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Short Note

High spin states in ^{128}Ba

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Abstract. High spin states in ^{128}Ba have been investigated with the fusion–evaporation reaction ^{96}Zr (^{36}S, 4n) ^{128}Ba at a beam energy of 150 MeV with the GASP-spectrometer at INFN in Legnaro, Italy. The level scheme could be extended to higher spins and six-quasiparticle states have been observed. The deduced alignments are compared to the predictions of previously reported cranked shell model calculations.

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The nuclei in the Xe-Ba-Ce region show at low spin band structures which can be interpreted assuming a γ-soft core [1]. The high spin structure in these nuclei is dominated by rotational bands. Some of the interesting features of these bands are the observation of two nearly degenerate 'S' bands, negative parity prolate neutron and proton 2-quasiparticle excitations. The aligned quasiparticles influence the shape of the nucleus and subsequent alignments [2]. In addition, 4-quasiparticle dipole bands are known to exist in some nuclei in this mass region at 4-5 MeV excitation energy [3]. It has been recently shown that these bands are based on the coupling of the neutron and proton negative parity 2-qp excitations [4,5]. The alignment features and additivity relations of routhians and g-factors firmly support this picture. The evolution of all these band structures at high spin is of significant interest.

High spin states in ^{128}Ba were populated using the fusion evaporation-reaction ^{96}Zr (^{36}S, 4n) ^{128}Ba at a beam energy of 150 MeV. The experiment was performed at the XTU TANDEM accelerator of the INFN in Legnaro, Italy. The target consisted of two parallel foils of Zirconium enriched to 85.25% in ^{96}Zr (0.5 mg/cm^2 each). Gamma-ray spectroscopy was performed with the GASP-spectrometer. In the present experiment this array was equipped with 40 Compton-suppressed HPGe-detectors and an 80-segment bismuth-germanate-ball (BGO). In four days of beam time, over 10^9 three fold gamma coincidence events were accumulated. The data was sorted into matrices employing the sum-energy and multiplicity information of the BGO-ball in order to separate the reaction channels. The two main reaction products were ^{127}Ba and ^{128}Ba.

The Radware software package was used to construct the level scheme [7]. The level scheme deduced from the present work is shown in Fig. 1. From the analysis of the coincidence spectra, 42 new γ-transitions were placed in the level scheme, establishing 24 new levels. Thus the known level scheme from the work of Neuneyer *et al.* [8] has been extended to higher spins. In addition, one new high spin band, labeled as band (8), could be observed. This band depopulates into states of band (7) via several γ-transitions. Almost all the other known band structures could be extended to higher spins.

The spin and parity assignments of the newly found states could be established from the analysis of the recent lifetime data [4], the experimental limits on lifetimes, and the ratio of directional correlation of oriented states R_{DCO}.

$$R_{DCO} = \frac{(I_{\gamma_1} \;\; at\ 36^\circ \quad \text{gated by} \quad \gamma_2 \;\; at\ 60^\circ)}{(I_{\gamma_1} \;\; at\ 60^\circ \quad \text{gated by} \quad \gamma_2 \;\; at\ 36^\circ)} \qquad (1)$$

Furthermore, within a band the lifetime limits constrain the multipolarity to either dipole or quadrupole. In the high spin section of the observed bands, a dipole mul-

