The cluster expansion method for cluster structure of light nuclei using one boson exchange potential with generalized Jastrow Factor (1)

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The generalized Jastrow factor including noncentral components is powerful to analyze the structure of light nuclei. In order to include the contribution of the tensor force, the noncentral component is necessary. Beside this fact, the noncentral component has two important roles. One is to satisfy the many body condition (from $n+1$ body problem to n body problem trandition condition). The other is to control central and noncentral effects and to give good variational values. Similar to Akashi's A.T.M method, the tensor force gives the main part of nuclear binding energies. It also gives cluster structure of light nuclei. This fact indicates that the tensor force has a similar role to the spin-orbit force in the shell model. Explaining this fact is the first purpose of this study. The second is to give energy levels and total energies of light nuclei by considering the nuclear force and structural correlations (this may be discussed in the future work). Sometimes, the latter is more important than the former, which is a merit of the Jastrow factor. Cluster calculations for N body problem is completed by N body cluster calculation, but corresponding to alpha cluster structure approximation is used. For the first purpose, the most important fact is that cluster property is given by cooperation of three and four body cluster calculations. Factorized Iwamoto Yamada (F.I.Y.) method is useful to study this, where a formula for physical operators is given. With M and N integers, we have.

$$\langle \text{total} \rangle + \langle \text{4body} \rangle + M \langle \text{3body} \rangle + N \langle \text{2body} \rangle \,, \quad (M < 0, N, > 0) \,. \tag{1}$$

The kinetic energy and radius (extract effect of center of mass) can be treated as 2 body operators. For He (five body problem) $M = -1$, $N = 1$. Here the wave function given by Wilderms et al is used. R_α means cluster

$$\Psi = R \exp\left(-\frac{A}{2} r_{cd}^2 - \frac{2}{5} B R^2 \right) \quad (r_{i\alpha} = r_i - R_\alpha \,,\ R = R_\alpha - r_5) \,. \tag{2}$$

The generalized Jastrow factor is given by(S is the tensor operator)

$$F = f + pSf \,, \tag{3}$$

where p is a variational parameter here. Gauss type Jastrow function is used. The feature of clusterization is given by ratio B/A, small value of this indicates clusterization. When B is changed and it's value become smaller step by step. Effects of 3 and 4 body clusters calculation are very important to cluster structure of nuclei. Let us discuss a simple example of He. Near shell structure, ($B = 0.6$) the sum of three body and four body effect of tensor force is very repulsive. Concerning three and four body problem, when B is very small, the contribution of an attractive component of the tensor force nearly overcomes the repulsive component of the cental force. The following table indicates this fact explicitly.

In conclusion, the tensor force contributes to develop cluster structure, while the central force does not. As the value of B decreaces, three body contribution of the tensor force

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decreases and the positive four body part changes the sign to negative. Perhaps the results shown here are not best but will explain how clusterization occurs. The results are shown in units of MeV for a fixed value of A=0.7. Three and four body kinetic energies are omitted here, and also some of parameters are omitted. The two body totals include the kinetic energies.

It is very interesting that contributions of the two body tensor forces and central forces almost do not change. And totally contribution of the tensor force is large for the binding and that of central force become small. Table indicates that the tensor force (about three and four body part) plays important roll for clusterization. This property may work independent of the number of nucleons, as the F.I.Y method roughly indicates this fact for light nuclei.

$A = 0.7$	Tensor			Central			2 body		
B	4 body	3 body	Total	4 body	3 body	Total	Total	Tensor	Central
0.6	-211	+261	150	-61	+73	12	-4	-52	-46
0.45	-211	+235	24	-51	+70	19	-8	-51	-45
0.25	-211	+203	-8	-43	+61	18	-12	-52	-45
0.2	-211	+196	-15	-42	+58	16	-14	-53	-46
0.15	-214	+195	-19	-41	+55	14	-15	-53	-46
0.12	-215	199	-16	-42	+54	12	-15	-54	-46

References

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