STUDY OF CHIRALITY IN ODD–ODD CS ISOTOPES; SEARCH FOR CRITICAL FREQUENCY*

T. Marchlewski, J. Srebrny

Heavy Ion Laboratory, University of Warsaw, 02-093 Warszawa, Poland

E. Grodner

National Center for Nuclear Research, 05-400 Świerk, Poland

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The study focuses on spontaneous chiral symmetry breaking in odd–odd nuclei in $A \sim 130$ mass region. The work presents a comparison of experimentally obtained values of $S(I)$, $B(\mathrm{M1})$, $B(\mathrm{E2})$, $B(\mathrm{M1})/B(\mathrm{E2})$ for ^{132}La and ^{124,126,128,130}Cs. This comparison is used to estimate a spin in Cs isotopes at which critical frequency occurs.

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1. Introduction

The spontaneous chiral symmetry breaking was introduced to nuclear physics 20 years ago by Frauendorf and Meng [1]. Since then the nuclear chirality has been experimentally studied by many groups around the world. This work will focus on odd–odd Cs isotopes within 120–130 mass range. The ^{132}La isotope is shown as an example of non-chiral odd–odd nuclei with $A \sim 130$. In the chiral nuclei, we expect to observe two almost degenerated partner bands. Those bands should have similar electromagnetic properties. The presence of the chiral bands in the ^{124,126,128,130}Cs nuclei was deduced mainly from the results of the lifetime measurements performed using the Doppler Shift Attenuation method. Analogical results for ^{132}La led to conclusion that this nuclei is not chiral. The above-mentioned La and Cs isotopes are supposed to have the same configuration of odd proton (particle-like) and odd neutron (hole-like) — $\pi h_{11/2} \otimes \nu h^{-1}_{11/2}$. This configuration along with triaxiality with $\gamma \approx 30°$ is responsible for the presence of

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chiral bands. The s-symmetry introduced by Próchniak *et al.* in Ref. [7] and by Rohoziński *et al.* in Ref. [8] as well as critical frequency (ω_{c}) discussed for the first time by Olbratowski *et al.* in Ref. [9] explain properties of chiral partner bands. In low spins region for chiral nuclei with the $\pi h_{11/2} \otimes \nu h_{11/2}^{-1}$ configuration, one should observe strong $S(I)$ staggering below critical frequency and staggering of $B(\mathrm{M1})$ above it. The $S(I)$ quantity is defined as

$$S(I) = (E(I) - E(I-1))/2I\,. \tag{1}$$

The obtained lifetimes are used to determine $B(\mathrm{M1}; I \to I-1)$ and $B(\mathrm{E2}; I \to I-2)$ values that should be, according to the main fingerprint of chirality, similar in both partner bands. Without information about level lifetimes, one is able to use branching ratios and transition energies to determine $B(\mathrm{M1}; I \to I-1)/B(\mathrm{E2}; I \to I-2)$ values that should also be similar in both bands for the states with the same spin. A staggering pattern visible in $B(\mathrm{M1})$ should occur in $B(\mathrm{M1})/B(\mathrm{E2})$ ratio as well.

This work attempts to estimate spin at which the transition between chiral and non-chiral configuration occurs for ^{124,126,128,130}Cs isotopes by comparing experimentally determined $B(\mathrm{M1})$, $B(\mathrm{E2})$, $S(I)$, $B(\mathrm{M1})/B(\mathrm{E2})$ values. Additionally, this comparison will be a basis for discussion on whether $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ yield a reliable and sufficient amount of information to distinguish between chiral and non-chiral nuclei.

2. Experimental data sources

The values of $S(I)$ (in keV/$\hbar$ units, see Eq. (1)), $B(\mathrm{M1})/B(\mathrm{E2})$ (in $\mu_N^2/(e^2\mathrm{b}^2)$ units), $B(\mathrm{M1})$ (in W.u.) and $B(\mathrm{E2})$ (in W.u.) for La and Cs isotopes were taken from various publications. More details one can find in figure captions.

