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A MICROSCOPIC OVERVIEW OF COEXISTENCE OF NUCLEAR SHAPE IN THE A~150 MASS AREA VIS A VIS SHELL CLOSURE AROUND MAGIC NUCLEI.

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Abstract: In this paper, we provide an outline of the empirical studies of shape coexistence, with a focus on the areas of the nuclear map that lately have been the subject of the most recent analysis. We first give an overview of the empirical symbols that can be used to emphasize the emergence of shape coexistence, and consequently nuclear collectivity. We then discuss how to prove it using experimental data, with special emphasis on the regions together across isotonic chains wherein the onset has been anticipated.

***Index Terms* – Collectivity, Deformation, Energy ratio ($R_{4/2}$), Valance neutron proton product (N_pN_n).**

1. INTRODUCTION

The anomaly known as nuclear shape coexistence occurs when distinguishable forms appear inside alike nuclei and at an allied energy [1]. A macroscopic item that can be compared to a liquid drop is the atomic nucleus, which is made up of an assembly of protons and neutrons. Because of the more dynamic nucleon-nucleon interaction than in atomic systems, nuclei can take on several shapes besides being spherical. Morinaga [2] initially reported the shape coexistence for the distorted 6.05-MeV O^+ state in ^{16}O although the ground state had a spherical shape. As per Heyde and Wood [3] what initially manifested as a rare and exceptional phenomena, is now recognized as a universal characteristic that may be present in nearly all nuclei. Coexistence of shapes has been reported in numerous areas of the nuclear chart [4] and looks to be a fundamental property of nuclear quantum multi-body systems. The interactions among nucleons have been thoroughly researched in order to unravel the nuclear structure. Understanding structural phase changes and the abrupt onset of distortion requires a thorough knowledge of proton-neutron interaction. The groundbreaking research of Federman and Pittel [5, 6] on the A~100 area provides a critical but contemporary rationale for the rapid and dramatic spherical distorted transformation that occurs in heavy nuclei. For $N \geq 60$, the majority of globular nuclei (including $N \leq 58$) exhibit significant distortions that emerge with additional valance nucleons. According to Federman and Campos [7] the neutron-proton interaction is at its strongest and most significant in terms of its deforming propensity whilst the nucleons occupy the spin orbit partner (SOP) trajectories. Talmi has repeatedly pointed out [8] that neutron-proton interactions have a major impact on the endurance of deformation. Casten *et al.* [9] determined the pattern of the first excited state energy E_2^+ on N and that of the energy ratio $R_{4/2}$ on Z, for the A~150 mass area. They also brought out the significance of the neutron-proton attractive interaction in promoting nuclear core deformation. Casten and McCutchan [10] agree that particle-hole excitations that go through considerable shell and sub shell closures, such as those present at Z ~ 50, 82 can be used to precisely describe collectivity and coexistence of shapes. According to Cenjar *et al.* [11] it is still unknown, if coexistence of shapes happen during the phase transformation between globular and distorted nuclei, in the N~90 isotonic range.

2. THEORY

As per Casten [12], nuclear data related to nuclear deformation, reflects a distinct pattern when mapped on the output of N_pN_n. Because of the significance of collectivity to the N_pN_n product, this analysis of $R_{4/2}$ (= E_4^+ / E_2^+) may offer fresh and insightful information. Perhaps the most well-known and extensively researched nuclear phase transformation is that involving spherical to quadrupole prolate distortion at N = 88–90. As N_pN_n values rise, there is a general inclining trend in the values of $R_{4/2}$ for the A ~150 mass area, contrary to the other areas. The consistency in $R_{4/2}$ is shattered when the Z=64 sub shell closing effect is combined with magic or almost magic nuclides (see tables 1, 2).

3. RESULTS AND DISCUSSION

Fig. 1 depicts the development of the energy ratio $R_{4/2}$ relative to N_pN_n in the A~150 mass region. This area has the most proton and neutron particle research because of the sub shell impact at $_{64}$Gd. It is discovered that the values of $R_{4/2}$ increase noticeably when N_pN_n increases.

