Octupole signatures in $^{124,125}Ba$

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Abstract

The γ decay of the nuclei $^{124,125}Ba$ has been measured with the EUROBALL array, using the reaction $^{64}Ni+^{64}Ni$ at E_{beam}=255 and 261 MeV. Six new E1 transitions have been found in the nucleus ^{125}Ba, suggesting a significant role of octupole correlations in the origin of its parity doublets. The $J^{\pi}=3^{-}$ level of the nucleus ^{124}Ba has been identified for the first time. Its excitation energy is in very good agreement with the prediction of octupole-including microscopic calculations.

Experimental fingerprints of octupole correlations, such as alternate-parity bands linked by enhanced E1 transitions, very collective E3 transitions and parity doublets in odd nuclei, are long established in the proximity of both the double octupole “shell closures” Z=56, N=88 (corresponding to the nucleus ^{144}Ba, see [1]) and Z=56, N=56 (corresponding to the so far unidentified – and perhaps unbound – nucleus ^{112}Ba, see for example [2]). In even light barium isotopes ($118 \leq A \leq 130$) the existence of low-lying negative-parity even-spin states is at variance with the symmetry properties of octupole correlations. Nevertheless, in these nuclei the lowest observed negative-parity states lie systematically below the threshold represented by twice the proton pairing gap [3], and in a work by Piepenbring and Leandri [4] it was proposed that the inclusion of an octupole-octupole force is indeed necessary in a microscopic description of low-lying negative-parity states in $^{124,126}Ba$. The excitation energies of the lowest-lying unidentified levels, which were stated to provide a stringent test of the model, were also calculated [4]. In particular, the $J^{\pi}=3^-$ level in ^{124}Ba was predicted to have the excitation energy of 1700 keV.

The experimental results presented in this work were obtained through the analysis of double and triple γ coincidences collected by the EUROBALL spectrometer [5] in a thin-target experiment performed at IRES Strasbourg (France) and primarily aimed at the search for hyperdeformed bands in the nucleus ^{126}Ba using the reaction ^{64}Ni+^{64}Ni@255-261 MeV [6]. Our analysis included the measurement of the angular distribution and degree of linear polarization of γ rays. For this latter purpose the composite CLOVER detectors were used. These four-crystal detectors allowed to measure the Compton-scattering asymmetry $A_{CS}\equiv(N_{\perp}-N_{\|})/(N_{\perp}+N_{\|})$, where $N_{\perp}$ and $N_{\|}$ denote the number of photons scattered in the orthogonal and parallel direction respectively, relative to the beam direction. This quantity is proportional to the actual degree of linear polarization P of γ rays at $\theta_{CLOVER}\approx 90°$ through the polarimeter's sensitivity $Q=A_{CS}/P$.

The first experimental result we report is the identification of six new E1 transitions linking the yrast positive-parity and negative-parity bands in the nucleus ^{125}Ba. This nuclide displays parity doublets, i.e. its yrast levels having the same angular momentum but opposite parity are very close in energy. In fact, the quadratic average of the difference between the excitation energies of J^+ and J^- levels in this nucleus corresponds to 335 keV (see level scheme in Ref.[7]), while in ^{143}Ba (see [3]), for example, it corresponds to 453 keV. Unlike ^{143}Ba, however, only few E1 transitions were known to connect opposite-parity levels in ^{125}Ba prior to our work [7]. We pinned down the $\Delta J=1$ electric dipole character of one of them, namely the $23/2^+\rightarrow 21/2^-$ transition, through the measurement of its angular distribution, resulting in Legendre polynomial coefficients $A_2=-0.27\pm0.02$ and $A_4=0.00\pm0.03$ (see Fig.1b), and of its linear polarization P=+0.2±0.2. In addition, and most importantly, we found evidence for five new E1s linking the positive-parity and negative-parity structures, as shown in Fig.1a. One more transition, although of very low intensity, presumably links the $27/2^+$ and $25/2^-$ states. It is now evident that basically all the levels below the excitation energy of ~3 MeV are

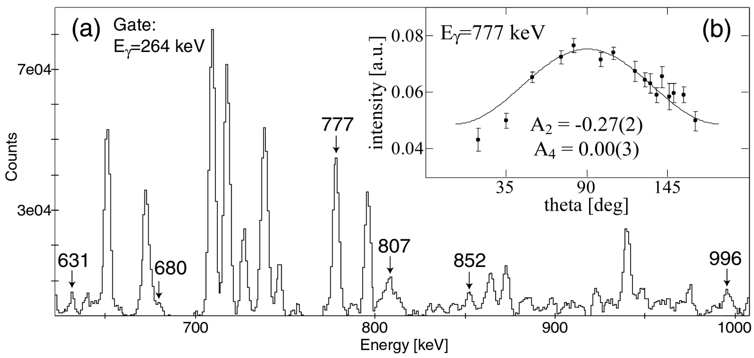

Figure 1: (a) Section of a single-gate spectrum showing five of the six new E1s identified in ^{125}Ba. (b) The angular distribution of the E_{γ}=777 keV transition linking the $23/2^+$ and $21/2^-$ levels in ^{125}Ba. The fitting curve corresponds, besides a normalization factor, to the function $1+A_2P_2(\cos(\theta))+A_4P_4(\cos(\theta))$, where P_n is the n-th Legendre polynomial. The best-fit values of Legendre polynomial coefficients are reported in the figure.

connected through electric dipole transitions to levels of opposite parity (see Fig.2), suggesting a significant role of octupole correlations in the origin of the parity doublets displayed by ^{125}Ba and, possibly, also of the parity doublets that are indeed observed in all odd barium isotopes with 119≤A≤129 [3]. In particular, ^{127}Ba is also known to exhibit a large number of E1s linking opposite-parity bands [8].

