Electric potential energy of a system of two point charges and of electric dipole in an electrostatic field

CLASS-XII

SUBJECT : PHYSICS
CHAPTER NUMBER: 02
CHAPTER NAME : ELECTROSTATIC POTENTIAL AND CAPACITANCE

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LEARNING OUTCOME

- Identify that the electric force is conservative and thus has an associated potential energy.
- To understand potential energy between various charge systems.
- For a charged particle placed at a point in an object's electric field, apply the relationship between the object's electric potential V at that point, the particle's charge q, and the potential energy U of the particle–object system.
- If a charged particle moves from an initial point to a final point in an electric field, apply the relationships between the change ΔV in the potential, the particle's charge q, the change ΔU in the potential energy, and the work W done by the electric force.
- Convert energies between units of joules and electron-volts.

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REVIEW

- How do you make an equipotential surface?
- How charge is distributed on the surface of a conductor ?
- How weak and strong fields are represented through surfaces?
- Why conductors are equipotential surfaces?

Electrostatic Potential Energy:

The work done in moving a charge q from infinity to a point in the field against the electric force is called electrostatic potential energy.

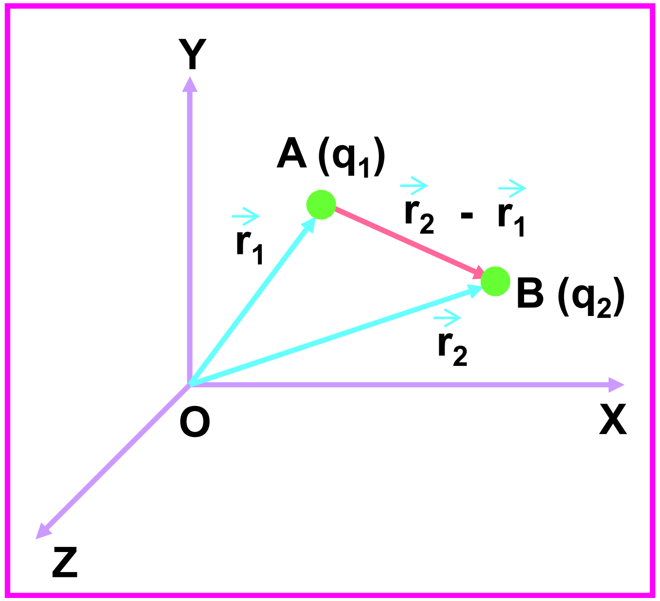
$$\boxed{W = q\,V}$$

i) Electrostatic Potential Energy of a Two Charge System:

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{|\vec{r}_2 - \vec{r}_1|}$$

or

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$



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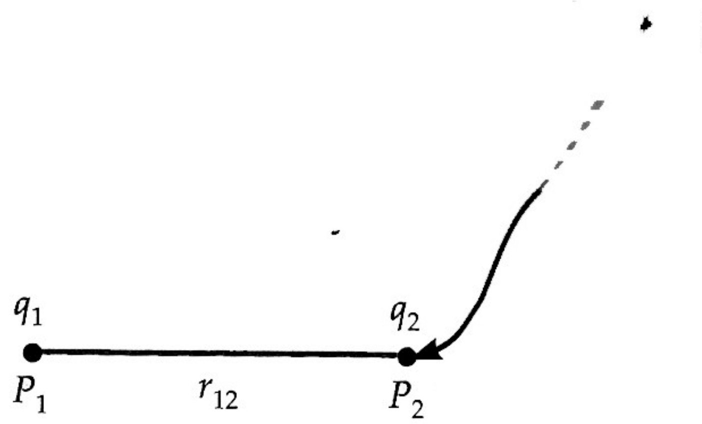
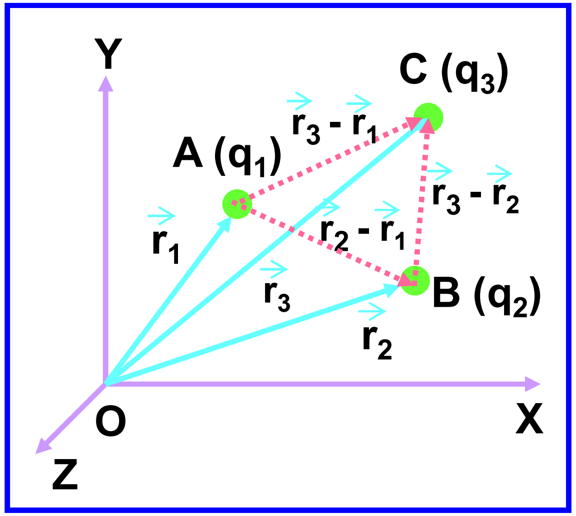
Electrostatic Potential Energy for a System of Charges:

