Nuclear And particle Physics.

→ forces Exerted under Nucleus
1.) Electromagnetic force (PP)
2.) Nuclear force (PP, nn, Pn)

→ properties of Nuclear force:
1.) strongest force 2.) Attractive in Nature
3.) short Range force (2fm - 5fm) 4.) charge independent 5.) Non-central 6.) spin-Dependent 6.) Isospin Independent.

→ Scattering of charge particle (electron, Alpha)
↳ charge distribution inside the nucleus.

→ Scattering of Neutral particles:
↳ Mass distribution inside the nucleus.

Visible light: (400-700nm).

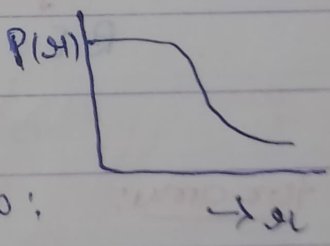
$v = f\lambda \Rightarrow \lambda = \frac{v}{f}$.
↓
speed.

De-Broglie wavelength: $\lambda = \frac{h}{p}$.

$\lambda = \frac{hc}{pc} = \frac{hc}{E}$ } $hc = 1240\,MeV\,fm$

Energy = $\frac{1240\,M.ev.fm}{\lambda}$

Size of Nucleus: $\frac{Mass}{\frac{4}{3}\pi R^3}$ = constant.

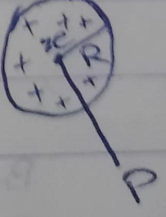


$R = R_0 A^{1/3}$

$R_0 \sim 1.2fm$; A = Mass No:

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

Electric field of Nucleus:



Inside: $r < R = E = \frac{\rho r}{3\epsilon_0} = \frac{KQr}{R^3}$
outside:
↳ $E = \frac{KQ}{r^2}$.

Self-energy of Nucleus:

$$U = \frac{1}{2}\varepsilon_0 \int E^2 \cdot dv$$

$$\Rightarrow \boxed{\frac{3}{5}\frac{kQ^2}{R}}$$

Self energy for Nucleus: $Q = Ze$; $R = R_0 A^{1/3}$

$$U = \frac{3}{5}\frac{kZe^2}{R_0 A^{1/3}}$$

$$\boxed{U \propto \frac{Z^2}{A^{1/3}}}$$

Minimum distance of Approach (Non-Relativistic case).

$$d_{min} = \frac{kqZe}{\frac{1}{2}mv^2}$$

Relativistic case: $\frac{3}{2}\frac{kZe}{R}$ [Minimum K.E of Nucleus].

No. Density: $\simeq 10^{44}$ Nucleon/vol.

Mass Density: 10^{17} kg/m3

$V \propto A$.

Binding Energy:

$$B.E = [Zm_p + (A-Z)m_n - M_N]c^2$$

m_p → Mass of proton; m_n → Mass of Neutron; M_N → Mass of Nucleus.

for amu:

$$[Zm_H + (A-Z)m_n - M(A,Z)_{atom}]c^2$$

$$B.E = \Delta mc^2$$

$$1 \text{ amu} = 931.5 \text{ Mev}/c^2$$

$$B.E = \Delta m\cancel{c^2} \times 931.5 \text{ Mev}/\cancel{c^2}$$

$$B.E = \Delta m \times 931.5 \text{ Mev}$$

Q-Value of Reaction: Energy Exchange during the Nuclear Reaction.

Method I: $Q = \left[\sum M_{Reactant} - \sum M_{Product}\right] c^2$

Method II: $Q = (B.E)_{Product} - (B.E)_{Reactant}$

Method III: $Q = (K.E)_{Product} - (K.E)_{Reactant}$

- If $Q > 0$ - Energy released - Exothermic Reaction.
- If $Q < 0$ - Energy absorbed - Endothermic Reaction.

