A fully microscopic model of total level density in spherical nuclei[†]

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The nuclear level density (NLD) is one of important inputs for the calculations of low-energy nuclear reactions and astrophysics. It also contains various information on the internal structure of atomic nuclei such as single-particle levels, pairing correlations, spin distributions, collective (vibrational and/or rotational) excitations, nuclear thermodynamics, *etc.* Although many theoretical studies have been carried out during the last seven decades to find a reliable and fully microscopic model of NLD, there has still been lacking a fully microscopic NLD model. Recently, we have proposed a microscopic NLD model based on the exact pairing plus independent-particle model at finite temperature (EP+IPM).[1)] The latter, which has a very short computing time and contains no fitting parameters to the experimental NLD data, can describe quite well the NLDs and thermodynamic properties of several hot nuclei. Nevertheless, the EP+IPM still contains two shortcomings, which limit its fully microscopic foundation. These shortcomings come from the use of empirical formulas for the spin cut-off σ and collective enhancement factors. The latter is a multiplication of the vibrational $k_{\rm vib}$ and rotational $k_{\rm rot}$ enhancement factors.[1)]

In this paper, we develop a fully microscopic version of the EP+IPM, limited to spherical nuclei (rotational enhancement factor $k_{\rm rot} = 1$), in which three significant improvements are included. First, the single-particle spectra are taken from the Hartree-Fock mean field plus exact pairing (HF+EP) with an effective MSk3 interaction,[2)] instead of the Woods-Saxon potential in the original version of EP+IPM. Second, the spin cut-off parameter is directly calculated by using the statistically thermodynamic method $\sigma^2 = \frac{1}{2}\sum_k m_k^2 \mathrm{sech}^2\left(\frac{1}{2}E_k/T\right)$, where m_k is the single-particle spin projection (in the deformed basis) and E_k is the quasiparticle energy. Last, the vibrational enhancement of NLD is directly calculated based on the vibrational partition function $Z_{\rm vib}(T) = \sum_{\lambda,i}(2\lambda+1)e^{-E_i^\lambda/T}$, where E_i^λ are all the eigenvalues obtained by solving the self-consistent HF+EP+RPA (SC-HFEPRPA) equation[3)] for the corresponding multipolarity λ, which runs from 0 to 5. The total partition function of the system is then calculated by combining this vibrational partition function with that of the EP+IPM (without vibrational enhancement), namely $\ln Z'_{\rm total} = \ln Z'_{\rm EP+IPM} + \ln Z'_{\rm vib}$, where $Z'(T)$ is the excitation partition function.[1)]

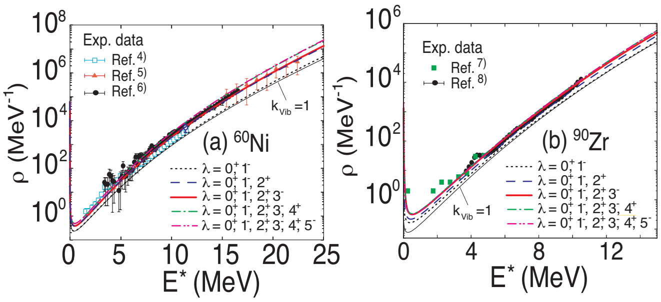

Fig. 1. Total NLDs obtained within the fully microscopic EP+IPM by gradually adding higher collective vibrational modes λ to the vibrational partition function versus the experimental data for ^{60}Ni (a) and ^{90}Zr (b). Experimental data are taken from Refs. 4–8).

The numerical tests for two spherical ^{60}Ni and ^{90}Zr nuclei (see Fig. 1) show that the monopole and dipole excitations ($\lambda = 0^+$ and 1^-) have little enhancement to the total NLD. By adding the quadrupole $\lambda = 2^+$ and octupole 3^- excitations, the EP+IPM NLDs are in excellent with the experimental data. However, adding higher hexadecapole $\lambda = 4^+$ and quintupole $\lambda = 5^-$ excitations enhances the NLD further but the results obtained slightly overestimate the experimental data because these states are always located at a very high-excitation energy, which goes beyond the vibrational excitation region. The results shown in Fig. 1 are of particular valuable as they are the first microscopic calculation, which confirms the important role of the quadrupole and octupole excitations in the description of NLD. We also found that the vibrational enhancement factor obtained within our fully microscopic approach is smaller than that calculated using the empirical and phenomenological formulas. In addition, the spin cut-off factor obtained within our microscopic approach are larger than that obtained by using the empirical formula.

References

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