Lifetime measurement of excited states in ^{134}Sm

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Abstract

Experimental fingerprints of the X(5) critical-point symmetry are: i) $E(4^+)/E(2^+) \sim 2.91$ ii) $B(E2; 4+ \rightarrow 2+)/B(E2; 2+ \rightarrow 0+) \sim 1.58$, iii) P-factor ~ 5. The first nucleus to be identified as exhibiting X(5) behaviour was ^{152}Sm [6] followed by ^{150}Nd. Further experiments on ^{152}Sm and ^{150}Nd support this conclusion. On the other hand, the data for the neutron deficient side of these nuclei reveal discrepancies due to different lifetime values in the literature. One of the possible candidates for X(5) is ^{134}Sm (N=72) with its $E(4^+)/E(2^+) = 2.93$ and P-factor ≅5. The lifetime values have been measured using single spectra and disagree with the X(5) excitation pattern of this nucleus. In the present proposal, we are aiming to remeasure lifetime of excited states in ^{134}Sm using 2n correlated gamma-gamma coincidence by employing the state of arts equipment such as EAGLE and NEDA in conjunction with state of arts techniques such recoil distance Doppler shift technique and differential decay curve method. To populate excited states in ^{134}Sm, we are planning to fire ^{32}S on ^{106}Cd at 155 MeV. The estimated reaction cross-section by HIVAP is 20 mb ^{134}Sm will be populated with 2p2n exit channel.

Scientific Motivation

Three different paradigms are generally employed to describe the deformation of the nucleus and listed as vibrator, symmetric rotor, and γ-soft or axially asymmetric rotor. Those paradigms correspond in the interacting boson approximation (IBA) to dynamical symmetries, namely U(5) for the vibrator, SU(3) for the symmetric rotor and O(6) for the γ-soft deformation. At the beginning of the 2000's, Iachello published two papers that were bringing two new solutions to the Hamiltonian in the collective model, which resulted in two critical-point symmetry of X(5) [1] and E(5) [2]. These two new critical-point symmetries are related to a first-order phase transition from U(5) ↔ SU(3) and a second-order phase transition from U(5) ↔ O(6), respectively. In the first-order transition, the quadrupole deformation varies discontinuously and there is a coexistence of spherical and deformed phases. Experimental fingerprints of the X(5) critical-point symmetry are: i) $E(4^+)/E(2^+) \sim 2.91$ ii) $B(E2; 4+ \rightarrow 2+)/B(E2; 2+ \rightarrow 0+) \sim 1.58$, iii) P-factor ~ 5. The first nucleus to be identified as exhibiting X(5) behaviour was ^{152}Sm [3] followed by ^{150}Nd [4]. Further experiments on ^{152}Sm[5-7] and ^{150}Nd[7, 8] support this conclusion. After the first examples of X(5)[7, 8] and E(5)[8,10] dynamical symmetries were identified, research efforts have focused towards the search for additional examples in different mass regions, both near and far from stability, in order to better understand the essential conditions for critical-point behaviour.

