Free Study Material from

All Lab Experiments

Nuclear & Particle Physics Notes for NET/GATE Physical Sciences

Particle Physics

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Books on Particle Physics and Nuclear Physics:

18.7.2015

1. Particle physics – Griffith.
2. Particle Physics – M.P. Khanna.
3. Nuclear and particle physics – Jobes and Buschum.
4. Nuclear and particle physics – Krane.
5. Nuclear and particle physics – D.C. Tayal.
6. Nuclear and particle physics – S.N. Ghoshal.

⇒ Topics of Nuclear Physics: –

1. Basic nuclear properties.
2. nuclear models (a) Liquid drop model.
   (b) Shell model.
   (c) Collective model.
3. nuclear ~~&~~ reactions (a) Conservation Laws.
   (b) Reaction mechanisms.
   (c) Reaction cross section etc.
4. Nuclear Decay (a) α decay.
   (b) β decay.
   (c) γ decay.
5. Nuclear forces (a) Deutron problem.
   (b) nucleon-nucleon scattering.
6. Nuclear Detectors.

⇒ Topics of Particle Physics (High energy physics): –

1. classification of elementary particles.
2. Basic Parameters of elementary particles.
3. conservation laws (a) Exact
   (b) Approximate.
4. Symmetry classification.
5. Quark model for Hadrons:
6. Unification of interactions.
7. Standard model.

.. 1 fermi = 10^{-15} m :

• Proton + Neutron = hadrons and they made Quarks.

Particle Physics.

⇒ four fundamental Interactions of Nature :-

Interactions.

1. Gravitational. } ⇒ Long range interaction
2. Electromagnetic Interaction (EM) } ⇒ both follow

$F \propto \frac{1}{r^2}$. As $r \to \infty$, $F \to 0$.

3. weak interaction } short range interaction.
4. Strong interaction }

⇒ Gravitational Interaction :- 1. attractive nature.

2. Independent of medium, velocity and orientation.

* Nuclear force depand on the direction of spin orientation and line joining vector.

3. Mediating particle is Graviton (not predicted till now).

* Predicted properties of Graviton, $S = 2$

$v = c$

$m = 0$.

* $\text{Range (R)} \propto \frac{1}{\text{mass of exchange particle}}$.

4. It is a weakest force of nature.

5. $F_G \approx 10^{-40} F_{EM}$.

2. EM Interaction :- 1. Attractive as well as Repulsive.

2. Independent of orientation but dependent on medium.

3. mediating particle (exchange particle) is photon.

- strange particles (K^+, Σ^+, Ω) are produced by high interaction but decay by weak interaction.
  - Gev (Gega electron volt)

predicted property of Photon → $S = 1$
$m = 0$
$v = c$

4. the strength of interaction is measured by fine structure constant.

$$\alpha = \frac{e^2}{\hbar c} \simeq \frac{1}{137} \quad (\text{C.G.S. e.s.u. system}).$$

* Life time of interaction $\propto \frac{1}{\text{strength}}$.

* if the range of lifetime or decay time is $10^{-16} - 10^{-20}$ sec then the decay of Electromagnetic interaction.

5. the lifetime of interaction or characteristic time of interaction.

$$\boxed{\tau_{EM} = 10^{-16} - 10^{-20} \text{ sec.}}$$

6. it depends on velocity.

3. Weak Interaction:- 1. this interaction plays important role in particle decays.
2. Range $R \simeq 10^{-17} - 10^{-18}$ m (short range).
3. Exchange particles are Intermediate Vector Bosons. [$W^{\pm}$, Z^0 (three particles)].
4. $R \propto \frac{1}{\text{mass}}$ so, $m_{W^{\pm}} \simeq$ Gev,
$m_{Z^0} \simeq$ Gev.
$S = 1$
$v \neq c$.

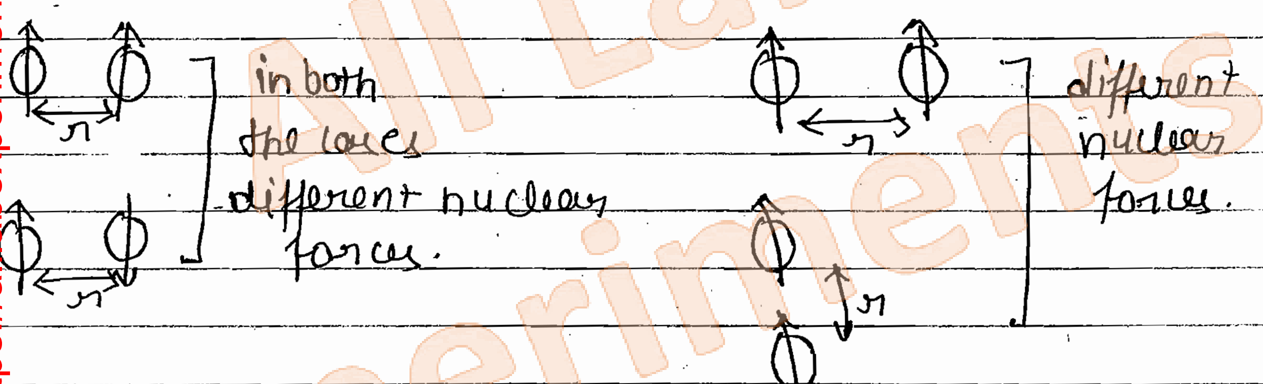
5. the strength of interaction is measured by $\frac{g_w^2}{\hbar c}$ (CGS esu system) g_w - weak interaction constant.

• // Central forces are oriented independent like EM forces.

6. life time of interaction. $\tau_W \simeq 10^{-10}$ sec.

4. <u>Strong interaction</u>:- 1. Short range. $R \simeq 10^{-15}$ m
(10^{-15}m - nuclear diameter)

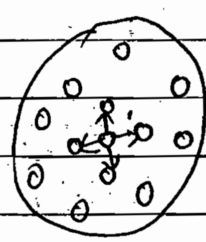
2. Strongest force of nature.
3. Independent of change.
4. Spin dependent, orientation dependent (b/c it is not a central force).
5. Saturated force.
6. Exchange nature.
7. Velocity dependent (high energy scattering data).



8. Exchange particles are mesons (pions)
$\pi^{\pm}, \pi^{0}$.

9. as range is finite so mass also finite,
$m_{\pi^{\pm}} \simeq 140$ MeV.
$m_{\pi^{0}} \simeq 135$ MeV.

• <u>Saturated force</u>.



• life time of interaction $\propto \frac{1}{\text{strength of interaction}}$

10. life time of interaction $\tau_s \approx 10^{-23}$ sec (nuclear life time).

* nuclear life time $(\tau) = \frac{\text{nuclear diameter}}{c} \approx \frac{2R}{c}$.

if $R \approx 1.5$ fm
$\tau \approx 10^{-23}$ sec.

{nuclear life time – time taken by a photon to traverse the nuclear diameter}.

Summary :–

Interaction	Range (m)	Exchange particle	mass of exchange particle	Relative strength	Characteristic time (sec)
Gravitational	∞	Graviton	0	$\approx 10^{-40}$	10^{+16}
Electromagnetic	∞	photon	0	$\approx 10^{-3}$	$10^{-16}-10^{-21}$
Weak	$10^{-14}-10^{-18}$	intermediate vector Boson $(W^{\pm}, Z^{0})$	$m_{W^{\pm}} \approx 82$ Gev, $m_{Z^0} \approx 92$ Gev	$\approx 10^{-13}$	10^{-10}
Strong	10^{-15}	Pions $(\pi^{\pm,0})$	$m_{\pi^{\pm}} \approx 140$ mev, $m_{\pi^0} \approx 135$ mev	1	10^{-2}

• Elementary particles – internal ~~less~~ structureless particles. particles which have no internal structure are termed as elementary particles.

⇒ Basic Parameters of Elementary Particles :–

1. Mass – mass of elementary particle will be written in energy unit.

$K^{+,0} \rightarrow$ kayons
$\Downarrow$
K^+, K^0

$\Xi^{-,0} \rightarrow$ cascade or Xi
$\Rightarrow \Xi^-, \Xi^0$

Particle	mass (MeV)	Particle	Mass (MeV)
e^-	0.511	π^0	134.5
p	938.3	K^+	493
n	939.6	K^0	497
$\pi^\pm$	139.5	η^0	549

2. Charge :- they have either +ve or -ve or zero ~~spin~~ charge.

3. Spin:-

Particles	Spin
• e^-, p, n	$\frac{1}{2}$
• $\Sigma^{\pm,0}, \Xi^{-,0}, \Lambda^0$, ~~$\Omega$~~	$\frac{1}{2}$
• Ω^- (omega)	$\frac{3}{2}$
• $\pi^{\pm,0}, K^{+,0}, \eta^0$	0
• γ photon	1.

• Behaviour of particles and antiparticles are same.

→ Boson $\Rightarrow s = 0, 1, 2 \ldots\ldots$
fermions $\Rightarrow s = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \ldots\ldots$

if $s=0 \rightarrow$ scalar or pseudoscalar.
if $s=1 \rightarrow$ vector or pseudovector.

4. Parity:- Parity ~~is~~ operation is such that
$P: \vec{r} \rightarrow -\vec{r}$
P - Parity operator.
~~then~~ & $\Psi(\vec{r}, t)$ - wavefunction of quantum system.

• nuclear force does not depend on ...

• 1 amu = 931 MeV.

$1 \text{ MeV} = \frac{1}{931}$ amu.

• Parity is conserved in strong and electromagnetic interaction only not in weak interaction.

then, $P\psi(\vec{r},t) = \psi(-\vec{r},t) = \pm\psi(\vec{r},t)$.

$P\psi(\vec{r},t) = \pm\psi(\vec{r},t)$.

$P^2\psi(\vec{r},t) = P[P\psi(\vec{r},t)] = \psi(\vec{r},t)$.

• P^2 has eigen value = 1.

$\Rightarrow P = \pm 1 \rightarrow P$ has eigen values +1 and −1.

P = +1 even parity.

= −1 odd parity.

⇒ Physical significance of parity :— it represents the mirror reflection of the system.

P = +1 ⇒ mirror symmetry exists.

P = −1 ⇒ mirror symmetry does not exist.

$\boxed{\text{total parity} = \text{orbital parity} \times \text{intrinsic parity.}}$

$\boxed{\text{Orbital parity} = (-1)^l}$

where, l = orbital quantum no.

if a particle in s-state → $l = 0$.

p-state → $l = 1$.

d-state → $l = 2$.

f-state → $l = 3$.

and so on....

Intrinsic parity :—

Particles	Intrinsic Parity.
• e^-, p, n	+1.
• $\Sigma^{\pm,0}$, $\Xi^{-,0}$, Λ^0, Ω^-	+1
• $\pi^{\pm,0}$, $K^{+,0}$, η^0	−1.

~~Pseudo~~ ~~leptons~~ ~~mesons~~

pseudo scalars mesons →

∴ e^-, p, ν(neutrino) and γ photon are stable particles and others are unstable.

for Intrinsic particles

• If

$$S = 0 \begin{cases} \rightarrow P = +1 \rightarrow \text{scalar} \\ \rightarrow P = -1 \rightarrow \text{Pseudoscalar} \end{cases}$$

$$S = 1 \begin{cases} \rightarrow P = -1 \rightarrow \text{vector pseudo scalary} \\ \rightarrow P = +1 \rightarrow \text{Pseudovector} \end{cases}$$

* Parity is a multiplicative physical quantity.
* Parity of Bosons and antibosons ~~are~~ is same while parity of fermions and antifermions are opposite.

• $P(K^+) = -1$] Bosons
$P(K^-) = -1$] same parity

Bosons — $S = 0, 1, 2, \ldots$

fermions — $S = 1/2, 3/2, 5/2$

• $P(K^0) = -1$] Bosons
$P(\bar{K}^0) = -1$] same parity

$S = 0 \rightarrow$ scalar or pseudoscalar

$S = 1 \rightarrow$ vector or pseudovector

• $P(e^-) = +1$] fermions
$P(e^+) = -1$] opposite parity

• $P(n) = +1$] fermions
$P(\bar{n}) = -1$] opposite parity.

5. Life time :— only e^-, p, ν(neutrino) and γ photon are stable particles and others are unstable.

Particles	Life time (sec).
neutron (n)	$\simeq$ 1000 (sec) (16.5 min.)
$\pi^\pm$	$\sim 10^{-8}$ sec.
π^0	$\sim 10^{-16}$ sec
μ^-	$\sim 10^{-6}$ sec.

