Meson and Baryon resonances

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Abstract

In this talk I review recent advances on the structure of the meson and baryon resonances which can be dynamically generated from the interaction of mesons or mesons and baryons. Particular emphasis is put on results involving vector mesons, which bring new light into the nature of some of the observed higher mass mesons and baryons and make predictions for new states.

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1. Introduction

The combination of chiral Lagrangians and unitarity in coupled channels has given rise to a new area of research, $U\chi PT$, which has proved very rich, enlarging the realm of applicability of the information contained in the chiral Lagrangians much beyond what the perturbative scheme of χPT allows. The nonperturbative scheme, unitarized chiral perturbation theory ($U\chi PT$) provides a reliable method to study meson baryon interactions and gives rise to a wealth of dynamically generated meson and baryon states, resulting from the interaction, which do not qualify as standard $q\bar{q}$ or $3q$ states [1]. Typical examples are the generation of low lying scalar meson states from the interaction of two pseudoscalars, the generation of low lying axial vector mesons from the interaction of a pseudoscalar and a vector, the generation of $J^P = 1/2^-$ baryons from the interaction of one pseudoscalar and one baryon of the octet or $J^P = 3/2^-$ baryons from the interaction of a pseudoscalar and one baryon of the decuplet.

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Very recently the interaction of vector mesons among themselves or with baryons has been tackled and novel results are appearing that will be reported here. The scheme that makes this study possible is the hidden gauge approach for vector mesons, pseudoscalars and photons [2], which contains the basic chiral Lagrangians for the interaction of pseudoscalars and extends the scheme to include explicitly vector mesons with the interaction among themselves and with other hadrons. We expose the basic ideas in the following section.

2. The hidden gauge formalism

The HGS formalism to deal with vector mesons [2] is a useful and internally consistent scheme which preserves chiral symmetry. In this formalism the vector meson fields are gauge bosons of a hidden local symmetry transforming inhomogeneously. After taking the unitary gauge, the vector meson fields transform exactly in the manner as in the non linear realization of chiral symmetry. The Lagrangian involving pseudoscalar mesons, photons and vector mesons can be written as

$$\mathcal{L} = \mathcal{L}^{(2)} + \mathcal{L}_{III}; \quad \mathcal{L}^{(2)} = \frac{1}{4} f^2 \langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + \chi^\dagger U \rangle \tag{1}$$

$$\mathcal{L}_{III} = -\frac{1}{4} \langle V_{\mu\nu} V^{\mu\nu} \rangle + \frac{1}{2} M_V^2 \langle [V_\mu - \frac{i}{g} \Gamma_\mu]^2 \rangle, \tag{2}$$

where $\langle ... \rangle$ represents a trace over $SU(3)$ matrices. The covariant derivative is defined by

$$D_\mu U = \partial_\mu U - ieQA_\mu U + ieUQA_\mu, \tag{3}$$

with $Q = diag(2, -1, -1)/3$, $e = -|e|$ the electron charge, and A_μ the photon field. The chiral matrix U is given by $U = e^{i\sqrt{2}\phi/f}$ with f the pion decay constant ($f = 93$ MeV). The ϕ and V_μ matrices are the usual $SU(3)$ matrices containing the pseudoscalar mesons and vector mesons respectively.

In this formalism one finds cancellations among terms, such that ultimately the photon couples to the pseudoscalars or vector mesons through direct coupling to a neutral vector, the basic feature of vector meson dominance, VMD.

In $\mathcal{L}_{III}$, $V_{\mu\nu}$ and Γ_μ are defined as

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - ig[V_\mu, V_\nu]; \ \Gamma_\mu = \frac{1}{2}[u^\dagger(\partial_\mu - ieQA_\mu)u + u(\partial_\mu - ieQA_\mu)u^\dagger] \tag{4}$$

with $u^2 = U$. The hidden gauge coupling constant g is related to f and the vector meson mass (M_V) through $g = \frac{M_V}{2f}$, which is one of the forms of the KSFR relation.

With these lagrangians one can then study meson-meson (pseudoscalars), meson-vector, meson-baryon, vector-vector or vector-baryon interactions. For the vector-vector case one has the contact term of the four vectors Lagrangian or the exchange of vector mesons using the three vector vertices. From the $\langle V_{\mu\nu} V^{\mu\nu} \rangle$ term of $\mathcal{L}_{III}$, (see Eq. (2)), one obtains the coupling of three vector mesons and four vector mesons, which are essential in the present work.

