

JEE AND NEET Syllabus

A. Nuclear Physics

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KEY CONCEPT

1. Introduction

(i) Rutherford's α -scattering experiment established that the mass of atom is concentrated within small positively charged region at the centre which is called 'nucleus'.

(ii) Radius of nucleus (R)

$$R = R_0 A^{1/3}$$

Where A = mass number

$$R \propto A^{1/3}$$

$$\text{Volume of nucleus} = \frac{4}{3} \pi R^3$$

$$\therefore \text{Volume} \propto A$$

(iii) $A \propto R^3$

A = Nucleon number or mass number

(iv) Any element X with mass number A and charge number Z can be represented by ${}_Z X^A$ or ${}_Z^A X$.

$$\text{Number of neutron} = A - Z$$

$$\text{Mass number} = A = P + N$$

(v) $1 \text{ amu} = \frac{1}{12}$ th mass of 12 gm of ${}_{6}\text{C}^{12}$ atom.

(vi) Isotopes \rightarrow Those set of nuclei's containing same number of protons but different numbers of neutrons.

(vii) Isobars \rightarrow Those set of nuclei's containing same mass number but different atomic number are known as isobars.

Example : ${}_{6}\text{C}^{14}$ and ${}_{7}\text{N}^{14}$

(viii) Isotones \rightarrow Those set of nuclei's containing same numbers of neutrons are known as isotones.

Example : ${}_{6}\text{C}^{14}$ and ${}_{8}\text{O}^{16}$

(ix) Mirror nuclei \rightarrow Nuclei with same mass number A but with proton and neutron numbers interchanged i.e. the number of protons in one is equal to the number of neutrons in the other are called mirror nuclei.

Example : ${}_{4}\text{Be}^7$ (Z = 4, N = 3) and ${}_{3}\text{Li}^7$ (Z = 3, N = 4)

(x) $\frac{\text{Radius of atom}}{\text{Radius of nucleus}} \cong 10^5$

(xi) $\frac{\text{Volume of atom}}{\text{Volume of nucleus}} \cong 10^{15}$

(xii) Density of nucleus (ρ)

(a) ρ is of the order of $\cong 10^{17} \text{ kg/m}^3$ for almost all nuclei's.

(b) $\rho = \frac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$

(c) Nuclear density is independent of its mass number.

(xiii) Neutron is electrically neutral particle and not deflected by electric or magnetic field.

(xiv) Neutron do not ionize gases

(xv) Angular momentum of electron = $\pm \frac{1}{2} \left(\frac{h}{2\pi} \right)$

(xvi) When a neutron strikes with the atoms it penetrates in to the atoms. This important property of neutron is used for nuclear fission.

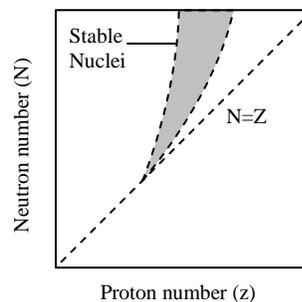
(xvii) Neutron was discovered by Chadwick.

(xviii) Proton was discovered by Goldstein.

(ixx) Nuclear Stability \rightarrow

For stable nuclides the following points many be noted.

(i) The light nuclides have almost equal number of protons and neutrons. In general light nuclei $A < 20$ contains approximately equal number of neutrons and protons.



Example : ${}_{2}^4\text{He}$ (Z = 2, N = 2),

${}_{6}^{12}\text{C}$ (Z = 6, N = 6),

${}_{4}^9\text{Be}$ (Z = 4, N = 5).

- (ii) In heavier stable nuclides, there are more neutrons than protons. The heaviest having about 50 percent more.

Example : ${}_{47}\text{Ag}^{107}$ ($Z = 47, N = 60$),

${}_{79}\text{Au}^{197}$ ($Z = 79, N = 118$),

${}_{82}\text{Pb}^{208}$ ($Z = 82, N = 126$)

- (iii) Most of the stable nuclides have both an even number of protons and even number of neutrons. Examples of the most stable nuclides are ${}^4_2\text{He}$ ($Z = N = 2$), ${}^{16}_8\text{O}$ ($Z = N = 8$), ${}^{28}_{14}\text{Si}$ ($Z = N = 14$), ${}^{56}_{26}\text{Fe}$ ($Z = 26, N = 30$). For unstable nuclides the following points may be noted.

- (i) Nuclei with $Z > 83$ spontaneously disintegrate with emission of α or β particles.
- (ii) A nuclide below the line of stability have excess number of protons. It decays by β^+ emission decreasing Z and increasing N . In β^+ emission, the N/Z ratio increases.

(iii) A heavy nuclide disintegrates by α -decay

(iv) Disintegration tends to produce new nuclides nearer the stability line and continue until a stable nuclide is formed.

(xx) Nuclear forces \rightarrow

Forces acting between n-n, n-p and p-p inside the nucleus is called nuclear forces.

- (a) They are short ranging forces ($10^{-15} \text{ m} - 10^{-14} \text{ m}$)
- (b) They are most strongest in nuclear ranges and their strength becomes zero when distance between nucleons becomes of the order of 10^{-12} m .
- (c) Order of strength of various nuclear forces.

$$F_{\text{nuclear}} : F_{\text{EM}} : F_{\text{weak}} : F_{\text{grav.}}$$

$$: : 10^{39} : 10^{36} : 10^{33} : 1$$

- (d) Nuclear forces are charge independent or they act alike between various nucleons.

$$F_{n-n} = F_{n-p} = F_{pp}$$

- (e) Net force between the nucleon

$$F_{n-n} = F_{n-p} > F_{pp}$$

- (f) Nuclear forces are non-central. The nuclear force depends on the relative spin orientation of nucleons.

2. Mass Defect

- (1) When proton and neutron combines together in order to form nucleus, then in this process some mass gets lost and this lost mass is known as mass defect (Δm). More is the mass defect, more is presumed to be stability of product nuclei.

