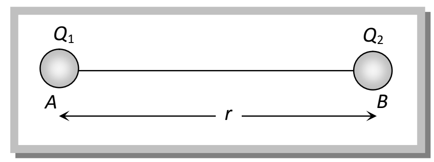
Electric Potential Energy.

(1) **Potential energy of a charge:**Work done in bringing the given charge from infinity to a point in the electric field is known as potential energy of the charge. Potential can also be written as potential energy per unit charge. i.e. $V = \frac{W}{Q} = \frac{U}{Q}$.

(2) **Potential energy of a system of two charges:**Since work done in bringing charge Q_2 from ∞ to point B is $W = Q_2 V_B$, where V_B is potential of point B due to charge Q_1 i.e. $V_B = \frac{1}{4\pi\varepsilon_0}\frac{Q_1}{r}$



So, $$W = U_2 = \frac{1}{4\pi\varepsilon_0}.\frac{Q_1 Q_2}{r}$$

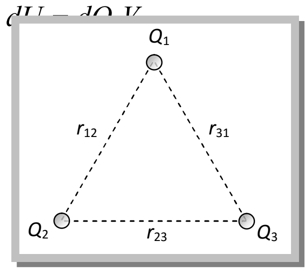
This is the potential energy of charge Q_2, similarly potential energy of charge Q_1 will be $U_1 = \frac{1}{4\pi\varepsilon_0}.\frac{Q_1 Q_2}{r}$

Hence potential energy of Q_1 = Potential energy of Q_2 = potential energy of system $U = k\frac{Q_1 Q_2}{r}$ (in C.G.S. $U = \frac{Q_1 Q_2}{r}$)

Note: Electric potential energy is a scalar quantity so in the above formula take sign of Q_1 and Q_2.

(3) **Potential energy of a system of n charges:**In a system of n charges electric potential energy is calculated for each pair and then all energies so obtained are added algebraically. i.e. $U = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q_1 Q_2}{r_{12}} + \frac{Q_2 Q_3}{r_{23}} + ...\right]$ and in case of continuous distribution of charge. As $dU = dQ\,V$

$\Rightarrow U = \int V\,dQ$



E.g. Electric potential energy for a system of three charges

Potential energy $= \frac{1}{4\pi\varepsilon_0}\left[\frac{Q_1 Q_2}{r_{12}} + \frac{Q_2 Q_3}{r_{23}} + \frac{Q_3 Q_1}{r_{31}}\right]$

While potential energy of any of the charge say Q_1 is $\frac{1}{4\pi\varepsilon_0}\left[\frac{Q_1Q_2}{r_{12}}+\frac{Q_3Q_1}{r_{31}}\right]$

Note: For the expression of total potential energy of a system of n charges consider $\frac{n(n-1)}{2}$ number of pair of charges.

(4) **Electron volt (eV):**It is the smallest practical unit of energy used in atomic and nuclear physics. As electron volt is defined as "the energy acquired by a particle having one quantum of charge 1e when accelerated by 1volt" i.e. $1eV = 1.6\times10^{-19}\,C\times\frac{1J}{C} = 1.6\times10^{-19}\,J$ = 1.6×10^{-12} erg

Energy acquired by a charged particle in eV when it is accelerated by V volt is E = (charge in quanta) × (p.d. in volt)

Commonly asked examples:

S.No.	Charge	Accelerated by p.d.	Gain in K.E.
(i)	Proton	5×10^4 V	K = e × 5 × 10^4 V = 5 × 10^4 eV = 8 × 10^{-15} J **[JIPMER 1999]**
(ii)	Electron	100 V	K = e × 100 V = 100 eV = 1.6 × 10^{-17} J **[MP PMT 2000; AFMC 1999]**
(iii)	Proton	1 V	K = e × 1 V = 1 eV = 1.6 × 10^{-19} J **[CBSE 1999]**
(iv)	0.5 C	2000 V	K = 0.5 × 2000 = 1000 J **[JIPMER 2002]**
(v)	α-particle	10^6 V	K = (2e) × 10^6 V = 2 MeV **[MP PET/PMT 1998]**

(5) **Electric potential energy of a uniformly charged sphere:**Consider a uniformly charged sphere of radius R having a total charge Q. The electric potential energy of this sphere is equal to the work done in bringing the charges from infinity to assemble the sphere.

$$U = \frac{3Q^2}{20\pi\varepsilon_0 R}$$

(6) **Electric potential energy of a uniformly charged thin spherical shell:**

$$U = \frac{Q^2}{8\pi\varepsilon_0 R}$$

(7) **Energy density:** The energy stored per unit volume around a point in an electric field is given by

$U_e = \frac{U}{\text{Volume}} = \frac{1}{2}\varepsilon_0 E^2$. If in place of vacuum some medium is present then $U_e = \frac{1}{2}\varepsilon_0 \varepsilon_r E^2$

Concepts

- Electric potential energy is not localized but is distributed all over the field
- If a charge moves from one position to another position in an electric field so it's potential energy change and work done in this changing is $W = U_f - U_i$
- If two similar charge comes closer potential energy of system increases while if two dissimilar charge comes closer potential energy of system decreases.