ΛΛ Hypernuclei and H dibaryon: A Theoretical Search

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Introduction

The data on strangeness $S = -2$ hypernuclear system is very less, and no data exist for systems with higher strangeness content. The study of double $-\Lambda$ hypernuclei could provide valuable information on $\Lambda\Lambda$ interaction. Experimentally, double hypernuclei can be produced by separated $K^-$ meson beam accelerator at Brookhaven National Laboratory (BNL), Japanese high energy accelerator research organization (KEK) and European Center for High Energy Physics (CERN). A high statistics measurement of double hypernuclear production has been made using high intensity AGS D6 $K^-$ beam line [1]. The double hypernuclei can be produced via the double strangeness exchange reaction ($K^-, K^+$) by both direct production or by $\Xi^-$ capture at rest by an emulsion atom. In later reaction meson beam is used to tag the production of $\Xi^-$ hyperon, which is then slowed down in emulsion and captured at rest by an emulsion atom. In the following sections we discuss the theoretical frontiers of double-$\Lambda$ hypernuclei.

The s-shell $\Lambda\Lambda^4H$, $\Lambda\Lambda^5H$, $\Lambda\Lambda^5He$ and $\Lambda\Lambda^6He$ Hypernuclei

The theoretical study of double-$\Lambda$ hypernuclei started soon after the discovery. Among the well established double-$\Lambda$ hypernuclei, the $\Lambda\Lambda^6He$ hypernucleus is best studied [2]. The knowledge of $\Lambda\Lambda$ interaction was too poor, the earliest theoretical efforts on $\Lambda\Lambda^6He$ are based on a Hartee-Fock mean field calculations, which dates back to 1969. With the advent of Quantum Monte Carlo techniques, the many-body approach aiming to perform microscopic calculations of nuclei and hypernuclei had taken a new turn. The realistic NN and NNN potentials in the non-strange sector to describe nuclear spectra have been evolving for quite a long time. Now, we have well established Argonne v18 N N potential and Urbana type NNN potential. The information on non-strange sector potentials is inevitably required for hypernuclei made up of nucleons and hyperons. Thus, for such systems, these potentials have to be used in conjunction with NN and $\Lambda N$, $\Lambda\Lambda$ and $\Lambda\Lambda N$ potentials.

The earlier calculations however were quite simple based upon central potentials and a wave function involving central correlations. In the simplest approach all the four nucleons of $\Lambda\Lambda^6He$ are treated as an alpha cluster and calculations have been performed using $\alpha\Lambda$ nuclear potentials. On the other hand, central $\Lambda N$ potentials have been used at a microscopic level. However, as a marked difference this was performed using Nijmegen simulated $\Lambda\Lambda$ potentials. Undoubtedly, this study is for from being realistic as it involves only central potentials and correlations. An improved VMC study involving a realistic Hamiltonian and operatorial correlations has also appeared but it ignores space-exchange correlation (SEC) in the wave function [3]. It is evident from a recent work that a study ignoring SEC would be deficient and misleading as it significantly affects every physical observable [4]. The SEC effects are expected to be more evident in $\Lambda\Lambda^6He$ hypernucleus because of the presence of a pair of hyperons. The Faddeev-Yakubovsky calculations have been extended to all the s-shell single- and double-$\Lambda$ hypernuclei. In this approach, several $\Lambda\Lambda$ potential models have been used to calculate $\Delta B_{\Lambda\Lambda}(\Lambda\Lambda^6He)$, $\Delta B_{\Lambda\Lambda}(\Lambda\Lambda^5He)$ and $\Delta B_{\Lambda\Lambda}(\Lambda\Lambda^5H)$. The $I=1/2$ ($\Lambda\Lambda^6H$ - $\Lambda\Lambda^5He$) hypernuclei are found to be particle stable for all the potential strengths. Calculations have also been performed on $\Lambda\Lambda^5H$ in order to explore bound state for it. However, calculations yield a negative result even for the strong $\Lambda\Lambda$ strenghts. In contradiction to it, Nemura found a bound state for $\Lambda\Lambda^4H$ in their variational research using 4×4 Hamiltonian. However, various strenghts of this Hamiltonian are uncertain specially those falling in the...
strangeness $S = -2$ sector. This subject is open for debate.

The $\Lambda\Lambda$ $^{10}$Be and $\Lambda\Lambda$ $^{13}$B hypernuclei

Theoretical complexities increase with increasing baryon number. As a consequence, microscopic calculations based on BB and BBB interactions have yet not performed on these two systems. However, some cluster model calculations on $\Lambda\Lambda$ $^{10}$Be are available in the literature. The most recent among them is FaddeevYakubovsky calculations. Some old VMC calculations also exist, where in this hypernucleus is treated as a system of $\alpha\Lambda\Lambda$ (two $\alpha$s+two $\Lambda$s). There are other $p$-shell hypernuclear calculations on $\Lambda = 7-10\Lambda\Lambda$ hypernuclei. Similar calculations are not available on the other event, $\Lambda\Lambda$ $^{13}$B.

H DIBARYON

The H dibaryon is a six quark state (uuddss) in a single QCD bag and not a deuteron like baryon molecule. It has strangeness -2, spin and isospin singlet, and positive parity. H dibaryons may exist separate entity inside double hypernucleus, or they can exist inside the core of neutron star. The H dibaryon are directly related to the double-$\Lambda$ hypernuclei, because the binding energy of two $\Lambda$s is directly related to the lower limit of H dibaryon mass. The first H dibaryon was predicted by Jaffe [5] using MIT bag model bound by attractive color magnetic interaction between the quarks. Using this model Jaffe calculated its mass about 2150 MeV, which is less than the $\Lambda\Lambda$ threshold (2231 MeV) by 81 MeV. Experimentally, the H dibaryon may be produced via ($K^-, K^+$) reaction, heavy ion collision, $p$-nucleus annihilation reaction etc. However, no clear experimental evidence has been found for existence of H dibaryon till now. Some theoretical models such as nonrelativistic quark cluster model, Skyrme model, QCD sum rule and lattice QCD which are applied to calculate the mass of H dibaryon. Some of them predict the bound states. The fully Variational Monte Carlo study with space-exchange correlations could provide valuable information about H dibaryon. We are proceeding in this direction.

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References