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EVIDENCE FOR X(5) CRITICAL POINT SYMMETRY IN ^{128}Ce

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Lifetimes of excited states in ^{128}Ce were measured using the recoil distance Doppler-shift (RDDS) and the Doppler-shift attenuation (DSAM) methods. The experiments were performed at the Wright Nuclear Structure Laboratory of Yale University. Excited states of ^{128}Ce were populated in the ^{100}Mo(^{32}Si,4n) reaction at 120 MeV and the nuclear γ decay was measured with an array of eight Clover detectors positioned at

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forward and backward angles. The deduced yrast transition strengths together with the energies of the levels within the ground-state (*gs*) band of ^{128}Ce are in agreement with the predicted values for the X(5) critical point symmetry. Thus, we suggest ^{128}Ce as a benchmark X(5) nucleus in the mass $A \approx 130$ region.

1. Introduction

The study of phase transitions in mesoscopic systems, such as nuclei, molecules or atomic clusters is a topic of interest in current physics research.[1] Critical-point symmetries,[2,3] describing nuclei at points of phase/shape transitions between the limiting symmetries of IBM-1,[4] attract considerable attention, since they yield parameter independent solutions (up to scale factors) which are found to be in good agreement with experiment.[5,6] The above descriptions are exact solutions of the differential equations associated with the the Bohr Hamiltonian.[7] A solution of this equation that is appropriate to the critical point of the spherical, U(5), to axially deformed, SU(3), transition, is called X(5).[3] This solution is not an exact solution of the Bohr Hamiltonian and its derivation involves certain approximations, and an open problem that remains is how to treat simultaneously the β and γ excitations.

The first nucleus to be identified as exhibiting X(5) behaviour was ^{152}Sm,[6] followed by ^{150}Nd.[8] Further experiments on ^{152}Sm[9–11] and ^{150}Nd[11,12] support this conclusion. After the first examples of X(5)[6,8] and E(5)[5,13] 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 behavior.

Here we report lifetime measurements of excited states in the ground state (*gs*) band of ^{128}Ce. On the basis of the energies of the levels in the *gs* band ($R_{4/2} = 2.93$) and its transitional P factor[14] ($P \approx 4.8$), this nucleus was suggested as a candidate for the X(5) symmetry. Prior to this experiment, lifetimes in the *gs* band of ^{128}Ce were measured by Wells et al.[15] with the RDDS method, and by Li et al.[16] with the DSAM method. The motivation of the present experiment was that the deduced $B(E2)$ values for the $I^\pi = 6_1^+$ state[15] and the $I^\pi = 10_1^+$ state,[15,16] although with large uncertainties, deviated from the X(5) limit. The derived $B(E2)$ transition strengths from our data were found to follow the X(5) limit.

2. Experimental Method

Excited states in the *gs* band of ^{128}Ce were populated using the ^{100}Mo(^{32}Si,4n) reaction at 120 MeV. The experiment was performed at the Wright Nuclear Structure Laboratory of Yale University. The nuclear γ decay was measured with an array of eight Clover detectors positioned at forward (41.5°) and backward (138.5°) angles with respect to the beam. Events were collected when at least two γ rays were detected by two independent Clover detectors. Lifetimes of excited states in ^{128}Ce were measured using the recoil distance Doppler-shift (RDDS) and the Doppler-shift attenuation (DSAM) methods. For the recoil-distance experiment the Yale

