Effective restoration of dipole sum rules within the renormalized random-phase approximation†

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The random-phase approximation (RPA) is one of the simple theoretical methods, which is widely used to describe the vibrational collective excitations of the nucleus. The RPA is derived basically based on the quasiboson approximation (QBA), which assumes that the operators of the particle-hole (ph) pairs have structure like ideal bosons, leading to the violation of the Pauli principle owing to their fermion structure. The application of the RPA to the light nuclear systems, where the concepts of the mean field and the QBA do not properly work well, is therefore questionable. One of the typical methods to preserve the Pauli principle between the RPA ph pairs is the renormalized RPA (phRRPA)[1)]. The latter includes the so-called ground-state correlation (GSC) factor $D_{ph} \equiv \sqrt{f_h - f_p}$ with f_p and f_h being occupation numbers of the particles and the holes, respectively. Within the RPA, D_{ph} is equal to 1, whereas within the phRRPA it is proportional to the RPA backward-going amplitudes $(Y_{ph})^2$ and is therefore always less than or equal to 1. However, the application of the phRRPA using this GSC factor has been limited so far to the energy and $B(E3)$ value of the lowest 3_1^- state in ^{146}Gd and ^{208}Pb only[2)]. For the dipole excitation 1^-, whose first moment m_1 known as the energy-weighted sum rule (EWSR) is the most important, no investigation was carried out. The RPA fulfills this EWSR sum rule. However, within the phRRPA, the matrix elements of the ph interactions are reduced by the factor D_{ph}, leading to the decrease of the $B(E1)$ values and therefore causing the violation of the EWSR. The goal of the present paper is to restore the EWSR violated within the conventional phRRPA in an approximate and effective way.

To restore the EWSR, we propose a simple RRPA calculations taking into account, in addition to the ph excitations, the contribution of the pp and hh excitations in a perturbative way. The total isovector (IV) and isoscalar (IS) (compressional) dipole transition probabilities are then given as $B(E1) = B^{ph}(E1) + B^{pp'}(E1) + B^{hh'}(E1)$, where $B^{ss'}(E1)$ are the transition probabilities of the ss' ($ss' = ph$ or pp' or hh') transitions. The numerical calculations are carried out using the self-consistent RPA code with Skyrme SLy5 interaction[3)] for IV and IS dipole strength distributions in ^{48,52,58}Ca (Fig. 1) and ^{90,96,110}Zr isotopes. The results obtained show that the GSC beyond the RPA reduce the IS transition strengths, whereas it slightly increases the total strength on the low-energy region (the pygmy dipole resonance – PDR) region and decreases the strength on the other side (the GDR region), leading to a significant decrease of the EWSRs for both IS and IV modes obtained within the phRRPA. This violation of the EWSR is then fully recovered by taking into account the contribution of pp and hh excitations within the RRPA. This result reveals the reason why all the RPA extensions that do not take into account the pp and hh excitations violate the EWSRs. Consequently, the ratio of the energy-weighted sum of strengths of the PDR to that of the GDR, which is almost zero in stable nuclei, increases with the neutron number. As compared to the RPA case, this ratio is in general significantly larger within the RRPA.

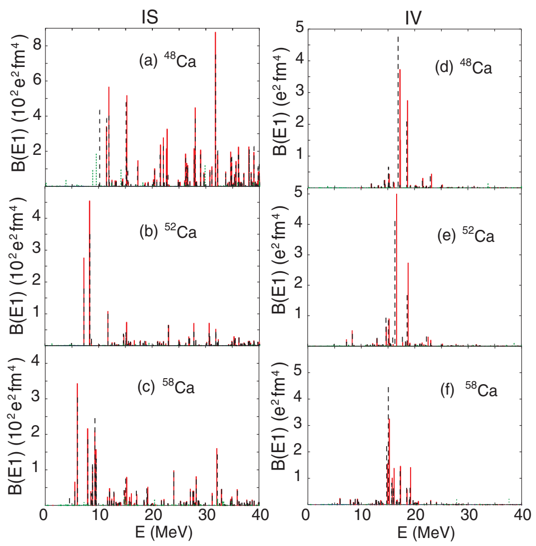

Fig. 1. Distributions of the IS and IV reduced transition probabilities $B(E1)$ for calcium obtained within the RPA, phRRPA, and RRPA. The solid and dashed vertical bars denote the $B(E1)$ values obtained within the RPA and phRRPA, respectively. The dotted vertical bars stand for the $B^{pp'}(E1)$.

References

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