Quasi-particle random phase approximation (QRPA) with quasi-particle-vibration coupling (QPVC): application to the Gamow-Teller response of a superfluid nucleus ^{120}Sn[†]

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The RPA+PVC approach is obviously limited to the case of magic nuclei. In this paper we propose the QRPA+QPVA formalism for spherical superfluid nuclei, describing the nuclear ground state within the Hartree-Fock-Bogoliubov (HFB) approximation, and the collective excitations of the system within QRPA. We consider the Gamow-Teller transitions in a well bound super-fluid nucleus ^{120}Sn in this study. As a unique feature in GT transitions of superfluid nuclei, both isovector (IV) and isoscalar (IS) pairing are expected to play a relevant role. While the usual IV pairing determines the ground-state structure, the IS pairing is present in the QRPA residual interaction for Gamow-Teller transitions.

The GT strength associated with QRPA+QPVC, is given by

$$S(E) = \frac{1}{\pi} \mathrm{Im} \sum_{\nu} \langle \nu | \hat{O}_{\mathrm{GT}^{\pm}} | 0 \rangle^2 \frac{1}{E - \Omega_\nu + i(\frac{\Gamma_\nu}{2} + \Delta)}, \quad (1)$$

where the GT operator is $\hat{O}_{\mathrm{GT}^{\pm}} = \sum_{i=1}^{A} \sigma(i) t_{\pm}(i)$ and Δ is a smearing parameter. In our calculation, we will only focus on the GT$^-$ excitations. $|\nu\rangle$ denotes the eigenstates associated with the complex eigenvalues $\Omega_\nu - i\frac{\Gamma_\nu}{2}$ obtained by diagonalizing the energy-dependent complex QRPA matrix.

The four theoretical strength functions are compared with experimental results in Fig. 1. We use a smearing parameter $\Delta = 0.5$ MeV in the QRPA and QRPA+QPVC calculation. In Fig. 1, the (^{3}He, t) experimental low-energy strength distribution is well reproduced by including isoscalar pairing, while the (p,n) data are better reproduced without it. The spreading width and lineshape of the giant resonance region are very well reproduced by the inclusion of the QPVC effect.

HFB+QRPA is an appropriate tool for neutron-rich and neutron-deficient, nuclei, especially for weakly bound nuclei. The QRPA+PVC calculation in these cases is a new research line which is still in its infancy. Improving the theoretical predictive power of such calculations is not only beneficial for our progress in understanding nuclear structure, but also of essential interest understanding weak-interaction processes in particle physics and astrophysics. Accordingly, we envisage the study of weak-interaction processes of astrophysical interest in our future research of the QRPA+QPVC model.

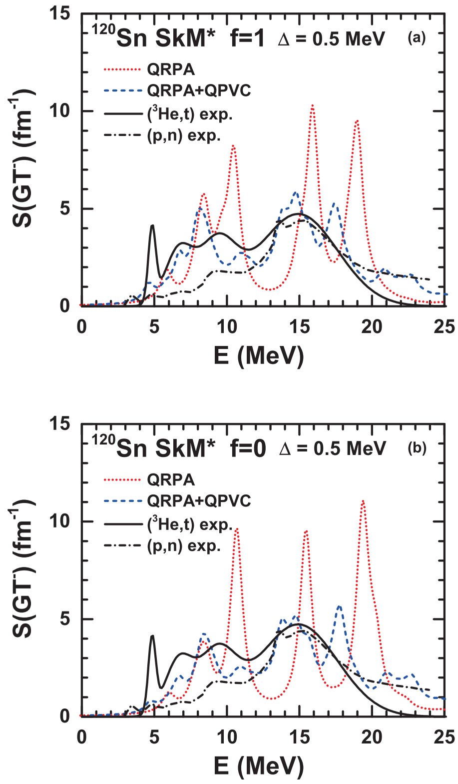

Fig. 1. (Color online) Gamow-Teller strength distributions for ^{120}Sn calculated by QRPA and QRPA+QPVC models, with [panel (a)] and without [panel (b)] isoscalar pairing, using the Skyrme interaction SkM*. The excitation energy is with respect to the ground state of ^{120}Sn. The smearing parameter $\Delta = 0.5$ MeV is used. The experimental results from (^{3}He, t) and (p,n) reactions are shown for comparison. The cross section from the (^{3}He, t) experiment is scaled by a factor of 1.6 so that the main GTR strength exhausts 65% of the Ikeda sum rule[1)]. The cross section from the (p,n) reaction is normalized by the unit cross section[2)]

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References

1) K. Pham et al., Phys. Rev. C**51**, 526 (1995).
2) M. Sasano et al., Phys. Rev. C**79**, 024602 (2009).