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Possible Chiral Doublet Bands in ^{122}Cs

Rajesh Kumar[1], Anil Kumar[2]

PG Department of Physics, JCDAV College, Dasuya (Punjab) 144205, India

Abstract: ***High-spin states in ^{122}Cs have been studied via ^{107}Ag(^{19}F, p3n)^{122}Cs fusion evaporation reaction at beam energy of 93 MeV. Properties of the chiral doublet bands of the ^{122}Cs nucleus built on the $\pi h_{11/2} \otimes \nu h_{11/2}$ configuration are investigated and discussed. The existence of these bands have been discussed in terms excitation energies, B(E2) and B(M1). We have performed the linear polarization measurements using the Clover detectors to assign the unknown spins and parities of a few bands. The observed two $\pi h_{11/2} \otimes \nu h_{11/2}$ bands are proposed to be a pair of chiral doublet bands based on the systematic comparison with those in the neighbouring odd–odd Cs isotopes.***

Keywords: Nuclear structure, chiral doublet bands, band definition, electromagnetic transition, energy-level crossing, triaxial particle rotor model.

1. Introduction

The transitional region (A ~120-130) has gained a substantial preference in high spin γ-spectroscopic studies due to the observation of various dynamical features such as backbending, signature splitting, signature inversion, shape coexistence, magnetic rotation and chirality. These properties arise mainly because of the softness [1, 2] of these nuclei towards gamma deformation resulting from the number of valence nucleons outside the close shell [3]. In this mass region both the valence protons and neutrons are expected to have a strong shape driving force on the core, when occupying the high j-orbital that are close to Fermi surface. In this mass region proton Fermi level lies below the mid $h_{11/2}$ orbital, which favour prolate nuclear shape, while neutron Fermi level lies above the $h_{11/2}$ midshell, which favour oblate nuclear shapes. The other available spherical shell model orbitals in this region are $g_{7/2}$, $d_{5/2}$, $g_{9/2}$ (extruder) and the negative parity $h_{11/2}$ (intruder) for the protons and $d_{3/2}$, $d_{5/2}$, $g_{7/2}$, and $h_{11/2}$ for neutrons. However in the deformed nucleus, these orbitals are strongly mixed and are no longer treated as a good quantum numbers for describing shell structure. Because of large nuclear quadrupole deformation induced by the occupation of the high j-orbital, the intruding $h_{11/2}$ proton orbital displays a large number of alignment properties. The shape driving force of the aligned pair also depends on the position of the neutron Fermi surface in the $h_{11/2}$ subshell. The alignment of the neutrons originating from the upper $h_{11/2}$ subshell is expected to polarize the gamma soft core towards $\gamma = -60^o$, resulting in a collective oblate nuclear shape. Chirality has been observed in many molecular structures but only recently has this phenomenon been attributed to Nuclear Structure. The occurrence of chirality in nuclear physics was suggested in 1997 by Frauendorf and Meng [4]. The definition is given when two structural forms are seen to have mirror images of one another referred to as left and right handed forms, atomic nuclei having this characteristic of 'handedness' when spinning around an asymmetric axis. It has been seen that chirality exists when the nuclei has axes of three different lengths as shown in figure 1, in other words is triaxial. Spontaneous chiral symmetry breaking can occur in triaxial doubly odd nuclei for configurations where the angular momenta of the valence proton, the valence neutron and the core are mutually perpendicular, and the nuclei that have a triaxial deformation near $\gamma = \pm 30^o$ are most likely to form chiral doublet bands [4, 5]. The experimental evidence for chirality is the observation of pairs of closely spaced energy states with the same amounts of angular momentum that correspond to otherwise identical nuclei. Based on one particle and one hole coupled to a triaxial rotor, a set of experimental signatures have been suggested as fingerprints of nuclear chirality, as shown in Refs. [6-8]. For energy spectra, the chiral bands should contain a pair of nearly degenerate ΔI = 1 bands with the same parity, and their energy staggering parameter $S(I) = [E(I)-E(I-1)]=2I$ should be spin independence. The selection rule for electromagnetic transitions in the chiral geometry has been proposed in Ref [7], which results in the odd-even staggering of intraband B(M1)/B(E2) ratios and of interband B(M1) values, as well as the vanishing of the interband B(E2) transitions at high spin region. Further, in ideal chiral pair bands all corresponding physics properties, such as spin alignments, moment of inertia, and electromagnetic transition probabilities, must be identical or, in practice, very similar [8,9] ,When we consider the yrast bands built on a $h_{11/2} \otimes h_{11/2}$ in odd-odd nuclei of the A = 130 region, the proton Fermi surface lies at the bottom of the πh11/2 subshell and the proton single-particle angular momenta j aligns along the short axis. In addition, the neutron Fermi surface lies at the top of the the $\nu h_{11/2}$ subshell and the neutron single-particle angular momentum j aligns along the long axis. The irrotational

