Nucleus

Nucleus

Rutherford's α-scattering experiment established that the mass of atom is concentrated within small +vely charged region at the inner core which is called nucleus having dimension about 10^{-15} m.

Electrons

They are -vely charged particles, mass equal to 9.1×10^{-31} kg and charge equal to -1.6×10^{-19} C. Electron has large angular momentum of -1/2 spin. Therefore, electrons are more unstable particles.

Protons

Protons are +vely charged particles, charge equal to basic charge of an e^- and mass is 1836.1 times greater than mass of an e^-. i.e.

$M_p = 1836.1 \times M_e$

$M_p = 1.6725 \times 10^{-27}$ kg

$e = + 1.6 \times 10^{-19}$ C

It has small angular momentum of +1/2 spin. Protons are more stable with compared to electrons.

Neutrons

Neutrons are neutral particles (i.e. chargeless). Mass is 1838.6 times greater than mass of an electron. Even it is chargeless, it has small angular momentum as like proton. It is more stable with compared to electron.

Mass of single neutron is

$M_n = 1838.6 \times M_e$

$M_n = 1.6748 \times 10^{-27}$ kg

- Actually, protons and neutrons are the constituents of the nucleus.
- Combiningly, they are called nucleons.
- Mass of nucleon is 1.66×10^{-27} kg or 1 amu.
- Mass of proton in amu is 1.007 amu.
- The number of electrons in every nucleus is zero.
- Proton was discovered by Rutherford whereas neutron by Chadwick.
- Symbolic representation of the atoms is $_Z X^A$ where
  Z = atomic number
  Z = either protons or electrons number
  A = mass number
  A = sum of protons & neutrons number
  & X = chemical symbol of atom

Isotopes

- Atoms having same atomic no. but differ in mass number.
- e.g. $_1H^1$, $_1H^2$, $_1H^3$; $_8O^{16}$, $_8O^{17}$, $_8O^{18}$ etc.
- They have same chemical properties.
- Isotopes are different in neutron number only.
- They have different position in periodic table.

Isobars

- Atoms having same mass no. but different in atomic number.
- e.g. $_{18}Ar^{40}$, $_{20}Ca^{40}$ etc.
- Protons, neutrons & electrons numbers are different.
- They have different chemical properties & different position in periodic table.

Isotones

- Atoms having same number of neutrons are called isotones.
- e.g. $_6C^{14}$ & $_8O^{16}$

Mirror nuclei

Nuclei with same mass number (A) but proton and neutron numbers are interchanged i.e. number of protons in one is equal to the number of neutrons in the other and vice versa are called mirror nuclei. e.g. $_4\mathrm{Be}^7$, $_3\mathrm{Li}^7$

Nuclear size

- Volume of nucleus is directly proportional to the mass number i.e. volume $\propto$ mass number (A)
  Let, R be the finite radius of the nucleus.
  $\frac{4}{3}\pi\mathrm{R}^3 \propto \mathrm{A}$
  $\mathrm{R}^3 \propto \mathrm{A}$
  $\mathrm{R} \propto \mathrm{A}^{1/3}$
  $\mathrm{R} = \mathrm{R}_0\ \mathrm{A}^{1/3}$

  This is the required equation for nuclear size.
  where R_0 is proportionality constant, known as the closest distance of the nucleus which is equal to
  $\mathrm{R} = 1.2 \times 10^{-15}$ m to 1.3×10^{-15} m

- Nuclear size depends on mass number. Mass number varies atoms to atoms. Therefore nuclear size varies atoms to atoms.

Nuclear density

Nuclear density $(\rho_{nu}) = \dfrac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$

$$\rho_{nu} = \frac{M_m}{V_m}$$
$$\rho_{nu} = \frac{A \times 1.66 \times 10^{-27}}{\frac{4}{3}\pi R^3}$$
$$\rho_{nu} = \frac{A \times 1.66 \times 10^{-27}}{\frac{4}{3}\pi\left(R_0 A^{1/3}\right)^3}$$
$$\rho_{nu} = \frac{1.66 \times 10^{-27}}{\frac{4}{3} \times 3.14 \times \left(1.2 \times 10^{-15}\right)^3}$$
$$\rho_{nu} = 2.3 \times 10^{17}\mathrm{kg/m^3}$$

- Nuclear density independent with mass number therefore, nuclear density is constant for every atom.