- (2) Mathematically :

$$\Delta m = \text{Mass of nucleons} - \text{mass of nucleus}$$

$$= A - M$$

$$= [Zm_p + Nm_n] - M$$

$$= [Zm_p + (\Delta - Z) m_n] - [\text{Mass of atom} - \text{mass of electron orbiting in circular orbits}]$$

- (3) Packing fraction (f) = mass defect per nucleons

$$= \frac{\Delta m}{A} = \frac{M - A}{A} = \frac{[Zm_p + (A - Z)m_n] - M}{A}$$

More the negative value of packing fraction, more is the stability of product nuclei.

3. Nuclear Binding Energy

In nucleus, proton and neutron are contained in very small sphere of radius of the order 10^{-15} m . At such small distance, two proton exerts a very large force of repulsion on each other. Therefore certain amount of energy needed to bind the nucleus. This energy is known as binding energy.

- (i) When nucleus formed, the mass of nucleons forming it decreases. The mass defect supplies the required binding energy.
- (ii) The energy equivalent to mass defect is called binding energy.

By Einstein mass energy relation Binding energy = (Mass defect) \times (velocity of light)² =

$$\Delta E = (\Delta m)c^2$$

Here Δm : mass defect

(iii) Binding energy of a nucleus may also be defined as the amount of work required to separate the nucleons at infinite distance .

(iv) Binding energy/nucleon :- Binding energy per

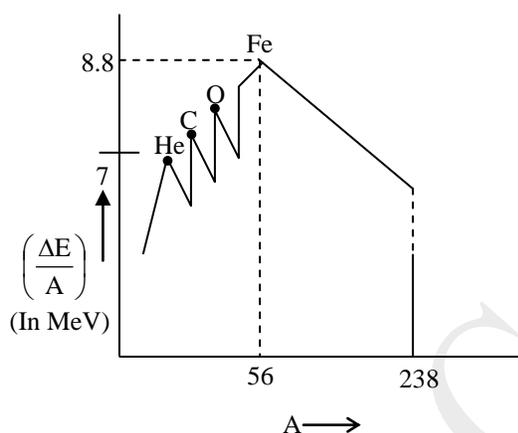
$$\text{nucleon} = \frac{\Delta E}{A} = \frac{\Delta mc^2}{A}$$

(v) It is the measure of stability of nucleus.

(vi) Greater the binding energy per nucleons greater will be nucleus stability.

4. Binding energy Curve

(i) Nature of the curve :



(ii) The curve plotted between binding energy per nucleon and mass number is known as binding energy curve.

(iii) The curve shows that BE per nucleon first increases, attains a maximum value and then decreases

(iv) The average binding energy per nucleon in a heavy nucleus is approximately 8 MeV.

(v) Positive value of BE per nucleon for most nuclei indicates that all the nucleus are stable.

(vi) For $30 \leq A \leq 170$, the nuclei are more highly bound than those for $A > 170$ or $A < 30$.

(vii) Light nuclei can fuse and form a heavier nuclei, and release energy (fusion).

(viii) Stable nuclei have N/Z ratio = 1.3 to 1.4.

(ix) Nuclei with even A, even Z are usually stable and most abundant. Nuclei with odd A and odd

Z are unstable, in general. Nuclei with odd Z and even A are also unstable with exceptions like ${}^2\text{H}$, ${}^6\text{Li}$, ${}^{10}\text{B}$, ${}^{14}\text{N}$, which are stable.

(x) A nucleus may be unstable in its ground state (may beta decay for example). But an atom in its ground state is always stable.

(xi) The heaviest stable nuclide is Bi (Half life $> 2 \times 10^{16}$ years greater than the age of the universe). All nuclide with $Z > 83$ are unstable.

5. Nuclear Fission

(i) It was discovered by scientist Otto Hann and F. Strassman.

(ii) Process of splitting up of heavy nuclei by the bombardment of neutron into two almost equal weight nuclei is known as nuclear fission and in this process on account of mass defect huge energy is liberated.

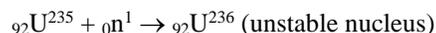
(iii) Natural uranium is obtained in the following proportions :

$${}_{92}\text{U}^{234} : {}_{92}\text{U}^{235} : {}_{92}\text{U}^{238} :: 0.006 : 0.7 : 99.3 \text{ (approx)}$$

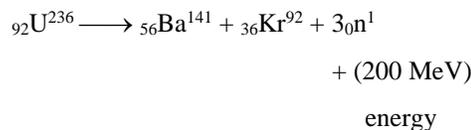
(iv) U^{238} is not used in fission as its fission is possible only by neutron of energy approximately 1 MeV.

(v) Fission of U^{235} is possible by slow neutrons of energy ($\sim 1\text{eV}$) or even by thermal neutrons of energy (0.025 eV)

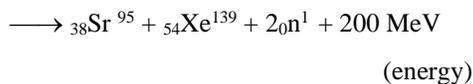
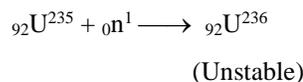
(vi) Fission reaction \rightarrow



(vii) (a) Because of instability, ${}_{92}\text{U}^{236}$ again fissions into two stable nucleus Ba and Kr with the three other neutrons.



(b) During ${}_{92}\text{U}^{235}$ fission we don't get only isotopes of Ba and Kr but we can get other type of pairs also like



- (c) By fission of one ${}_{92}\text{U}^{235}$ we get approximately 200 MeV energy.
- (viii) By fission of ${}_{92}\text{U}^{235}$, on an average 2.5 neutrons are liberated.
- (ix) Most part of liberated energy is in the form of kinetic energy of fragmented nuclei.
- (x) Neutrons emitted from nuclear fission have energy equal to 2.0 MeV. These fast neutrons can escape from the reaction so as to proceed the chain reaction they are need to slow down.

