Effect of isoscalar spin-triplet pairings on spin-isospin responses†

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The spin-isospin response is a fundamental process in nuclear physics and astrophysics. The Gamow-Teller (GT) transition induced by $\vec{\sigma}t_{\pm}$ and, in a no-charge-exchange channel, magnetic dipole (M1) transitions are extensively observed in a broad region of the mass table. Recent high-resolution proton inelastic scattering measurements at $E_p = 295$ MeV have revealed that the isoscalar (IS) quenching is substantially smaller than the isovector (IV) quenching in the spin M1 excitations for several $N = Z$ sd-shell nuclei.[1)] In this paper, we study the effect of IS spin-triplet pairing correlations on the IS and IV spin M1 responses based on modern shell model effective interactions for the same set of $N = Z$ nuclei as those in Ref. 1.

We consider the IS and IV spin M1 operators, which are given as $\hat{O}_{\rm IS} = \sum_i \vec{\sigma}(i)$ and $\hat{O}_{\rm IV} = \sum_i \vec{\sigma}(i)\tau_z(i)$, respectively. The proton-neutron spin-spin correlation is defined as

$$\begin{aligned}\Delta_{\rm S} &= \frac{1}{16}\left(S(\vec{\sigma}) - S(\vec{\sigma}\tau_z)\right)\\ &= \sum_f \langle i|\sum_i \frac{\vec{\sigma}_n(i)+\vec{\sigma}_p(i)}{4}|f\rangle\langle f|\sum_i \frac{\vec{\sigma}_n(i)+\vec{\sigma}_p(i)}{4}|i\rangle\\ &- \sum_f \langle i|\sum_i \frac{\vec{\sigma}_n(i)-\vec{\sigma}_p(i)}{4}|f\rangle\langle f|\sum_i \frac{\vec{\sigma}_n(i)-\vec{\sigma}_p(i)}{4}|i\rangle\\ &= \langle i|\vec{S}_p\cdot\vec{S}_n|i\rangle, \qquad (1)\end{aligned}$$

where $\vec{S}_p = \sum_{i\in p}\vec{s}_p(i)$ and $\vec{S}_n = \sum_{i\in n}\vec{s}_n(i)$. The correlation value is 0.25 and -0.75 for a proton-neutron pair with a pure spin triplet and a spin singlet, respectively. The former corresponds to the ferromagnet limit of the spin alignment, while the latter is the anti-ferromagnetic one.

Shell model calculations are performed in the full sd-shell model space with a USDB effective interaction. In the results of USDB*, the IS spin-triplet interactions are enhanced by multiplying the relevant matrix elements by a factor of 1.2 compared to the original USDB interaction. For the results of the IV spin-M1 transitions, a quenching factor $q = 0.9$ is used for USDB**. The calculations for ^{28}Si reproduce quite well the experimental IS 1^+ state with a strong spin transition at $E_{\rm x} = 9.50$ MeV. The enhanced IS pairing has a quenching effect of approximately 20% on the transition strength [i.e., $B(\sigma) = 6.82(5.63)$ in USDB(USDB*)], but the excitation energies are less affected within a few hundred keV change. Two IV 1^+ states with strong spin strengths of $B(\sigma\tau) = 2.05$ and 0.92 are reported at $E_{\rm x} = 11.45$ and 14.01 MeV, respectively. The shell model gives strong IV M1 states at similar excitation energies. The enhanced IS pairing reduces the IV spin transition strength, corresponding to a renormalization factor of $g_s^{\rm eff}({\rm IV})/g_s({\rm IV}) = 0.87$.

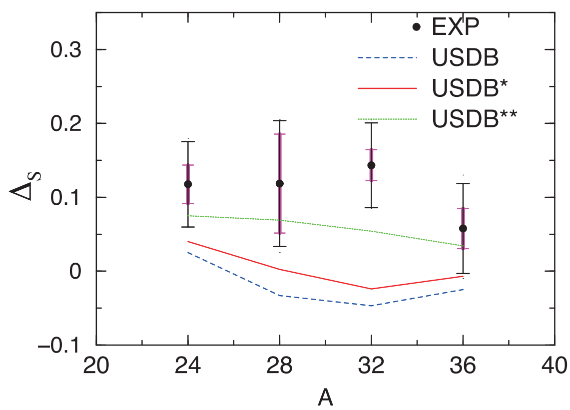

Fig. 1. (Color online) Experimental and calculated proton-neutron spin-spin correlation $\Delta_{\rm S}$. See the text for details. Experimental data are taken from Ref. 1. See Ref. 1 for a description of the experimental error bars.

Figure 1 shows the experimental and calculated proton-neutron spin-spin correlations (1). The results calculated with the USDB interaction show poor agreement with the experimental data. The results with an enhanced IS spin-triplet pairing improve the agreement to some extent. A quenching factor close to unity, $q = 0.9$, for only the IV matrix elements, results eventually in a fine agreement with the experimental values. The positive value of the correlation indicates that the population of spin triplet pairs in the ground state is larger than that of the spin singlet pairs.

In summary, we studied the IS and IV spin M1 transitions in even-even $N = Z$ sd-shell nuclei using shell model calculations with USDB interactions in full sd-shell model space. The quenching effects on the spin M1 transition matrices are larger in the IV case than in the IS case. Positive contributions for the spin-spin correlations are obtained via an enhanced isoscalar spin-triplet pairing interaction. The effect of the Δ-hole coupling is also examined on the IV spin transition, and the empirical spin-spin correlations in the ground states are reproduced well by a combined effect of the IS pairing and a quenching factor of $q = 0.9$ on the IV spin transition matrix elements.

Reference

1) H. Matsubara et al., Phys. Rev. Lett. **115**, 102501 (2015).

† Condensed from the article in Phys. Rev. C **94**, 041303(R) (2016)

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