3. Discussion and conclusions

Figures 1–4 for the ^{124,126,128,130}Cs nuclei show a similarity between $B(\mathrm{M1})$ and $B(\mathrm{M1})/B(\mathrm{E2})$ plotted as a function of spin. In both cases, staggering pattern is present. It may lead to the conclusion that $B(\mathrm{M1})/B(\mathrm{E2})$ is a good indicator and can be used in further studies of chirality. Moreover, the $B(\mathrm{M1})/B(\mathrm{E2})$ ratio can be easily obtained from experiments. The example of this could be ^{120,122}Cs, where only $B(\mathrm{M1})/B(\mathrm{E2})$ ratio was measured (see Figs. 5, 6). However, one should remember that the $B(\mathrm{M1})/B(\mathrm{E2})$ values lack information that the $B(\mathrm{M1})$ and $B(\mathrm{E2})$ values can yield when determined separately. The $B(\mathrm{M1})/B(\mathrm{E2})$ ratio can be similar in both bands, meanwhile the $B(\mathrm{M1})$ and $B(\mathrm{E2})$ values in both bands are significantly different. Such a situation is observed in the case of ^{132}La (Fig. 7). Therefore,

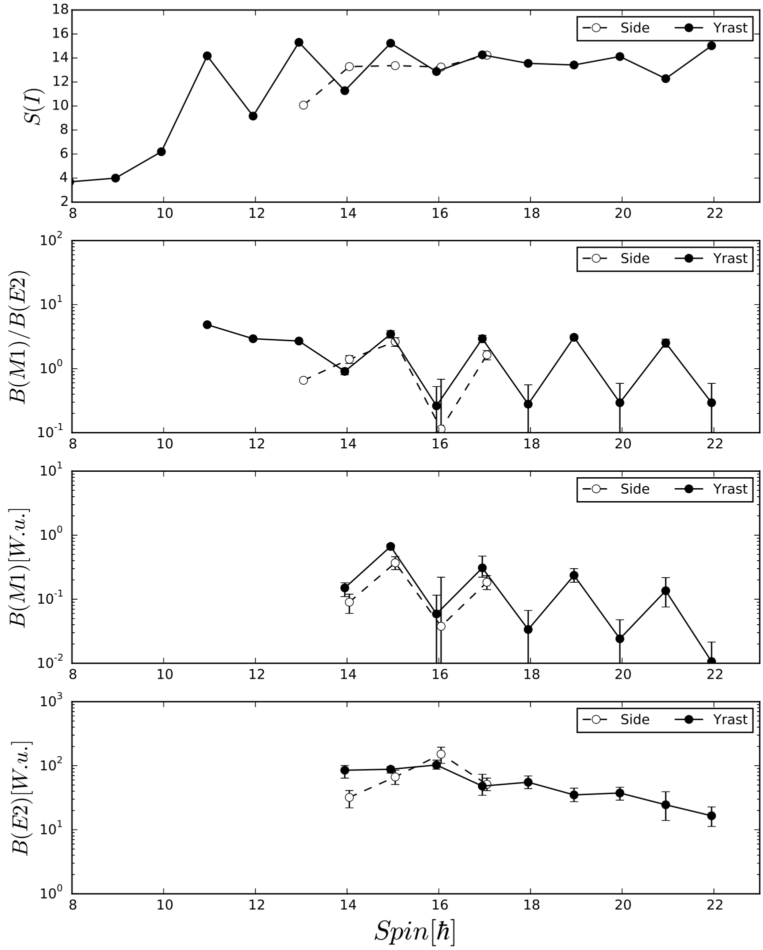

Fig. 1. Values of $S(I)$, $B(\mathrm{M1})/B(\mathrm{E2})$, $B(\mathrm{M1})$ and $B(\mathrm{E2})$ for ^{124}Cs. The $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ values were calculated with data taken from Ref. [12], $B(\mathrm{M1})$ and $B(\mathrm{E2})$ were taken from Ref. [2, 13].

one can see that conclusions based only on the $B(\mathrm{M1})/B(\mathrm{E2})$ ratios can be misleading. It is worth adding that the $B(\mathrm{M1})$ and $B(\mathrm{E2})$ values can be directly compared with theoretical calculations.

