Shape evolution of nuclei in A ∼ 55 region

S. Basu[1,2*] and G. Mukherjee[1,2]
[1] *Variable Energy Cyclotron Centre, Kolkata 700064, India and*
[2] *Homi Bhabha National Institute, Anushaktinagar, Mumbai 400094, India*

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

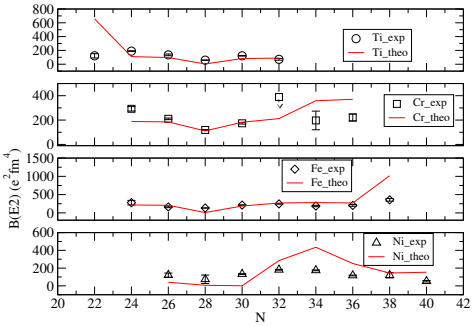

FIG. 1: The experimental values (symbols) of $B(E2)$ for the Ti, Cr, Fe and Ni isotopes are compared with those obtained from the β_2 and γ deformation parameters obtained from the TRS calculations (solid line) in this work.

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 ($Z = 28$)

*Electronic address: s.basu@vecc.gov.in

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.

Acknowledgments

S. Basu acknowledge UGC, Govt. of India for providing PhD fellowships.

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