Chiral Properties of Flavor SU(3) Baryon Fields

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As the chiral symmetry of QCD is spontaneously broken, $SU(N_f)_L \otimes SU(N_f)_R \to SU(N_f)_V$ (N_f being the number of flavors), the observed hadrons are classified by the residual symmetry group representations of $SU(N_f)_V$. The full chiral symmetry may then conveniently be represented by its non-linear realization and this broken symmetry plays a dynamical role in the presence of the Nambu-Goldstone bosons and their interactions.

Yet, as pointed out by Weinberg [1], there are situations when it makes sense to consider algebraic aspects of chiral symmetry, i.e. the chiral multiplets of hadrons. Such hadrons may be classified in linear representations of the chiral symmetry group with some representations mixing. If hadrons belong to certain representations of the chiral symmetry group, some physical properties such as the axial coupling constants are determined by this symmetry. Therefore, the question as to what chiral representations, possibly with mixing, the hadrons belong to is of fundamental interest [2].

Motivated by this argument, we perform a complete classification of baryon fields written as local products (without derivatives) of three quarks according to chiral symmetry group $SU(3)_L \otimes SU(3)_R$ [3]. Technically, the $SU(3)$ algebra introduces more complications, which makes insight less at work. Hence, here we attempt to explore a rather technical aspect which enables one to perform systematic classification. We derive general transformation rules for baryon fields for the classification, while maximally utilizing the Fierz transformations in order to implement the Pauli principle among the quarks.

We find that the three-quark fields take several different Lorentz group representations which put some constraints on possible chiral representations. As explained in the above, since the present results reflect essentially the Pauli principle, they can conveniently summarized as shown in Table 1 by using the permutation symmetry properties. This table explains also the previous results for the case of isospin $SU(2)_L \times SU(2)_R$ [4]. From this table we have explicitly shown that the role of the Pauli principle effective in separate sector of the left and right handed fermions.

Table 1: Structure of allowed three-quark baryon fields.

Lorentz	Spin	Young table for Chiral	Chiral $SU(2)$	Chiral $SU(3)$	Flavor
$(\frac{1}{2},0)\oplus(0,\frac{1}{2})$	1/2	$([21],-)\oplus(-,[21])$ $([1],[11])\oplus([11],[1])$	$(2,1)\oplus(1,2)$	$(8,1)\oplus(1,8)$ $(3,\bar{3})\oplus(\bar{3},3)$	8 1, 8
$(1,1/2)\oplus(1/2,1)$	1/2, 3/2	$([2],[1])\oplus([1],[2])$	$(3,2)\oplus(2,3)$	$(6,3)\oplus(3,6)$	8, 10
$(3/2,0)\oplus(0,3/2)$	3/2	$([3],-)\oplus(-,[3])$	$(4,1)\oplus(1,4)$	$(10,1)\oplus(1,10)$	10

In the present world with spontaneously breaking of chiral symmetry, states of pure chiral (axial) symmetry representation do not occur, but in general they can mix in a state having a definite flavor symmetry. The present result shows, three-quark structure accommodates only a few number of (or unique) representations, for instance, for the spin 1/2 field of Dirac spinor, the allowed chiral representations are two having the structure of Young tableaux ([21], −) and ([1],[11]), where − indicates singlet. The ([21], −) representation corresponds respectively to $(2,1)$ and $(8,1)$ for $SU(2)$ and $SU(3)$, while ([1], [11]) to $(2,1)$ and $(3,6)$, respectively. They have the same permutation symmetry structure as that of the Lorentz group. In this way, the Lorentz (spin) and flavor structures are combined into the structure of total symmetry. We have also calculated axial coupling constants as well as their F/D ratios. We find that they are determined by the chiral representation which is a feature of the linear realization of chiral symmetry.

References

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