Shell model nuclear level densities and it's astrophysical importance

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Introduction

For complete understanding of nuclear astrophysical network calculations like, r-process, astrophysical reaction rates at a fixed temperature in terms of Maxwellian average of cross-sections over a wide range of energy for radiative neutron capture processes are crucial. Within a statistical framework, the radiative neutron capture cross-sections and relevant reaction rates calculation primarily requires (i) neutron-nucleus optical model potential (OMP), (ii) γ-ray strength function (γSF), and (iii) nuclear level density (NLD). The uncertainties due to OMP are relatively smaller while γSF and NLD have significant impact on calculated neutron capture rates. The NLD describes the total number of states accessible in a given nucleus at a specific excitation energy. The NLDs have been calculated using various methods which ranges from simple phenomenological models based on non-interacting degenerate Fermi gas [1–4] to more complex microscopic mean-field models [5, 6]. In these models, the collective effects are included through the rotational and vibrational enhancement factors. These NLDs are normalized with the experimental data at low energy and neutron resonances.

Using the framework of shell model which naturally incorporates for the collective excitations through the residual interaction, one obtain more realistic values of NLDs. Few different approaches to calculate the NLDs within the framework of shell model have been performed. One of them is the shell model Monte Carlo [7] which utilizes auxiliary fields to compute the thermal trace for the energy and further inverse Laplace transform to obtain the NLDs. Another efficient way to construct the NLDs is based on the spectral distribution method (SDM) [8, 9] for many-body shell model Hamiltonian in full configuration space, which avoids the diagonalization of huge dimensional matrices. The SDM has further been extended for the construction of the NLDs for many body shell model Hamiltonian using calculation of the first and second moments of Hamiltonian for different configurations at fixed spin and parity. The NLDs so obtained also agree reasonably with those corresponding to the exact diagonalization of shell model Hamiltonian in full configurational space [10]. However, the SDM requires an accurate estimation of the shell model ground state energy, which is very time consuming as the full shell model calculation. This difficulty has been overcome using the exponential convergence method [9, 11].

Results and Discussion

In this work, realistic NLDs are obtained from spectral distribution method applied to many-body shell model Hamiltonian for $pfg_{9/2}$-model space. But, we have found $pfg_{9/2}$-model space too small to give a realistic parity ratio, hence, used appropriate parity equilibration scheme. The NLDs so obtained and s-wave neutron resonance spacings agree reasonably well with the available experimental data. We further calculate the neutron capture reaction cross-sections and

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astrophysical reaction rates for few seed nuclei for the nucleosynthesis in and around the Fe-group. We show in Fig. 1, the astrophysical reaction rates obtained using the NLDs from SDM* (for $pfg_{9/2}$-model space) and compare them with the recommended values from ENDF [12] and 'KADoNiS v0.3' [13]. The results from other phenomenological, microscopic models (BSFG, GSM, HFB and HFB-u(unnormalised)) and earlier SDM calculations (For pf-model space) [9] are also shown for comparison. SDM (both pf and $pfg_{9/2}$-model space) results explain the recommended values from ENDF [12] quite well in all the cases.

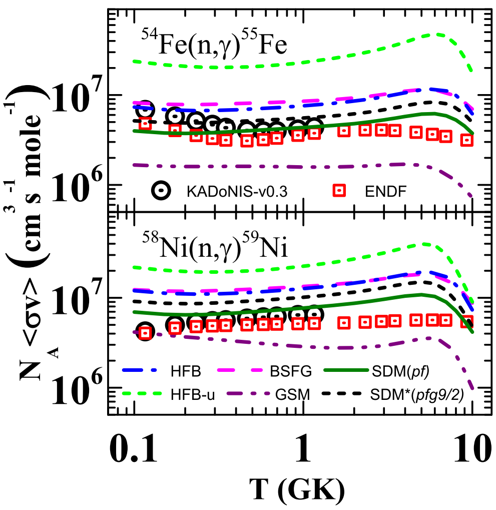

FIG. 1: The astrophysical reaction rates as a function of temperature using NLDs from SDM* ($pfg_{9/2}$-model space) and SDM (pf-model space [9]) compared with those obtained for other models. For comparison, the recommended values from ENDF [12] and 'KADoNiS v0.3' [13] are shown.

Conclusions and Outlook

In present work, we have extended our previous work [9] for $pfg_{9/2}$-model space. We compare our results with those obtained with NLDs from other phenomenological and microscopic models as commonly employed and found to be in harmony with experimental data compared to other models, particularly for the incident neutron energies of astrophysical interest.

Since the present method is quite general, can be explored in various model spaces and other reactions of astrophysical interest. Realistic shell-model NLDs of both parities can be obtained naturally performing calculations for sufficiently larger and proper model space, which will involve huge computation.

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