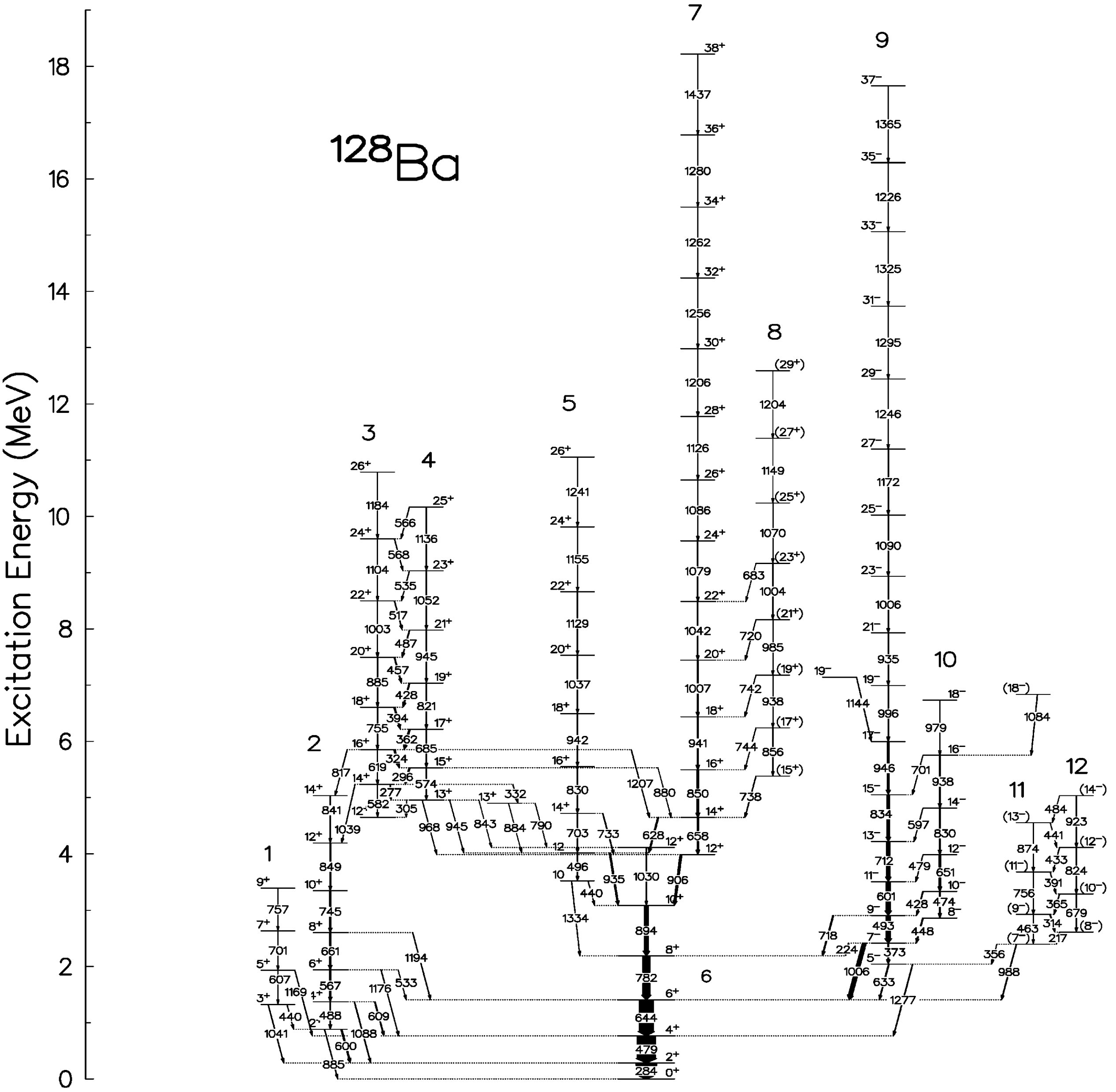

Fig. 1. High spin level scheme of ^{128}Ba as populated in the ^{96}Zr (^{32}S, 4n) ^{128}Ba reaction

tipolarity is extremely unlikely. If one assumes a dipole multipolarity for the gamma-transitions depopulating the high spin states in the bands, then the cross-over E2 γ-transitions would have a transition probability much greater than the inband-dipole γ-transitions. This rules out a dipole assignment. Details of the (R_{DCO}) method can be found in [9]. The newly developed SPEEDCO method for large detector arrays [10]was also used to make spin assignments. Stretched quadrupole γ-transitions were used for gating purpose.

The alignment plots of the observed bands are depicted in Fig. 2. The configuration assignments in the following are partly based on the cranked shell model calculations described in ref. [11]. The deformation parameters were $\beta_2 = 0.21$, $\beta_4 = -0.015$, $\gamma = -4.7$ and -48 degrees [4, 11]. Bands (1),(2) are the signature partners of the quasi-gamma band [8]. Bands (3),(4) are the signature partners of the dipole band, the detailed study of which has been reported in refs. [3,4,10]. On the basis of additivity relations of quasiparticle alignment, g-factors and excitation energy, bands (3),(4) were suggested to be based on a prolate configuration consisting of four different quasiparticles, i.e., $(\pi h_{11/2} \otimes \pi d_{5/2}) \bigotimes (\nu h_{11/2} \otimes \nu g_{7/2})$. The non-yrast S-band, i.e. band (5), could be extended from $20\hbar$ to $26\hbar$. Band (6) is the ground state band. Lifetime measurements suggest a deformation value close to $\beta_2 = 0.21$ for this band [6]. Two new gamma-transitions were added to the top of the yrast S-band, band (7), and the ordering of the 1256 and 1262 keV γ-transitions is interchanged compared to the earlier work [8]. This band extends to a spin