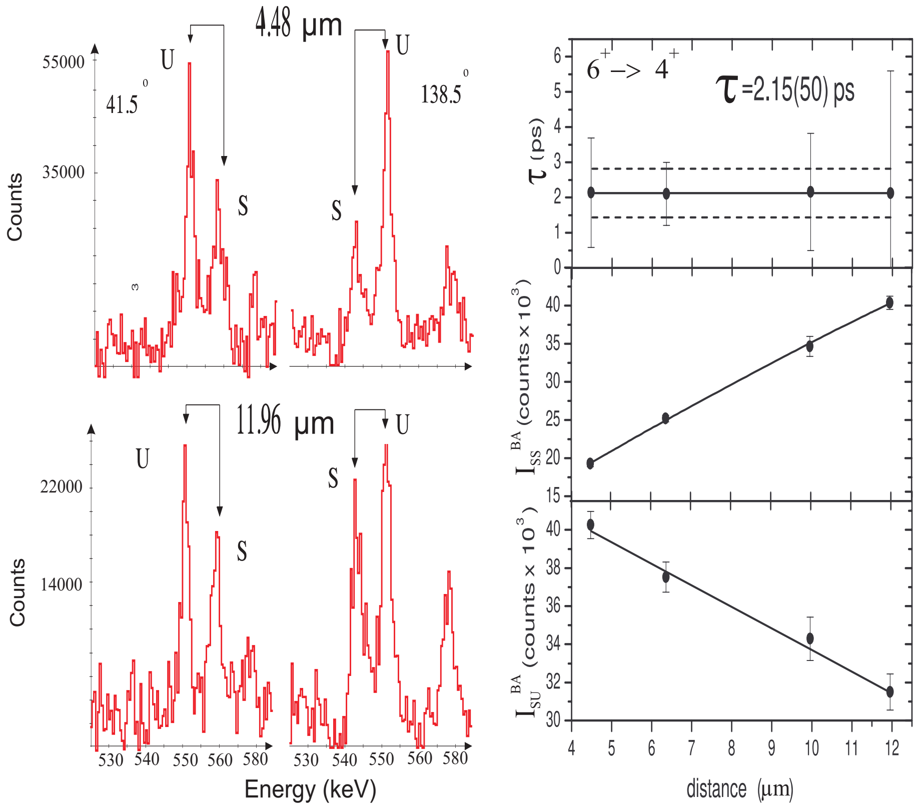


Fig. 1. Left: Gated γ-ray spectra for the $6^+ \rightarrow 4^+$ transition in ^{128}Ce detected at forward and backward angles for two different distances. Right: In the top frame the experimental points represent the lifetime of the 6_1^+ state as a function of the target-to-stopper distance. The solid and the dashed lines indicates the average value and its uncertainty, correspondingly. The bottom frame displays the denominator in Eq. (1), whereas the numerator is displayed in the middle frame.

plunger device was used. The target was a ≈ 1 mg/cm^2 thick self-supporting ^{100}Mo foil, while a 10 mg/cm^2 ^{197}Au foil was used as stopper for the recoils. The mean recoil velocity was $v/c = 1.9\%$. Measurements at four target-to-stopper distances (of 4.48, 6.36, 9.96 and 11.96 μm with respect to the electrical contact between the foils) were carried out. The separation of the foils was kept constant to within a few percent by a feedback system that relies on the capacitance between the foils and the distance corrections are done by using a piezoelectric crystal.

For the RDDS measurement, $\gamma\gamma$ coincidence spectra were obtained for each target-to-stopper distance by gating on the Doppler-shifted components of the transitions in the *gs* band. The peak intensities of both, the shifted (S) and the unshifeted (U) components of all transitions of interest were determined at each target-to-stopper position in order to analyze the data by the Differential Decay Curve Method (DDCM)^{17} and derive the corresponding decay curves.

According to the DDCM, if transition B is populating a level of interest, and it is depopulated via transition A, in the special case of gating on the Doppler-shifted component of the direct feeding transition, the mean lifetime τ can be derived for each target-to-stopper distance by applying the following equation:

$$\tau(x) = \frac{I_{SU}^{BA}(x)}{\frac{d}{dx} I_{SS}^{BA}(x)} \frac{1}{v} \qquad (1)$$

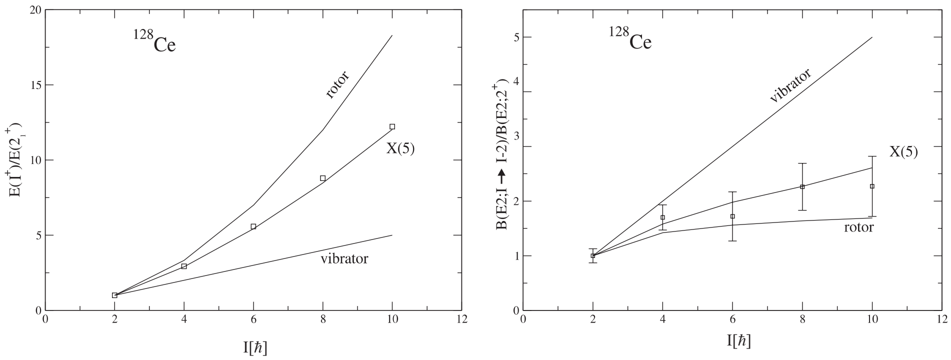
where v denotes the recoil velocity. The quantities $I_{SU}^{BA}(x)$ and $I_{SS}^{BA}(x)$ denote the normalized, measured intensities of the shifted (S) and unshifted (U) components of the depopulating γ transition A in coincidence with the shifted (S) component of a populating γ transition B. Examples of γ-ray spectra, measured at different target-to-stopper distances, together with the corresponding decay curves for the 550-keV $6^+ \rightarrow 4^+$ transition in ^{128}Ce are presented in Fig. 1.