• Strange particles decay by weak interaction. Except π^0 decay by strong interaction (Electromagnetic interaction).
• magnetic moment = due to charge distribution.

⇒ Particles and Antiparticles :— • Except a few particles have their antiparticles.
• Self conjugate particles are those for which particles and antiparticles are same.
⇓
$[\pi^0, \eta^0, \nu, \phi^0, \omega^0$ (self conjugate)$]$

• Particles and ~~antieles~~ anti particles have same mass, spin and life time.
• They may have same parity (in case of Bosons) or opposite parity (in case of fermions).
• they have opposite magnetic moment and helicity.

Helicity —

$$H = \frac{\vec{\sigma}\cdot\vec{p}}{|\vec{\sigma}||\vec{p}|} \qquad \vec{\sigma} = 2\vec{s} - \text{spin}$$
$$\vec{p} - \text{Linear momentum.}$$

$$H = \frac{\vec{S}\cdot\vec{p}}{|\vec{S}||\vec{p}|}$$

for ex:—

neutron and antineutron (n and $\bar{n}$) :—

magnetic moment (μ) of neutron (μ_n) = $-1.91\,\mu_N$
" " " " antineutron ($\mu_{\bar{n}}$) = $+1.91\,\mu_N$ — opp μ

μ - magnetic moment.

$$\mu_N = \frac{e\hbar}{4\pi m_p} \quad \text{nuclear magneton.}$$

• neutron is ~~neo~~ having negative magnetic moment b/c the charge distribution ~~ø~~ is not symmetric.

• the negative magnetic moment of neutron can be explained in following way.

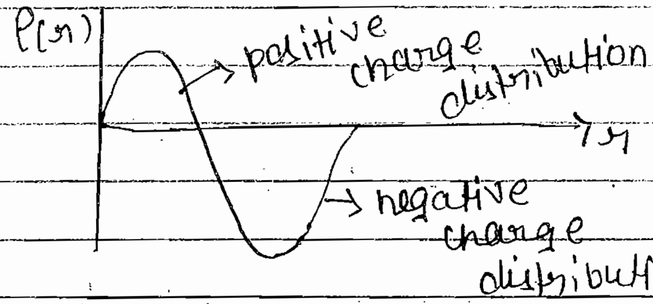
$\frac{2}{3}e \quad \frac{1}{3} - \frac{1}{3}$

$\frac{2}{3}e - \frac{2e}{3} = 0$

$Q_u = \frac{2}{3}e$

$Q_d = -\frac{1}{3}e$

1. the charge distribution of -ve and +ve charge inside the neutron is not symmetrical.



2. this explanation is confirmed by quark model.

$n = udd$

$Q_u = +\frac{2}{3}e$. [neutron is formed by the one upward quark and two downward quark].

$Q_d = -\frac{1}{3}e$.

two d quarks charge distribution and one u quark distribution are not symmetrical. that is why μ_n is -ve.

2. Neutrino and antineutrino (ν and $\bar{\nu}$): — • it is a ~~two~~ true particle. it does not have any internal structure.

for neutrino (ν) → anticlockwise or inward.

$\vec{p}$, $\vec{s}$

$$H = \frac{\vec{s}\cdot\vec{p}}{|\vec{s}|\cdot|\vec{p}|} = -1$$

left handed.

for antineutrino ($\bar{\nu}$) →

Clockwise or outward

$\vec{p}$, $\vec{s}$

$$H = \frac{\vec{s}\cdot\vec{p}}{|\vec{s}|\cdot|\vec{p}|} = +1$$

Righthanded.

• ν and $\bar{\nu}$ have opposite helical.

• Leptons particles – these particles do not feel strong interaction but they feel weak, and electromagnetic interaction.
• Hadrons – these particles feel strong as well as weak and Electromagnetic interactions.

⇒ Classification of Elementary Particles :-

Classification.
1. On the Basis of mass.
2. On the basis of interaction.

Ⓐ on the basis of mass :-
Particles.
1. Light mass particles (0–134 MeV). These are called leptons
2. intermediate mass particles (>134 MeV but < m_p (mass of proton).
3. Heavy mass particles. (≥ m_p – mass of proton.).

Leptons :-

S.No.	Particles	mass(MeV)	Spin	life time.
1.	e^-	0.511	1/2	stable
2.	ν_e	0	1/2	stable
3.	μ^-	105.6	1/2	unstable.
4.	ν_μ	0	1/2	stable.

* But the discovery of τ^- particles distributed this scheme.
Because m_τ = 1784 MeV.

5.	τ^-	1784	1/2	unstable.
6.	ν_τ	0	1/2	stable.

* τ^- should be placed in heavy mass category.

But it has most of the properties similar to other leptons
(e.g. it does not feel strong interaction) :

so a problem is originated. ⇒ choose a new basis which is on the basis of interaction.

1. nucleons p and n
2. Hyperons sigma, Lambda, cascade, Omega

3. On the basis of interaction :-
Particles.

1. Leptons – those particles which do not feel strong interaction. They feel electromagnetic and weak interaction.

2. Hadrons – those particle which feel strong interaction as well as electromagnetic and week interaction.

Leptons.

Three Generations.

- Ist Generation.
  e^-, ν_e
  and their antiparticles
  e^+ and $\bar{\nu}_e$
- IInd Generation.
  μ^-, ν_μ
  and their antiparticles
  μ^+ and $\bar{\nu}_\mu$
- IIIrd Generation
  τ^-, ν_τ
  and their antiparticles
  τ^+ and $\bar{\nu}_e$.

total particles $= 4 \times 3 = 12$.

Hadrons.

- Mesons
  - Pions $\pi^{\pm,0}$ — triplet
  - Kaons $K^{+,0}$ — doublet
  - Eta mesons η^0 — singlet

  pseudo scalar mesons.
- Baryons
  - Nucleons p and n — doublet
  - Hyperons
    - Sigma $\Sigma^{\pm,0}$ — triplet
    - Cascades $\Xi^{-,0}$ — doublet
    - Lambda Λ^0 — singlet
    - Omega Ω^- — singlet

⇒ conservation laws :- two types.

1. Exact (universal) – physical quantity are conserved in all interaction.
   - energy (E)
   - momentum (P)
   - angular momentum (J)
   - charge (Q)
   - lepton no. (L)
   - Baryon no. (B).
   - CPT – {charge & ~~momentum~~ parity and time}.

2. approximate – physical quantities are not conserved in one or more than one interactions.
   - isospin (I)
   - component of isospin (I_3)
   - strangeness (S)
   - Parity (P)
   - charge conjugation (C)
   - time reversal (T)
   - CP (charge, parity).

(A) Exact conservation laws :–

1. Energy (E) :– Let us consider a reaction.

$$A + B \longrightarrow C + D$$

B – target assumed to be at rest.

Energy conservation $E_i = E_f$.

$$E_A + E_B = E_C + E_D$$

$$m_A c^2 + K_A + m_B c^2 = m_C c^2 + K_C + m_D c^2 + K_D$$

K – kinetic energy.

mc^2 – rest energy.

the Kinetic energy provided to the incident particle must be slightly greater than the difference in rest energy of products and reagents so that the linear momentum is simultaneously conserved.

ex:— $p + p \longrightarrow p + p + p + \bar{p}$

Decay Reaction:— $A \to B + C$

A at rest

Energy conservation

$$m_A c^2 = m_B c^2 + K_B + m_C c^2 + K_C$$

$$\Rightarrow m_A c^2 = (m_B + m_C)c^2 + (K_B + K_C)$$

For reaction to occur

$$m_A c^2 \geq (m_B + m_C)c^2$$

$$\Rightarrow m_A \geq (m_B + m_C)$$

- a heavy weight particle can decay into two light particles but light particles can't decay into heavy particles.

- $p \to n + e^-$ this reaction is not possible in free state. it is possible in nuclear field.

Example:— 1. Decay of neutron.

$$n \to p + e^-$$

n: 939.6 mev, p: 938.3, e^-: 0.511

938.811 Mev.

$\Rightarrow m_n > (m_p + m_e)$.

- Reaction is allowed (the difference is rest energy will appear as k.E. of p and e^-):

p: proton.

• $e^- + e^+ = \gamma$ this reaction is called pair annihilation

e^+ – positron · n – neutron ·

2Ex:– $p \rightarrow n + e^+$

938.3 ↓ 939.6, ↓ 0.511 → 940.11117eV.

$\Rightarrow m_p < (m_n + m_e)$

$\Rightarrow$ Reaction is not allowed in free state. However reaction may occur in the nuclear field where it gets initial momentum in nuclear vicinity and decays into n and e^+.

(2) Linear momentum ($\vec{p}$):– $\vec{P_i} = \vec{P_f}$ we can image ~~reactant~~ or product and keep it at rest, product should be two.

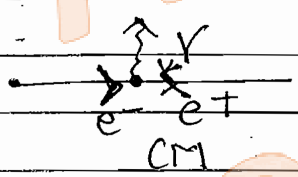
Reaction

$A + B \rightarrow C + D$

$\vec{P_A} + \vec{P_B} = \vec{P_C} + \vec{P_D}$

Ex:–

$e^- + e^+ \longrightarrow \gamma$



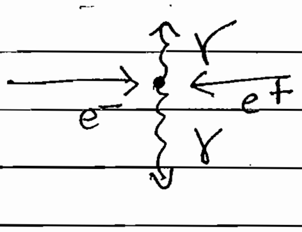
In CM (centre of mass) frame $P_i = 0$

$P_f = \frac{h\nu}{c}$ $\Rightarrow P_i \neq P_f$

Reaction is not possible.

But

$e^- + e^+ \longrightarrow 2\gamma$



$\vec{P_i} = 0$

$\vec{P_f} = 0$

$\Rightarrow \vec{P_i} = \vec{P_f}$ $\Rightarrow$ reaction is allowed.

3. Angular momentum ($\vec{J}$) :- $\vec{J_i} = \vec{J_f}$

Ex:- Conserve according to spin

$n \rightarrow p + e^-$

$\frac{1}{2} \quad \frac{1}{2}\uparrow \; \frac{1}{2}\uparrow \Rightarrow J = 1$

$\frac{1}{2}\downarrow \; \frac{1}{2}\uparrow \Rightarrow J = 0$

$\Rightarrow \vec{J_i} \neq \vec{J_f}$

But

$n \rightarrow p + e^- + \bar{\nu}_e$

$\frac{1}{2} \quad \frac{1}{2}\uparrow \; \frac{1}{2}\uparrow \; \frac{1}{2}\uparrow \Rightarrow J = \frac{3}{2}$ not allowed

$\frac{1}{2}\uparrow \; \frac{1}{2}\uparrow \; \frac{1}{2}\downarrow \Rightarrow J = \frac{1}{2}$ allowed

$\frac{1}{2}\uparrow \; \frac{1}{2}\downarrow \; \frac{1}{2}\uparrow \Rightarrow J = \frac{1}{2}$. allowed

this means angular momentum is conserved.

Ex:- $\pi^0 \rightarrow \gamma + \gamma$

$0 \quad 1 \quad 1$ if they will coupled they will give 0, 1.

$0, 1$

$\therefore \vec{J_i} = \vec{J_f}$

$\Rightarrow$ reaction is allowed.

2.8.2015

(4) Charge (Q) :- $Q_i = Q_f$ see its charge.

Ex :- stability electron.

e^- ~~mag~~ mass 0.511 MeV. the mass is small

⇒ suppose e^- is not stable then it will decay in two lighter mass particle which are ?

⇒ $\nu_e, \nu_\mu, \nu_e, \gamma$, possible modes of decay will be

$e^- \rightarrow \nu\gamma$

$e^- \rightarrow \nu_e + \bar{\nu}$

etc.

• In all above possibel reaction, e^- found no particles to which can transfer its charge [However E and P conserved].

⇓

charge not conserved.

⇓

e^- will not decay.

⇓

e^- will be stable.

5. Lepton No. conservation :- Lepton no. is assigned to Lepton.

L = +1 for all Leptons.

L = -1 for antileptons.

= 0 for others.

⇒ seperate lepton no. have been defined for three generation of lepton.

⇒ for e & ν_e = +1 for e^- or ν_e

= -1 for e^+ or $\bar{\nu_e}$

= 0 for others.

⇒ for μ & ν_μ = +1 for μ^- or ν_μ

= -1 for μ^+ or $\bar{\nu_\mu}$

= 0 for others.

⇒ for τ lepton = +1 for τ or ν_τ

= -1 for τ^+ or $\bar{\nu_\tau}$

= 0 others.

Stable particles — e, ν, p, ...

