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CHIRALITY IN THE MASS 80 REGION: ^{79}Kr

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The high spin states of ^{79}Kr were studied via the ^{70}Zn(^{13}C, 4n) reaction to search for chiral doublet bands based on the three-quasi-particle configuration, $\pi g_{9/2}{}^{2} \otimes \nu g_{9/2}{}^{-1}$. The ^{13}C beam of 65 MeV was provided by the 930 AVF Cyclotron at CYclotron and RadioIsotope Center (CYRIC) facility at Tohoku University. The triple coincidence γ rays were detected by the Hyperball2 array. The side band structure to the $\pi g_{9/2}{}^{2} \otimes \nu g_{9/2}{}^{-1}$ yrast band has been identified in ^{79}Kr. Spin and parity assignments are made based on the DCO ratio and linear polarization analysis.

1. Introduction

Spontaneous formation of handedness in nuclei was suggested by Frauendorf and Meng in 1997.[1] Its manifestation is an appearance of degenerate pair of ΔI=1 bands, chiral doublets. Introductions to nuclear (spin-)chirality are given elsewhere in these proceedings and omitted here. The experimental evidence was pointed in Ref.[1] to ^{134}Pr in which two bands having the same unique-parity $\pi h_{11/2} \otimes \nu h_{11/2}$ single particle configuration were observed with a degeneracy of $\sim$ 30 keV at some spin. Subsequently, a systematic search for similar doublet structures surrounding ^{134}Pr was started at SUNY at Stony Brook, U.S.A. Indeed, the doublet structures, albeit with less energy degeneracy compared to those in ^{134}Pr, were identified in N=75 and 77 isotones in the mass A $\sim$130 region.[2,3] Since then, about thirty chiral doublet candidates were reported as summarized in Ref.[4]. These bands are identified in odd-odd, odd-A and even-even nuclei involving two, three and four quasi-particle configurations, respectively. The islands of doublet structures appear to exist in the mass A $\sim$130 and 105 regions. On the other hand, only one candidate has been hinted in the mass A $\sim$180 region,[5] and no case has yet been found in the mass A $\sim$80 region.

Chiral geometry can be expected in the A $\sim$80 region involving the single high-j orbital such as $\pi g_{9/2} \otimes \nu g_{9/2}{}^{-1}$ for odd-odd and $\pi g_{9/2}{}^{2} \otimes \nu g_{9/2}$ for odd-A nucleus with a triaxial core. Because of similarity in the single particle configuration between the A $\sim$80 and 130 regions where both are composed of single high-j unique parity orbitals with a valence proton(s) and neutron in the low and high sub-shell, respectively. Thus, naively one would expect observation of doublet bands in this mass region. In fact, the 3D Tilted Axis Cranking calculations have predicted the onset of weak formation of chirality, namely chiral vibration, in ^{79}Br.[6]

2. Experimental setup and the Hyperball2 array

High spin states in ^{79}Kr were produced following the ^{70}Zn (^{13}C, 4n) reaction. The beam energy was chosen at 65 MeV based on a separate excitation function measurement. The beam was provided by the 930 cyclotron at CYclotron and RadioIsotope Center (CYRIC) at Tohoku University. The target consists of two self-supporting 500 μg/cm^2 of 70 %-enriched ^{70}Zn, which are seperated by 1mm. The gamma rays were detected by the Ge array, Hyperball2.

Hyperball2 was developed at Tohoku University in 2005 which was designed to be used in gamma-ray spectroscopy of normal nuclei and of Λ- hypernuclei with a