The target for the DSAM measurement consisted of 0.5 mg/cm^2 ^{100}Mo evaporated on a 9 mg/cm^2 ^{197}Au foil. For the data analysis we performed a Monte Carlo simulation of the slowing-down histories of the recoils.[18] The analysis of the line shapes was carried out following the DDCM procedure for DSAM data.[19,20] The lifetimes of the 8_1^+ and 10_1^+ levels of the *gs* band were deduced from these data. For the 8_1^+ state, the lifetime value (albeit the large uncertainty) in excellent agreement with the value obtained from the RDDS measurement. The lifetime of the 10_1^+ state, $\tau = 0.45(10)$ ps is much smaller compared to the values published previously.[15,16] The reason is that there are several γ rays in the vicinity of the 712-keV transition (as noted also in Ref.[16]). Detailed knowledge of every component of the spectra at forward and backward angles is necessary in order to extract a correct lifetime value.

3. Results and Discussion

Lifetimes (and the corresponding $B(E2)$ reduced transition probabilities) were derived from the data for the 4_1^+, 6_1^+, 8_1^+ and 10_1^+ levels in ^{128}Ce and a limit was set for the 4_2^+ level. The quality of the current data is demonstrated by the agreement of the present results with literature values for the 4_1^+[15,21] and 8_1^+[15,16] levels.

After it was shown that ^{152}Sm is a X(5) nucleus,[6] attempts to find examples in other mass regions were made. In the mass $A \approx 100$ region ^{104}Mo was considered a X(5) candidate, based on the energies of the levels in the *gs* band which follow the X(5) limit.[22] The lifetime measurement and the derived $B(E2)$ reduced transition probabilities in this case turned out to follow the rotor limit.[23] Here we report an experiment in the mass $A \approx 130$ region. The nucleus ^{128}Ce is an interesting candidate for X(5) since the ratio of the energies in the *gs* band $R_{4/2} = 2.93$ is close to the X(5) value, $R_{4/2}^{X(5)} = 2.91$. The energy of the first excited 0_2^+ state is also close to the reference value in X(5): $R_{0/2} = E(0_2^+)/E(2_1^+) = 5.08$, compared to the X(5) value $R_{0/2}^{X(5)} = 5.64$. Yrast energies and $B(E2)$ values deduced from this



(a) (b)

Fig. 2. Left: Excitation energy ratios $R_i = E_i/E_{2^+}, i = 4^+, 6^+, 8^+, 10^+$ 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.

experiment for the *gs* band in ^{128}Ce are presented in Fig. 2. The agreement with the X(5) limit in both cases is excellent.

It is interesting to note that all three nuclei, ^{152}Sm, ^{104}Mo and ^{128}Ce are valence analogues in the N_pN_n scheme[14] with $N_pN_n = 96$ and $P = 4.8$. They have eight (or twelve) valence protons (or proton holes) and twelve (or eight) neutrons (or neutron holes). In the cases of ^{152}Sm and ^{128}Ce, both of which follow the X(5) limit, the number of protons is below mid-shell, which poses the question on the role of the particle and hole states for critical point behavior of X(5) type.

4. Conclusions

Lifetime measurements of excited states in the *gs* band in ^{128}Ce have been performed. The derived $B(E2)$ reduced transition probabilities indicate that this nucleus lies close to the U(5)-SU(3) phase shape transition. The excitation energies of the γ band are in agreement with the X(5) values.[2,10,22] It is necessary to investigate the transition strengths in and out of the β and γ bands in ^{128}Ce in order to establish it firmly as a X(5) critical point nucleus.

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