ISOMERIC STATE 8^- IN ^{130}Ba STUDIED BY CONVERSION-ELECTRON AND GAMMA-RAY SPECTROSCOPY*

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The decay of the $I^\pi = K^\pi = 8^-$ isomeric state in ^{130}Ba was investigated using the ^{122}Sn(^{12}C,4n)^{130}Ba reaction. The measurement was carried out in e–γ and γ–γ coincidence modes using an electron spectrometer coupled to the EAGLE gamma-ray array at the Heavy Ion Laboratory, University of Warsaw. Multipolarities and mixing ratios for the $8^- \to 6^+$ and $8^- \to 5^+$ transitions in ^{130}Ba were derived from experimentally obtained internal conversion coefficients.

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1. Introduction

The problem of the K selection rule violation for electromagnetic transitions in nuclei, in spite of being a subject of extensive investigations, is not yet well understood. One of possible reasons of the phenomenon is the Coriolis interaction, which is responsible for mixing of states with different K values [1, 2, 3, 4, 5]. However, the non-axial deformation may cause the

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same experimental effects. Measurements of absolute values of the transition probability can help clarifying the underlying mechanism. The nuclei with the mass number close to $A = 130$, exhibiting large triaxiality (γ around $20^\circ \div 30^\circ$), constitute an excellent testing ground to study this phenomenon.

The main goal of the experiment described in this work was to determine multipolarities and mixing ratios for gamma transitions de-exciting the $I^\pi = K^\pi = 8^-$ isomeric state ($T_{1/2} = 9.4$ ms) in ^{130}Ba. This isomeric state was interpreted as a two quasi-neutron $7/2^+[404] \otimes 9/2^-[514]$ configuration [2, 3]. The 8^- isomers arising from such configuration are known in all even–even $N = 74$ isotones with atomic number $Z = 54 \div 64$ [2, 3, 4] and their half-lives vary by six orders of magnitude, from nanoseconds (Xe) to milliseconds (Ce, Ba) [6]. Decay modes of these isomers change from one nucleus to another, but in several cases (^{130}Ba, ^{132}Ce, ^{134}Nd, ^{136}Sm, ^{138}Gd) decay branches of $E1$, $E3/M2$ transitions leading directly to the band with $K = 0$ were observed. In addition, decays to $K = 2$ band are known for ^{130}Ba and ^{132}Ce. These branches severely violate the K selection rule. The de-excitation of $I^\pi = K^\pi = 8^-$ isomeric state in ^{130}Ba was already investigated [7, 8], but with large difference between presented results. Authors of the work [7] report that the value of internal conversion coefficient of K line for 882 keV transition is equal 0.0075(8). The corresponding value in the second publication is 0.0052(5) [8]. The scheme of decay of the 8^- isomeric state in ^{130}Ba is presented in Fig. 1 (a) [6].

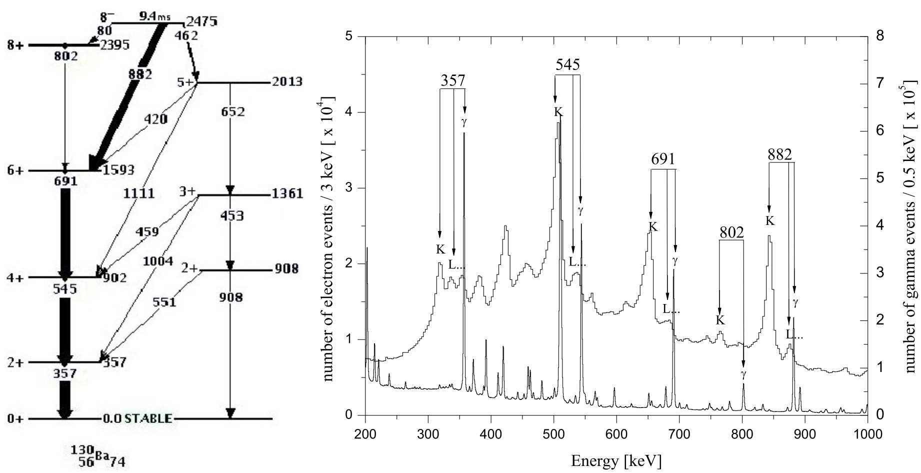

Fig. 1. (a) Decay paths of the $I^\pi = 8^-$, $K = 8$ isomeric state [6], (b) The "beam-off" total electron (upper spectrum) and gamma (lower spectrum) spectra collected during 8 days with an average beam current 40 enA. The strongest transitions belonging to the decay of the isomeric state in ^{130}Ba are labeled.

