Study of Odd-Odd N=53 Isotones near N=50 Shell Closure

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Abstract: Negative parity yrast energy states of the odd-odd Rh and Ag nuclei with N = 53 have been studied by employing projected shell model, which succeeds in reproducing experimentally observed energy levels. The model successfully describes how the yrast band is formed from the contribution of various multi-qyasi-particle bands in these N = 53 isotones in a systematic manner.

Keywords: Projected shell model; yrast spectra; multi-quasi-particle configuration.

1. Introduction

With the advent of present day experimental techniques, it is now possible to excite nucleus to high angular momentum states and to study the nuclear structure in the realm of high-angular momentum. It has been observed that as we go to higher angular momentum, the Coriolis and centrifugal forces become more and more significant. They affect the properties of the nuclei by changing the pairing correlations, equilibrium shape of the nucleus and most importantly by changing the pattern of angular momentum generation. This gives rise to the observation of the well-known interesting phenomena which provide information regarding the structure of the nuclei [1-8]. Nuclei with A~100 are situated in a transitional region between spherical and deformed nuclei and are characterized by a small quadrupole deformation. Their structure, which is also influenced by the co-existence of deformed and spherical shapes, is complex to study. It is even more complex for odd-odd nuclei whose properties at low and moderate angular momentum derive mainly from the odd proton in orbitals situated below the Z=50 gap ($g_{9/2}$,$p_{1/2}$,$f_{5/2}$) and odd neutron in the orbitals situated above N=50 gap ($d_{5/2}$,$g_{7/2}$,$h_{11/2}$). The N=53 nuclei in the mass region A~100 are in a region where nuclei are characterized by shape co-existence and shape transition [9-11]. The main aim of the present work is to elucidate the nuclear structure of odd-odd ^{98}Rh and ^{100}Ag nuclei (N=53 isotones) lying in this mass region in terms of yrast spectra before and after configuration mixing. Systematic calculations are performed in quantum-mechanical framework-known as - Projected Shell Model. The calculated results are also comparison with the available experimental data in order to test the efficacy of the chosen valence space for this mass region and the reliability of the framework in explaining the nuclear structure of these nuclei.

2. The Model

The choice of the Hamiltonian in the present calculational framework is the first step and the Hamiltonian used in this work consists of a sum of schematic (Quadrupole-Quadrupole + Monopole +

Quadrupole pairing) forces which represent different kinds of characteristic correlations between active nucleons. The total Hamiltonian is of the form

$$\hat{H} = \hat{H}_0 - \frac{\chi}{2}\sum_{\mu}\hat{Q}^{\dagger}_{\mu}\hat{Q}_{\mu} - G_M \hat{P}^{\dagger}\hat{P} - G_Q \sum_{\mu}\hat{P}^{\dagger}_{\mu}\hat{P}_{\mu} \tag{1}$$

where, the first term represents the Nilsson spherical single particle Hamiltonian and is given by

$$\hat{H}_0 = \sum_{\alpha} c^{\dagger}_{\alpha} E_{\alpha} c_{\alpha} \tag{2}$$

where,

$$E_{\alpha} = \hbar\omega[N - 2\kappa\hat{l}\cdot\hat{s} - \kappa\mu(\hat{l}^2 - \langle\hat{l}\rangle^2)]$$

Here, E_α is the single-particle energy. Note that the value of l is known when N and j are specified. ω is the harmonic-oscillator parameter which incorporates the principle of volume conservation for nuclei deformed from spherical shapes, s and l represent the intrinsic nucleon spins and orbital angular momenta in the stretched co-ordinate basis. κ and μ are the Nilsson parameters and are in the present set of calculations they are taken from Ref. [Zhang et al.,]. The remaining terms in Equation (3) are residual quadrupole-quadrupole, monopole pairing and quadrupole pairing interactions, respectively. Finally, the Hamiltonian is diagonalized in the deformed projected basis to get the energy eigen values. For doubly-odd nuclei, the following set of multi-quasi-particle configurations is used in the present calculations:

$$a^{+}_{\nu}a^{+}_{\pi}|0\rangle \tag{3}$$

where $a^{+}_{\nu}(a^{+}_{\pi})$ is the neutron (proton) quasi-particle creation operator constructed in the Nilsson + BCS basis, and $|0\rangle$ is the quasi-particle vacuum state and P^{I}_{MK} be the angular-momentum projection operator. The index ν(π) runs over selected neutron(proton) quasi-particle (qp) states. The present calculations are carried out with same set of interaction parameters and the deformation used for ^{98}Rh and ^{100}Ag nuclei are 0.2881and 0.2810 respectively.

