Breakdown of Grodzins product rule in N=88 isotones, a revealing puzzle

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1. Introduction

For the collective motion in the medium mass even Z-even N nuclei, the energy $E(2_1)$ of the 2_1 state falls with the increase in the number of valence nucleons. Simultaneously, B(E2)↑, the reduced E2 excitation strength from ground state 0_1^+ to 2_1^+ increases. Long ago, Grodzins [1] noted a close relationship between the energy of the first excited state $E(2_1)$ and the excitation strength B(E2)↑, which can be written in the product form:

$$E(2_1)\times B(E2)\uparrow \sim \text{const.} \qquad (1)$$

Two or three neutron and proton pairs are needed to build up the collectivity. Greater is the number of valence proton pairs and neutron pairs, (see the N_pN_n scheme [2]), faster is the growth of collectivity. In the present work we use the Grodzins relation to study the collectivity with varying N, Z in the medium mass region.

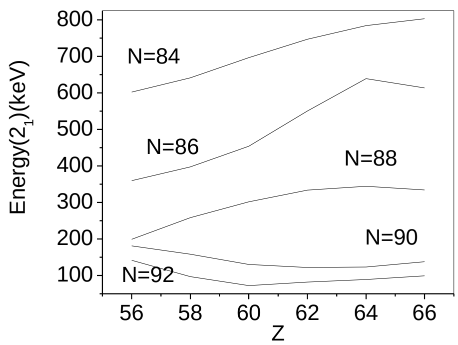

Fig. 1 variation of $E(2_1)$ versus Z, N [3].

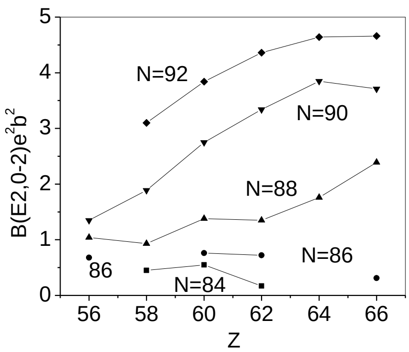

Fig. 2. variation of B(E2,0-2) versus Z [4]..

Fig 1 illustrates the variation of $E(2_1)$ versus Z, for N=86-92 isotones. At N=84, 86, $E(2_1)$ increases with Z. The same is true for N=88 Ba, Ce, Nd and Sm. This behavior of $E(2_1)$, contrary to the N_pN_n scheme, is explained on the basis of *Z=64 subshhell effect*, which yields reduced Np values At N>88, the sub-shell effect disappears, and $E(2_1)$ falls initially with increasing Z, and then saturates. On the other hand, for N=90, 92, B(E2)↑ increases with Z (Fig.2), as expected. But it increases for N=88 as well, where the Z=64 subshell effect is operating

The product $E(2_1) \times B(E2)\uparrow$ are plotted versus Z for N = 86, 88, 90 and 92 for Ba to Dy in Fig.3 (slow Z, A dependence neglected). The product value is somewhat irregular for N=84, and N=86, though it is increasing with Z. At *N=88, there is a regular sharp increase with increasing Z.* (curve with open circles). The slope of the curves decreases with increasing N. For N=90 and 92 the slope is slowly increasing

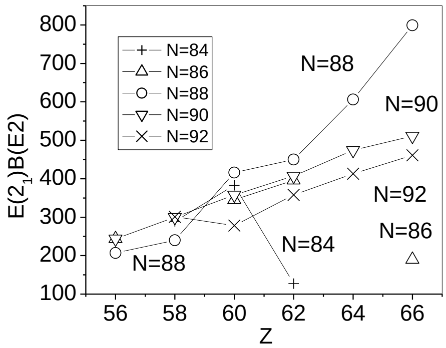

Fig. 3. Product E_2 B(E2) versus Z.

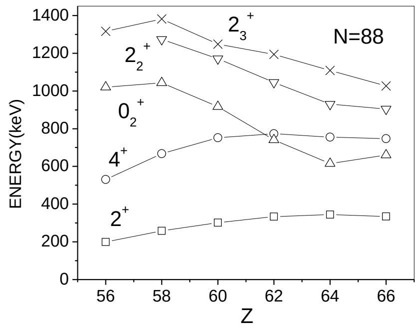

Fig. 4. N=88 energy levels. 2_2=2_β, 2_3=2_γ. I=2+, 4+ rise and 0+ is falling with Z.

At N==88 isotones, we note an interesting anomaly. The E_2 increasing with Z implies a decreasing moment of inertia (MoI). The increasing B(E2)↑ value implies increasing quadrupole moment and deformation β. This interesting phenomenon presents a challenge for nuclear theory. What is the underlying Physics in the N=88 isotones. How to reconcile the differing correlations of energy and B(E2), is the important issue?

Some of these features are also visible in the energy level diagram (Fig. 4). Note the movement of 2_2=2_β with 0_2^+ with Z. The K= 2 2_3=2_γ state lies higher. Here we see, that though E(2_1) and E(4_1) are rising with Z, the band head energy E(0_2^+) is falling at N=88 for Nd-Dy. Also E(2_γ) is decreasing with increasing Z. This gives an indication of a decreasing deformation, but an increasing β-softness of the nuclear core, which promotes the increasing B(E2)↑, and thus leads to the break down of the product rule. If the slopes of the potential energy surface (PES) V(β) increase, it will make the nucleus softer. Also, it is a problem of static deformation versus the full dynamics of the nucleus.

Conclusion

It leads to the conclusion that the constancy of the Grodzins product rule breaks down in the combined effects of the Z=64 subshell and the shape transition leading to beta softness .It leads to a very interesting phenomena. Further exploration of this phenomenon would give an insight into the nature of collectivity. The nature of the subshell at Z=64 also needs further elucidation. In a recent study, [6], we gave a microscopic view of the Z=64 subshell and the shape transition at N=88-90, but the present anomaly presents a further enigma.

References

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