Conversion-electron spectroscopy plays an important role in study of excited states populated in nuclear reactions induced by heavy ions. Coincidence gamma-electron measurements allow determining internal conversion coefficients and, in consequence, transition multipolarities.

2. Experiment

The gamma and conversion electron spectroscopy of excited states in ^{130}Ba were carried out following the ^{122}Sn(^{12}C,4n)^{130}Ba reaction induced by a ^{12}C beam of 68 MeV energy delivered by the U-200P cyclotron of the Heavy Ion Laboratory, University of Warsaw. Self-supporting metallic target (3.5 mg/cm^2 thick) made of ^{122}Sn isotopically enriched to 99.9% was used in the experiment. The thickness of the target was chosen as a compromise between energy straggling of electrons in the target material at energies corresponding to transitions of interest ($300 \div 1000$ keV) and total production rate for ^{130}Ba nuclei. The EAGLE array of 12 HPGe ACS detectors [9] was coupled to the electron spectrometer [10] for γ–γ and γ–e measurements. The distance between HPGe detector collimators and the target was equal to about 8 cm in average. The electron spectrometer was significantly upgraded for this study: 6 Si(Li) and PIPS detectors used previously were replaced by a new segmented Si(Li) detector manufactured by Dr W. Czarnacki and his team at the National Centre for Nuclear Research in Świerk. The detector, 2.5 mm thick, is electrically divided into 12 segments and its total active area is equal to 60 cm^2 [11]. This upgrade increased the efficiency of the device by almost a factor of 4 and it achieves maximum value 4% for energy 350 keV. The energetic resolution of all segments (FWHM) equals about 1% for 976 keV electron line from ^{207}Bi. As the transitions of interest depopulate a $\sim$ millisecond isomeric state, the experiment could benefit from the macrostructure of beams delivered by the Warsaw Cyclotron. For this study, beam pulses were 2 ms long and the measurement was carried out during the 4 ms "beam-off" time periods. The total gamma and electron spectra obtained in the experiment are shown in Fig. 1 (b). One can notice gamma and electron lines from de-excitation of the $I^\pi = K^\pi = 8^-$ isomeric state in ^{130}Ba.

3. Results

The internal conversion coefficient can be calculated experimentally from the measured ratio of electrons and gammas emitted for a given transition, using the following formula

$$\alpha = \frac{N_e}{N_\gamma}\frac{\epsilon_\gamma}{\epsilon_e}\,, \tag{1}$$

where N_e and N_γ are the number of electrons and photons, respectively. The N_e and N_γ values were taken from the spectra gated on the same gamma-ray transitions in the gamma–gamma and electron–gamma matrices. The ratio $\epsilon_\gamma/\epsilon_e$ (where ϵ_e and ϵ_γ represent the efficiency of registration of electrons and photons, respectively) can be determined from experimental data for transitions with well known multipolarity. The efficiency curve used for this study (Fig. 2), was obtained as fit to efficiency ratios $\epsilon_\gamma/\epsilon_e$ measured for γ-ray transitions (357, 545, 691 and 802 keV) in ^{130}Ba (internal calibration) as well as gamma lines emitted by a ^{207}Bi calibration source (570 and 1064 keV). Multipolarity $E2$ was assumed for all transitions in ^{130}Ba used for the internal calibration. The technical aspects of analysis of data collected in electron–gamma coincidence measurements were described in a detailed way in Ref. [12].

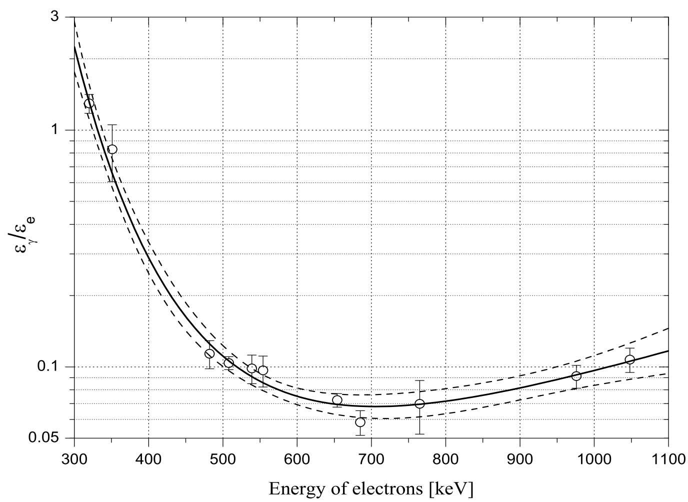

Fig. 2. The efficiency of the experimental set-up. Data points correspond to transitions with well known multipolarity. The fitted curve is represented by the solid line, while the dashed lines show the error corridor.

