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Quadrupole Moments of Super Deformed Bands in Different Isotopes of Elements in the Range 30 $\leq$ Z $\leq$ 82

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Quadrupole moments for super deformed (SD) bands in different isotopes of elements $30 \leq Z \leq 82$ have been found to vary regularly with mass number. An attempt has been made to find an empirical relation between quadrupole moments and mass numbers for different bands.

Key Words: Deformation, Super deformed bands, Quadrupole moments and Deformation parameters.

INTRODUCTION

The basic theme of nuclear physics is to understand how nuclear structure and internal interactions change with the change in the number of two kinds of particles, protons and neutrons. Sometimes, a change in the number of neutron (proton) by one drastically changes the nuclear structure. This is the very reason for the importance of individual structure studies of nuclei and to accumulate data in wide region of nuclei including extreme limits. The nuclei those have substantial distortions from spherical shape are called deformed nuclei. The deformed nuclei demonstrate minimum in their potential energy surface. Moreover, in several mass regions the nuclei possess second minimum in their potential surface that mostly gives rise to high spin superdeformed bands[1]. The deformed nuclei can be schematically subdivided into prolate, oblate and tri-axial deformed nuclei depending on the relative axis values of the ellipsoid. For the axis ratio 2:1, inferred from lifetime measurements, the rotational band corresponds to superdeformation[2].

In recent spectroscopic studies using new-generation of large arrays of Compton suppressed Germanium detectors, Gammasphere and Eurogram etc[3,4], the parameters: the energies and spins of excited levels, transition quadrupole moments, magnetic dipole moments and transition probabilities etc. which play a crucial role in nuclear structure studies have been measured for superdeformed nuclei. Today, the details of measurements of quadrupole moments (extracted from lifetime measurements) exist for several superdeformed nuclei[5]. The measured values agreed with expected large values for superdeformed shapes, but also the smaller variations in the quadrupole moment from band to band and from nucleus to nucleus were found consistent with variations of the nuclear shape as expected from detailed calculations[6]. Therefore, quadrupole moments plays an important role in deciding the structure of nuclei. An attempt has been made to analyse the existing data on quadrupole moment for different bands of isotopic nuclei in the atomic number region $30 \leq Z \leq 82$. The details of the existing data and its analysis are given below.

Superdeformation and quadrupole moment

The shell correction method due to Strutinsky[7] provided the theoretical framework of calculating a minimum in second potential well of deformed nuclei and associated shell gaps. A strong superdeformed minimum in Dy-152 was predicted[8]. Subsequently, a discrete set of gamma-ray transitions was observed and assigned to the predicted superdeformed band. Extensive research using gamma-ray detector arrays at several laboratories has focussed on searching for superdeformation and hyperdeformation in different mass regions. These bands have been found in several distinct regions near A = 40, 80, 130, 150, 163 and 190. Superdeformation has also been predicted in low mass regions[9]. Up to now more than 300 SD bands have been discovered in different mass regions. The experimental progress has been accompanied by the development of sophisticated theoretical models, which use the concept of mean field and cranking model. The measured quadrupole moments for a large number of cases in each mass region were found to be consistent with the assigning of bands to the excitations in second local minimum. Recently, Balraj[10] produced an extensive compilation of experimental data on quadrupole moments for superdeformed nuclei. The SD quadrupole moment is typically an average value for the band corresponds to the intrinsic transition moment.

Empirical relation and the data generation

For different isotopes of an element, the quadrupole moments are different, from this it is clear that it varies with change in number of neutrons. On a minute scanning of the data for quadrupole moments for different SD bands, it was found that as the number of neutrons increases the quadrupole moment also increases.

As judged from the pattern of variation, different polynomials were fitted to the measured quadrupole moment data for different SD bands. Wherever, the data value was available from more than one source, the weighted average of all source values was taken. The squares of inverse of errors in the quadrupole moment values were used as weights to respective data values for polynomial fittings. A polynomial with powers varying from 0 to -2 was found to produce the fitted values in agreement with the actual values (plots of actual and fitted values vs. mass number for Pr and Gd are shown in Fig. 1 and 2).

So the empirical relation comes out to be

$$\ln(Q_i) = \sum_{j=0}^{2} a_{ij}(Z)A^{-j} \qquad (1)$$

i=0,1,2, 3………

where a_{ij} are coefficients of fit and depend upon atomic number (Z)

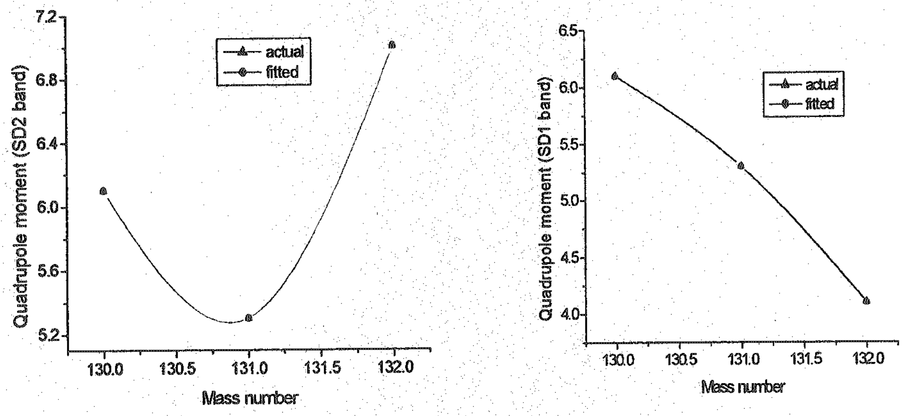

Fig. 1. Plot of quadrupole moments of SD-1 and SD-2 bands *vs.* mass number for Pr