Mass defect

- Mass difference in between the rest mass of nucleus and sum of mass of the constituents.
- Mass of the constituents always greater than the rest mass of the nucleus.
- The fraction of rest mass of nucleus is converted into energy according to Einstein's mass energy relation, therefore rest mass is less than the mass of the constituents.
- Mass defect = mass of constituents - rest mass
  $\Delta\mathrm{m} = [\{\mathrm{Zm}_p + (\mathrm{A} - \mathrm{Z})\ \mathrm{m}_n\} - \mathrm{M}_0]$
  Unit $\rightarrow$ kg, a.m.u.
  1 amu = 1.66×10^{-27} kg

- Packing fraction is defined as the total amount of mass defect per unit nucleon denoted f and written as
  $$f = \frac{\text{Mass defect}}{\text{Mass number}}$$
  $$f = \frac{\left[Z_{M_p} + (A - Z)m_n - M_0\right]}{A}(kg/amu)$$
  $$f = \frac{\Delta m}{A}$$
  $$\Delta m = fA$$

Binding energy

Amount of energy required to separate protons and neutrons far apart in the nucleus, equivalent energy is known as binding energy or Energy equivalent to mass defect is known as binding energy which is expressed as, B.E. = $\Delta\mathrm{mc}^2$

i. If $\Delta\mathrm{m}\rightarrow$ is in kg, B.E. = $\Delta\mathrm{mc}^2$
   If $\Delta\mathrm{m}\rightarrow$ amu, B.E. = MeV
   1 amu is equivalent to B.E. $\sim$ 931 MeV

ii. If $\Delta\mathrm{m}$ is in kg, B.E. measured in Joule.
B.E. = $\Delta\mathrm{mc}^2$
B.E. = (- kg) $\times$ (3 $\times$ $10^8)^2$ = -J
B.E. = $\Delta\mathrm{mc}^2$ = fAc^2
B.E. = $[\mathrm{Zm}_p$ + (A -Z) m_n -$\mathrm{M}_0]$ c^2
$\Rightarrow$ Binding energy per nucleon

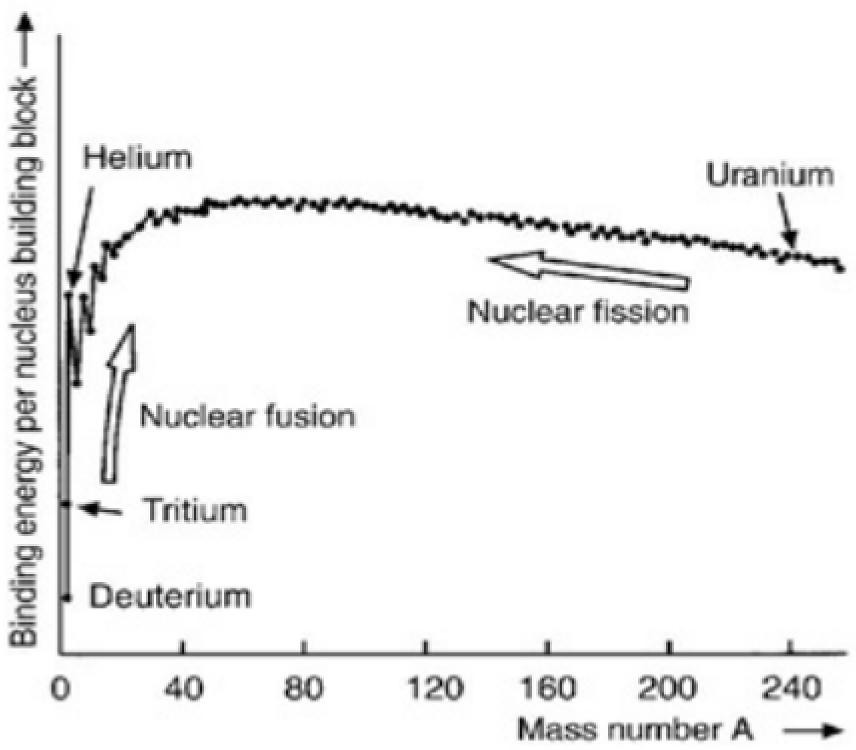
$$= \frac{\text{Binding energy}}{\text{Mass number}} = \frac{B.E.}{A}$$

