Rotational Behavior at High Angular Momentum in Even-Even Nuclei in the Region of Nuclear Shells N=78-98

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Abstract: The yrast sequence in the even-even nuclei with N=78-98 has been extended to I_x>32 and at studying their properties are presented. At high rotational frequencies the +ve band has little spin alignment and have moments of inertia which remain constant as a function of frequency. Information obtained suggests the existence of a deformation close to the neutron shell N=82. In the band of ^{160}Yb displays a strong up bending at $\hbar\omega \simeq$ 0.40MeV, where as in the ^{158}Er at $\hbar\omega \simeq 0.35\ MeV. In\ the\ odd-Z\ nucleus$ ^{150}Tm, no alignment effect has been observed between $\hbar\omega \simeq 0.35$-0.45 Mev. The second backbending in the yrast band of even-even nuclei near A≅ 158 (^{158}Er, ^{160}Yb) due to an $h_{11/2}$ proton. The second backbending in the yrast band in the same even-even nuclei alignment [N. A. Mansour and N. M. Eldebawi **Rotational Behavior at High Angular Momentum in Even-Even Nuclei in the Region of Nuclear Shells N=78-98**]. Journal of American Science 2011; 7(11):265-268]. (ISSN: 1545-1003). http://www.americanscience.org.

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1. Introduction

The γ- ray decay de-exciting a deformed nucleus with large angular momentum proceeds along a sequence which is composed of various rotational bands [2]. Following the discovery of the second backbending in the yrast band in some even-even nuclei, most experimental and theoretical [3,4] work has focused on an understanding of the rotational frequencies [2] at which such a decay crosses from one rotational band to another i.e., band crossing frequencies. Even-even isotopes was chosen for the present study as, by virtue of its deformation and the positions of its Fermi levels for neutrons and protons, it is expected to be a case where the frequency different between the lowest and next-lowest band crossings along the yrast sequence is as large as possible. This feature allows the study of rotational bands over a large range of angular momentum (or angular frequency ħω ~$E_\gamma/2$). In the present work, we report on an calculated investigation of the yrast bands in the odd-neutron nucleus $^{157}_{68}Er_{89}$ and in $^{159}_{69}Tm_{90}$ odd-proton nucleus, up to the range of rotational frequencies [5] where the second backbending has been seen in the neighboring even-even nuclei ($\hbar\omega \simeq$ 0.40 MeV).

These two odd-mass nuclei were selected because both of them between even-even nuclei that are known to display a second backbending, i.e., ^{156}Er [6,7] and ^{158}Er for ^{159}Er, and ^{158}Er and ^{160}Yb for ^{159}Tm [6]. In these two nuclei the based extended up to $69^+/2$ in ^{157}Er and $43^+/2$ in ^{159}Tm, corresponding to [7,9] rotational frequencies well above the critical value for the second backbending.

2- Results and Discussion

2- 1) Calculated Alignments:

The aligned spin I_x of the yrast states in the even-even isotopes ^{156,158}Er, ^{160}Yb [6,7,8] is plotted as a function of the rotational frequency $\hbar\omega$ in Fig (1). For comparison the results in ref.[11] are also included in the figure. The following interesting features can be observed:

(i)With decreasing mass number (decreasing deformation and decreasing moments of inertia in the ground band) the first backbending become sharpers which reflects decreasing interaction energy between the ground band and the two neutron $i_{13/2}$ band (s-band). The decrease in the interaction energy is predicted by Cranked shell model [12]

At high frequencies the behavior of the three nuclei is rather different. In the range between 0.38 and 0.45 MeV I_x depends linearly on $\hbar\omega$ for ^{156}Er. In this frequency region ^{158}Er shows a gradual increase of Ix, where ^{160}Yb and ^{159}Tm show a sharp backbending. The yrast bands of ^{157}Er and ^{159}Tm are compared with the yrast bands of the even-even nuclei ^{156}Er and ^{158}Er (Z=68 isotopes), and of ^{158}Er and ^{160}Yb (N=90 isotones) respectively.

