Variational energy for Θ^+ - ^2H bound state

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Introduction

Pentaquark is considered to be a exotic particle with valency structure of four quarks and antiquark. Diakonov *et. al.* [1] have made a prediction for the existence of strangeness S= +1 and isospin zero pentaquark Θ^+ ($uudd\bar{s}$) of mass 1.54 GeV with a narrow width and $J^P = 1/2^+$ which is a member of an antidecuplet. Small width is assumed to be a consequence of even parity. We may point out that many experimental searches [2,3] for the existence of Θ^+ that have been made in the past have remained inconclusive. Miller [4] has proposed a schematic model where coherent interaction of $u\bar{s}$ and $d\bar{s}$ pairs leads to very large attractive residual interaction which in turn produces a strongly attractive Θ-nucleon spin-independent local potential, sufficient to produce a bound state of Θ-nuclear matter that is stable against strong decay. In the model under discussion the Θ has been regarded as a collective vibration of nucleon. The spin-independent potential $v_{\Theta\mathrm{N}}(r)$ (figure1) for distance r between the nucleon and the even parity Θ has the following radial dependence:

$$v_{\Theta\mathrm{N}}(r) = -V_0(1 - \frac{x^2}{6} + \frac{x^4}{48}) \exp(-\frac{x^2}{4}) \quad , \qquad \ldots\ldots\ldots\ldots(1)$$

where $x = r/\beta$, β is of the order of nucleon size~ 1fm and lowest value of $V_0 = 420\ MeV$ has been chosen. For odd parity of Θ the stability of Θ-nuclear matter against strong decay is not predicted. Therefore, discovery of stable Θ-nuclear matter would be a definitive proof for even parity. Keeping in view the aforesaid property we have made a preliminary analysis of Θ- ^2H as a three-body Θ-NN problem in the variational Monte Carlo (VMC) framework. For NN pair simple and widely used Malfliet-Tjon spin-independent potential [5] (V_{NN}) that gives deuteron binding energy consistent with experimental value, has been employed. In the next section Hamiltonian and wavefunction have been discussed. Result and discussion form the part of the last section.

Hamiltonian and Wavefunction

We have analysed Θ- ^2H as a three-body Θ-NN problem in the variational Monte Carlo (VMC) framework. Hamiltonian of the system ignoring coulomb energy and three-body force may be written as:

$$H_\Theta^{NN} = K_\Theta(1) + K_N(2) + K_N(3) + \sum_{i=2}^{3} v_{\Theta N}(r_{1i}) + V_{NN}(r_{23}) \ , \qquad \ldots\ldots\ldots\ldots..(2)$$

where $K_x(j)$ is the kinetic energy operator for particle x numbered as j and V_{NN} is Malfliet-Tjon potential. The trial wavefunction for a system Θ- ^2H in the ground state is the product of two-body correlation functions as:

$$\Psi_H^\Theta = f_{NN}(r_{23}) \prod_{j=2}^{3} f_{\Theta\mathrm{N}}(r_{1j}), \qquad \ldots\ldots\ldots\ldots(3)$$

where $f_{xN}(r)$ two-body central correlation for the pair $xN (x = \Theta\ or\ N)$. The correlation functions $f_{xN}(r)$ that have the appropriate asymptotic behavior are obtained from the solution of the Schrodinger-type equation for the relative angular momentum state $\ell = 0$ of the xN pair. The correlation functions depend on the eight variational parameters which are : κ_{xN}, C_{xN} , $a_{xN}\ and\ R_{xN}\ for\ x = N\ and\ \Theta$. $\kappa\ has\ unit\ fm^{-1}$ and other parameters are in fm.

Results and Discussion

The variational energy -B for the system Θ-^{2}H using equations (2) and (3) can be written as:

$$-B=\langle \Psi_H^{\Theta} | H_{\Theta}^{NN} | \Psi_H^{\Theta} \rangle \Big/ \langle \Psi_H^{\Theta} | \Psi_H^{\Theta} \rangle \; . \qquad \ldots\ldots\ldots(4)$$

The VMC energy calculations were made for 100 000 points and statistical error is much less than 1% and is, therefore, not quoted. The integrations were carried out up to 20 fm.

The energy is minimized with respect to variational parameters. The binding energy B of the system is found to be 180.48 MeV for the following variational parameters:

$\kappa_{NN} = 0.45$, $C_{NN} = 3.0$, $a_{NN} = 4.6$ *and* $R_{NN} = 5.0$, $\kappa_{\Theta N} = 5.1$, $C_{\Theta N} = 0.3$, $a_{\Theta N}$ 2.6 *and* $R_{\Theta N} = 1.3$.

Our preliminary calculation shows that the system is very strongly bound. The identification of Θ- ^{2}H system will be a proof for positive parity of Θ quark. The r_{NN}, **rms** separation between NN is 0.801 *fm* , an indication of almost overlapping of quark bags. Similarly$r_{\Theta N}$, **rms** separation of Θ and N pair is 0.56 *fm* which means thereby quarks bags are overlapping. This aspect is very intriguing and cast doubt on our calculation. Whether our calculations have meaning or an alternative approach in terms of quark degrees of freedom is required to study the properties of Θ- ^{2}H .

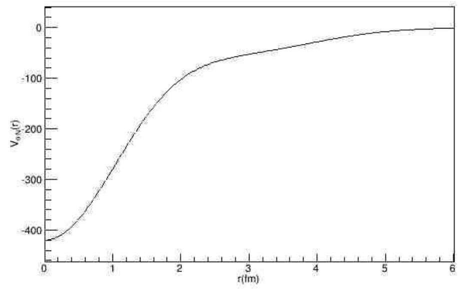

Figure 1: Pentaquark ***Θ***N potential ref.[4]

References

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