Tensor correlation in He isotopes

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Tensor force is an important component in nuclear force and plays an important role in the nuclear structure. For example, the contribution of the tensor force in the binding energy of ^{4}He is comparable to that of the central force[1], and triplet-even part is dominant. It has also been discussed that tensor force is important in nuclear clustering phenomena of light nuclei[3].

In this report, we investigate the role of tensor force in the structures of the two neutron halo nuclei ^{6}He and ^{11}Li. In most theoretical studies of these nuclei, the core+n+n model is often used, where the core nucleus is treated as inert, such as the $(0s)^4$ configuration of ^{4}He for ^{6}He. However, under this assumption, tensor force cannot be incorporated in the core nucleus or in the coupling to the core and valence parts. Therefore, the effects of tensor force in the two neutron halo nuclei have not been realized yet. For ^{11}Li and ^{10}Li, the lowering of the $1s$ orbit near the $0p$ orbit has been discussed, however, the essential mechanism of this phenomenon is still unclear. It is of interest to examine the effect of the correlation induced by tensor force on this problem.

We examine what kind of correlation tensor force (tensor correlation) produces. Tensor force tends to change the parity of the nucleon single particle orbit due to the operator of $(\boldsymbol{\sigma}\cdot\boldsymbol{r})$. This originates from the nature of the pion (pseudoscalar meson) because tensor force mostly comes from the one-pion-exchange potential. Then, in ^{4}He, the $0s$ and $0p$ orbits can be coupled by tensor force and the description of ^{4}He is extended to $(0s)^4 + (0s)^2(0p)^2$. The amount of dissolution of ^{4}He can be estimated to be about 10% of the D-state probability by the exact four-body calculation.

The $2p$-$2h$ excitation from $0s$ to $0p$ orbits is also applicable in ^{9}Li. In ^{11}Li and ^{10}Li, the mixing of such configurations in ^{9}Li couples to the motion of the p-wave valence neutron. This produces the Pauli-blocking effect, and the total energies of p-wave configurations of ^{10}Li and ^{11}Li are lost, which may be sufficient to cause the energy to degenerate to that of s-wave configurations. We expect that tensor correlation can be important to produce the halo structure.

We show the effect of tensor correlation in the calculation of ^{4}He, where we use the harmonic oscillator wave function, and set the length parameter of the $0s$ orbit as 1.4 fm to fit the charge radius with the $(0s)^4$ configuration. The length parameter of the $0p$ orbit is free to include the higher shell component effectively. For effective NN interactions, we use the Volkov No.2 with $M = 0.6$, Furutani[4] and G3RS forces for the central, tensor, and LS parts, respectively. These are used in the cluster model calculation.

In Table 1, we show the results of ^{4}He with three length parameters of $0p$ orbit. It is found that when the $0p$ orbit shrinks, the binding energy increases and the contribution of tensor force and the $2p$-$2h$ probability become large. We calculate the case using the tensor force by strengthening its strength by fifty percent.

In particular, the $0p_{1/2}$ orbit is well mixed via 0^- coupling to the $0s_{1/2}$ orbit. This is

Table 1: Results of ^{4}He wave functions

length of $0p$ orbit [fm]	2.0	1.4	0.8	0.5	0.8 with $V_T \times 1.5$
E [MeV]	-28.4	-30.5	-36.3	-31.9	-46.3
$\langle V_{\rm tensor} \rangle$ [MeV]	-0.6	-5.2	-16.4	-7.6	-34.7
R.M.S.radius [fm]	1.52	1.47	1.48	1.48	1.48
$2p$-$2h$ [%]	1.8	4.4	5.4	1.1	11.2
$(0p_{1/2})^2$	0.7	3.5	4.5	0.7	9.8
$(0p_{3/2})^2$	0.3	0.1	0.3	0.2	0.5
$(0p_{3/2})(0p_{1/2})$	0.8	0.8	0.6	0.2	0.8

Table 2: Splitting energies in ^{5}He from two models.

	Present	$V_T \times 1.5$	KKNN
$3/2^-$	(0.74, 0.60)	(0.74, 0.60)	(0.74, 0.60)
$1/2^-$	(1.10, 1.45)	(1.47, 3.10)	(2.13, 5.84)

related to the pion nature. having a 0^- quantum number.

We also analyze the p-wave resonances of ^{5}He by solving the coupled channel problem of ^{4}He+n, where the length parameter of $0p$ orbit of ^{4}He is 0.8 fm. we adjust the triplet-even part of this force to fit the binding energy of ^{4}He, since the Volkov No.2 force includes the effect of tensor force. Since Pauli blocking mainly occurs in the $1/2^-$ state due to the $0p_{1/2}$ component in ^{4}He, doublet splitting of $1/2^-$-$3/2^-$ is induced in ^{5}He. A one range Gaussian potential to reproduce the resonance position of ^{5}He($3/2^-$) is used between ^{4}He and n without an LS interaction. The results of resonant poles are shown in Table 2, where KKNN is the phenomenological ^{4}He-n potential that fits the observed phase shifts[5]. Our model produces half of the observed splitting, which is consistent with other studies[6, 7]. From the results, the LS interaction of ^{4}He-n should be reexamined, and the structures of ^{6}He related to the $0p_{1/2}$ orbit can be improved.

Tensor correlation and Pauli principle strongly affect the properties of the $0p_{1/2}$ orbit. This is crucial in the inversion problem in ^{11}Li and ^{10}Li.

References

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