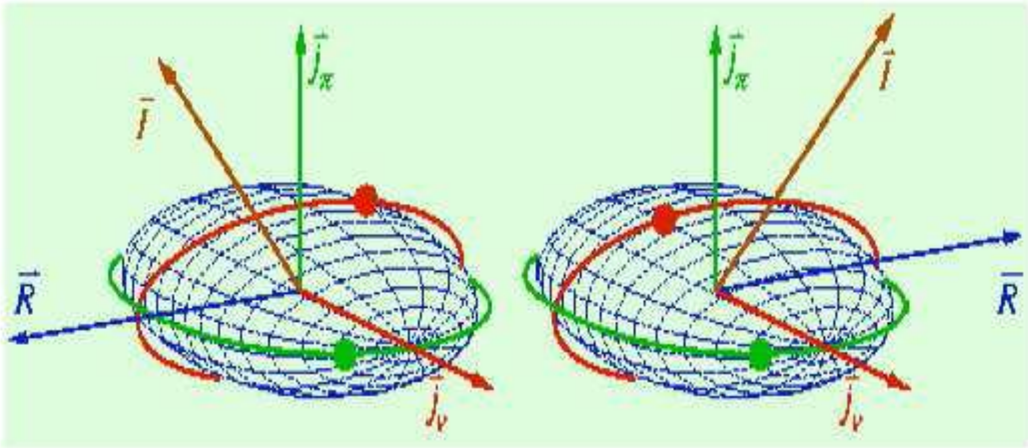

Figure 1: Left and right handed symmetry in atomic nucleus

moment of inertia is largest for $\gamma = 30^0$, and the angular momentum of the rotating core itself aligns along the intermediate axis. So the most likely region for chiral symmetry breaking to exist was predicted to be the A = 130 region. In experimental studies [10–12], the chiral bands have been observed for odd-odd nuclei adjacent to ^{134}Pr, that is in ^{128}Cs, ^{130}La and ^{132}Pr, in ^{130}Cs, ^{132}La, ^{134}Pr, and ^{136}Pm and in ^{132}Cs and has also been proposed for ^{126}Cs [13, 14] nucleus. They form a small chiral rotation island. Therefore, it is important to explore continuously the neighbouring odd-odd nuclei for a complete definition of Z and N boundaries of this island. For the odd-odd Cesium isotopes, candidate chiral doublet bands have been proposed in the ^{126}Cs[13,14], ^{128}Cs[10, 15], ^{130}Cs,[10-11,16-17] and ^{132}Cs[10,18] There the main and side bands were assigned to the simplest chiral configuration, with one proton particle on the $\pi h_{11/2}$ orbital, and one neutron hole on the $\pi h_{11/2}$ orbital, providing a good opportunity to investigate the chiral condition change with the number of the valence neutron in high-j shell.. We have also proposed the chiral doublet bands in ^{122}Cs. In the present work a study of chiral doublet bands in ^{122}Cs nucleus and some new results on ^{122}Cs nucleus have been reported.