6. Chain Reaction

- (i) When Uranium is bombard by neutrons, each Uranium nucleus is broken into two nearly equal fragments and along with it huge energy and two or more (avg. 2.5 neutron) fresh neutrons are liberated. Under formable condition, three neutrons fission other uranium nuclei in the same way. Thus a chain of nuclear fission, is established which continues until the whole of Uranium is consumed.
- (ii) There are following main difficulties in establishing a chain reaction :-
 - (a) Leaking or escaping of neutrons from the system
 - (b) Absorption of neutron by unbroken nuclei present in the system
 - (c) Absorption of Neutrons by U^{238} .
Hence it is not necessary that all neutrons will proceed chain reaction.
- (iii) **Critical mass :-** Minimum mass of Uranium system or any other system for which chain reaction is possible is called critical mass. It is 10 kg for U^{235} .
- (iv) The necessary condition for nuclear fission is that there must be at least one neutron which takes part in nuclear fission. This condition is defined by multiplication factor or reproduction factor (K)

$$K = \frac{\text{No. of neutrons present in a step of nuclear fission reaction}}{\text{No. of neutrons present in one step before the above reaction}}$$

If $K < 1$ then chain reaction will finally stop because in further step no. of neutrons decreases.

If $K \geq 1$ chain reaction will continue

- (v) No. of neutrons emitted during fission reaction depends upon volume of system (or $\propto r^3$)
- (vi) Rate of leaking of neutrons from the system is directly proportional to area of system ($\propto r^2$)

7. Types of Chain reactions

- (a) controlled
- (b) uncontrolled

7.1 Controlled chain reaction :-

- (a) Rate of reproduction in controlled reaction is equal to one.
- (b) $K = 1$
- (c) Energy liberated in this types of reaction is always less than explosive energy and it proceed with a certain velocity.
- (d) This type of energy is used in constructive work.
- (e) Nuclear reactor uses this principle exactly.

7.1.1 Nuclear Reactor :

- (i) Nuclear reactor is device in which a self sustaining controlled chain reaction is established to produce energy.
- (ii) In this reactor at least one neutron liberated in a step can fission next nucleus it is control by artificial manner.
- (iii) A modern reactor has following important parts :
 - (a) **Fission substance (Fuel) :-** This is substance used for fission. Natural uranium or U^{235} rich Uranium are used for this purpose. Other fuels are Pu^{239} and U^{233} . Quantity of fissionable material should be equal to critical mass.
 - (b) **Moderator :-** It is used to slow down the fast neutrons and changes to thermionic neutron. Heavy water, graphite or beryllium oxide is used for this purpose. Heavy water is best moderator.
 - (c) **Neutron's source :-** It is used to start the chain reaction.
 - (d) **Controller :-** Cadmium rods are used to controll the rate of fission in the reactor. Cd is very good absorber of neutrons.
 - (e) **Coolant :-** The energy released inside the reactor in the form of heat is removed by coolant. For this

purpose air, ice, cold water or CO₂ is flown in the reactor.

- (e) **Shield :-** Various types of harmful intense rays are emitted from these reactor so it is surrounded by 7 to 8 ft. thick concrete walls.

7.1.2 Uses :

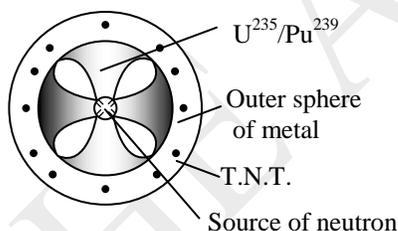
- In energy production.
- In manufacturing of radioactive isotopes which are used in agriculture, medical, industry, biological & scientific discoveries etc.
- In manufacturing of Pu²³⁹ which is used in atom bomb

7.2 Uncontrolled chain reaction :

- There is no control over this type of nuclear reaction.
- In this type of reaction more than one neutron takes part into reaction. Due to this speed nuclear fission increases.
- For this type of reaction: Reproduction factor (K)>1
- A huge amount of energy is liberated in this type of reaction.
- In atom bomb, uncontrolled chain reaction takes place.

7.2.1 Atom Bomb :-

- (i) This is based on uncontrolled chain reaction.



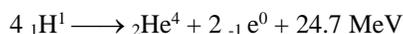
- In atom bomb manufacturing two or more parts of U²³⁵ or Pu²³⁹ is used whose mass slightly more than half of critical mass. These parts are arranged in a sphere of metal.
- T.N.T is used to separate these parts.
- These parts are totally safe till these parts are separate.
- When these individual sizes are joined together, their combined size becomes larger than the

critical size. Thus speed of fission enhances & more energy is liberated.

- Due to explosion in fraction of minute the temperature and atmospheric pressure multiplies and reaches to 10⁷ K.
- First nuclear test for peace work was done at Pokhran in Rajasthan in 18th may 1974.

8. Nuclear fusion

- Process of combining two light weight nucleus into one heavy weight nucleus at high temperature and pressure is called nuclear fusion .
- This reaction is possible only at high pr. ($\cong 10^6$ atm) and high temperature ($\cong 10^7 - 10^8$ °C)
- The vast amount of energy emitted in this reaction is also called thermonuclear energy and this reaction is called thermonuclear reaction .
- Sun and stars get energy produced from nuclear fusion.
- Four hydrogen atom combined into one ${}^4_2\text{He}$ nucleus and 24.7 MeV energy emits in the whole reaction.



- Hydrogen bomb is also based on above principle and it is much more disastrous than the atom bomb.
- Hydrogen bomb explosion needs atom bomb explosion so that 10⁷ – 10⁸K temperature could be reached for fusion reaction.
- Fusion reactor is still not available to get energy from nuclear fusion

9. Point To Remember

- Rutherford discovered nucleus.
- Neutron was discovered by Chadwick.
- Packing fraction = $\frac{\Delta m}{A} = \left(\frac{M - A}{A} \right)$
- Nuclei with negative packing fraction are more stable.
- Greater the binding energy per nucleon, greater is the stability.

