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^{182}Pt as a possible candidate for X(5) symmetry

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Abstract.
Recently, a new island of X(5) nuclei has been suggested around A=180 exemplified by some Osmium isotopes. To investigate the limits of its region, a Recoil-distance Doppler shift lifetime measurement has been performed for ^{182}Pt. For the data analysis, the Differential decay curve method has been applied in a newly developed version convenient for low recoil velocities and a non-negligible fraction of nuclei stopped already in the target. The level energies and the newly deduced transition quadrupole moments in the yrast band reveal the persistence of X(5) features in the investigated nucleus, but other spectroscopic data and IBM and GCM calculations indicate shape coexistence and a position of ^{182}Pt close but not at the critical point of the shape-transition.

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As it is well known, the Critical point symmetry (CPS) X(5) [1] describes nuclei at the phase transition between a spherical vibrator and an axially deformed rotor. This model provides a parameter free (up to scaling factors) prediction for the level scheme and B(E2) transition strengths for nuclei at the critical point. Realizations of the X(5) CPS were first found in some isotones with N=90 in the mass region A$\approx$ 150 (^{150}Nd [2], ^{152}Sm [3], ^{154}Gd [4]). Recently, in the region of Os isotopes with A$\approx$ 180, a new island of X(5)-like nuclei has been discovered [5]. It is of interest to establish the limits of this island on the nuclear landscape, as well as to investigate for possible reminiscences of the X(5) structure in neighboring nuclei. In the present work, we concentrate on the nucleus ^{182}Pt whose level scheme is well known from previous investigations (cf. [6, 7] and references therein). Prior to the present study, no lifetimes were known in this nucleus, and thus a precious data set for comparisons with nuclear models, namely electromagnetic transition strengths, was missing. Therefore we decided to perform Recoil distance Doppler-shift (RDDS) measurements in order to determine lifetimes in the yrast band.

The reaction ^{170}Yb(^{16}O,4n) at a beam energy of 87 MeV was used to populate excited states in ^{182}Pt. The beam was provided by the FN Tandem of the Institute für

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Kernphysik of the Universität zu Köln. The target consisted of 1.0 mg/cm^2 isotopically enriched ^{170}Yb evaporated onto a 2.1 mg/cm^2 Ta foil serving as a backing and facing the beam. The recoiling nuclei were stopped in a 3.5 mg/cm^2 gold foil after a flight in vacuum with a mean velocity of about 0.63% of the velocity of light, c. The target and stopper foils were mounted in the Cologne plunger apparatus [8]. A setup consisting of five large volume Germanium detectors positioned symmetrically at the backward angle of 143^o and a Euroball cluster detector positioned at 0^o with respect to the beam axis registered the coincident deexciting γ-rays. The Germanium crystals used were grouped in three rings. Data were taken for 10 target-to-stopper distances x in the range from 3.0 μm to 1500 μm. The data were sorted into 80 8k$\times$8k γ-γ coincidence matrices after corrections for energy shifts and gain matching. The normalization of the data taken at different target-to-stopper distances was performed using coincidence events corresponding to pairs of strong transitions in the yrast band (cf. ref. [8]).

The RDDS method is a well established technique for the determination of picosecond lifetimes of excited nuclear states (for a detailed presentation see e.g. ref. [9] and references therein). For the case of coincidence RDDS measurements where a gate is set on the shifted component of a transition directly feeding the level of interest, a solution of most of the experimental problems was proposed in Ref. [10]. In the present work, because of the relatively small Doppler-shifts of the transitions of interest, it was not possible to use such gating without a significant loss of statistics. Therefore we used the procedure [10] in a variant [11] which is relevant for a case where the gating condition does not influence the timing information for the investigated level and represents a further application of the Differential decay curve method (DDCM) [12, 13] developed in Cologne. Namely, gates were set on the complete line (both shifted and unshifted components included) of the feeding transition and of the transition of interest, respectively. In this way, the problem with the unobserved feeding was solved by using coincidences of a feeding transition with the transition of interest. We summed up the spectra corresponding to gates set in the three independent rings in order to increase statistics. To apply in practice the formalism of Ref. [11], we performed a Monte-Carlo (MC) simulation in three-dimensions of the time evolution of the velocity distribution of the recoils. Further, the "velocity histories" were randomized with respect to the registering detectors. A modified version of the computer code DESASTOP [10, 14] was used for the Monte-Carlo simulation. Details about the code and more specifically, the treatment of the electron and nuclear stoppings can be found in Ref. [15]. In the procedure for the analysis, the background-subtracted line-shapes corresponding to the transition of interest at all distances and the shifted decay curve are fitted simultaneously. For the analysis, the latter is represented by continuously interconnected second-order polynomials over an arbitrarily chosen set of neighboring time-intervals. The fitting problem is linear with respect to the polynomial parameters and the areas of the unshifted peak. To illustrate the application of the procedure, we show in fig. 1 an example of the analysis of the data for the 355 keV transition which depopulates the I^π = 6^+ level of the yrast band. The final result for the lifetime is obtained by averaging

