Mass spectra of hidden-charm molecular four quarks states

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Introduction

Recently, there have been lots of progresses in the study of the multiquark states which normally refer to hadrons containing four or higher number of quarks. Among multiquarks, tetraquarks are quite interesting as there have been several studies suggesting plausible evidences for their existence especially for hadrons containing heavy quarks. In recent years, a large number of new hadrons were discovered experimentally following the developments in the high-energy experiments and the accumulation of the precise data in the low energy exclusive measurements. Study of exotic hadrons has become a central topic of hadron spectroscopy in the past decade. Many theoretical works have focused on the issue of resolving the status as tetraquarks or dimesonic molecular states of the the recently discovered $Z_c^+(3900)$ state by BES III [1] and BELLE Collabaration [2]. The interpretations of these new states have initiated considerable amount of theoretical work, especially due to the their mysterious internal structure.

Phenomenology

Many theoretical works have paid much attention on the issue of resolving the structure of multiquark states as di-hadronic molecules [3–7]. Scrutinizing the existence of multiquark states have begun in the early days of QCD [4, 5]. Understanding the mechanisms underlying confinement in QCD is among the most fundamental questions in hadron physics. However, little success has been achieved even in understanding tetraquark states due to the non-perturbative nature of QCD at the hadronic scale. The hadron molecular considerations does simplify this difficulty by replacing interquark color interaction with a residual strong interactions between two color singlet hadrons. We study di-hadronic systems here by considering the molecular interaction between the two hadrons as the well known Yukawa type interaction V(r) and is given by

$$V(r) = \frac{-g^2}{r} e^{-kr} \tag{1}$$

Where g being the coupling constant and k is the molecular interaction strength. The potential parameters employed here are taken from Ref.[6, 8]. By using Mathematica code [9] we obtained the binding energies and then computed the masses of low lying di-hadronic molecules same as done in Ref. [6]. The non-relativistic Schrödinger bound-state mass(spin average mass) of the di-hadronic system is obtained as

$$M_{cw} = m_1 + m_2 + BE \tag{2}$$

Where m_1 and m_2 are the masses of the constituent hadrons, BE represents the binding energy of the di-hadronic system. Further, we have added spin and isospin contribution. Accordingly, the mass of a di-hadronic molecular state is obtained as

$$M_{Total} = M_{cw} + E_{(j_1,j_2;J)} \tag{3}$$

The hyperfine interaction is computed using the expression similar to the hyperfine interactions for quarkonia but without considering color factor which is same as in Ref. [6].

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TABLE I: Mass spectra of di-mesonic systems (in MeV).

Molecule	J^{PC}	$E_{(j_1,j_2;J)}$	M_{cw}	M_J	EXP.	Others
$D^{+*}\bar{D}^*$	2^{++}	0.00358	3923	3927	$Z_c^+(3898 \pm 5)$[1, 2]	4062[3], 4012^{+4}_{-9}[10]
	1^{+-}	-0.0038		3918		3974[3], 3958^{+24}_{-27}[10]
	0^{++}	-0.0077		3915		3930[3]
$D\bar{D}^*$	1^{++}	0.0	3784	3784	-	3878[3], 3880±110[11]
$D\bar{D}$	0^{++}	0.0	3647	3647	-	3760±100[11], 3715^{+24}_{-27}[5], 3738[3]
$D^+\bar{D}^*$	1^{+-}	0.0	3788	3788	-	-

Results and conclusion

The predicted mass spectra of low lying four quark states in the charm sector as di-hadronic molecular states using Yukawa type potential are listed in Table I. The recent experimental exotic states and other theoretical results are also presented for comparision. Recent $Z_c^+(3900)$ state is found to be the $D^{+*}\bar{D}^*$ molecular state. Other positive parity molecular states are predicted around 3780 MeV. In the present work, the mass of $D\bar{D}^*$ is below than the other theoretical results value. Other di-mesonic molecular states in the charm sector are also presented in table I. Many of these states require further experimental support. Their underlying nature is still unknown and considerable experimental and theoretical work remains to be done before a satisfying understanding of these states will be achieved.

References

[1] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. Lett. **110**, 252001 (2013).

[2] Z. Q. Liu et al. (Belle Collaboration), Phys. Rev. Lett. **110**, 252002 (2013).

[3] A. K. Rai et al., Nuclear Physics A **782**, 406 (2007); Eur. Phys. J. C **75**, 462(2015).

[4] R. L. Jaffe, Phys. Rev. Lett. **38**, 195 (1977); Phys. Rev. D **15**, 281(1977).

[5] D Strottman, Phys. Rev. D **20**, 748 (1979).

[6] Smruti Patel et. al., Proceedings of the DAE Symp. on Nucl. Phys. **59**, 646 (2014).

[7] Smruti Patel and P. C. Vinodkumar, Eur. Phys. J. C **76**, 356 (2016); AIP Conference Proceedings **1728**, 020197 (2016).

[8] K. A. Olive et. al. (Particle Data Group), Chinese Physics C, Vol. **38**, No.9, 090001 (2014).

[9] W Lucha and F Shoberl, Int. J. Mod. Phys. C **10** (1999).

[10] C. Hidalgo- Duque et al.Phys. Rev. D **87**,076006 (2013).

[11] Jian-rong et. al. Phys. Rev. D **80**, 056004 (2009).