Magnetic dipole excitations in magic nuclei with subtracted second random-phase approximation†

M. J. Yang,*1 C. L. Bai,*1 H. Sagawa,*2,*3 and H. Q. Zhang*4

Magnetic dipole (M1) excitations of nuclei have been extensively studied through numerous experimental and theoretical works for several decades. A like-particle particle-hole (p-h) spin-flip M1 excitation is an analog of the charge-exchange Gamow-Teller (GT) transition, and shows a typical quenching problem commonly observed in spin-isopin responses such as β-decay and nuclear matrix elements of double β-decay. The M1 excitation is a sensitive tool for probing the spin-isospin channel of nuclear effective interaction, which is difficult to obtain from the ground state properties of nuclei. In this study, we investigate the effects of $2p$-$2h$ configuration mixing and tensor forces on M1 excitations in magic nuclei ^{48}Ca, ^{90}Zr, and ^{132}Sn using a self-consistent Hartree-Fock (HF) plus subtracted second random-phase-approximation (SSRPA) with Skyrme energy density functionals (EDFs).

Figure 1 shows the strength distributions and corresponding cumulative sums of M1 transition in ^{48}Ca calculated by RPA and SSRPA with SGII+TUb including or excluding tensor terms. The SGII+TUb has the tensor terms $(T, U) = (500, -280)$ MeVfm^5, where $T(U)$ represents the coupling strength of a triplet-even (-odd) tensor interaction. The triplet-odd term strongly affects the excitation energies of M1 states, which is different from the cases of charge-exchange GT and spin-dipole excitations, wherein the triplet-even term has a large influence on the excitation energies. This can be understood from the nature of triplet-even and triplet-odd tensor effects on spin-orbit splitting. The triplet-odd term dominates like-particle spin-orbit splitting, whereas the triplet-even term affects the proton-neutron exchange spin-orbit splitting.

Qualitatively, the excitation energy of the main M1 state in ^{48}Ca is shifted downwards 1.5 MeV by the $2p$-$2h$ configuration mixings in SSRPA with SGII without the tensor terms, compared with RPA calculations shown in Fig. 1. However, the tensor interactions shift the energy upward by 1.7 MeV, and the net result is close to the experimental excitation energy.

The cumulative sums of B(M1) are counted up to $E_{max} = 15$ MeV to compare with the experiment measured up to 15 MeV in Figs. 1(b) and 1(d). The effects of the $2p$-$2h$ configuration mixings in SSRPA are clear in this figure. The RPA calculations, either with or without tensor terms, produce the main peak with a strength larger than 10 μ_N^2, which is more than twice the experiment data. In SSRPA calculations, the M1 strengths are reduced largely, and the strength of main peak ($\simeq$4.09 μ_N^2) becomes almost the same as the experimental one ($\simeq$4.0 μ_N^2). Besides the main peak, some states with small strength are distributed around the main peak in SSRPA. The tensor terms in SSRPA shift the main peak energy upwards by $\sim$1.8 MeV, which is still almost 1 MeV lower than the experimental one. Figure 1(d) indicates that the cumulative sum of B(M1) by SSRPA up to 15 MeV is reduced by $\sim$15% of the total sum via tensor correlations.

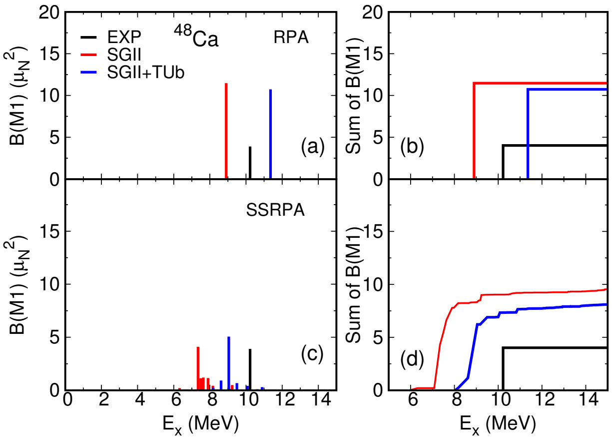

Fig. 1. (Color online) Strength distributions (left panels) and corresponding cumulative sums (right panels) of M1 excitations in ^{48}Ca calculated with the SGII, SGII+TUb EDFs by RPA (upper panels) and SSRPA (lower panels). The experimental data[1] are shown by the black lines. The figure draw the energy regions Ex $\leq$ 15 MeV where the experiment data exist.

Magnetic dipole (M1) excitations of other magic nuclei, ^{90}Zr, and ^{132}Sn, are also investigated using the self-consistent HF+SSRPA model. In ^{90}Zr, the same mechanism occurs as in the case of ^{48}Ca. The $2p$-$2h$ configuration mixings shift downward the M1 energy; however, the tensor terms push up the energy and the final result is consistent with the observed energy spectra. Further, we show that the $2p$-$2h$ configurations largely fragment the M1 strength, and reduce the cumulative strengths around the main M1 peak by $\sim$27% in ^{90}Zr compared with those of RPA, as an outcome of the combined effect with the tensor force.

Reference

1) J. Birkhan *et al.*, Phys. Rev. C **93**, 041302(R) (2016).

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*1 College of Physics, Sichuan University
*2 RIKEN Nishina Center
*3 Center for Mathematics and Physics, University of Aizu
*4 China Institute of Atomic Energy

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