2-2) The structure changes far from stability line.

One of the most challenging goals of nuclear structure physics is to determine how the structure of nuclei changes [13] far away from the stability line. Recent results on such nuclei suggest that some major shell gaps are weakened when large isospin values are encountered (large neutron excess). Figure (2) displays the gamma ray energy of the first 2^+ level for even-even nuclei for the N range 78-98. We can clearly see a peak corresponding to doubly magic nuclei Z, N=64, 82 respectively.

The S_{2n} values deduced from the calculations are shown in figure (3). If we consider the behavior of S_{2n} for Dy isotopes as a reference of the standard shell structure. From N=86 to N=90 the S_{2n} values include an extra energy given by deformation, which allows the nuclei to minimize their binding energy with one more degree of freedoms. At N > 90 a strong decrease is observed. This may be result of the possible vanishing of shell closure.

In figure (4) we plotted the energy gap for proton Δ_p versus the angular frequency. It shows that Δ_p decreases gradually at first, for small values of ω. As ω increases Δp has a constant value and suddenly falls off sharply, and at certain critical value of ω, Δ_p approach to zero.

Table (1): Comparison between the calculated values of $\hbar\omega$ vs. I_x for (Z = 68) ^{156}Er , ^{157}Er and ^{158}Er Isotopes, and for (N = 90) ^{160}Er , ^{158}Yb and ^{159}Tm Isotones .

^{156}Er		^{158}Er		^{157}Er		^{160}Er		^{158}Yb		^{159}Tm	
$\hbar\omega$	I_x	$\hbar\omega$	I_x	$\hbar\omega$	I_x	$\hbar\omega$	I_x	$\hbar\omega$	I_x	$\hbar\omega$	I_x
0.233	4	0.173	4	0.134	8.5	0.136	4	0.246	4	0.107	8.5
0.275	6	0.224	6	0.208	10.5	0.19	6	0.288	6	0.247	10.5
0.311	8	0.264	8	0.264	12.5	0.233	8	0.324	8	0.282	12.5
0.339	10	0.291	10	0.534	14.5	0.267	10	0.35	10	0.302	14.5
0.342	12	0.406	12	0.353	16.5	0.29	12	0.342	12	0.221	16.5
0.262	14	0.155	14	0.383	18.5	0.392	14	0.255	14	0.181	18.5
0.273	16	0.236	16	0.402	20.5	0.267	16	0.284	16	0.246	20.5
0.313	18	0.284	18	0.405	22.5	0.328	18	0.314	18	0.308	22.5
0.356	20	0.329	20	0.403	24.5	0.341	20	0.367	20	0.361	24.5
0.387	22	0.371	22	0.397	26.5	0.37	22	0.363	22	0.107	26.5
0.414	24	0.403	24	0.417	28.5	0.4	24	0.367	24	0.247	28.5
0.383	26	0.423	26	-	-	0.383	26	0.371	26	-	-
0.442	28	0.43	28	-	-	0.422	28	0.393	28	-	-
0.45	30	0.438	30	-	-	0.43	30	0.397	30	-	-
-	-	0.453	32	-	-	0.452	32	0.393	32	-	-