2. Experimental Details

High spin states in the ^{122}Cs nucleus were populated using the ^{107}Ag(^{19}F,p3n)^{122}Cs fusion evaporation reaction at beam energy of 93 MeV. The beam was provided by the 14UD Pelletron facility at TIFR, Mumbai India. An isotopically enriched 1mg/cm^2 thick ^{107}Ag target on a 10mg/cm^2 thick Au backing was used. The de-exciting gamma rays were detected using the Indian National Gamma Array consisting of eight Clover detectors in conjunction with a 14-element NaI(Tl) multiplicity filter. The photo peak efficiency for the array was 1.6 %. The detectors were coplanar and placed at 60^0, 90^0, 120^0, 150^0, 210^0, 250^0, 285^0, and 325^0 with respect to the beam direction. A total of about 200 million triple or higher-fold coincidence events were recorded in the experiment. Efficiency and energy calibration were performed with the standard γ-ray ^{152}Eu and ^{133}Ba radioactive sources.

3. Results and Discussion

Figure 2 shows the level scheme of ^{122}Cs from the present work, where the ordering of transitions are based on relative γ-ray intensities and γ –γ coincidence using gates. Some of our work on ^{122}Cs has already been reported in ref [19].

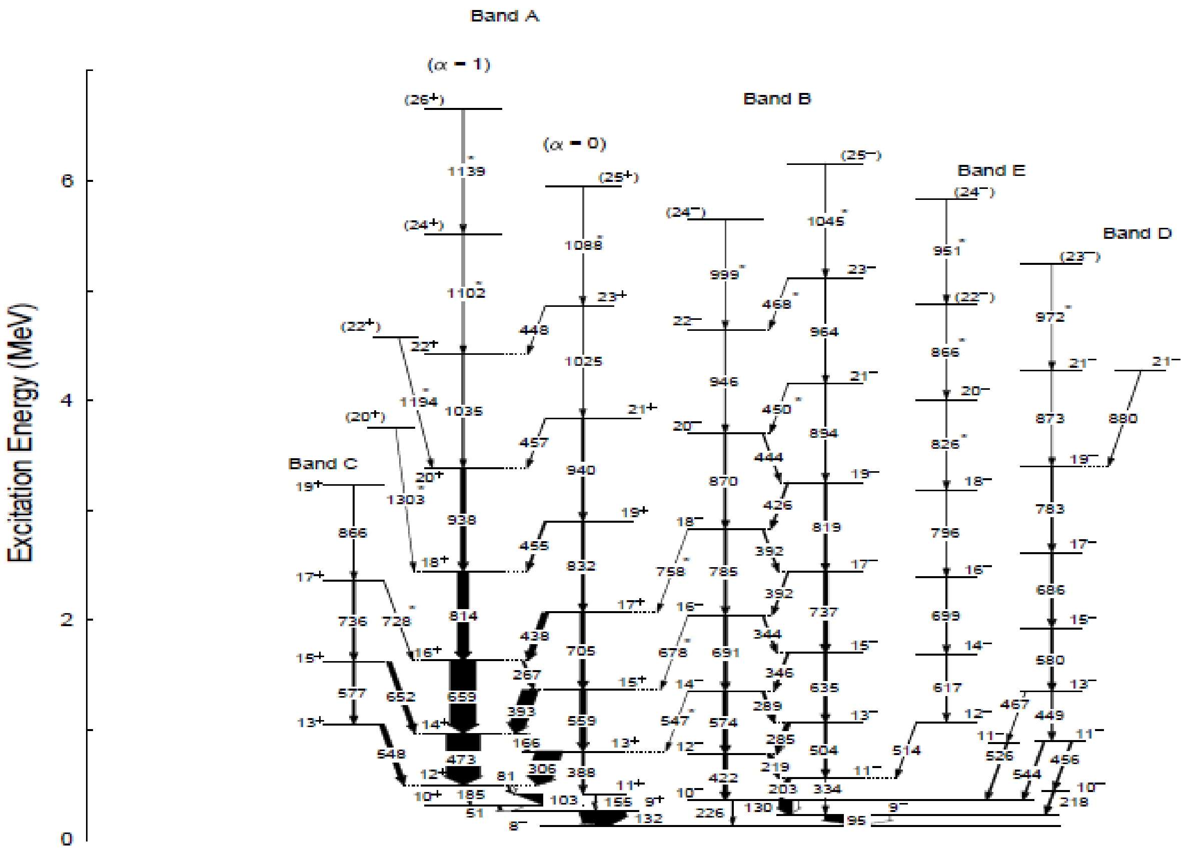

Figure 2: Level scheme for ^{122}Cs populated in ^{107}Ag(^{19}F,p3n)^{122}Cs reaction. Newly observed transitions are marked with an asterisk. The energies are marked within ±1 keV. The spin and parity assignments, given in parentheses, are tentative

The bands in the level scheme are labeled as band A, band B, band C, band D and band E. In the present work we will concentrate on chiral bands. The configuration $\pi h_{11/2} \otimes \nu h_{11/2}$ is confirmed by Rajesh Kumar et al. , [19] for the ground state band A on the basis of the systematic and the our theoretical HF calculations as well as quasi-particle Routhians and alignments for proton and neutron. The linear polarization of the γ-rays can be detected through Compton scattering.

