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Dynamically Generated Resonances in the Partial Wave Analysis of the Vector Meson-octet Baryon Interaction

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Abstract: The interaction kernels between vector mesons and octet baryons are calculated explicitly with a summation of t-, s-, u- channel diagrams and a contact term originating from the tensor interaction. Many resonances are generated dynamically in different channels of strangeness zero by solving the coupled-channel Lippman-Schwinger equations with the method of partial wave analysis, and their total angular momenta are determined. The spin partners N(1650)$1/2^-$ and N(1700)$3/2^-$, N(1895)$1/2^-$ and N(1875)$3/2^-$, and the state N(2120)$3/2^-$ are all produced respectively in the isospin $I = 1/2$ sector. In the isospin $I = 3/2$ sector, the spin partners Δ(1620)$1/2^-$ and Δ(1700)$3/2^-$ are also associated with the pole in the complex energy plane. According to the calculation results, a $J^P = 1/2^-$ state around 2 000 MeV is predicted as the spin partner of N(2120)$3/2^-$.

Key words: chiral unitary theory; hadronic resonance; coupled-channel Lippman-Schwinger equations
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1 Introduction

The combination of chiral Lagrangian with non-perturbative unitary techniques in coupled channels of mesons and baryons has become a powerful method to study the meson-meson and meson-baryon interactions and new states in the resonance region, which are not easily explained using the conventional constituent quark model. The theory on the hidden gauge symmetry supplies a mechanism to include vector mesons in the chiral Lagrangian[1–5]. Therefore, the study on the interaction between vector mesons and other hadrons becomes possible. Along this clue, the dynamically generated resonances from pseudoscalar meson-vector meson interaction are discussed by solving the coupled-channel Lippman-Schwinger equations[6]. Similarly, the interaction between vector mesons are also studied and some resonances are produced[7–8]. In the baryon sector, the interaction of vector mesons and decuplet baryons is addressed in Refs. [9–10], where only t- channel amplitudes are analyzed in the S-wave approximation. This method is also extended to study the interaction of vector mesons and octet baryons, and several baryon resonances have been found as a result of solving the coupled-channel Lippman-Schwinger equations[11–13]. However, the resonances generated dynamically are spin degenerate since the amplitude obtained from t- channel interaction is independent of spin. Because the masses of vector mesons are comparable to those of baryons, only t- channel diagrams might be incomplete to obtain a reliable interaction of vector mesons and baryons. Thus in Ref. [14], the t-, s-, u- channel diagrams and a contact diagram originating from the tensor term of the vector meson-octet baryon interaction are all taken into account, and four spin-determined resonances are found in a non-relativistic approximation of the coupled-channel Lippman-Schwinger equations.

In the present work, we deduce the interaction kernel of vector mesons and octet baryons including a vector meson exchange in t- channel, octet baryon exchange in s-, u- channels, and a contact diagram related only to the tensor interaction term in a fully relativistic framework, and then calculate the scattering amplitudes of vector mesons and octet baryons by solving the coupled-channel Lippman-Schwinger equations. The amplitude of the vector mesons and octet baryons will be expanded in terms of partial waves,

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and then the poles of the amplitudes in different partial waves are detected in the complex energy plane in center of mass system, which can be associated to some well-known resonances.

2 Framework

The Lagrangian including the self-interaction of vector mesons can be written as

$$\mathcal{L}_V = -\frac{1}{2}\langle V^{\mu\nu}V_{\mu\nu}\rangle , \tag{1}$$

where the symbol $\langle\rangle$ stands for the trace in the $SU(3)$ flavor space and the tensor of vector mesons is given by

$$V^{\mu\nu}=\partial^\mu V^\nu-\partial^\nu V^\mu-ig[V^\mu,V^\nu], \tag{2}$$

with

$$g = \frac{M_V}{\sqrt{2}f_\pi} , \tag{3}$$

$f_\pi = 93$ MeV the pion decay constant, and M_V the mass of the ρ meson. The vector meson field V_μ is defined by the matrix

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

The interaction of $\mathcal{L}_V$ leads to a three-vector vertex form

$$\mathcal{L}_{(3V)}=i2g\langle(\partial_\mu V_\nu-\partial_\nu V_\mu)V^\mu V^\nu\rangle , \tag{5}$$

which will contribute to the t- channel of the vector meson-octet baryon interaction.

