χ-SU(3) BETHE SALPETER MODEL: EXTENSION TO SU(6) AND SU(8) SPIN-FLAVOR SYMMETRIES

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Consistent SU(6) and SU(8) spin-flavor extensions of the SU(3) flavor Weinberg-Tomozawa (WT) meson-baryon chiral Lagrangian are constructed, which incorporate vector meson degrees of freedom. In the charmless sector, the on-shell approximation to the Bethe-Salpeter (BS) approach successfully reproduces previous SU(3) WT results for the lowest-lying s–wave negative parity baryon resonances. It also provides some information on the dynamics of heavier ones and of the lightest d-wave negative parity resonances, as e.g. the $\Lambda(1520)$. For charmed baryons the scheme is consistent with heavy quark symmetry, and our preliminary results in the strangeness-less charm $C = +1$ sector describe the main features of the three-star $J^P = 1/2^-$ $\Lambda_c(2595)$ and $J^P = 3/2^-$ $\Lambda_c(2625)$ resonances. We also find a second broad $J^P = 1/2^-$ state close to the $\Lambda_c(2595)$.

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I. χSU(6)-BS MODEL

A consistent SU(6) extension of the WT SU(3) chiral Lagrangian has been recently derived in Ref. [1]. The building blocks of this extension are the {35} (for mesons) and {56} (for baryons) representations[1] of SU(6). These representations can accommodate the 0^- meson octet (K, π, η and $\bar{K}$), and the 1^- meson nonet (K^*, ρ, ω, $\bar{K}^*$ and ϕ); and the the spin $1/2^+$ members of the nucleon octet (N, Σ, Λ and Ξ) and the spin $3/2^+$ members of the Δ decuplet (Δ, Σ^*, Ξ^* and Ω), respectively. The scheme of Ref. [1] starts by assuming that the s-wave effective meson–baryon Hamiltonian is SU(6)-spin-flavor invariant, and it makes use of the underlying chiral symmetry to determine the value of the SU(6) irreducible matrix elements from the SU(3)-flavor WT interaction. This is possible since the WT Lagrangian is not just SU(3) symmetric but also chiral ($\mathrm{SU}_L(3) \otimes \mathrm{SU}_R(3)$) invariant. Symbolically,

$$\mathcal{L}_{\mathrm{WT}}^{\mathrm{SU(3)}} = \mathrm{Tr}\left([M^\dagger, M][B^\dagger, B]\right) \tag{1}$$

This structure, dictated by chiral symmetry, is more suitably analyzed in the t-channel. The mesons M fall in the SU(3) representation {8} which is also the adjoint representation. The commutator $[M^\dagger, M]$ indicates a t-channel coupling to the $\{8\}_a$ (antisymmetric) representation, thus

$$\mathcal{L}_{\mathrm{WT}}^{\mathrm{SU(3)}} = \left[(M^\dagger \otimes M)_{\{8\}_a} \otimes (B^\dagger \otimes B)_{\{8\}}\right]_{\{1\}} \tag{2}$$

Since the {35} is the adjoint representation of SU(6), the unique SU(6) extension is

$$\mathcal{L}_{\mathrm{WT}}^{\mathrm{SU(6)}} = \left[(M^\dagger \otimes M)_{\{35\}_a} \otimes (B^\dagger \otimes B)_{\{35\}}\right]_{\{1\}} \tag{3}$$

The potentials, $V_{IY}^J(s)$, deduced from this SU(6) Lagrangian[2] are used to solve the coupled channel Bethe Salpeter Equation (BSE)[2, 3] within the so-called on shell renormalization scheme[4, 5], leading to unitarized s-wave meson–baryon scattering amplitudes T_{IY}^J (I, Y, J are the isospin, hypercharge and total angular momentum)

$$T_{IY}^J(s) = \frac{1}{1 - V_{IY}^J(s) J_{IY}^J(s)} V_{IY}^J(s) \tag{4}$$

[1] We label the SU(N) multiplets by their dimensionality enclosed between curly brackets.

[2] Some explicit SU(6) breaking effects, due to the use of physical (experimental) hadron masses and meson decay constants, are taken into account[2].

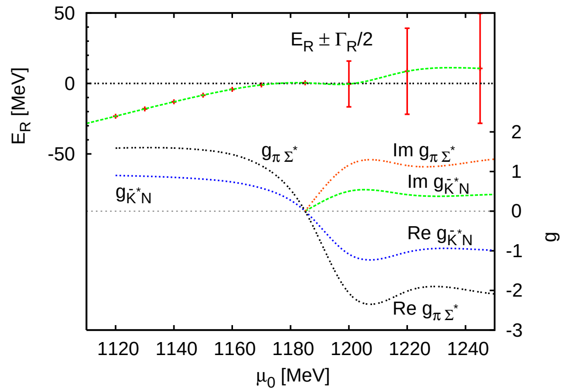

FIG. 1: Results[2] for the $3/2^-$ $\Lambda(1520)$ pole position ($M_R = m_\pi + M_{\Sigma^*} + E_R$, Γ_R) and couplings to the $\pi\Sigma^*$ and $\bar{K}^*N$ channels as function of the renormalization scale μ_0.