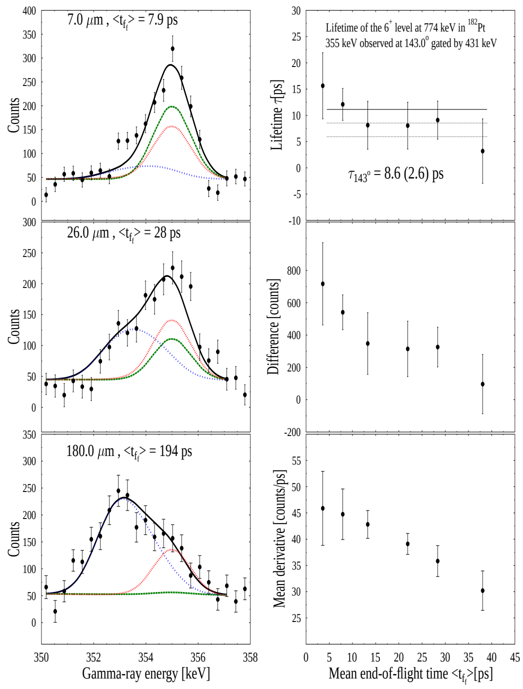

Figure 1. Example of the lifetime analysis of the 355 keV transition. The fits in the left panels illustrate the contributions of the shifted peak (blue dotted line), unshifted peak (green short-dashed line) and decays in the target and DSA-effects (red dot-dashed line). In the top right panel, the τ-curve is displayed. It is a result of the division of the numerator in the middle panel on the r.h.s by the corresponding denominator in the bottom panel on the r.h.s. See also text.

the values derived at the different rings with paying attention to possible systematic errors (see e.g. Ref. [11]). In this way, the lifetimes of five levels in the yrast band till the 10^+ one were derived from the RDDS data giving yield to absolute B(E2) reduced transition probabilities.

The comparison of the X(5) predictions to the data with respect to the level energies and B(E2) branching ratios gives a relatively good agreement with one big exception - the energy of the 0_2^+ state. Experimentally, it lies at about 3.22 times the energy of the 2_1^+ level while according to X(5) it should lie at 5.67 E(2_1^+). Therefore one can conclude that ^{182}Pt is not a perfect candidate for a realization of the X(5) symmetry but possess some of its features, as it will become clear from the discussion below. We performed calculations within two widely exploited models to describe the low-lying states in ^{182}Pt and to make some conclusions about its place in the shape-transitional region. First, we employed the Interacting boson model-1 (IBM-1) [16] in its version called extended consistent Q formalism (ECQF) where the parameters of the Hamiltonian were taken from a systematic study [17] as presented in Ref. [18]. The second model employed in our work is the General collective model (GCM) or Frankfurt model[19, 20]. Both theoretical models describe quite satisfactorily the level scheme and the transitions strengths. The IBM calculation reproduces better the energies in the yrast band and the branching ratios while the GCM gives superior results for the yrast B(E2)'s and the level energies of the side-bands. It is interesting to consider the nuclear shape associated with the fitted parameters of the models, namely with those of the GCM. Since β and γ are dynamic variables in the GCM, the maximum of their probability

