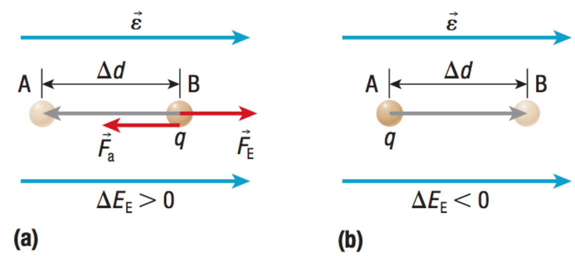
Lesson 3.5: Electric Potential Energy and Electric Potential in Parallel Plate (Chapter 7.4)

Electric potential energy: is the energy stored in a system of two charges a distance ***d*** apart, or is an energy stored in an electric field that can do work on a positively charged particle.

Mathematically, $\boldsymbol{W = \vec{F}\Delta d = q_1\vec{\varepsilon}\Delta d}$

- W is the work done by electric force, + q has electric force $\overrightarrow{F_E}$ along the direction of electric field $\vec{\varepsilon}$,
  - q has electric force $\overrightarrow{F_E}$ against the direction of $\vec{\varepsilon}$.
- Work done by electric force is independent of the path it takes.



Change in electric potential energy: $\boldsymbol{W_E = -\Delta E_E = -(E_f - E_i)}$

Hence $\boldsymbol{\Delta E_E = -q_1\vec{\varepsilon}\Delta d = -q_1\vec{\varepsilon}(d_2 - d_1)}$

- Positive ΔE_E indicates electric potential energy is stored in the moving charge.
- In Figure a): You apply a force $\overrightarrow{F_a}$ by hand to move a +q against the electric field from B to A, and the electric force $\overrightarrow{F_E}$ is opposite to the displacement.
- So $\overrightarrow{F_E}$ is doing a negative work.
- In terms of $W_E = -\Delta \vec{E}_E$, ΔE_E is positive and so electric potential energy is stored in the charge.
- If the charge does not have any initial kinetic energy, then such movement must need an extra applied force to allow it happen, $W_{applied\ force}$ much be positive.
- If the charge does have an initial kinetic energy, then the decrease of $\boldsymbol{E_k}$ must balance off the increase of $\boldsymbol{E_E}$, due to $E_{Ei} + E_{ki} = E_{Ef} + E_{kf}\ or - \Delta E_E = \Delta E_k = W_E$.
- In Figure b): If a +q is moving along the electric field from A to B, $\overrightarrow{F_E}$ will do positive work by which leads the charge moving faster and $\Delta \vec{E}_E$ become negative.

Question: What if placing a negative charge???

Example 1 (pg348): A charged particle moves from **rest** in a uniform electric field.

a) For a proton, calculate the change in electric potential energy when the magnitude of the electric field is 250 N/C, the starting position is 2.4 m from the origin, and the final position is 3.9 from the origin.

b) Calculate the change in electric potential energy for an electron in the same field and with the same displacement.

Dynamics of charged particles

c) Using the law of conservation of energy, calculate the speed of the proton in part a) for the given displacement. Assume that the proton starts from rest.

d) Determine the initial speed of the electron in part b), assuming its speed has decreased to half of its initial speed after the same displacement, $\Delta \boldsymbol{d}$.

Practice: pg349. #1 – 3

Electric Potential (V):

Electric potential: The potential energy per unit positive charge for a point in an electric field. It's a **scalar** quantity.
Equation: $V = \frac{E_E}{q_1}$, **unit Volt, V.**

Electric potential difference: the work required per unit charge to move a positive charge in an electric field.
Equation: $\Delta V = \frac{\Delta E_E}{q_1}$

Uniform electric field: $\Delta V = \frac{-W}{q_1} = \frac{-F_E \Delta d}{q_1} = \frac{-q_1 \vec{\varepsilon} \Delta d}{q_1} = -\vec{\varepsilon} \Delta d$

$$\vec{\varepsilon} = -\frac{\Delta V}{\Delta d}$$

Example 2: An electron leaves the negative plate of a cathode-ray tube and travels toward the positive plate. The electric potential difference between the plates is $1.5 \times 10^4 V$.

a) Calculate the speed of an electron as it reaches the positive plate. Assume that the electron is initially at rest. the mass of an electron is $9.11 \times 10^{-31} kg$.

b) Calculate the magnitude of the electric field at a distance of 15 cm, which is at the end of the cathode-ray tube.