where $J^J_{IY}(s)$ is a diagonal loop function in the coupled channel space, which needs to be renormalized[2, 6]. In a given JIY sector, physical resonances appear as complex poles in the second Riemann sheet[6] of all matrix elements of $T(s)$ in the coupled channel space. The pole position determines the mass and width of each resonance, while the different residues for each meson-baryon channel give the respective couplings and branching ratios[7]. This model[2, 8] reproduces the essential features of previous studies[3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14] (properties of the lowest lying $1/2^-$ and $3/2^-$ resonances) and, in addition, it sheds some light on the role played by the vector mesons in this context. For instance, we show in Fig. 1 some predictions for the d–wave $\Lambda(1520)$ resonance[2]. We naturally find that this resonance is placed quite close to the $\pi\Sigma^*$ threshold and that its coupling to $\bar{K}^*N$ channel is quite small. Indeed, we obtain a coupling much smaller than the value used by phenomenological studies of the $\Lambda(1520)$ photoproduction[15, 16], which brings in interesting conclusions on the dominant reaction mechanism in these processes[2].

II. χSU(8)-BS MODEL

The extension of the above model to describe charmed baryon resonances is straightforward. We use the $\{63\}$ and $\{120\}$ SU(8) representations to accommodate mesons and baryons, respectively. In addition to those particles considered so far, these representations also contain the 0^- $D_s, D, \eta_c, \bar{D}, \bar{D}_s$ and 1^- $D^*_s, D^*, J/\Psi, \bar{D}^*, \bar{D}^*_s$ mesons, and the $1/2^+$ $\Xi_{cc}, \Omega_{cc}, \Lambda_c, \Sigma_c, \Xi_c, \Xi'_c, \Omega_c$ and the $3/2^+$ $\Omega^*_{ccc}, \Xi^*_{cc}, \Omega^*_{cc}, \Sigma^*_c, \Xi^*_c, \Omega^*_c$ charmed baryons. Since the $\{63\}$ is the SU(8) adjoint representation, from the discussion above, the natural extension of the WT lagrangian to the SU(8) spin-flavor symmetry group is

$$\mathcal{L}^{\rm SU(8)}_{\rm WT} = \left[(M^\dagger \otimes M)_{\{63\}_a} \otimes (B^\dagger \otimes B)_{\{63\}}\right]_{\{1\}} \tag{5}$$

We use the above interaction, with some explicit SU(8) breaking effects induced by the use of experimental hadron masses and meson decay constants, to construct the kernel of the corresponding two body meson-baryon BSE. So far, we have only analyzed the strangeness-less charm $C = +1$ sector, where we have naturally found the $1/2^-$ $\Lambda_c(2595)$ (with a very small coupling to the open $\Sigma_c\pi$ channel) and the $3/2^-$ $\Lambda_c(2625)$ resonances. These resonances have a clear parallelism with the four star resonances $\Lambda(1405)$ and $\Lambda(1520)$, which appear in the (charmless) strangeness -1 sector. Besides, similarly to what happens in the case of the $\Lambda(1405)$ resonance, we have also found a second (broad) $J^P = 1/2^-$ state close to the $\Lambda_c(2595)$, but with a much larger coupling to the open $\pi\Sigma_c$ channel.

There have been several works[17, 18, 19] on $s-$ and $d-$wave negative parity charmed baryon resonances. In all these works the zero-range t-channel exchange of vector mesons is identified as the driving force for the $s-$wave scattering of pseudo-scalar mesons off the baryon ground states. A serious limitation of this t-channel vector meson-exchange (TVME) model is that while the pseudo-scalar mesons D and D_s are included in the coupled-channel dynamics, their vector partners D^* and D^*_s are completely ignored. This is not justified since QCD acquires a new spin-flavor symmetry[20], Heavy Quark Symmetry (HQS), when the quark masses are much larger than the typical confinement scale, $\Lambda_{\rm QCD}$. HQS predicts that all type of spin interactions vanish for infinitely massive quarks. Neglecting corrections of the order $\Lambda_{\rm QCD}/m_c$, the D and D^* or D_s and D^*_s mesons form a multiplet of degenerate hadrons[20]. For finite charm quark mass, the D and the D^* meson masses differ in just about one pion mass, even less for the strange charmed mesons, and thus it is reasonable to expect that the coupling $DN - D^*N$ might play an important role.

Our scheme naturally respects HQS, which justifies, at least in the charm sector, the assumption that the quark interactions are spin independent. The inclusion of D^* degrees of freedom in the coupled channel formalism changes the dynamics. For instance, we find that D^*N component, absent in the TVME model, of the $\Lambda_c(2595)$ is sizable and much larger than the DN and the $\Sigma_c\pi$ ones. As a consequence, we predict a totally different dynamical picture for this resonance.

Acknowledgments

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