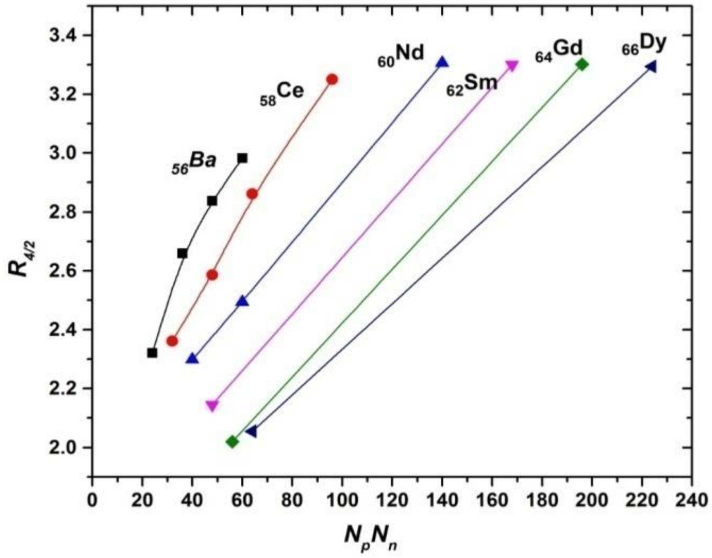

Figure 1: Systematics of $R_{4/2}$ against N_pN_n showing nuclear collectivity in the A~150, (N=86-96), mass area.

Additionally, Casten *et al.* [9] have shown that the sharp transition region from globular to distorted nuclei is minimal at Ba and maximal at Sm with N_pN_n ~ 72 and Gd-Dy nuclei at N_pN_n ~120 (N=88-90), and for more information, see table 2. The sub shell impact at Z=64 is supported by the increase in $R_{4/2}$ with increasing N_pN_n at Gd, and it vanishes at $N_pN_n \geq 140$ (N≥ 90), which demonstrates the change of Gd nuclei from globular to distorted ones.

Table 1: Even-even nuclei in the A~ 150 mass areas shown against them are the N_pN_n values with their corresponding $R_{4/2}$ values taken from the national nuclear data centre [13].

Z	N	NpNn	$R_{4/2}$
56	86	24	2.321
56	88	36	2.659
56	90	48	2.837
56	92	60	2.983
58	86	32	2.361
58	88	48	2.586
58	90	64	2.861
58	94	96	3.251
60	86	40	2.298
60	88	60	2.249
60	96	140	3.306
62	86	48	2.144
62	96	168	3.300
64	86	56	2.019
64	96	196	3.301
66	86	64	2.054
66	96	224	3.293

With the same energy ratio $R_{4/2}$ plotted against the mass number provided against each line, the correlating isotonic chains, a more elucidating picture of the nuclear phase transition in the A~150 mass area has been offered (see fig. 2). Gupta *et al.* [14] assert that gently sloped rotational spectra of the even-even nuclides are more steady for the isotonic multiplets. According to Gupta *et al.* [15] the energy of shape fluctuation for nuclei with N = 82–104 is basically autonomous of Z and monotonous for the isotones. Bindra and Mittal [16] have also shown that the rotational behavior for N=82-104 area also rises with rising N_pN_n. The aforementioned holds are clearly obvious for magic nuclei and universally demonstrate the reverse for N ≥ 90, at which the isotones are marked out to cause an inevitable deformation near N=88, Gd nuclei. These plots (N-dependent) so reveal, that for each neutron number, a spectacular deformation is obtained in addition to a magic nucleus.

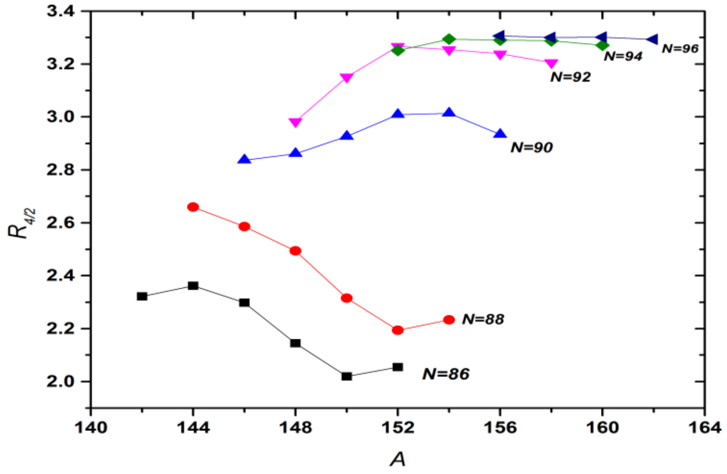

Figure 2: Systematics of $R_{4/2}$ in the A~ 150 mass area for even- even nuclei, shown against which are the isotonic lines, in the most robust area of the nuclear chart (N=86-96), showing the rotational spectra depend for N~88.

In their discussion of the relationship between the rotational content of energy E_2^+ and the N_pN_n product, Gupta and Kavathekar [17] discovered that the rotational component also grows as the N_pN_n product grows. This aptly captures the nature of the E_2^+ energy state, as can be observed in table 2. There is a dramatic shift in E_2^+ around $^{200–206}$Hg, which is supportive of collectivity in the h–h area [Ref. 8] and in support of the shell and sub shell closures reported in Ref. [18].