$K_{threshold}$ | Minimum K.E

$$= -Q\left[1 + \frac{M_{projected}}{m_{Target}}\right]$$

Threshold energy for More than 2-particles:

$$K_{threshold} = -Q\left[\frac{\text{Sum of all Masses}}{2\ \text{Mass of Target}}\right]$$

- Semi-Empirical Mass formula:

$$E = a_v A - a_s A^{2/3} - \frac{a_c Z(Z-1)}{A^{1/3}} - \frac{a_{sym}(A-2Z)^2}{A} \pm \delta$$

$a_v A$ → Vol. energy term; $a_s A^{2/3}$ → Surface energy term; $\frac{a_c Z(Z-1)}{A^{1/3}}$ → Coulombic interaction; $\frac{a_{sym}(A-2Z)^2}{A}$ → Assymetric; $\pm\delta$ → Parity

$\delta =$
- 0 → Even-odd
- $\frac{a_p}{A^{3/4}}$ → Even-Even
- $-\frac{a_p}{A^{3/4}}$ → odd-odd

- $\frac{d(B.E)}{dZ} = 0$ | • $Z = \frac{A}{2 + \left(\frac{a_c}{2a_{sy}}\right)A^{2/3}}$

- $Z = \frac{A/2}{1 + 0.0078 A^{2/3}}$

- Shell Model: Applications.

*) Spin and parity:-

i.) Even-Even case: proton- Even
Neutron- Even

$J^\pi = 0^+$ | parity $= (-1)^l$

ii) Even-odd case: Proton } Even-
Neutron } odd

Step 1: filling of odd Nucleon.
Step 2: last unpaired Nucleon will give spin and parity.

Parity $= (-1)^l$ | filling: $(2J+1)$

$l \rightarrow$ odd $\rightarrow$ -ve sign

$l \rightarrow$ Even $\rightarrow$ +ve sign

iii) odd-odd case: Proton } odd-odd.
Neutron }

Step 1: we will do configuration for both.

Step 2: for proton - $J_p\ l_p$

for Neutron - $J_n\ l_n$

Step 3: If $|J_p + J_n + l_p + l_n|$ = even no

$J = |J_p - J_n|$

If $|J_p + J_n + l_p + l_n|$ = odd no

- Spin $\leftarrow J = |J_p + J_n|$
- parity $\Rightarrow (\pi) = (-1)^{l_p + l_n}$

*) Magnetic Moment: last unpaired Nucleon will decide the Magnetic Moment.

- If $J = l + 1/2$

$\rightarrow$ for proton $\langle \mu_z \rangle = [J + 2.29] \mu_N$

$\rightarrow$ for Neutron $\langle \mu_z \rangle = -1.91\ \mu_N$.

• If $J = l - 1/2$

→ for proton $\langle \mu_z \rangle = \frac{J}{J+1} (J - 1.292) \mu_N$

→ for Neutron $\langle \mu_z \rangle = \frac{J}{J+1} 1.91 \mu_N$

Energy level Diagram;

$n = 1$ 1s

$n = 2$ 2s 2p

$n = 3$ 3s 3p 3d

$n = 4$ 4s 4p 4d 4f

$n = 5$ 5s 5p 5d 5f

$n = 6$ 6s 6p 6d

$n = 7$ 7s 7p

• β - Selection Rule:

$n \rightarrow p + e^- + \bar{\nu}$ → β^- decay

$p \rightarrow n + e^+ + \nu$ → β^+ decay

• l of the outgoing particle will decide the Reaction is allowed or forbidden.

Transition

- $l = 0$ (allowed Reac.)
- $l \neq 0$
  - $l = 1$ → first forbidden
  - $l = 2$ → second forbidden

• If the parity will change, then the reaction will not be an allowed Reaction.

• Rule

- $S = 0$ fermi-rule
- $S = 1$ GT rule.

$J_I^i \rightarrow J_I^f$

Steps: ① $\Delta J = |J_I + J_F|$ to $|J_I - J_F|$

② $\Delta S = 0, 1$

③

$\Delta J = \Delta l + \Delta s$

$\Delta S = |S_1 + S_2|$ to $|S_1 - S_2|$

- "l" could be odd ; if the parity will change.
  ↳ (1).

- γ- Selection Rule : $J_i^{P} \rightarrow J_f + l$

  L will decide :

  $l = 1$ = Dipole
  $l = 2$ = quadrapole
  $l = 3$ = Octapole.