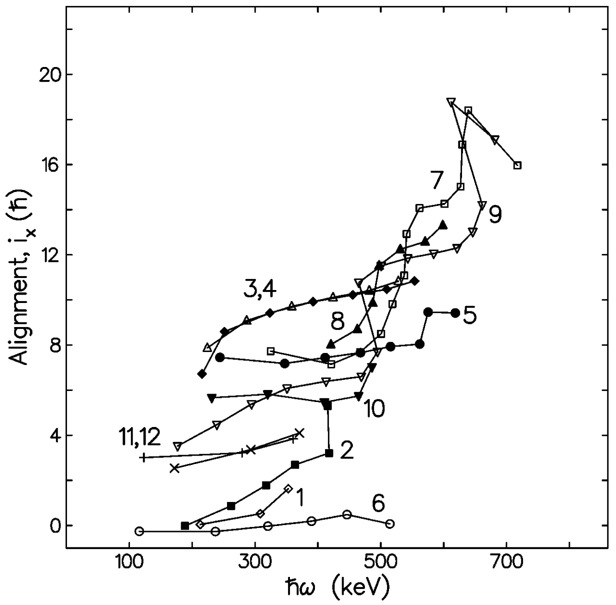

Fig. 2. Alignment plots of the bands in ^{128}Ba calculated with the Harris parameters $J_0 = 14.0$ MeV$^{-1}\hbar^2$ and $J_1 = 31$ MeV$^{-3}\hbar^4$

of $38\hbar$ and the recent lifetime measurement suggests a deformation value close to $\beta_2 = 0.23$ [4]. Bands (9),(10) and (11), (12) are signature partners. Band (9) was extended from $33\hbar$ to $37\hbar$.

Band (5) and band (7) are the two 'S' bands suggested to be based on oblate aligned $h_{11/2}$ neutrons and prolate aligned $h_{11/2}$ protons [11]. It has been shown that band (7) can be desribed with a configuration having a prolate shape [4]. For an oblate shape, the cranked shell model calculations predict a large alignment gain due to the alignment of the first and second pair of neutrons in the upper half of the N=4 oscillator shell. The experimental data does not show the predicted large gain in alignment. It may be possible that band (5) is also based on a prolate shape with aligned $h_{11/2}$ protons. Bands (5) and (7) may then correspond to two different deformations. Interestingly, the analysis of the lifetimes of some states in band (7) suggests a γ-value close to zero [4]. Lifetime measurements in band (5) are desirable to sort out the corresponding issue. Band (9) and its signature partner, band (10), were suggested to be based on a proton 2-qp configuration of the type $(\pi h_{11/2} \otimes \pi d_{5/2})$. Configurations containing an $h_{11/2}$ proton are favored compared to configurations containing an $h_{11/2}$ neutron because of the large initial gain in the alignment of the [550]1/2 orbital. The occupation of the low Ω states of the $\pi h_{11/2}$ orbital results in the observed large signature splitting. Bands (7) and (9) undergo alignments close to frequencies 0.54 Mev/$\hbar$ and 0.48 MeV/$\hbar$, respectively. This may be due to the alignment of a pair of $h_{11/2}$ neutrons . The cranking calculations predict the crossing to occur at 0.40 MeV/$\hbar$. The gain in alignment in the two bands is about 6 and 8 $\hbar$, respectively compared to the predicted gain of about $5.5\hbar$. A change in shape may be one reason for the discrepancy between the theory and experiment. Similar arguments were put forth in ^{126}Ba by Ward et al. [12].

Band	*Configuration*
band 1,2	γ-band
band 3,4	$(\pi h_{11/2} \otimes \pi d_{5/2}) \bigotimes (\nu h_{11/2} \otimes \nu g_{7/2})$
band 5	$\pi h^2_{11/2}$
band 6	gsb
band 7	$(\pi h^2_{11/2} \otimes \nu h^4_{11/2})$
band 8	possibly γ-S band
band 9,10	$(\pi h_{11/2} \otimes \pi d_{5/2} \otimes \nu h^4_{11/2})$
band 11,12	$(\nu h_{11/2} \otimes \nu g_{7/2})$

A further alignment is also observed in these bands at a frequency of about 0.63 MeV/$\hbar$, with a gain in alignment of about $4\hbar$. The gains should be treated as approximate as the reference rotor value may not be reliable at high frequencies. The calculations suggest that this alignment is due to the second pair of $h_{11/2}$ neutrons. Alignments due to other quasiparticles occur at higher frequencies and therefore can be ruled out. Bands (11),(12) were suggested to be based on a prolate neutron 2-qp configuration of the type $(\nu h_{11/2} \otimes \nu g_{7/2})$ [8]. For neutron number N=72 the Fermi surface is close to high-Ω states of these orbitals. The absence of significant signature splitting, in addition, supports this assignment. Band (8) has been tentatively assigned a positive parity. Comparison with the level scheme of ^{126}Ba [12] would suggest a γ-S band interpretation. Further lifetime measurements and refined cranking calculations including γ-vibration would be desirable to make a configuration assignment for this band. In the table above, we summarize the configurations of the bands observed in the experiment.

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