The Lagrangian for the vector meson-octet baryon interaction due to the $SU(3)$ hidden gauge symmetry can be written as

$$\begin{aligned}\mathcal{L}_{VB}=-g\Big\{&F_V\langle\bar{B}\gamma_\mu[V^\mu,B]\rangle+D_V\langle\bar{B}\gamma_\mu\{V^\mu,B\}\rangle+\\ &\langle\bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle\ .+\frac{1}{4M}\Big(F_T\langle\bar{B}\sigma_{\mu\nu}[V^{\mu\nu},B]\rangle+\\ &D_T\langle\bar{B}\sigma_{\mu\nu}\{V^{\mu\nu},B\}\rangle\Big)\Big\} ,\end{aligned} \tag{6}$$

where B is the $SU(3)$ matrix of octet baryons

$$B=\begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda+\frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda-\frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{pmatrix}, \tag{7}$$

and M is the mass of the nucleon.

For the singlet states we have

$$\begin{aligned}\mathcal{L}_{V_0BB}=-g\Big\{&\frac{C_V}{3}\langle\bar{B}\gamma_\mu B\rangle\langle V_0^\mu\rangle+\\ &\frac{C_T}{4M}\langle\bar{B}\sigma_{\mu\nu}V_0^{\mu\nu}B\rangle\Big\}.\end{aligned} \tag{8}$$

The kernels for the t-, s-, u- channel and contact interactions between vector mesons and octet baryons can be obtained from the interaction Lagrangian in Eqs. (6) and (8). If the momentum of the initial vector meson is similar to that of the final vector meson, the momentum transfer is trivial null approximately, and then the t- channel interaction can be written as

$$\begin{aligned}V_{ij}^{\mathrm{t}}=-\frac{g}{\mu^2}&\big(\bar{U}(p_2,\lambda_2)\Gamma_\mu(p_2,p_1)U(p_1,\lambda_1)\times\\ &(q_1^\mu+q_2^\mu)\big)\varepsilon(q_1,\delta_1)\cdot\varepsilon^*(q_2,\delta_2),\end{aligned} \tag{9}$$

with the vertex

$$\Gamma^\mu(p_2,p_1) = g_1\gamma^\mu + g_2(p_2^\mu + p_1^\mu). \tag{10}$$

The coupling constants g_1 and g_2 for different octet baryons and vector mesons can be obtained according to the $SU(3)$ symmetry. In the above equation, $U(p_1,\lambda_1)$ and $\bar{U}(p_2,\lambda_2)$ are the wave functions of the incoming and outgoing baryons, and $\varepsilon(q_1,\delta_1)$ and $\varepsilon^*(q_2,\delta_2)$ are polarization vectors of the initial and final mesons, respectively[15]. However, if the difference between q_2 and q_1 is taken into account, an additional part in Eq. (11) must be supplemented in the t- channel interaction of vector mesons and octet baryons.

$$\begin{aligned}V_{\mathrm{supp},ij}^{\mathrm{t}}=\frac{2g}{\mu^2}\Big\{&\big[\bar{U}(p_2,\lambda_2)\Gamma^\mu(p_2,p_1)\varepsilon_\mu^*(q_2,\delta_2)U(p_1,\lambda_1)\big]\,q_2\cdot\varepsilon(q_1,\delta_1)+\\ &\big\{\bar{U}(p_2,\lambda_2)\Gamma_\mu(p_2,p_1)\varepsilon^\mu(q_1,\delta_1)U(p_1,\lambda_1)\big\}\,q_1\cdot\varepsilon^*(q_2,\delta_2)\Big\}\end{aligned} \tag{11}$$

In addition to the t- channel mechanism, the u- channel and s- channel mechanisms depicted in Fig. 1 are also considered in this work. The s- channel interaction of vector mesons and octet baryons can be written as

$$V_{ij}^{\mathrm{s}} =\bar{U}(p_2,\lambda_2)\Gamma^\mu(p_2,p_1+q_1)\varepsilon_\mu^*(q_2,\delta_2)\frac{\not{p}_1+\not{q}_1+M}{s-M^2}\Gamma^\nu(p_1+q_1,p_1)\varepsilon_\nu(q_1,\delta_1)U(p_1,\lambda_1) \tag{12}$$

with $s=(p_1+q_1)^2$, while the u- channel interaction is

$$V_{ij}^{\mathrm{u}} = \bar{U}(p_2,\lambda_2)\Gamma^{\mu}(p_2,p_1-q_2)\varepsilon_{\mu}(q_1,\delta_1)\frac{\not p_1-\not q_2+M}{(p_1-q_2)^2-M^2}\times\Gamma^{\nu}(p_1,p_1-q_2)\varepsilon_{\nu}^{*}(q_2,\delta_2)U(p_1,\lambda_1)\ . \tag{13}$$