In odd-odd ^{98}Rh and ^{100}Ag isotones, odd-proton occupies orbitals situated below the Z = 50 shell gap and the odd-neutron occupies orbitals situated above the N = 50 shell gap. So, in the present PSM calculations, the configuration space used consists of three major oscillator shells: N=2,3,4 and N= 3,4,5 for protons and neutrons respectively, for obtaining positive parity bands, whereas for obtaining negative parity bands, N=2,3,4 and N=3,4,5 for protons and neutrons, respectively have been chosen.

3. Results and Discussions

In the present calculations, the main focus is to determine the structure of yrast states from the contribution of various. These yrast states appear below the energies of the lowest band in the band diagram and thus one can have a clear idea of which band is diving down in the yrast region and contributing towards the formation of yrast spectra. After diagonalization process, we are able to get an ensemble of projected band energies for intrinsic configurations, all plotted in one figure is known as band diagram.

The energy of theoretically calculated band κ, is defined by

$$E_{\kappa}(I) = \frac{\langle\phi_{\kappa}|\hat{H}\hat{P}^{I}_{KK}|\phi_{\kappa}\rangle}{\langle\phi_{\kappa}|\hat{P}^{I}_{KK}|\phi_{\kappa}\rangle} = \frac{H^{I}_{\kappa\kappa}}{N^{I}_{\kappa\kappa}} \tag{4}$$

3.1 Band Diagrams

The band structure of these doubly-odd nuclei has been understood using the contribution of various low lying bands present in the band diagrams which are presented in the figures 1(a)-(b) for negative parity bands.

i) For ^{98}Rh nuclei, yrast band is formed due to the contribution of four 2-*qp* bands identified as: [ν1/2, π-7/2], K= -3; [ν1/2, π1/2], K= 1, [ν-3/2, π-7/2], K=-5 [ν-3/2, π1/2], K=-1upto the spin 12. At this spin one more band having configuration: [ν1/2, π5/2], K=3 get mixed with the previous bands thereby forming the yrast spectra up to the last calculated spin value.

ii) In case of ^{100}Ag, yrast band at low spin (up to spin value 12^-) is obtained from the contribution of two 2-qp bands having configurations: [ν1/2, π1/2], K = 1; [ν1/2, π-7/2], K = -3. At this spin i.e.12^-, one more 2-qp bands having configuration: [ν-3/2, π-7/2], K = -5 gets down in energy and it then combines with the previously mentioned bands to form the yrast band. After this spin value, one more band identified as: [ν-3/2, π1/2], K = -1 along with afore mentioned bands contribute to the yrast spectra upto the spin 22^-. At this spin value, the band having configuration: [ν1/2, π5/2], K = 3 move together with all the above said 2-qp bands to form the remaining part of the yrast band.

3.2 Yrast band

The yrast band is obtained after the configuration mixing of various multi-quasi-particle configurations of projected deformed Nillson states. The PSM results on negative parity yrast energy levels after configuration mixing are plotted against the spin for the ^{98}Rh and ^{100}Ag nuclei (N=53 isotones) in figures 2(a-b) along with their experimental counterparts [12,13]. The PSM results are found to be in good agreement with the amount of available experimental data. The band head spin of all these isotones have also been successfully reproduced by the present set of calculations. From the band diagrams (See Fig. 1(a)-(b), one may say that the yrast states are found to arise not only from single band but from mixing of large number of bands also.

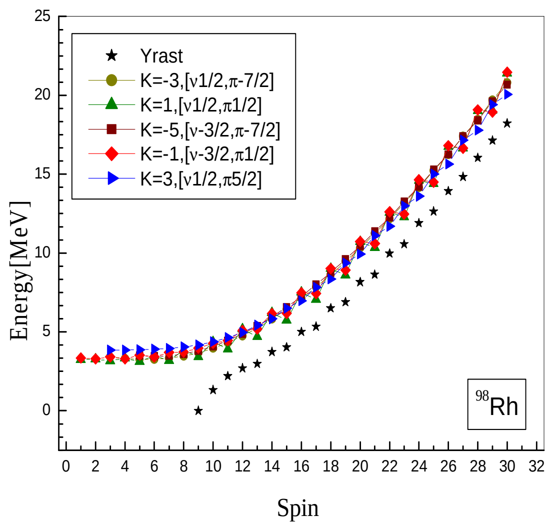

Fig. 1(a): Negative parity band diagram for ^{100}Ag.