Baryons — p, n, $\Sigma^+, \Sigma^0, \Sigma^-$ = +1
$\bar{\Sigma}^-, \bar{\Sigma}^0, \bar{\Sigma}^+$ = −1.

ν_e, ν_μ, ν_τ should be separately conserved in all reaction.

eg:- 1. $n \rightarrow p + e^- + \nu_e$

angular momentum ~~$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$~~ $0 \rightarrow 0 + 1 + 1$

$\Delta L_e = 2 \neq 0$.

⇒ lepton no. is not conserve, so reaction is not allowed.

but $n \rightarrow p + e^- + \bar{\nu}_e$

L_e:- 0 · 0 + 1 − 1 $\Delta L_e = 0$.

Reaction is ~~not~~ allowed by lepton no. conservation.

Ex:- $\pi^+ \rightarrow \mu^+ + \nu_\mu$

L_e: 0 −1 +1 $\boxed{\Delta L_e = 0}$

so reaction is allowed by lepton no. conservation.

⇒ Baryon no. conservation (B):-

B = +1 for all Baryon ($p, n, \Sigma^+, \Sigma^0, \Sigma^-$)
= −1 for all antiBaryon ($\bar{\Sigma}^-, \bar{\Sigma}^0, \bar{\Sigma}^+$)
= 0 for others.

Ex:- $\Sigma^0 \rightarrow \pi^0 + \gamma$

B_e: +1 → 0 0 $\Delta B \neq 0$

not conserve

But the reaction

$\Sigma^0 \rightarrow \bar{\pi}^0 + \gamma$ ✗.

B_e: 1 −1 0 $\Delta B = 0$.

⇒ B is conserved.

Q. Why proton is stable. Explain on the basis of Baryon no. conservation?

Sol^n:- Suppose proton is not stable then it will decay into lighter mass particles.

- nucleon forces are not depend on charge.
- nucleon forces depends on the spin orientation and line joining them.

[$p \to \pi^{\pm,0}, K^{+,0}, \eta^0, e^-, \mu^-, \nu_e, \nu_\mu, \bar{\nu}_e, \gamma$]

the possible combination of will be of the form

$$p \to \pi^+ + \gamma$$
$$\to \gamma + \gamma$$
$$\to K^+ + \nu_e + \nu_e^- + \gamma$$
$$\to K^+ + \gamma \text{ etc.}$$

but in all possible reaction proton will find no particle to which it would transfer its Baryonic charge

$\Downarrow$ means

Baryon no's will not be conserved

$\Downarrow$

proton will not decay

$\Downarrow$

proton will remain stable.

⇒ Approximate Conservation Laws: — Physical Quantities may not be conserve in one or more than one interactions.

1. Isospin → (I) or (T): — the concepts of isospin originated with a very important property of nuclear forces i.e. charge independence nature.

⇒ Particles exist in multiplets in nature viz

singlet	doublet	triplet	Quartet etc.
$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$
η^0, $\cancel{\Lambda^0}$	p and n	π^+, π^0, π^-	$\Delta^{++}, \Delta^+, \Delta^0, \Delta^-$
	Ξ^0 and Ξ^-	$\Sigma^+, \Sigma^0, \Sigma^-$	
	K^+ or K^0		

- the members of a multiplet family have nearly same mass and same spin but they have different charges.

$M = 2J + 1$

- since nuclear forces are charge independent so if members of a multiplets family are put in nuclear field then it will not be possible to distinguish them. they appear as a single entity

$\Downarrow$

Something is common among all.

$\Downarrow$

Common Quantum no. is isospin, Quantum no. as Isospin.

Multiplicity, $\boxed{M = 2I + 1}$

for singlet, $M = 1 \Rightarrow \boxed{I = 0}$ $\quad \Lambda^0, \Lambda^0 \to$ Lambda

Doublets, $M = 2 \Rightarrow 2I + 1 = 2$
$\Rightarrow \boxed{I = 1/2}$ $\quad$ p and n, K^+, K^0, Ξ^-, Ξ^0

triplets, $M = 3 \Rightarrow 2I + 1 = 3$
$\boxed{I = 1}$ $\quad \Sigma^{\pm, 0}, \pi^{\pm, 0}$
Pions

- Isospin is represent in an abstract space and Isospace.
Components $I_3 \longleftrightarrow$

- different charges states of multiplets family are represented by I_3.

$I_3 \to -I, -I+1, -I+2, \ldots, +I$

Singlets:- $I = 0$, $I_3 = 0$

Doublets:- $I = 1/2$, $I_3 = -1/2, +1/2$

n	p
K^0	K^+
Ξ	Ξ^0
Ξ	Ξ

$M = 2I+1$
$4 = 2I$
$3/2 = I$

• Parity is conserved in strong and electromagnetic interaction but not only in weak interaction

Triplets $I=1$ $I_3 = -1, 0, +1$

$\pi^- \quad \pi^0 \quad \pi^+$

$\Sigma^- \quad \Sigma^0 \quad \Sigma^+$

Quartet $I = 3/2$ $I_3 = -3/2, -1/2, +1/2, +3/2$

$\Delta^- \quad \Delta^0 \quad \Delta^+ \quad \Delta^{++}$

• I is added according to vector addition laws (same as angular momentum addition).

• I_3 is added algebrically (simply as number).

Conservation of I and I_3: —

Interactions	Conservation of I	Conservation of I_3
Strong	Yes	✓
Weak	No	✗ (NO)
E.M.	No	✓

• Lepton does not feel strong interactions.

⇒ Isospin is not define for Lepton and gamma photon — these do not feel strong interactions.

Ex:— $p + \pi^0 \rightarrow \Sigma^+ + K^0$ [for ΔI atleast one value must be same].

I: $1/2 \quad 1 \quad\quad 1 \quad 1/2$ $\Delta I = 0$

I_3: $1/2 \quad 0 \quad\quad 1 \quad -1/2$ $\Delta I_3 = 0$

$1/2 \quad\quad 1/2$

• If I and I_3 both are conserved, then it would be strong interaction.
• If I will not conserve only I_3 will conserve, it will EM

→ Both I and I_3 are conserved :-
⇓
Strong interaction

Ex:- $\pi^0 \rightarrow \gamma + \gamma$ → Em conservation.

I: 1 0 0 $\Delta I \neq 0$
I_3: 0 0 0 $\Delta I_3 = 0$ → conserve

As here I is not conserve but I_3 → conserve

→ Strangness (S) :- Kaons.
The concept of strangeness is associated with special features of kaons and hyperons $\{\Sigma^{+,0}, \Lambda^0, \Omega^-, \frac{\Xi^{0,-}}{}\}$ $\{K^{+,0}\}$
kaons and hyperons have 2 special properties.
1. Associate production → Kaons and hyperons are never produced singly they are always produced in associate manner.
2. Production by strong interaction but decay via weak interaction except Σ^0 which decay via Em interaction.

$$p + \pi^- \xrightarrow{\text{strong}} \Lambda^0 + K^0$$
$\Lambda^0 \to p + \pi^-$, $K^0 \to \pi^+ + \pi^0$ (Both decay via strong interaction).

in similar reaction there may produce.

$$p + \pi^- \xrightarrow{\text{strong}} \Sigma^- + K^+$$
weak → $\Sigma^- \to n + \pi^-$, $K^+ \to \pi^0 + \pi^+$

strangeness quantum no. is defined for strange particles only (kaons and hyperons).

∴ $S = 0$ for non strange particle.
$\neq 0$ for strange particle.
↓
1, 2, 3 - - -

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

⇒ Assignment of strangeness :— By Gellmann-Nishijima-formula.

where Q = charge.
I_3 - isospin.
B - Boron no.
S - strangeness.

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

for Kaons :—

$K^+ \Rightarrow Q = +1,\ I_3 = +1/2,\ B = 0.$

$1 = 1/2 + 0 + \frac{S}{2} \Rightarrow 1 - 1/2 \Rightarrow \frac{S}{2}$

$\Rightarrow \frac{1}{\cancel{2}} \times \cancel{2} = S \Rightarrow \boxed{S = 1}$

thus for Kaons → strangeness = +1.
∀ multiplets family, S will be same.

for Hyperons :— Σ^+

$Q = +1,\ I_3 = +1,\ B = 1.$

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

$1 = 1 + \frac{1+S}{2} \Rightarrow 1-1 = \frac{1+S}{2}$

$\Rightarrow \boxed{S = -1}$

similarly for Σ^0 and Σ^- $\Rightarrow \boxed{S = -1}$

cascades :— Ξ^-

$Q = -1,\ I_3 = -1/2,\ B = 1.$

$-1 = -1/2 + \frac{1+S}{2} \Rightarrow -1 + 1/2 = \frac{1+S}{2}$

$\Rightarrow -1/\cancel{2} = 1+S/\cancel{2}$ $\quad \boxed{S = -2}$

⋮

$M = 2I+1$

$I - 1 = 2I$

$\mathcal{S} = 0$

$I_3 = 0$

Lambda

Proof: — Λ^0

$Q = 0,\ I_3 = 0,\ B = 1,\ S = ?$

$\boxed{S = -1}$

$K^{+,0}$ +1

$\Sigma^{\pm,0}$ -1

-2

$\Xi^{-,0}$

-3

Ξ

Ω^{-1}

omega (Ω^-): —

$Q = -1,\ I_3 = 0,\ B = 1,\ S = ?$

$\Rightarrow \boxed{S = -3}$

Summary: —

Particles	Strangeness (S)
$K^{+,0}$	+1
$\Sigma^{\pm,0}$ Λ^0	-1
$\Xi^{-,0}$	-2
Ω^{-1}	-3

• For ~~Strange~~ anti particles of strange particles have opp. strangeness of respective particles.

→ Conservation of Strangeness: —

Interaction	conservation of S.
Strong	✓
E.M.	✓
weak	×

weak ⟶ strangeness changes

strange preserve

1. $\Lambda^0 \longrightarrow p + \pi^-$ $\quad \boxed{|\Delta S| = 1}$ weak interaction

$-1 \qquad 0 \quad 0$

• $|\Delta S| = 0$ for strong and E.M. interaction.
• $= 1$ for weak interaction.
$= 2$ for higher ⇒ not allowed.

2. $K^0 \longrightarrow \pi^+ + \pi^-$ $\boxed{|\Delta S| = 1}$
$+1 \quad 0 \quad 0$

3. $\Sigma^- \longrightarrow n + \pi^-$ $\boxed{|\Delta S| = +1}$
$-1 \quad 0 \quad 0$

4. $K^+ \longrightarrow \pi^+ + \pi^0$ $\boxed{|\Delta S| = 1}$
$+1 \quad 0 \quad 0$

All these reaction proceed via weak interactions.

• $|\Delta S| = 0$ for strong and E.M. interaction.
$= 1$ for weak interaction.
$= 2$ for higher ⇒ not allowed.

weak process :- 1. Strangeness changing $|\Delta S| = 1$.
2. Strangeness preserving $|\Delta S| = 0$.
↓
eg :- $n \rightarrow p + e^- + \bar{\nu}_e$

Strangeness changing $|\Delta S| = 1$.

1. $\Lambda^0 \longrightarrow p + \pi^-$ ⇒ $\Delta S = 1$.
I : $0 \quad 1/2 \quad 1$ $\quad \Delta I = 1/2$ or $3/2$.
I_3 : $0 \quad +1/2 \quad -1$ $\quad \Delta I_3 = 1/2$

2. $K^0 \rightarrow \pi^+ + \pi^-$ $\quad \Delta S = 1$ $\quad$ S: $1 \quad 0 \quad 0$ $\quad |\Delta S| = 1$
I : $1/2 \quad \underbrace{1 \quad 1}_{0,1,2}$ $\quad \Delta I \neq 0$.
$\Delta I = 1/2$ or $3/2$.

I_3 : $1/2 \quad \underbrace{+1 \quad -1}_{0}$ $\quad \Delta I_3 = 1/2$.

⇒ Hypercharge (Y) :- $Y = 2$ [average charge of multiplet family members].

Nuclear family :- $\quad p \quad n$
Q ⇒ $+1 \quad 0$

$Y = 2\left[\frac{0+1}{2}\right] = 1.$

$\boxed{Y=1}$ for p and n.

Pions

	π^+	π^0	π^-
Q	+1	0	-1

$Y = 2\left[\frac{1+0-1}{3}\right] = 0$

$\boxed{Y=0}$ for $\pi^{I,0}$.

Alternative method: —

$Y = 2$ (charge on particle $- I_3$).