$J_1^{\pi} \rightarrow J_2^{\pi}$

$\Delta L = |J_1 + J_2| \leq L \leq |J_1 - J_2|$.

- parity Rule :

1.) for Electric Multipoles : $\pi_f = \pi_i (-1)^l$

2.) for Magnetic Multipoles : $\pi_f = \pi_i (-1)^{l+1}$

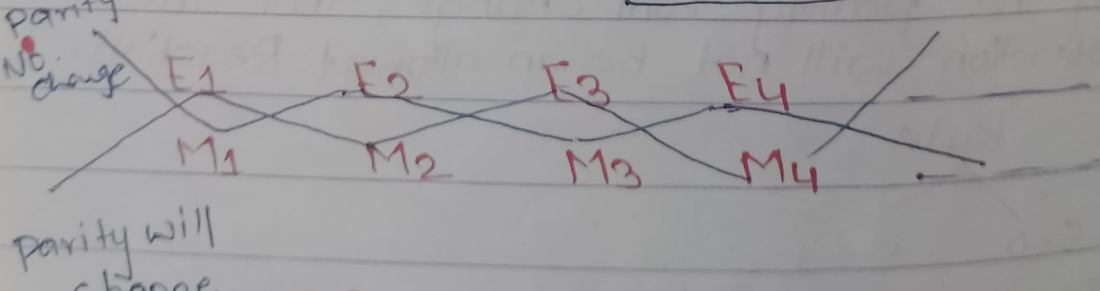
Imp : If the value of L is different ; then :
Smaller value of "L" will dominant first :

$$\frac{\text{Prob}(L+1)}{\text{Prob}(L)} \sim 10^{-5}$$

If the value of l is Same ;

$$\frac{\text{Prob}(EL)}{\text{Prob}(ML)} \sim 10^{2}$$

↳ the value of "Electric L" will dominant



(3) Radioactivity : (α - Decay) :

$$X_{Z}^{A} \rightarrow Y_{Z-2}^{A-4} + He_{2}^{4} + Q$$

K.E of α-particle: $K_\alpha = Q\left(\frac{A-4}{A}\right)$

K.E of daughter Nuclei:

$$K_d = \frac{4Q}{A}.$$

For Heavy Nuclei:
K.E of daughter Nuclei < K.E of α-particle

Based on Interactions:

- (EM, weak inter.) → **Leptons**
  - e, μ^-, τ^-
  - e^-, μ^+, τ^+
  - ν_e, ν_μ, ν_τ
  - $\bar{\nu}_e$, $\bar{\nu}_\mu$, $\bar{\nu}_\tau$
- (EM, strong inter.) → **Hydrons**
  - **Meson** (Pions, kions, eta)
    - (π^+, π^-, π^0) → Triplet
    - (K^0, K^+) → Doublet
    - (η) → Singlet
  - **Baryon**
    - **Nucleon** (n, P)
    - **Hyprons**
      - Sigma Σ → Triplet
      - cascade [O] → Doublet
      - lemda (λ) → Singlet
      - omega (Ω) → Singlet

- All leptons and Baryons are fermions.
- Mesons are Boson.
- lepton family participates in weak and EM interaction only.
- Hydrons family participates in strong and EM interaction only.

Types of interaction:

1.) Strong force
2.) EM interaction
3.) Gravitational
4.) Weak interaction

- Strong interaction: → take place between Hydrons and quarks.
  → Exchange particle - Quarks - Gluons (Rest Mass = 0)
  → Exchange particle - Hydrons - Pions.
  → Strong interaction (↑) : with distance → Quarks, but (↓) ; with distance → Hydrons
  → Str. Int. for hydrons is short-Range.
- Weak interaction:
  → Exchange particle - $W^{\pm}$ & Z-bosons.
  → happens in β-decay
  → $p \rightarrow n + e^- + \nu$ } β-decay.
  → β-decay possible only inside the nucleus.
- EM-interaction:
  → Exchange particle - photon ($m_p = 0$)
  → $\left[F \propto \frac{1}{r^2}\right]$ [Range = ∞]
- Gravitational interaction:
  → Exchange particle - (Graviton) ($m = 0$)
  → [Range = ∞]
  → $F \propto m_1 m_2 \rightarrow \propto \frac{1}{r^2}$ (Attractive in Nature)

Range of interaction:

$$R = \frac{h}{m_0 c} \Rightarrow R \propto \frac{1}{m_0}$$

m_0 ↓ Mass of Exchange Particle.

