

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

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Abstract

The γ decay of the nuclei $^{124,125}\text{Ba}$ has been investigated with the EUROBALL array, using the reaction $^{64}\text{Ni}+^{64}\text{Ni}$ at $E_{\text{beam}} = 255$ 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

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of the nucleus ^{124}Ba has been identified for the first time. Its excitation energy is in very good agreement with a prediction based on a microscopic model including octupole interactions.

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 argued that the inclusion of an octupole–octupole force is indeed necessary in a microscopic description of low-lying negative-parity states in $^{124,126}\text{Ba}$. The excitation energies of the lowest-lying unidentified levels, 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, 6] 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 $^{64}\text{Ni} + ^{64}\text{Ni} @ 255\text{--}261\text{ MeV}$ [7]. (The DIAMANT array of charged-particle detectors [8] was also used for the purpose of channel selection.) Our analysis involved the measurement of the degree of linear polarization of γ rays, performed by means of the composite CLOVER detectors. These four-crystal detectors allowed us to measure the Compton-scattering asymmetry $A_{\text{CS}} \equiv (N_{\perp} - N_{\parallel}) / (N_{\perp} + N_{\parallel})$, where $N_{\perp}$ and $N_{\parallel}$ 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 $\theta_{\text{CLOVER}} \approx 90^\circ$ through the polarimeter’s sensitivity $Q = A_{\text{CS}}/P$.

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 [9]), while in ^{143}Ba (see [10]), for instance, it corresponds to 453 keV. Unlike ^{143}Ba , however, only three E1 transitions were known to connect opposite-parity levels in ^{125}Ba prior to our work [9, 11]. We clinched 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 (see figures 1(b) and 2) and its linear polarization, which was found to be $P = +0.2(2)$. The measurement of branching ratios, moreover, allowed us to deduce the $B(\text{E1})/B(\text{E2})$ ratio for the $23/2^+$ level. The value we found is $1.8(3) \times 10^{-7} \text{ fm}^{-2}$, which has the same order of magnitude as some values measured in $^{143,145}\text{Ba}$ [10]. Finally, we found evidence for five new E1 transitions linking the positive-parity and negative-parity structures, as shown in figure 1(a). (A further tentative transition, linking the $27/2^+$ and $25/2^-$ states, has been observed.) It is now evident that basically all the levels below the excitation energy of $\sim 3\text{ MeV}$ are connected through electric dipole transitions to levels of opposite parity (see figure 2), hinting at a significant role of octupole correlations in the origin of the parity doublets displayed by ^{125}Ba .

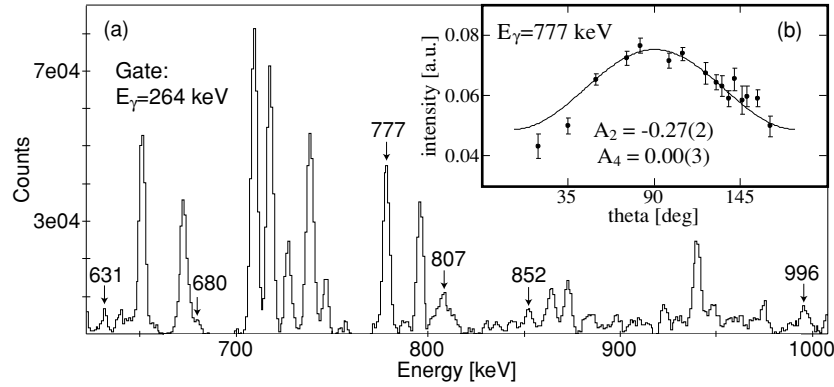


Figure 1. (a) Section of a single-gate spectrum showing five of the six new E1 transitions identified in ^{125}Ba . (b) The angular distribution of the $E_\gamma = 777$ keV transition linking the $23/2^+$ and $21/2^-$ levels in ^{125}Ba . The fitting curve corresponds, besides a normalization factor, to the function $1 + A_2 P_2(\cos(\theta)) + A_4 P_4(\cos(\theta))$, where P_n is the n th Legendre polynomial. The best-fit values of Legendre polynomial coefficients are reported in the figure.