$Y = 2[Q - I_3]$ ---(2)

p and n

p:— $Q = +1$ $\quad I_3 = +1/2$

$Y = 2[1 - 1/2] \Rightarrow +1$

$\boxed{Y=+1}$

n:— $Q = 0$, $I_3 = -1/2$

$\Rightarrow \boxed{Y=1}$

⇒ Gellman - Nishinja formula: —

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

from (2), we get.

$\boxed{Y = B+S}$

Conservation of Y: —

interaction	Conservation of Y
Strong	✓
EM	✓
weak	✗

4. Parity (P):- Space parity:- Parity of P is such that

$P: \vec{r} \to -\vec{r}$ in the wave function associated with the system.

$$P\psi(\vec{r},t) = \psi(-\vec{r},t).$$
$$P^2\psi(\vec{r},t) = \psi(\vec{r},t).$$

P^2 has eigen value $= +1$.
Phase eigen values $= \pm 1$.

$P = +1$ even parity, $P = -1$ odd parity.

$\psi(-\vec{r},t) = \psi(\vec{r},t)$ or ~~$-\psi$~~
$- \psi(\vec{r},t)$.

$\boxed{\text{total parity} = \text{orbital parity} \times \text{intrinsic parity.}}$

if Hamiltonian of the system commutes with parity operator then parity remains conserved.
$\boxed{PH - HP = 0} \Rightarrow$ P is conserved.

⇒ Effect of Parity operator on different physical quantities:-

Electric field

$P: \vec{E} = -\vec{E}$ $\qquad \vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q\vec{r}}{|\vec{r}|^3} \qquad P = -1$

$P: \vec{B} = \vec{B}$ $\qquad \vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{l} \times \vec{r}}{|\vec{r}|^3}, \quad P = 1$

Physical Quantity	Invariance of P
$P: \vec{p} \to -\vec{p}$	Variant
$P: \vec{J} \to \vec{J}$	Invariant
$P: \vec{F} = -\vec{F}$	Variant
$P: \vec{E} = -\vec{E}$	Variant
$P: \vec{B} = \vec{B}$	Invariant.

Upto 1956 it was assumed that parity is conserve in weak interaction process but Young's and Lee sugestion (1956) and subsequent experimental verifaction by Wu and others suggested that parity is not conserve always in weak interactions.

Interaction	Conservation of P
Strong	✓
weak	×
EM.	✓

$[n \to p + e^- + \bar{\nu}_e$
$\quad 1 \quad 1 \quad 1 \quad -1]$

1. $P + \pi^0 \longrightarrow \Lambda^0 + K^0$ strong interaction
$P: \ +1 \ -1 \qquad +1 \quad -1$ $\qquad \therefore \Delta P = 0$

$\Downarrow$

Parity conserve.

2. $\pi^0 \rightarrow \gamma + \gamma$ Parity of γ depends on its origin i.e. transmission emission.

3. $n \rightarrow p + e^- + \bar{\nu}_e$
P: 1 1 1 -1 $\Delta P \neq 0$ Parity non conser

5. <u>charge conjugation (or charge parity C):-</u>
charge conjugation operation is such that

$$C: q \rightarrow -q$$

charge conjugation operator.

• In this process not only electronic charge but all other charges i.e. leptonic, Baryonic, hypercharge, strangeness etc are also reversed.

Let us take the reaction.

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

On charge conjugation operation the reaction becomes

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

In the probability of occurance of this reaction is same as before the application of charge conjugation operation then we say that charge conjugation symmetric holds.

Let p be the particle state then

$$C|p\rangle = |\bar{p}\rangle$$

$$C^2|p\rangle = C[|\bar{p}\rangle] = |p\rangle$$

$$\Rightarrow C^2 = 1 \Rightarrow \boxed{C = \pm 1} \Rightarrow \text{char eigen value} = \pm 1$$

$$C|\pi^0\rangle = |\pi^0\rangle$$
$$C|\pi^+\rangle = |\pi^-\rangle$$

Thus we can write $C|p\rangle = \pm 1|p\rangle$

all particles states are not state vectors of charge conjugation operators only.

Only particles which have all charge zero (i.e. $Q = 0$, $L = 0$, $S = 0$, $B = 0$) are state vector of charge conjugation operator.

- all self conjugate particles are state vectors of C.

$$= C|\pi^0\rangle = |\pi^0\rangle$$
$$= C|\eta^0\rangle = |\eta^0\rangle$$
$$= C|n\gamma\rangle = (-1)^n|n\gamma\rangle$$

- for particles and antiparticles ~~are state vectors~~ of Pairs of Bosons

$$\boxed{C = (-1)^{l+s}}$$

Ex:- 1. $\pi^0 \to \gamma + \gamma$

π^0 ↓ Pions; γ: $C = -1$, γ: $C = -1$; net $C = +1$.

if decay from g.s. ($l = 0$) ⇒ C is conserved.

$C = (-1)^{0+0} = 1$.

2. $\pi^0 \to \gamma + \gamma + \gamma$

if $l = 0$, $C = 1$. $-1 \quad -1 \quad -1$

net charge $= -1$.

C is not conserve.

⇒ reaction not allowed by charge conjugation.

3. $\omega^0 \to \pi^0 + \gamma + \gamma$ scalars ⇒ $S = 0$

ω^0 ↓ vector mesons; $+1 \quad -1 \quad -1$, $C = 1$ Vector $S = 1$

if $l = 0$ tensor of rank 2 ⇒ $S = 2$

$C = (-1)^{0+1}$
$= -1$

- C is not conserve
- reaction not allowed.

But $\omega^0 \rightarrow \pi^0 + \gamma$
$C = -1 \quad\quad 1 \quad -1$
$\quad\quad\quad\quad c = -1 \quad \Rightarrow$ C is conserved.

$\Rightarrow$ reaction is allowed by charge conjugation.

Summary -

Interaction	Conservation of C
Strong	✓
EM	✓
Weak	✗

6. Time Parity (or Time Reversal T) :- time reversal operation is such that
$$T : t \rightarrow -t$$
time reversal operator.

- On applying time reversal operation we find the probability of reaction to be same before the application of operation then we say that time reversal symmetry holds.

- if the hamiltonian of the system is real and independent of time then time reversal symmetry holds.

Effect of time Reversal Operator :-

Physical Quantity	Invariance
• $T : \vec{p} \Rightarrow -\vec{p}$	changed
• $T : \vec{J} \Rightarrow -\vec{J}$	changed

Pions; Kaons = -ve.

$T: \vec{B} = -\vec{B}$	changed.
$T: \vec{F} = +\vec{F}$	unchanged.
$T: \vec{E} = +\vec{E}$	unchanged.

* Universal Conservation OR CPT conservation CPT theorem Or Liidders Pauli theorem:-

Statement - It states that all interaction in nature are invariant under combined operations of charge conjugation (C), invariance of space (space parity) and reversal of time (T).
If some interaction is not invariant under any one of operations then other two operations will compensative.

Equation:- $A + B \rightarrow C + D + E$

$$C: \quad \underbrace{+1 \;\; -1}_{-1} \qquad \underbrace{+1 \;\; -1 \;\; -1}_{+1}$$

$$P: \quad \underbrace{-1 \;\; -1}_{+1} \qquad \underbrace{+1 \;\; -1 \;\; -1}_{+1}$$

$$T: \quad \underbrace{+1 \;\; -1}_{-1} \qquad \underbrace{+1 \;\; +1 \;\; +1}_{+1}$$

Net CPT $= +1$ Net CPT $= +1$

⇒ CP violation in Neutral Kaon Decay:-

Let $|K^0\rangle$ and $|\bar{K}^0\rangle$ be particle states of K^0 and $\bar{K}^0$
then $P|K^0\rangle = -|K^0\rangle$ ---(1) parity of $K^0 = -1$.

$P|\bar{K}^0\rangle = -|\bar{K}^0\rangle$ --- (2) Bosons and antibosons have same parity.

$C|K^0\rangle = |\bar{K}^0\rangle$ --- (3)

$C|\bar{K}^0\rangle = |K^0\rangle$ --- (4).

now, $CP|K^0\rangle = -|\bar{K}^0\rangle$ --- (5)

$CP|\bar{K}^0\rangle = -|K^0\rangle$ --- (6)

⇒ Both $|K^0\rangle$ and $|\bar{K}^0\rangle$ are not eigen states of operator CP.

• Let us choose two new-state vectors.

$|K^0_S\rangle = \frac{1}{\sqrt{2}}[|K^0\rangle - |\bar{K}^0\rangle]$ --- (7)

$|K^0_L\rangle = \frac{1}{\sqrt{2}}[|K^0\rangle + |\bar{K}^0\rangle]$ --- (8)

now $CP|K^0_S\rangle = \frac{1}{\sqrt{2}}[CP|K^0\rangle - CP|\bar{K}^0\rangle]$

$= \frac{1}{\sqrt{2}}[-|\bar{K}^0\rangle + |K^0\rangle]$

$CP|K^0_S\rangle = |K^0_S\rangle$ --- (9)

⇒ CP ~~Ks~~ eigen values $= +1$

Again $CP|K^0_L\rangle = -|K^0_L\rangle$ --- (10)

⇒ Eigen values $= -1$.

Decay of neutral Kaons:- K^0_S, K^0_L

Decay of Both are :-

$K^0_S \rightarrow \pi^0 + \pi^0$ or $\pi^+ + \pi^-$ (two pion mode).

$K^0_L \rightarrow \pi^0 + \pi^0 + \pi^0$ or $\pi^+ + \pi^- + \pi^0$ (three pion mode)

$K^0_S \rightarrow \pi^0 + \pi^0$.

CP : $+1 \rightarrow -1 \quad -1$

net CP = 1.

$\Rightarrow$ L.H.S. = R.H.S. $\Rightarrow$ CP is conserved.

$\rightarrow K^0_L \rightarrow \pi^0 + \pi^0 + \pi^0$

CP : $-1 \rightarrow -1 \quad -1 \quad -1$

-1

$\left[CP|\pi^0\rangle = C[P|\pi^0\rangle] = C[-1|\pi^0\rangle] \quad CP|\pi^0\rangle = -|\pi^0\rangle \right]$.

L.H.S. = R.H.S.

$\Rightarrow$ CP is conserved.

$\Rightarrow$ But christenes experiment is 1964 confirm that there is very very small probability of about 0.02% that K_L may decay via two pions model.

if this occurs

$K^0_L \rightarrow \pi^0 + \pi^0$

CP : $-1 \quad -1 \quad -1$

net CP = +1

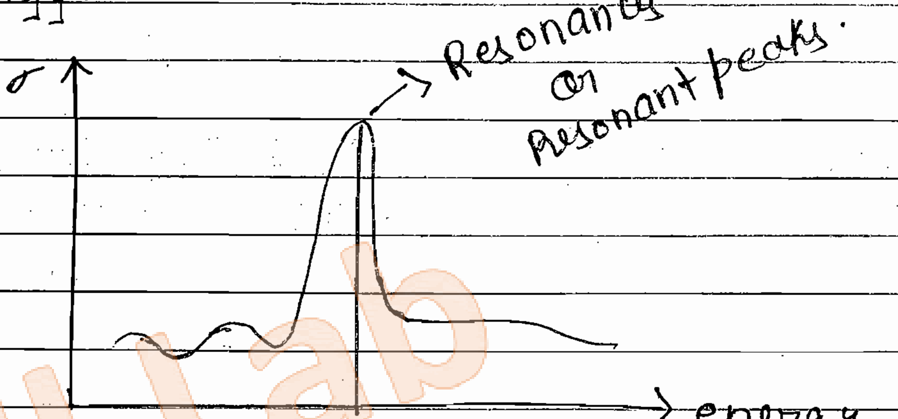
L.H.S. $\neq$ R.H.S.

$\Rightarrow$ CP violated.

16·8·2015

Resonance Particles or Resonance: — these are very short lived particles. they are produced and decay via strong interaction. life time ($\tau \sim 10^{-23}$ sec.).

• they appear as peaks in the graphs. showing the cross-section vs energy.



Since, the life time of resonance particle is very small. therefore indirect methods are used to castimate their mass and life time. The positions of peak gives estimate of its mass.

A – position of peak.

$$E_A = mc^2$$

$$\boxed{m = \frac{E_A}{c^2}}$$

the width of peak ΔE gives estimate of its lifetime.

$$\Delta E \Delta t \sim \hbar$$

$$\Delta E \cdot \tau \sim \hbar$$

$$\boxed{\tau = \frac{\hbar}{\Delta E}}$$

Resonances are of two categories

1. Mesonic
2. Baryonic

$S = 0 \rightarrow P = +1$ – Scalar.
$\quad\;\; \rightarrow P = -1 \rightarrow$ Pseudo scalar.
$S = 1 \rightarrow P = -1 \rightarrow$ Vector.
$\quad\;\; \rightarrow P = +1 \rightarrow$ Pseudo vector.