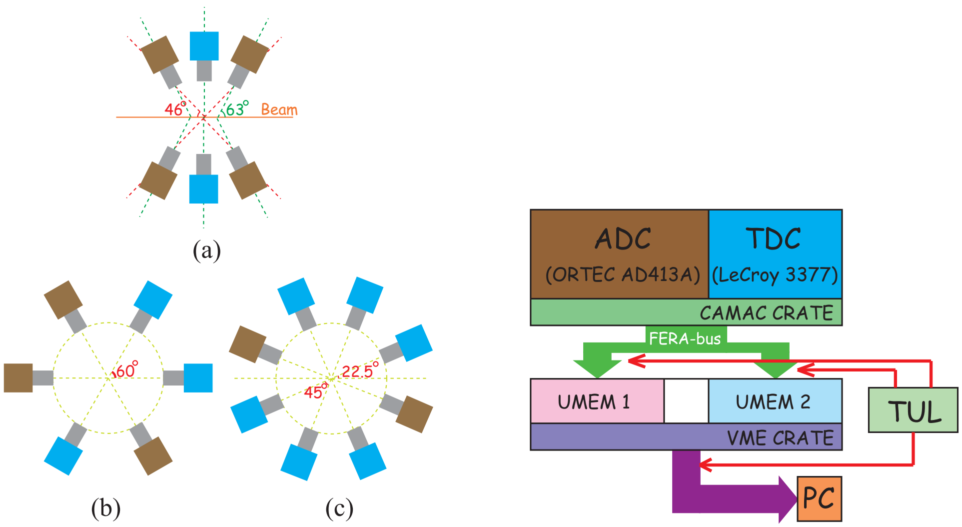

Fig. 1. (Left panel) Hyperball2 detector geometry – side view (a) and a view looking into the beam axis: Ring 1 (up stream) and 3 (down stream) (b), and Ring 2 (middle) (c). (Right panel) The double buffer DAQ system.

strangeness degree of freedom. Because of the latter experiment, all Ge detectors are of transistor-reset type with a low gain of $\sim$ 20 mV/MeV. Thirteen co-axial detectors of n-type with 60 % relative efficiency are mounted on the upper and lower rings, while 6 clover detectors are placed at the middle ring at 90° with respect to the beam axis as in Fig. 1 (left panel). The total photo peak efficiency of Hyperball2 is 4.5% for 1.33 MeV γ ray. Each detector is equipped with a BGO Compton background suppressor. A real time anti-coincidence between the Ge and the suppressors is made via a FPGA circuit with a use of the Tohoku Universal Logic module (TUL), which is capable of carrying out a relatively complicated anti-coincidence logic required for clover detectors. DAQ system for Hyperball2 employs a double buffer scheme where ADC and TDC data are transfered via FERA-bus to two memory modules in alternating sequence in such a way that one memory module stores the data from the ADC and TDC while the other transfers data to a computer as schematically shown in Fig. 1 (right panel); this system reduces the DAQ dead time achieving 80% live time against 250 kB/s data rate.

3. Results and discussion

A total of 370 million un-folded triple gamma coincidence events were collected. The deduced partial level scheme is shown in Fig. 2. Relative spin and parity assignments were made by DCO analysis and linear polarization analysis where possible. Several new transitions were identified in the present work which may constitute lower part of band structures with linking transitions to the yrast band; these are labeled

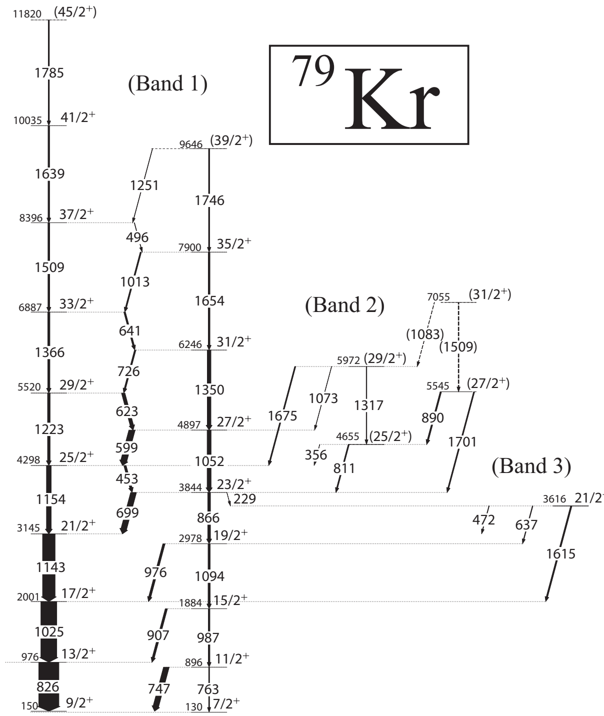

Fig. 2. A partial level scheme deduced form the present study for positive parity bands