Table 2: Systematics of E_2^+ with N_pN_n values for a few even -even nuclei at Z ~ 82, shown against them are their corresponding $R_{4/2}$ values.

^{A}Nuclei	Z	N	NpNn	E_2^+ (Mev)	$R_{4/2}$
^{194}Hg	80	114	24	0.427	2.487
^{196}Hg	80	116	20	0.425	2.491
^{198}Hg	80	118	16	0.411	2.546
^{200}Hg	80	120	12	0.367	2.574
^{202}Hg	80	122	8	0.439	2.547
^{204}Hg	80	124	4	0.436	2.584

In fig.3 the graph of $R_{4/2}$ with N_pN_n, provides a rise in contour for N_pN_n ~112 (N~94), and a substantial improvement is seen for N_pN_n ≥140 (^{160}Er, N=92), which shows a phase transition from globular to distorted rotor and coincides with the observation of Casten *et al*. [9].

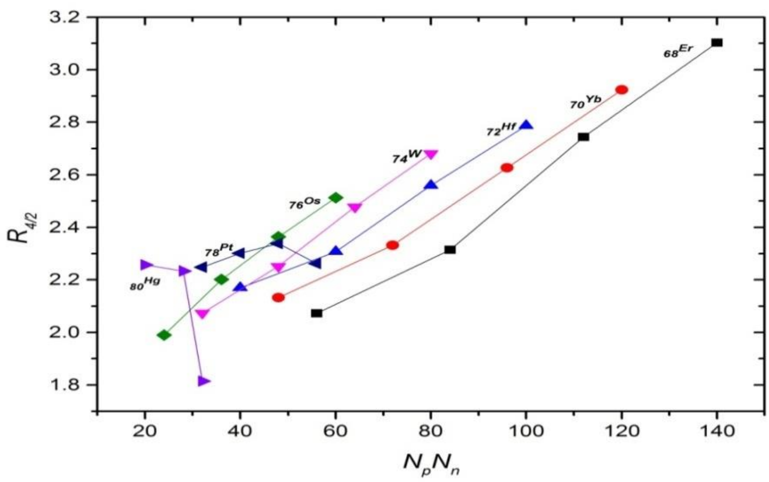

Figure 3: Systematics of $R_{4/2}$ against N_pN_n showing nuclear collectivity in the A~160, (N=86-96), mass area.

When comparing the graphs of figures 1 and 3, it is clear that the A~ 150 mass area has a higher collectivity growth rate than does the other areas. The growth rate rises when nucleons fill the first part of the shell (or they fill the second part), as opposed to when a nucleon fills beneath whilst the another fills after mid shell (N=104). See table 3.

Table 3: Even-even nuclei in the A~ 160 mass areas shown against them are the N_pN_n values with their corresponding $R_{4/2}$ values.

Z	N	N_pN_n	$R_{4/2}$
68	86	56	2.072
68	88	84	2.314
68	90	112	2.743
68	92	140	3.103
70	86	48	2.132
70	88	72	2.331
70	90	96	2.627
70	92	120	2.923
72	86	40	2.169
72	88	60	2.306
72	90	80	2.559
72	92	100	2.786
74	86	32	2.073
74	88	48	2.252
74	90	64	2.477
74	92	80	2.681
76	86	24	1.990
76	88	36	2.201
76	90	48	2.363
76	92	60	2.512
78	90	32	2.248
78	92	40	2.301
78	94	48	2.338
78	96	56	2.262
80	92	20	2.571
80	96	28	2.233
80	98	32	1.814

Fig.4 reflects a clear flip in the phase transition from nearly magic nuclei (N≤126) to distorted rotors (N≥106). It is interesting that the values of $R_{4/2}$ fluctuate from 108 to 120 in $_{76}$Os nuclei, at the same instant, which could be the reason for the sudden fluctuation. In the case of $_{74}$W, a bent rotor structure is visible.