2.1 Axial vector mesons.

This is one example where this theory shows its value. The t-exchange of a vector meson between a vector and a pseudoscalar leads to this interaction, which in the limit of neglecting the three momentum of the particles versus the mass of the vector mesons gives the effective chiral Lagrangian used in [3,4] by means of which the low lying axial vector resonances, a_1, b_1, K_1, f_1, h_1 are dynamically generated. An interesting novelty to be recalled in this presentation is the fact that in [4] two states for the $K_1(1270)$ were found while the $K_1(1400)$ did not show up in the approach as a pole of the t-matrix. The novel interesting thing to note is that there was already experimental information supporting the existence of the two $K_1(1270)$ states in the $K^- p \to K^- \pi^+ \pi^- p$ reaction of [5], however the experimental analysis had been forced with just one resonance at the expense of introducing a large background, much larger than the resonance contribution, which upon interference produced the experimental shape of the $K^*\pi$ and ρK mass distributions. However, in a reanalysis of the reaction [6] it was shown that two poles can be found at (1195-i123) MeV and (1284-i73) (the width is double the imaginary part), the first one coupling mostly to $K^*\pi$ and the second one to ρK. According to this, an experiment where the resonance is excited and leads to $K^*\pi$ in the final state should put more weight on the first resonance and if it produces ρK on the second resonance, as a consequence of which, the peaks of these two reactions should be displaced by about 90 MeV and the width in the second experiment should be narrower. This is indeed what the experiment of [5] shows and it was naturally interpreted in favor of the two resonances in the reanalysis of [6].

2.2 Scalar and axial vector mesons with charm.

There is a special session devoted to charm, so here I will be deliberately short, just to recall that within this framework several states are dynamically generated like the scalars $D_{s0}(2317)$ or $D_0(2400)$ [7,8,9], or the axial vector mesons like the X(3872) [7,10,11]. Actually two states with different C-parity are predicted in [11]. Another interesting finding of [9] is a new scalar state of hidden charm nature (mostly $D\bar{D}$), called X(3700) for the approximate mass, for which there seems to be experimental support in the reaction $e^+e^- \to J/\psi D\bar{D}$ close to threshold of [12], as shown in the analysis of the experiment of [13].

2.3 $\rho\rho$ interaction.

In a recent paper the search for dynamically generated states from the vector-vector interaction has been tackled for the first time and the results are very interesting. Taking into account the contact term and the vector exchange terms in the t- and u-channel one finds in [14] that this interaction leads naturally to two states, one scalar, which can be identified with the $f_0(1370)$ although the mass appears around 1500 MeV, and another state of spin 2, which can be neatly identified with the $f_2(1270)$. Once one includes the $\pi\pi$ decay channel, provided also by the theory through a box diagram coming from the ρ decay into two pions, the agreement of mass and width is acceptable. It is interesting to note that the theory provides an interaction which is stronger for the case of the tensor state, leading naturally to a more bound state for the tensor than for the scalar.

A further support for this association to the physical states comes from the study of the radiative decay of these resonances into $\gamma\gamma$ [15]. The evaluation is quite easy since in the hidden gauge approach the photon couples to the hadrons always through a direct coupling to the neutral vector mesons (vector meson dominance). Thus the amplitude for

$I^G(J^{PC})$	Theory			PDG data		
	pole position	real axis		name	mass	width
		$\Lambda_b = 1.4$ GeV	$\Lambda_b = 1.5$ GeV			
$0^+(0^{++})$	(1512,51)	(1523,257)	(1517,396)	$f_0(1370)$	1200∼1500	200∼500
$0^+(0^{++})$	(1726,28)	(1721,133)	(1717,151)	$f_0(1710)$	1724 ± 7	137 ± 8
$0^+(1^{++})$	(1802,78)	(1802,49)		f_1		
$0^+(2^{++})$	(1275,2)	(1276,97)	(1275,111)	$f_2(1270)$	1275.1 ± 1.2	$185.0^{+2.9}_{-2.4}$
$0^+(2^{++})$	(1525,6)	(1525,45)	(1525,51)	$f'_2(1525)$	1525 ± 5	73^{+6}_{-5}
$1^-(0^{++})$	(1780,133)	(1777,148)	(1777,172)	a_0		
$1^+(1^{+-})$	(1679,235)	(1703,188)			b_1	
$1^-(2^{++})$	(1569,32)	(1567,47)	(1566,51)	$a_2(1700)$??		
$1/2(0^+)$	(1643,47)	(1639,139)	(1637,162)	K		
$1/2(1^+)$	(1737,165)	(1743,126)		$K_1(1650)$?		
$1/2(2^+)$	(1431,1)	(1431,56)	(1431,63)	$K_2^*(1430)$	1429 ± 1.4	104 ± 4

Table 1

Predictions of states and association to known resonances in the possible cases. In brackets (Mass, Width). Λ_b is the range of a monopole form factor for vector to two pseudoscalars.

this radiative decay is a factor times the coupling of the resonance to $\rho^0\rho^0$ in this case, which is obtained from the residues at the pole of the resonance in the $\rho\rho$ scattering amplitude. The interesting results are $\Gamma(f_0(1370) \to \gamma\gamma) = 0.54$ keV, $\Gamma(f_2(1270) \to \gamma\gamma) = 2.6$ keV. The PDG quotes the result $\Gamma(f_2(1270) \to \gamma\gamma) = 2.71^{+0.26}_{-0.23}$ keV [16]. The situation of the $\gamma\gamma$ decay of the $f_0(1370)$ is rather unclear. The latest edition of the PDG [16] does not quote any value, superseding old results which were ambiguous. The Belle collaboration is pursuing work in this direction, with no final result yet, but strong hints that the $f_0(1370)$ could actually appear at higher energies, around 1470 MeV and with a two gamma width about one order of magnitude smaller than the one of the $f_2(1270)$ [17].

