Spectroscopy of ^{25}Mg

H. Sultana[1], A. Chakraborty[1],* R. Bhattacharjee[2], S.S. Bhattacharjee[2], R. Chakrabarti[2], S.K. Das[2], S. Samanta[2], S.S. Ghugre[2], R. Raut[2], A.K. Sinha[3], T. Trivedi[4], L. Chaturvedi[4], S. Saha[5], J. Sethi[5], and R. Palit[5]
[1] *Department of Physics, Siksha Bhavana, Visva-Bharati, Santiniketan 731 235, West Bengal*
[2] *UGC-DAE CSR, III/LB-8, Bidhan Nagar, Kolkata 700 098*
[3] *UGC-DAE CSR, Indore 452 017*
[4] *Guru Ghasidas University, Bilaspur 495 009 and*
[5] *Tata Institute of Fundamental Research, Mumbai 400 005*

Introduction

^{25}Mg is known to be one of the best examples of quadrupole-deformed nuclei (with $\beta_2 \sim 0.33$ at the ground state) in the *sd*-shell region. Experimental observations suggest that the ground state $K^\pi = 5/2^+$ rotational band in ^{25}Mg develops nicely up to the $11/2^+$ state with $E_x = 5.3$ MeV. The yrast $13/2^+$ state comes very close in energy (within 200 keV) to that of the yrast $11/2^+$ state and does not fit into the rotational picture. In fact, the $13/2^+_2$ state becomes one of the members of the ground state rotational band. Thus, there appears to be a structural change occurring at the excitation regime of the $13/2^+$ state as mentioned in Ref.[1]. The present report highlights the description of the rotational band structure of ^{25}Mg up to the yrast $11/2^+$ spin in terms of the large-basis shell model results along with the limited experimental findings.

Experimental procedure and results

A few low-lying states in ^{25}Mg was produced as a bi-product of an experiment with ^{13}C beam on ^{18}O target carried out using the BARC-TIFR Pelletron Linac facility at TIFR, Mumbai. The de-excited gamma transitions were detected using the **INGA** comprised of 15 Compton suppressed Clover detectors. The main motivation of the experiment was to investigate the high-spin level structure of ^{26}Mg and the new experimental findings of ^{26}Mg have already been published in Ref.[2]. The available data from the experiment offered us a scope to re-investigate the low-lying states in ^{25}Mg. It has been possible to undertake the angular distribution measurement of the $390(3/2^+_1 \rightarrow 1/2^+_1)$-keV transition, decaying from the 975-keV second-excited state, with the effective treatment of the data in "singles" mode. The angular distribution plot of the transition is presented in Fig. 1. A careful analysis of the angular distribution data resulted in the mixing ratio (δ) values of $+0.19^{+2}_{-3}$ and -0.79^{+3}_{-2} with the similar χ^2 values (obtained from χ^2 vs $\tan^{-}\delta$ plot). The resulting transition strengths for the larger δ are $B(E2) = 253(36) W.u.$ and $B(M1) = 0.019(2)\mu_N^2$. If this $B(E2)$ value is considered to be nonphysical, then the corresponding δ value should be discarded. The strengths obtained from the smaller δ value are: $B(M1) = 0.029^{+4}_{-3}\ \mu_N^2$ and $B(E2) = 23(8) W.u.$ This value of $E2$ strength is found to be somewhat larger than the value available in NNDC data base. This is suggestive of the onset of enhanced collectivity in the second excited state of ^{25}Mg.

Shell model calculations

Shell model calculations have been carried out for the positive parity states of ^{25}Mg using the shell-model code NuShellX @ MSU [3]. A model space (named as *sdpf*) comprising the $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$, $1f_{7/2}$, $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$ orbitals has been used. The interaction used is *sdpfmw*. Calculations were carried out without any adjustments to the single-particle energies. However, the model space has been truncated appropriately as the unrestricted calculations are found to be compu-