Since the three-momenta of vector mesons and octet baryons are far smaller than their masses in the concerned energy region, we make an approximation of $(p_1-q_2)^2\approx M_1^2+m_2^2-2M_1m_2$ in the propagator in Eq. (13), where M_1 and m_2 are the masses of initial octet baryons and final vector mesons, respectively.

The contact interaction of vector mesons and octet baryons is obtained as

$$V_{ij}^{\mathrm{CT}} = -iC_{\mathrm{IS}}^{\mathrm{CT}}2\bar{U}(p_2,\lambda_2)\varepsilon_{\mu}^{*}(q_2,\delta_2)\sigma^{\mu\nu}\times \varepsilon_{\nu}(q_1,\delta_1)U(p_1,\lambda_1)\ . \tag{14}$$

Altogether, the total kernel of the vector menson-octet baryon interaction can be written as

$$V_{ij}(s,t)=V_{ij}^{\mathrm{t}}+V_{\mathrm{supp},ij}^{\mathrm{t}}+V_{ij}^{\mathrm{s}}+V_{ij}^{\mathrm{u}}+V_{ij}^{\mathrm{CT}}\ , \tag{15}$$

which is a summation of the t-, s-, u- channels and contact interaction.

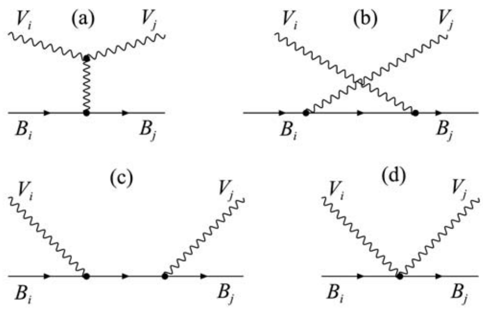

Fig. 1 Feynman diagrams of the vector meson-baryon interaction. (a) t- channel, (b) u- channel, (c) s-channel, and (d) contact term.

The amplitude can be obtained by solving the coupled-channel Lippman-Schwinger equations in the on-shell factorization scheme,

$$T(\sqrt{s},\cos\theta)=\left[1-V(\sqrt{s},\cos\theta)G(s)\right]^{-1}V(\sqrt{s},\cos\theta)\ , \tag{16}$$

which is a function of the total energy $\sqrt{s}$ in the center of mass system and the scattering angle θ. In Eq. (16), $G(s)$ is the propagator of a vector meson and a baryon, and it can be calculated explicitly in dimensional regularization[16]

$$G_l(s)=i2M_l\int\frac{\mathrm{d}^4q}{(2\pi)^4}\frac{1}{(P-q)^2-M_l^2+i\epsilon}\frac{1}{q^2-m_l^2+i\epsilon}=\frac{2M_l}{16\pi^2}\Bigg\{a_l(\mu)+\ln\frac{M_l^2}{\mu^2}+\frac{m_l^2-M_l^2+s}{2s}\ln\frac{m_l^2}{M_l^2}+ \frac{\bar{q}_l}{\sqrt{s}}\Big[\ln(s-(M_l^2-m_l^2)+2\bar{q}_l\sqrt{s})+\ln(s+(M_l^2-m_l^2)+2\bar{q}_l\sqrt{s})-\ln(-s+(M_l^2-m_l^2)+2\bar{q}_l\sqrt{s})- \ln(-s-(M_l^2-m_l^2)+2\bar{q}_l\sqrt{s})\Big]\Bigg\}\ , \tag{17}$$

with μ a regularization scale, which is taken to be 630 MeV, and with a natural value of the subtraction constant $a_l(\mu)=-2$, as determined in Refs. [11, 16].

In Eq. (17), $\bar{q}_l$ denotes the three-momentum of the vector meson or the octet baryon in the center of mass frame and is given by

$$\bar{q}_l=\frac{\lambda^{1/2}(s,m_l^2,M_l^2)}{2\sqrt{s}}=\frac{\sqrt{s-(M_l+m_l)^2}\sqrt{s-(M_l-m_l)^2}}{2\sqrt{s}}, \tag{18}$$

where λ is the triangular function and M_l and m_l are the masses of octet baryons and vector mesons, respectively.