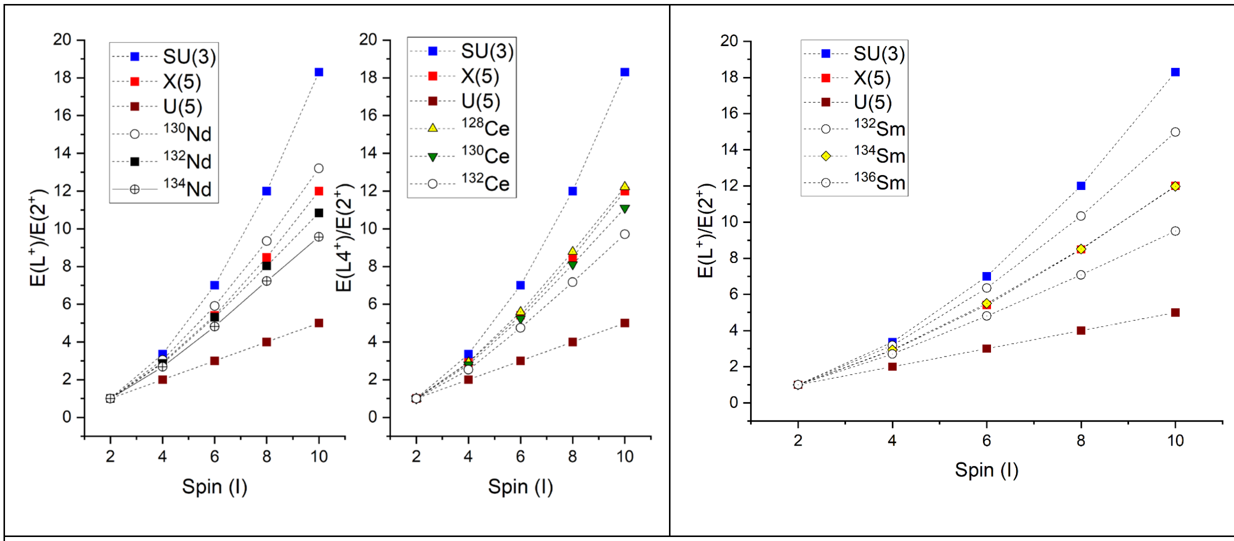

Figure 1: Excitation energy ratios $R_i = E_i/E2+$, i = 4^+, 6^+, 8^+, 10^+ in Nd, Ce and Sm nuclei and the corresponding X(5) predictions.

In the present proposal we would like to focus on 130 mass region. Figure 1 shows excitation energies of excited states in Sm, Nd and Ce nuclei as a function of spin-quantum number and also compares the evolution of excitation energies with SU(3), X(5) and U(5) limits. In this figure we can see four possible nuclei exhibiting X(5) symmetry, namely ^{128}Ce, and three isotones ^{130}Ce, ^{132}Nd and ^{134}Sm.

On the basis of the energies of the levels in the gs band (R4/2 = 2.93) and its transitional P factor[11] ($P \approx 4.8$), the ^{128}Ce (N=) isotope was suggested as a candidate for the X(5) symmetry. However, lifetime of excited states in the gs band of ^{128}Ce (N=70) were measured by Wells et al.[12] with the RDDS method, and by Li et al.[13] with the DSAM method and the deduced B(E2) values for the $I^\pi = 6^+$ state [15] and the $I^\pi = 10^+$ state [12, 13], although with large uncertainties, deviated from the X(5) limit. In order to remove this discrepancy due to B(E2) values, Balabanksi et al.[18] have conducted an experiment and the derived B(E2) transition strengths from their data were found to follow the X(5) limit (See Figure 2).

The second possible candidate for X(5) symmetry in the region plotted in Figure 1 is ^{130}Ce (N=72). Based on its P factor of 4.4, which is not too far from the P ~ 5 prediction for X(5) candidates, and its $R_{4/2} \equiv E(4+)/E(2+)$ ratio of 2.80, which is close to the value of 2.91 predicted by X(5). Figure 3 show the predictions of the X(5) and X(5)-β^4 models for the ^{130}Ce isotope [14]. The low-lying states of ^{130}Ce are compared with the predictions of the X(5) critical-point model and the X(5)-β^4 model, and the latter is found to give better agreement with the data in terms of energies. On the other hand, discrepancies in the relative B(E2) values in ^{130}Ce again make it difficult to give a final decision on this nucleus (see Figure 3). Several lifetime measurements are available in the literature for ^{130}Ce. Lifetime of the first excited states had been measured by Todd et al [15] and Husar et al [16]. They provided the values 180(15) and 209(15) ps respectively. Dewald et al. [17] measured the lifetime of excited states in ^{130}Ce from 4^+ to 16^+ using RDDS. The X(5) symmetry of ^{130}Ce depends how the normalization of reduced transition probabilities is done. Figure 4 shows evolution of $B(EL^+)/B(E2^+)$ values as a function spin number. If we use the tau value provided by Todd et al then we obtain a X(5) symmetry in ^{130}Ce, on the other hand if we take into account the value provided by Husar et al then we diverge from this symmetry.