- (6) Nuclear fission was discovered by Otto Hahn & Strassmann.
- (7) Nuclear forces are the strongest known force in nature.
- (8) Relative strength of the gravitational, coulomb's and nuclear force is
 $F_g : F_e : F_n :: 1 : 10^{36} : 10^{38}$
- (9) The high density of the nucleus suggests that the nucleus is compact.
- (10) The first nuclear reactor was made by fermi.
- (11) Neutrons having energy ~ 0.03 are called thermal neutrons.
- (12) Critical mass of uranium is 10 kg.
- (13) Nuclear reactor is based on controlled chain reaction.
- (14) The nuclear forces between two protons, two neutrons and a neutron and a proton have the same magnitude.
- (15) Fusion takes place at high temperature of 10^7 °C.
- (16) The fusion of nuclei is an uncontrolled process.
- (17) Density of the nuclei of all the atoms is same.
- (18) The actual discovery of pi-mesons was made from the study of cosmic radiation.
- (19) Neutron is neutral and its spin angular momentum is $\left(\frac{1}{2}, \frac{h}{2\pi}\right)$
- (20) Escape of neutron is proportional to r^2 .
- (21) ${}_1\text{H}^2 + {}_1\text{H}^2 \rightarrow {}_2\text{He}^3 + n + 3.27 \text{ MeV}$
 ${}_1\text{H}^2 + {}_1\text{H}^3 \rightarrow {}_2\text{He}^4 + n + 17.59 \text{ MeV}$
- (22) He was awarded nobel prize for his work related to fusion reactions in sun and other stars.
- (23) To achieve fusion in laboratory a Tokamak is used. It is a device to confine plasma (collection of deuterium, tritium nuclei, in this case)
- (24) **(i) Research atomic reactors -**
 (a) Apsara - This is 1MW reactor and was made in Bombay. An alloy of Uranium and aluminum is used as fuel in it. This is also known as swimming pool type reactor.

(b) Cirus - It is a 40MW reactor, made in collaboration with Canada and is used to produce radioisotopes.

(c) Zerlina - OMW reactor

(d) Purnima - OMW reactor.

(ii) Power reactors -

(a) In Tarapur (Maharashtra) 400MW

(b) In Rana Pratap Sagar (Raj.) 400 MW

(c) In Kalpakkam (Madras) 220 MW

(d) In Narora (U.P.) 200 MW

(e) In Kaiga (Karnataka) 200 MW

(f) In Kakrapar (Gujarat) 200 MW

(g) Fusion reactors are better than fission reactors because no unwanted radioactive substances are produced in them- and these are available in abundance.

(25) Difference between nuclear fission and nuclear fusion

Nuclear fission

Neutrons are required for it.

It is possible at normal temperature and pressure.

For this the energy released per nucleon

$$\frac{\Delta E}{A} = \frac{200}{236} \sim 0.8 \text{ MeV}$$

The fissionable materials are expensive.

Nuclear fusion

Protons are required for it.

It is possible at high temperature and pressure.

For this $\frac{\Delta E}{A} = \frac{27}{4} \sim 6.75$

The materials used in it are cheap

(e.g. heavy water)

(26) Difference between atom bomb and hydrogen bomb -

S.No. Atom Bomb

1. It is based on the fission process
2. In this critical size is important

- In this the explosion is possible at normal temperature and pressure
- In this the harmful radiations are produced

Hydrogen Bomb

- It is based on fusion process
 - There is no limit to critical size
 - In this high temperature and pressure are required.
 - In this the harmful radiations are not produced
- (27) In all nuclear reactions following quantities remains conserved
- Mass - energy
 - Linear momentum
 - Angular momentum
 - Nucleon number
 - Charge number
- (28) Enriched uranium - The uranium, in which the fraction of ${}_{92}\text{U}^{233}$ is increased from 0.7% to 2.3%, is known as enriched uranium.

10. Introduction

- The phenomenon of radioactivity was discovered by Henry Becquerel in uranium salts. (1896)
- After the discovery of radioactivity in uranium, Piere curie & Madame curie discovered a new radioactive element called 'radium'. It is 10^6 times more radioactive than uranium. Radium was extracted from pitch blende (a kind of coal tar) for which curies were honoured by nobel prize in 1903.
- Definition : -The self, spontaneous, disintegration (i.e. decay) of unstable radioactive nuclei's is known as radioactivity & the nuclei exhibiting this phenomenon are known as radioactive nuclei.
- Some example of radio active substance (or elements) are :
Uranium, Radium, Thorium, Polonium, Neptunium etc.
- All elements having atomic number greater than 83 are radio active element.

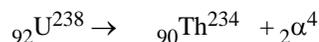
- (6) Lead ($Z = 82$) is the most stable element in high atomic number elements that's why all radio active elements emits radio active radiation till they are converted into Lead.

- (7) Radioactivity is a nuclear event & not atomic. Hence electronic configuration of atom don't have any relationship with radio activity.

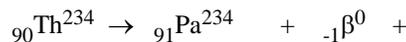
- (8) Decay processes are random. Here one simply knows that in a radioactive element, radioactivity is taking place or it is definite that a certain no. of atoms will decay in a given time interval but one never knows that which particular radioactive nuclei will decay when. It is just a matter of chance i.e. probability which is explained by quantum mechanics. It is statistical in nature.

- (9) This process is spontaneous i.e. it can neither be started, stopped, accelerated nor retarded by any physical (i.e. by changing temperature pressure, force) or chemical change.

- (10) In this phenomenon parent-daughter chain continues. Original radio active element are called parent element or nucleus but new element is called Daughter element or disintegrated nucleus.



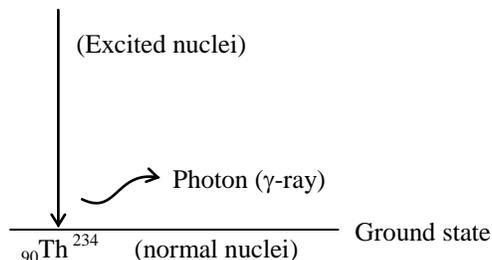
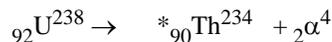
(Parent) (Daughter)

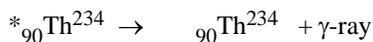


(Parent) (Daughter) (Antineutrino)

- (11) In this phenomenon, α , β particles and γ -rays are emitted. For a given nuclei at a particular time emission of either α or β takes place, never both at time.

- (12) γ -rays are emitted in when an excited nuclei makes transition to any lower or ground energy state the form of photon.