$$= \frac{\Delta mc^2}{A} = [Zm_p + (A-Z)m_n - M_0]\frac{c^2}{A}$$

$$= \Delta m\frac{c^2}{A} = \frac{fAc^2}{A}$$

$$= fc^2 \qquad \left(f = \frac{\Delta m}{A}\right)$$

Binding energy curve is shown in flowing graph.



- The curve plotted between the binding energy per nucleon and mass number is known as binding energy curve.
- The binding energy curve shows that the binding energy per nucleon first increases, attain maximum value and then decreases.
- Average binding energy per nucleon in a heavy nucleus is approximately 8 MeV.
- Positive value of B.E. per nucleon for most nuclei indicates that they are stable nucleus.
- 30 $\leq\mathrm{A}\leq$ 170. These nucleii are more stable (highly bound) than $\mathrm{A}>$ 170 or $\mathrm{A}<$ 30.
- Light nucleii can fuse and form a heavier nucleus and release energy.
- In stable nucleus, the ratio of neutron to proton numbers is 1.3 to 1.4.
- Nucleii with even A and even Z are usually stable.
- Nucleii with odd A and odd Z are in general unstable.
- Nucleii with odd Z & even A are also unstable with exceptions like $_1H^2$, $_3Li^6$, $_5B^{10}$, $_7N^{14}$ which are stable.
- A nucleus may be unstable in its ground state but an atom in its ground state is always stable.
- The heaviest stable nucleus is $_{83}Bi^{209}$ (Half life $>$ 2 $\times$ 10^{16} years) greater than the age of universe.
- Atoms having $\mathrm{Z}>$ 83 are unstable.

Radioactivity

- The phenomenon of spontaneous emission of radiations by certain nucleii is called radioactivity.
- The phenomenon radioactivity was discovered by Henry Becquerel (In 1896).
- Radioactivity is independent of all physical and chemical conditions.
- The disintegration is random and spontaneous. It is matter of chance for any atom to disintegrate first.
- Radioactive substances are Uranium, Radium, Thorium, Polonium, Neptunium etc.
- All atoms having atomic no. greater than 83 are more unstable.
- Atoms having atomic no. less than 23 are more stable.
- Radioactivity is the nuclear event and not atomic. Therefore electronic configurations of atoms do not have any relationship with phenomenon radioactivity.
- This process is spontaneous i.e. it neither be started, stopped, accelerated nor retarded by any physical and chemical changes.
- In this phenomenon, parent-daughter chain continues.

Decay Law:

I. α -decay: $z^{X^4} \rightarrow_{Z-2} Y^{4^{-4}} +_2 \mathrm{He}^4(\alpha)$
During α-decay, atomic no. decreased by 2 unit and mass number decreased by 4unit in the daughter nucleus.

$92\mathrm{U}^{238} \rightarrow_{90} \mathrm{Th}^{234} +_{2} \mathrm{He}^{4}(\alpha)$

II. β-decay:

a. Electron emission $zX^{4} \rightarrow_{Z+1} Y^{A} +_{-1} \mathrm{e}^{0}(\beta)$
During β-decay, in the daughter nucleus atomic no. increased by 1 unit and mass number remains constant.
$\mathrm{e} \cdot \mathrm{g} \cdot 90\mathrm{Th}^{234} \rightarrow_{91} \mathrm{P}^{234} +_{-1} \mathrm{e}^{0}(\beta)$

b. Positron emission, $_{Z}X^{A} \rightarrow_{z-1} Y^{A} +_{+1} \mathrm{e}^{0}\ (\beta^{+})$
During β^{+}-decay, in the daughter nucleus atomic no. decreases by 1 unit and mass number remains same.

