Double phonon excitation with a subtracted second random-phase approximation

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Random-Phase-Approximation (RPA) is a useful tool to understand nuclear resonant states. It describes nuclear excited states as coherent one-particle one-hole (1p1h) excitations of the single-particle picture and has provided valuable information on nuclear structure from the microscopic point of view. However, due to the limitation of model space within 1p1h level, RPA cannot fully describe the effect of higher-order correlations like spreading width. Recently, it is pointed out that couplings with two-particle two-hole (2p2h) excitations are crucial to describe particle emission after muon capture reactions.[1] It is also confirmed that theoretical model cannot reproduce experimental data measured at RIKEN-RAL without the 2p2h effect. In addition to the effect of higher-order correlations, the so-called meson-exchange current (MEC) plays an important role for muon captures and high-energy neutrino-nucleus reactions. MEC is a two-body force and therefore can excite two particles simultaneously. Namely double phonons are created in nuclei by the action of MEC. Microscopic understanding of MEC in nuclei is now highly demanded because activities making muon nuclear data is running in RIBF.

Second RPA (SRPA), the method extending RPA to 2p2h spaces, is a powerful tool to study MEC effect as well as 2p2h effects. To this end, we developed a new computational code of SRPA. In this report, we demonstrate its brief feature and the result of double-phonon excitations. In the SRPA, the phonon creation operator $Q^\dagger_{\lambda;JM}$ is defined as[2]

$$Q^\dagger = \sum_{mi} X_{mi} O^\dagger_{mi} + \sum_{m<n,i<j} \mathcal{X}_{mnij} O^\dagger_{mnij} - \cdots . \tag{1}$$

Indices $m(n)$ and $i(j)$ stand for particle and hole states. The operators $O^\dagger_{mi}$ and $O^\dagger_{mnij}$ create 1p1h and 2p2h states, respectively, and its detailed form can be found in Ref. 2). Note that terms annihilating 1p1h and 2p2h states are omitted in Eq. (1) (Y and $\mathcal{Y}$ in Ref. 2)). To carry out SRPA, the single-particle basis is computed from the Skyrme-Hartree-Fock (SHF) method with the SkO' interaction and the box size 14 fm. It is recognized that excitation energies calculated by SRPA are badly small rather than 1p1h RPA because some part of matrix elements of two-body force are already taken into account in SHF level.[3] To overcome this problem, we applied the subtraction method.[4]

Transition strength of double phonon operator $V_J \equiv [O_L P_L]^J$ is given by

$$\langle J||V_J||0\rangle = \sum_{mi} X_{mi} V^J_{mi} + \sum_{mnij}\sum_{J_pJ_h} \mathcal{X}^{J_pJ_hJ}_{mnij} V^{J_pJ_hJ}_{mnij} + \cdots \tag{2}$$

$$V^J_{mi} = (-1)^{j_m+j_i+J} \sum_n \begin{Bmatrix} j_i & j_m & J \\ L & L & j_n \end{Bmatrix} \cdot \langle m||O_L||n\rangle\langle n||P_L||i\rangle + (-1)^{j_m+j_i+1} \sum_j \begin{Bmatrix} j_i & j_m & J \\ L & L & j_j \end{Bmatrix} \cdot \langle m||O_L||j\rangle\langle j||P_L||i\rangle \tag{3}$$

$$V^{J_pJ_hJ}_{mnij} = 2\frac{\hat{J}_p}{\sqrt{1+\delta_{mn}}}\frac{\hat{J}_h}{\sqrt{1+\delta_{ij}}} \left[\begin{pmatrix} j_m & j_n & J_p \\ j_i & j_j & J_h \\ L & L & J \end{pmatrix} \times O^L_{mi} P^L_{nj} - (-1)^{j_i+j_j-J_h} \begin{pmatrix} j_m & j_n & J_p \\ j_j & j_i & J_h \\ L & L & J \end{pmatrix} O^L_{mj} P^L_{ni} \right]. \tag{4}$$

Figure 1 shows the result of double isoscalar monopole excitation for ^{16}O. The SRPA calculation is performed with energies of the single-particle and 2p2h excitation energies less than 50 MeV. We obtained a main resonance around $E = 45$ MeV, which is about 2 times higher than a single monopole excitation.

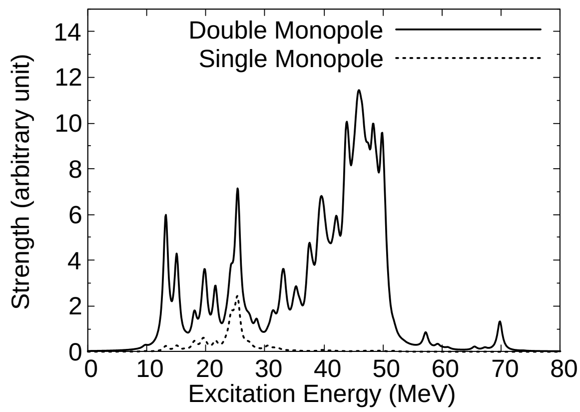

Fig. 1. Strength distribution of single and double isoscalar monopole excitations for ^{16}O.

Our perspective is to apply the SRPA to study the effect of MEC in muon captures. New experiments about particle emissions following muon capture are planned and the result will help us to confirm if SRPA is effective to study MEC effects on muon captures.

References
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