In most of the cases uncertainty in quoted quadrupole moment values for different SD bands is of the order of 10%, so keeping this in view the agreement (mostly < 10% as in Table-1) between actual and fitted values supports the relation. Since the number of data values in each fit was greater than the number of coefficients of fit, this justifies the optimization of the coefficients. For some elements the relation was tried on different permutations and combinations of 4-5 data values for an element. Each combination gives the same closeness of fitted data with actual values, which represents the uniqueness of this relation.

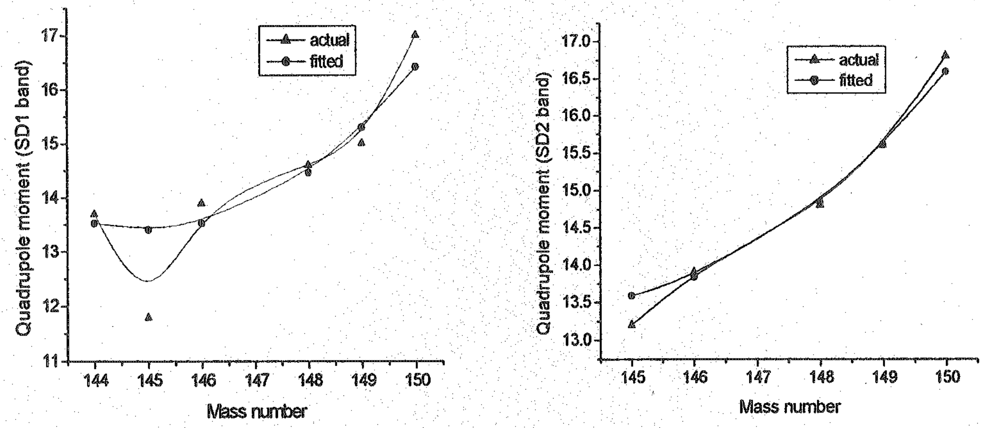

Fig. 2. Plot of quadrupole moments of SD-1 and SD-2 bands *vs.* mass number for Gd

Conclusion

The successful extensive use of the relation to the wide spread data on quadrupole moments of different bands in isotopes of respective elements justifies its application to generate the quadrupole moment for expected band of intermediate isotopes.

To generate the quadrupole moment for different SD bands for different mass numbers at an atomic number, the relation (1) requires at least three input data values at that atomic number to evaluate the three coefficients of fit a_{ij}. Therefore by knowing the coefficients one can generate the quadrupole moment for different mass numbers in the range $30 \leq Z \leq 82$.

TABLE- 1

SD BAND QUADRUPOLE MOMENTS: VALUES GENERATED FROM RELATION (1), ACTUAL VALUES[10] AND PERCENTAGE DEVIATIONS BETWEEN THE TWO BANDS

Z	N	SD – 1 BAND			SD – 2 BAND		
		actual	fitted	% dev.	actual	fitted	% dev.
58	131	7.30 (40)	7.30	0.00	8.50 (40)	8.50	0.00
	132	7.40 (30)	7.40	0.00	7.30 (40)	7.30	0.00
	133	7.40 (70)	7.40	0.00	7.50 (80)	7.50	0.00
59	130	6.10 (50)	6.099	0.009	6.10 (50)	6.10	0.00
	131	5.30 (40)	5.299	0.011	5.30 (40)	5.30	0.00
	132	4.10 (30)	4.10	0.00	7.00 (70)	6.999	0.008
64	144	13.70 (100)	13.53	1.26			
	145	11.80 (80)	13.41	13.67	13.20 (100)	13.59	2.98
	146	13.90 (40)	13.53	2.65	13.90 (30)	13.84	0.44
	148	14.60 (20)	14.46	0.97	14.80 (30)	14.84	0.24
	149	15.00 (20)	15.29	1.96	15.60 (30)	15.61	0.04
	150	17.00 (45)	16.41	3.45	16.80 (120)	16.59	1.28
80	190	17.70 (250)	15.86	10.41	17.60 (250)	17.40	1.12
	191	17.50 (80)	18.11	3.48	17.50 (80)	17.71	1.21
	192	20.20 (120)	19.09	3.52	19.50 (150)	17.94	8.02
	193	18.40 (85)	18.60	1.09	17.30 (100)	18.07	4.48
	194	16.80 (70)	16.81	0.06	19.00 (200)	18.13	4.59
82	193	17.30 (75)	17.55	1.43			
	194	20.10 (40)	19.92	0.87			
	195	19.50 (95)	20.60	5.64			
	196	19.70 (30)	19.45	0.25			

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