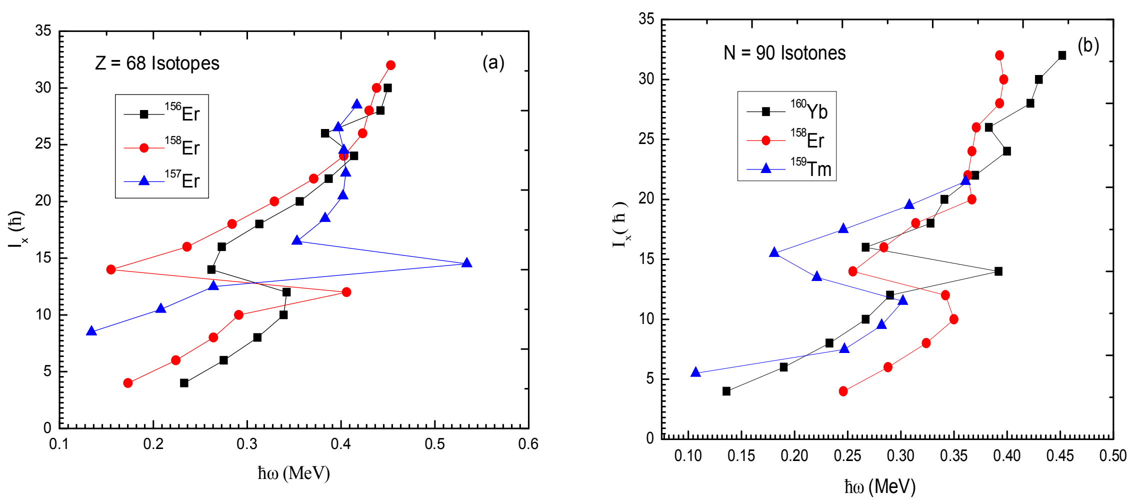

Fig. (1): Comparison between the alignment plots of I_x vs $\hbar\omega$
(a) For the Z = 68 Isotopes
(b) For the N = 90 Isotones (positives band).

Table (2): Experimental ɤ-ray transition energy of the first 2^+ level for even – even nuclei Ce, Nd, Gd, Dy, Er, Yb, and Hf isotopic nuclei [6, 7, 8, 9].

$_{58}$Ce		$_{60}$Nd		$_{62}$Sm		$_{64}$Gd		$_{66}$Dy		$_{68}$Er		$_{70}$Yb		$_{72}$Hf	
N	E_2^+	N	E_2^+	N	E_2^+	N	E_2^+	N	E_2^+	N	E_2^+	N	E_2^+	N	E_2^+
86	0.397	84	0.697	82	1.66	80	0.743	78	0.493	80	0.647	82	1.532	82	1.513
88	0.259	86	0.454	84	0.747	82	1.972	80	0.683	82	1.579	84	0.821	84	0.858
90	0.159	88	0.302	86	0.55	84	0.784	82	1.677	84	0.808	86	0.536	86	0.557
92	0.097	90	0.13	88	0.334	86	0.638	84	0.804	86	0.561	88	0.358	88	0.39
94	0.082	92	0.073	90	0.122	88	0.344	86	0.614	88	0.345	90	0.243	-	-
-	-	94	0.071	92	0.082	90	0.123	88	0.335	90	0.192	-	-	-	-
-	-	96	0.067	94	0.076	92	0.089	90	0.138	92	0.126	-	-	-	-
-	-	-	-	96	0.073	94	0.08	92	0.099		-	-	-	-	-
-	-	-	-	98	0.071	96	0.075	94	0.087	-	-	-	-	-	-

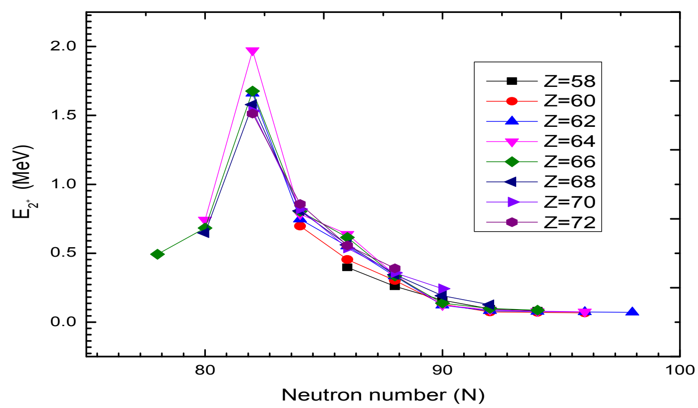

Fig. (2): Gamma-ray energy of the first 2^+ level for even – even nuclei Ce, Nd, Gd, Dy, Er, Yb, and Hf

Table (3): The calculated two neutron separation energy (S_{2n}) values for the isotopic nuclei between the N = 82 and N = 94 shell closures.

