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EXPERIMENTAL TESTS OF BROKEN $\tilde{U}(12)$ AND APPROXIMATE $U(6) \times U(6)$

Symmetry breaking has recently been introduced into calculations based on the $\tilde{U}(12)$ theory[1] in order to treat disagreements with experiment and difficulties in principle which follow from the assumption of strict $\tilde{U}(12)$ invariance. Although the use of momentum spurions (kinetons) and simple derivative couplings[2] lead to some useful results, the number of independent amplitudes and free parameters appearing in these treatments greatly reduces the predictive power of the symmetry scheme. We should like to point out that predictions from certain subgroups of $\tilde{U}(12)$ remain valid for appropriately chosen sets of processes to any order in such symmetry-breaking terms. The chain of subgroups obtained in this way is just the chain proposed by DASHEN and GELL-MANN[3], in their non-chiral $U(6) \times U(6)$ approximate symmetry. Predictions based on these subgroups are therefore valid both in broken $\tilde{U}(12)$ to all orders in kinetons and simple derivative couplings and in the DGM theory. We also give some examples of new predictions which follow from the W-spin collinear subgroup[4].

The kinetic spurion has the form $\gamma^\mu p_\mu$, where the gamma matrices can be considered as acting individually on each "quark component" in a meson or baryon. If all four γ-matrices are present and break the symmetry, $\tilde{U}(12)$ is reduced to ordinary $SU(3)$ and no new predictions are obtained. However, if any component of the momentum is zero for all particles in the process considered in a particular Lorentz frame, the corresponding γ-matrix does not appear in any symmetry-breaking term, and a non-trivial subgroup of $\tilde{U}(12)$ remains unperturbed to all orders in the symmetry breaking. Consider the following cases:

1. "Zero-dimensional processes." If all particles in a particular state are at rest, $p_x = p_y = p_z = 0$ and the $\tilde{U}(12)$ symmetry is broken only by $\gamma^0 p_0$ spurions. The subgroup of $\tilde{U}(12)$ which commutes with γ^0 remains a good symmetry for these states and can be used to classify particles at rest. This subgroup is just the non-chiral $U(6) \times U(6)$ of DGM, defined by the operators

$(1\pm\gamma^{0})\sigma_i\lambda_j$; $i=0,1,2,3; j=0,1,\ldots,8$, where $\sigma_0=\lambda_0=1$, and λ_j are the generators of a U(3) algebra. The multiplets of particles obtained from broken $\tilde{U}(12)$ are thus identical to those of U(6) x U(6), i.e. 56 baryons, 36 (not 35) mesons, etc.[5]

2. "One-dimensional processes". If all particles in a given set of processes are moving in the z-direction in a particular Lorentz frame, $p_x=p_y=0$ for all particles and $\tilde{U}(12)$ symmetry is broken only by $\gamma^{0}p_0$ and $\gamma^{z}p_z$ spurions. The subgroup of $\tilde{U}(12)$ which commutes with γ^{0} and γ^{z} remains a good symmetry for these processes. This is the $SU(6)_W$ group defined[4] by the operators λ_j, $\sigma_z\lambda_j$, $\gamma_0\sigma_x\lambda_j$ and $\gamma_0\sigma_y\lambda_j$, which commutes with Lorentz transformations in the z-direction and therefore gives a momentum-independent classification of all particle states with momenta only in the z-direction. This group has been used to obtain many predictions for collinear processes[6] such as vertex functions, form factors, forward and backward scattering, and two-body decays, including electromagnetic and weak decays.

3. "Two-dimensional processes". If $p_x=0$ for all particles, the symmetry breaking terms transform like γ^{y}, γ^{z} and γ^{0}. The subgroup which commutes with these as well as with all Lorentz transformations in the y-z plane is the U(3) x U(3) defined[3] by $(1\pm\gamma_0\sigma_x)\lambda_j$.

In this discussion we have defined subgroups of $\tilde{U}(12)$ which are unperturbed by the commonly-used symmetry-breaking mechanisms. There is no proof that these are the dominant symmetry breakers, and a complete justification of these procedures probably awaits a more detailed dynamical description. The subgroups defined above are those under which the equations of motion for free particles are invariant in the subspace of free-particle states defined by the vanishing of certain momentum components. The predictions obtained from these subgroups assume the following properties of the dynamics: (a). The interaction or vertex function is invariant under the appropriate subgroup. (b). In a dynamical theory in which a given transition amplitude is expressed as a sum over intermediate states, the contribution can be neglected from intermediate states outside the appropriate subspace, (e.g. from those with non-vanishing values of p_x for collinear processes). Note that condition (a) allows the use of derivative couplings which are expressible as functions of $\not p$ as well as those invariant under the full $\tilde{U}(12)$. More complicated derivative couplings, involving components of γ-matrices which are not parallel to the momenta are neglected. Note also that for collinear processes, the contributions from intermediate states arising in simple pole diagrams are in the subspace and are included. This includes all one-particle exchange graphs and resonances in the direct channel[7].

