Molecular Interpretation of Exotic Hadrons

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Introduction

Bound state of the two hadrons i.e. the hadronic molecules, have studied in this thesis. The study of the interaction between two color neutral states has main concern of the present work. In the potential model framework, which has been proved as a successful theoretical tool in the study of perturbative QCD (Quantum Chromo Dynamics), the mass spectra and decay properties of di-hadronic systems have presented in present thesis.

The subject of the hadronic molecules have been attempted since long time. The *deuteron* (the bound state of a proton and a neutron) is only candidate who has its confirmed place in the family of hadronic molecules, and still waiting for other members to join the hadronic molecule family. On the other hand, the expected fundamental theory of the strong interaction, so called QCD, is a non abelian gauge theory, and its direct consequences predicted the complicated color neutral states (exotic states) and large numbers of hadronic molecules. The new experimental developments at the Belle, BES, FAIR, LHC, BABAR are brought out enormous data and came with large numbers of surprises from last two decades and the number of new states are observed which could not explained in the conventional meson or baryon scheme. However, the observed states are still struggling to get confirmation regarding their specific substructure on both theoretical and experimental point of view, and waiting for allotment of their specific family like glueball, hybrid, multiquark or molecules.

For example, in partial wave analysis of $J/\psi \to \gamma\eta\eta$, the BES III collaboration observed most promising candidate for glueballs or multiquark structure below 2.5 GeV. In the $\pi^- P \to \eta\pi^0\eta$ channel, the GAMS group at CERN reported a state near 1400 MeV [1, 2]where others have reported some other states near near 1600 MeV [3–5]. In the low energy sector various states like $f_0(980)$, $a_0(980)$, $f_0(1500)$, $f_0(1710)$ etc. were observed experimentally, but their specific structure and properties are still in debate. In 2003, Belle has reported the discovery of a charmonium like neutral state X(3872) with mass $3872 \pm 0.6 \pm 0.5$ MeV and width < 2.3 MeV which has latter confirmed by DO, CDF and BARBAR [6–8]. After the discovery of X(3872) the large numbers of charge, neutral and vector states have detected in various experiments and became famous as the XYZ states. Recently, LHC [9] has reported a new states $P_c(4450)$ and $P_c(4380)$ in hidden charm sector which could be a strong candidate for pentaquark. All these states may have the exotic structures like tetraquark, pentaquark, hexaquark, hybrid, glueball or molecular, where the molecular interpretation is the subject of this thesis work.

In the variational approach, by using the hydrogen-like trial wave function, the mass spectra of the di-mesonic, meson-baryon, dibaryon combinations have calculated. The di-hadronic molecules are approximated as a bound systems, just like deuteron. Thus, molecular systems need to be closed to the s-wave threshold.

For the study of the deuteron, various realistic potentials have been developed. The exchange of particles has basis for all these realistic potentials and to be known as a One Boson Exchange (OBE) potentials. In OBE, the long, mid and short distance interaction have introduced through exchange of mesons where the range of the force depends on the masses

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of the exchange mesons. We have used this s-wave meson exchange potentials and found them very weak to form a bound states and thus the additional phenomenological potential has used along with them. With this entire thesis work, we arrived with a proposal that the two color neutral states are experiencing dipole like interaction, just like polar molecules. In the present study, our aim is to draw an attention on some interesting possibilities for molecular (deuteron-like) structures with proposed interactions and predict the mass spectra and discuss their identification with observables at experiments. Apart from the interaction potential, the issue of the identification of the hadronic molecules has also attempted, for that we have used Weinberg's compositeness theorem.

In view of the above mentioned facts, the following objectives of the thesis are outlined:

In the chapter-1, we have presented the basic building blocks of matter and fundamental introduction of standard model and discussed the exotic hadrons, their classification, possible theoretical models and experimental tools for their production.

In chapter-2, we concentrate on the hadronic molecules which is the subject of the thesis. we provide the various theoretical efforts and experimental discoveries made over the time and then present the motivation and theoretical framework used in this work [10–13]. In the variational approach, we have used Hydrogen-like trial wave function[10–17].

The s-wave mass spectra and decay properties of the dimesonic state with proposed interaction as a One Pion Exchange plus Hellmann potential are presented in chapter-3 [10, 12, 14].

The mass spectra of the meson-baryon molecular (molecular pentaquark) and dibaryonic (molecular hexaquark) states with proposed interaction as s-wave One Boson Exchange (OBE) plus Yukawa-like screen potential are presented in chapter-4 [13].

We discuss the Weinberg's compositeness theorem to distinguish the molecular states from confine states and by using this theorem we present the results of scattering length a_s and effective range r_e for di-hadronic systems in chapter-5 [13].

To achieve this objectives the present thesis entitled Molecular Interpretation of Exotic Hadrons is structured into six chapters.

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