

Nuclear structure of ^{122}Xe studied via high-statistics β^+ / EC -decay

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Abstract. The nuclear structure of ^{122}Xe has been investigated with measurements of the β^+ / EC decay of ^{122}Cs with the 8π γ -ray spectrometer at the TRIUMF-ISAC facility. The data collected have enabled the determination of relative $B(E2)$ values of some low-energy transitions, and the in-band transitions of the excited 0^+ bands have been observed. As a result, the 2^+ rotational band members for the 0_2^+ and 0_3^+ states have been firmly identified.

1 Introduction

Nuclei in the $Z > 50$, $N < 82$ region exhibit a very smooth evolution of collectivity; however, collectivity in this region is poorly characterized because of a general lack of high-quality spectroscopic data for low-spin states. It is the characterization of low-spin states, e.g., relative and absolute $B(E2)$ decay strengths and the occurrence of $E0$ decays, that are essential in describing the collective nature of these nuclei.

The excited 0_3^+ states in $^{124-132}\text{Xe}$ isotopes [1] are very strongly populated in $(^3\text{He}, n)$ reactions, suggesting that there are important proton subshell gaps influencing the low-lying structure of these isotopes. The strongly populated 0^+ states, which are candidates for the main fragments of the proton pairing vibration, appear to have a similar deformation as the ground state band based on the similarity of the spacing of their possible rotational band members. The assigned band members, however, are generally based on energy considerations since, in most cases, the in-band transitions have remained unobserved. In nuclei with $Z \leq 50$, there is ample evidence for shape coexistence [2, 3] of the bands that are also strongly populated in the $(^3\text{He}, n)$ reactions. Shape coexistence with mixing of the configurations would lead to strong $E0$ transitions, and $E0$ transitions are observed in $^{118-124}\text{Xe}$ [4] and in $^{114-126}\text{Te}$ [5], but they are not fully characterized. To date, no evidence for shape coexistence in the Xe isotopes has been found, but it remains an interesting question if the Xe isotopes might manifest shape coexistence given their proximity to the $Z = 50$ closed shell.

The Xe isotopes were thought to be γ -soft nuclei or, in the language of the IBM, possess $O(6)$ symmetry. How-

ever, recent Coulomb excitation work, in particular ^{124}Xe [6] showed that $O(6)$ was badly broken while on ^{128}Xe [7] showed that ^{128}Xe is not an $E(5)$ nucleus as previously suggested. The $B(E2)$ values determined in Ref. [6] were refined with highly sensitive γ -ray measurements with the 8π spectrometer following ^{124}Cs β decay [8]. The 0_3^+ level identified as the proton pairing vibration based on previous $(^3\text{He}, n)$ work [6] was shown to have a nearly identical absolute value of deformation, $|\beta|$ as the ground state band. Key observations that enabled this determination in the β -decay measurement were the in-band $2^+ \rightarrow 0^+$ transitions that established firmly the 2^+ rotational band members.

The systematics of the excited 0^+ bands are shown in Fig. 1, where in ^{120}Xe and ^{122}Xe there are no candidates for the 2^+ members of the 0_3^+ bands. This deficiency makes characterizing their behaviors difficult, and thus they need to be investigated further. In order to provide detailed spectroscopic data, especially of weak low-energy decay branches and possible key $E2$ transitions, a high-statistics ^{122}Cs β^+ / EC -decay experiment was performed at the TRIUMF-ISAC facility.

2 Experimental detail

The experiment to study the β^+ / EC of ^{122}Cs was performed at the TRIUMF-ISAC facility located in Vancouver, B.C., Canada. A $65\text{-}\mu\text{A}$, 500-MeV proton beam 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 1.1×10^7 ions/s of ^{122}Cs in the 1^+ ground state with a 21.18 s half life, and 2.1×10^6 ions/s

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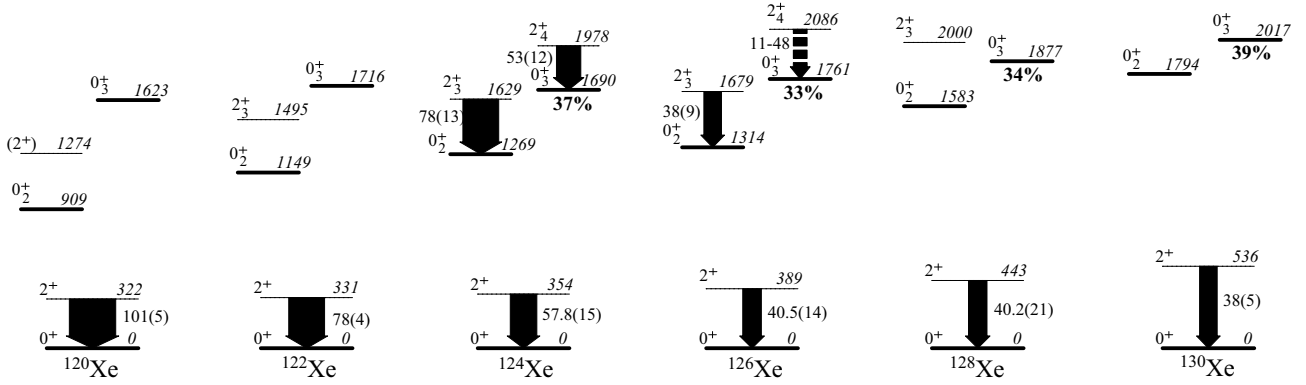