We now consider several collinear processes which can be treated by $SU(6)_W$.

1. Decays of 2^+ Mesons. Consider mesons classified in the representations that can be constructed from two quarks and two antiquarks[5], such as the 4212 of $\tilde{U}(12)$ or the $(21,\overline{21})$ of $U(6) \times U(6)$. The W-spin classification of the various polarization states are as follows[8]. The state $S_z = W_z = 2$ has $W=2$, the state $S_z = W_z = 1$ has $W=1$, and the $S_z = W_z = 0$ state is a mixture of $W=0$ and $W=2$. The longitudinally polarized vector meson state V_0 has $W=0$ and the pseudoscalar meson has $W=1$. The following decay is therefore forbidden in both the broken $\tilde{U}(12)$ abd DGM theories.

$$2^+ \longrightarrow P + V_0 \qquad \text{(forbidden)} \qquad (1)$$

This selection rule does not provide an experimental test for the theory, as it also follows from conservation of angular momentum and parity. This is similar to the case of the three meson couplings (PPP) and (PV_oV_o) which are forbidden by angular momentum and parity conservation and also independently by W-spin conservation[8]. In other internal symmetries, parity and angular momentum are external and give selection rules in addition to those imposed by the symmetry. It is remarkable that W-spin, which does not explicitly include orbital angular momentum, independently gives the same selection rules in these cases.

2. Proton-Antiproton Annihilation at Rest into Two Mesons. This process is forbidden[9] by $\tilde{U}(12)$, and results from a Γ^0 selection rule[10]. This selection rule is broken by a kinetic spurion which does not commute with Γ^0, and the process is not forbidden in $SU(6)_W$.

The result obtained[11] is

$$(\bar{p}p|\pi^+\pi^-):(\bar{p}p|K^+K^-):(\bar{p}p|\bar{K}^0K^0)=1:2:1 \qquad (2)$$

3. Vector Meson Exchange in B* Production. The vanishing of the (BB^*V_0) vertex follows from W-spin conservation[4]. This is just the vertex neglected in the Stodolsky-Sakurai vector-meson-photon analogy used in treating peripheral reactions[12]. It would be of interest to check the validity of this model in more detail.

In addition to these results, we note that all predictions for collinear processes which have been obtained from $\tilde{U}(12)$ calculations are unaffected by simple symmetry breaking of the types considered here[13], if they follow from invariance under $SU(6)_W$. Such predictions follow from both broken $\tilde{U}(12)$ and $U(6) \times U(6)$, and therefore cannot distinguish between the two theories.

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7. We wish to thank A. SALAM, R. DELBOURGO and J. STRATHDEE for a discussion of this point.

8. This is obtained by the methods of Ref. 4. The classification of the state $W_z = S_z = 2$ is trivial, and the others are obtained by using the S-spin and W-spin lowering operators, taking into account that the total spins of the quarks and antiquarks both remain equal to one, and that there is a phase difference between the W-spin and S-spin lowering operators for antiquarks.

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11. F. HUSSEIN and P. ROTELLI, Phys. Letters 16, 183 (1965) and R. DELBOURGO *et al.*[9], Footnote 7, obtain this result using symmetry breaking. Note that our result (2) does not include the kinematic factors resulting from the $K\pi$ mass difference, whereas the ratio quoted in Ref. 9 includes a large kinematic factor. This result is equivalent to ours when the kinematic factor is removed. We suggest that results including such kinematic factors should not be rounded off to the nearest integer, as these give the impression of being ratios of Clebsch-Gordan coefficients which do not include kinematic factors.

12. L. STODOLSKY and J.J. SAKURAI, Phys. Rev. Letters 11, 90 (1963). We thank D. SUTHERLAND and W.W. ALLISON for calling our attention to this point.

13. One example is the stability of the Johnson-Treiman relations against symmetry-breaking. This was determined by direct calculations by Charap and Matthews[2] and follows directly from $SU(6)_W$.