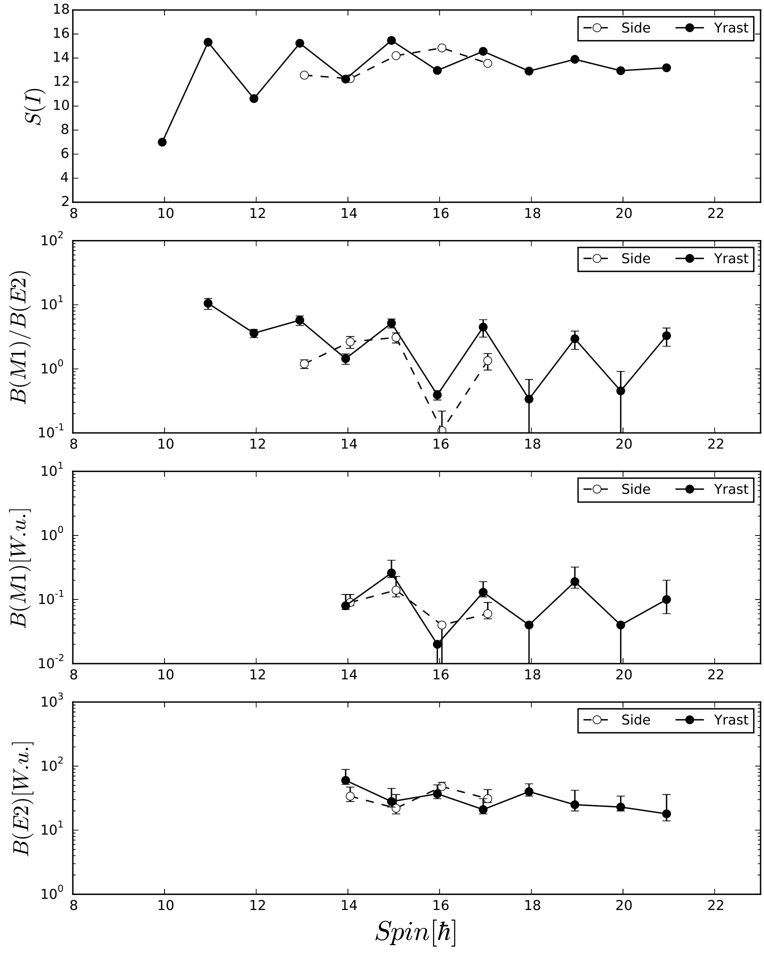

Fig. 2. Values of $S(I)$, $B(\mathrm{M1})/B(\mathrm{E2})$, $B(\mathrm{M1})$ and $B(\mathrm{E2})$ for ^{126}Cs. The $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ values were calculated with data taken from Ref. [14], $B(\mathrm{M1})$ and $B(\mathrm{E2})$ were taken from Ref. [3].

As mentioned above, we expect $S(I)$ staggering to be visible below ω_{c} and not present or suppressed above it. In turn, $B(\mathrm{M1})$ should exhibit an opposite property — staggering above ω_{c}. These properties could be used to estimate the spin corresponding to transition between chiral and non-chiral configuration.

The experimental data concerning ^{120}Cs and ^{122}Cs are very scarce. In such circumstances, $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ might be used as a preliminary test for chirality. These both nuclei seem to reveal staggering patterns predicted for spontaneous breaking of chiral symmetry.

