Dynamically generated resonances from the vector octet-baryon decuplet interaction and their radiative decays into γ-baryon decuplet *

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Abstract The dynamically generated resonances from vector meson-baryon decuplet are studied using Lagrangians of the hidden gauge theory for vector interactions. One shows that some of the generated states can be associated with some known baryon resonances in the PDG data, while others are predictions for new states. Furthermore, we calculate the radiative decay widths of these resonances into a photon and a baryon decuplet.

Key words dynamically generated resonances, chiral dynamics, hidden gauge formalism for vector meson interaction

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1 Introduction

The chiral unitary approach has been broadly used in the study of pseudoscalar-pseudoscalar and pseudoscalar-baryon interactions, where it is shown to generate many mesonic and baryonic resonances, respectively[1—5]. From the hidden gauge symmetry formalism, the vector meson interaction is included in the Lagrangian, and then the resonances generated in the vector-vector meson interaction and vector-baryon interaction are obtained[6—10]. In this talk, we will introduce our recent work on how to generate resonances dynamically from the vector octet-baryon decuplet interaction, and then we will discuss the radiative decay into γ-baryon decuplet of these dynamically generated resonances[9, 11].

2 Formalism

The interacting Lagrangian of three vector mesons in the hidden gauge formalism can be written as[12]

$$\mathcal{L}_{VVV} = \mathrm{i}\frac{M_V}{2f}\langle(\partial_\mu V_\nu - \partial_\nu V_\mu)V^\mu V^\nu\rangle = \mathrm{i}\frac{M_V}{2f}\langle(V^\nu\partial_\mu V_\nu - \partial_\mu V_\nu V^\nu)V^\mu\rangle, \quad (1)$$

with M_V the vector meson mass and $f=93$ MeV the pion decay constant.

The coupling of two pseudoscalar mesons and a vector meson takes the the similar form of

$$\mathcal{L}_{VPP} = -\mathrm{i}\frac{M_V}{2f}\langle(\phi\partial_\mu\phi - \partial_\mu\phi\phi)V^\mu\rangle. \quad (2)$$

The ϕ and V_μ matrices are the usual $SU(3)$ matrices containing the pseudoscalar mesons and vector mesons respectively

$$\phi \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{pmatrix}, \quad (3)$$

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and

$$V_\mu \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0+\frac{1}{\sqrt{2}}\omega & \rho^+ & K^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0+\frac{1}{\sqrt{2}}\omega & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu . \quad (4)$$

Therefore, the same approximations that we make for the vector mesons as in Fig. 1, neglecting the the three-momentum versus their mass, are also done for the baryons and then all the amplitudes take the form

$$V_{ij} = -C_{ij}\,\frac{1}{4f^2}\,(k^0+k'^0)\;\vec{\epsilon}\cdot\vec{\epsilon}', \quad (5)$$

where k^0, k'^0 are the energies of the incoming and outgoing vector meson respectively. The amplitudes are thus exactly the ones for PB → PB apart for the factor $\vec{\epsilon}\cdot\vec{\epsilon}'$.

Comparing Eq. (1) and Eq. (2), we can obtain the coupling constants for the reaction B + V → B′ + V′ similarly to the baryon decuplet-pseudoscalar meson coupling constants in Ref. [5].

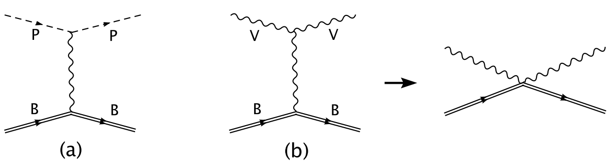

Fig. 1. Diagrams contributing to the pseudoscalar-baryon (a) or vector- baryon (b) interaction via the exchange of a vector meson leading to the effective vector-baryon contact interaction which is used in the Bethe-Salpeter equation

The anomalous term on the process ρΔ → ρΔ is depicted in Fig. 2, where an intermediate ωN state is included. The contributions of the anomalous term to the ρΔ → ρΔ amplitude compared to V are shown in Fig. 3. It is apparent that the contribution of the anomalous term is reasonably smaller than the dominant one of vector meson exchange, hence, in the following calculation, all contributions from anomalous terms are neglected.

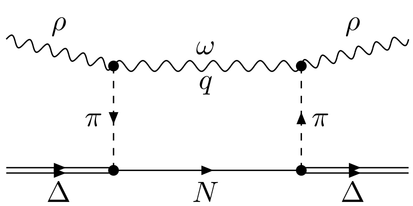

Fig. 2. Term with intermediate ωN in the ρΔ → ρΔ interaction, involving the anomalous ρωπ coupling and pion exchange.

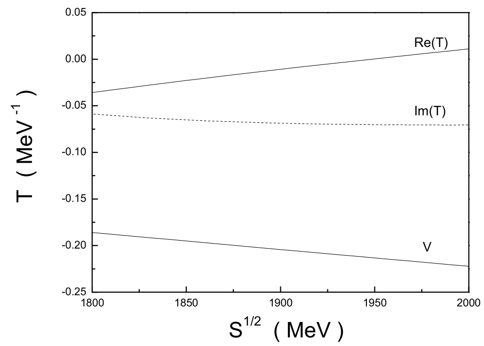

Fig. 3. The real and imaginary parts of the anomalous $T_{\rho\Delta\to\rho\Delta}$ with a intermediate ωN state compared to V as a function of $\sqrt{s}$ for $q_{\max} = 770$ MeV.