III. γ-decay: $_{Z}\mathrm{X}^{A} \rightarrow _{Z}\mathrm{X}^{A}$ * + γ (photon)
During γ-decay, the atomic & mass number of the new product remain same. γ-decay, when a excited nucleii makes transition to any lower energy state as the form of photon.
e.g. $_{90}\mathrm{Th}^{234} \rightarrow _{90}\mathrm{Th}^{234}$ + γ-rays

- Velocity of α is less than light, velocity of β is nearly equal to light & velocity of γ-rays is equal to velocity of light in vacuum.
- α & β are deflected by electric & magnetic fields but γ-rays are not deflected by fields.
- α & β-radiations are called particles (changeful & possess mass).
- γ-radiation is known as rays (chargeless & possess no mass).
- Ionization power of α is greatest, β is less than α and greater than γ but ionization power of γ is least of all.
- Penetrating power of γ is the highest.
- Penetrating power of α is the least.
- Penetrating power of β is greater than α and less than γ-radiations.
- Photon is not emitted during radioactive decay.

Laws of radioactive disintegration

N_0 = initial no. of radioactive atoms (t = 0) in the radioactive source

N = final no. of atoms remain undecay after time t

dN = no. of atoms decayed after time t

$\mathrm{dN} = \mathrm{N}_0 - \mathrm{N}$

$\frac{dn}{dt}$ = rate of no. of radioactive atoms disintegrate with respect to time which is proportional to final no. of atoms remain undecay.

$$\frac{dN}{dt} \propto N$$

$$\frac{dN}{dt} = -\lambda N \ldots\ldots\ldots (1)$$

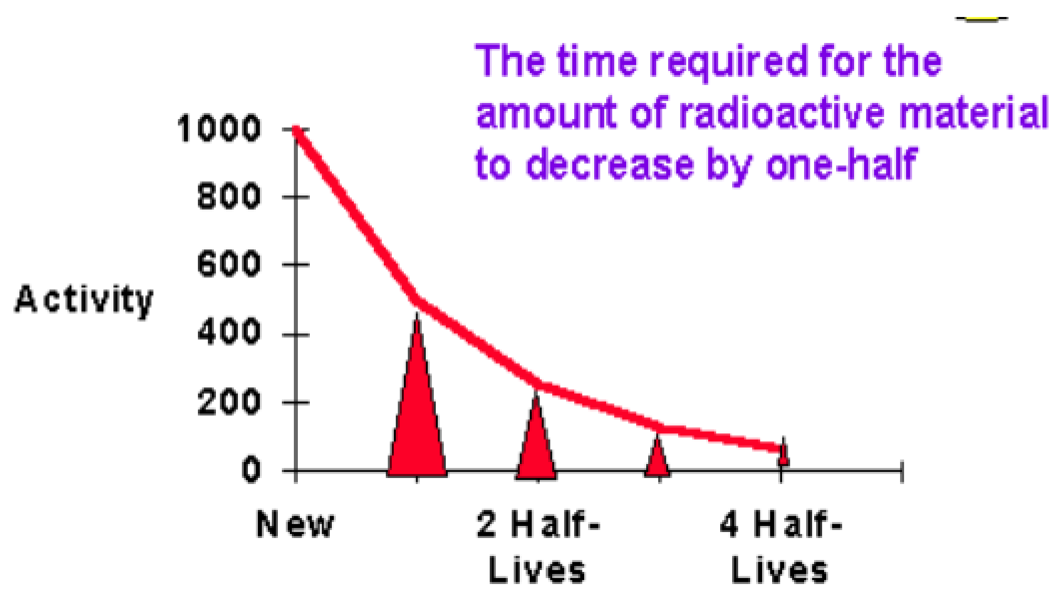
$\lambda \rightarrow$ decay constant

$$\lambda = \frac{-\left(\frac{dN}{dt}\right)}{N}$$

Integrating equation 1 ,
$\mathrm{N} = \mathrm{N}_0\ \mathrm{e}^{-\lambda t}$ .... (2)
Hence, final no. of atoms in terms of initial no. of atoms is exponentially decay with respect to time. It is due to decay constant (λ).

