Microscopic description of the origin of collectivity development at N=42 in Zinc isotopic chain

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The structure study of neutron-rich nuclei with protons near Z=28 shell closure is a current topic in nuclear physics. With two protons outside the Z=28 proton shell and the gradual occupation of neutrons in the $1g_{9/2}$ orbital, even-even Zn nuclei close to N=40 should provide ideal test ground if one has to try to pin down the potential connection between the phenomena of strong core polarization and maximum collectivity at N=42. Recently Niikura et al. [1] have made first direct lifetime measurement of 2^+ state in ^{72,74}Zn that provided a new evidence for a shape transition between N=40 and N=42 close to Z=28. All recent large scale shell model calculations show that neutrons are present in the $1g_{9/2}$ orbital before N=40 crossing. In order to understand the possible microscopic origin of collectivity development at N=42, Zn nuclei are studied in the framework of variation after projection technique in conjunction with Hartree Bogoliubov (HB) ansatz. The two body interaction that is employed is of pairing plus quadrupole quadrupole plus hexadecapole hexadecapole type.

The procedure for obtaining the axially symmetric HB intrinsic states has been discussed in Ref. [2] The methods developed by Onishi and Yoshida [3] for carrying out projection of the states of good angular momentum from axially symmetric HB intrinsic states has been used for obtaining the spectra.

In the Table 1, the experimental and calculated values of E_2^+ energy and E_4^+/E_2^+ ratio are presented for $^{70-76}$Zn. In the same table the calculated intrinsic quadrupole moments are also presented. It is observed from the systematics of E_2^+ energy that it shows a decreasing trend up to ^{76}Zn. For ^{70}Zn, its value is 0.885 MeV and it decreases to a value of 0.599 MeV for ^{76}Zn meaning there by that there is an increase of deformation in going from ^{70}Zn to ^{76}Zn. This fact is also confirmed by the increasing trend of the values of the ratio E_4^+/E_2^+ up to ^{74}Zn. For example, the value of the E_4^+/E_2^+ ratio in ^{70}Zn is 2.02 whereas in ^{74}Zn it is 2.34. As we know that the quadrupole moments have an inverse relationship with the E_2^+ energy. This means that the trend of the quadrupole moments of the ground states of these nuclei should be such that they should increase as one goes from ^{70}Zn to ^{76}Zn. The theoretical results reproduces the increasing trend of quadrupole moments. In addition to this we have also calculated the sub-shell occupation numbers of protons and neutrons. The proton sub shell occupation numbers show an increasing trend for $1f_{5/2}$ orbit. In case of neutron sub shell occupation numbers, $2d_{5/2}$ orbit shows maximum occupation for ^{74}Zn and $1g_{9/2}$ orbit shows an increasing trend with neutron number (N). The observed structure transition from N=40 to 42 seems to originate from Federman-Pittel –like phenomenon.

Further, the reliability and goodness of the HB wave function is examined by calculating the $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ values. These values are calculated from the values of intrinsic quadrupole moments of protons and neutrons by using the formula of Bhatt et al. [4]. They have developed a formula for the calculation of $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ transition probabilities in units of e^2b^2 given by the relation

$$B(E2;\ 0_1^+ \rightarrow 2_1^+) = (1.02\times10^{-5})A^{2/3}\ c^2_{model}\ [e_\pi(Q^2_0)_\pi + e_\nu(Q^2_0)_\nu]^2 ,$$

where $(Q^2_0)_\pi$ and $(Q^2_0)_\nu$ are the intrinsic quadrupole moments of valence protons and neutrons and e_π and e_ν are the effective charges of protons and neutrons, respectively. The effective charges of protons and neutrons are taken as 1.8 and 0.8, respectively. In Table 2, a comparison of the calculated B(E2) values obtained with pairing-plus-quadrupole-

quadrupole (PQ) and pairing-plus-quadrupole-quadrupole-plus hexadecapole-hexadecapole (PQH) interaction with the experimental data [5] is presented. The experimental value of B(E2) transition probability is maximum for ^{72}Zn that is reproduced by the present calculation. Thus, the present calculation reproduces the observed maximum collectivity at N=42 for neutron-rich Zn isotopes. It may be noted that the PQH model of interaction reproduces the experimental data with better accuracy than PQ model of interaction.

Table 1. Comparison of experimental and theoretical values of excitation energy (E_2^+) and E_4^+/E_2^+ ratio. Theoretical values of quadrupole moments of intrinsic states associated with yrast levels for $^{70-76}$Zn are given in last six columns.

A	E_2^+		E_4^+/E_2^+		Intrinsic Quadrupole moments ($\langle Q^2_0\rangle_{HB}$)					
	Exp	Th.	Exp.	Th.	0^+	2^+	4^+	6^+	8^+	10^+
70	0.885	0.56	2.02	2.35	20.83	20.83	20.83	20.83	20.83	20.83
72	0.653	0.61	2.29	2.44	27.28	27.28	27.28	27.28	27.28	15.92
74	0.606	0.51	2.34	2.43	27.30	27.30	27.30	27.30	27.30	27.30
76	0.599	0.43	2.16	2.76	28.13	28.13	28.13	26.19	27.21	27.21

Table 2. Comparison of experimental and calculated values of B(E2) transition probabilities (in units of e^2b^2) in $^{70-76}$Zn.

Mass Number. (A)	PQ	PQH	Exp.
70	0.003	0.123	0.14(1)
72	0.091	0.21	0.1925(195)
74	0.12	0.183	0.1850(165)
76	0.16	0.19	0.145(18)

References

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