N AND ∆ HIDDEN-CHARM RESONANCES WITH HEAVY-QUARK SPIN SYMMETRY *

OLENA ROMANETS
Theory Group, Kernfysisch Versneller Instituut, University of Groningen,
Zernikelaan 25, Groningen, 9747 AA, The Netherlands
o.romanets@rug.nl

CARMEN GARCÍA-RECIO AND LORENZO LUIS SALCEDO
Departamento de Física Atómica, Molecular y Nuclear,
and Instituto Carlos I de Física Teórica y Computacional, Universidad de Granada,
Granada, E-18071, Spain

JUAN NIEVES
Instituto de Física Corpuscular (centro mixto CSIC-UV), Institutos de Investigación de Paterna,
Aptdo. 22085, Valencia, 46071, Spain

LAURA TOLÓS
Institut de Ciències de l’Espai (IEEC/CSIC), Campus Universitat Autònoma de Barcelona,
Facultat de Ciències, Torre C5, Bellaterra, E-08193, Spain

Received 3 August 2013
Revised 18 September 2013

We study N and ∆ hidden-charm baryon resonances that are generated dynamically from the s-wave interaction of pseudoscalar and vector mesons with 1/2^- and 3/2^- baryons. We use a unitary coupled-channels model that fulfills heavy-quark spin symmetry and respects spin-flavor symmetry in the light sector. We predict seven N-like and five ∆-like states with masses around 4 GeV, most of them as bound states. Some of these states form heavy-quark spin multiplets, which are almost degenerate in mass.

Keywords: Hidden charm; heavy-quark spin symmetry; baryon resonances.

PACS numbers: 14.20.Gk, 14.20.Pt, 11.10.St, 11.30.Ly

*Supported by Spanish Ministerio de Economía y Competitividad (FIS2011-28853-C02-02, FIS2011-24149, FPA2010-16063), Junta de Andalucía (FQM-225), Generalitat Valenciana (PROMETEO/2009/0090) and EU HadronPhysics2 project (grant 227431). O. R. acknowledges support from the Rosalind Franklin Fellowship. L. T. acknowledges support from RyC Program, and FP7-PEOPLE-2011-CIG (PCIG09-GA-2011-291679).
1. Introduction

The possible observation of new states with the charm degree of freedom has attracted a lot of attention over the past years in connection with past and on-going experiments such as CLEO, Belle, BABAR\textsuperscript{1}, and planned PANDA and CBM experiments at FAIR\textsuperscript{2}. In this regard, it is important to understand the nature of possible new states, e.g. whether baryon resonances can be interpreted as three-quark states or molecular states. The attention of the theoretical community has turned towards predicting features of possible hidden-charm states. Such baryon states were studied using zero-range vector exchange models\textsuperscript{3}, hidden-gauge formalism\textsuperscript{4}, and constituent-quark model\textsuperscript{5}. Recently, hidden-charm baryon resonances were studied within the unitarized model in coupled channels, that uses the Weinberg-Tomozawa (WT) potential extended to the SU(8) spin-flavor symmetry and appropriately modified to respect heavy-quark spin symmetry (HQSS)\textsuperscript{6}. Here we review some results of this last work.

2. Theoretical Framework

We start with the extension of the WT interaction to SU(8) spin-flavor symmetry. The corresponding Hamiltonian for number of flavors $N_F$ and number of colors 3 reads\textsuperscript{7}

$$H_{\text{WT}}^s(x) = -\frac{i}{4f^2} :[\Phi, \partial_0 \Phi]^A_{BCD} B_{A}^{BCD} :, \quad A, B, \ldots = 1, \ldots, 2N_F,$$

where $\Phi^A_{BC}(x)$ is the meson field, which contains the fields of $0^-$ (pseudoscalar) and $1^-$ (vector) mesons, and $B_{ABC}^{AB}$ is a completely symmetric tensor, which contains fields the lowest-lying baryons with $J^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$. The Hamiltonian incorporates two distinct mechanisms: the exchange part $H_{\text{ex}}$, in which a quark is transferred from the meson to the baryon, as another one is transferred from baryon to meson; and the annihilation-creation $H_{\text{ac}}$ mechanism, where an antiquark in the meson annihilates with a similar quark in the baryon, with subsequent creation of a quark and an antiquark. The $H_{\text{ac}}$ can violate HQSS when the annihilation or creation of $q\bar{q}$ pairs involve heavy quarks, as in the heavy-quark limit the number of charm quarks and the number of charm antiquarks are separately conserved (implying $U_c(1) \times U_{\bar{c}}(1)$). The HQSS group, which also includes a group of separate rotations of the $c$ quark and $\bar{c}$ antiquark, reads as $SU_c(2) \times SU_{\bar{c}}(2) \times U_c(1) \times U_{\bar{c}}(1)$. In the hidden-charm sectors, where in $H_{\text{ac}}$ the annihilated and created antiquark is necessarily $\bar{c}$, we simply remove the offending annihilation-creation part of the Hamiltonian\textsuperscript{6}.