ON the nuclear Dimension:

Strong force : EM : Weak : Gravitational

1 : 10^{-2} : 10^{-5} : 10^{-40}

- Quantum Numbers: will Explain the Reaction feasibility (will take place or not)

1.) leptonic No:

e^-	e^+	ν_e	$\bar{\nu}_e$	1 for leptons
μ^-	μ^+	ν_μ	$\bar{\nu}_\mu$	-1 for Anti-leptons
τ^-	τ^+	ν_τ	$\bar{\nu}_\tau$	0 Otherwise.

Baryon No: $(n, p) + (\Sigma, [0], \lambda, \Omega)$

$B = \begin{cases} 1 & \text{for Baryon} \\ -1 & \text{for Anti-Baryon} \end{cases}$

- Total leptonic and Baryon no. should be conserved.
- Isospin: only defined for Hydrons particle.
- Just like Angular Momentum in Q.M $|I_1 + I_2|$ to $|I_1 - I_2|$
- Added vectroally.
- Third component (I_3): $-I < I_3 < +I$ (in units of 1)
- Multiplicity of family: $(2I+1)$
- pions (π^+, π^-, π^0) – Triplet family $\to I = 1$.
- Nucleons (n, p) – Doublet family $\to I = 1/2$
- lemda (λ) – singlet family $\to I = 0$.
- I and I_3 combined to Define the state:

$|\pi^+\rangle = |1, 1\rangle$ | $|\pi^-\rangle = |1, -1\rangle$ | $|\pi^0\rangle = |1, 0\rangle$

- kions $(K^+, K^0) \Rightarrow I = 1/2$

$-I < I_3 < I \Rightarrow -1/2, 1/2$

$|K^+\rangle = |1/2, +1/2\rangle$ | $|K^0\rangle = |1/2, -1/2\rangle$

Types of Interaction	I	I_3
Strong	✓	×
EM	✓	×
Weak	×	×

Resonance particle: Excited states of particle.

- Structureless particle – lange factor = 2
- life-time – resonance particle – 10^{-23} sec
- ρ meson $(\rho^- \rho \rho^0)$ – Excited states of pions
- Delta Baryon $(\Delta^{++}, \Delta^+, \Delta^0, \Delta^-)$

Δ^0 – Excited state of Neutron.

Δ^+ – Excited state of proton

- Isospin of Delta Baryons: $2I + 1 = 4$
  $I = 3/2$

$\{3/2, 1/2, -1/2, -3/2\}$

$|\Delta^{++}\rangle = |3/2, 3/2\rangle$ $|\Delta^+\rangle = |3/2, 1/2\rangle$ $|\Delta^0\rangle = |3/2, -1/2\rangle$

$|\Delta^-\rangle = |3/2, -3/2\rangle$

- strange particle: Produce by strong interaction and decay by weak interactions
- -> Hyperons and kions – strange particles
  $[\Sigma, \pi^0, \Omega, [0], K^+, K^0]$

- $Q = I_3 + \frac{B+S}{2}$

- Strangeness: $S \Rightarrow 2(Q - I_3) - B$

Particles	Q	I_3	B	S
1.) K^+	1	1/2	0	1
2.) K^0	0	-1/2	0	1
3.) Σ^+	1	1	1	-1
4.) Σ^-	-1	-1	1	-1
5.) Σ^0	0	0	1	-1
6.) $[0]^-$	-1	-1/2	1	-2
7.) $[0]^0$	0	1/2	1	-2
8.) π^0	0	0	1	-1
9.) Ω^-	-1	0	1	-3

-

Types of Interaction	ΔI	ΔI_3	ΔS
Strong	✓	✓	0 ✓
EM	×	✓	0 ✓
Weak	×	×	$\Delta S = \pm 1$ (×)

-> strangeness is conserved in weak and EM.
-> $\Delta S > 1$ (Reaction is not allowed).
-> In any Reaction, if photon involved the reaction followed by EM interaction.
-> Neutrino involved - weak interaction.