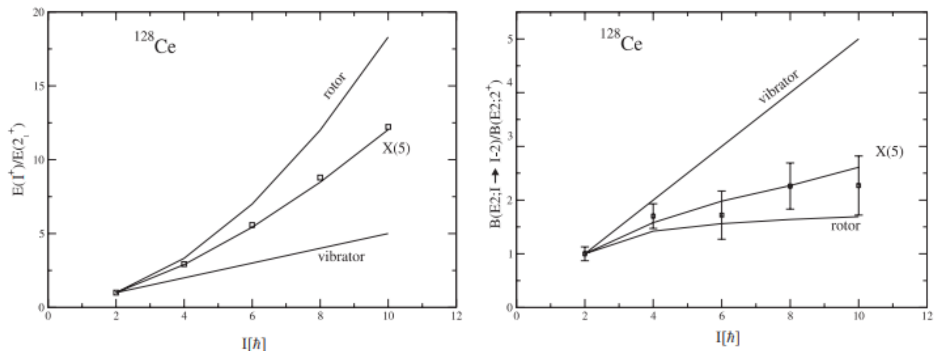

Figure 2: Left: Excitation energy ratios $R_i = E_i/E2+$, i = 4^+, 6^+, 8^+, 10^+ in ^{128}Ce and the corresponding X(5) predictions. Right: Relative B(E2) values measured in the gs band in ^{128}Ce compared to the corresponding X(5) prediction [18].

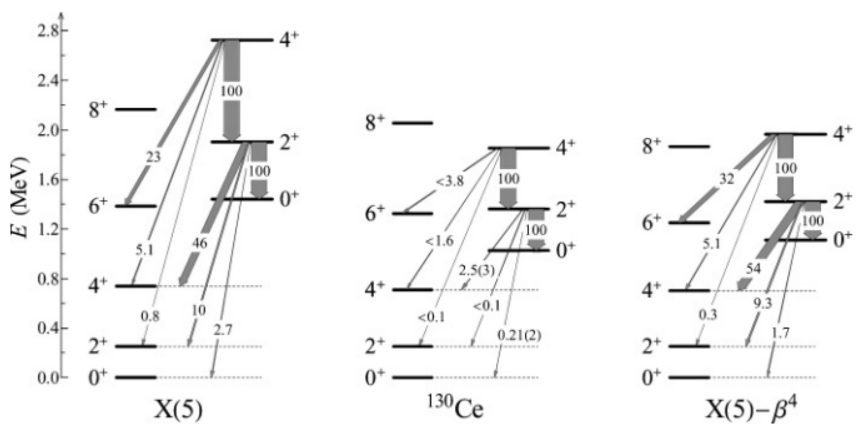

Figure 3: Experimental level energies and relative B(E2) strengths for ^{130}Ce compared with the predictions for the X(5) and X(5)-β^4 models[14].

The third possible candidate for X(5) symmetry in the region plotted in Figure 1 is ^{132}Nd (N=72) due to its $E(4^+)/E(2^+)$ = 2.86 and P-factor =5. However, we are not able to decide based on the lifetime measurements. Similar problem occurs also for ^{132}Nd. In the literature, there are four different measurements for ^{132}Nd (See Table 1). Wadsworth et al[19] had measured the first 4 excite states. Krücken et al[20] had provided the data for 4^+, 6^+ and 8^+. Makishima et al. [21] measured the first two states and Moscrop et al. [22] provided the tau for the first excited states. Although excitation energies as a function of the spin number indicate an X(5) symmetry (see Figure 1), different combinations of these measurements tell us different stories (see Table 1, Figure 5 and 6). First lifetime measurement had been done by Wadsworth et al.[19] up to 8+. They employed recoil distance Doppler shift technique, but due to the lack of Differential Decay Curve Method at that time, they were not able to eliminate the effects of side feeding and unobserved transition (see left panel of Figure 5). The extracted B(E2) values from this measurement indicate a decreasing deformation as a function of spin-quantum number. Krücken et al. [20] performed a measurement employing RDDS using DDCM and provided the B(E2) values for 4^+, 6^+ and 8^+. If we take those values and normalize them with the tau values of 2+ found in the literature from different authors, we obtained Figure 5 and Figure 6.