Having thus obtained the matrix V of Eq. (5), it is used as the kernel of the Bethe Salpeter equation to obtain the transition matrix fulfilling exact unitarity in coupled channels. This leads us to the matrix equation

$$T = (1-VG)^{-1}V. \quad (6)$$

In Eq. (6), V factorizes on shell and the diagonal matrix G stands for the loop function of a vector meson and a baryon. Since we calculate the inverse of the matrix $1-VG$ in the program directly, the self-consistency of Bethe-Salpeter is realized automatically.

3 Results

A summary is presented in Table 1 where the 10 dynamically generated states have been listed along with their possible PDG counterparts including their present status and properties. We found the states are furthermore degenerate in $J^P = 1/2^-, 3/2^-, 5/2^-$.

With the interaction Lagrangian between the vector meson and the photon[12]

$$\mathcal{L}_{V\gamma} = -M_V^2 \frac{e}{\tilde{g}} A_\mu \langle V^\mu Q\rangle, \quad (7)$$

the radiative decay width can be calculated as[11]

$$\Gamma_\gamma = \frac{1}{2\pi}\frac{2}{3}\,\frac{M_B}{M_R}\;q\;|t_\gamma|^2. \quad (8)$$

The radiative decay widths for the 10 dynamically generated resonances into a photon and a baryon decuplet for the different strangeness and isospin are listed in Table 2. It can be seen that the radiative decay widths are of the order of 1 MeV. Moreover, we found the radiative decay widths are different about one order of magnitude between the widths for different charge states of the same resonance, which should justify efforts for a systematic measurement of these observables.

Table 1. The properties of the 10 dynamically generated resonances and their possible PDG counterparts[13]. We also include the N* bump around 2270 MeV and the Δ* bump around 2200 MeV.

S, I	theory			PDG data				
	pole position	real axis		name	J^P	status	mass	width
		mass	width					
$0, 1/2$	$1850+i5$	1850	11	N(2090)	$1/2^-$	⋆	1880-2180	95-414
				N(2080)	$3/2^-$	⋆⋆	1804-2081	180-450
		2270(bump)		N(2200)	$5/2^-$	⋆⋆	1900-2228	130-400
$0, 3/2$	$1972+i49$	1971	52	Δ(1900)	$1/2^-$	⋆⋆	1850-1950	140-240
				Δ(1940)	$3/2^-$	⋆	1940-2057	198-460
				Δ(1930)	$5/2^-$	⋆⋆⋆	1900-2020	220-500
		2200 (bump)		Δ(2150)	$1/2^-$	⋆	2050-2200	120-200
$-1, 0$	$2052+i10$	2050	19	Λ(2000)	$?^?$	⋆	1935-2030	73-180
$-1, 1$	$1987+i1$	1985	10	Σ(1940)	$3/2^-$	⋆⋆⋆	1900-1950	150-300
	$2145+i58$	2144	57	Σ(2000)	$1/2^-$	⋆	1944-2004	116-413
	$2383+i73$	2370	99	Σ(2250)	$?^?$	⋆⋆⋆	2210-2280	60-150
				Σ(2455)	$?^?$	⋆⋆	2455±10	100-140
$-2, 1/2$	$2214+i4$	2215	9	Ξ(2250)	$?^?$	⋆⋆	2189-2295	30-130
	$2305+i66$	2308	66	Ξ(2370)	$?^?$	⋆⋆	2356-2392	75-80
	$2522+i38$	2512	60	Ξ(2500)	$?^?$	⋆	2430-2505	59-150
$-3, 0$	$2449+i7$	2445	13	Ω(2470)	$?^?$	⋆⋆	2474±12	72±33

Table 2. The predicted radiative decay widths of the 10 dynamically generated resonances for different isospin projection I_3. Their possible PDG counterparts are also listed[13]. Note that the Σ(2000) could be the spin parter of the Σ(1940), in which case the radiative decay widths would be those of the Σ(1940).

S, I	theory	PDG data		Predicted width (keV) for I_3						
	pole position/MeV	name	J^P	$-3/2$	-1	$-1/2$	0	$1/2$	1	$3/2$
$0, 1/2$	$1850+i5$	N(2090)	$1/2^-$			722		722		
		N(2080)	$3/2^-$							
$0, 3/2$	$1972+i49$	Δ(1900)	$1/2^-$	1582		203		143		1402
		Δ(1940)	$3/2^-$							
		Δ(1930)	$5/2^-$							
$-1, 0$	$2052+i10$	Λ(2000)	$?^?$				583			
$-1, 1$	$1987+i1$	Σ(1940)	$3/2^-$		20		199		561	
	$2145+i58$	Σ(2000)	$1/2^-$		2029		206		399	
	$2383+i73$	Σ(2250)	$?^?$		537		277		182	
		Σ(2455)	$?^?$							
$-2, 1/2$	$2214+i4$	Ξ(2250)	$?^?$			54		815		
	$2305+i66$	Ξ(2370)	$?^?$			1902		320		
	$2522+i38$	Ξ(2500)	$?^?$			165		44		
$-3, 0$	$2449+i7$	Ω(2470)	$?^?$				330			

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