The K internal conversion coefficients calculated for transitions belonging to the decay of the $I^\pi = K^\pi = 8^-$ isomeric state in ^{130}Ba are presented in Fig. 3 in comparison to theoretical predictions for various multipolarities taken from [13]. Results for $L + M + \ldots$ lines are shown in Fig. 4 in an analogous way.

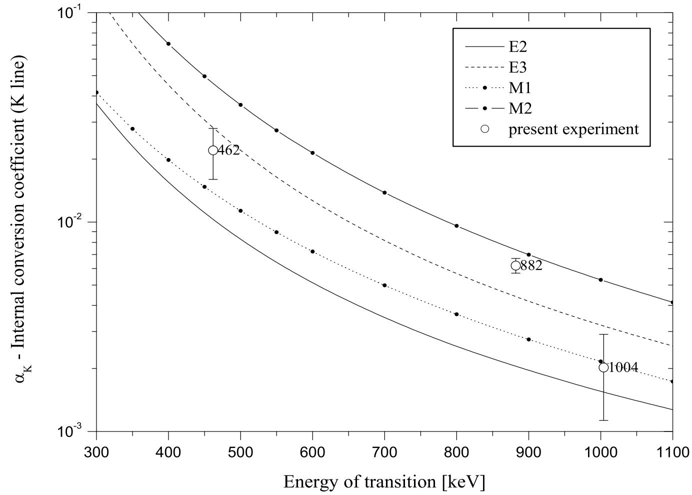

Fig. 3. The experimental values of internal conversion coefficients for K lines (open circles) and theoretically predicted multipolarities [13] (denoted by different styles of lines as explained in the figure).

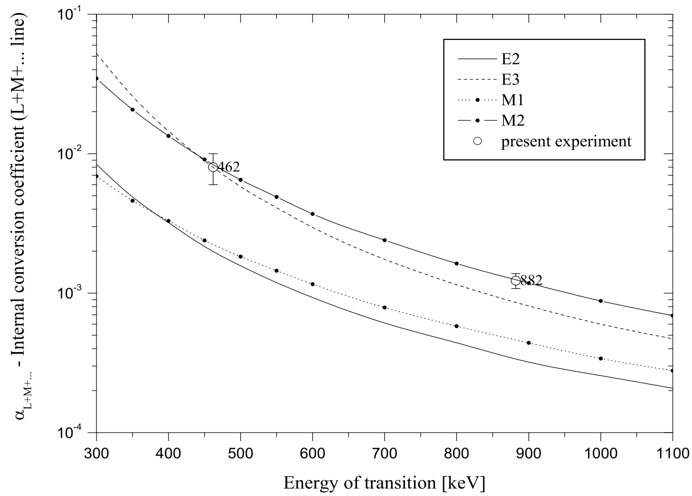

Fig. 4. The same as Fig. 3 for $L + M + \ldots$ lines.

4. Conclusions

The experimentally obtained values of the conversion coefficients for K and $L+M+\ldots$ lines for the $8^- \rightarrow 6^+$ 882 keV transition are $\alpha_K = 0.0062(5)$ and $\alpha_{L+M+\ldots} = 0.00123(15)$. Comparison of measured values with theoretically predicted conversion coefficients ($\alpha_K(M2) = 0.00737$, $\alpha_{L+M+\ldots}(M2) =$

0.00125, $\alpha_K(E3) = 0.00441$, $\alpha_{L+M+\ldots}(E3) = 0.00086$) [13] leads to the conclusion that this transition has a 34% $E3 + 66\% M2$ mixed character with a mixing parameter $\delta^2(E3/M2) = 0.5(4)$. The values of conversion coefficients for the second transition of interest (462 keV, $8^- \to 5^+$) were determined as $\alpha_K = 0.022(6)$ and $\alpha_{L+M+\ldots} = 0.008(2)$. Both numbers are in agreement with the theoretical values for $E3$ transitions ($\alpha_K(\text{theor.}) = 0.02823$ and $\alpha_{L+M+\ldots}(\text{theor.}) = 0.00795$) and confirm the pure $E3$ character of this transition. The internal conversion coefficient of the 1004 keV transition for K line was also obtained. The value $\alpha_K = 0.0020(9)$ indicates that it is a mixed $E2/M1$ transition. The theoretical interpretation of the present results, similar to that proposed in [5] is in progress.

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