INTRODUCTION

In the present work we have tried to analyse various interactions of elementary particle physics on the basis of a four preon model of quarks and leptons recently suggested.

To build up a framework for this we discuss new symmetries of elementary particle physics in the first chapter. We begin with the paradoxes of simple quark model of Gell-Mann and Zweig and examine how these are removed by the idea of colour symmetry first postulated by O.Greenberg. We mention two schemes of the colour quark model viz.

1. The fractionally charged coloured quarks of Greenberg-Zwargier-Gell Mann and
2. The integral charged coloured quarks of Han and Nambu.

In the second chapter, we examine the problem of structure and elementarity. We discuss the relation between scale invariance and the point-like aspect of the fundamental constituents. Thus compared to a nucleon of the size of 1 fm., the dimensions of the quarks ($\sim 10^{-3}$ fm. from recent experiments) will be point-like. The preons are said to be the constituents of partons and leptons. Further in this chapter we discuss a new flavour charm and discuss the charmed particles. We pointout the similarity between the positronium and charmonium and study the charmonium spectrum. We extend these ideas to incorporate the study of new quarkonia formed in electron-positron collision. We give the brief comments regarding the quarkonium potential and mention the new flavours beauty and truth.

In the third chapter we tackel the problem of unification of fundamental interactions. Discussing briefly the features of the standard model, we show how it is transcendented in grand unified theories. We discuss briefly the simplest GUT SU(5) of Georgi and Glashow. Further we point out the quark-lepton unification aspect of GUT and discuss the particle spectrum of SU(5).

In the fourth chapter we discuss briefly the preon hypothesis and the two important preon models viz. the Pati-Salam model and the rishon model of Harari and Sharpe. We further briefly sketch how the rishon model has been further extended in a recent work of Rajpoot and Samuel which will form the basis for our discussion of the mechanism of elementary particle interactions.

The fifth chapter presents our analysis of typical interactions, decay schemes and conservation laws of elementary particles. We reduce a particle level interaction to quark and lepton level, and analyse the quark level process in terms of the rishons. Our analysis includes the strong interactions, proposal of a new generation quantum number and a new selection rule governing the weak interactions. We further analyse the weak interactions and then test the validity of conservation laws by visualising the forbidden decays at the preon level. Next we study a few leptoquark mediated interactions predicted by grand unified theories and postulate a new class of interactions viz. the F boson mediated generation changing horizontal interactions. This if followed by a rough sketch of the conclusions of our study and indications of further possible work.

Physics will change even more .....

If it is radical and unfamiliar .... we

think that the future will be only more radical

and not less,

only more strange and not more familiar,

and that it will have its own new insights

for the inquiring human spirit"

J.R.Oppenheimer

quoted by Abdus Salam

in his Nobel Prize (in

Physics) Award Address 1979.

CHAPTER - 1

NEW SYMMETRIES OF ELEMENTARY PARTICLE PHYSICS

1.1 Paradoxes of Simple Quark Model 1,2

By simple quark model, we mean the model of three or more types of quarks as originally invented, with no hidden degree of freedom.

This model has following difficulties :

1. The quarks have fractional charges, whereas all the observed hadrons have integral charges. No fractionally charged particles have been observed.
2. Hadrons have either quarkonium ($q\bar{q}$-mesons) or three nuclei (qqq-baryon) structure.

There is no evidence for qq or qqqq bound state. This is difficult to understand on the basis of simple quark model.

3. The most serious problem : $J^P = 3/2^+$ decuplet baryon wave-functions seem to violate the connection between spin and statistics. Consider e.g. $N^{*++} \sim uuu$. This is a ground state for system of three u quarks.

Spatial wavefunction has zero angular momentum and is totally symmetric. But N^{*++} has spin $+3/2$ and the spins of all u quarks must be lined up in the same direction for the N^{*++} wavefunction so that the spin wave function is also totally symmetric. Hence the overall wave function is totally symmetric with respect to the interchange of any two pairs of constituent quarks. This violets the Fermi-Dirac statistics since the u-quark is a spin $+1/2$ fermion.

1.2 Coloured Quarks :

Symmetric Quark Model :

In simple quark model, Baryons are built from three quarks and the total SU(6) x O(3) three quark wave function is symmetric under interchange of any two quarks.

But the Baryons are antisymmetrized with respect to each other since they are fermions.

