**$N^*(1920)(1/2^+)$ state in the $N\bar{K}K$ system**

Ju-Jun Xie  

Institute of modern physics, Chinese Academy of Sciences, Lanzhou 730000, China  
State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China  
xiejunjun@impcas.ac.cn

A. Martínez Torres  

Instituto de Física, Universidade de São Paulo, C.P. 66318, 05389-970 São Paulo, SP, Brazil

E. Oset  

Departamento de Física Teórica and IFIC, Centro Mixto CSIC-Universidad de Valencia, Institutos de Investigación de Paterna, Aptd. 22085, E-46071 Valencia, Spain

We study the three body $N\bar{K}K$ system by using the fixed center approximation to the Faddeev equations, taking the interaction between $N$ and $\bar{K}$, $N$ and $K$, and $\bar{K}$ and $K$ from the chiral unitary approach. Our results suggest that a $N\bar{K}K$ hadron state, with spin-parity $J^P = 1/2^+$, and mass around 1920 MeV, can be formed.

*Keywords*: Faddeev fixed-center approximation; $N\bar{K}K$ system; $N^*(1920)$ resonance.

*PACS numbers*: 11.25.Hf, 123.1K

1. Introduction

The study of hadron structure is one of the important issues in contemporary hadron-nuclear physics and is attracting much attention. For example, the $\Lambda(1405)$ state, which is cataloged as a four-star $\Lambda$ resonance in the Particle Data Group (PDG) review book [1], has structure and properties which are still controversial. Within the unitary chiral theory, two $\Lambda(1405)$ states are dynamically generated [2-10]. The heavier one corresponds to basically a $\bar{K}N$ bound state and the lighter one is more looking like a $\pi\Sigma$ resonance. For mesonic resonances, the $f_0(980)$ and $a_0(980)$ are also dynamically generated from the interaction of $\bar{KK}$, $\pi\pi$, and $\eta\pi$ treated as coupled channels in $I = 0$ and $I = 1$, respectively [11-17].

For the three body $N\bar{K}K$ system, it is naturally expected that the three hadrons $N\bar{K}K$ form a bound state because of the strong attraction in the $\bar{K}N$ and $\bar{K}K$ subsystems. Indeed, this state has been studied with nonrelativistic three-body variational calculations [18] and by solving the Faddeev equations in a coupled channel approach [19]. They all found a bound state of the $N\bar{K}K$ system with total isospin
\( I = 1/2 \) and spin-parity \( J^P = 1/2^+ \).

Along this line, in the present work, we reinvestigate the three-body \( NKK \) system by considering the interaction of the three particles among themselves. With the two-body \( NK, NK \) and \( K\bar{K}, KN \) scattering amplitudes from the chiral unitary approach, we solve the Faddeev equations by using the Fixed Center Approximation (FCA), which has been used before, in particular in the study of the \( \bar{K}d \) interaction at low energies.\(^{20,21,22,23}\) This approach was also used to describe the \( f_2(1270), \rho_3(1690), f_4(2050), \rho_5(2350) \) and \( f_6(2510) \) resonances as multi-\( \rho \) states\(^{24}\), and also to study the \( f^*_2(1430), f^*_3(1780), f^*_4(2045), f^*_5(2380), \) and \( f^*_6 \) resonances as \( K^*\text{-multi-}\rho \) states\(^{25}\). Furthermore, it has been recently argued that the \( \Delta_{5/2}^+ \) should be interpreted instead as two distinctive resonances based on a solution of the \( \pi\Delta\rho \) system by using the FCA\(^{26}\).

2. Formalism

We consider the \( f_0/a_0(980) \) scalar meson as a bound state of \( \bar{K}K \) in one case, and the \( \Lambda(1405) \) state as a bound state of \( \bar{K}N \) in the other, which allows us to use the FCA to solve the Faddeev equations. The analysis of the \( N - (\bar{K}K)_{f_0/a_0(980)} \) and \( K - (\bar{K}N)_{\Lambda(1405)} \) scattering amplitudes will allow us to study dynamically generated resonances.