as Band2 in Fig. 2. In the previous work, only the 811-keV transition in Band2 was known. There is another level which decays to the lower part of the yrast below the proton pair breaking, which is also observed previously and confirmed in the present study. The yrast band is also extended to I=(45/2). As the $S(I) = [E(I) - E(I-2)]/2I$ plot of Fig. 3(c) shows, breaking of a pair of protons can be seen as a change in the $S(I)$ pattern. Considering that the broken pair of protons are in the lower $g_{9/2}$ sub-shell, flatness of $S(I)$ values between I=12 and 14 are not expected for an axially symmetric core when coupled with low-K particles. Therefore, this is suggestive of a perpendicular coupling of angular momentum blades of protons to the core rotation. On the other hand, a sizable $S(I)$ staggering at low spin indicates some angular momentum component of the valence neutron along the collective rotation which may be a result of Fermi level being in the middle of a $g_{9/2}$ sub-shell for neutron.

Energy degeneracy between Band 1 and Band 2 are more than 500 keV. Near the band head, non-degeneracy alone cannot exclude chiral interpretation for the side band, but shows its strongly vibrational character if it is chiral. Although it is necessary to extend this band to a higher spin to draw more conclusions, re-appearance of $S(I)$ staggering at $I = 33/2$ in the yrast band points to a change in the band structure.

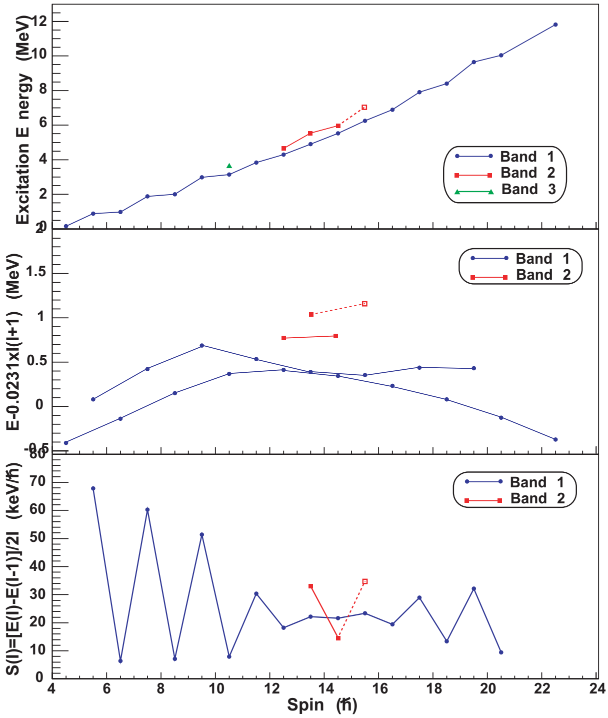

Fig. 3. Excitation energy v.s. spin:(a), Excitation energy−rotor v.s. spin: (b), $S(I) = [E(I) - E(I-1)]/2I$: (c).

4. Conclusion

The excited sates of ^{79}Kr was studied at CYRIC at Tohoku university using the Hyperball2 array. Addition of several new transitions to the previously observed ones constitute possible side band structures with linking transitions to the yrast $\pi g_{9/2}{}^2 \otimes \nu g_{9/2}$ band. Energy degeneracies are more than 500 keV, which indicate unfavorable condition to chiral structure at least near the band head. Extension of this band to a higher spin states is needed for a further study of the side structure. The next nuclei to be studied in this mass region will be odd-odd ^{80}Br using Hyperball2 and a charge particle Si detector, SiBallNeo from Kyushu university.

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