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# High-Statistics $\beta^+$/EC-Decay Study of $^{122}$Xe

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**Abstract**

Low-lying excited states of $^{122}$Xe have been studied via the $\beta^+$/EC decay of $^{122}$Cs with the $8\pi$ $\gamma$-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 $\beta^+$/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.