Figure 1. Systematics of the low-lying 0^+ states in the $^{120}\text{Xe} - ^{130}\text{Xe}$ isotopes. Absolute in-band $B(E2; 2^+ \rightarrow 0^+)$ values are shown in W.u. with uncertainties in parentheses. For $^{124-130}\text{Xe}$, the values of the ratio of the proton pairing contribution to the 0_3^+ state are written below the 0_3^+ levels in percentages [8].

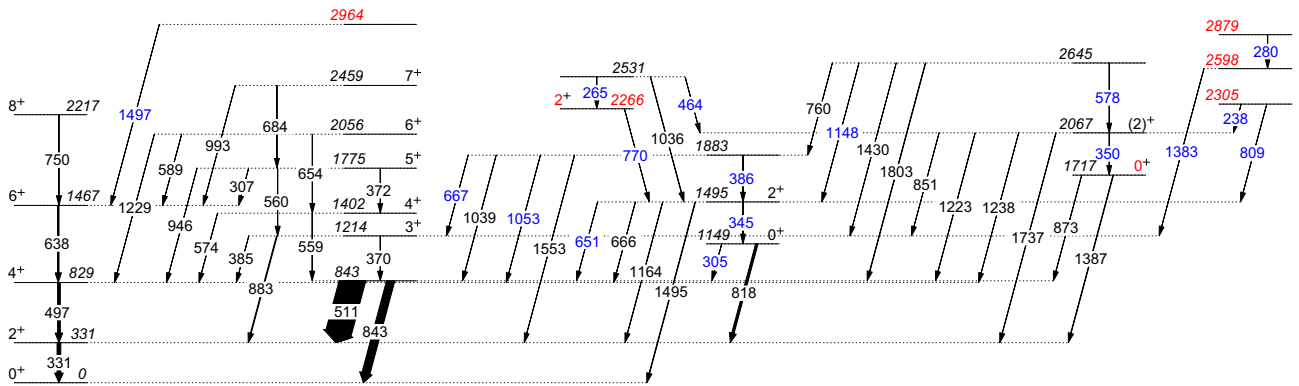


Figure 2. (Color online) A portion of the level scheme of low-lying states of ^{122}Xe . Blue colored numbers indicate newly observed transitions, and the labels of suggested spin assignments and new level energies are indicated in red.

of ^{122}Cs in the 8^- isomeric state with a 3.7 minute half life was delivered to the center of the 8π γ -ray spectrometer [9–12] and implanted into a FeO-coated mylar tape. The 8π spectrometer consisted of 20 high-purity Ge detectors surrounded by bismuth-germanate (BGO) Compton-suppression shields. The average source-to-Ge-detector distance was approximately 14 cm. A BC-422Q fast plastic scintillator with a solid angle of approximately 20% of 4π was located immediately behind the beam deposition point, while the 5 Si(Li) detectors of the PACES array for conversion-electron detection were 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 in Refs. [10, 12], and PACES is described in Refs. [12, 13]. 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 $\gamma - \gamma$ and $\gamma - e^-$ coincidences. The 8π Ge 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 $\gamma - \gamma$ and $\gamma - e^-$ random-background-subtracted coincidence matrices. Analyses of

the matrices and fitting of the spectra were performed with the Radware package [14].

3 Results and discussions

The data collected enables the observation of hundreds of new transitions including those that feed the 0_2^+ and 0_3^+ states. As an example of data quality, a portion of the level scheme of the low-lying states of ^{122}Xe is presented in Fig. 2. Newly observed transitions are indicated in blue colored arrows and numbers while new levels, with their energies and assigned spins, are shown in red. Examples of coincidence γ -ray spectra that clearly show newly observed transitions are given in Figs. 3, 4, and 5. The peaks in the spectra are labelled with γ -ray energies and newly observed γ rays are presented with blue colored numbers.