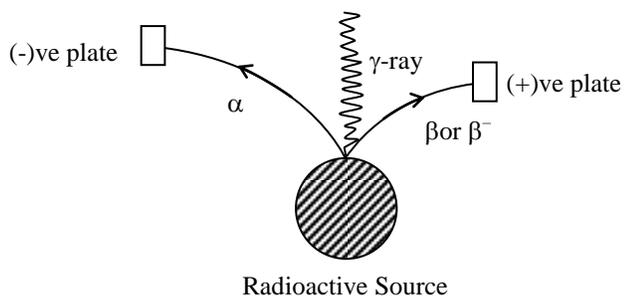
(higher energy nuclei) (lower energy nuclei)

(lower stability) (higher stability)

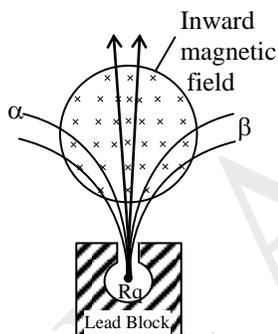
excited nuclei and normal nuclei are known as radioactive isomers.

- (13) Due to emission of α, β, γ during radioactive decay, mass of parent nuclei goes on decreasing.

- (14) Deflection of radioactive radiations was measured by rutherford in electric field & it is as below.



- (15) Deflection in magnetic field.



- (16) **Remember** : Proton is not emitted during radioactive decay.

11. Laws of radioactive disintegration

- (1) If $N = N_0$ of active nuclei at time t
 $N - dN = N_0$ of active nuclei after time interval of dt .
 \therefore Rate of decay = $-\frac{dN}{dt}$
- (2) According to the Rutherford and Soddy law for radio active decay, "At any instant the rate of decay of radioactive atom is proportional to the

number of atoms present at that instant " Rate of decay $\propto N$

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

$$\text{or } -\frac{dN}{dt} = \lambda N$$

λ is called decay constant.

- (3) If $N_i = N_0$ of active nuclei at time t_i .

$N_f = N_0$ of active nuclei left at time t_f .

$$\int_{N_i}^{N_f} \frac{dN}{N} = - \int_{t_i}^{t_f} \lambda dt$$

$$[\ell n n]_{N_i}^{N_f} - \lambda [t]_{t_i}^{t_f}$$

$$\ell n \frac{N_f}{N_i} = -\lambda [t_f - t_i]$$

$$\frac{N_f}{N_i} = e^{-\lambda[t_f - t_i]}$$

If $t_f = t$ & $N_f = N$

& $t_i = 0$ $N_i = N_0$

$$\text{then } \frac{N}{N_0} = e^{-\lambda t} \quad N = N_0 e^{-\lambda t} \dots\dots (1)$$

- (4) eq. (1) is known as Rutherford & Soddy's exponential equation of radioactivity.

- (5) If $t = \infty$ then $N = 0$

Therefore, for a complete decay of a radioactive nuclei, it takes infinite time.

- (6) **Half life ($T_{1/2}$)** \rightarrow

Half life of a radioactive element is the time or time interval in which 50% of radioactive nuclei will disintegrate.

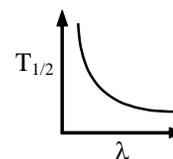
$$\text{or when } t = T_{1/2} \text{ then } N = \frac{N_0}{2}$$

$$\text{From } N = N_0 e^{-\lambda t}$$

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}$$

$$T_{1/2} = \frac{\ell n 2}{\lambda}$$

$$= \frac{0.693}{\lambda}$$

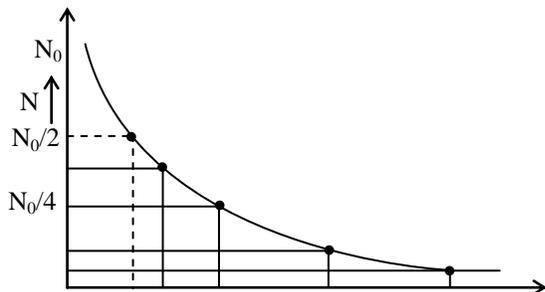


(7) **Physical significance of Half life.**

If half life of a radio active nuclei is more then in a given time interval probability of its availability is also more. Half life of a element does not depend on physical & chemical circumstances.

$$\frac{N}{N_0} = \frac{1}{(2)^{t/T}}$$

(8) Graph between no. of active nuclei left & time of decay



(9) Average life or mean life (τ) \rightarrow

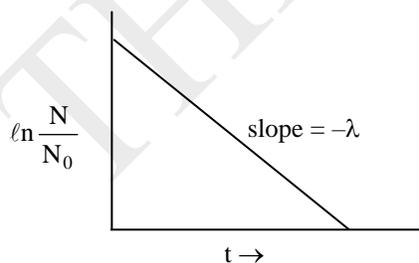
(i) The time, for which a radioactive material remains active, is defined as mean life of that material.

(ii) $\tau = \frac{\text{Sum of lives of all nuclei's}}{\text{Total no. of nuclei present}} = \frac{\int_0^{\infty} t \, dN}{N_0}$

(iii) The average time taken in decaying by the nuclei of an element is defined as its mean life τ .

(iv) $\tau = \frac{1}{\lambda}$

(v) $\ln \frac{N}{N_0} = -\lambda t$



The magnitude of inverse of slope of $\ln \left(\frac{N}{N_0} \right)$ & t curve is known as mean life.

(vi) $\ln N = N_0 e^{-\lambda t}$

If $t = \frac{1}{\lambda}$

then $N = N_0 e^{-1}$

$$= \frac{N_0}{e} = \frac{N_0}{2.718} = 0.3676 N_0 \approx 0.37 N_0$$

Therefore if $\tau = t = \frac{1}{\lambda}$ then $N = \frac{N_0}{e} \approx 0.37 N_0$

Mean life of a radio active nuclei is equal to that time is which no of nuclei left becomes either $\frac{1}{e}$ times the original nuclei or approximately 37% of the original nuclei.

or, Number of decayed nuclei in mean life

$$\begin{aligned} &= N_0 - N = N_0 - \frac{N_0}{e} \\ &= N_0 \left[1 - \frac{1}{e} \right] \approx 0.63 N_0 \end{aligned}$$

Mean life is equal to that time in which no. of decayed nuclei becomes either $\left(\frac{e-1}{e} \right)$ times original nuclei or approximately 63% of original nuclei.