Half life

Time period required to disintegrate initial no. of atoms into its half value is known as half life which is denoted by $\mathrm{t}_{1/2}$.



When, $\mathrm{N}=$, $\mathrm{t}=\mathrm{t}_{1/2}$
We have,
$N=N_0e^{-\lambda t}$
$$\frac{N_0}{2}=N_0e^{-\lambda t_{1/2}}$$
$2=e^{-\lambda t_{1/2}}$
$\ln 2=\lambda t_{1/2}$
$$t_{1/2}=\frac{\ln 2}{\lambda}=\frac{0.693}{\lambda}\ldots\ldots\ldots\ldots(3)$$
$$\text{and } \lambda=\frac{0.693}{t_{1/2}}\ldots\ldots\ldots\ldots(4)$$

We have,
$$N=\frac{N_0}{2} \qquad t=t_{1/2}$$
$$N=\frac{1}{2^n}N_0 \quad t=nt_{1/2}$$
$$N=\frac{1}{2^n}N_0$$
$$\text{Then, } n=\frac{t}{t_{1/2}}$$
$T_m=1.44t_{1/2}\ldots\ldots\ldots\ldots(7)$

Average (mean) life
$$(T_m)=\frac{\text{total life time for all atoms}}{\text{total no. of atoms}}$$
$$T_m=\frac{1}{\lambda}$$
$$T_m=\frac{1}{\dfrac{0.693}{t_{1/2}}}$$
$T_m=1.44t_{1/2}$

Activity Rate
$$R_t=\text{ final rate }=\left(\frac{dN}{dt}\right)=-\lambda N$$
$$R_0=\text{ initial rate }=\left(\frac{dM}{dt}\right)_{t=0}=-\lambda N_0$$
$$\frac{R_0}{R_t}=\frac{N_0}{N}=\frac{N_0}{N_0e^{-\lambda t}}\Rightarrow R_t=R_0e^{-\lambda t}\ldots\ldots\ldots\ldots(8)$$

Finally
$N_t=N_0e^{-\lambda t}$ No. is exponentially decay
$R_t=R_0e^{-\lambda t}$ Rate is exponentially decay
$M_t=M_0e^{-\lambda t}$ Mass is exponentially decay
$C_t=C_0e^{-\lambda t}$ Count is exponentially decay

We have,
$$\frac{N}{N_0}=\frac{R}{R_o}=\frac{M}{M_0}=\frac{C}{C_0}=e^{-\lambda t}=\left(\frac{1}{2}\right)^{\dfrac{t}{t_{1/2}}}\ldots\ldots\ldots\ldots(9)$$

N = Final no. of atoms, N_0 = initial no. of atom

R = Final rate remain undecay, R_0 = initial rate

M = Final mass remain undecay, M_0 = initial mass

C = Final count rate, C_0 = initial count rate

Units of Radioactivity

1. Curie: It is defined as the amount of radioactive substance which gives 3.7×10^{10} disintegration/sec which is also equal to the radioactivity of 1 gm of pure radium.
   1 Cu $\rightarrow 3.7\times10^{10}$ dis/sec
   1 mCu $\rightarrow 3.7\times10^{7}$ dis/sec