	States	Makishima[3]	Moscrop[4]	Wadsworthf[5]		Krücken[6]
^{132}Nd	2+	192(11)	268(19)	350(30)		Not avaliable
	4+	11(2)	<40	17.5(7)	20.5(7)	11.0(4)
	$B(E2)_{4+/2+}$	0.88(17)	Not avaliable	1.01(10)	0.86(8)	-
	$B(E2)_{4+/2+}$	K/Ma=0.88(6)	K/Mo=1.23(10)	K/W= 1.60(15)		

Table 1: Lifetime measurements of 2^+ and 4^+ excited states of ^{132Nd} and $B(E2)_{4+/2+}$ ratios based on those lifetimes from different authors [19-22].

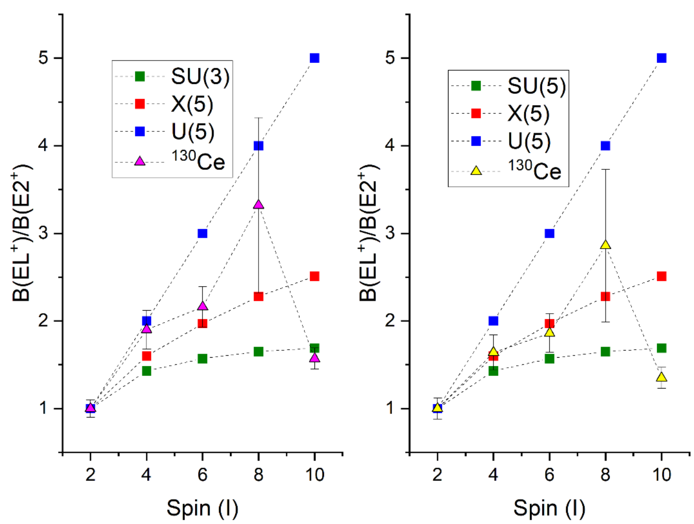

Figure 4: Comparison of B(E2) values of excited states in ^{130}Ce. Lifetime values of 4^+ to 10^+ were obtained from Dewald et al. Unfortunately, they did not provide tau for 2+. The left panel shows the values normalized to tau of 2+ is equal to 209(15) ps. The right side of the panel shows the values normalized to tau of 2^+ is equal to 180(15) ps [15-17].

Normalization of the data given by Krücken et al. [20] using 2^+ data from Wadsworth et al. [19] Nd isotope follows the X(5) pattern up to 6^+. But we do not observe a similar trend if we normalize the data using Moscrop et al. [22] and Makishima et al. [21] in Figure 6. Different combination make it complicated to decide whether ^{132}Nd reveal a first order quantum phase transitions due to lack of a solid lifetime measurement from 2^+ to 10^+ using state of art techniques.

The last possible candidate for X(5) symmetry in the region plotted in Figure 1 is ^{134}Sm (N=72) (see also Figure 7) due to its $E(4^+)/E(2^+) = 2.93$ and P-factor ≅5. Excitation energies of ^{134}Sm in the left panel Figure 7 perfectly follow the X(5) prediction. On the other hand, available existence B(E2) values disagree with trend[19]. The derived values come from Wadsworth et al. [19] that indicates that deformation of excited states stay almost constant as a function of spin-quantum states. The review of literature showed us that a similar issue arisen in ^{132}Nd has been resolved by Krücken et al. [20] in a later measurement.

In conclusion, the ^{128}Ce (N=70), ^{130}Ce (N=72), ^{132}Nd (N=72) and ^{134}Sm (N=72) nuclide display X(5) symmetry in their excitation pattern, however it is hard to decide due to different lifetime measurements of the related levels. One of this discrepancy has been resolved in ^{128}Ce. But still keep its position in the isotones ^{130}Ce, ^{132}Nd and ^{134}Sm.