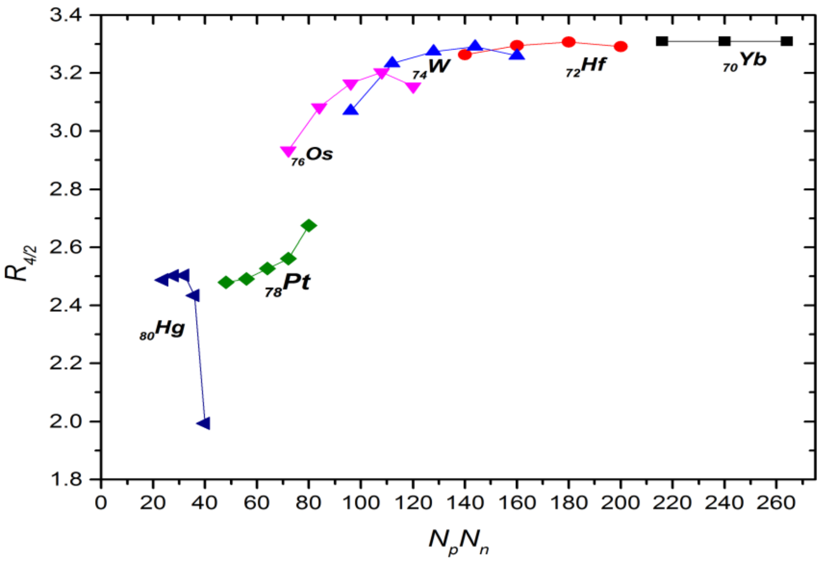

Figure 4: Systematics of $R_{4/2}$ against N_pN_n showing nuclear collectivity in the A~180, (N=106-114), mass area.

In comparison to the Os nuclei, this is also true for the $R_{4/2}$ versus nucleon product of the $_{70}$Yb and $_{72}$Hf nuclei. The $R_{4/2}$ values show uniformity for $_{70}$Yb and $_{72}$Hf since they both are well deformed nuclei. As suggested by Casten *et al.* [9] the $R_{4/2}$ values for $_{80}$Hg seem to decrease as the N_pN_n product increases, presumably because of the shell closure effect near magic nuclei (see table 4).

Table 4: Even-even nuclei in the A~ 180 mass areas shown against them are the N_pN_n values with their corresponding $R_{4/2}$ values.

Z	N	N_pN_n	$R_{4/2}$
70	104	264	3.309
70	106	240	3.309
70	108	216	3.309
72	106	200	3.290
72	108	180	3.306
72	110	160	3.294
72	112	140	3.264
74	106	160	3.259
74	108	144	3.290
74	110	128	3.273
74	112	112	3.233
74	114	96	3.069
76	106	120	3.154
76	108	108	3.203
76	110	96	3.164
76	112	84	3.082
76	114	72	2.934
78	106	80	2.674
78	108	72	2.560
78	110	64	2.526
78	112	56	2.491
78	114	48	2.478
80	106	40	1.993
80	108	36	2.433
80	110	32	2.502
80	112	28	2.501
80	114	24	2.487

Similarly to what is stated in Ref [14, 15], the $_{72}$Hf-$_{76}$Os nuclei all along isotopic lines are autonomous of N (for N≥106), as is clearly evident from the curves of fig.5. It relies on N (for N~104) for the $_{68}$Er-$_{70}$Yb nuclei all along isotopic lines and minimal variability can be seen in the $R_{4/2}$ readings of $_{76}$Os (due lesser values of N_pN_n). When Z exceeds 76, the $R_{4/2}$ levels tend to drop, and the nuclei begin to be driven into the area of the globular framework, in agreement with the results of Bindra [19].

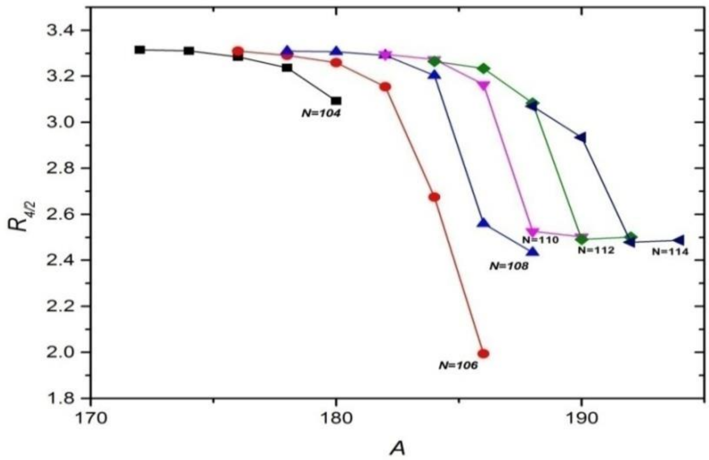

Figure 5: Systematics of $R_{4/2}$ in the A~ 180 mass area for even- even nuclei, shown against which are the isotonic lines, indicating the rotational spectra are independent for N≥106 and they depend for N≤ 104.

4. CONCLUSION

The massive sections of the nuclear chart were also demonstrated by Cakirli and Casten [20] and the overall finding of the aforementioned research is that they are more saturated there than in the other parts, as seen in the systematic of the figures above. Despite that the collectivity in heavy nuclei is found in the A~150 mass range, it makes sense that they are more saturated there than in the other parts. An operational link exists between this tendency of nuclear collectivity and that it derives from fundamental p-n interactions, that is, the worth of p-n interaction in terms of strengths are also more prevalent in similar sections in comparison to when protons and neutrons are occupying the different sections.

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