1 μCu $\rightarrow$ 3.7 $\times$ 10^4 dis/sec

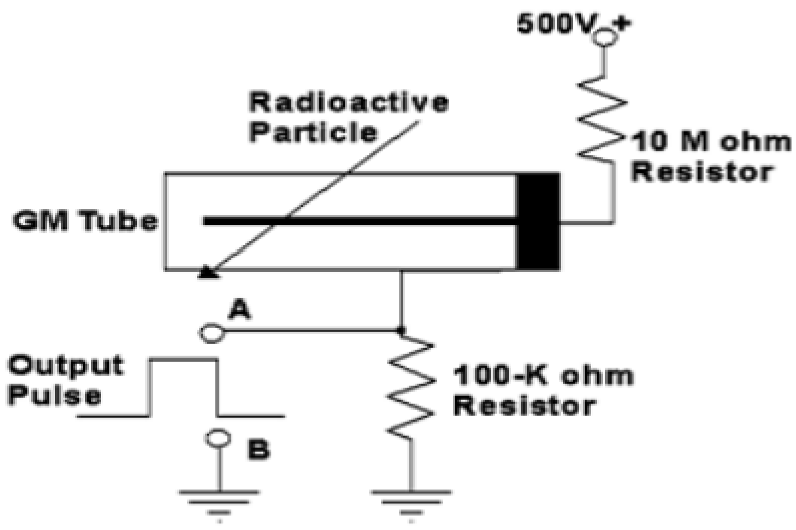
2. Rutherford: It is defined as the amount of radioactive substance which gives rise to 10^6 disintegration/sec.
   1 Rd $\rightarrow$ 10^6 dis/sec
   1 mRd $\rightarrow$ 10^3 dis/sec
   1 μRd $\rightarrow$ 1 dis/sec

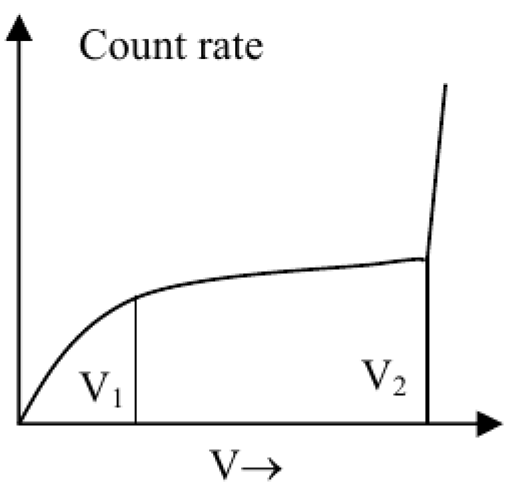
3. Becquerel: In S.I. system the unit of radioactivity is Becquerel.
   1 Becquerell = 1 disintegration/sec

G.M. Tube (Counter):

- It is a nuclear detector, used to detect nuclear radiations.
- Count rate $\propto \dfrac{1}{(distance)^2}$
  $C \propto \dfrac{1}{d^2}$, where d be the distance of source from the counter.
- $\mathrm{C} = \mathrm{C}_0\ \mathrm{e}^{-t}$, count rate of the radioactive source is exponentially decay.
  Where,
  C = final count rate
  C_0 = initial count rate

- Plateau region: The range of applied potential difference upto which count rate registered in the counter remain constant.





- Amount of applied voltage at which G.M. tube show the true count is known as working voltage denoted by V_w.
  Mathematically,
  $$V_w = \frac{V_1 + V_2}{2}$$

- We have to operate G.M. tube at the working voltage.

Radio carbon dating

- Process of age estimation of an archeological and geological objects like rocks and minerals is called dating.
- For an age estimation, radio-isotopes of carbon $({}_6\mathrm{C}^{14})$ is used.
- Slow neutron strike to atmospheric nitrogen radio isotope of carbon -14 is formed with emission of proton. i.e.
  ${}_0n^1 + {}_7N^{14} \rightarrow {}_6C^{14} + {}_1H^1$

- ${}_6C^{14}$ are taken by plants and animals. After the death of plants & animals, ${}_6C^{14}$ are intake in an environment.