In the present proposal we would like to focus on ^{134}Sm and to investigate evolution of B(E2) values as a function of spin-quantum number for the nucleus of interest using recoil distance Doppler shift method with differential decay curve method. Therefore we are aiming to provide a solid information on the lifetime values of excited states from 2^+ to 10^+ in order to examine whether the ^{134}Sm isotope reveal a X(5) symmetry or not. We believe the possible results of this experiment will help to get insight for the underlying mechanism which shaping the nuclei in this region.

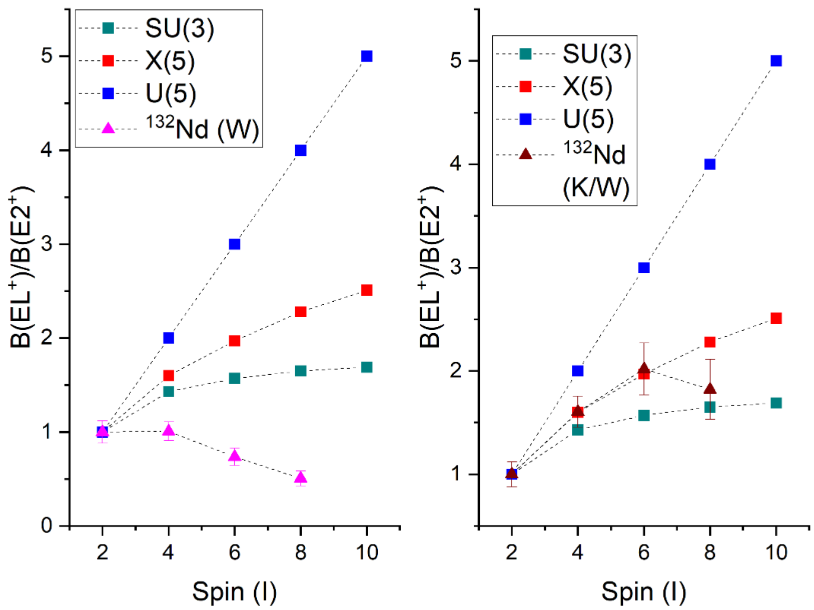

Figure 5: Comparison of B(E2) values of excited states in ^{132}Nd. The data represent the measurements by Wadsworth et al.[19] in the left panel of the figure. Right panel shows the normalization of the data from Krücken et al by Wadsworth et al[19-20].

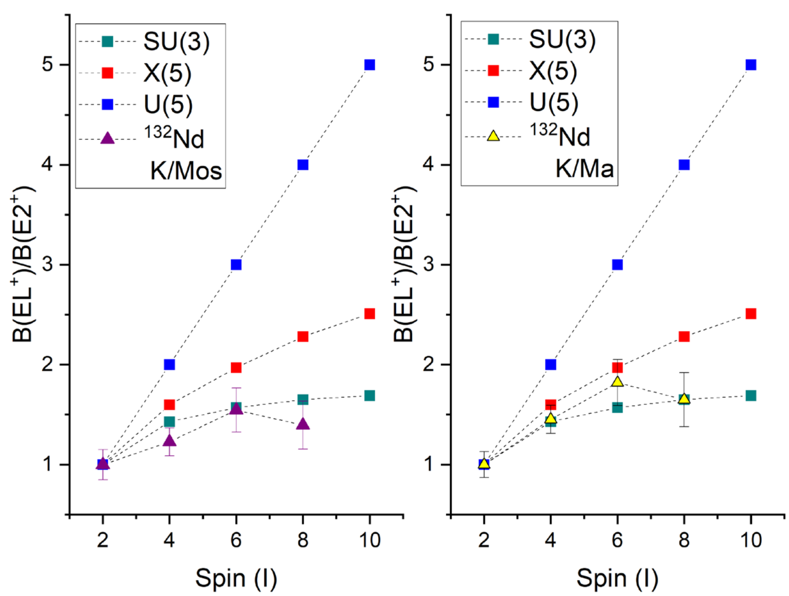

Figure 6: Comparison of B(E2) values of excited states in ^{132}Nd. Left panel shows the normalization of the data from Krücken et al by Moscrop et al. Right panel shows the normalization of the data from Krücken et al by Makishima et al[20-22].