- Charge conjugation: it will change particle to Anti-particle.

$$Q \xrightarrow{\hat{C}} -Q$$

$$|e^-\rangle \xrightarrow{\hat{C}} |e^+\rangle$$

$$|\nu_e\rangle \xrightarrow{\hat{C}} |\bar{\nu}_e\rangle$$

- Parity operation: To reverse the coordinate.

$$A(-x,-y,-z) = \begin{cases} -A(x,y,z) & \text{- Parity odd} \\ A(x,y,z) & \text{- Parity Even} \end{cases}$$

- $P = mv = m\frac{dv}{dt}$ -> Involvement of co-ordinate will change the position, that lead to change in the parity.

- parity is conserved - Strong And EM.
- Parity of fermions = +1
  " " Anti-fermions = -1
- Parity of Baryons = +1
  " " Anti-Baryons = -1

-> weak interaction - Not conserved
-> Strong, EM - conserved.

	C	P	T	CPT
Strong	✓	✓	✓	✓
EM	✓	✓	✓	✓
Weak	×	×	×	✓

- Conservation laws: (Exact)

1.) charge conservation -> Q, L, B
2.) Momentum conservation
3.) Energy "
4.) Angular Momentum "

- Approximate conservation laws: Explains the interactions of the Reactions.

1.) Isospin conservation
2.) Strangness "
3.) I_3
4.) Charge conservation
5.) Parity

- Cherenkov Radiation: Radiation Emitted by the particle moving in a medium faster than speed of light.

$$\left[v \geq \frac{c}{\mu} \right].$$

- Minimum Energy: $E = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{m_0 c^2}{\sqrt{1 - \frac{1}{\mu^2}}}$

μ = R.I of Medium.

- life-time:
  1.) Strong Interaction: 10^{-23} sec
  2.) weak Interaction: $10^{-13} - 10^{-6}$ sec
  3.) EM Interaction: $10^{-20} - 10^{-16}$ sec

$$\{ \tau_W > \tau_{EM} > \tau_{St.} \}$$

- Quark Model:
  -> Theoretical concept
  -> Introduced for hydrons = Baryons + Mesons.

- Total - 6 quarks.

1st generation: up(u), down(d)
2nd " : Strang(s), charm(c)
3rd " : Top(t), Bott (B).

- for charge:

C	U	T	d	S	B
2/3	2/3	2/3	-1/3	-1/3	-1/3

Quark	Q	I	I_3	B	S
u	2/3	1/2	1/2	1/3	0
d	-1/3	1/2	-1/2	1/3	0
s	-1/3	0	0	1/3	-1
c	2/3	0	0	1/3	0
B	-1/3	0	0	1/3	0
T	2/3	0	0	1/3	0

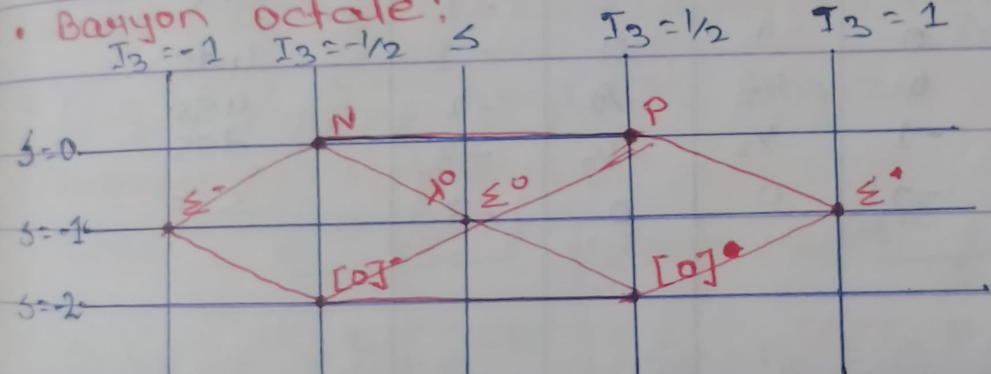
-> Baryons - made off - 3 quark (qqq)
-> Mesons - made off - 2 quark - ($q\bar{q}$), one is quark(q) & other is Anti-quark($\bar{q}$)