From this, it is seen that quarks are funny : they are symmetrized in sets of three but one set of three is antisymmetrized with respect to another set.

Greenberg suggested that, quarks are parafermions of order 3 and obey parastatistics.

Colour degree of Freedom :

We can retain the symmetric quark in SU(6)xO(3) system and antisymmetrize the baryons only by introducing a new degree of freedom called colour. The quarks can have three primary colours namely Red, Yellow and Blue. The proton requires each of its quarks to have a different colour. Denoting the 'flavours' of the quark by u,d,s..... etc. and the 'colours' by subscripts 1,2,3 we have

Table 1.1 colour and flavour assignment of quarks

$$\text{flavour}\ \updownarrow\quad \begin{array}{l} u_\alpha = (u_1, u_2, u_3) \\ d_\alpha = (d_1, d_2, d_3) \\ s_\alpha = (s_1, s_2, s_3) \\ c_\alpha = (c_1, c_2, c_3) \\ b_\alpha = (b_1, b_2, b_3) \\ t_\alpha = (t_1, t_2, t_3) \\ \longleftarrow \text{colour} \longrightarrow \end{array}$$

The six types (flavours) of quarks correspond to six distinct colour triplets. The colour $SU(3)^c$ group operators change the quark from one colour to another but leave the flavour unchanged:

$u_1 \longleftrightarrow u_2$, $u_2 \longleftrightarrow u_3$, $u_3 \longleftrightarrow u_1$

or

$d_1 \longleftrightarrow d_2$, $d_2 \longleftrightarrow d_3$, $d_3 \longleftrightarrow d_1$ and so on.

Salient features of the scheme

1. Along with the hypothesis of an extra degree of freedom, it is postulated that only colour singlets are physically observable states.

2. Since there are colour singlets in the product $3 \otimes 3^*$ and $3 \otimes 3 \otimes 3$, only $q\bar{q}$ and qqq configurations can bind into physically observable hadrons while q, qq, or qqqq states cannot be seen experimentally q : 3

$\checkmark\ q\bar{q}\ :\ 3 \otimes \bar{3} = 1 \oplus 8$ $\qquad qq\bar{q} = 3 \otimes 3 \otimes \bar{3} = 3 \oplus 6 + \bar{3} \oplus 15$

$qq\ :\ 3 \otimes 3 = 6 \oplus 3$ $\qquad \checkmark\ qqq = 3 \otimes 3 \otimes 3 = 1 \oplus 8 + 8 \oplus 10$

3. The N^{*++} wavefunction is now antisymmetric

$N^{*++} \simeq U^{\alpha}(X_1) u^{\beta}(x_2) u^{\gamma}(x_3)\ \epsilon_{\alpha\beta\gamma}$

where, α, β, γ are colour indices 1,2,3.

Hence spin-statistics relation is maintained.

We note that the colour SU(3) has nothing to do with ordinary SU(3) which deals with Isospin and Hypercharge. The flavour SU(n) symmetries with n= 2,3,4 ..... break, giving rise to mass-differences of particles, but colour SU(3) is an exact symmetry which cannot be broken. Thus we have a peculiar situation where hadrons are composed of particles which themselves cannot be observed. Quarks can exist only inside the hadrons and can never be free. This property is known as quark confinement.

Further, physicist C.N.Yang and Robert Laurance Mills in 1954 have developed a gauge theory for strong interactions called Quantum Chromodynamics (QCD) in which the colour quantum number plays a similar role to that of the electric charge in QED.

In QCD, the coloured quarks will interact with each other through the exchange of gluons in a manner analogous to the exchange of the photon between the charged particles. These interactions are responsible for colour-dependent and flavour-independent binding of quarks into hadrons.

1.3 Charges of Coloured Quarks :[2]

The (u,d,s) triplet in the colour states RBY will have charges

Table 1.2, Charges of quarks

Flavour / Colour	u	d	s
R	Z_R	Z_R-1	Z_R-1
B	Z_B	Z_B-1	Z_B-1
Y	Z_Y	Z_Y-1	Z_Y-1

with constraint that,

$$Z_R + Z_B + Z_Y = 2$$

The constraint follows from the requirement that $N^{*++} \sim (u_R u_B u_Y)$ has charge 2.