The experimental values on coupling constants of vector mesons to octet baryons are taken from Ref. [17]. Thus we can fit the parameters F_V, D_V and C_V in the Lagrangian with these data, and we set the parameters F_T, D_T and C_T related to the tensor terms to be equal to F_V, D_V and C_V, respectively. The values of these parameters are listed in Table 1.

Table 1 The parameters used in the calculation.

F_V	D_V	F_T	D_T	C_V	C_T
1.640 5	0.222 5	1.640 5	0.222 5	−5.144	−5.144

3 Partial wave analysis

We set l, j and μ the orbital angular momentum, the total angular momentum and the orientation of total angular momentum of the initial vector meson, l', j' and μ' those of the final vector meson, and J the total angular momentum of the system, and then in the S-wave approximation of partial wave analysis, the final state with the orbital angular momentum $l'=0$ is studied. Since the parity is conserved, the contribution from the initial state with the orbital angular momentum $l=0,2$ must be taken into account. Thus the scattering amplitudes can be expanded in terms of the total angular momentum J of the system, the orbital angular momentum l and the total angular momentum j of the initial vector meson.

$$\begin{aligned}\langle\rho',\nu'|T|\rho,\nu\rangle=&\sum_{l,j,J,M}\langle 1,\frac{1}{2};\rho',\nu'|J,M\rangle T^{J}_{1,j;0,l}\langle J,M|j,\frac{1}{2},\rho,\nu\rangle\langle l,1;0,\rho|j,\rho\rangle\left(\frac{2l+1}{4\pi}\right)^{1/2}\\
=&\langle 1,\frac{1}{2};\rho',\nu'|\frac{1}{2},\rho'+\nu'\rangle T^{J=1/2}_{1,1;0,0}\langle 1,\frac{1}{2};\rho,\nu|\frac{1}{2},\rho+\nu\rangle\left(\frac{1}{4\pi}\right)^{1/2}+\langle 1,\frac{1}{2};\rho',\nu'|\frac{3}{2},\rho'+\nu'\rangle\times\\
&T^{J=3/2}_{1,1;0,0}\langle 1,\frac{1}{2};\rho,\nu|\frac{3}{2},\rho+\nu\rangle\left(\frac{1}{4\pi}\right)^{1/2}+\langle 1,\frac{1}{2};\rho',\nu'|\frac{1}{2},\rho'+\nu'\rangle\times\\
&T^{J=1/2}_{1,1;0,2}\langle 1,\frac{1}{2};\rho,\nu|\frac{1}{2},\rho+\nu\rangle\langle 2,1;0,\rho|1,\rho\rangle\left(\frac{5}{4\pi}\right)^{1/2}+\langle 1,\frac{1}{2};\rho',\nu'|\frac{3}{2},\rho'+\nu'\rangle\times\\
&T^{J=1/2}_{1,1;0,2}\langle 1,1/2;\rho,\nu|3/2,\rho+\nu\rangle\langle 2,1;0,\rho|1,\rho\rangle\left(\frac{5}{4\pi}\right)^{1/2}+\langle 1,\frac{1}{2};\rho',\nu'|\frac{3}{2},\rho'+\nu'\rangle\times\\
&T^{J=1/2}_{1,2;0,2}\langle 2,\frac{1}{2};\rho,\nu|\frac{3}{2},\rho+\nu\rangle\langle 2,1;0,\rho|2,\rho\rangle\left(\frac{5}{4\pi}\right)^{1/2},\end{aligned}\tag{19}$$

where ρ and ρ' denote the orientations of spins for the inial and final vector mesons, and ν and ν' the orientations of spins for the inial and final baryons, respectively.

Five amplitudes with different spin states of the initial and final vector mesons and octet baryons need to be calculated in order to obtain the values of amplitudes $T^{J=1/2}_{1,1;0,0}$, $T^{J=3/2}_{1,1;0,0}$, $T^{J=1/2}_{1,1;0,2}$, $T^{J=3/2}_{1,1;0,2}$ and $T^{J=3/2}_{1,2;0,2}$. We choose the amplitudes $\langle 1,1/2|T|1,1/2\rangle$, $\langle 0,1/2|T|0,1/2\rangle$, $\langle -1,1/2|T|-1,1/2\rangle$, $\langle 1,-1/2|T|0,1/2\rangle$ and $\langle 0,-1/2|T|-1,1/2\rangle$ to obtain these values when the spin symmetry is taken into account.