To determine the experimental symmetry the list mode data is analyzed to identify events in which a γ-ray incident on one of the four crystals undergoes Compton scattering parallel or perpendicular to the reaction plane. The linear polarization of the radiation can typically be determined through a difference between the number of Compton scattered γ-rays in the reaction plane Npar, perpendicular to it, Nper. From these spectra, the asymmetry parameter Δ_{IPDCO} was obtained using the relation

$$\Delta_{IPDCO} = [a(E_\gamma)N_{per}] - N_{par} / [a(E_\gamma)N_{per}] + N_{par}$$

Where N_{per} and N_{par} were the intensities of the scattered photon perpendicular and parallel to the direction of the reaction plane respectively. The parameter '**a**' denotes the correction due to the asymmetry in response of the Clover segments. Positive and negative values of Δ_{IPDCO} correspond to stretched electric and magnetic transitions, respectively. A near-zero value is indicative of a possible admixture. As we use the data from detectors at all angles in the reaction plane, we may not perform the quantitative polarization measurements. However, we may get the useful information about the nature of γ-ray of interest. The polarization sensitivity is measured by measuring the asymmetry parameter (Δ_{IPDCO}) and verifying the multipolarity for the well known E2 and M1 transitions. Figure 3 illustrates the results of these measurements. The negative value (-0.1) of the asymmetry parameter for the 514 keV γ-ray, which connects the band E to the band B, indicates the M1 nature for this transition. Since the band B has been established as a negative parity band from previous work, hence, it is deduced that the band E also has the negative parity. Further, since all the in-band members of band E involve a ΔJ = 2 change in angular momentum, these have been assigned as E2 transitions as indicated in figure 3. Similarly the asymmetry parameter Δ_{IPDCO} is negative for the 544 keV and 526 keV transitions linking the bands D and B. This is indicative of M1 nature to the 544 keV (-0.064) and 526 keV (-0.056) transitions. Hence the band D has also been assigned negative parity. The ΔJ = 2 nature and positive value of the asymmetry parameter for the members of this band are suggestive of E2 character. The negative value (-0.05) of Δ_{IPDCO} for the 548 keV linking transition between bands C and A is indicative of M1 nature for this transition.