$_{58}$Ce		$_{60}$Nd		$_{62}$Sm		$_{64}$Gd		$_{66}$Dy		$_{68}$Er		$_{70}$Yb		$_{72}$Hf	
N	S_{2n} (KeV)	N	S_{2n} (KeV)	N	S_{2n} (KeV)	N	S_{2n} (KeV)	N	S_{2n} (KeV)	N	S_{2n} (KeV)	N	S_{2n} (KeV)	N	S_{2n} (KeV)
86	12059	84	13943	82	19002	82	20140	84	17460	84	18660	85	19260	87	19840
87	11660	85	13577	83	17313	83	18428	85	17224	85	18190	86	19220	88	19190
88	11479	86	13326	84	15187	84	16479	86	17101	86	18120	87	18930	89	18950
89	11260	87	12868	85	14796	85	16062	87	16685	87	17900	88	18370	90	19110
90	11090	88	12626	86	14513	86	15660	88	16438	88	17440	89	18070	-	-
-	-	89	12392	87	14013	87	15254	89	16175	89	17130	90	18170	-	-
-	-	90	12424	88	13859	88	15129	90	16282	90	17360	-	-	-	-
-	-	91	12665	89	13578	89	15063	91	16416	91	17490	-	-	-	-
-	-	92	12607	90	13861	90	15128	92	16036	92	17160	-	-	-	-
-	-	-	-	91	14136	91	15106	93	15887	93	16965	-	-	-	-
--	-	-	-	-	-	92	14973	94	15408	-	-	-	-	-	-

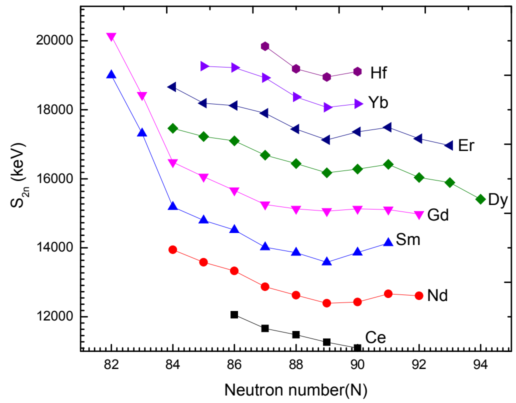

Fig. (3): Calculated S_{2n} values between the N = 82 and N = 94 shell closures.

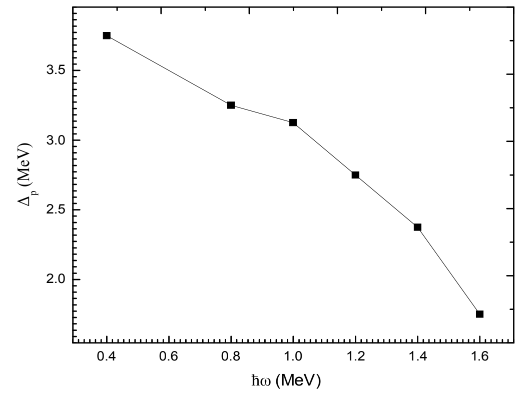

Fig. (4): Change of energy gap for proton (Δ_p) with angular frequency

3-Conclusion

In this work we investigated high angular momentum properties in the odd-N nucleus ^{157}Er and in the odd-Z nucleus ^{159}Tm, corresponding to a rotational frequency $\hbar\omega \approx .42$ MeV, in ^{157}Er and $\hbar\omega \approx .45$ MeV in ^{158}Tb. This is well above the frequency region where a second backbending is known to occur in the neighboring even-even nuclei. A sharp up bending has been observed in favored band of ^{157}Er at $\hbar\omega \approx .40$MeV, wheres in ^{159}Tm, no evidence for a pair alignment in the frequency range 0.30M $\leq \hbar\omega \leq 0.40 MeV$ *has been obtained.* The study of the shell closures N = 82 is particularly interesting since the vanishing of the latter one could be the first piece of evidence for the weakening of the spin-orbit force.

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