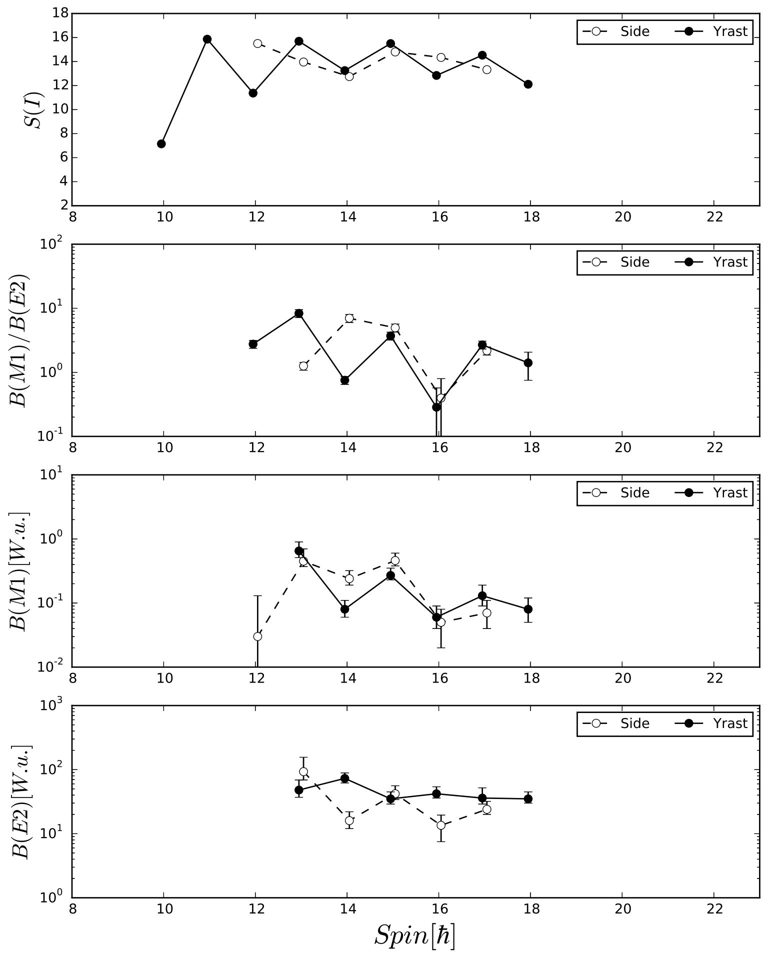

Fig. 3. Values of $S(I)$, $B(\mathrm{M1})/B(\mathrm{E2})$, $B(\mathrm{M1})$ and $B(\mathrm{E2})$ for ^{128}Cs. The $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ values were calculated with data taken from Ref. [15], $B(\mathrm{M1})$ and $B(\mathrm{E2})$ were taken from Ref. [4].

The experimental data shown in Fgs. 1 and 2, the $B(\mathrm{M1})/B(\mathrm{E2})$ and $S(I)$ values for the ^{124,126}Cs nuclei, suggest that transition between chiral and non-chiral configuration occurs. The case of ^{130}Cs might be the first experimental observation of such a transition concluded from the $B(\mathrm{M1})$ values which, as mentioned above, are reliable observables. Upon looking at presented figures, one can assume that the transition occurs around spin $14\,\hbar$–$16\,\hbar$. The precise value for each nuclei might be different. The question whether transition between chiral and non-chiral configuration as a function of spin is smooth or rapid remains open.