Experimental Details

In the present proposal, we aim to measure the lifetime of excited states in ^{134}Sm using state-of-the-art techniques (RDDS + DDCM) and devices (NEDA + Plunger) in conjunction with EAGLE Ge array. To populate excited states in ^{134}Sm, we are planning to fire ^{32}S on ^{106}Cd at 155 MeV. The estimated reaction cross-section by HIVAP is 20 mb ^{134}Sm will be populated with 2p2n exit channel as the second highly populated recoil. According to 3 pnA beam current and 1 mg/cm^2 target material with a cross section of 20 mb, we assume 2044 ^{134}Sm produced per second and 40 ^{134}Sm will be detected according to 2% efficiency of NEDA for 2n detection. We are expecting 0.02 gamma event from ^{134}Sm per second in coincidence mode which lead us to 1776 counts per 24 hours for the nucleus of interest. A recoil velocity difference typical separations of the fully Doppler-shifted and stopped components would be 3 keV for γ-ray energies around 163 keV ($2^+ \rightarrow 0^+$) and 12 keV around 642 keV ($10^+ \rightarrow 8^+$) at 143◦.

In conclusion, we are planning to measure lifetime of excited states up to 10^+ in the yrast band of ^{134}Sm. To achieve our goals, we are requesting 14 days of beam time (including 1 day for beam, target, and plunger arrangements). We are planning to run each target-to-stopper distance per 24 hours. In total, we propose to measure 13 different foil separations between 5 µm and 4000 µm which correspond to a sensitivity to (effective) lifetimes between 1,5 ps (10 µm) and 600 ps (4000 µm).

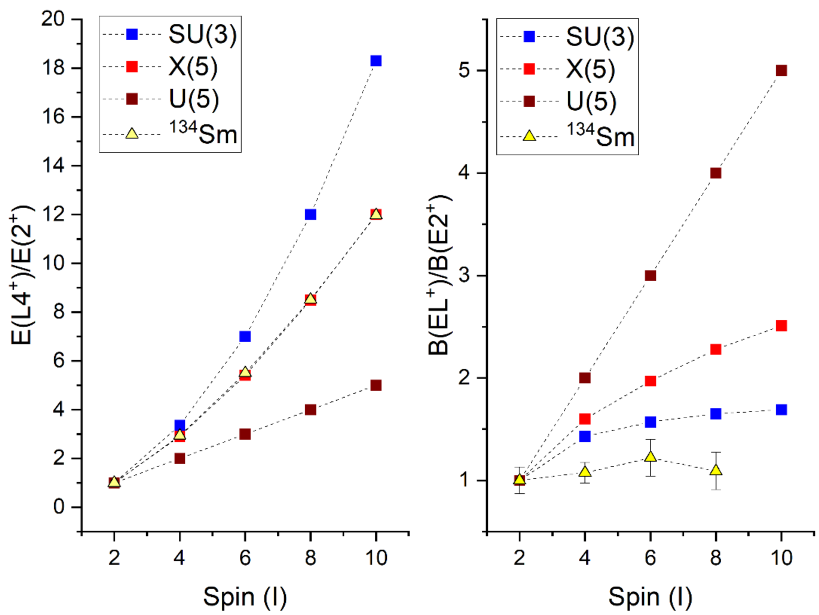

Figure 7: Comparison of B(E2) values of excited states in ^{134}Sm[19].

Requested beam time (in 8-hour shifts): [42] shifts [3 for beam, target, and plunger and 39 for measurements]
Experimental setup: [EAGLE + NEDA + Plunger]

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