A Variety of Particle Alignments in $N \approx Z$ nuclei around $A \sim 64$

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The study of $N \approx Z$ proton-rich nuclei with $A = 60-100$ calls much attention in the nuclear structure physics. The study has explored interesting aspects of structure such as oblate-prolate shape coexistence and delayed alignment in $N = Z$ fpg-shell nuclei. Strong residual correlations between protons and neutrons in the same orbits are considered to play a key role in those nuclei. Experiments are accumulating more detailed data, which demand precise theoretical explanation.

Recently, we have studied the above problems by means of large scale shell model calculations in the $pf_{5/2}g_{9/2}$ space. We have obtained a useful effective interaction (extended $P + QQ$ Hamiltonian) which describes very well energy levels of not only low-lying sates but high-spin states (up to $J = 28$) and other properties in ^{66}Ge and ^{68}Ge. The shell model Hamiltonian is fit for detailed study of $A = 60 - 68$ nuclei. We have found a unique phenomenon of $T = 0$ one-proton-one-neutron ($1p1n$) alignment which has not been expected in even-even nuclei [1]. Our study using the good Hamiltonian has clarified prolate-oblate shape transition from ^{64}Ge to ^{68}Se and oblate-prolate shape coexistence in ^{68}Se [2].

The focus of this paper is to discuss that a variety of particle alignments takes place one after another in every nucleus of $A = 60 - 68$ region [3]. The shell model approach makes it possible to investigate wave functions and variation of structure with increasing spin. We analyze the structure by calculating spin and isospin of respective single-particle orbits. This analysis reveals clearly change of the aligned structure in the $N \approx Z$ nuclei. The high-j $g_{9/2}$ orbit coming down near the pf shell plays an essential role in the alignment. We show that the $1p1n$ aligned states compete with two-neutron ($2n$) aligned states for the yrast position at medium high spins, and other states with more aligned nucleons in the $g_{9/2}$ orbit appear at higher spins. The competition between the $T = 0$ $1p1n$ alignment and the $T = 1$ $2n$ alignment in the $g_{9/2}$ orbit is related to the existence of suitable low-energy states with different isospin T in the $A - 2$ subsystem excluding the $g_{9/2}$ nucleons, which is a unique phenomenon in $N \approx Z$ nuclei of this region.

First, we clarify in detail several series of bands observed in ^{66}Ge and ^{68}Ge by different alignments in the $g_{9/2}$ orbit. Secondly, we show different appearances of alignments in neighboring Zn and Se isotopes. The $T = 0$ high-spin states in the odd-odd $N = Z$ nucleus ^{66}As are considered also in the light of particle alignment. The alignments in these nuclei depend on the condition where the Fermi level lies. We discuss that the first band crossing (backbending) point changes depending on the neutron number and the alignment delays at $N = Z$ in the Zn, Ge and Se isotopes.

[1] M. Hasegawa, K. Kaneko, and T. Mizusaki, Phys. Rev. C 70, No.3, 031301(R), 2004.
[2] K. Kaneko, M. Hasegawa, and T. Mizusaki, Phys. Rev. C 70, No.5, 051301(R), 2004.
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