For the case of the \( K - (\bar{K}N)_{\Lambda(1405)} \) configuration, the \( K \) is assumed to scatter successively with the \( \bar{K} \) and \( N \). Then the FCA equations are written in terms of two partition functions \( T_1 \) and \( T_2 \), which sum up to the total three body scattering amplitude \( T_{\Lambda(1405)\rightarrow\Lambda(1405)} \):

\[
T_1 = t_1 + t_1 G_0 T_2, \quad T_2 = t_2 + t_2 G_0 T_1, \quad T_{\Lambda(1405)\rightarrow\Lambda(1405)} = T_1 + T_2,
\]

where \( t_i \) represent the \( \bar{K}K \) and \( KN \) unitarized scattering amplitudes, and \( G_0 \) is the loop function for the \( K \) meson propagating inside the \( \Lambda(1405) \) cluster (see Ref.\(^{27}\) for more details).

3. Results and discussion

We calculate the three body scattering amplitude \( T \) with total isospin \( I = 1/2 \) and spin-parity \( J^P = 1/2^+ \) and associate the peaks in the modulus squared \( |T|^2 \) to resonances. In Fig. 1 we show our results for the modulus squared \( |T|^2 \). The results show a clear peak in the case of \( Na_0 \rightarrow Na_0 \) around 1915 MeV. For the \( \Lambda(1405) \rightarrow K\Lambda(1405) \) scattering, we see a clear peak around 1925 MeV. The strength of \( |T|^2 \) at the peak is similar to that for the \( Na_0 \rightarrow Na_0 \) scattering. With the proper comparison: \( T_{Na_0\rightarrow Na_0} \) versus \( \frac{M_{a_0(980)}}{m_K} T_{\Lambda(1405)\rightarrow K\Lambda(1405)} \), we obtain \( \frac{M_{a_0(980)}}{m_K} T_{\Lambda(1405)\rightarrow K\Lambda(1405)} |^2 \approx 4|T_{Na_0\rightarrow Na_0}|^2 \), which indicates that the preferred configuration is \( K\Lambda(1405) \).

From our results, the clear peak around 1920 MeV in the scattering amplitude for the \( NKK \) system, indicates that we have a resonant state made of these components. Furthermore, the main \( K\Lambda(1405) \) component over the \( Na_0(a_0(980)) \) serves to
$N^*(1920)(1/2^+)$ state in the $N\bar{K}K$ system

Fig. 1. Modulus squared of the $N f_0(a_0(980))$ and the $K\Lambda(1405)$ scattering amplitude in $I_{\text{total}} = 1/2$. Left: solid line and dashed line stand for the $N f_0 \rightarrow N f_0$ scattering and the $N a_0 \rightarrow N a_0$ scattering. Right: $K\Lambda(1405) \rightarrow K\Lambda(1405)$ scattering.

put the peaks with moderate strength around 1950 MeV seen in Fig. 1 in a proper context, indicating that the effect of this configuration in that energy region can be diluted when other large components of the wave functions are considered, such that we should not expect that these peaks would have much repercussion in any physical observable.

4. Conclusions

We have performed a calculation for the three body $N\bar{K}K$ scattering amplitude by using the FCA to the Faddeev equations, taking the interaction between $N$ and $\bar{K}$, $N$ and $K$, and $\bar{K}$ and $K$ from the chiral unitary approach. It is found that in both $N a_0(980)$ and $K\Lambda(1405)$ configurations there is a clear peak around 1920 MeV indicating the formation of a resonant $N\bar{K}K$ state around this energy. This result is in agreement with those obtained in previous calculations \cite{1819}, which support the existence of a $N^*$ state with spin-parity $J^P = 1/2^+$ around 1920 MeV. We also found that the $K\Lambda(1405)$ configuration is the dominant one, where the $\bar{K}K$ subsystem can still couple to the $f_0(980)$ and $a_0(980)$ resonances.