(vii) Fraction of active nuclei left = $\frac{N}{N_0}$

(probability of survival)

(viii) Fraction of decayed nuclei

$$= 1 - \frac{N}{N_0} = \frac{N_0 - N}{N_0}$$

(Probability of decay)

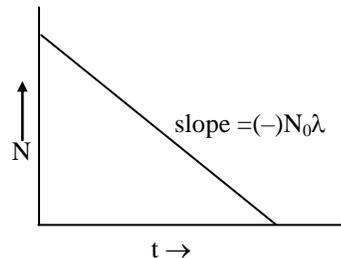
(ix) When decay process is too slow

then $N = N_0 [e^{-\lambda t}]$

$$N = N_0 [1 - \lambda t]$$

$$N = [-N_0 \lambda] t + N_0$$

On comparing = $m x + c$



(x) Half life, mean life & decay constant for a particular nuclei always remains constant.

(xi) **Decay constant (λ) :**

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

$$= \frac{\text{Rate of decay at a given instant}}{\text{No. of active nuclei at that instant}}$$

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

$$= \text{Probability of decay in unit time.}$$

(iii) If $\lambda = t^{-1}$ then $N = \frac{N_0}{e} = 0.3676$

$$N_0 \approx 0.37 N_0$$

Decay constant is equal to inverse of that time in which no. of active nuclei left becomes

either $\frac{1}{e}$ times or approx 37% original nuclei.

(iv) $N = N_0 e^{-\lambda t}$

can be written in the form of mass as below

$$m = m_0 e^{-\lambda t}$$

When m = mass of radio active nuclei at time t
& m_0 = mass of radioactive nuclei at time $t = 0$

$$\frac{m}{m_0} = \frac{1}{(2)^{t/T}}$$

(v) Decay constant is equal to inverse of the time in which 63% of initial atoms (N_0) is being decayed.

(vi) Unit :- (second)⁻¹ or (minute)⁻¹ or (year)⁻¹

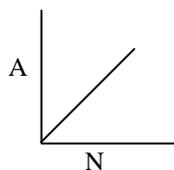
12. Activity (A or R)

(1) Activity of any element shows instability of the element at any time (t).

(2) Activity is defined as rate of decay at given instant.

$$A = - \frac{dN}{dt} = N\lambda$$

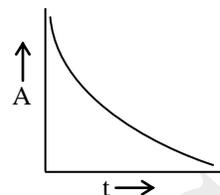
$$\therefore A \propto N$$



(3) Original activity

$$A_0 = \lambda N_0$$

$$\therefore \frac{A}{A_0} = \frac{N}{N_0} = e^{-\lambda t} = \frac{1}{(2)^{t/T}}$$



(4) **Units of Activity**

(a) 1 disintegration / sec = 1 becquerd (Bq)

(b) 1 curie = 3.7×10^{10} dps

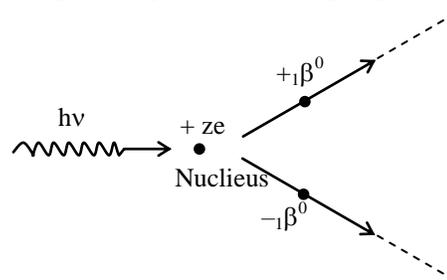
(c) 1 Rutherford = 10^6 dps

(5) 1 mille curie = 37 Rutherford

(6) **Specific Activity** → Activity per gram of a substance is known as specific activity. The specific activity for 1 gm of radium 226 is 1 curie.

13. Pair production & pair-annihilation

Collision of γ -ray photon by a nucleus & production of electron positron pair is known as pair production.



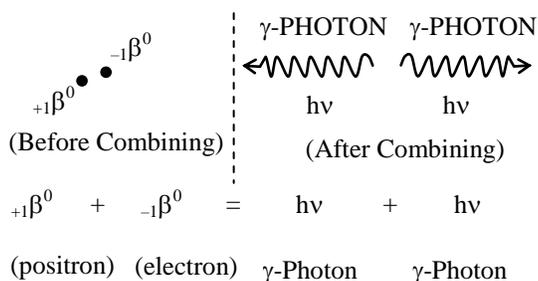
The rest mass of each of the electron & the positron is 9.1×10^{-31} kg. so, the rest mass energy of each of them is

$$E_0 = m_0 c^2 = (9.1 \times 10^{-31}) (3 \times 10^8)^2$$

$$= 8.2 \times 10^{-14} \text{ Joule}$$

$$= 0.51 \text{ MeV}$$

Hence for pair-production, it is essential that the energy of γ -photon must be at least $2 \times 0.51 = 1.02 \text{ MeV}$.



14. Fundamental particles & their Antiparticles

The particles which are not constituted by any other particles i.e., which have no structure, are called 'fundamental particles'

- (1) **Electron** : It is the first fundamental particle which was discovered by Thomson in 1897. It revolves around the nucleus of an atom in different orbits. Electron plays an important role in explaining the physical and chemical properties of substances. Its charge is -1.6×10^{-19} coulomb and mass is 9.1×10^{-31} kg. Its symbol is e^- (or $-1\beta^0$).
- (2) **Proton** : It was discovered by Rutherford in 1919 in artificial nuclear disintegration. It has a positive charge ($+1.6 \times 10^{-19}$ coulomb) equal to the electronic charge and its mass is $(1.673 \times 10^{-27} \text{ kg})$ 1836 times the electronic mass. In free state, the proton is a stable particle. Its symbol is p^+ . It is also written as ${}_1H^1$.
- (3) **Neutron** : It was discovered by Chadwick in 1932. It carries no charge. Its mass is 1839 times the electronic mass (1.675×10^{-27} kg). In free state the neutron is unstable (its mean life is about 17 minutes), but it constitutes a stable nucleus along with proton. Its symbol is n or ${}_0n^1$.
- (4) **Positron** : It was also discovered in 1932 by Anderson. Its charge and mass are same as those of electron, the only difference being that it is positively-charged whereas the electron is negatively-charged. Its symbol is e^+ (or $+1\beta^0$).
- (5) **Antiproton** : It was discovered in 1955. Its charge and mass are same as those of proton, the only difference being that it is negatively charged. Its symbol is p^- .