Practice

1. An electron enters a uniform electric field of 145 N/C pointed toward the right. The point of entry is 1.5 m to the right of a given mark, and the point where the electron leaves the field is 4.6 m to the right of that mark. T/I A
   (a) Determine the change in the electric potential energy of the electron. [ans: 7.2×10^{-17} J]
   (b) The initial speed of the electron was 1.7×10^7 m/s when it entered the electric field. Determine its final speed. [ans: 1.1×10^7 m/s]
2. Calculate the work done in moving a proton 0.75 m in the same direction as the electric field with a strength of 23 N/C. T/I A [ans: 2.8×10^{-18} J]
3. An electron experiences a change in kinetic energy of $+4.2 \times 10^{-16}$ J. Calculate the magnitude and direction of the electric field when the electron travels 0.18 m toward the right. T/I A [ans: 1.5×10^4 N/C [toward the left]]

$\vec{\varepsilon} = \frac{F_E}{q_1}$ **(Unit: N/C)**

$\vec{\varepsilon} = \frac{kq_2}{r^2}$

$W = \vec{F}\Delta d = q_1\vec{\varepsilon}\Delta d = -\Delta\vec{E}_E$

$\Delta\vec{E}_E = -q_1\vec{\varepsilon}\Delta d$

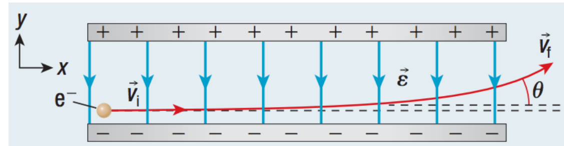
$\Delta E_E + \Delta E_k = 0$

$V = \frac{E_E}{q_1}$

$\Delta V = \frac{\Delta E_E}{q_1} = \frac{-F_E\Delta d}{q_1} = \frac{-q_1\vec{\varepsilon}\Delta d}{q_1} = -\vec{\varepsilon}\Delta d$

$\vec{\varepsilon} = -\frac{\Delta V}{\Delta d}$

Example 3: An electron moves horizontally with a speed of $1.6 \times 10^6 m/s$ between two horizontal parallel plates. The plates have a length of 12.5 cm, and a plate separation that allows a charged particle to escape even after being deflected. The magnitude of the electric field within the plates is 150N/C. Calculate the final velocity of an electron as it leaves the plates.



Practice

1. An old television cathode-ray tube creates a potential difference of 1.6×10^4 V across the parallel accelerating plates. These plates accelerate a beam of electrons toward the target phosphor screen. The separation between the plates is 12 cm. K/U T/I
   (a) Using the principle of energy conservation and the definition of electric potential difference, calculate the speed at which the electrons strike the screen. [ans: 7.5×10^7 m/s]
   (b) Calculate the magnitude of the electric field. [ans: 1.3×10^5 N/C]
2. Four parallel plates are connected in a vacuum as shown in **Figure 6**. An electron at rest in the hole of plate X is accelerated to the right. The electron passes through holes at W and Y with no acceleration at all. It then passes through the hole at Y and slows down as it heads to plate Z. T/I

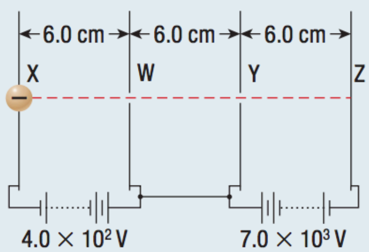


Figure 6

   (a) Calculate the speed of the electron at hole W. [ans: 1.2×10^7 m/s]
   (b) Calculate the distance, in centimetres, from plate Z to the point at which the electron changes direction. [ans: 5.7 cm [to the left of Z]]
3. An electron enters a parallel plate apparatus that is 8.0 cm long and 4.0 cm wide, as shown in **Figure 7**. The electron has a horizontal speed of 6.0×10^7 m/s. The potential difference between the plates is 6.0×10^2 V. Calculate the electron's velocity as it leaves the plates. K/U A [ans: 6.0×10^7 m/s [E 3.3° N]]

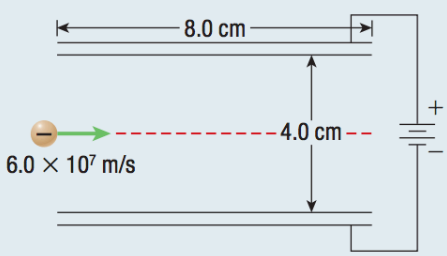


Figure 7

$\vec{\varepsilon} = \frac{F_E}{q_1}$ **(Unit: N/C)**

$\vec{\varepsilon} = \frac{kq_2}{r^2}$

$W = \vec{F}\Delta d = q_1\vec{\varepsilon}\Delta d = -\Delta \vec{E}_E$

$\Delta \vec{E}_E = -q_1\vec{\varepsilon}\Delta d$

$\Delta E_E + \Delta E_k = 0$

$V = \frac{E_E}{q_1}$

$\Delta V = \frac{\Delta E_E}{q_1} = \frac{-F_E \Delta d}{q_1} = \frac{-q_1 \vec{\varepsilon} \Delta d}{q_1} = -\vec{\varepsilon}\Delta d$

$\vec{\varepsilon} = -\frac{\Delta V}{\Delta d}$

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