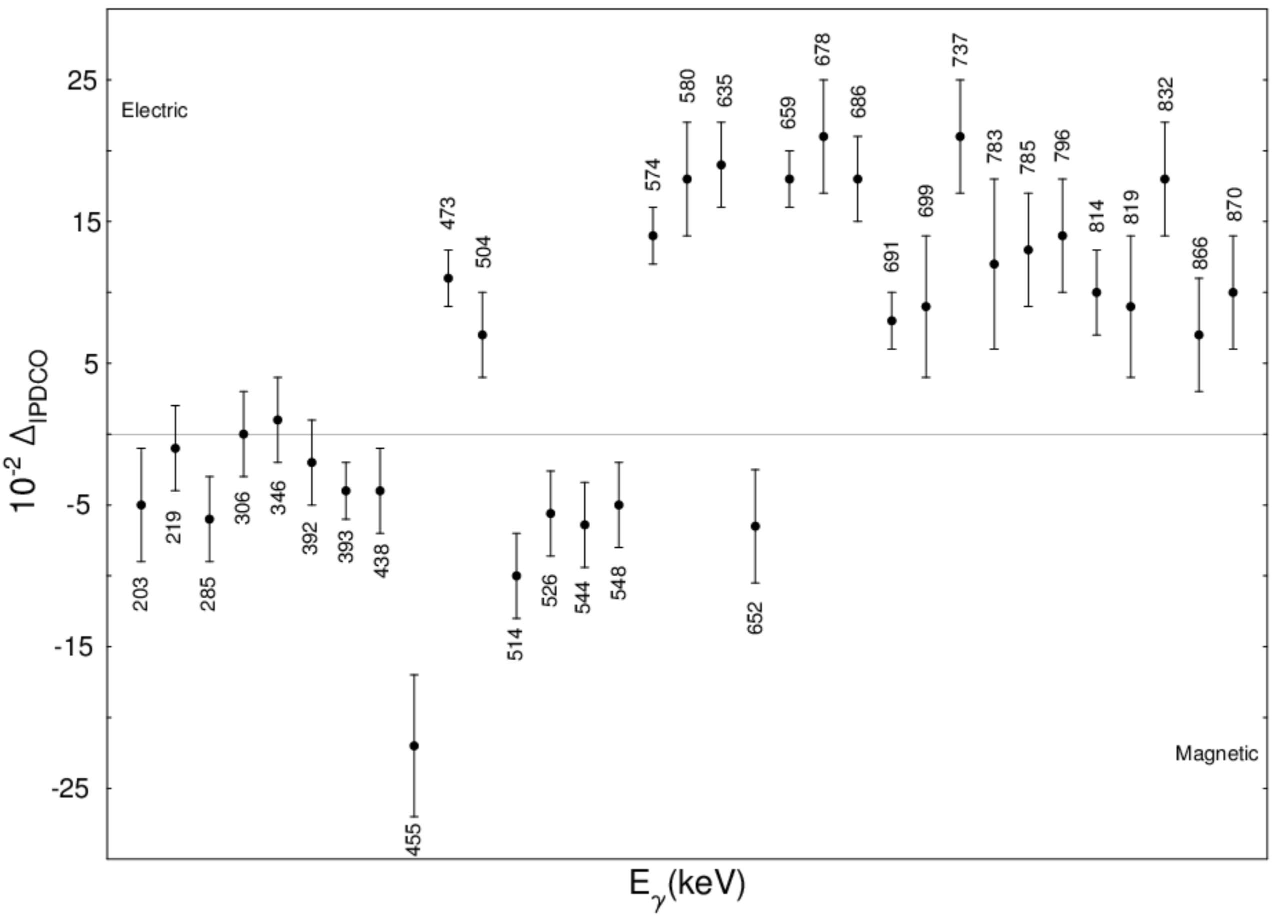

Figure 3: Level Experimental γ-ray asymmetry parameter Δ_{IPDCO} from polarization measurements plotted for γ-ray transitions of ^{122}Cs. A positive value corresponds to an electric transition and a negative value indicates the magnetic transition. The quoted errors are because of background.