The second experimental result we present is the identification of the $J^{\pi}=3^{-}$ level in ^{124}Ba. As shown in Fig.3, two new coincident transitions of energy $E_{\gamma}=312$ and 1492 keV respectively are observed following the $6^{-}\rightarrow 4^{-}$, $E_{\gamma}=326$ keV transition. The ΔJ=1 basically pure dipole character of the new $E_{\gamma}=312$ keV transition was determined on the basis of its ADO ratio [9]. The E1/M1 ambiguity was solved through the measurement of the transition's degree of linear polarization. In this case we performed a simple integration of the parallel- and orthogonal-scattering spectra, in the interval containing the 312-keV peak and in other two peak-free

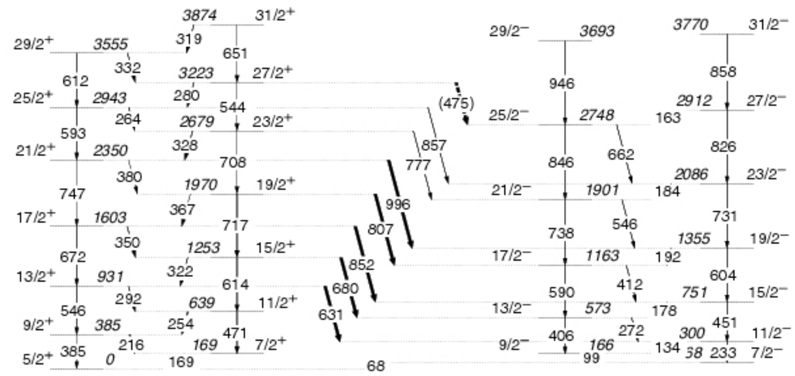

Figure 2: Partial level scheme for ^{125}Ba including all the E1 transitions connecting the positive-parity yrast structure (i.e. the coupled bands on the left-hand side of the picture) with the negative-parity one (right-hand side). The new-found transitions are shown with thicker arrows. Previously known levels and transitions are taken from Ref.[7].

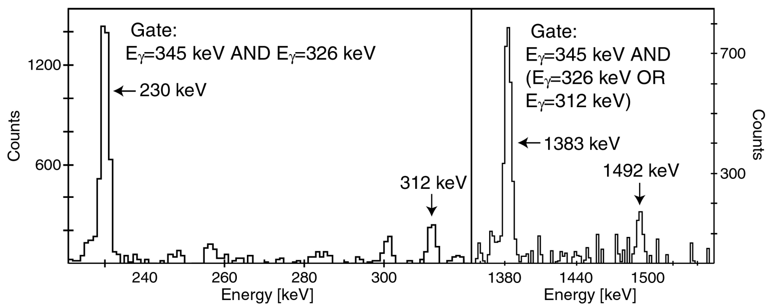

Figure 3: Intervals of double-gate spectra showing the new Eγ=312 keV and Eγ=1492 keV transitions in ^{124}Ba.

intervals close to it. A value A_{CS}=-0.015±0.028 was found to correspond to the first interval, while the scattering asymmetry of the background surrounding the peak turned out to be A_{CS}=+0.06±0.03. This clearly means that the degree of linear polarization of the E_γ=312 keV transition is negative, exactly as expected in the case of a ΔJ=1 M1(+E2) character with δ≈0. The level fed by this transition and decaying through the E_γ=1492 keV transition to the 2^+ state, therefore, has $J^\pi=3^-$; its excitation energy, namely $E_{ex}(3^-)$=1722 keV, is in very good agreement with the prediction $E_{th}(3^-)$=1700 keV given in Ref.[4]. Our work, thus, provides new evidence supporting the conclusion drawn in Ref.[4] that, in order to reproduce the excitation energies of low-lying negative-parity states in ^{124,126}Ba, the use of an octupole-octupole residual interaction is actually necessary [4].

In conclusion, we have presented new evidence for the existence of octupole correlations in light barium isotopes. The first piece of evidence consists in the identification of the 3^- level in ^{124}Ba, at an energy well reproduced by octupole-including microscopic calculations. In addition, the existence of several new E1s in the nucleus ^{125}Ba, linking opposite-parity couples of bands whose levels form closely-spaced parity doublets, has been established.

Future work on this subject should include the determination of the strength of these correlations through the measurement of B(E1) values. No such measurement has ever been performed in light barium isotopes but, on the basis of TRS calculations and experimental branching ratios, B(E1) values which are comparable in size to those observed for instance in ^{114}Xe [2] were proposed in the nucleus ^{118}Ba [10]. The observation of low-lying negative-parity states in ^{114,116}Ba (only the ground states of these nuclei have been hitherto identified [11]) would also be of great interest.

Acknowledgements

This work was supported in part by the Hungarian Scientific Research Fund OTKA (contract numbers T046901 and T038404), and the Bolyai János Foundation of HAS.

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