(6) **Antineutron** : It was discovered in 1956. It has no charge and its mass is equal to the mass of neutron. The only difference between neutron and antineutron is that if they spin in the same direction, their magnetic moment will be in opposite directions. The symbol for antineutron is \bar{n} .

(7) **Neutrino and Anti-neutrino** : The existence of these particles was predicted in 1930 by Pauli while explaining the emission of β -particles from radio-active nuclei, but they were observed experimentally in 1956. Their rest-mass and charge are both zero but they have energy and momentum. Both neutrino and anti-neutrino are stable particles. The only difference between them is that their spins are in opposite directions. Their symbols are ν and $\bar{\nu}$ respectively.

(8) **Pi-mesons** : The existence of these particles was predicted by Yukawa in 1935 as originator of exchange-forces between the nucleons, but they were actually discovered in 1947 in cosmic rays. Pi-mesons are of three types.

(i) **Positive pi-meson** : It is a positively charged particle whose charge is equal to the electronic charge and whose mass is 274 times the electronic mass. It is an unstable particle. Its mean life is of the order of 10^{-8} second. Its symbol is π^+ .

(ii) **Negative pi-meson** : It is a negatively charged particle whose charge is equal to the electronic charge and whose mass is 274 times the electronic mass. Its mean life is also of the order of 10^{-8} second. Its symbol is π^- .

(iii) **Neutral pi-meson** : This particle has no charge. Its mass is nearly 274 times the electronic mass. Its mean life is of the order of 10^{-15} second. Its symbol is π^0 . On disintegration, it forms two γ -photons: $\pi^0 \rightarrow \gamma + \gamma$.

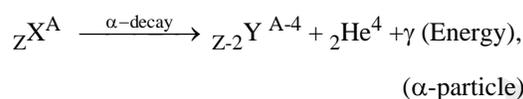
(9) **Photon** : These are the bundles of electromagnetic energy and travel with the speed of light. If the frequency of waves be ν , then the energy of a photon is $h\nu$ and momentum is $h\nu/c$. Its symbol is γ .

Name of particle	Symbol	Antiparticle	Mass (in comparison to mass of electron)	Average life (in second)
Photon	γ	(γ)	0	Stable
Electron	e^{-1}	e^{+1}	1	Stable
Proton	p^{+}	p^{-}	1836	Stable
Neutron	n	n^{-}	1839	1010
Neutrino Charged	ν	ν^{-}	0	Stable
pi-meson Uncharged	π^{+}	π^{-}	274	2.6×10^{-8}
pi-meson	π^{0}	(π^{0})	264	0.9×10^{-16}

15. Characteristics of radioactive radiations

6.1 Characteristics of α - decay

- (1) α - particle are two times ionised Helium atoms.
- (2) α - particle carry 2- proton and 2 neutrons.
- (3) ${}^2\text{He}^4$ (Nucleus) = α -particle
- (4) In general α - decay is given by



atomic number decreases by 2 & mass no. decreases by 4.

- (5) Mass of α - particle = $(2p + 2n)$
 $= 6.68 \times 10^{-27}$ kg
 Charge of α - particle = $+ 2e$
 $= 2 \times 1.6 \times 10^{-19}$ coulomb, (+) Ve.
- (6) In α - particle emission an element goes two column backward in periodic table.
- (7) Energy in α - particle emission
 $= (M_x - M_y - M_{{}_2\text{He}^4}) C^2$
 Energy in α - particle emission varies from 4.5 MeV to 11 MeV. Through calculation α - Particle has to crop potential barrier of 21 MeV for their emission. Hence α -particle emission can not be explained on the basis of classical theory.
- (8) Emission of α -particle can be explained on the basis of quantum mechanics (Tunnel effect).
- (9) Energy spectrum of α - particle is line spectrum.
- (10) Energy spectrum of α -particle also has micro details

- (11) Energy spectrum of α -particle shows that a nucleus also has energy levels like atoms have.
- (12) Energy of α -particle emitted from a single nucleus are not same. These emit in various energy groups.
- (13) Range of α - particle \propto (velocity)³
 $R \propto v^3$
- (14) When α -particle emission takes place, γ -rays are also emitted.
- (15) $R \propto E^{3/2}$ or $R = 0.318 E^{3/2}$
 E : Energy of α - particle
- (16) (Geiger's and Nuttal law) : \rightarrow
 Relation between decay constant of a element and range of α -particle as follows:-

$$\log \lambda = A + B \log R$$

A and B are constant. B has equal value while A have different values for radioactive series.

6.2 Characteristics of β - decay

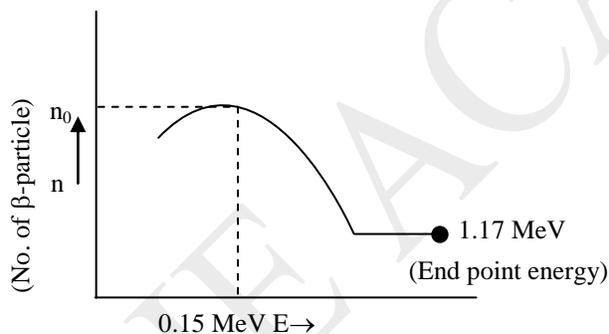
- (1) β -particle are high energy electron or positron.
 (a) β^{-} or ${}_{-1}e^0$ (electron)
 (b) β^{+} or ${}_{+1}e^0$ (Positron)
- (2) Resultant charge on β -particle
 $= \pm 1.6 \times 10^{-19}$ coulomb
- (3) Rest mass of β -particle are equal to mass of electron.
- (4) β -particle emission can be represented by following reactions:-

$${}_Z\text{X}^A \xrightarrow{\beta^{-}\text{-particle}} {}_{Z+1}\text{Y}^A + {}_{-1}e^0 + Q$$

$${}_Z\text{X}^A \xrightarrow{\beta^{+}\text{-particle}} {}_{Z-1}\text{Y}^A + {}_{+1}e^0 + Q$$
 where Q = Energy
- (5) In β^{-} particle , atomic no. increase by one and in β^{+} emission, atomic no. decreases by one.
- (6) Mass number does not changes in β -emission.
- (7) Emission of β particle can be explained by conversion of neutron in proton & vice versa in the nucleus.