When a pole of the amplitude $T^{J}_{j',j;l',l}$ is produced in the complex plane of $\sqrt{s}$, not only the mass, the decay width, the parity and the total angular momentum J of the corresponding resonance are determined, but the detailed information on the orbital and total angular momenta l,j and l',j' of the initial and final vector mesons to generate this resonance can also be obtained.

4 Result and discussion

The couplings of these resonances to vector mesons and octet baryons are different when the quantum numbers (j',j,l',l) take different values. In follows, we only calculate their coupling constants to different vector mesons and octet baryons in the channel of $l=l'=0$, *i.e.*, $j=j'=1$. The couplings of the resonances to different channels for the $(I,J,j',j,l',l)=(1/2,1/2,1,1,0,0)$ sector are shown in Table 2. It is apparent that the poles at 1715+i4 MeV and 1728+i0 MeV couple strongly to the ϕN channel, while the poles at 1855+i1 MeV and 1868+i6 MeV couple strongly to the $K^*\Lambda$ channels. For the two poles around 2 000 MeV, at the positions of 1982+i4 MeV and 1999+i5 MeV, mainly interact with the $K^*\Sigma$ channel.

Table 2 Pole positions and coupling constants to various channels of resonances found in the isospin $I=1/2$ and spin $J=1/2$ sector.

Pole positions	ρN	ωN	ϕN	$K^*\Lambda$	$K^*\Sigma$
1715+i4 MeV	−0.60−i0.28	0.43−i0.03	4.29−i0.05	−1.98−i0.08	0.18+i0.03
1728+i0 MeV	0.0−i0.63	0.0+i0.40	0.0+i7.42	0.0−i3.03	0.0+i0.37
1855+i1 MeV	−0.14−i0.14	−0.31−i0.32	1.52−i0.01	4.50+i0.00	1.85+i0.03
1868+i6 MeV	−0.13−i0.14	−0.31−i0.37	1.26−i0.07	2.99−i0.06	1.53+i0.02
1982+i4 MeV	0.10+i0.27	−0.03+i0.02	−0.28−i0.19	−1.01−i0.17	5.62−i0.18
1999+i5 MeV	0.07+i0.21	−0.02+i0.02	−0.20−i0.16	−0.59−i0.12	2.75−i0.12

The couplings of the resonances to different channels for the $(I,J,j',j,l',l)=(1/2,3/2,1,1,0,0)$ sector are listed in Table 3. Comparing with the $(I,J,j',j,l',l)=(1/2,1/2,1,1,0,0)$ sector, we can see both $J=3/2$ and $J=1/2$ resonances are generated dynamically at the same positions of the complex plane of $\sqrt{s}$, *i.e.*, 1715+i4 MeV, 1868+i6 MeV and 1982+i4 MeV. Furthermore, the couplings of some $J=3/2$ resonances to different channels take the same values as those of the $J=1/2$ case, especially at the positions of 1715+i4 MeV and 1868+i6 MeV.

Table 3 Pole positions and coupling constants to various channels of resonances found in the isospin $I=1/2$ and spin $J=3/2$ sector.

Pole positions	ρN	ωN	ϕN	$K^*\Lambda$	$K^*\Sigma$
1715+i4 MeV	−0.60−i0.28	0.43−i0.02	4.29−i0.05	−1.98−i0.08	0.18+i0.03
1868+i6 MeV	−0.13−i0.14	−0.31−i0.37	1.26−i0.07	2.99−i0.06	1.53+i0.02
1982+i4 MeV	0.05+i0.13	−0.01+i0.01	−0.14−i0.10	−0.51−i0.08	2.81−i0.09
1999+i5 MeV	0.07+i0.21	−0.02+i0.02	−0.19−i0.16	−0.59−i0.12	2.75−i0.12
2045+i25 MeV	0.02+i0.48	−0.25+i0.10	−0.21−i0.48	−0.66−i0.59	3.03−i0.46

The poles at 1982+i4 MeV, 1999+i5 MeV and 2045+i25 MeV all couple strongly to the $K^*\Sigma$ channel, and their couplings to different channels are similar to each other. It implies that these three poles might correspond to one resonance.

In Table 4, the resonances and their association to known states are summarized.