*Electronic address: anagha.chakraborty@visva-bharati.ac.in

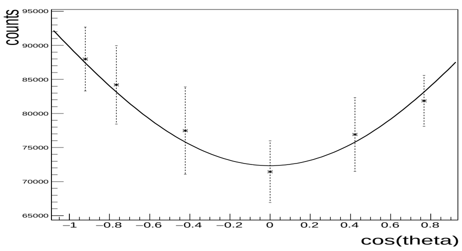

FIG. 1: Angular distribution plot for the $390(3/2_1^+ \to 1/2_1^+)$-keV transition in ^{25}Mg. The data has been fitted with the standard equation: $W(\theta) = 1 + a_2P_2Cos(\theta) + a_4P_4Cos(\theta)$. The values of the angular distribution co-coefficients obtained from the fit are: $a_2 = 0.15(5)$ and $a_4 = -0.01(8)$.

tationally prohibitive. The calculated ground state binding energy of ^{25}Mg is found to be -94.382 MeV and is in agreement with the experimental value of -94.434 MeV. Also, a very nice agreement between the experimental and calculated values for the ground state static electric quadrupole (Q_{expt} = +0.201(3) barn vs Q_{theory} = +0.226 barn) and magnetic dipole (μ_{expt} = -0.85545(8) μ_N vs μ_{theory} = -0.908 μ_N) moments have also been obtained. The comparison between the experimental and theoretical level energies for the yrast and non-yrast states up to $E_x \sim 5$ MeV and $J^\pi = 11/2^+$ has been shown Fig. 2. The comparison looks reasonable for most of the states. Except for the $3/2_2^+$ and $7/2_2^+$ states, the experimental ordering of the levels have been nicely reproduced by the present shell model calculations. The comparison between the transition strengths have been made in Table I. The calculated occupation numbers for the protons and neutrons indicate that the $\nu(1d_{5/2})$ orbital remains almost closed for majority of the yrast states. On the average, a single-proton excitation occurs from the $\pi(1d_{5/2)} \to \pi(1d_{3/2}, 2s_{1/2})$ orbitals for all the states.

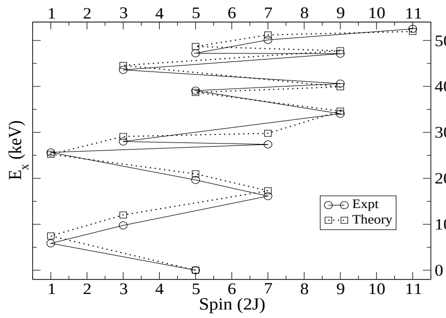

FIG. 2: Comparison of the experimental energies of the positive-parity states of ^{25}Mg with the predicted values of the shell-model calculation. The spin values of the states have been plotted with the $2J$-notation.

TABLE I: Comparison of transition strengths for the transitions decaying from the third excited state to the first excited and the ground state in ^{25}Mg. Each column describes the experimental values followed by the corresponding theoretical values. Numbers in parentheses indicate uncertainties in the last digit of the quoted experimental values. $B(E2)$ and $B(M1)$ strengths are expressed in the units of e^2fm^4 and μ_N^2, respectively. The commonly used effective charges of e_p = $1.5e$ for protons and $e_n = 0.5e$ for neutrons were employed to calculate $B(E2)$'s. For the calculation of $B(M1)$'s, the value of free g factors used for protons and neutrons are $g_p^s = +5.586$, $g_n^s =$ -3.826. $g_p^l = +1$, and $g_n^l = 0$.

$J_i^\pi \to J_f^\pi$	$B(M1)$	$B(E2)$
$3/2_1^+ \to 1/2_1^+$	0.029_{-3}^{+4}	100(35)
	0.035	81
$\to 5/2_1^+$	0.0020(2)	4(1)
	0.008	5.4

Acknowledgments

This work was carried out as a part of the Collaborative Research Scheme of UGC-DAE CSR, Kolkata (No. UGC-DAE-CSR-KC/CRS/13/NP04/02).

References

[1] D.M. Headly *et al.*, Phys. Lettr. B **198**, 433 (1987).

[2] S.S. Bhattacharjee *et al.*, Phys. Rev. C **89**, 024324 (2014).

[3] Nushell @ MSU, B.A. Brown, and W.D.M. Rae, MSU-NSCL Report 2007.