Role of pion mean field for ^{12}C and ^{16}O

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We apply the charge and parity projected relativistic mean field (CPPRMF) model[1] for the ^{12}C and ^{16}O nuclei. This framework explicitly introduces the pion mean field by using mixed-parity and mixed-charge number single-particle states as a basis in the projection scheme based on the chiral σ model Lagrangian. We study the role of the pion mean field on the structure of finite nuclei from a point of view of the chiral symmetry. We have already obtained the knowledge of the role of pion mean field for the ground state property of ^{4}He nucleus. We study now whether the mechanism of the energy gain by the pionic correlation in the ^{4}He nucleus is held also for heavier nuclei like the ^{12}C and ^{16}O nuclei.

In the ^{4}He nucleus the pion-mean field contributes to the energy gain due to the coupling of the (0p-0h)-state to the (2p-2h)-state. To reach the (2p-2h)-state, two nucleons jump from a $0s_{1/2}$ orbital to the $0p_{1/2}$ orbital across the major shell and require a large kinetic energy. For this reason, the spatial distribution of $0p_{1/2}$ becomes quite compact compared with that of the normal harmonic-oscillator p-shell wave function. This is the mechanism of the energy gain by the pionic correlation in the ^{4}He nucleus. ^{12}C has the configuration $(0s_{1/2})^4(0p_{3/2})^8$ in the shell model language. The particles in the $0s_{1/2}$ shell can jump into the $p_{1/2}$ shell due to the pionic correlation, because the $0p_{1/2}$ shell is not occupied. Further, the particles in the $0p_{3/2}$ shell are also active by jumping up to the $0d_{3/2}$ shell due to the pionic correlation.

The configuration of the ground state of ^{16}O is $(0s_{1/2})^4(0p_{3/2})^8(0p_{1/2})^4$. In this case $0p_{1/2}$ shell is already occupied and the mechanism of the energy gain like ^{4}He nucleus is depressed due to the Pauli blocking. The pionic correlation arises between $0p_{1/2}$ state and $1s_{1/2}$ state, however, the particles in the $0s_{1/2}$ state can excite to the hole-state in the $0p_{1/2}$ state. This is the mechanism of energy gain in the ^{4}He nucleus. Thus there are two kinds of wave function in the $0p_{1/2}$ state. One is the component of the particle-state, which has the normal size, while that of the hole-state is quite compact. The particle in the Fermi level is feasible to the pionic correlation. The energy gain owing to the pionic correlation is depressed due to the Pauli blocking in the ground state of ^{16}O.

We consider another configuration $(0s_{1/2})^4(0p_{3/2})^8(0d_{5/2})^4$ for the ^{16}O nucleus. In this case the mechanism of the energy gain due to the pionic correlation arises as in the ^{4}He and the ^{12}C cases. Since $0p_{1/2}$ sate is not occupied and the Pauli blocking dose not work, the pionic energy gain per particle is almost same as that of ^{12}C case. The total energy of this state is near the second 0^+ state of ^{16}O, which is a level at 6.05 MeV experimentally. We can reproduce the ground state and the second 0^+ state energy level simultaneously using the same Hamiltonian. The pion-mean field plays an important role to construct the property of the excited state. This fact is impressive, because any theoretical model could not reproduce both states of energy levels systematically until now.

The density distribution of the ground state of the ^{12}C and the ^{16}O is not good, however. It has a large depression at the central part of the density. This problem is the characteristic feature of the chiral σ model, irrespective of pion-mean field being finite or not. This problem might be solved by taking into account the vacuum effect properly[2].

References

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