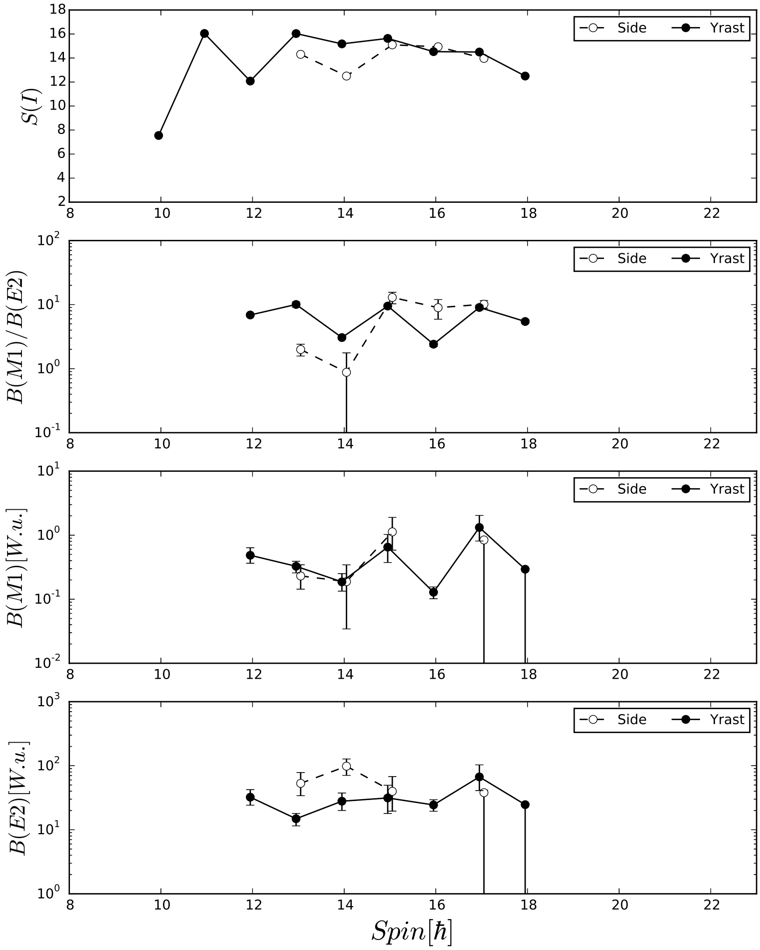

Fig. 4. Values of $S(I)$, B(M1)/B(E2), B(M1) and B(E2) for ^{130}Cs. The $S(I)$ and B(M1)/B(E2) values were calculated with data taken from Ref. [16], B(M1) and B(E2) were calculated using lifetimes from Ref. [5] as well as branching ratios taken from Ref. [16].

Further study of transition between chiral and non-chiral configuration requires more experimental results on lifetime of low spin states in chiral partner bands. It can be performed using the Doppler Shift Attenuation and Recoil Distance methods. It is worth adding that recent measurements of magnetic dipole moments open new opportunities to study this phenomenon [18].

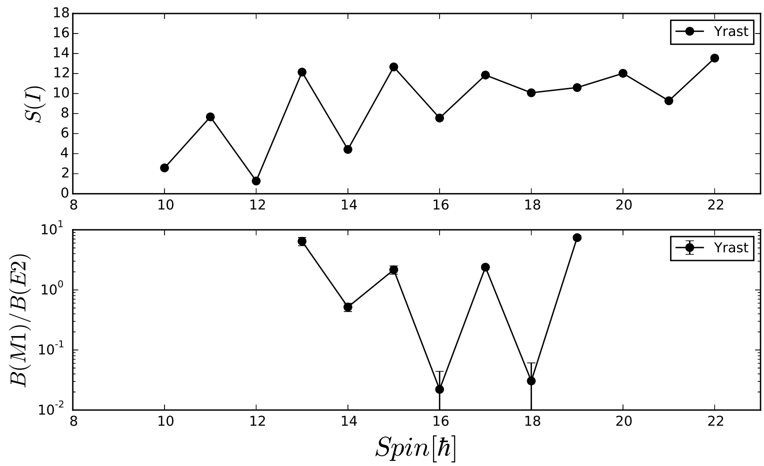

Fig. 5. $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ for ^{120}Cs. For ^{120}Cs, $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ values were calculated with data taken from Ref. [10]. Due to the lack of gamma-ray intensity (I_γ) values for M1 transitions, which can be suppressed by s-symmetry selection rules, this work assumes that those transitions have lower I_γ values than the weakest transition listed in Ref. [10].