2.4 Extension to the SU(3) vector-vector interaction.

The generalization of the work of [14] to the interaction of the octet of vector mesons with themselves has been done recently [18] and many states are obtained in the coupled channel formalism. A summary of the results obtained and their possible association to states of the PDG are shown in the table below

3. Baryonic resonances.

3.1 Transition form factors.

In the baryonic sector we can quote as interesting developments the evaluation for the first time of transition form factors for resonances dynamically generated. This has been done for the case of the $N^*(1535)$ in [19], where the $A_{1/2}$ and $S_{1/2}$ amplitudes for protons and neutrons for the $N^*(1535) \to p(n)\gamma^*$ have been evaluated. It is interesting to compare the values of our p^* and n^* helicity amplitudes $A_{1/2}$ at $Q^2 = 0$ with those of the PDG. We obtain 0.065 $\mathrm{GeV}^{-1/2}$ and -0.052 $\mathrm{GeV}^{-1/2}$ for the p^* and n^*, respectively, versus the values quoted in the PDG, which include uncertainties from the compilation of data of several analyses, 0.090 ± 0.030 $\mathrm{GeV}^{-1/2}$ for the p^* and -0.046 ± 0.027 $\mathrm{GeV}^{-1/2}$ for the n^*. As one can see, the agreement, within uncertainties, is good. The agreement is particularly good with the recent MAID2007 analyis [20] of $A^p_{1/2} = 66 \pm 7 \cdot 10^{-3} \mathrm{GeV}^{-1/2}$.

The main discrepancy of the results of [19] with the data is in the Q^2 dependence. The theoretical results fall faster than experiment at large Q^2, indicating that there should be a contribution from some other components of the resonance, most probably a three quark component, even if small.

3.2 Mixture of configurations.

It is also worth mentioning a work which goes one step forward in the investigation of the nature of the resonances [21]. The work starts from the realization that in the generation of the $N^*(1535)$ of [22] one needs different subtraction constants for different channels in the dispersion relation, unlike the case of the two $\Lambda(1405)$ states [23]. This is interpreted in [21] as an indication that there are extra components in the wave function apart from the meson baryon components. A reanalysis of the data is done by imposing the same natural subtraction constants in all channels and then adding a CDD pole that accounts for a genuine component of the resonance of non meson-baryon nature, such as to get the same results obtained before with the different subtraction constants. The exercise in [21] shows that such a genuine component is needed for the case of the $N^*(1535)$ but not for the case of the two $\Lambda(1405)$ states.

3.3 Size of dynamically generated resonances.

This has been a frequently asked question since for most scattering observables an answer can be obtained without resorting to describe the spatial distribution of the meson baryon components. However, recently there has been a step forward in this direction in the work of [24] where by coupling the photon to all components of the resonance in the diagonal transition of the resonance to the same resonance, one can obtain the charge distribution of the state. The results obtained in [24] are interesting. The lower mass $\Lambda(1405)$ resonance, around 1390 MeV, has a very small radius reflecting its basic $\pi\Sigma$ nature where there are cancellations between the cloud of the π^+ and the π^-. But this is not he case in the higher mass resonance around 1426 MeV, which is basically the I=0 combination of $K^- p, \bar{K}^0 n$, where the cloud of the K^- is responsible for a large and negative mean square radius.

3.4 Baryon resonances from the vector meson-baryon interaction.

This field is developing fast. In [25] the interaction of the octet of vector mesons with the octet of baryons of the proton are studied along the lines followed for the study of vectors with vectors discussed in the previous section. The results are very interesting. Many states are obtained in this way, all of them degenerate in spin $J^P = 1/2^-, 3/2^-$. Most of the states obtained can be associated to known resonances like the $N^*(1700)(3/2^-)$, $N^*(2080)(3/2^-)$, $N^*(2090)(1/2^-)$, $\Lambda(1800)(1/2^-)$, $\Lambda(2000)(?^?)$, $\Sigma(1750)(1/2^-)$, $\Sigma(1940)(3/2^-)$, $\Sigma(2000)(1/2^-)$, $\Xi(2030)(\geq 5/2^?)$.

Developments with the interactions of vector mesons and the decuplet of baryons have also started [26] with equally interesting results.

4. Conclusions

We have reported recent developments along the lines of chiral unitary theory for the study of meson-meson or meson-baryon interaction, which show that many more mesonic and baryonic states than expected can qualify as dynamically generated. The introduction of elements of the hidden gauge formalism to deal with vector mesons has opened a new door and new states appear involving vector mesons as components. We also reported about further steps given to investigate the nature of resonances, as well as to determine the distribution of electric charge. Altogether, we have given a perspective of the evolution and recent interests of the field, for which one can anticipate a fruitful future.

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