- Age of the radio-isotopes is
  t = $\frac{t_{1/2}}{0.693}\ln\left(\mathrm{R_0/R}\right)$
  where, $R_0 = \left(\frac{dN}{dt}\right)_{t=0} = \text{ initial rate}$
  $R = \left(\frac{dN}{dt}\right)_t = \text{ final rate}$

  Age of the source is $\mathrm{t} = \frac{t_{1/2}}{0.693} log(R_0/R)$

Nuclear Energy (Reaction)

- Nuclear transmutation of the heavy (unstable) nucleus into the products with emission of energy, the word equation is known as nuclear reaction and associated energy with it is known as nuclear energy.
  i. Spontaneous nuclear reaction:
  $_{90}\mathrm{Th}^{227} \rightarrow {}_{88}\mathrm{Ra}^{223} + {}_{2}\mathrm{He}^{4} + \mathrm{Q}$
  ii. Artificial nuclear reaction:
  $_{0}\mathrm{n}^{1} + {}_{92}\mathrm{U}^{235} \rightarrow {}_{92}\mathrm{U}^{236} \rightarrow {}_{56}\mathrm{Ba}^{141} + {}_{36}\mathrm{Kr}^{92} + {}_{30}\mathrm{n}^{1} + \mathrm{Q}$

Q-value:
Total energy of a nuclear reaction is called Q-value. It is carried by the product as a form of kinetic energy.

- If mass of reactants is greater than mass of products, Q-value is +ve. In this case, amount of energy released during the reaction, such type of nuclear reaction is known as exothermic nuclear reaction.
- If mass of reactants is less than mass of products, Q-value is -ve. In this case, amount of energy is required to be a nuclear reaction, such type of nuclear reaction is known as endothermic nuclear reaction.
- The protons and neutrons inside the nucleus are held together by strong attractive forces. These attractive forces can't be gravitational since forces of repulsion between protons is greater than attractive gravitational forces between the protons. The forces are short which is known as nuclear forces.
- The nuclear forces are charge independent therefore, forces between protons & protons equal to the forces between neutrons & neutrons and protons & neutrons.

Nuclear fission

- Nuclear fission was discovered by Otto Hann and Strassman.
- The process of splitting of the heavy nucleus into the stable or less unstable products with emission of energy is known as nuclear fission.
- To be a nuclear fission a projectile is needed.
- During nuclear fission many isotopes are produced.
- Uranium-238 is not used in fission.
- Fission of U^{238} is possible only by the neutron of energy 1 MeV as a projectile.
- Fission of U^{235} is possible by the slow neutron of energy tends of 1 eV.
  e.g. $_{0}\mathrm{n}^{1} + {}_{92}\mathrm{U}^{235} \rightarrow {}_{92}\mathrm{U}^{236}$ (Unstable)
  $_{92}\mathrm{U}^{236} \rightarrow {}_{56}\mathrm{Ba}^{141} + {}_{36}\mathrm{Kr}^{92} + 3_{0}\mathrm{n}^{1} + \mathrm{Q}$
  where, $\mathrm{Q} \geq$ 200 MeV

- Most part of the liberated energy is in the form of kinetic energy carried by the products.
- Neutrons emitted from the fission have energy equal to 2 MeV. Therefore, neutrons can escape from the reaction so as to produce chain reaction therefore neutrons are needed to slow down.

Chain Reaction

The uncontrolled nuclear reaction is called chain reaction. It acts as the real source of energy and triggering for next nuclear reaction upto when fissionable fuel remains in a device. During chain reaction, large amount of energy produced as a geometric sum and neutron production is the multiple of three.

When uranium is bombarded by neutrons, each uranium is broken into two nearly equal fragments and along with huge energy about 200 MeV and two or more two fresh neutrons are liberated. Under the favorable condition, these neutrons fission other uranium as the same process. Therefore, chain of nuclear fission is established.

- For the chain reaction, many difficulties are
  i. Escaping of neutrons from the system
  ii. Absorption of neutrons by unbroken nuclei present in the system
- It is not necessary that all neutrons will proceed chain reaction.
- Minimum mass for which chain reaction is possible is called critical mass.
  It is 10 kg for U^{236}.
- The necessary condition for nuclear fission is that there must be at least one neutron which takes part in nuclear fission.
- Multiplication factor (reproduction factor) is $K = \frac{\text{No. of neutrons produced}}{\text{No. of neutrons present before reaction}}$
  i. $\mathrm{K} <$ 1, the chain reaction will finally stop.

ii. $K \geq 1$, chain reaction will continue

- No. of neutrons emitted during fission reaction depends upon volume of system.
  Chain reaction is two types:
  a. Controlled chain reaction
  b. Uncontrolled chain reaction

Controlled chain reaction:

i. Rate of production of neutron in controlled reaction is equal to one.
ii. $K = 1$
iii. This type of reaction, energy liberated is less than explosive energy.
iv. This type of energy is used in constructive purpose.
v. Nuclear reactor work on this principle.