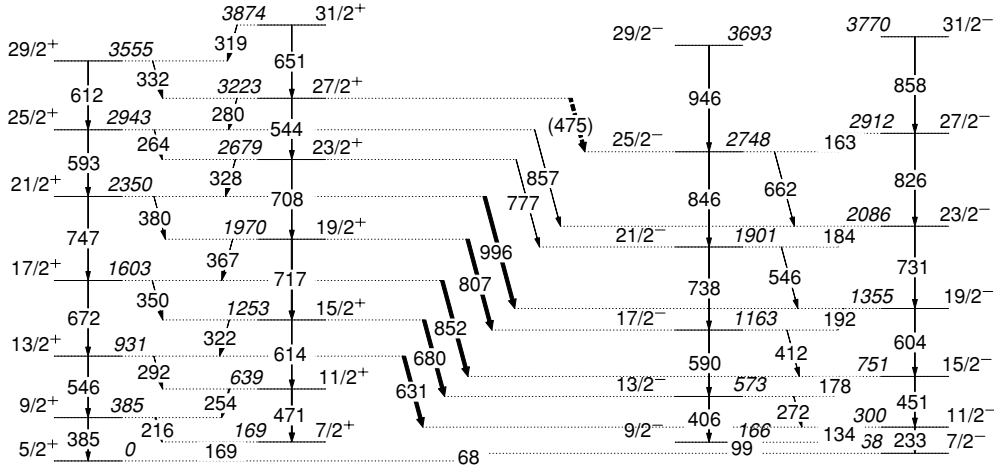


Figure 2. Partial level scheme for ^{125}Ba including the new E1 transitions connecting the positive-parity yrast structure (i.e. the coupled bands on the left-hand side of the picture) with the negative-parity one (right-hand side). Thick arrows indicate newly-found transitions. Previously known levels and transitions are taken from [9].

and, possibly, also of the parity doublets that are indeed observed in all odd barium isotopes with $119 \leq A \leq 129$ [3]. In particular, ^{127}Ba is also known to exhibit a large number of E1 transitions linking opposite-parity bands [12].

The second experimental result we present is the identification of the $J^\pi = 3^-$ level in ^{124}Ba . As shown in figure 3, two new coincident transitions of energy $E_\gamma = 312$ and 1492 keV, respectively, are observed following the $8^- \rightarrow 6^-$, $E_\gamma = 345$ keV and $6^- \rightarrow 4^-$, $E_\gamma = 326$ keV transitions (see level scheme in [13]). The $\Delta J = 1, \delta \approx 0$ dipole(+quadrupole) character of the new $E_\gamma = 312$ keV transition was determined on the basis of its angular distribution. 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

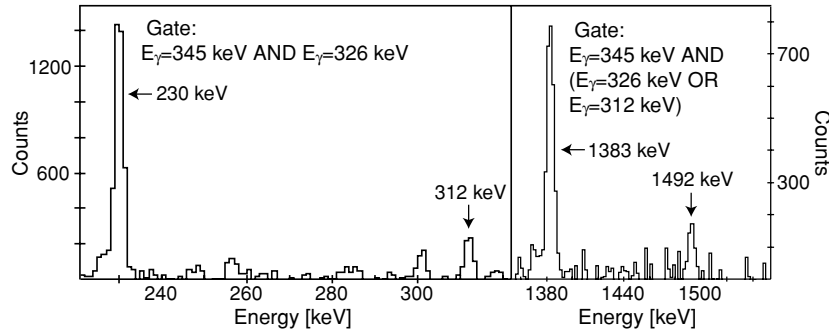


Figure 3. Intervals of double-gate spectra showing the new $E_\gamma = 312$ keV and $E_\gamma = 1492$ keV transitions in ^{124}Ba .

parallel- and orthogonal-scattering spectra, in the interval containing the $E_\gamma = 312$ keV peak and in two peak-free intervals close to it. A value $A_{\text{CS}} = -0.015(28)$ was found to correspond to the first interval, while the scattering asymmetry of the background surrounding the peak turned out to be $A_{\text{CS}} = +0.06(3)$. This means that the degree of linear polarization of the $E_\gamma = 312$ keV transition is negative, exactly as expected in the case of a $\Delta J = 1$ M1(+E2) character with $\delta \approx 0$. The level fed by this transition and decaying through the $E_\gamma = 1492$ keV transition to the 2^+ state, therefore, has $J^\pi = 3^-$; its excitation energy, namely $E_{\text{ex}}(3^-) = 1722$ keV, is in very good agreement with the prediction $E_{\text{th}}(3^-) = 1700$ keV given in [4]. Our work, thus, provides new evidence supporting the conclusion drawn in [4] that, in order to reproduce the excitation energies of low-lying negative-parity states in $^{124,126}\text{Ba}$, octupole interactions must indeed be considered.

In conclusion, we have presented new evidence for the existence of octupole correlations in light barium isotopes. The $J^\pi = 3^-$ level in ^{124}Ba was identified, at an energy well reproduced by a microscopic model including an octupole–octupole force. In addition, the existence of several new E1 transitions in the nucleus ^{125}Ba , linking opposite-parity structures whose levels form closely-spaced parity doublets, was established.

Future work on this subject should include the determination of the strength of these correlations through the measurement of $B(\text{E}1)$ values. No such measurement has ever been performed in light barium isotopes but, on the basis of experimental branching ratios and TRS calculations, $B(\text{E}1)$ values which are comparable in size to those observed for instance in ^{114}Xe [2] were argued in the nucleus ^{118}Ba [14]. The observation of low-lying negative-parity states in $^{114,116}\text{Ba}$ (only the ground states of these nuclei have been hitherto identified [3]) would also be of great interest.

Acknowledgments

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