The average charges of uds is therefore,

$$e_u = 1/3\ (Z_R+Z_B+Z_Y) = 2/3.$$

$$e_d = e_s = 1/3\ [(Z_R-1)+(Z_B-1)+(Z_Y-1)] = 1/3[Z_R+Z_B+Z_Y-3]$$

$$= 1/3[2-3] = -1/3$$

Hence all baryons made up of one R, one B and one Y quark will have the same charges as in the simple quark model, since average quark charges are same as for uncoloured quarks.

There are two models :

(1) Greenberg-Zwargier(1966), Gell-Mann(1972).

This is a model in which Electromagnetism is 'colour-blind.'

$\therefore Z_R = Z_B = Z_Y = 2/3$

Table 1.3 Charge assignment of quarks in Gell-Mann model.

Flavour / Colour	u	d	s
R	2/3	-1/3	-1/3
B	2/3	-1/3	-1/3
Y	2/3	-1/3	-1/3

This model contains three identical triplets. If RBY generate a symmetry SU(3)colour, then that will be exact symmetry in nature.

(2) Han-Nambu Model (1965)

In this model Electromagnetism can distinguish, or 'spectrum analyse' the quarks.

$Z_R = 0, \; Z_B = Z_Y = 1$

Table 1.4 Charges of quarks in Han-Nambu Scheme

Flavour / Colour	u	d	s
R	0	-1	-1
B	1	0	0
Y	1	0	0

In this model, quarks can have integral charges.

1.4 Colour as Symmetry :

Let the RYB degree of freedom generate an [SU(3)] colour group.

Then the Baryons will be

$[SU(6)^{\text{flavour}} \otimes O(3)^{\text{Ang.momt}} \otimes SU(3)^{\text{colour}}]$ antisymmetric.

Because Pauli exclusion principle is to be satisfied, $\therefore$ The familiar Baryons of the symmetric quark model will be

$[SU(6) \otimes O(3)]_{symmetric} \otimes [SU(3)_{colour}]$ antisymmetric.

This requires that they are coloured singlets, because the totally antisymmetric three body state in SU(3) is a singlet.

Again the antisymmetric singlet colour state requires that the three quarks to be one R, one B and one Y.

The quarks form a representation of

$SU(3)_{flavour} \otimes SU(3)_{colour}$

We may write the Gell-Mann-Nishijima relation as

$Q = (I_3 + Y/2) + \alpha\tilde{I}_3 + \beta\tilde{Y}/2)$

where α and β are arbitrary constants and the tildas refer to $SU(3)_{colour}$ group.

We will define R,B to be the $\tilde{I}_3$ = +1/2, −1/2 states respectively.

Then the charges of u quarks are

$Z_R = 2/3 + \alpha/2 + \beta/6$

$Z_B = 2/3 - \alpha/2 + \beta/6$

$Z_Y = 2/3 - \beta/3$

This is consistent with the constraint that

$Z_R + Z_B + Z_Y = 2$

In Gell-Mann scheme, $\alpha = \beta = 0$

$\therefore$ The quark charges are singlet under SU(3) colour.

In Han-Nambu scheme,

$\alpha = \beta = -1 \Rightarrow Z_R = 0,\ Z_B = +1,\ Z_Y = 1.$

Thus the charges are 3^* under SU(3) colour.

In conclusion we say that, the charge is $[3,3^*]$ under $[SU(3)_{flavour} \otimes SU(3)_{colour}]$.