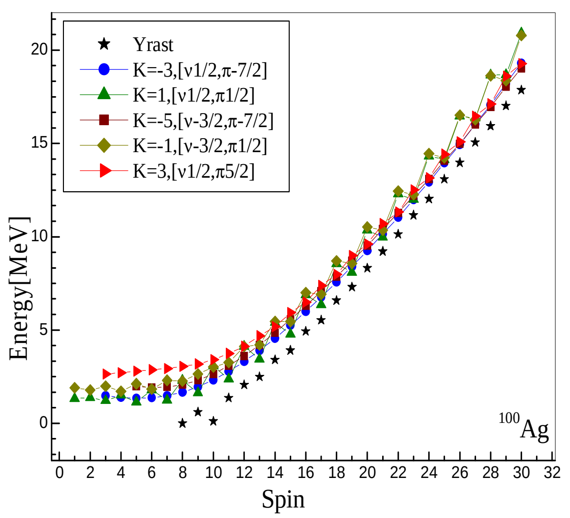

Fig. 1(b): Negative parity band diagram for ^{100}Ag.

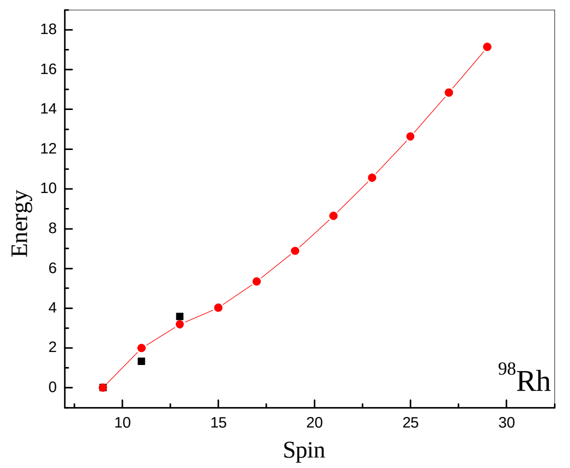

Fig. 2(b): Yrast spectra of ^{98}Rh nucleus for negative parity.

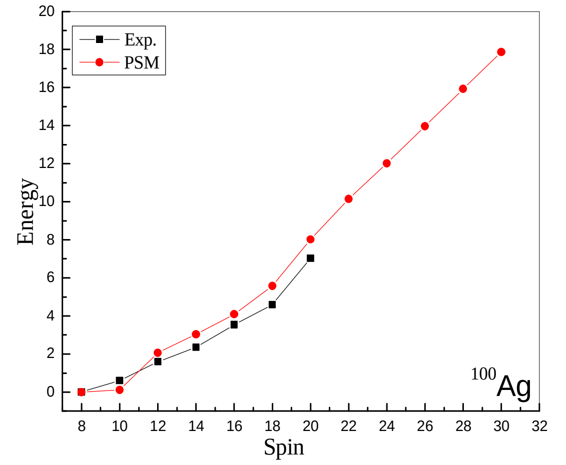

Fig. 2(b): Yrast spectra of ^{100}Ag nucleus for negative parity.

1. Summary

In order to check the consistency of the chosen configuration space, the present calculations has been carried out for the doubly odd N = 53 isotones (^{98}Rh and ^{100}Ag). The results of the present PSM study on doubly-odd ^{98}Rh and ^{100}Ag isotones are summed up as follows:

- The PSM calculations carried out with quadrupole-quadrupole plus monopole pairing plus quadrupole interactions have reproduced the yrast bands for these nuclei.
- The model employed reproduces correctly the band head spin for negative parity yrast bands.
- The calculated data predicted the high spin states in these nuclei where available experimental data on these isotones is still sparse.
- Band structures of these nuclei have also been understood with the help of band-diagrams. From the band diagrams, it is quite clear that the yrast spectra are dominated by the 2-*qp* bands for the whole range of calculated spins.

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