Application of the hyperspherical functions method to the description of light nuclei

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A new method to construct hyperspherical functions basis for A identical particles, beyond the minimal approximation, is presented. This method is based on the link between the hyperspherical function method (HSFM) and the oscillator no-core shell model and uses a Slater determinant representation of the hyperspherical functions. It is shown that, because of this representation, the HSFM matrix elements are related to the inverse Laplace transforms of the oscillator shell model matrix elements, on the condition that the centre-of-mass motion and the hyperradial excitations are removed from the shell model states.

The applicability of the new method is demonstrated for the case of $^{3-7}$H, $^{4-10}$He and ^{4}n. Using the proposed technique, with the current version of the computer code, it was possible to go up to $\Delta K_{max} = 16$ for ^{3}H, $\Delta K_{max} = 14$ for ^{4}n, $\Delta K_{max} = 12$ for ^{4}H and ^{4}He, $\Delta K_{max} = 10$ for ^{5}H, $\Delta K_{max} = 8$ for ^{5,6}He, $\Delta K_{max} = 6$ for ^{6,7}H and ^{8}He and $\Delta K_{max} = 4$ for ^{7,9,10}He, where $\Delta K_{max} = K_{max} - K_{min}$.

The numerical calculations have been done using the Volkov V1 effective NN interaction. With this potential, the ^{3}H and ^{4}He ground states binding energies are found to converge rapidly. The binding energies of ^{4,5}H and ^{5,6,8}He decrease exponentially with K and, for K_{max} used, these nuclei are underbound by maximum of 12% with respect to the values obtained by the exponential extrapolation. Exponential extrapolation estimates of the converged energies for the ^{6,8}He isotopes agree surprisingly well with experiment while the estimated converged energies of ^{4}H and ^{5}H are only 0.33 MeV and 0.6 MeV lower than the experimental ones. The binding energy of ^{7}H estimated by exponential extrapolation is about 300 KeV lower that that for ^{5}H. If this result is confirmed by more detailed calculations, this would imply that ^{7}H may exist as a low lying resonance with the only decay channel being $^7\text{H} \rightarrow {}^3\text{H} + \text{n} + \text{n} + \text{n} + \text{n}$.

The HSFM has also been used to search for a bound state of the tetraneutron. Is has been shown that due to the large probability for a pair of neutrons to be in the triplet odd state, the two-body nucleon-nucleon force cannot by itself bind four neutrons, even if it can bind a dineutron. A very strong phenomenological four-nucleon force is needed in order to bind the tetraneutron. Such a 4N force, if it existed, would bind ^{4}He by about 100 MeV.