Shape evolution of nuclei in A ∼ 55 region

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Introduction

The nuclear structure of A ∼ 55 region are governed by $1f2p$ and intruder $g_{9/2}$ orbitals across $N = Z = 28$ shell closure. The nature of this shell closure, which is the first shell closure originated due to the spin-orbit coupling term, is in debate from various theoretical and experimental findings. Further, the presence of shape driving orbitals like $1f_{7/2}$ and $1g_{9/2}$ can induce deformation in the system. There are limited informations regarding the observation of different nuclear shapes in this mass region with nuclei around doubly magic ^{56}Ni $(Z = 28, N = 28)$.

In this work, we have calculated the deformations for even-even nuclei from $Z = 22$ (Ti) to $Z = 28$ (Ni) for different N to get an idea regarding the evolution of nuclear shapes with change in proton and neutron Fermi surfaces in this mass region. The transition rate and quadrupole moment, $B(E2)$ and Q_t, have been deduced from the deformation parameters, obtained from the calculation, and compared with the experimental ones. The experimental $B(E2)$ and Q_t values were deduced from the measured lifetimes (τ) reported for the 1^{st} (2^+) and using the equations given in [1]. These calculations have been performed for lower rotational frequencies corresponding to spin value of $2\hbar$.

Method of the calculation

The shape of a nucleus has been obtained from the Total Routhian Surface (TRS) calculations. In this method, the potential energies in the body-fixed frame are calculated in the Nilsson-Strutinsky formalism [2]. A deformed Woods-Saxon potential with universal parameters is used to calculate the single particle energies. The nuclear deformation is defined by the β_2, $\beta_4$and γ parameters. In the Lund convention, used here, $\gamma = 0°(-60°)$ is for axially deformed prolate (oblate) shape and any other value of γ indicate triaxial shape. The detailed technical procedure has been given in [3, 4]. The total Routhians are obtained at different values of β_2, β_4, γ and are plotted in the β_2, γ surface after minimizing on β_4. The calculations are done for different quasi-particle configurations and at several rotational frequencies ($\hbar\omega$). The shape of a nucleus for a particular $\hbar\omega$ at a particular configuration is obtained from the values of β_2 and γ corresponding to the minimum of the TRS at that $\hbar\omega$ for that configuration.

Results and Discussions

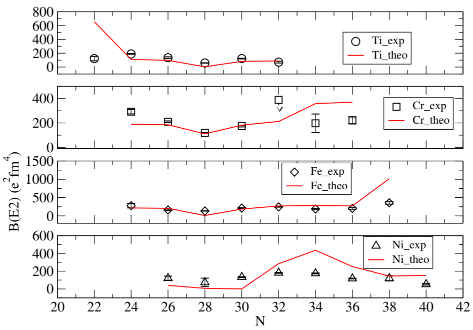

FIG. 1: The experimental values (symbols) of $B(E2)$ for the Ti, Cr, Fe and Ni isotopes are compared with those obtained from the β_2 and γ deformation parameters obtained from the TRS calculations (solid line) in this work.

The theoretical results are summarized in Table I. It contains the deformation parameters β_2 and γ, obtained from the present calculation, for various nuclei with even Z from Ti ($Z = 22$) isotopes to Ni ($Z = 28$)

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TABLE I: Deformation parameters (β_2 and γ) of the nuclei near the ground state obtained in this work.

Z	N	Nucleus	β_2	γ	$B(E2)(e^2fm^4)$
22	22	^{44}Ti	0.4	-21.8	656.83
22	24	^{46}Ti	0.19	-2.7	110.55
22	26	^{48}Ti	0.17	-5.6	97.06
22	28	^{50}Ti	0.03	-30	3.49
22	30	^{52}Ti	0.15	-5.4	82.67
22	32	^{54}Ti	0.14	-21	88.76
24	24	^{48}Cr	0.22	-2.2	188.75
24	26	^{50}Cr	0.21	-3.6	184.96
24	28	^{52}Cr	0.15	-14.8	110.83
24	30	^{54}Cr	0.2	-2.8	182.07
24	32	^{56}Cr	0.2	-9.6	212.24
24	34	^{58}Cr	0.26	-3.9	359.08
24	36	^{60}Cr	0.26	-3.1	370.49
26	24	^{50}Fe	0.21	-3.4	216.32
26	26	^{52}Fe	0.2	-4	207.50
26	28	^{54}Fe	0.04	-18.6	9.30
26	30	^{56}Fe	0.18	-5.4	187.32
26	32	^{58}Fe	0.2	-12.4	269.95
26	34	^{60}Fe	0.21	-4.8	282.47
26	36	^{62}Fe	0.2	-6.1	271.44
26	38	^{64}Fe	0.38	-0.7	1016.86
28	26	^{54}Ni	0.08	-8.7	40.07
28	28	^{56}Ni	0.03	-30	6.58
28	30	^{58}Ni	0.01	-23.8	0.75
28	32	^{60}Ni	0.18	-36.8	284.07
28	34	^{62}Ni	0.23	-52.3	435.01
28	36	^{64}Ni	0.17	-47.9	251.91
28	38	^{66}Ni	0.13	-50.4	144.88
28	40	^{68}Ni	0.18	-77.8	153.61

isotopes. These shapes are calculated near the ground state at lower $\hbar\omega$.

The calculated values of the deformation parameters are used to calculate the other parameters like the quadrupole moment Q_t and the transition strengths $B(E2)$. The experimental values of these parameters are extracted from the measured lifetimes (τ) reported in the ENSDF [5]. The expressions used for determining these quantities in both the cases are taken from reference [1]. These measured quantities are for the 1^{st} 2^+ states in all these cases. The experimental and theoretical values of Q_t and $B(E2)$ are compared in Fig. 1. It can be seen that the experimental values are well reproduced by the calculations.

Summary and Conclusion

The calculated results predict different shapes for different N/Z. At $N = 28$, which is the magic number, in all the isotopes the deformation seems to decrease and shape tends towards triaxilaity. For Ti and Cr isotopes, the shapes are mostly prolate except $N = 28$. In Fe isotope, N=28 and 32 are triaxial while other N are prolate in shape. Thus the evolution of shapes from prolate to triaxial and again to prolate are predicted for these isotopes from these calculations. The Ni isotope ($Z = 28$) is predicted to have evolution of shape from prolate to oblate via triaxial shape with increase in N. The experimental $B(E2)$ values are well reproduced by the theoretical calculations which validate the present calculations. Experimental observations of this shape evolution in these nuclei will be interesting.

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