$E = -\frac{\Delta V}{\Delta s}$$

20-2 Energy conversation

At two points, kinetic and electric potential energy must be conservative at two points:

$$\frac{1}{2}mv_A^2 + qV_A = \frac{1}{2}mv_B^2 + qV_B$$
Exercise 20-1

Find the change in electric potential energy, $\Delta U$, as a charge of (a) $2.20 \times 10^{-6}$ C or (b) $-1.10 \times 10^{-6}$ C moves from point A to point B, given the change in electric potential is $\Delta V = V_B - V_A = 24.0 \text{ V}$
Solution

(a) Solving $\Delta V = \Delta U / q_0$, we have

$$\Delta U = q_0 \Delta V = (2.20 \times 10^{-6} \, \text{C}) \times (24.0 \, \text{V}) = 5.28 \times 10^{-5} \, \text{J}$$

(b) For $q_0 = -1.10 \times 10^{-6} \, \text{C}$, we obtain

$$\Delta U = q_0 \Delta V = (-1.10 \times 10^{-6} \, \text{C}) \times (24.0 \, \text{V}) = -2.64 \times 10^{-5} \, \text{J}$$
Example 20-1  Plates at different potentials

A uniform electric field is established by connecting the plates of a parallel-plate capacitor to a 12-V battery. (a) If the plates are separated by 0.75 cm, what is the magnitude of the electric field in the capacitor? (b) A charge of $+6.24 \times 10^{-6}$ C moves from the positive plate to the negative plate. Find the change in electric potential energy for this charge.

Picture the problem:  Example 20-1
Plates at Different Potentials
Solution

a) Electric field ($\Delta V=-12V$)

$$E = -\frac{\Delta V}{\Delta s} = -\frac{(-12V)}{0.0075m} = 1600V/m$$

b) The change in electric potential energy

$$\Delta U = q \Delta V = (6.24 \times 10^{-6} \text{ C})(-12 \text{ V}) = -7.5 \times 10^{-5} \text{ J}$$
Active Example 20-1

Electric field and potential difference

The electric potential at point B in the parallel-plate capacitor shown below is less than that at point A by 4.5 V. The separation between A and B is 0.120 cm, and the separation between the plates is 2.55 cm. Find (a) the electric field within the capacitor and (b) the potential difference between the plates.
Solution

a) Electric field

since $\Delta V = V_B - V_A = -4.5 \text{ V}$

$$E = -\frac{\Delta V}{\Delta S} = -\frac{-4.5 \text{ V}}{0.00120 \text{ m}} = 3750 \text{ V/m}$$

b) The potential difference between the plates

$$\Delta V = -E\Delta S = 3750 \text{ V/m} \times 0.0255 \text{ m}$$

$$= -95.6 \text{ V}$$
Active Example 20-2  Find the speed with a running start

A particle of mass $m=1.75\times10^{-5}$ kg and charge $q=5.20\times10^{-5}$ C has a speed of 5.00 m/s at point A. As the particle moves to position B, the electric potential decreases by 60.0 V; What is the speed at point B?
Solution

1) According to the energy conservation:

\[
\frac{1}{2} m v_B^2 = \frac{1}{2} m v_A^2 + q(V_A - V_B)
\]

2) Solve for \( v_B \):

\[
\frac{1}{2} m v_B^2 = \frac{1}{2} m v_A^2 + q(V_A - V_B)
\]

\[
\frac{1}{2}(1.75 \times 10^5 \text{ kg}) \times v_B^2 = \frac{1}{2}(1.75 \times 10^5 \text{ kg}) \times (5.00 \text{ m/s})^2 + 5.20 \times 10^{-5} \text{ C} \times (60.0 \text{ V})
\]

\[
v_B = 19.5 \text{ m/s} = 1.95 \text{ m/s}
\]
Example 20-2 From Plate to Plate

A particle of charge \( q = 6.24 \times 10^{-6} \) C is released from rest at the positive plate and it reaches the negative plate with a speed of 3.4 m/s. The plates is connected to a 12-V battery. What is (a) the mass of the charge and (b) its final kinetic energy?
Solution

Part A)

1) Apply energy conversation:

\[ \frac{1}{2} m v_A^2 + q(V_A - V_B) = \frac{1}{2} m v_B^2 \]

2) Solve for the mass, \( m \)

\[ \frac{1}{2} m \times (0m/s)^2 + (6.24 \times 10^{-6} C) \times (12V) = \frac{1}{2} m \times (3.4 m/s)^2 \]

\[ m = 1.3 \times 10^{-5} \text{ kg} \]

Part B

3) Calculate the final kinetic energy

\[ K_B = \frac{1}{2} m v_B^2 \]

\[ = \frac{1}{2} (1.3 \times 10^{-5} \text{ kg})(3.4 m/s)^2 = 7.5 \text{ J} \]