Competition between T=1 and T=0 pairing in pf shell nuclei with $N = Z$[†]

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The role of the neutron-proton isoscalar spin-triplet (T=0, S=1) pairing interaction in finite nuclei has been a topic of discussion for long.[1–3] The isoscalar spin-triplet pairing interaction is known to be stronger than the isovector spin-singlet (T=1, S=0) one in nuclear matter.[4] Nevertheless, nuclei favor the spin-singlet T=1 pairing between identical particles. A straightforward explanation for this contradiction is that most stable nuclei have different numbers of neutrons and protons; thus, protons and neutrons occupy different single-particle orbits near the Fermi surface, which leads to the inhibition of T=0 pairing. It was also suggested that the nuclear spin-orbit field largely suppresses the spin-triplet pairing, much more than the spin-singlet pairing.[5,6]

To clarify the role of $T = 0$ pairing, we diagonalize the Hamiltonian with the spin-singlet and spin-triplet pairing terms in pf shell model configurations for nuclei with the same number of protons and neutrons, $N = Z$. The pairing correlation energies of the ($J^\pi = 0^+$, T=1) and ($J = 1^+$, T=0) states are shown in Fig. 1 as a function of the scaling factor f for the $T = 0$ pairing. The lowest energy state with J^π=0^+ for the $l = 3$ case acquires more binding energy than the J^π=1^+ state for the strength factor $f < 1.5$. In the case of strong T=0 pairing, that is, $f \geq 1.6$, the J^π=1^+ state acquires more binding energy than the lowest J^π=0^+ state. These results are largely attributed to the quenching of the T=0 pairing matrix element by the transformation coefficient corrsponding to a change of the scheme from the jj coupling to LS coupling. This quenching never happens for the T=1 pairing matrix element, since the mapping of the two-particle wave function between the two coupling schemes is simply implemented by a factor $\sqrt{j+1/2}$. For the $l = 1$ case, there is a competition between the J^π=0^+ and the J^π=1^+ states as seen in Fig. 1. Because of smaller spin-orbit splitting in this case, the couplings among the available configurations are rather strong, and the lowest J^π=1^+ state acquires more binding energy than the J^π=0^+ state when $f \geq 1.4$. These results are consistent with the spins observed for $N = Z$ odd-odd nuclei in the pf shell, where all the ground states have the spin-parity $J^\pi = 0^+$, except for $^{58}_{29}$Cu. The ground state of $^{58}_{29}$Cu has $J^\pi = 1^+$, because the odd proton and odd neutron occupy mainly the $2p$ orbits, wherein the spin-orbit splitting is expected to be much smaller than in $1f$ orbits.

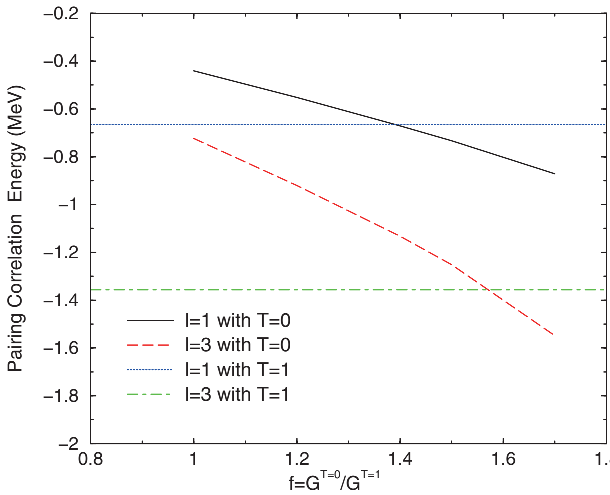

Fig. 1. (Color online) Pairing correlation energies for the lowest ($J^\pi = 0^+$, T=1) and ($J = 1^+$, T=0) states with the $l = 3$ and $l = 1$ configurations as a function of the scaling factor f of the $T = 0$ pairing. The strength of the spin-singlet T=1 pairing interaction is fixed at $G^{(T=1)}$=24/A MeV with mass A=56, while the strength for the spin-triplet T=0 pairing interaction, $G^{(T=0)}$, is varied with the factor f multiplied by $G^{(T=1)}$.

In summary, by diagonalizing the pairing Hamiltonian, we have shown that the spin-triplet pairing correlation energy in the $1f$ shell configuration becomes larger than the spin-singlet pairing energy when the strength of the spin-triplet pairing is larger than that of the spin-singlet pairing by a factor of 1.6 or more. However, for the $2p$ configuration, the spin-triplet pairing correlation becomes dominant even when the factor f is approximately 1.4.

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