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High-Statistics β^+/EC-Decay Study of ^{122}Xe

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Abstract

Low-lying excited states of ^{122}Xe have been studied via the β^+/EC decay of ^{122}Cs with the 8π γ-ray spectrometer at the TRIUMF Isotope Separator and Accelerator facility. The data collected have enabled the observation of new in-band transitions in the excited 0^+ state bands. In addition, the 2^+ members of the second 0^+ and third 0^+ state bands have been firmly confirmed by angular correlation analysis.

Keywords: Gamma-ray spectroscopy; Angular correlation analysis; Xe-122; Excited low-lying states; Beta decay; 0^+ states

1. Introduction

This work is a part of systematic study of collectivity in even-even nuclei in the Z > 50 and N < 82 region. Nuclei

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in this region exhibit a very smooth evolution of simple collective signatures, such as the energy ratio of the first 4^+ state to the first 2^+ state. However, the collectivity of excited low-lying states in this region is rather poorly characterized, especially for some Xe isotopes, because of a lack of spectroscopic data that provide measures of collective properties. Among the Xe isotopes, $^{124\text{-}132}$Xe were studied by Alford, et al., (1979) and reveal that the third 0^+ states in these isotopes are very strongly populated with (^{3}He,n) reactions, suggesting a pairing vibrational structure influenced by proton sub-shell gaps. In other mass regions, such as $Z < 50$, strong population of 0^+ states occurs in two-neutron transfer reactions, and is related to shape-coexistence where strong E0 transitions occur between the 0^+ states and the ground state (J. Kumpulainen *et al*., (1992) and M. Deleze et al., (1993)). Recent work by Radich *et al*., (2015) on ^{124}Xe has established nearly identical quadrupole collectivity for the pairing-vibrational third 0^+ band and the ground state band. The present work is focused on ^{122}Xe. The first result was the establishment of the 2^+ band members of the second and third 0^+ state bands with in-band transitions observed for the first time (Jigmeddorj *et al*., (2016)). To confirm the spin of the new member states, angular correlation data from the ^{122}Cs decay experiment have been analyzed.

2. Experimental details

The experiment to study the β^+/EC of ^{122}Cs was performed at the TRIUMF-ISAC facility located in Vancouver, B.C., Canada. A 65-μA, 500-MeV proton beam from the TRIUMF main cyclotron was delivered to the ISAC facility and bombarded a thick ^{nat}Ta foil target. Products of the spallation reaction diffused to the surface of the Ta target foils, were ionized with a Re surface ion source, and passed through a magnetic mass separator that was set to select singly charged A=122 ions. The high-intensity beam of $1.1\text{x}10^7$ ions/s of ^{122}Cs in the 1^+ ground state with a 21.18 s half-life and $2.1\text{x}10^6$ ions/s of ^{122}Cs in the 8^- isomeric state with a 3.7 minute half-life was delivered to the centre of the 8π γ-ray spectrometer and implanted into a FeO-coated mylar tape; details are given in Garrett *et al*., (2007), Garnsworthy and Garrett (2014), and Garnsworthy *et al*., (2015). The 8π spectrometer consists of 20 HPGe detectors surrounded by bismuth-germanate (BGO) Compton suppression shields. The free inner volume of the 8π has a diameter of 19.8 cm and can receive a variety of auxiliary detection systems including Pentagonal Array of Conversion Electron Spectrometers (PACES). PACES is an array of 5 liquid nitrogen cooled Si(Li) detectors for conversion-electron detection and was positioned upstream and aligned to the beam-spot position. The average source-to-Si-detector distance was 3 cm. More details of the 8π spectrometer are given by Garrett et al. (2015). Two sets of data were collected for short- and long-half-life decays in repeated cycles. Each set of data was collected in a mixed trigger mode involving scaled-down γ-ray and e^- singles, and γ-γ and γ-e^- coincidences. The Ge detector efficiency was measured using standard radioactive sources of ^{133}Ba, ^{152}Eu, ^{56}Co, and ^{60}Co. The data were sorted into γ-ray and e^- spectra, and γ-γ and γ-e^- random-background-subtracted coincidence matrices. Analyses of the matrices and fitting of the spectra were performed with the Radware package (see Radford).

3. Results and discussions

As discussed in Jigmeddorj *et al*., (2016), the data collected enabled the observation of more than a hundred new transitions and new levels including the third 0^+ state and the 2^+ band member of the third 0^+ state band. The third 0^+ state was suggested based on energy systematics (see Radich *et al*., (2015)) but was not definitively identified. Also, the spin of the suggested 2^+ member of the third 0^+ band needed confirmation. To assign the spins of those states, angular correlation data have been analyzed.