As baryon resonances appear as poles of the scattering amplitude, we calculate the latter by solving the on-shell Bethe-Salpeter equation in coupled channels. The poles of the scattering amplitude on the first Riemann sheet that appear on the real axis below threshold are bound states, and the ones in the second Riemann sheet below the real axis and above threshold are identified with resonances. Often we refer to all poles generically as resonances, regardless of their concrete nature, since usually they can decay through other channels not included in the model space.
The WT potential with HQSS constraints possesses SU(6) × HQSS symmetry (SU(6) is the spin-flavor symmetry for the three light flavors). We break this symmetry adiabatically, by implementing the physical hadron masses and meson decay constants, following the chain SU(6) × HQSS → SU(3) × HQSS → SU(2) × HQSS → SU(2), where SU(3) is the flavor symmetry and the SU(2) is the isospin symmetry. In this way we could follow the evolution of the poles while breaking the symmetry and classify the found states under the corresponding group multiplets.

3. Dynamically-generated $N$ and $\Delta$ states

![Graph showing the evolution of the poles as symmetries are sequentially broken to reach the isospin symmetric final crypto-exotic $N$ and $\Delta$ odd-parity resonances.](image)

Fig. 1. Evolution of the poles as symmetries, starting from SU(6) × HQSS, are sequentially broken to reach the isospin symmetric final crypto-exotic $N$ and $\Delta$ odd-parity resonances. The lower index of the final states stands for the spin $J$ of the corresponding resonance. The thresholds (red dashed lines) are marked together with the respective baryon-meson channel. The SU(6) × HQSS labels $^{70}_{2,0}$, $^{56}_{2,0}$, and $^{56}_{4,0}$ are also shown at the corresponding symmetric points.

There are two attractive representations in the hidden-charm sector with $C = 0$, $^{56}_{2,0}$ and $^{70}_{2,0}$, where the first index stands for $2J_c + 1$, with $J_c$ being the spin...
of the charm quark, and the second index is the total charm. The evolution of the poles that correspond to the $N$ and $\Delta$ resonances is shown Fig. 1. The masses of the final states and their spins $J$ can also be found on the figure. We find three $N_{1/2}$ (the lower index indicates $J$), three $N_{3/2}$, and one $N_{5/2}$, with masses between 3918 and 4027 MeV. Some of the states are degenerated when the HQSS is unbroken, thus forming the HQSS multiplets, as can be seen from the Fig. 1. Almost all found $N$ resonances are bound states, excluding $N_{1/2}(3926)$ which has a small width of 0.1 MeV, and $N_{1/2}(3974)$, with a width of 2.8 MeV.

The $N$ resonances studied in the zero-range vector exchange model are about 500 MeV lighter than those found in our model. The hidden-gauge formalism predicts these masses to be about 400 MeV larger, however this difference comes mostly from using a different renormalization prescription. Our results are close to those predicted by the chiral interaction, studied in the constituent quark model of Ref. [5], whereas the instanton-induced interaction and color-magnetic interaction produce higher masses for the resonances.

Further, we find three $\Delta_{1/2}$ and two $\Delta_{3/2}$ bound states. Two of them, $\Delta_{1/2}(4306)$ and $\Delta_{3/2}(4307)$, which stem from the $56_{2,0}$ representation, appear as cusps in the scattering amplitude.

4. Summary

We use a suitable broken SU(8) spin-flavor extended WT potential for studying the hidden-charm $N$ and $\Delta$ resonances. Heavy-quark symmetry is enforced by removing heavy quark-antiquark annihilation-creation mechanisms that would violate this symmetry. Our model predicts the existence of seven $N$ states, and five $\Delta$ states, with masses around 3.9-4.3 GeV. These results can be compared with the predictions of other models, and can be tested in the future PANDA and CBM experiments at FAIR facility.

5. References

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