Acknowledgments

A. Martínez Torres thanks the financial support from the brazilian funding agency FAPESP. This work is partly supported by the Spanish Ministerio de Economía y Competitividad and European FEDER funds under the contract number FIS2011-28853-C02-01 and FIS2011-28853-C02-02, and the Generalitat Valenciana in the program Prometeo, 2009/090. We acknowledge the support of the European Community-Research Infrastructure Integrating Activity Study of Strongly Interacting Matter (acronym HadronPhysics3, Grant Agreement n. 283286) under the Seventh Framework Programme of EU. This work is also partly supported by the National Natural Science Foundation of China under grant 11105126.
References

1. J. Beringer et al. (Particle Data Group), Phys. Rev. D 86, 010001 (2012).
2. E. Oset and A. Ramos, Nucl. Phys. A 635, 99 (1998).
3. C. García-Recio, J. Nieves, E. Ruiz Arriola and M. J. Vicente Vacas, Phys. Rev. D 67, 076009 (2003).
4. T. Hyodo, S. I. Nam, D. Jido and A. Hosaka, Phys. Rev. C 68, 018201 (2003).
5. Tetsuo Hyodo and Wolfram Weise, Phys. Rev. C 77, 035204 (2008).
6. D. Jido, J. A. Oller, E. Oset, A. Ramos, and U. G. Meißner, Nucl. Phys. A 725, 181 (2003).
7. J. A. Oller and U.-G. Meißner, Phys. Lett. B 500, 263 (2001).
8. B. Borasoy, R. Nissler and W. Weise, Eur. Phys. J. A 25, 79 (2005).
9. J. A. Oller, Eur. Phys. J. A 28, 63 (2006).
10. B. Borasoy, U.-G. Meißner, and R. Nissler, Phys. Rev. C 74, 055201 (2006).
11. J. A. Oller, and E. Oset, Nucl. Phys. A 620, 438 (1997).
12. J. A. Oller, E. Oset and J. R. Pelaez, Phys. Rev. Lett. 80, 3452 (1998).
13. J. A. Oller, and E. Oset, Phys. Rev. D 60, 074023 (1999).
14. A. Gómez Nicola, and J. R. Peláez, Phys. Rev. D 65, 054009 (2002).
15. J. R. Pelaez, G. Rios, Phys. Rev. Lett. 97, 242002 (2006).
16. N. Kaiser, Eur. Phys. J. A 3, 207 (1998).
17. V. E. Markushin, Eur. Phys. J. A 8, 389 (2000).
18. D. Jido and Y. Kanada-En’yo, Phys. Rev. C 78, 035203 (2008).
19. A. Martínez Torres, K. P. Khemchandani, U. G. Meißner, and E. Oset, Eur. Phys. J. A 41, 361 (2009); A. Martínez Torres, K. P. Khemchandani, and E. Oset, Phys. Rev. C 79, 065207 (2009); A. Martínez Torres and D. Jido, Phys. Rev. C 82, 038202 (2010).
20. R. Chand and R. H. Dalitz, Annals Phys. 20, 1 (1962).
21. R. C. Barrett and A. Deloff, Phys. Rev. C 60, 025201 (1999).
22. A. Deloff, Phys. Rev. C 61, 024004 (2000).
23. S. S. Kamalov, E. Oset and A. Ramos, Nucl. Phys. A 690, 494 (2001).
24. L. Roca, and E. Oset, Phys. Rev. D 82, 054013 (2010).
25. J. Yamagata-Sekihara, L. Roca and E. Oset, Phys. Rev. D 82, 094017 (2010).
26. J. -J. Xie, A. Martinez Torres, E. Oset and P. Gonzalez, Phys. Rev. C 83, 055204 (2011).
27. J. -J. Xie, A. Martinez Torres and E. Oset, Phys. Rev. C 83, 065207 (2011).