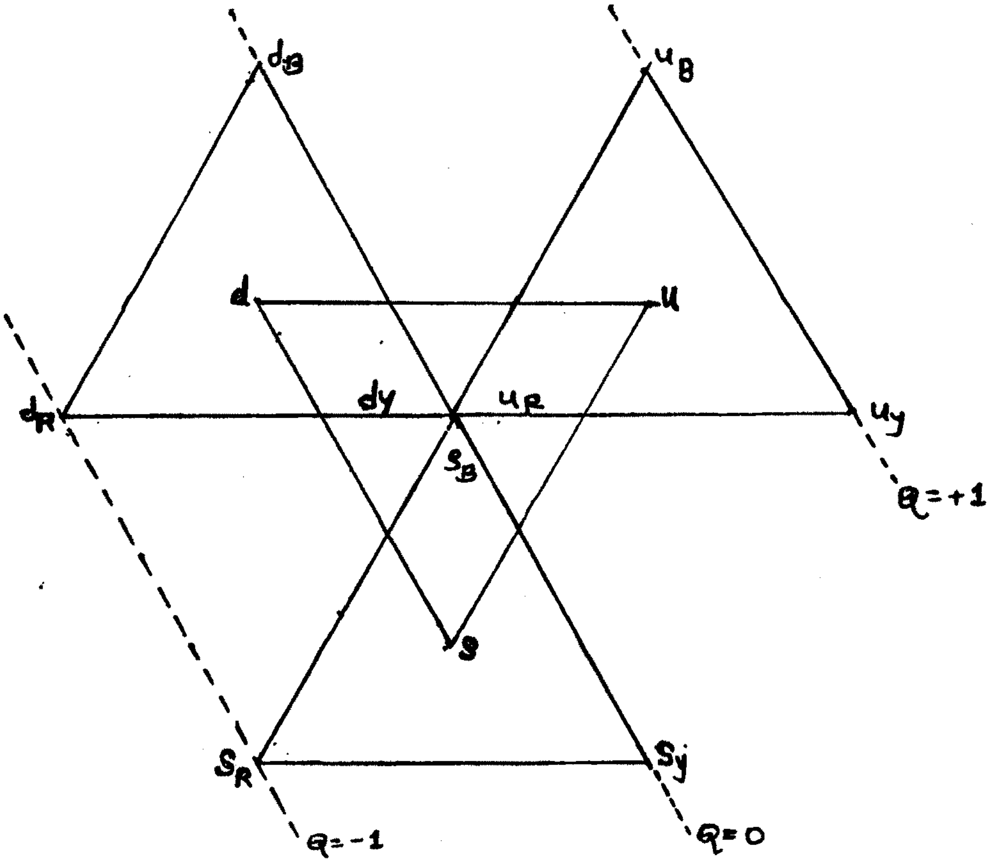

Fig. 1.1 Weight diagram of Han-Nambu quarks.

The inverted triangle represents the triplet uds whereas the triangles (antitriplets) show the spectrum analysis of each quark into RBY of $SU(3)_c$.

1.5 Meson Spectroscopy :

This places no constraints on $Z_R Z_B Z_Y$.

Consider uncoloured quark model.

we have, $\pi^+ = u\bar{d}$

The charge is given by,

$\langle u\bar{d} \,|\, e_q + e_{\bar{q}} \,|\, u\bar{d} \rangle = e_u + e_{\bar{d}} = 2/3 + 1/3 = 1.$

Consider the coloured quarks. The colour singlet π^+ can be written as,

$$\left(u\bar{d}, \frac{1}{\sqrt{3}} (R\bar{R} + B\bar{B} + Y\bar{Y}) \right) = \frac{1}{\sqrt{3}} (u_R\bar{d}_R + u_B\bar{d}_B + u_Y\bar{d}_Y)$$

The charge is given by,

$$\langle \pi^+, \hat{1} | \hat{Q} | \pi^+, \hat{1} \rangle = \frac{1}{3} \langle u_R\bar{d}_R + u_B\bar{d}_B + u_Y\bar{d}_Y \,|\, e_q + e_{\bar{q}} \,|\, u_R\bar{d}_R + u_B\bar{d}_B + u_Y\bar{d}_Y \rangle$$
$$= \frac{1}{3} [(Z_R + Z_B + Z_Y) + (1-z_R) + (1-Z_B) + (1-Z_Y)]$$
$$= 3/3 = 1$$

This result is obtained without any constraint on $Z_{R,B,Y}$.

Conclusion :

Meson spectroscopy requires only that uds form a triplet and that in $SU(3)_c$ the mesons are colour neutral ($R\bar{R}$, $B\bar{B}$, $Y\bar{Y}$) in arbitrary weights but not $R\bar{B}$ etc.)

We do not see nine coloured pions, therefore the conventional pion singlet must be colour singlets.

If colour reveals itself, then it would do so in 'exotic' states like mesons with charge 2. (e.g. $u_y\bar{d}_R$) or baryons with charge 3.

Once the colour is revealed, there is no reason why coloured quarks cannot be produced.

But the energies so far probed in e^+e^- annihilation give no suggestion that colour is revealed.

Thus, we may conclude that, colour singlets lie low in mass and colour non-singlets (e.g. 8,3, ...etc.)have much higher masses.

When colour non-singlet states are pushed to infinite masses, then only colour $\hat{1}$ (singlet)would exist as a physically observable states and quarks would be permanently confined. At any finite energy, we see only 'average' quark charges, which we cannot distinguish from Gell-Mann's simple quark model.