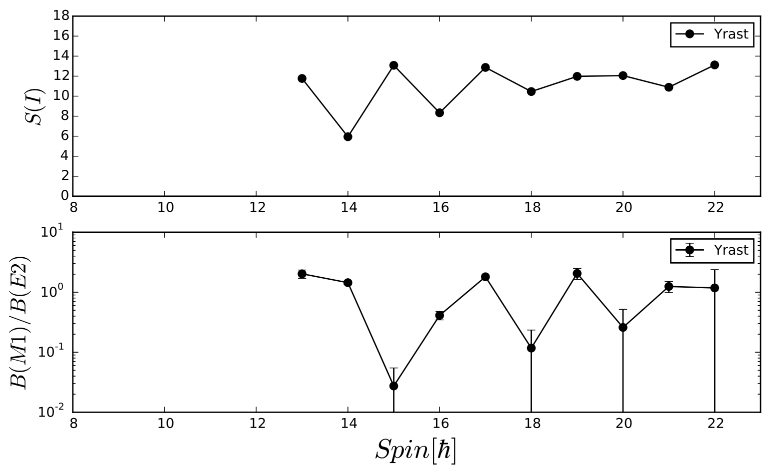

Fig. 6. $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ for ^{122}Cs. For ^{122}Cs, $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ values were calculated with data taken from Ref. [11]. Missing I_γ values were adopted in the same way as in the case of ^{120}Cs (see Fig. 5).

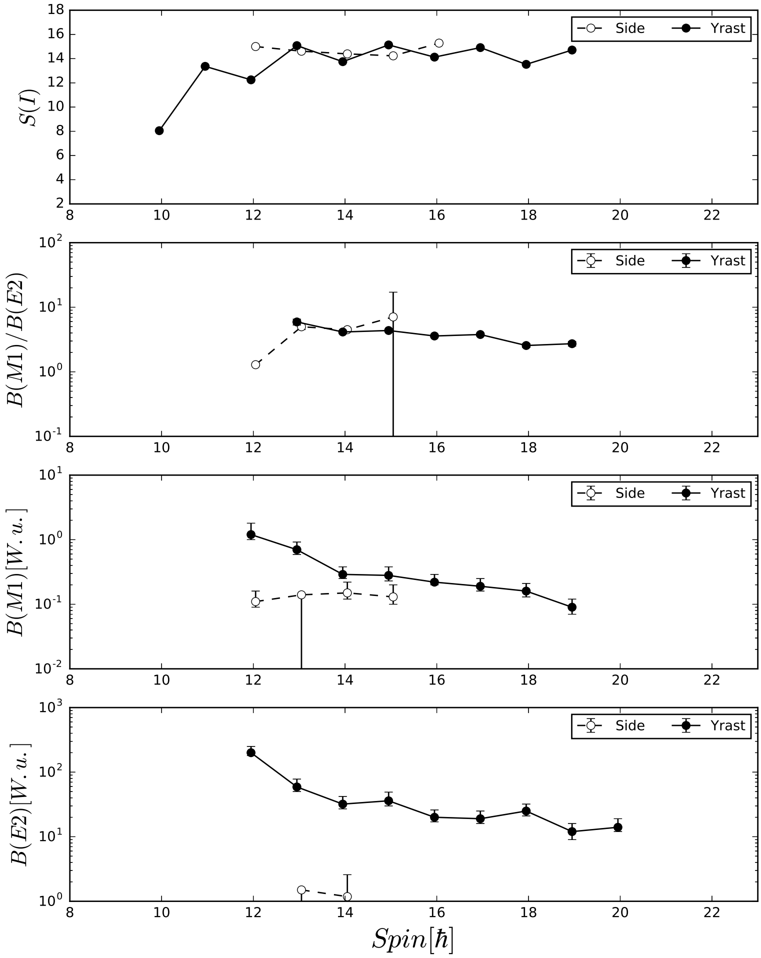

Fig. 7. Values of $S(I)$, $B(\mathrm{M1})/B(\mathrm{E2})$, $B(\mathrm{M1})$ and $B(\mathrm{E2})$ for ^{132}La. The $S(I)$ and $B(\mathrm{M1})/B(\mathrm{E2})$ values were calculated with data taken from Ref. [17], $B(\mathrm{M1})$ and $B(\mathrm{E2})$ were taken from Ref. [6]. One should pay attention to the difference between $B(\mathrm{E2})$ values in yrast and side band.

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