Ⓐ Mesonic Resonance :–

$\boxed{J^P = 1^-}$ [Spin-1, Parity → -1].

Vector mesons.

Non-strange resonance of pions

ρ mesons – $\underbrace{\rho^+, \rho^0, \rho^-}_{\text{triplet}}$ $M \simeq 770$ MeV.

ω meson → ω^0 – singlet $M \simeq 783$ MeV

ϕ meson. → ϕ^0 – singlet $M \simeq 1020$ MeV

$J^P = 0^-$ Pseudoscalar.

	mass
π	135–140
K	493–497
η^0	549

Strange resonance of kaons.

K^* meson → K^{*+}, K^{*0} – Doublet

$M \simeq 892 \sim 897$ MeV.

K^{*-} $\bar{K}^{*0}$ → antiparticles.

Ⓑ Baryonic Resonance :

$\boxed{J^P = 3/2^+}$

• $\Delta^s \rightarrow \underbrace{\Delta^{++}, \Delta^+, \Delta^0, \Delta^-}_{\text{Quartet}}$ $M \simeq 1232$ MeV.

(nucleonic resonance).

• $\Sigma^{*s} \rightarrow \underbrace{\Sigma^{*+}, \Sigma^{*0}, \Sigma^{*-}}_{\text{triplet}}$ $M \simeq 1383 - 1387$ MeV.

• $\Xi^{*s} \rightarrow \underbrace{\Xi^{*-}, \Xi^{*0}}_{\text{Doublet}}$ $M \simeq 1532 - 1535$ MeV.

• Ω^- → singlet Resonant particle. $M \simeq 1672$ MeV.

binary operation :– by applying some operation, resu
should belong to same set. (closure property).
1. $a*b = c \in G$. → closure property
3. $a*e = e*a = a$ [e=
2. $a*(b*c) = (a*b)*c$ → associative prop.
4. $a*a^{-1} = a^{-1}*a = e$

⇒ SU(3) Symmetry Classification of elementary particles :–
Operations which when performed on the system
→ system remains invariant.
Ex:– rotation, Reflection, Inversion etc.

→ Symmetry operations.
⇓
symmetry operator.
⇓
symmetry matrices
⇓
Set of symmetry matrices :– If this forms a group with some binary operation.
⇓
symmetry ~~operatio~~ Group.
⇓
If matrices are unitary $U^\dagger U = I$.
and unimodulus $|U| = 1$.
⇓
SU(n) Group special unitary Group of order n.
SU(2) – 2×2 – matrices
SU(3) – 3×3 matrices.

⇒ Significance of Symmetry in Nuclear Physics :–

→ Conservation law – corresponds to symmetry.
→ Symmetry Breaking – Conservation law fails.
Ex:– • Linear momentum conservation → translational symmetry of space. ($\Delta p \cdot \Delta x \sim \hbar$)
• Energy conservation – ~~the~~ time symmetry of space.
($\Delta E \cdot \Delta t \sim \hbar$)
• Angular momentum conservation – Rotational symmetry of spa

Super multiplet :- J^P = same "

multiplets $\left\{ \begin{array}{l} \left[\begin{array}{l} p \\ n \end{array} \right. \\ \left[\begin{array}{l} \Sigma^+ \\ \Sigma^0 \\ \Sigma^- \end{array} \right. \end{array} \right.$ multiplets $\left[\begin{array}{l} H^+ \\ H^0 \\ H \\ H \end{array} \right.$ → multiplets $[\Lambda^0$ 8.

The simplest unitary Group contains transformation which adds a phase factor only to the particle wave function.

$A\psi \Rightarrow \psi e^{i\delta}$

- the invariance under such operations gives the conservation of electric charge (Q), Baryon's no. (B), Lepton's no. (L), Hypercharge (Y).

⇒ SU(2) Symmetry Group :-

no. of generators $= 2 \times 2 - 1$

$= 3$ → Restriction due to special condition $|U| = 1$.

- Strong interactions are invariant under rotation of isospace
- Rotation of isospace is related with SU(2).

(I is conserved in strong interactions).

⇓

SU(2) symmetry ~~is not~~ holds in strong interaction.

- But SU(2) symmetry is violated in E.M. interaction.

(as isospin is not conserved in EM interaction).

⇒ SU(3) Symmetry Group and classification :-

SU(3) symmetry Group → no. of generators.

$= 3 \times 3 - 1 = 8$.

→ SU(3) symmetry classification is also known as Eight-fold-way.

→ It treats eight conserved quantities due to which the name eight fold way (Buddha's Eight fold path to Nirvan).

→ Super multiplets are formed by many multiplets have same J^P value.

These are completed at some particular no. of particles 1, 8, 10, 27.

→ $J^P = 0^-$ [antiparticles are also includes b/c there will be no effect on parity].

$\begin{bmatrix} \pi^+ \\ \pi^0 \\ \pi^- \end{bmatrix}$ $\begin{bmatrix} K^+ \\ K^0 \end{bmatrix}$ $[\eta^0]$ (8)

$\begin{bmatrix} K^- \\ \bar{K}^0 \end{bmatrix}$

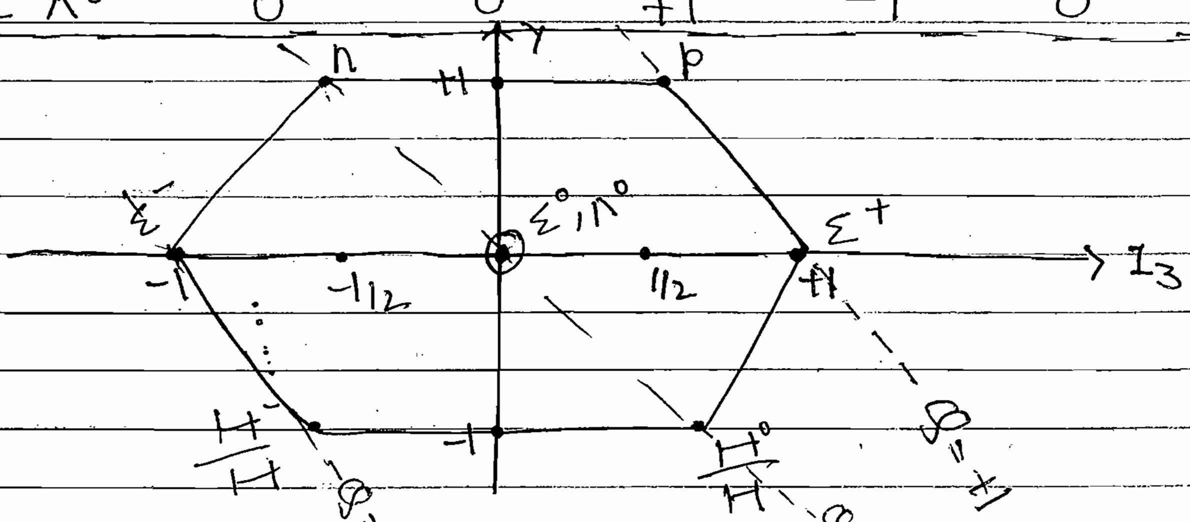
→ $J^P = 3/2^+$ Baryonic Resonance.

$\begin{bmatrix} \Delta^{++} \\ \Delta^+ \\ \Delta^0 \\ \Delta^- \end{bmatrix}$ $[\Sigma^{*+,0}$ Ω^- $\bar{K}$. (10)

$\begin{bmatrix} \Xi^{*-,0} \\ \Xi \end{bmatrix}$

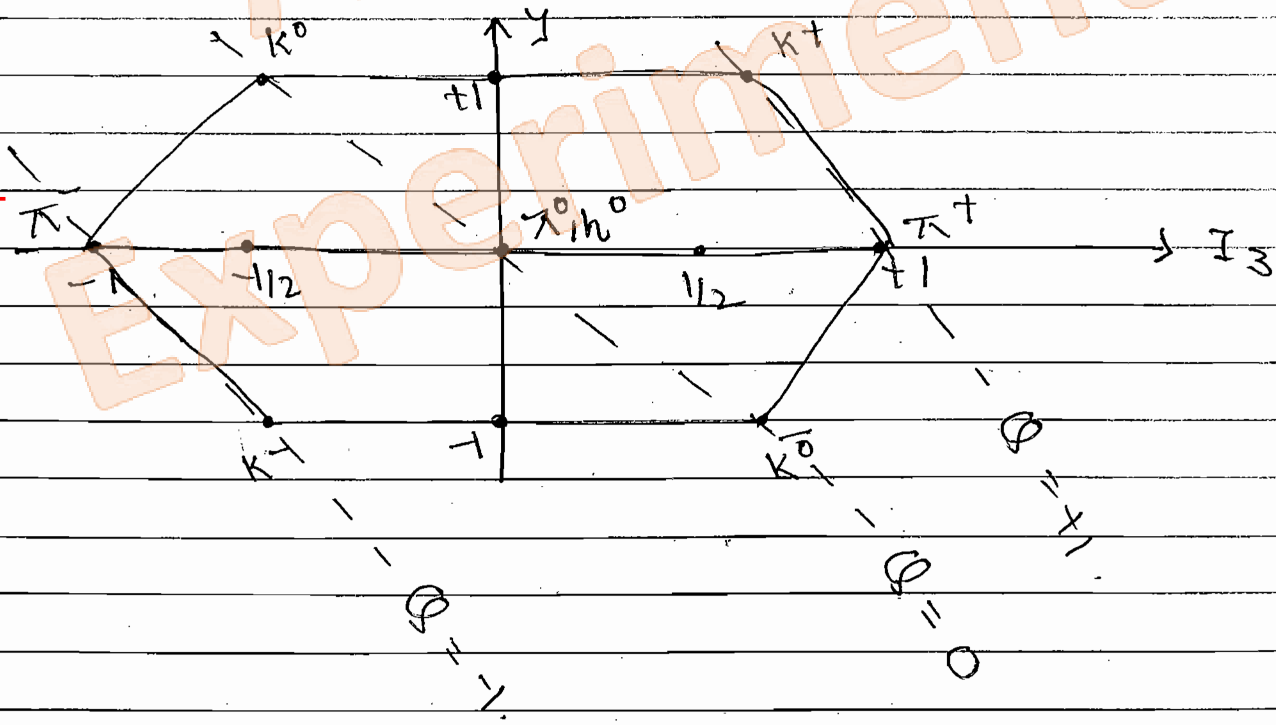
I. Baryon octet $[J^P = 1/2^+]$:-

Particle	I	I_3	B	S (strangeness)	$Y = B + S$ (hypercharge)
p	$1/2$	$+1/2$	$+1$	0	$+1$
n	$1/2$	$-1/2$	$+1$	0	$+1$
Σ^+	1	$+1$	$+1$	-1	0
Σ^0	1	0	$+1$	-1	0
Σ^-	1	-1	$+1$	-1	0
Ξ^- / $\bar{\Xi}$	$1/2$	$-1/2$	$+1$	-2	-1
Ξ^0 / $\bar{\Xi}$	$1/2$	$+1/2$	$+1$	-2	-1
Λ^0	0	0	$+1$	-1	0



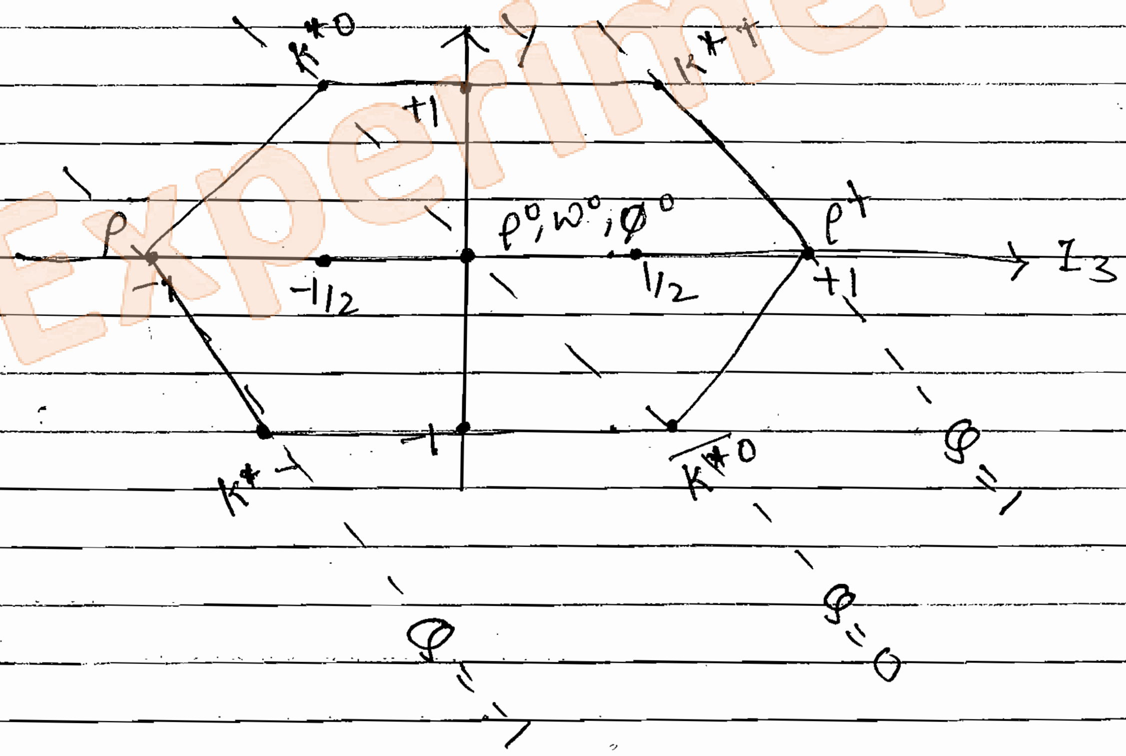
2. Meson Octet ($J^P = 0^-$) :- Pseudoscalar mesonons.