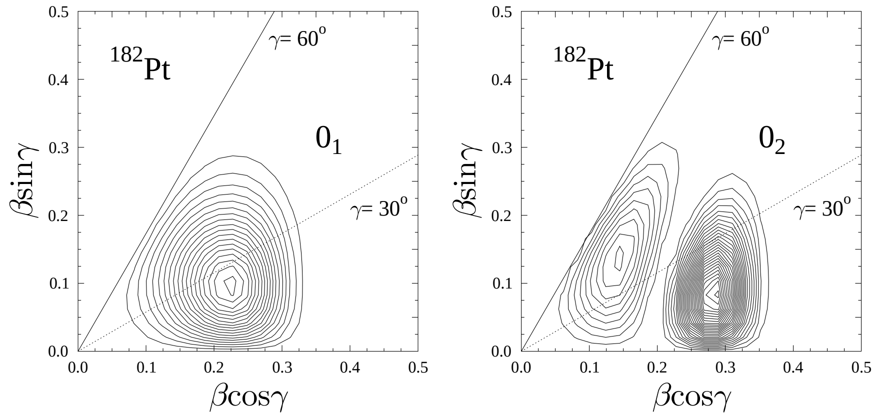

Figure 2. Probability distributions in the β-γ plane of the wave functions of the first two 0^+ states in ^{182}Pt according to the GCM.

distribution (the squared wave function multiplied by the volume element $\beta^4 sin(3\gamma)$) does not necessarily coincide with the potential minimum. Thus, we show in fig. 2 these distributions for the first two 0^+ states. The 0_2^+ state can be interpreted as a β-vibration, its probability distribution has roughly one node in β. On the other hand,

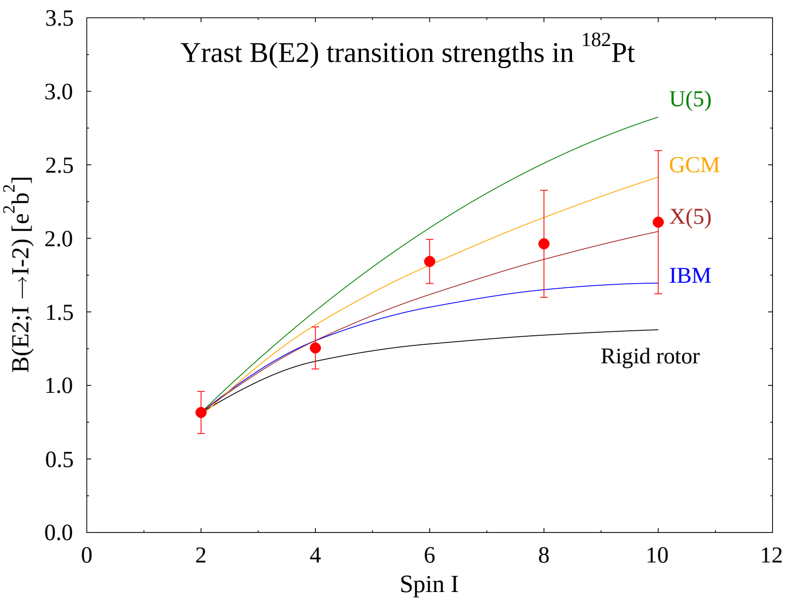

Figure 3. Transition quadrupole moments in the yrast band of ^{182}Pt. The different theoretical models used are indicated. With the exception of the GCM, all models are normalized to the Q_t value for the $2_1^+ \rightarrow 0_1^+$ transition. .

this state is characterized by two composing components: one prolate, more deformed than the 0_1^+ band structure, and one more triaxial to oblate, less deformed structure. Similar observations for a multi-component structure can be made also for the other, higher-lying 0^+ states. In this sense, the GCM predicts a shape coexistence in ^{182}Pt in the framework of a mixing of bands with different quadrupole deformation, confirming earlier experimental findings (e.g. [21]) for the light Pt isotopes. In fig. 3, we present the experimental transition quadrupole moments in the ground-state band compared to model calculations. The best description is provided by the GCM followed by X(5) and IBM. These results for the transition quadrupole moments in the ground-state band may be interpreted as an indication that some X(5) features persist in ^{182}Pt coexisting with excitations corresponding to different nuclear shapes. This is corroborated also by the experimental B(E2) branchings of the transitions from the side bands to the ground-state band. The exact position of ^{182}Pt in the IBM parameter space and its closeness to the shape/phase transitional region may be found in fig.4 of Ref. [17]. In that figure, the Pt isotopes from A=176 to 194 are positioned in the Casten triangle, and ^{182}Pt lies very close, but not in the X(5) transitional region. It deviates somewhat toward the O(6) vertex of the triangle, indicating the importance of the γ-softness effects.

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