Uncontrolled chain reaction:

- It is uncontrolled i.e. violent reaction.
- In this type, more than one neutron take part into the reaction.
- Nuclear fission increases.
- Reproduction factor, $K > 1$
- Large amount of energy is produced during violent reaction.
- An atom bomb works on principle of uncontrolled nuclear reaction.

Nuclear Reactor

- Nuclear reactor is device which takes nuclear chain reaction under the command.
- Nuclear reactor is device in which a self sustaining controlled chain reaction is established to produce energy.
- Nuclear reactor has following parts:
  a. Fuels (fissionable substance)
  e.g. U^{235}, Pu^{239}, U^{233} etc.
  The quality of fissionable material should be equal to critical mass.
  b. Moderator: used to slow down the fast moving neutrons. Heavy water is best moderator.
  c. Neutron source: used to start chain reaction.
  d. Controlled rod (Cd-rod): Controlled rod made of cadmium which is good absorber of neutrons.
  e. Coolant: is a cooler which maintains heat in the system.
  f. Protective shield: Various harmful intense rays are emitted from these reactors therefore which is surround by thick wall. Actually, it is the outer glass jacket.
- An atom bomb is the nuclear war weapon which works on principle of nuclear fission.
- This is based on uncontrolled chain reaction.

Nuclear fusion

- The process of fusing of two or more than two lighter nucleii into a stable nucleus with emission of large amount of energy is known as nuclear fusion.
- E.g. when hydrogen isotopes fuses at high temperature & pressure, a stable helium is formed with emission of energy.
  i.e. ${}_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + {}_0n^1 + Q$
  ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + Q$ where, $Q \sim 24$ MeV
- To be a nuclear fusion, no projectile is needed.
- To be a nuclear fusion, high temperature & pressure is required.
- During nuclear fusion, no isotopes are produced.
- Large amount of energy produced is also called thermo nuclear energy and reaction is also known as thermo-nuclear reaction.
- This type of reaction occurs in sun and stars.
- Hydrogen bomb is the nuclear war weapon which works on principle of nuclear fusion.
- It is more dangerous than the atom bomb.
- To explode hydrogen bomb, first of all an atom bomb is exploded to reach sufficient temperature & pressure for nuclear fusion.
- Fusion reactor is still not available to get energy from nuclear fusion.

Uses of radiations (Radio isotopes)

- Highly used in medical fields
  i. for cancer treatment (Co-60)
  ii. detecting fault of thyroid gland (I-131)
  iii. detecting brain tumour (mercury-203)
  iv. detecting blood circulation (sodium-24)
  v. for skin diseases treatment (phosphorus-31)
- Used in agriculture
  i. protecting potato from earthworm
  ii. used in fertilizer
  iii. for artificial rains
- Used in determining the age of archeological objects.
- Used for age estimation of earth-lead isotopes.
- Used in industry

i. for determining the age of planets
ii. for detecting leakage of oil or water pipe lines.

- Radiation dose is measured in Sieverts (Sv).
- The interaction responsible for beta decay is called weak interaction.
- Coefficient of absorption depends on wavelength of γ-rays & the nature of material.
- Size of nucleus is decreased by α-emission.
- α-decay is explained on the basis of tunnel effect.

In nuclear reaction:
M = mass of reactants
m = mass of products
M -m = $\Delta\mathrm{m}$ = mass defect
Q-value is
Q = $\Delta\mathrm{mc}^2$
Q = $(\mathrm{M}$ -$\mathrm{m})\ \mathrm{c}^2$