Particles	I	I_3	Bosons	S	$Y = B + S$
π^+	1	+1	0	0	0
π^0	1	0	0	0	0
π^-	1	-1	0	0	0
K^+	1/2	+1/2	0	+1	+1
K^0	1/2	-1/2	0	+1	+1
K^-	1/2	-1/2	0	-1 [opp. to	-1
$\bar{K}^0$	1/2	+1/2	0	-1 particles]	-1
η^0	0	0	0	0	0



3. Vector Mesons (Meson Resonance $J^P = 1^-$) :-

Particles	I	I_3	B	S	Y = B + S.
ρ^+	1	+1	0	0	0
ρ^0	1	0	0	0	0
ρ^-	1	-1	0	0	0
ω^0	0	0	0	0	0
ϕ^0	0	0	0	0	0
K^{*+}	1/2	+1/2	0	+1	+1
K^{*0}	1/2	-1/2	0	+1	+1
K^{*-}	1/2	-1/2	0	-1	-1
$\bar{K}^{*0}$	1/2	+1/2	0	-1	-1



Vector - meson - nonet.

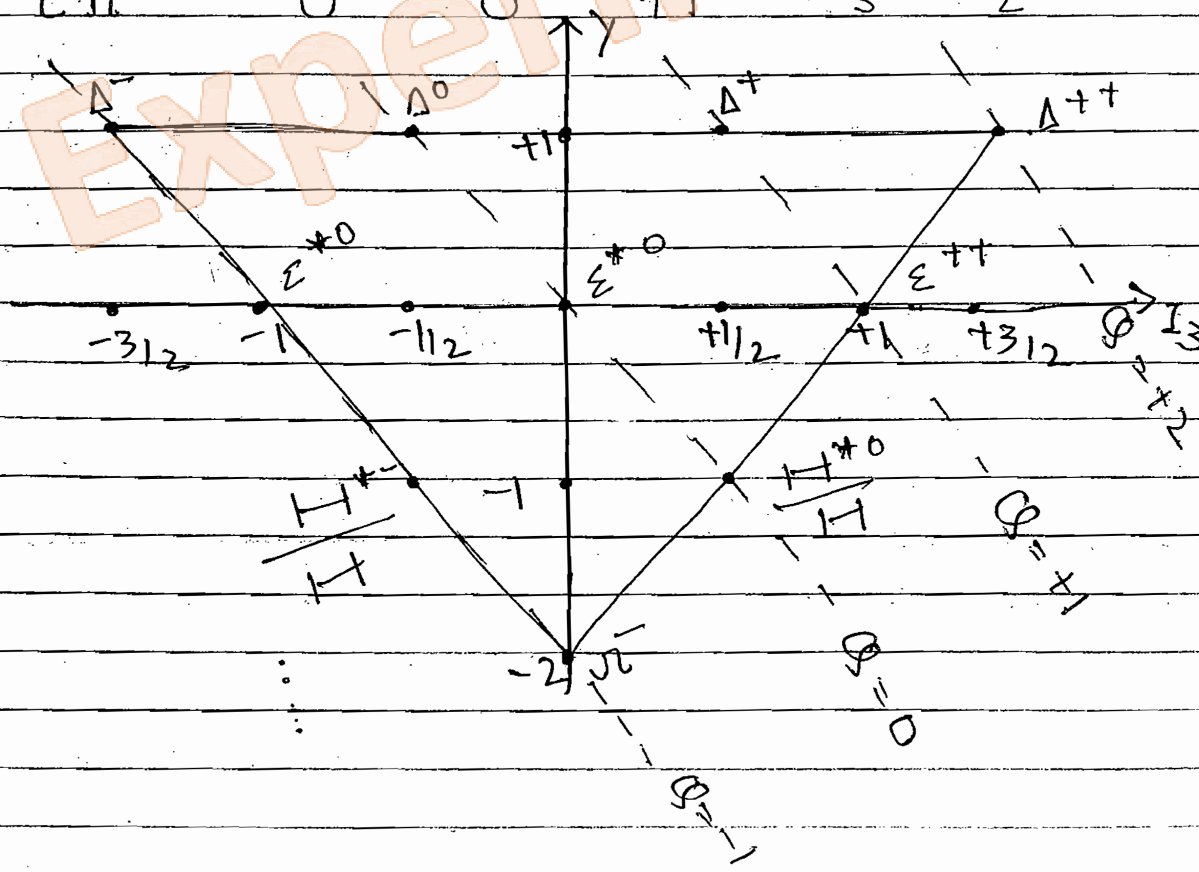
$2I+1=4$

$I=3/2$

$I_3 = -\frac{3}{2}, -1/2, +1/2, +3/2.$

Baryon - Decuplet ($J^P = 3/2^+$)

Particles	I	I_3	B	S	Y = B + S.
Δ^{++}	3/2	+3/2	+1	0	+1
Δ^{+}	3/2	+1/2	+1	0	+1
Δ^{0}	3/2	-1/2	+1	0	+1
Δ^{-}	3/2	-3/2	+1	0	+1
Σ^{*+}	1	+1	+1	-1	0
Σ^{*0}	1	0	+1	-1	0
Σ^{*-}	1	-1	+1	-1	0
$\frac{\Xi^{*-}}{\Xi}$	$\frac{1}{2}$	$-\frac{1}{2}$	+1	-2	-1
$\frac{\Xi^{*0}}{\Xi}$	$\frac{1}{2}$	$+\frac{1}{2}$	+1	-2	-1
Ω^{-}	0	0	+1	-3	-2



- Hadrons = Baryons + mesons.
- all quarks are spin = 1/2 (fermions) with Baryon no. B = 1/3
- $Q = \frac{2}{3}e$ or $-\frac{1}{3}e$.

⇒ **Quark Model for Hadrons:** — this model is based on the hypothesis that Hadrons (Baryons + mesons) are made up from more fundamental particles called quarks.

- all quarks are spin $s = 1/2$ particles (fermions) with Baryon no. $B = 1/3$.

there are fractional charge particles $Q = +\frac{2}{3}e$ or $-\frac{1}{3}e$.

- there are three generations of quarks.

Ist gen. — u and d (up and down)

IInd gen. — s and c (strange and charm)

IIIrd gen. — t and b (top and bottom).

- u, d, s, c, t and b are 6 flavours of quarks.
- $\bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{t}$ and $\bar{b}$ are antiparticles of quarks.

Properties: —
Q – charge
I – spin
I_3 – isospin
u – upness
d – downness
s – strangeness
c – charmness
t – topness
b – bottomness.

Flavour	Q	I	I_3	U	d	S	C	t	b
u	$+\frac{2}{3}e$	$+\frac{1}{2}$	$+\frac{1}{2}$	+1	0	0	0	0	0
d	$-\frac{1}{3}e$	$\frac{1}{2}$	$-\frac{1}{2}$	0	-1	0	0	0	0
s	$-\frac{1}{3}e$	0	0	0	0	-1	0	0	0
c	$+\frac{2}{3}e$	0	0	0	0	0	+1	0	0
t	$+\frac{2}{3}e$	0	0	0	0	0	0	+1	0
b	$-\frac{1}{3}e$	0	0	0	0	0	0	0	-1

multiplicity – $M = 2I + 1$.

if $I = 1/2$

$I_3 = -1/2, 1/2$.

* $m_u \approx m_d \approx 0.4$ GeV → form a doublet

$2I + 1 = 2$

$\Rightarrow I = \frac{1}{2}$

$\therefore I_3 = -\frac{1}{2}, +\frac{1}{2}$

$\Downarrow$ d (for $-\frac{1}{2}$), $\Downarrow$ u (for $+\frac{1}{2}$).

$m_s \approx .5$ GeV

$m_c \approx 1.65$ GeV

$m_b \approx 5$ GeV.

$m_t \approx 180$ GeV.

⇒ assumptions:–

Hadrons.

Mesons → $B = 0$ → to get $B = 0$, the combination of quarks is $q + \bar{q}$ (Quark + antiquark)

Baryons. (for each quark $B = 1/3$) → $B = 1$. → to get $B = 1$, the combination of 3 quarks is required i.e. $q + q + q$.

• antiparticles for Baryons have antiquarks combination i.e. $\bar{q} + \bar{q} + \bar{q}$.

* Real world particles are made up from u, d and s quarks.

⇒ Compositions of Mesons On the Basis of Quark model:–

1. Pseudo-Scalar Mesons ($J^P = 0^-$):– $S = 0$, $P = -1$ pseudo scalar mesons.

Particles	Q	strangeness	Quark content
π^+	+1	0	$u\bar{d}$
π^0	0	0	$u\bar{u}, d\bar{d}$
π^-	[illegible]	0	$\bar{u}d$

$\to$ antisymmetric

$\eta_0 \left[\frac{1}{\sqrt{2}} (u\bar{u} - d\bar{d}) \right] \to$ Quark wavefunction of π^0

K^+	+1	+1	$u\bar{s}$	strangeness involve
K^0	0	+1	$d\bar{s}$	
$\bar{K}^-$	−1	−1	$\bar{u}s$	
$\bar{K}^0$	0	−1	$\bar{d}s$	
η^0	0	0	$u\bar{u}, d\bar{d}, s\bar{s}$	

$\eta_0 \frac{1}{\sqrt{6}} (u\bar{u} + d\bar{d} - 2s\bar{s}) \to$ antisymmet Quark wavefunction of η^0.

Resonance mesonic.

$\Rightarrow$ Vector mesons ($J^P = 1^-$) :-

Particles	Q	Strangeness	Quark-content
ρ^+	+1	0	$u\bar{d}$
ρ^0	0	0	$u\bar{u}, d\bar{d}$
ρ^-	−1	0	$\bar{u}d$
ω^0	0	0	$u\bar{u}, d\bar{d}$
ϕ^0	0	0	$u\bar{u}, d\bar{d}$
K^{*+}	+1	+1	$u\bar{s}$
K^{*0}	0	+1	$d\bar{s}$
$\bar{K}^{*-}$	−1	−1	$\bar{u}s$
$\bar{K}^{*0}$	0	−1	$u\bar{u}, d\bar{d}$

$\Rightarrow$ Composition of Baryons:-

1. Baryon octet ($J^P = \frac{1}{2}^+$)

Particle	Q	S	Quark content
p	+1	0	uud
n	0	0	udd
Σ^+	+1	−1	uus
Σ^0	[illegible]	−1	[illegible]

$u \Rightarrow 2/3$ $\quad \frac{2}{3}+\frac{2}{3}+\frac{2}{3} = \frac{6}{3} = 2$

$d \Rightarrow -1/3$

$s \Rightarrow -1/3$.

Σ^-	-1	-1	dds
$\Xi^- \over \Xi$	-1	-2	dss
$\Xi^0 \over \Xi$	0	-2	uss
Λ^0	0	-1	uds

(2) Baryon Decouplet ($J^P = \frac{3}{2}^+$) :-

Particle	Q	S	Quark content
Δ^{++}	$+2$	0	uuu
Δ^+	$+1$	0	uud
Δ^0	0	0	udd
Δ^-	-1	0	ddd
Σ^{*+}	$+1$	-1	uus
Σ^{*0}	0	-1	uds
Σ^{*-}	-1	-1	dds
$\Xi^{*-} \over \Xi$	-1	-2	dss
$\Xi^{*0} \over \Xi$	0	-2	uss

Ω^- -1 -3 sss.