Hence the band-head for band C has been assigned as J = 13^{+}. The parities of the bands C, D and E have been assigned for the first time in the present work. A positive sign of the Δ_{IPDCO} characterize the E1/E3 nature of the 678 keV transition linking the negative parity band B with the positive parity Band A. We have assigned the positive parity to band C on the basis of the polarization measurements. The Routhian of band C lies about 350 keV above that of band A and it decays to the even I branch of band A via the intense γ-rays of 548 and 652 keV. The aligned angular momentum of 9.0ħ of this band is similar to the unfavoured partner of band A and may be attributed to $\pi h_{11/2}(\alpha = +1/2)\otimes\nu h_{11/2}(\alpha = -1/2)$ configuration. The observed favoured partner of band C is therefore likely to be a good candidate for the chiral band. The unfavoured partner of band C has not been observed in the present experiment. Yong-Nam et al. [20] have proposed band A as the chiral partner of band C using only ten Ge detectors. Figure 4 shows the schemes of the chiral doublet bands of the $\pi h_{11/2}\otimes\nu h_{11/2}$ configuration in ^{122}Cs observed by Yong et. al., and in ^{126,128}Cs reported in [10-12], and figure 5 shows the variation of systematic experimental energies as a function of spin for the chiral doublet bands in ^{122}Cs as well as those in ^{126,128,130}Cs [9–13]. In order to examine the chiral doublet bands character, they measured the $B(M1; I \rightarrow I-1)/B(E2; I \rightarrow I-2)$ ratios in the yrast band (1) in ^{122}Cs.

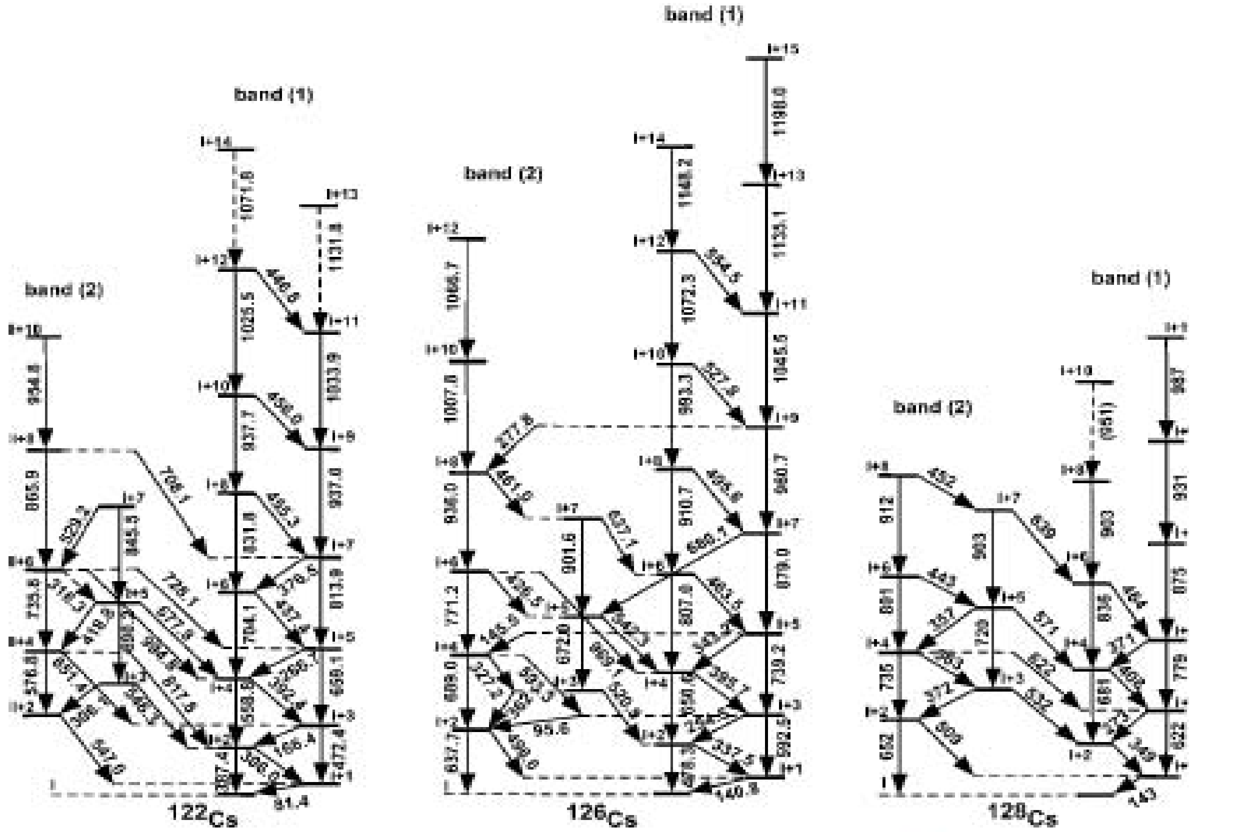

Figure 4: Comparison of the level scheme of the $\pi h_{11/2} \otimes \nu h_{11/2}$ bands in ^{122}Cs in the Yong et al., and with those in ^{126,128}Cs