3.1.Angular correlation analysis

The experiment was performed with the 8π spectrometer at TRIUMF-ISAC. The probability for observing coincident γ-rays at certain angles is given in terms of the Legendre polynomials as given in Eq. 1, where a_k is a coefficient dependent on spins of states involved in the cascade from which the γ-rays are emitted and the multipolarities of the γ-rays and $P_k(cos(\theta))$ is Legendre polynomials.

$$W(\theta)=\sum_{k=0}^{\infty} a_k P_k(\cos(\theta)) \qquad (1)$$

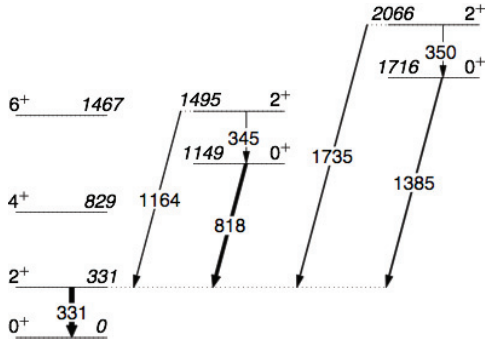

Fig. 1. Partial level scheme of ^{122}Xe showing all cascades examined in this work.

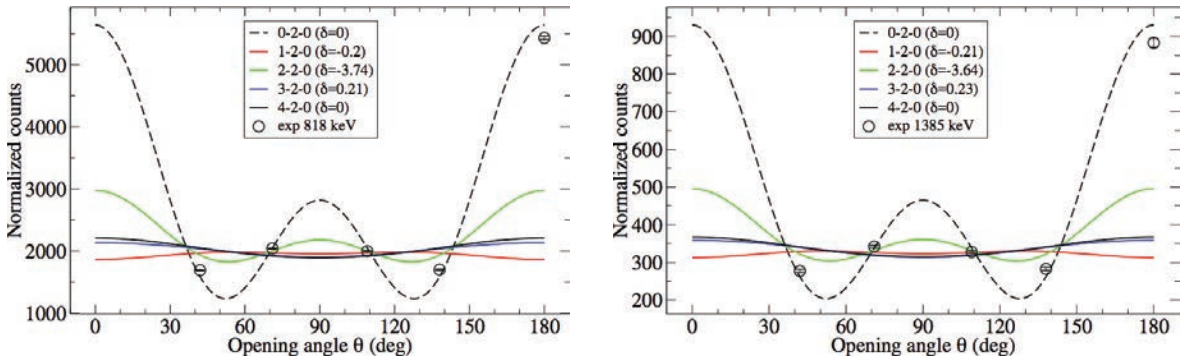

Fig. 2. Angular correlation of 818- and 331-keV γ-rays (left), 1385- and 331-keV γ-rays (right). Experimentally measured angular correlation counts normalized to the number of detector pairs and corrected for detector geometry effects are indicated in circle, while theoretically drawn curves for different possible cascades are given in different colours.

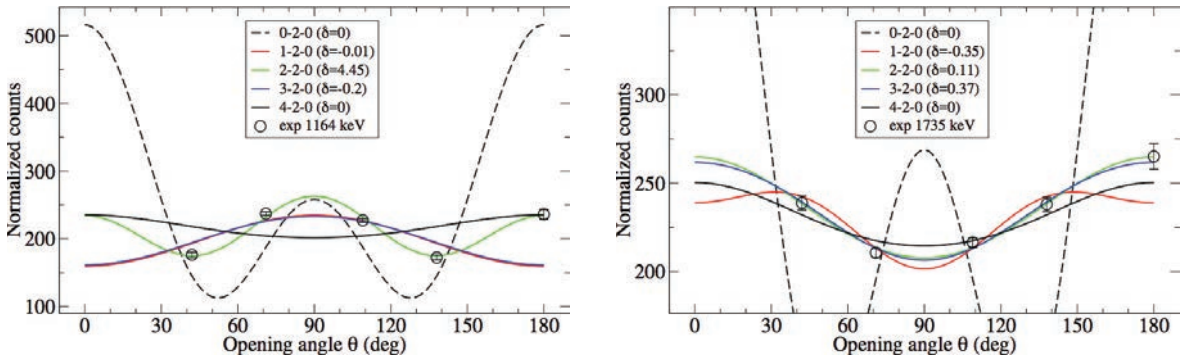

Fig. 3. Angular correlation of 1164- and 331-keV γ-rays (left), 1735- and 331-keV γ-rays (right).