⇒ Concept of Coloured Quarks: — (to follow the paulli exclusion princi

$uuu \rightarrow u_R u_B u_G$.

in the following Quark structures we have the problem of violation of pauli principle (Quarks are fermions = follow pauli principle).

$\Omega^- \equiv sss$] three same quarks.
$\Delta^- \equiv ddd$.
$p \equiv uud$] → two same quarks.

- to resolve this difficulty the concept of Coloured quarks was introduced.
- Each quark flavour has three colours (it is colour q.no. no connection with visual colours).
  i.e. Red (R)
  Blue (B)
  Green (G).

→ Antiquarks have anti colours.
  i.e. antired ($\bar{R}$)
  antiblue ($\bar{B}$)
  anti Green ($\bar{G}$).

- In case of Baryons three quarks of different colours combine to given net colour quantum no. = 0.

$$q_R + q_B + q_G \Rightarrow \text{Net colour} = 0.$$

In case of Mesons → one quark colour and one antiquark with anticolour combine to give net colour quantum no. = 0.

$$q_R + \bar{q}_{\bar{R}} \text{ or } q_B + \bar{q}_{\bar{B}} \text{ or } q_G + \bar{q}_{\bar{G}} = \Rightarrow \text{net colour q.no.} = 0.$$

Gluons / $S=1$ $m=0$ $v=c$

Therefore in view of above assumptions the modified quark structure will be

$$\Omega^- \equiv s_R s_B s_G$$
$$\Delta^- \equiv d_R d_B d_G$$
$$p \equiv u_R u_B d_G \text{ or } u_B u_G d_R \text{ or } u_G u_R d_B.$$

$$\pi^0 \rightarrow u_R \bar{u}_{\bar{R}} \text{ or } u_B \bar{u}_{\bar{B}} \text{ or } u_G \bar{u}_{\bar{G}}$$
$$d_R \bar{d}_{\bar{R}} \text{ or } d_B \bar{d}_{\bar{B}} \text{ or } d_G \bar{d}_{\bar{G}}$$

⇒ **Interaction Between Quarks:—**

- The interaction between the quarks is mediated by massless spin $S=1$ particles called gluons.

Gluons → $S=1$
$m=0$
$v=c$
charged particles (colour charge).

- The field of strong interaction is called colour field and the quanta of this field are gluons.

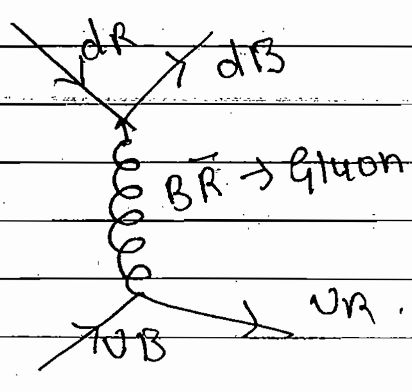
$\boxed{R\bar{R}}$ → net colour = 0.

$R\bar{B}$, $B\bar{G}$, $B\bar{R}$ → net colour.

- Gluons change the quark colour of particular flavour.

$$u_R \xrightarrow{g} u_B, \quad u_B \xrightarrow{g} u_G,$$
$$d_R \xrightarrow{g} d_B, \quad d_B \xrightarrow{g} d_G.$$

Illustration—



Here two quarks UB and dR are interacting via $B\bar{R}$ gluon.

potential b/w two quarks $\Rightarrow U = \alpha r - \frac{\beta}{r}$

→ Blue, U quark emits ~~to~~ its blueness and converts into red and U quarks on the other side red d quark absorbs this gluon, cancel its redness and converts into blue d gluons.

• Total no. of predicted gluons = 8. $R\bar{B}$, $R\bar{G}$, $B\bar{R}$, $B\bar{G}$, $G\bar{R}$, $G\bar{B}$, $R\bar{R} - G\bar{G}$, $R\bar{R} + G\bar{G} - 2B\bar{B}$

⇒ Glue balls :- Since Gluons are themselves coloured particles (they have net colour charge). therefore they interact with each other. the mediating particles of gluons are named as glue-balls

Quark Confinement :- 1. Quarks have not been found outside the hadrons inspite of many efforts. 2. they are always allowed confined inside the hadrons.

3. as one tries to seperate out the quarks. the force increase very fast and it becomes impossible to find the quarks, outside the hadrons.

• the potential b/w two quarks is of the form.

$$\boxed{U = \alpha r - \frac{\beta}{r}}$$

α, β - constants.

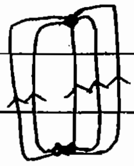
at short distances :-

$$U \simeq -\frac{\beta}{r}.$$

at large - distance :-

$$U \simeq \alpha r.$$

• the lines of force b/w quarks appear as below.

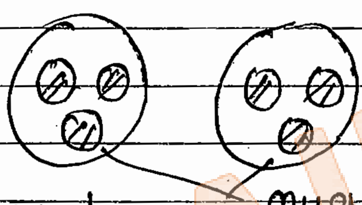


for a short distance they spread out and then become essentially parallel.

-9-2015

⇒ Evidences about Quarks: — no direct evidences about the existence of quark but there are many indirect evidances which support the quark hypothesis.

1. Deep Inelastic scattering of electrons (DIS experiment):—
→ similar to the rutherford scattering experiment.
→ Beam of high energy e^-s scatters from the nucleons and scattered data reveals that both p and n have three scatters inside them.



n = udd.

p = uud

Quarks of scattered.

2. Quark model can explains abnormal magnetic moment of nucleons.

(1.91/2.79.)

$$\left(\frac{\mu_n}{\mu_p}\right)_{\text{theoretical}} = -\frac{2}{3} \quad \text{(Quark model).}$$

$$\left(\frac{\mu_n}{\mu_p}\right)_{\text{experimental}} = -.68 \approx -\frac{2}{3}$$

⇒ good resemblance b/w theoretical and obs. values.

3. the ratio of cross section of different hadronic reactions can be explained on the basis of quark model.

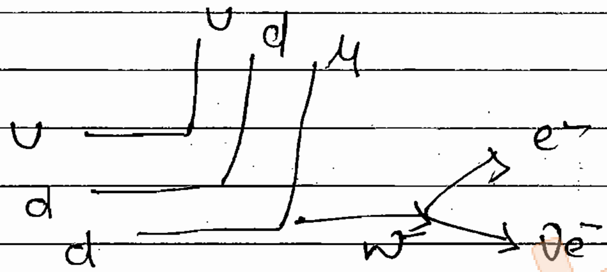
$$\frac{\sigma_{NN} + \sigma_{\bar{N}N}}{\sigma_{\pi N}} = 3. \qquad \sigma \text{ -- cross-section.}$$

4. SU(3) symmetry of Hadrons can be explained correctly using the quark hypothesis.

5. the weak interaction process can be explain in terms of quark model.

$$n \rightarrow p + e^- + \bar{\nu}_e$$

udd   uud



6. Existence of three colour have been confirm by comparision of the ratio

$$R = \frac{\sigma(e^+e^- \rightarrow hadrons)}{\sigma(e^+e^- \rightarrow muons)}.$$

⇒ Unification of interaction :-

four fundamental interactions are.

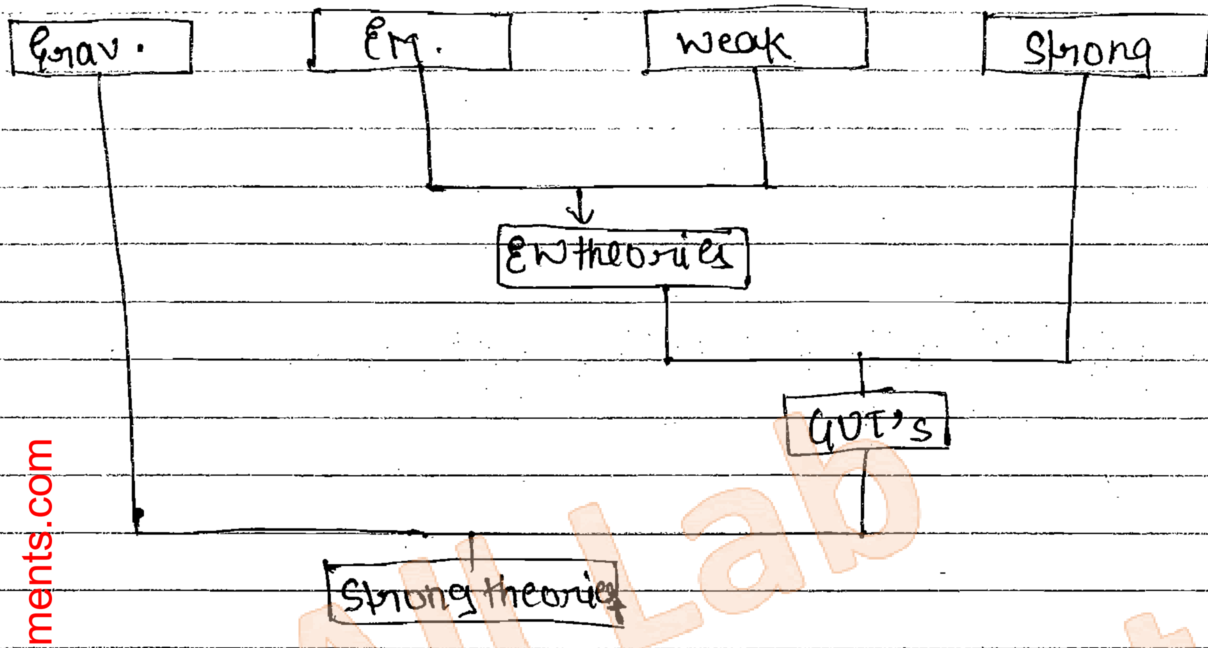
1. Gravitational.
2. Electromagnetic
3. weak.
4. strong.

It has been dream of physicists to unify four fundamental interaction into one unified interaction.

→ 1967, Salam, weinberg and others developed a theory to unify EM and weak interactions into electron weak interaction. this theory was subsequently confirmed by experiments.

→ Grand unified theories (GUTs) are meant for the unification of strong interactions with EW interactions.

→ String theories are effort to unify all four interactions.



→ Unification of interactions occur at particular (unification energy) energy. As we come down from this energy the separation of interactions take place.

→ Consequences of GUT's :- 1. Leptons and quarks will be at equal footing and exchange of one into other may take place.
2. Heavy magnetic monopoles will exist.
3. Proton will be unstable particle with lifetime $\approx 10^{28}$ years

Standard Model :- Standard model is based on the unification of strong and electroweak interaction there a single picture has been developed by combining the theory of ~~with~~ strong interaction with EM interaction where Leptons and quarks are foot at equal footing.

Following particles are included in the ~~strong~~ standard model.

1. Three generations of leptons:–

I: $\bar{e}, \nu_e$

II: μ, ν_μ

III: τ, ν_e

Particles = 6
Antiparticles = 6

total leptons = 6 + 6 = 12.

2. Three generations of Quarks:–

I	II	III	
u	s	t	} 6 quarks.
d	c	b	
$\bar{u}$	$\bar{s}$	$\bar{t}$	} 6 antiquarks.
$\bar{d}$	$\bar{c}$	$\bar{b}$	

→ Each quarks has three colours R, B and G.
→ Each antiquarks has three colours $\bar{R}$, $\bar{B}$ and $\bar{G}$.

total particles = 6×3 + 6×3
= 36.

3. Quanta of EM field → γ Photon = 1.
4. Quanta of weak field → $W^{\pm}, Z^0$ = 3.
5. Quanta of strong colour field ⇒ Gluons = 8.
6. Quanta of Higgs field → Higgs Boson H^0 = 1.

<u>Higgs Boson</u>:– ~~this particle~~ Peter Higgs proposed that there is a universal invisible field known as Higgs field. By interacting this field different particles acquire mass. more is the interaction with the Higgs field more will be the mass.
If a particle has no interaction with higgs field, it will have no mass.

→ the quanta of Higgs field is called Higgs boson.

symbol – H^0

Spins = 0

Parity $P = +1$

$\Rightarrow J^P = 0^+$ Truely scalar particles.

mass $m_H \approx 126\ GeV/c^2$.

lifetime $\tau \approx 1.6 \times 10^{-22}$ sec.