Table 4 The properties of the dynamically generated resonances with isospin $I=1/2$ and their possible Particle Data Group(PDG) counterparts.

J	Theory	PDG data			
	Pole positions	Name and J^P	Status	Mass	Width
1/2	1715+i4 MeV	N(1650)1/2⁻	****	1645～1670 MeV	120～180 MeV
3/2	1715+i4 MeV	N(1700)3/2⁻	***	1650～1750 MeV	100～250 MeV
1/2	1728+i0 MeV				
1/2	1855+i1 MeV				
1/2	1868+i6 MeV	N(1895)1/2⁻	**	≈2090 MeV	100～400 MeV
3/2	1868+i6 MeV	N(1875)3/2⁻	***	1820～1920 MeV	160～320 MeV
1/2	1982+i4 MeV				
3/2	1982+i4 MeV	N(2120)3/2⁻	**	≈2120 MeV	≈300 MeV
1/2	1999+i5 MeV				
3/2	1999+i5 MeV				
3/2	2045+i25 MeV				

The state $N(1700)3/2^-$ could be associated with the resonance we find with the same quantum number at 1715+i4 MeV in the $(I,J)=(1/2,3/2)$ case. There are two resonances $N(1700)3/2^-$ and $N(1685)?^?$ in the same energy region of PDG data, while the total angular momentum J and parity of the latter are not determined. Since the state $N(1685)?^?$ does not gain status by being a sought-after member of a baryon anti-decuplet, we tend to assume the pole appeared at 1715+i4 MeV might be the resonance $N(1700)3/2^-$. We also find the resonance at 1715+i4 MeV in the $J^P=1/2^-$ sector, and this $J^P=1/2^-$ states could correspond to the $N(1650)1/2^-$, which could be the spin partner of the $N(1700)3/2^-$. Our calculation shows the $N(1650)1/2^-$ couples strongly to the ϕN and $K^*\Lambda$ channels. At this point, it is different from the results obtained in Ref. [11], where the coupling constant to the channel ρN is the largest.

In the $J=3/2$ sector the poles at 1868+i6 MeV and 1982+i4 MeV could correspond to the resonances $N(1875)3/2^-$ and $N(2120)3/2^-$, respectively. These two resonances had been labeled as one resonance N(2080) before the 2012 PDG Review[1].

In the region above 1 800 MeV, only one resonance N(1895) is listed with $J^P=1/2^-$ in the PDG data, which appears in the PDG review as $N^*(2090)\ S_{11}$ before 2012[1]. Although an estimated mass value of the state $N(1895)1/2^-$ about 2 090 MeV is listed in the PDG review[1], the newest multichannel analysis manifests the mass of this state is 1 895 MeV in Ref. [18], which is close to the mass of the state $N(1875)3/2^-$. Thus we treat the $N(1895)1/2^-$ as a spin partner of the $N(1875)3/2^-$, and assume the pole at $1868+i6$ MeV in the $J=1/2$ sector could correspond to the $N(1895)1/2^-$.

In addition, a high peak is also found at $1982+i4$ MeV in the $J=1/2$ sector, and no counterpart is listed in the PDG data. It might supply a clue to look for the resonance around 2000 MeV experimentally, which might be a spin partner of the $N(2120)3/2^-$ and couple strongly to the $K^*\Sigma$ channel as listed in Table 2.

For the case of $(I,J)=(3/2,1/2)$ there is one state in the PDG, the $\Delta(1620)1/2^-$, which has the spin partner $\Delta(1700)3/2^-$ with $J^P=3/2^-$. These two states could be associated with the pole at 1654+i11 MeV, which appeared both in the $J=1/2$ and $J=3/2$ sectors by the method of partial wave analysis in Eq. (19).

We find a narrow peak at 1758+i0 MeV in the $J=1/2$ and $J=3/2$ sectors, and its couplings to ρN and $K^*\Sigma$ are smaller by far than those of other states. We suspect it could be a cusp. The poles and their coupling constants to various channels in the $J=1/2$ and $J=3/2$ sectors are listed in Tables 5 and 6, respectively.

In Ref. [11], no resonance is found in the channel of isospin $I=3/2$ and strangeness zero since only t-channel is taken into account, which supply a repulsive interaction between vector mesons and octet baryons. However, our calculation results manifest some resonances can be produced dynamically in the $I=3/2$ sector when we take into account the other interaction modes besides t- channel, especially the contact term between vector mesons and octet baryons. At this point, our results are consistent to those in Ref. [14].