The probability is restricted to even values of k due to symmetry about 90 degrees, and taken as k = 0, 2, and 4. The truncation at 2 or 4 is due to the transition multipolarities as dipole (k = 2) or quadrupole (k = 4). The twenty HPGe detectors of the 8π spectrometer are positioned such that they make opening angles at 42, 71, 109, 138 and 180 degrees.

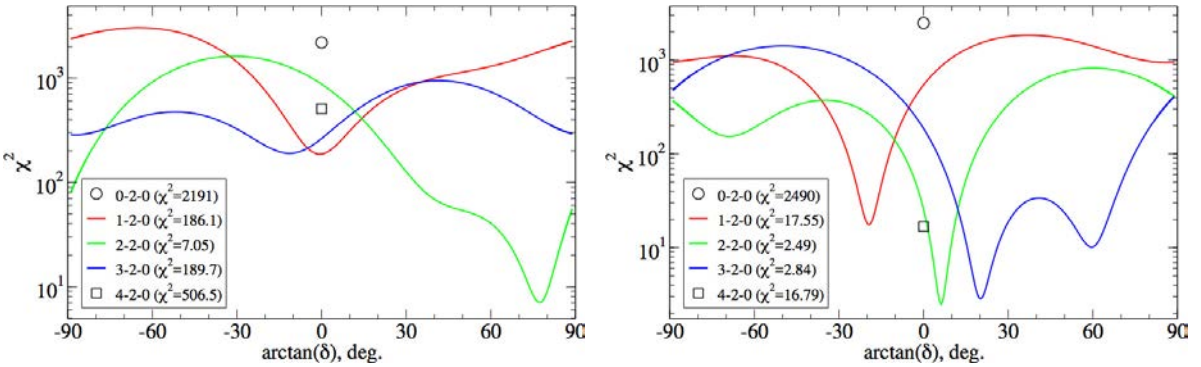

Fig. 4. χ^2 plot of the angular correlation of 1164- and 331-keV γ-rays (left) and 1735- and 331-keV γ-rays (right) are given in different colours for various cascades in terms of the mixing ratio.

The number of detector pairs varies and there are 30, 60, 60, 30, and 10 detector pairs, respectively, expected for the array. However, in the analysis of the data, not all detectors were used, and three were removed from the sorting routines. For the 17 detectors remaining, the number of detector pairs for the five opening angles listed above are 21, 45, 42, 21 and 7, respectively. Shown in Fig. 1 is a partial level scheme displaying the second and third 0^+ states and the 2^+ band members of those 0^+ bands. The gate is taken on the 331 keV γ ray and angular correlation plots of the γ rays above the gate are given in Figs. 2 and 3. The in-band 345- and 350-keV transitions were observed here for the first time, reported in Jigmeddorj *et al*., (2016). The γ-γ coincidence spectra that clearly show the placement of those transitions are given in Jigmeddorj *et al*., (2016). As shown in Fig. 2, the spin of the 1149-keV state is clearly 0^+, as was known before, and the spin of the 1716-keV state is firmly 0^+, as was assigned previously. As shown in Fig. 3, the spin of the 1495 keV state is clearly 2^+ (also known previously) and the spin of the 2066 keV state is also 2^+. This is a new firm assignment. The plots shown in Fig. 3 are the angular correlation data for the 1164- and 1735-keV γ-rays. The χ^2 plots for these transitions are given in Fig. 4 and are plotted as a function of the E2/M1 mixing ratio. It is clear that the green coloured curve, in the case for the 2-2-0 spin sequence for the cascade, reaches a minimum χ^2 value both cases. While the angular correlation for the 1735-331 keV γ-ray sequence cannot clearly differentiate between an assignment of spin 2 or 3 for the 2066-keV state, its decay to the 1716-keV 0^+ state rules out the spin of 3, leaving the 2^+ assignment as the only possibility.

4. Summary

Low-lying excited states of ^{122}Xe have been investigated via β^+/EC-decay of ^{122}Cs and the collected data enabled us to observe important new transitions including those in-band transitions for the second and third 0^+ bands. The systematically assigned third 0^+ state and the previously suggested 2^+ member states of the second and third 0^+ bands have been confirmed by angular correlation analysis.

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