$${}_1p^1 \rightarrow {}_0n^1 + {}_1e^0 (\beta^{+})$$
 or
$${}_0n^1 \rightarrow {}_1p^1 + {}_{-1}e^0 (\beta^{-})$$

- (8) To explain energy conservation, linear momentum conservation and angular momentum conservation, a hypothetical neutrino was considered
- (9) Neutrino was first given Pauli.
- (10) According to neutrino hypothesis, some particle also emits with β -emission, which is called neutrino.
- (11) Rest mass and charge of neutrino are both zero and angular or spin momentum of neutrino is $\pm \frac{1}{2} (\hbar / 2\pi)$. It travel with speed of light and it's spin value is $\pm \frac{1}{2}$.
- (12) So by neutrino hypothesis , emission of β particle reaction
- $${}_0n^1 \rightarrow {}_1p^1 + {}_{-1}e^0 + (\text{Anti-Neutrino})$$
- $${}_1p^1 \rightarrow {}_0n^1 + {}_1e^0 + \nu (\text{Neutrino})$$
- Hence reaction ${}_Z X^A \rightarrow {}_{Z-1} Y^A + {}_{+1}e^0 + \nu + Q$
- $${}_Z X^A \rightarrow {}_{Z+1} Y^A + {}_{-1}e^0 + \nu + Q$$
- (13) Existence of neutrino is practically explained by Rein's Collin.
- (14) Energy spectrum of β -emission is continuous.



6.3 Characteristic of β spectrum

- (1) Energy range of emitted β - particle has all possible energy's β -particle.
- (2) Maximum value of energy of β -particle is called end point energy.
- (3) During β -emission the decreases in energy of parent nucleus is equal to end point energy of β -particle, latter it is shared by β -particle and neutrino.

6.4 Characteristics of γ - rays:-

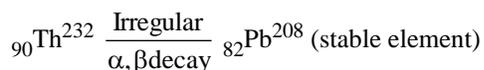
- (1) γ - rays are electromagnetic waves of short wavelength ($\cong 10^{-12}m$)
- (2) They emit from nucleus.
- (3) They travel with speed of light (3×10^8 m/sec)
- (4) These are high energy rays (of photons)
- (5) When α or β particle emission takes place, nucleus come in excited state and during coming back to normal state γ radiation emission takes place
- $${}_{27}Co^{60} \rightarrow {}_{28}Ni^{60}(\text{excited state}) + {}_{-1}e^0$$
- $${}_{28}Ni^{60}(\text{excited state}) \rightarrow {}_{28}Ni^{60} (\text{ground state}) + Q (\text{gama rays})$$
- (6) In γ -decay atomic no. and mass no does not changes.
- (7) Energy spectrum of γ -rays is line spectrum.
- (8) This spectrum verifies that same energy levels are found in nucleus as that of in atom outside the nucleus.
- (9) It affects photographic plate.
- (10) It has ionising power.
- (11) It also has penetration power.
- (12) It is not affected by electric & magnetic field.
- (13) Intensity of γ -rays after travelling x- distance is $I = I_0 e^{-\mu x}$ [same as x-rays]
- I_0 -Initial intensity, μ - Absorption coefficient. I- Intensity of γ -rays after x- distance
- (14) γ -rays also shows diffraction by crystal grating like x- rays.

- (15) γ -rays radiations after entering into substance are absorbed in three process depending upon energy
- (A) Photoelectric effect
 (B) Compton effect
 (C) Pair production.

16. Radioactive series

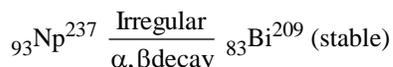
There are mainly four radio active series. Three are natural and one is artificial.

(1) Thorium series (4n series)

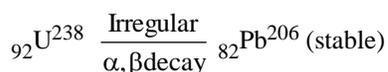


(2) Neptunium series (4n + 1 series)

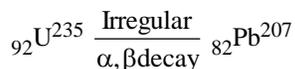
This is artificial series



(3) Uranium series (4n + 2 series) :-



(4) Actinium series (4n+3 series) :-



Last element of radio active series is stable and decay constant of that element has value equal to zero.

17. Radioactive equilibrium

$$N_A \lambda_A = N_B \lambda_B = \dots\dots\dots$$

$$\text{or } \frac{N_A}{T_A} = \frac{N_B}{T_B} = \dots\dots\dots$$

18. Uses of radioactive isotopes

(a) In Medicine -

- (i) For testing blood-Chromium - 51
 (ii) For testing blood circulation - Sodium - 24
 (iii) For detecting brain tumor-Radio mercury-203
 (iv) For detecting fault in thyroid gland-Radio iodine-131

- (v) For cancer - cobalt - 60
 (vi) For blood-Gold-189
 (vii) For skin diseases-Phosphorous-31

(b) In Archaeology -

- (i) For determining age of archaeological sample (Carbon dating) C^{14}
 (ii) For determining age of meteorities- K^{40}
 (iii) For determining age of earth-Lead isotopes

(c) In Agriculture -

- (i) For protecting potato crop from earthworm - CO^{60}
 (ii) For artificial rains-AgI
 (iii) As fertilizers- P^{32}

(d) As tracers - (Tracer) -

Very small quantity of radioisotopes present in a mixture is known as Tracer

- (i) Tracer technique is used for studying biochemical reaction in tracer and animals.

(e) In industries -

- (i) For detecting leakage in oil or water pipe lines.
 (ii) For determining the age of planets