Table 5 Pole positions and coupling constants to various channels of resonances found in the isospin $I=3/2$ and spin $J=1/2$ sector.

Pole positions	ρN	$K^*\Sigma$
1619+i160 MeV	0.87−i2.64	4.93−i4.95
1654+i11 MeV	3.04+i0.40	12.35+i0.04
1680+i163 MeV	−1.14−i0.87	4.09−i3.72
1726+i9 MeV	1.34+i0.41	8.89+i0.01
1758+i0 MeV	0.00+i0.57	0.00+i2.08
1780+i14 MeV	0.68+i0.27	6.45+i0.05

Table 6 Pole positions and coupling constants to various channels of resonances found in the isospin $I=3/2$ and spin $J=3/2$ sector.

Pole positions	ρN	$K^*\Sigma$
1619+i160 MeV	0.43−i1.32	2.47−i2.48
1654+i11 MeV	1.52+i0.20	6.17+i0.01
1726+i9 MeV	0.67+i0.21	4.45+i0.01
1758+i0 MeV	0.00+i0.44	0.00+i1.11

The states found in the $I=3/2$ sector are summarized in Table 7, where the properties of the possible counterparts are also listed. Except the states at 1654+i11 MeV with $J=1/2$ and $J=3/2$, there are not PDG counterparts associated with the other states.

Table 7 The properties of dynamically generated resonances with isospin $I=3/2$ and its possible PDG counterparts.

J	Theory	PDG data			
	Pole positions	Name and J^P	Status	Mass	Width
1/2	1619+i160 MeV				
3/2	1619+i160 MeV				
1/2	1654+i11 MeV	$\Delta(1620)1/2^-$	****	1600∼1660 MeV	130∼150 MeV
3/2	1654+i11 MeV	$\Delta(1700)3/2^-$	****	1670∼1750 MeV	200∼400 MeV
1/2	1680+i163 MeV				
1/2	1726+i9 MeV				
3/2	1726+i9 MeV				
1/2	1758+i0 MeV				
3/2	1758+i0 MeV				
1/2	1780+i14 MeV				

As a conclusion, in the $I=1/2$ sector, the poles found at 1715+i4 MeV with different J in the complex energy plane might correspond to the states $N(1650)1/2^-$ in the $J=1/2$ case, and its spin partner $N(1700)3/2^-$ in the $J=3/2$ case. Similarly, the poles at 1868+i6 MeV with $J=1/2$ and $J=3/2$ could correspond to another pair of spin partners, $N(1895)1/2^-$ and $N(1875)3/2^-$ respectively. The $N(2120)3/2^-$ could be associated with the pole at 1982+i4 MeV in the $J=3/2$ case. However, the spin partner of $N(2120)3/2^-$ is absent in the PDG data, and we predict that there should be a state around 2000 MeV in the $J=1/2$ case, which should be associated with the pole at 1982+i4 MeV with $J=1/2$ as a spin partner of the state $N(2120)3/2^-$. In the $I=3/2$ sector, we also find some poles in the complex energy plane, and we assume the spin partners $\Delta(1620)1/2^-$ and $\Delta(1700)3/2^-$ could be associated with the poles at 1654+i11 MeV in the $J = 1/2$ and $J = 3/2$ cases. Some resonances are well fitted with the states listed in the newest review of PDG[1], while others might supply some hints for the experimental observation in these energy regions in the future.

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矢量介子和重子八重态相互作用及其动力学生成的共振态的分波分析

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摘要: 研究了t道、s道、u道和由张量相互作用项导致的接触项对矢量介子和重子八重态之间的相互作用势的贡献。在分波分析的框架下，求解了耦合道的李普曼–施温格方程，研究了动力学生成的奇异数$S = 0$，同位旋为$I = 1/2$的重子共振态N(1650)$1/2^-$和N(1700)$3/2^-$，N(1895)$1/2^-$和N(1875)$3/2^-$，N(2120)$3/2^-$，以及同位旋$I = 3/2$的重子共振态$\Delta(1620)1/2^-$和$\Delta(1700)3/2^-$的质量、衰变宽度、和角动量等性质。另外，计算结果表明，在2000 MeV附近存在着$J^P = 1/2^-$的N(2120)$3/2^-$的对偶共振态。

关键词: 手征幺正理论；强子共振态；耦合道李普曼–施温格方程

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