Decay modes :-

$H^0 \rightarrow W^+ + W^-$

$H^0 \rightarrow Z^0 + Z^0$

$H \rightarrow WW$

$H \rightarrow \gamma\gamma$

$H \rightarrow ZZ$

$H \rightarrow b\bar{b}$

$H \rightarrow t\bar{t}$ ($t \rightarrow$ top quark).

The confirmation of existance of higgs boson was done by LHC experiment at CERN.

L - angular momentum.
S - Strangeness.

Problems :-

Some facts :-

1. Strong interactions :- $\Delta L = 0$, $\Delta B = 0$ (in all interactions), $\Delta S = 0$, $\Delta I = 0$, $\Delta I_3 = 0$, $\Delta Y = 0$, $\Delta P = 0$, $\Delta C = 0$, $\Delta T = 0$

2. EM interactions :- $\Delta S = 0$, $\Delta I \neq 0$, $\Delta I_3 = 0$, $\Delta Y = 0$, $\Delta P = 0$, $\Delta C = 0$, $\Delta T = 0$

3. weak interactions :- $\Delta S \neq 0$, $\Delta I = 0$, $\Delta I_3 \neq 0$, $\Delta Y \neq 0$, $\Delta P \neq 0$, $\Delta C \neq 0$, $\Delta T \neq 0$.

2. Nucleon - Nucleon, Pion-nucleon reaction occur via strong interaction.
absorption of or emission of γ photon in a reaction - EM interaction.
$\Delta S = 1 \rightarrow$ weak interaction.

3. In strangness changing in weak interaction processes.

$$\boxed{|\Delta I_3| = \frac{1}{2}}$$

4. threshold Energy of incident particle :- if a particle of mass m_i strikes a particle of mass m_s in lab frame. the collision produces several particles of total mass m_f. then threshold energy for the reaction in lab frame

$$E_{th} = \frac{m_f^2 - (m_i + m_s)^2}{2m_s} \cdot c^2 .$$

$$\underset{m_i}{A} + \underset{m_s}{B} \rightarrow \underbrace{C + D + G}_{m_f}$$

Gate-2011

Q:- the isospin and strangness of Ω^- are
(a) 1, -3 (b) 0, -3 (c) 1, 3 (d) 0, 3

singlet → isospin = 0

$M = 2I+1$

$1 = 2I+1 \Rightarrow I = 0$

NET-2012

Q:- Consider the following particles p, n, π^0, Δ^+. When ordered in terms of decreasing life time, the correct ~~ordere~~ arrangement is:

1. π^0, n, p, Δ^+
2. p, n, Δ^+, π^0
3. p, n, π^0, Δ^+
4. Δ^+, n, π^0, p

Proton is most stable.

$\pi^0 \to \gamma + \gamma$

Strong → $10^{-16} - 10^{-20}$

weak → 10^{-10} sec

Δ^+ → resonance particle ($\tau = \tau$ of nucleus)

$\tau \sim 10^{-23}$ sec

NET-2012

Q:- the dominant interaction underlying following process.

A: $K^- + p \longrightarrow \Sigma^- + \pi^+$

B: $\mu^- + \mu^+ \longrightarrow K^- + K^+$ (~~lepton~~ muons do not interact strongly).

C: $\Sigma^+ \longrightarrow p + \pi^0$ → decay reaction.

decay be weak-interaction] strange particle.

1. A: strong, B: EM, C: weak.
2. A: weak, B: EM, C: weak.
3. A: weak; B: EM, C: strong.
4. A: weak, B: EM, C: weak.

Gate-2012

Q:- which of the following sets corresponds to the fundamental particles?

(a) Proton, e^-, neutron.

(b) p, e^-, γ.

(c) e, γ, neutrino

Gate-2013

Q:- The isospin and Baryon no. of up quark is.

(a) $I = 1,\ B = 1$.

(b) $I = 1,\ B = \frac{1}{3}$

(c) $I = \frac{1}{2},\ B = \frac{1}{3}$ ✓

(d) $I = \frac{1}{2},\ B = 1$.

$u \} I_3 = +1/2$
$d \} I_3 = -1/2$
$I = \frac{1}{2}$.

Gate-2013

Q:- The decay process $n \to p + e^- + \bar{\nu}_e$ violates.

(a) Baryon no.

(b) Lepton no.

(c) Isospin ✓

(d) Strangeness.

Gate-2013

Q:- Consider the decay of pion into a muon and an anti-neutrino

$$\pi^- \to \mu^- + \bar{\nu}_\mu$$

in the pion rest frame.

$m_\pi = 139.6\ \frac{MeV}{c^2},\ m_\mu = 105.7\ \frac{MeV}{c^2},\ m_\nu = 0.$

The energy (in MeV) of emitted neutrino to the nearest integer is ___30 MeV___

Sol:-
$$\pi^- \to \mu^- + \bar{\nu}_\mu$$

Energy conservation.

$$E_\pi = E_\mu + E_\nu$$ (Pion at rest, so K.E. = 0, $E_\pi = m_\pi c^2$).

$$139.6 = E_\mu + E_\nu$$

$$E_\mu + E_\nu = 139.6 \quad --- (1).$$

momentum conservation.

$$\vec{P_i} = 0.$$

$$\vec{P_f} = \vec{P_\mu} + \vec{P_\nu}$$

$$\vec{P_i} = \vec{P_f} \Rightarrow 0 = P_f$$

$\boxed{P_\mu = P_\nu}$ numerically.

$$E^2 = p^2c^2 + m^2c^4$$

$$E^2_\mu = P^2_\mu c^2 + m^2_\mu c^4 \quad ---(2)$$

$$E_\nu = P_\nu c = P_\mu c \quad ---(3)$$

$$E^2_\mu = P^2_\nu c^2 + m^2_\mu c^4$$

$$E^2_\mu = E^2_\nu + m^2_\mu c^4 \quad ---(4)$$

from (4)

$$E^2_\mu - E^2_\nu = (105.7)^2$$

$$(E_\mu + E_\nu)(E_\mu - E_\nu) = (105.7)^2$$

$$E_\mu - E_\nu = \frac{(105.7)^2}{139.6} \quad \text{from (1).}$$

$$E_\mu - E_\nu = \frac{105.7 \times 105.7}{139.6}$$

$$E_\mu - E_\nu = 80.$$

$$E_\mu + E_\nu = 139.6$$

$$E_\mu - E_\nu = 80$$

$$2E_\nu = 59.6$$

$$\boxed{E_\nu \approx 30 \text{ meV}}$$

Q:- Calculate the threshold energy of pions for the following reactions

(a) $\pi^- + p \rightarrow \Sigma^- + K^+$ $\quad E_{th} \approx 904$ meV

(b) $\pi^0 + p \longrightarrow K^+ + \pi^0$ $\quad E_{th} \approx 770$ meV.

Given that

$m_{\pi^-} = 140$ mev

$m_p = 938.3$ mev

$m_{\pi^0} = 135$ Mev

$m_{\Sigma^-} = 1197$ Mev.

$M_{K^+} = 493$ Mev.

$\Rightarrow m_p = \underline{938.3}$

Sol:- $E_{th} = \dfrac{m_f^2 - (m_i + m_s)^2}{2m_s} c^2$

(a) $= \dfrac{(1690)^2 - (1078.3)^2}{2 \times 938.3} \times (3 \times 10^8)^2$

$$\begin{array}{r} 1197 \\ +\ 493 \\ \hline 1690 \end{array} \quad ①$$

$= \dfrac{2856100 - 1162731}{1876.6} \times 9 \times 10^{16}$

$= 902.3601 \times 9 \times 10^6$

$= 8121.241$

Q:- A proton of K.E. T strikes a stationary hydrogen target and gives reaction of

$p + p \rightarrow p + p + p + \bar{p}$

and $p + p \rightarrow p + p + \pi^0$

Find the threshold energies in both reaction.

Sol:- for 1st case:-

$E_{th} = \dfrac{(4m_p)^2 - (2m_p)^2}{2m_p}$

$= \dfrac{16m_p^2 - 4m_p^2}{2m_p} = \dfrac{12m_p^2}{2m_p} = 6m_p$

$= 6 \times 938.3$ MeV.

$= 5.6298$ GeV.

$= 5.62$ GeV.

for IInd case -

Q:- Identify the unknown particles in the following reaction:-

(a) $\mu^- + p \rightarrow n + ?_0$

(b) $\pi^- + p \rightarrow K^0 + ?_0$

(c) $K^- + p \rightarrow K^+ + ?_0$ → $\frac{H^-}{H}$

Sol:- (a) $\mu^- + p \rightarrow n + ?_0$

	μ^-	p	n	$?_0$	
Q	-1	+1	0	$?_0$	$\Rightarrow Q = 0$
B	0	1	1	$?_0$	$\Rightarrow B = 0$
L_μ	+1	0	0	$?_0$	$\Rightarrow L_\mu = +1$

⇓

Particle is ν_μ.

(b) $\pi^- + p \rightarrow K^0 + ?_0$ → strong interaction so, S should be conserve and I_3 also conserve

	π^-	p	K^0	$?_0$	
Q :	-1	+1	0	?	$\Rightarrow Q = 0$
B :	0	+1	0	$?_0$	$\Rightarrow B = +1$
S :	0	0	+1	$?_0$	$\Rightarrow S = -1$
I_3 :	-1	+1/2	-1/2	$?_0$	$\Rightarrow I_3 = 0$
I :	1	1/2	1/2	$?_0$	$\Rightarrow I = 0, 1.$

$\underbrace{-1 \quad +1/2}_{-1/2}$

$\underbrace{1 \quad 1/2}_{1/2,\ 3/2}$

⇓

Particle is Λ^0 and Σ^0.

Q:- Examine the type of interaction involved in following reactions.

(a) $\pi^- + p \to \Lambda^0 + K^0$ → strong interaction (associated production)

(b) $\pi^- + p \to n + \pi^0$ → strong interaction.

(c) $p + \gamma \to p + \pi^0$ → EM (absorption of γ).

(d) $\Sigma^0 \to \Lambda^0 + \gamma$ → EM int.

(e) $\pi^0 \to \gamma + \gamma$ → EM int.

(f) $K^0 \to \pi^+ + \pi^-$ → weak interaction.

(g) $\frac{H^-}{H} \to \Lambda^0 + \pi^0$ → weak interact.

(h) $\Lambda^0 \to p + \pi^-$ — weak int.

(i) $\Lambda^0 \to p + e^- + \bar{\nu}$ - weak

if I is not conserve then it would be EM interaction

Sol:- (a) $\pi^- + p \to \Lambda^0 + K^0$.

	π^-	p	Λ^0	K^0	
B:	0	1	1	0	$\Delta B = 0$.
Q:	-1	1	0	0	$\Delta Q = 0$.
strangeness → S:	0	0	-1	+1	$\Delta S = 0$
I:	1	1/2	0	1/2	$\Delta I = 0$.
	$\underbrace{\quad}_{1/2,\ 3/2}$		$\underbrace{\quad}_{1/2}$		
I_3:	-1	+1/2	0	-1/2	$\Delta I_3 = 0$.
	$\underbrace{\quad}_{-1/2}$		$\underbrace{\quad}_{-1/2}$		

Strong Int.

Q:- $K^0 \to \pi^+ + \pi^-$

S: 1 0 0 $\Delta S = 1$.

I: 1/2 $\underbrace{1 \quad 1}_{0,1,2}$ $\Delta I \neq 0$.

weak.

basic process underlying neutron and decay.
correct option is
1. $d \rightarrow u + e^- + \bar{\nu}_e$
2. $d \rightarrow u + e^-$
3. $s \rightarrow u + e^- + \bar{\nu}_e$
4. $s \rightarrow d + e^- + \bar{\nu}_e$

Sol:- $n \rightarrow p + e + \bar{\nu}_e$
$udd \quad uud$

$d \rightarrow u + e^- + \bar{\nu}_e$

Q:- The intrinsic spin J, Parity P and isospin I of f^0, w^0 and η^0 mesons are $(2^+, 0)$ $(1^-, 0)$ and $(0^-, 0)$ respectively. Assuming isospin and parity to be conserved which of the three particles undergoes decay into two pions?

Sol:- ✓ $f^0 \rightarrow \pi^0 + \pi^0$ or $\pi^+ + \pi^-$ — Parity conserve.
$w^0 \rightarrow \pi^0 + \pi^0$ or $\pi^+ + \pi^-$
$\eta^0 \rightarrow \pi^0 + \pi^0$ or $\pi^+ + \pi^-$.