Electrostatic Potential Energy of a system of two-point charges

$$U = W = \frac{k q_1 q_2}{r_{12}}$$



ii) Electrostatic Potential Energy of a Three Charges System:



$$U = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{|\vec{r}_2 - \vec{r}_1|} + \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_3}{|\vec{r}_3 - \vec{r}_1|} + \frac{1}{4\pi\varepsilon_0} \frac{q_2 q_3}{|\vec{r}_3 - \vec{r}_2|}$$

or

$$\boxed{U = \frac{1}{4\pi\varepsilon_0} \left[\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{31}} + \frac{q_2 q_3}{r_{32}} \right]}$$

iii) Electrostatic Potential Energy of an n - Charges System:

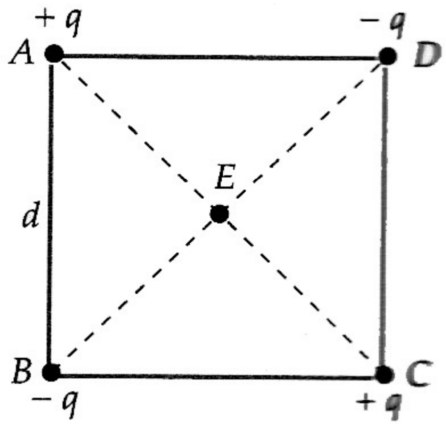
$$\boxed{U = \frac{1}{2} \left[\frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} \frac{q_i \, q_j}{\vec{r}_j - \vec{r}_i} \right]}$$

NCERT NUMERICAL

Question:- Four charges are arranged at the corners of a square ABCD of side "d"

(a) Find the work required to put together this arrangement.

(b) A charge q_0 is brought to the center "E" of the square, the four charges being held fixed at its corners. How much extra work is needed to do this?



Electrostatic Potential Energy in an external field:

1. For Single charge:-

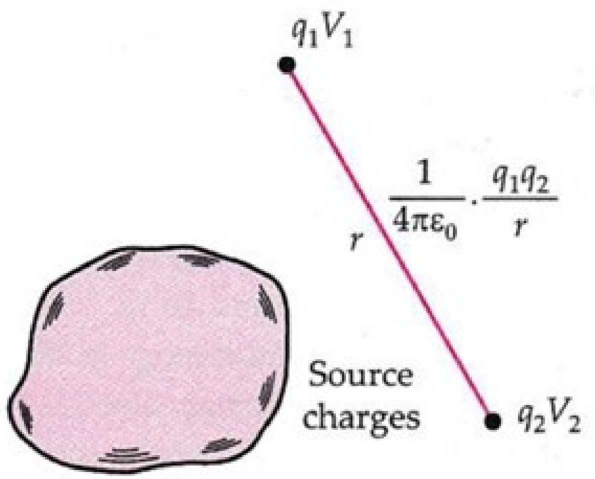
The potential energy of the charge ‘q’ = work done in bringing the charge from ∞ to that point

$$U = qV$$

2. Two Charges:-

Total potential energy of the system = The work done in assembling the two charges

or $U = q_1V(\vec{r_1}) + q_2V(\vec{r_2}) + \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1q_2}{r_{12}}$



NCERT NUMERICAL

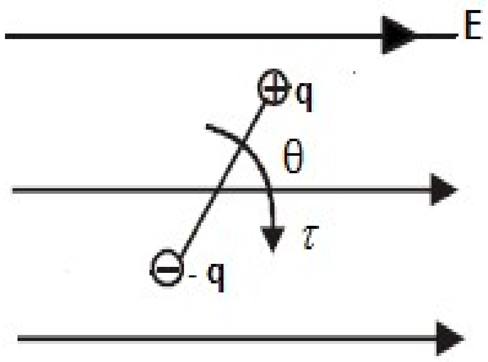
(a) Determine the electrostatic potential energy of a system consisting of two charges $7\mu C and -2\mu C$ (and with no external field) placed at($-9cm, 0, 0$) and (9cm, 0, 0) respectively.