- All quarks are fermions
- u, d, s are the light quarks.
- parity of all quarks will be +1
- spin of all quarks = 1/2

- Baryon for 1/2 spin:

Particles	Q	I	I_3	S	B	Combination
p	1	1/2	1/2	0	1	uud
n	0	1/2	-1/2	0	1	udd
Σ^+	1	1	1	-1	1	uus
Σ^-	-1	1	-1	-1	1	dds
Σ^0	0	1	0	-1	1	uds
Ξ^0	0	1/2	1/2	-2	1	uss
Ξ^-	-1	1/2	-1/2	-2	1	dss
Λ^0	0	0	0	-1	1	uds

- Baryon octale:



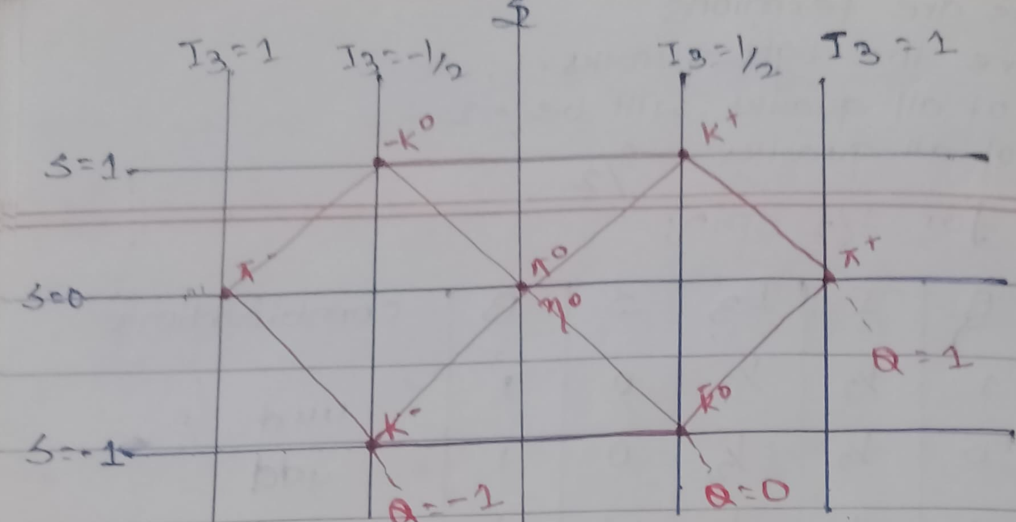
Meson ($q\bar q$) : Spin of Meson = $\frac{1}{2} \oplus \frac{1}{2} \Rightarrow 0, 1$

Parity $1 \times (-1) = -1$

$J^P = 0^-$ and 1^-.

→ Meson with spin 0^-

Particle	Q	I	I_3	S	Quark Structure.
π^+	1	1	1	0	$u\bar d$ $(2/3 + 1/3) = 1$
π^-	-1	1	-1	0	$\bar u d$
π^0	0	1	0	0	$u\bar u$ or $d\bar d$
K^+	1	1/2	1/2	1	$u\bar s$
K^0	0	1/2	-1/2	1	$d\bar s$
K^-	-1	1/2	-1/2	-1	$\bar u s$
$\bar K^0$	0	1/2	1/2	-1	$\bar d s$
η^0	0	0	0	0	$u\bar u$ or $d\bar d$



Baryon with spin $J^P = 3/2^+$

Particle	Q	I	I_3	S	Quark structure
Δ^{++}	2	3/2	3/2	0	uuu
Δ^{+}	1	3/2	1/2	0	uud
Δ^{0}	0	3/2	-1/2	0	udd
Δ^{-}	-1	3/2	-3/2	0	ddd
Σ^{+*}	1	1	1	-1	uus
Σ^{-*}	-1	1	-1	-1	dds
Σ^{0*}	0	1	0	-1	uds
Ξ^{0*}	0	1/2	1/2	-2	uss
Ξ^{-*}	-1	1/2	-1/2	-2	dss
Ω^{-}	-1	0	0	-3	sss