Study of high spin states in neutron deficient ^{133}Sm isotope

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Introduction

The study of neutron deficient nuclei in the mass region A~130 has been an interesting subject in the nuclear structure physics [1] as this region provides an opportunity to test nuclear models. For the neutron deficient nuclei in this mass region, the proton Fermi surface lies in lower part of the $h_{11/2}$ sub-shell, which suggests a proton driving force that could trigger the nucleus towards the collective prolate shape. Therefore, it is of interest to determine the extent to which the present calculations carried out in projected shell model framework [2] can account for the ground state and excited state deformation of ^{133}Sm isotope, which lies in the A~130 mass region. Regan et al. [3] have investigated the low lying rotational band structures of ^{133}Sm using the ^{40}Ca+^{96}Ru reaction at a beam energy of approximately 180 MeV and observed five new bands in ^{133}Sm, out of which two are strongly coupled bands predicted to be built upon Nilsson configurations $\nu h_{11/2}[523]7/2^-$ and $\nu d_{5/2}[402]5/2^+$. Parry et al. [4] have studied high spin states, rotational band structures and their characteristics in ^{133}Sm via the ^{96}Ru (^{40}Ca,2pn) reaction. The calculations of Parry et al. [4] predict strong polarization effects for different configurations which result in quadrupole deformations that vary from $\beta_2 \sim 0.28$ to ≥ 0.38. Experimentally seven energy bands have been identified in this nucleus, out of which six are coupled bands and a decoupled band. Two bands are said to be coupled if they are linked with each other by dipole transitions E1. The two pairs of bands in ^{133}Sm are strongly coupled bands, indicated by large experimental B(M1)/B(E2) strength ratios [4]. In the case of decoupled bands, M1/E2 transitions are either absent or weak, depending on the amount of decoupling.

Theory

A systematic and microscopic high spin study of neutron deficient and well deformed ^{133}Sm isotope have been carried out by employing computer code [5] of projected shell model [2]. In the present study, three major harmonic oscillator shells with N=3,4,5 for both protons and neutrons are taken. The Hamiltonian that has been used in the present calculation contains the single particle energies, monopole pairing between like particles, quadrupole-quadrupole and quadrupole pairing interactions. The monopole pairing interaction constant G_M is adjusted via G_1 and G_2 and is taken as

$$G_M = \left[G_1 \pm G_2 \frac{N-Z}{A}\right] A^{-1}$$

where minus (plus) sign is for neutrons (protons). The pairing interaction strengths G_1 and G_2 are taken as 20.00 and 13.00 respectively for calculation of all bands of ^{133}Sm. The quadrupole pairing strength G_Q is assumed to be proportional to G_M with proportionality constant 0.050 for ^{133}Sm. The quadrupole (ε_2) and hexadecapole (ε_4) parameters used for the present calculations are 0.340 and 0.040 respectively, for ^{133}Sm.

Results and discussion

The present calculations have been able to reproduce successfully the formation of positive parity ground state band structure based on configuration $1\nu 2d_{5/2}[5/2]K=5/2$ for ^{133}Sm shown in Fig.1. The bands represented as bands 1 and 2 in Fig.2, have been found to be the signature partners of the lowest positive parity band with structure $1\nu 2d_{5/2}[5/2]K=5/2$ up to the spin of band crossing $35/2^+$. This is consistent with the experimentally observed ground state band of ^{133}Sm. From the band crossing spin $35/2^+$, the yrast states are predicted to arise from the superposition of 3-qp bands having configurations $1\nu 2d_{5/2}[5/2]+2\pi 1h_{11/2}[3/2,5/2]$, K=7/2 and $1\nu 2d_{5/2}[5/2]+2\pi 1h_{11/2}[3/2,5/2]$,K=3/2.

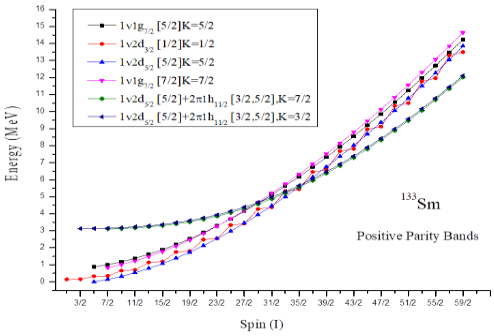

Fig.1 Band diagram for positive parity bands of ^{133}Sm.

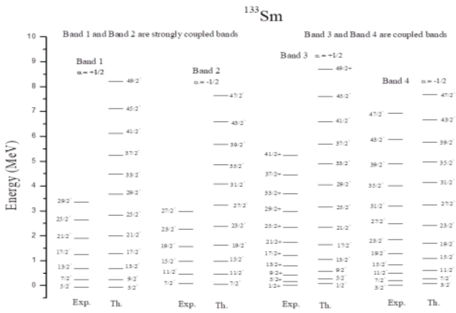

Fig.2 Comparison of experimental [6] and calculated (Th.) energy levels of positive parity bands of ^{133}Sm.

Also the present calculations predicted that 1-qp neutron band built on K=1/2 and having configuration $1\nu 2d_{3/2}[1/2]$K=1/2 is the first excited positive parity band (Fig.1) which is again very much consistent with the experimentally observed first excited positive parity band built upon Nilsson orbital $[411]1/2^+(d_{3/2})$. The bands represented as bands 3 and 4 (Fig.2) have been found to be the signature partners of the first excited positive parity band with structure $1\nu 2d_{3/2}[5/2]$K=5/2 up to the spin of band crossing around $35/2^+$, where crossing by $2\pi h_{11/2}$ takes place. The present calculations have also been reasonably successful in reproducing the dipole transition energies E1 and the quadrupole transition energies E2 for positive parity bands 1,2 and 3,4 shown in Fig.3 and Fig.4.

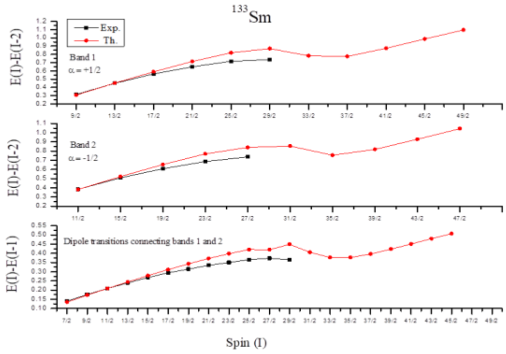

Fig.3 Comparison of theoretical (Th.) and experimental (Exp.) [4,6] transition energies in bands 1 and 2.

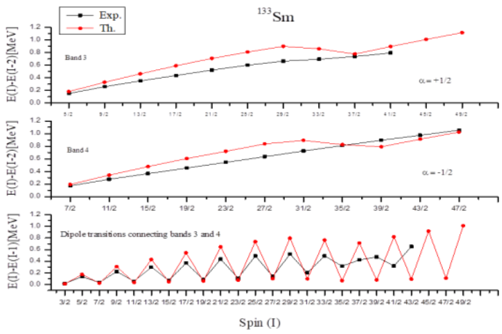

Fig.4 Comparison of theoretical (Th.) and experimental (Exp.)[4,6] transition energies in bands 3 and 4.

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