(b) How much work is required to separate the two charges infinitely away from each other?

(c) Suppose that the same system of charges is now placed in an external field $E = \frac{A}{r^2}$, $A = 9 \times 10^5 cm^2$. What would be the electrostatic energy of the configuration be?

NUMERICAL

An electric dipole of dipole moment $(\vec{P})$ is placed in a uniform electric field $(\vec{E})$ in a stable equilibrium position. Its moment of inertia about the central axis is I. It is displaced slightly from its mean position. Find the period of small oscillation.



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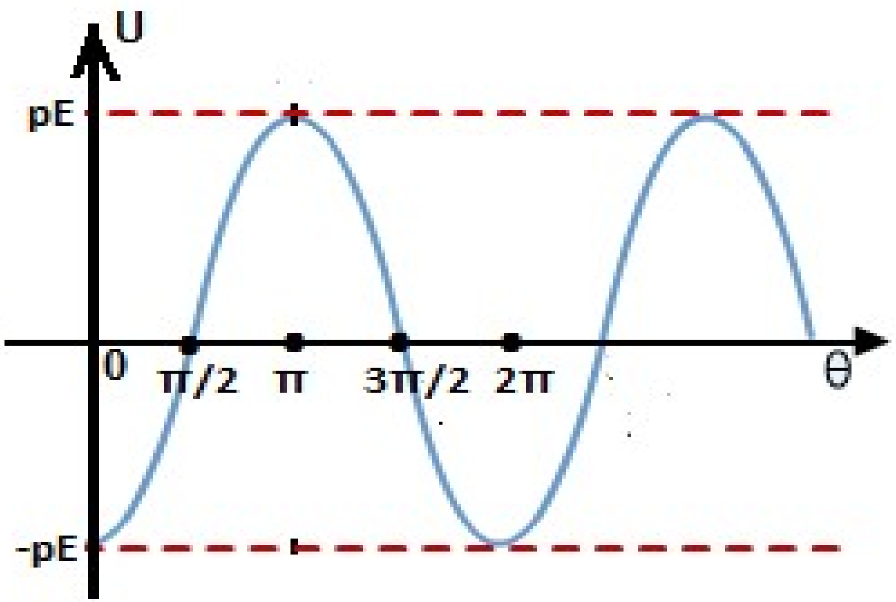
NUMERICAL

Draw the variation of the potential energy of an electric dipole in the electric field with θ



CONVERSION

Electron volt :
1eV = charge of 1e x 1 volt $=$ $(1.6 \times 10^{-19}C) \times 1volt =$ $1.6 \times 10^{-19}C.V$

Kilo electron volt :$1keV = 10^3 eV =$ $1.6 \times 10^{-19} \times 10^3$ $= 1.6 \times 10^{-16} J$

Mega electron volt:- $1MeV = 10^6 eV =$ $1.6 \times 10^{-19} \times 10^6$ $= 1.6 \times 10^{-13} J$

Giga electron volt:- $1GeV = 10^9 eV =$ $1.6 \times 10^{-10} J$

Tera electron volt:- $1TeV = 10^{12} eV =$ $1.6 \times 10^{-7} J$

HOME ASSIGNMENT

1. Two charges, of magnitude 5 nC and - 2 nC, are placed at points (2 cm, 0, 0) and (x cm, 0, 0) in a region of space, where there is no other external field. If the electrostatic potential energy of the system is - 0.5 µJ, what is the value of x ?
2. Find the amount of work done in rotating an electric dipole, of dipole moment 3.2×10^{-8} Cm, from its position of stable equilibrium, to the position of unstable equilibrium, in a uniform electric field of intensity 10^4 N / C.
3. A test charge *q* is made to move in the electric field of a point charge Q along two different closed paths (Fig. 2.6). First path has sections along and perpendicular to lines of electric field. Second path is a rectangular loop of the same area as the first loop. How does the work done compare in the two cases?

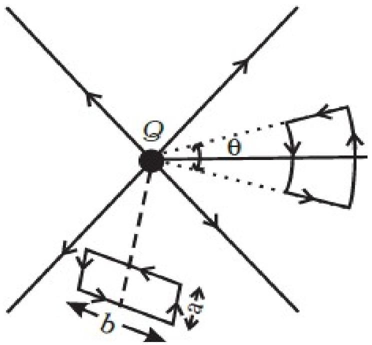


Fig. 2.6

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