A very brief discussion on theoretical results has been reported by Yong-Nam et al. They have used the relativistic mean field (RMF) to calculate the triaxial deformation parameters (β and γ values). Then, using these calculated parameters, the excitation energies of the chiral doublet bands were calculated using the triaxial particle rotor-model [21]. They calculated deformation parameters for the $\pi h_{11/2} \otimes \nu h_{11/2}$ configuration in ^{122}Cs are: $\beta = 0.22$ and $\gamma = 28^{\circ}$. They reported that these result indicates that the stable triaxial deformation occurs in ^{122}Cs and indeed the chiral doublet bands can appear in this nucleus. The calculated curve of the excitation energy changed as spins for the yrast band and the side band in ^{122}Cs is also shown and found good agreement with the experimental values. On the bases of newly observed gamma- ray transition viz. 691 keV and 845.5 keV and with few linking transitions (546, 306 ad 678) the Yong-Nam et al. conclude that these transitions form the unfavoured signature partner of band C. But it seems in our result that that band B is also feeding the band A with some of these transitions. Also they were not sure about the spin and parity of the bands. Bands A and C warrant further detailed experimental and theoretical studies to corroborate their chiral nature. The parity has been confirmed by us unambiguously from the polarization measurements.

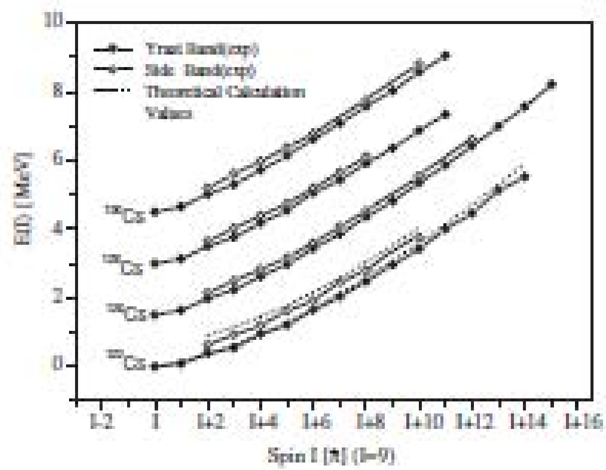

Figure 5: Experimental energies for the $\pi h_{11/2} \otimes \nu h_{11/2}$ yrast bands (filled symbols) and side bands (open symbols) in ^{122}Cs. Bandhead energies are separated by 1.5 MeV for display. Theoretical calculation energies for yrast band and side band in ^{122}Cs are shown by dashed lines.

4. Conclusion

The significant progresses of the chirality in Cs nucleus is reviewed and some results on ^{122}Cs nucleus which has been studied with eight Clover detectors array using ^{107}Ag (^{19}F, p3n)^{122}Cs fusion evaporation reaction are reported. The observed two $\pi h11/2 \otimes \nu h11/2$ bands are proposed to be a pair of chiral doublet bands based on the systematic comparison with those in the neighbouring odd–odd Cs isotopes. The Chiral doublet bands have been discussed in terms excitation energies, B(E2) and B(M1). We have performed the linear polarization measurements using the

Clover detectors to assign the unknown spins and parities of a few bands. No lifetime measurements results are available for ^{122}Cs nucleus. The existence of chiral bands in ^{122}Cs is questionable. Therefore the identification of chiral doublet bands ^{122}Cs is still an open question, which needs more efforts from both experimental and theoretical side.

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