The relative $B(E2)$ values for transitions draining the 2_3^+ and 2_4^+ levels were determined via

$$\frac{B(E2)}{B(E2)_{ref}} = \frac{E_{\gamma_{ref}}^5 BR}{E_{\gamma}^5 BR_{ref}} \quad (1)$$

where the subscript *ref* denotes the reference transition, and *BR* refers to the branching ratio. Branching ratios

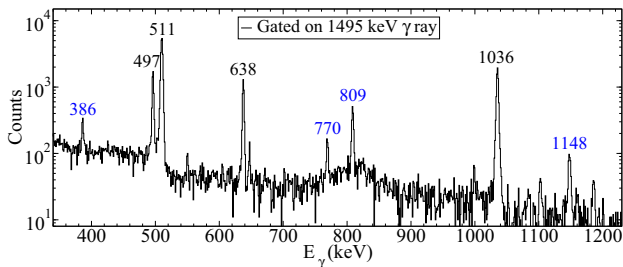


Figure 3. (Color online) Portion of the γ -ray coincidence spectrum gated on the 1495-keV γ ray showing newly placed 386-, 770-, 809-, and 1148-keV γ rays labelled in blue.

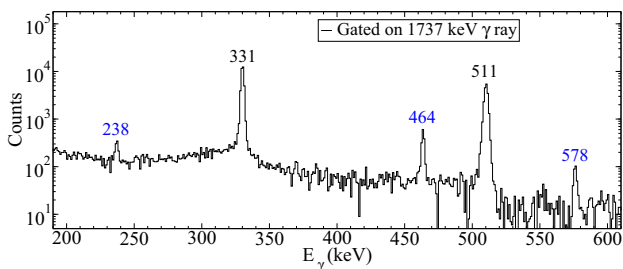


Figure 4. (Color online) Portion of the γ -ray coincidence spectrum gated on the 1737-keV γ ray showing newly placed 238-, 464-, and 578-keV γ rays labelled in blue.

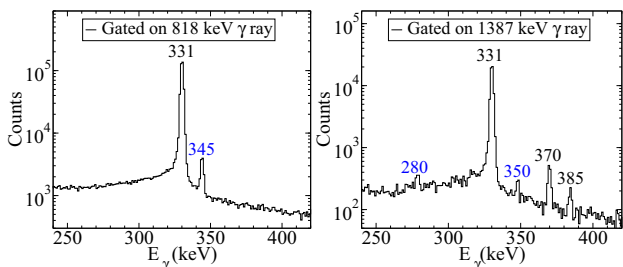


Figure 5. (Color online) Portions of the γ -ray coincidence spectra gated on the 818- and 1387-keV γ ray showing the newly placed 345-, 280- and 350-keV γ rays labelled in blue.

were determined by taking a gate on the strongest feeding γ ray and dividing the peak intensity by the total intensity out of the level of interest. In Fig. 6, the relative $B(E2)$ values obtained from this work are given in red numbers inside the brackets.

As seen in Fig. 6, the in-band $2^+ \rightarrow 0^+$ transitions have $B(E2)$ values that strongly dominate the out-of-band transitions. This fact, together with the energies of the 2^+ states, leaves little doubt that the 2^+ band members have been firmly identified. The energy spacing of the 2^+ band members suggests that the excited 0^+ bands have similar deformation, but as shown in Ref. [8] this can be deceiving and the 0_2^+ band in ^{124}Xe , in particular, was found to have a significantly larger $|\beta|$ value than the ground-state band. Absolute $B(E2)$ values are required to make any conclu-

sions in ^{122}Xe . It is suggested that the 0^+ band at 1717-keV is the analogue of the proton-pairing vibrational 0_3^+ bands in the heavier Xe isotopes.

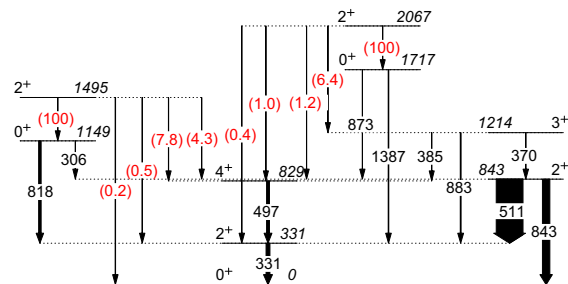


Figure 6. (Color online) Portion of the level scheme obtained in this work with relative $B(E2)$ values in red.

4 Conclusions

This work is part of a systematic study of the Xe isotopes with high-statistics β decay. We have firmly identified for the first time the 2^+ rotational band members of the 0_2^+ and 0_3^+ states in ^{122}Xe . The rotational spacing is similar that of the ground state band. The analysis is going on and, to date, we have observed more than 160 new transitions and more than 100 new levels that expands dramatically the level scheme for ^{122}Xe . The analysis has been concentrated on the γ -ray data but the conversion electron data will be also analyzed to provide a comprehensive picture of the low-lying states of ^{122}Xe .

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